Retrofitting South Africa's cities with green roofs: Cost benefit analyses for large scale green roof implementation

by
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Abstract

Cities are most at risk to climate change and South African cities are no exception. To a large extent, cities are also the cause of their own demise in terms of environmental concerns and need to adapt to become more resilient. Retrofitting existing buildings with green roofs may be a key step in reducing and/or mitigating some of the environmental concerns common within urban centres.

Research proposed in this thesis considers the feasibility of retrofitting existing buildings with green roofs given the current state of the green roofing industry in South African cities, specifically Johannesburg. Policies and incentives available to encourage the green roof industry and the implementation of green roofs were researched and identified. Costs and benefits associated with retrofitting the typical building situated in Johannesburg CBD were investigated.

Retrofitting buildings with green roofs comes at a premium cost in countries where the green roof industry is not established. A Cost Benefit Analysis (CBA) for retrofitting an existing building with a green roof without the help of policies or incentives was compared to the "do nothing" approach. This comparison showed retrofitting is not feasible under these conditions, as the building owner will never be able to make up the additional expenses.

The same comparison was made assuming different conditions, such as incentives and additional benefits. Results showed retrofitting a building becomes feasible given the following conditions: (1) the green roof can reduce the building's energy consumption by 3%, (2) the municipality offers to subsidise 80% of the green roof installation costs and (3) reduce property tax by 2% during the green roof's lifetime. Given these conditions a building owner will have a payback period of 7 years.

Motivations for why the City would consider offering such incentives are as follows: (1) air pollution in an area of implementation will reduce given that the green roofs can increase the green fraction in the area by at least 18%. (2) The reduction in air pollution will reduce the health costs especially those related to air pollution, these savings will be equivalent to an additional 5% in property tax received from all the buildings in the area of implementation. (3) The Government of South Africa aims to reduce greenhouse gas emissions with 34% by 2020 with the implementation of carbon tax. Carbon tax has not yet been implemented: the implementation thereof is receiving much criticism and there are currently no other plans to reduce emissions. Thus, the proposed incentives can be used to reduce air pollution and offer savings to both the City and the building owners in the area where the incentives are implemented. However, the city will need 15 years to pay off these incentives.

Opsomming

Klimaatsverandering is ‘n groot risiko vir stede, en stede in Suid-Afrika word nie hiervan uitgesonder nie. Bestaande stede is meestal die oorwegende rede van die ondergang van hulle eie omgewing. Stede moet aanpas en meer omgewingsvriendelik word om toekomstige omgewingsprobleme te verminder en te voorkom. Groen dakke is ‘n groen tegnologie wat die potensiaal het om ‘n groot rol te speel in die omskepping van bestaande stede in meer omgewingsvriendelike areas.

Navorsing wat in hierdie verhandeling voorgestel word kyk na die lewensvatbaarheid daarvan om bestaande gebou se dakke met groen dakke te vervang. Geboue spesifiek in Johannesburg se middestad was beskou in die lig van die huidige tekort aan ‘n groen dak industrie. Die moontlikheid om gebruik te maak van aansporings en beleide wat die groen dak industrie van Suid-Afrika kan aanmoedig en bevoordeel was ondersoek, asook kostes en voordele verbonde aan die gebruik van groendakke.

Sonder ‘n groen dak industrie is die aanvanklike kostes van ‘n groen dak teen ‘n premie, wat beteken die gebruik daarvan is nie ekonomies regverdigbaar nie. Die lewensvatbaarheid van die gebruik van groen dakke was met ‘n koste en voordele analise bepaal. Die analise is vergelyk met die opsie om niks te doen nie, en was onderhewe aan die feit dat daar huidiglik geen aansporings of beleide vir die gebruik van groen dakke is nie. Die resultate het getoon dat groen dakke nie ekonomies regverdigbaar is indien daar nie addisionele voordele en aansporings in ag geneem word nie.

‘n Koste en voordele analise waar moontlike voordele en aansporings in ag geneem is het gewys dat ‘n groen dak ekonomies haalbaar sal wees indien: (1) die elektrisiteitsverbruik van die gebou verminder met 3%, (2) die aanvanklike koste van die groen dak verminder word met 80% as gevolg van ‘n aansporing van die stad, en (3) die gebou se erf belasting verminder word met 2% oor die lengte van die groen dak se leeftyd, ook ‘n aansporing van die stad. Hierdie aansporings en die voordeel sal die terugbetalingsperiode van die dak 7 jaar maak.

Redes waarom die stad aansporings sal gee is omdat dit voordeling is vir die stad. Groen dakke kan die lugbesoedeling verminder, wat die jaarlikse koste van gesondheid kan verminder. Die stad sal jaarliks spaar in gesondheidskostes, en die lewenskwaliteit van die mense in die stad sal verbeter.

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List of Abbreviations

B : Benefit
BMP : Best Management Practices
C : Cost
CBA : Cost Benefit Analysis
CBD : Central Business District
CDP : Carbon Disclosure Project
CFD : Computational Fluid Dynamics
d : Discount rate
ECC : Electricity Cost of Conventional building
ECR : Electricity Cost of Retrofitted building
EUI : Energy Usage Intensity
FLL : Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau
GBCSA : Green Building Council South Africa
GBD : Global Burden of Disease
GDP : Gross Domestic Product
GHG : Greenhouse Gas
GLA : Gross Lettable Area
GRM : Green Roof Maintenance cost
h : hours
IGC : International Growth Centre
L : number of Labourers
LEED : Leadership in Energy and Environmental Design
LF : Labour Fee
LCA : Life Cycle Analysis
LCI : Life Cycle Inventory
OF : Overhead Factor
O&M : Operations and Maintenance
PM : Particulate Matter
PUCM : Princeton Urban Canopy Model

PV : Photovoltaic

SF : Supervisor Fee

SOER : State of Environmental Reports

TSS : Total Suspended solids

UCM : Urban Canopy Model

UHI : Urban Heat Island

UHIE : Urban Heat Island Effect

W : Waterproofing cost

WGBT : World Green Building Trends

1 Introduction

Cities hold more than half the world's population and most of its built assets and economic activities. It is predicted that 70% of the world's population will be living in cities by 2050(Kari, 2016). This proportion of the population and economic activities are most at risk to climate change (IPCC (Intergovernmental Panel on Climate Change), 2014).

Urban centres such as the City of Johannesburg are currently experiencing an increased air temperature. Research suggests that the temperatures for the City of Johannesburg may increase by 2.3 °C in the near future (around years 2056-2065) and within 4.4 °C between the years 2081-2100 (CDP, 2014). The average increase in air temperature seen in cities such as Johannesburg can be attributed to the Urban Heat Island Effect (UHIE). In a report by the World Health Organisation (WHO) it was stated that Urban Heat Islands will have to disappear this century if future generations are to live healthy lives in cities (Kings, 2015).

Furthermore, Johannesburg has been ranked as one of the most polluted cities in the world. This is due the heat island trapping dust from mining and other pollutants. According to the WHO Pretoria is the second most polluted city in South Africa, followed by Cape Town and Durban (Kings, 2015)

The research in this thesis considers the use of green roofs to reduce air pollution in cities, thereby increasing the health of the city's population and mitigating the UHIE. This will create a better living environment by making the city more sustainable and resilient to climate change. The costs and benefits associated with retrofitting existing buildings with green roofs are investigated to determine whether it is feasible to retrofit a building in the City of Johannesburg with a green roof.

1.1 Background

Urban Heat Islands (UHI) are a natural phenomenon seen in cities all over the world, which both raise temperatures and trap pollutants within the city. In a city where the UHIE is apparent, the city's air temperature will be several degrees higher than that of its surrounding rural areas. This phenomenon has been documented over the past decades in numerous studies. The UHIE has many adverse effect, most noticeably are heat-related mortality and the substantial rise in energy consumption (Kleerekoper, Esch and Baldiri, 2012).

The UHIE is mainly due to the lack of greenery and the high level of solar radiation absorbed by the urban impervious surfaces (Gago et al., 2013), such as asphalt and concrete. The increased air and surface temperatures of a rural area versus an urban area are due to replacement of greenery with these impervious surfaces. Urban centres such as Johannesburg and Pretoria are as much as 6 °C hotter than they should be due to the UHIE (Kings, 2015).

Urban greening moderates temperatures and favours processes such as evapotranspiration and shading of surfaces (Gago et al., 2013). One possible solution to reduce the UHIE is to retrofit green roofs on building roof tops within cities (Carter and Fowler, 2008; Li, Bou-Zeid and Oppenheimer, 2014), which is a form of urban greening. A green roof is a rooftop with soil and vegetation on top of it. Different types of green roofs exist and are used for different purposes. Green roofs have been used in numerous cities around the world for various reasons such as reducing air pollution, reducing stormwater runoff, reducing a building's energy needs in regard to cooling and heating, creating a more aesthetically pleasing environment, enhancing biodiversity and reducing the UHIE. Extensive green roofs, which are green roof with a thin soil layer, would be considered the most practical for all these uses mentioned.

The World Green Building Council's World Green Building Trends (WGBT) 2016 report indicated that South Africa currently has the highest share in green property development in the world, with 61% of the South African property developers surveyed saying that they expect over 60% of their projects to be sustainable or green by 2018. The WGBT 2016 report also found that green retrofits of existing buildings ranked first among sectors for green work in the next three years with South African respondents indicating that 46% of green work will be for the retrofitting of existing buildings (Dodge Data & Analytics, 2016). These retrofits refer to energy efficient and sustainable technologies, of which green roofs are included. The respondents in this study consisted mainly of architect and design firms, contractors, builders, consultants and engineers.

Retrofitting and green sustainable buildings do however include high costs, which is one of the reasons why smaller tenants and landlords in South Africa do not tend to support retrofitting. According to an un-refereed article in Earthworks concerning the green building trends in South Africa (Mannak, 2016), there is a misconception among landlords around the financial and investment benefits of having a green building and landlords tend to focus too much on short-term paybacks instead of return on investment.

1.2 Significance of Research

The implementation of green retrofits and green buildings has become more common in South Africa among larger companies. The technology used in green designs in a South African context is mainly the installation of solar panels and the use of facades and energy efficient systems. Smaller tenants and building owners however are reluctant and do not show much interest in green building and sustainable designs. Simple reasons for this may be that the smaller tenant and private building owners are not aware of the need for adaptation; furthermore they might not be aware of the technology available in green designs. Lastly they may have the perception that green designs and retrofitting are very expensive and thus do not make sense economically (Mannak, 2016). However, this perception is not wrong as the initial cost associated with green retrofits such as green roofs are high since the green roof industry in South Africa is still in the initial phase. This study investigates possible ways to encourage the use of green roofs on existing buildings.

1.3 Aims and Objectives

The research aims to determine whether the large scale implementation of green roofs can be economically beneficial for both the public and private sector.

The research objectives are to:

1. Identify the policies that can help in establishing the green roof industry in South Africa.
2. Identify incentives that will encourage developers and building owners to retrofit an existing building with a green roof.
3. Investigate and determine the costs and benefits associated with retrofitting an existing building with a modular extensive green roof.
4. Determine the feasibility of retrofitting a building with a green roof with the use of cost benefit analyses.
5. Determine how increasing the green fraction of an urban environment can be beneficial towards both the private and public sector.

1.4 Research Methodology

The research in this study considers the cost of mitigating environmental concerns apparent in urban areas for both the private and public sectors. The costs associated with mitigating environmental concerns by retrofitting buildings in a city with green roofs were investigated. This was done by conducting a Cost Benefit Analysis (CBA) for a building retrofitted with a green roof. The building considered was situated in the Central Business District (CBD) of Johannesburg. A CBA was used since the costs of retrofitting versus the costs of not retrofitting can be compared to determine the feasibility of retrofitting. The CBA was also used to determine which costs have the most significant impact on the costs of the green roof over its lifetime. Incentives that can be used to reduce the annual and initial costs of retrofitting were investigated. This investigation together with the CBA was used to determine which incentives should be used to make retrofitting a building with a green roof feasible for the private sector. The data from the CBA, as well as data from literature were used to investigate how the city will be able to fund the incentives required to make retrofitting feasible for the private sector. This investigation was conducted to determine whether the city can benefit from funding incentives to mitigate and reduce the environmental concerns apparent in urban centres.

1.5 Thesis Layout

The content of each chapter presented in this thesis is briefly discussed.

Chapter 2: Literature review

Literature concerning the broad spectrum of factors influencing the urban environment and its environmental problems are reviewed. The use of green roofs in urban environments form the focal point of the review.

Chapter 3: Incentives from literature

Policies and incentives used to promote green roof implementation are reviewed and incentives that can be used to promote green roof implementation in South Africa are investigated and identified.

Chapter 4: Feasibility study parameters

The study area used for the analysis and constraints of the CBA is presented. The dimensions and characteristics of a typical building in Johannesburg were determined and the size of a green roof for such a building is discussed.

Chapter 5: Costs and benefits data

The data used in the CBA is explained and determined. All additional costs assumed for a building retrofitted with a green roof are considered.

Chapter 6: Cost benefit analysis

Results of the CBA are presented and discussed, as well as the additional costs accumulated over a 40 year period, of a building retrofitted with a green roof.

Chapter 7: Sensitivity analysis

Results of sensitivity analyses performed, to determine whether a reduction in energy consumption of a building retrofitted with a green roof, or a reduction in the initial costs of a green roof can improve the net present value of such a building, are presented and discussed.

Chapter 8: Monte Carlo analysis

The results of a Monte Carlo analyses performed are presented. The analyses were done to determine the range of possible answers when some of the factors influencing the outcome of the CBA have a range of possible values. These analyses were done since there were uncertainties in some of the factors used to determine the costs used in the incremental CBA.

Chapter 9: Large scale green roof implementation

Motivations for why a municipality would consider offering incentives to promote large scale green roof implementation are considered. Possible ways of funding such incentives are investigated. The benefits that the City of Johannesburg can receive when increasing the green fraction in an area in the city are evaluated.

Chapter 10: Summary of findings

A summary of the findings of the different CBA are presented, conclusions are made in terms of green roofs and the incentives needed for their implementation in South African cities.

Chapter 11: Final conclusions

Conclusions for the aim and objectives of this study are reviewed and discussed. Recommendations for future research are also presented.

1.6 Scope and Limitations

The study considered the feasibility of retrofitting an existing building with a green roof system. The use of extensive modular green roof systems was considered. Intensive or direct systems were not considered since there are additional expenses related to these systems, as well as additional structural considerations. Green roof construction standards were partially investigated. The use of green walls were not considered in this study.

All results are based on a study area within Johannesburg CBD and not for the whole City of Johannesburg. The characteristics of the building used for the purpose of this study were based on an estimated average building and not a real building. Data used to determine the costs associated with the building and the green roof was based on costs and estimations from previous years: all these costs were converted to present value where applicable.

Policies and incentives that promote the use of green roofs were considered. The legal aspects concerned with the implementation of green roofs do not form part of this study.

The data used to determine the possible reduction in energy consumption and the reduction in particulate matter are not data for South Africa specifically since no such data exists to the knowledge of the author. The results presented in Chapters 7 and 9 are based on the assumptions made concerning the reduction in energy consumption and the reduction in particulate matter.

The reduction in energy consumption due to the green roof was based on data from Madrid, Spain, Athens, Greece and Toronto, Canada. It was assumed that a non-linear relationship exists between the height of a building and the corresponding reduction in energy consumption due to the green roof. The reduction in energy consumption assumed was based on the typical building considered in this study, which has 7 floors. The number of floors for the typical building was based on the average number of floors for the buildings analysed in the study area. The reduction in energy consumption could have been determined differently, considering the different heights of the buildings analysed instead of the average building height and calculating the average reduction in energy consumption.

The reduction in particulate matter, due to the increase in greenspace cover in an area, was based on data from Sydney, Australia. The increase in greenspace cover was determined considering the exposed surface area of the study area. The exposed surface area was considered to be the total road, roof and exposed wall area. It was assumed that the exposed wall area of a building was 75% of the total wall area.

2 Literature Review

Literature concerning the following topics was reviewed; typical environmental aspects associated with urban centres, green roofs and the implementation thereof, as well as the use of cost benefit analyses for determining the feasibility of implementing a new technology such as green roofs. These topics were reviewed to determine whether green roofs can be used to aid in the current and future environmental problems of the cities in South Africa. Figure 1 shows a diagram of the literature reviewed and also gives an overview of the chapter layout.

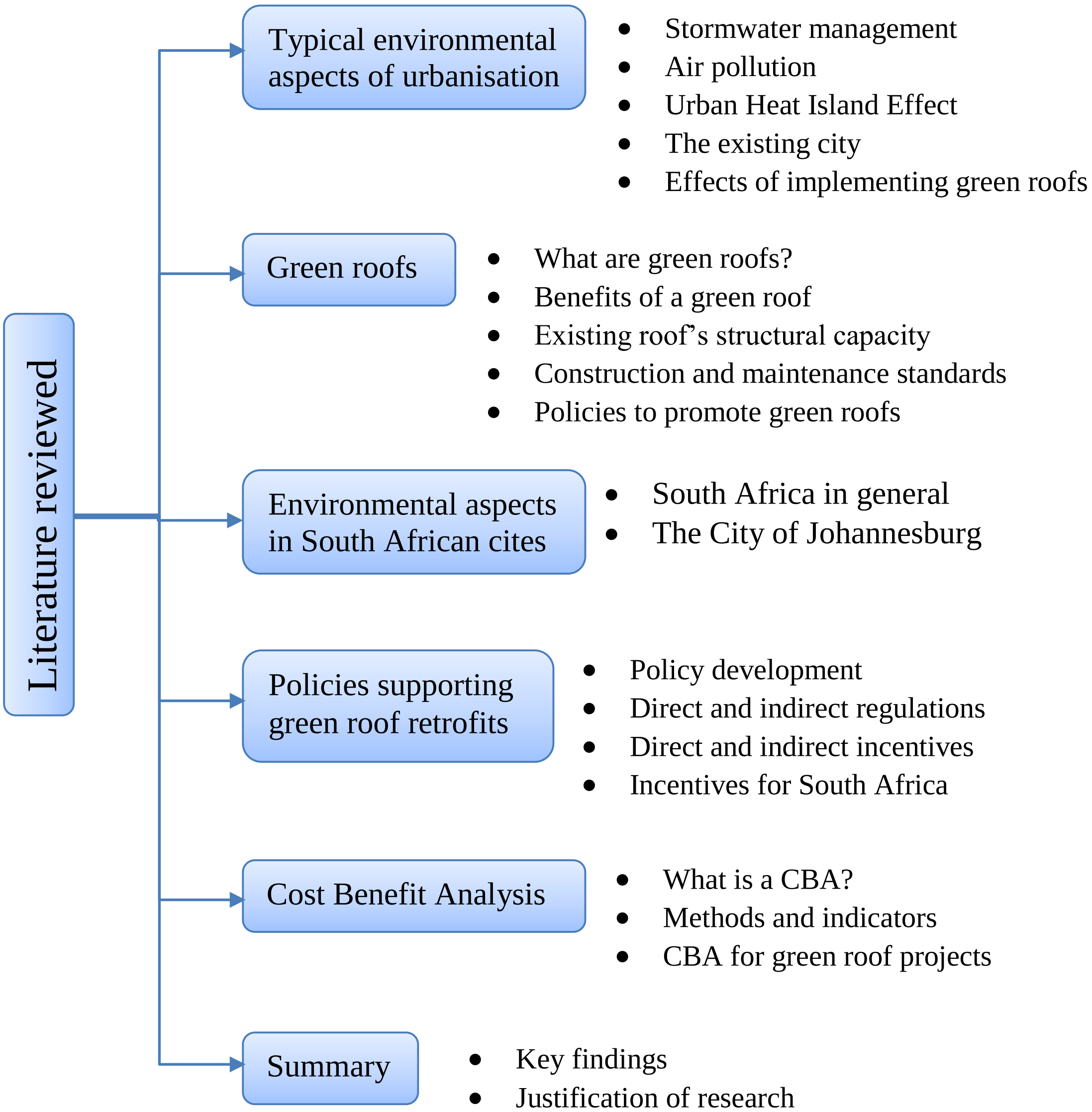


Figure 1 Chapter 2 Overview

2.1 Typical Environmental Aspects of Urbanisation

The urbanisation of an area changes its environment through the consumption of food, energy, water and land (Torrey, 2004). Environmental concerns that typically exist in cities due to the increased consumption of land and energy are stormwater runoff, air and water pollution, and the Urban Heat Island Effect (UHIE) (Grimmond, 2007). These environmental concerns are considered in this section.

The management of stormwater quality and quantity becomes a concern when existing cities become more urbanised and dense. The increase in population and impervious surfaces causes increased water pollution and increased runoff with a more rapid peak (Grimmond, 2007). Air pollution worsens with the increase in population, as more greenhouse gasses are emitted as daily traffic and human activity increases. With the increase in emissions, impervious surfaces and increase in building density, UHIs become more and more apparent. Figure 2 shows the cycle of urbanisation with respects to stormwater management and the UHIE.

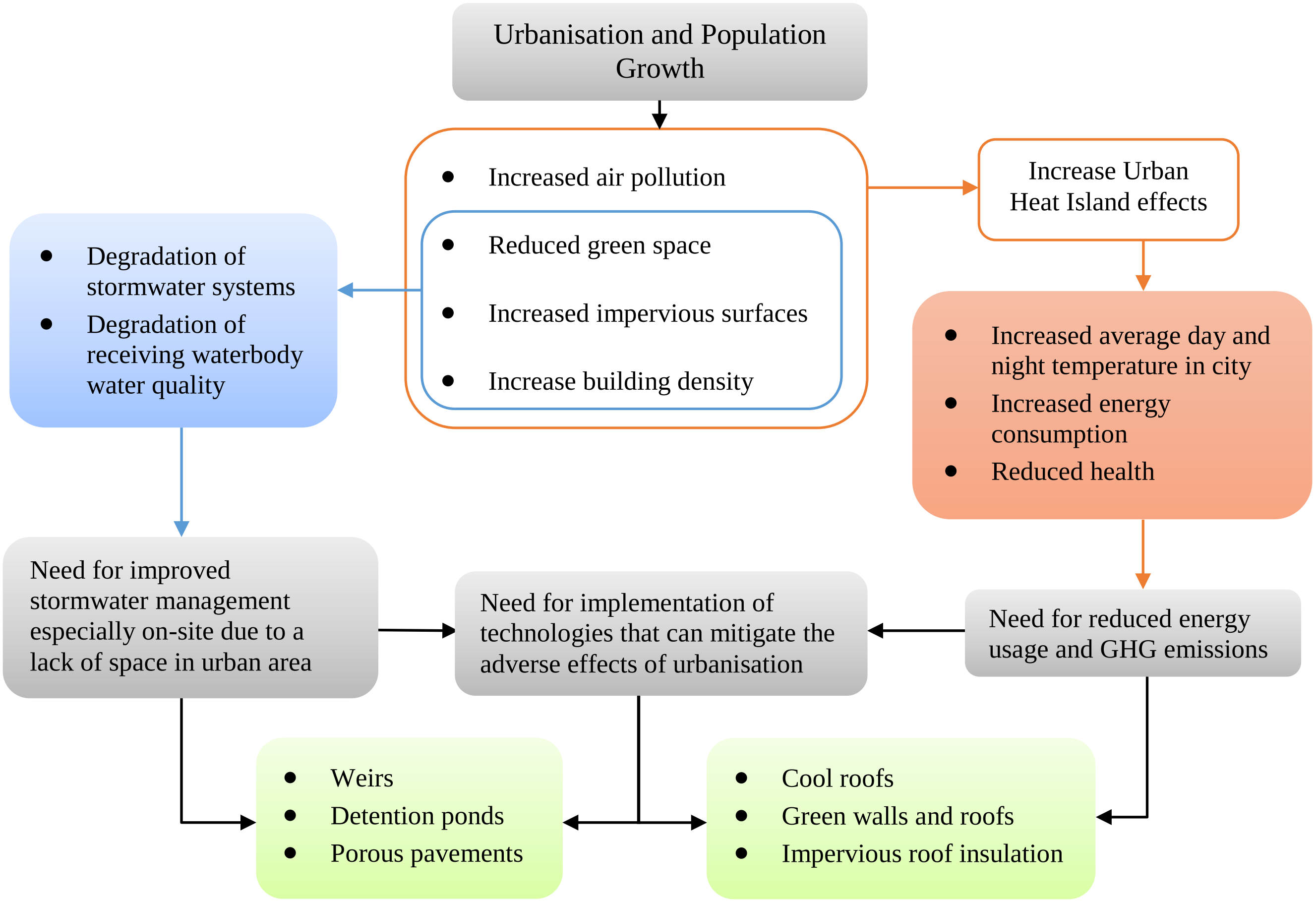


Figure 2 Urbanisation Cycle

2.1.1 Stormwater Pollution

Urbanisation results in the replacement of vegetated areas with impervious surfaces, such as concrete and asphalt which seals the ground surface. The increase of impervious surfaces increases the volume of stormwater runoff and adversely affects the quality of the stormwater, since the rainwater cannot filter through surface. The quality of the stormwater influences the quality of the receiving water body. Thus the more polluted the stormwater the more polluted the receiving water body.

Improving the stormwater management of an area will improve the quality and reduce the quantity of stormwater runoff which will reduce erosion and sedimentation and benefits the habitat of the receiving water body (City of Waterloo 2005). Best Management Practice (BMP) used to mitigate the effect of increased impervious surfaces in urban areas are the design and construction of structures to retain stormwater volumes and removal and filtering of pollutants. Technologies typically used are stormwater ponds, constructed wetlands, detention ponds, bio-retention areas and sand filters (Carter and Butler, 2008). Other technologies used to retain runoff according to stormwater BMP include porous pavement, rain barrels and green roofs (Carter and Keeler, 2008). Different costs are associated with all these stormwater management BMPs. For example bio-retention areas consume valuable urban land, which leads to opportunity costs that are more expensive than the other alternatives (Carter and Keeler, 2008).

BMP for stormwater management in existing cities where the availability of space is limited would be on-site stormwater management systems or systems that typically need less space. On-site stormwater management reduces the need for repairs on municipal infrastructure (Fisher-Jeffes and Armitage, 2013) as the stormwater is filtered and stored for a period of time and released at a slower rate. On-site stormwater management technologies include porous pavement, rain barrels and green roofs. Figure 3 gives a summary of the BMP available for stormwater management.

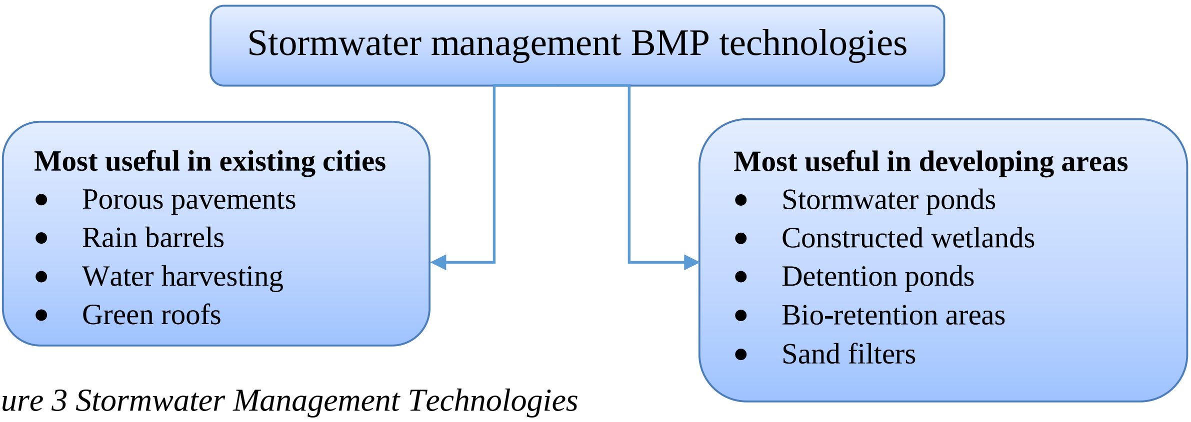


Figure 3 Stormwater Management Technologies

2.1.2 *Air Pollution*

Air pollution affects the economy of a country. According to OECD (2016) air pollution impacts the market directly through reduced labour productivity, increased health expenditures and crop yield losses. Air pollution also results in premature deaths. The welfare cost from premature deaths caused by air pollution in sub-Saharan Africa is predicted to increase from 40 billion USD in 2015 to 340 billion USD in 2060 (OECD, 2016), with South Africa contributing the largest part of these estimated costs. Furthermore, estimates indicate that urban air pollution costs 5% of the GDP in developing countries and is the cause of one million premature deaths each year (Lomborg, 2013; Ksenija, 2016).

According to the WHO, air pollution will increase globally, which will result in increased economic costs globally (WHO Regional Office for Europe OECD, 2015). Policies that can be implemented to reduce air pollution include the implementation of air quality standards such as reducing the concentration of particulate matter and nitrous oxides. Implementation of emission taxes and incentivising or requiring the use of cleaner technologies that produce less pollution can help reduce air pollution. Implementation of such policies can lead to immediate and long term benefits due to improved air quality (OECD, 2016).

The building industry accounts for approximately 23% to 40% of the world’s greenhouse gas (GHG) emissions (Gunnell et al., 2009). This includes the construction, operation and demolition of buildings. A building’s operating period does, however, have the largest contribution to the building industry’s GHG emissions.

Technologies to reduce air pollution in cities vary widely. The transport sector can account for approximately 22% to 50% in energy consumption in a city (City of Cape Town, 2011). Increased energy consumption leads to increased GHG emissions. Possible ways to reduce emissions from the transport sector are by reducing the amount of cars in the area by updating public transport, changing central business districts into car free zones, using electric cars, or adapting the fuel to improve the combustion cycle in existing vehicles (Howard, 2016; Bane, 2017).

An example of a solution that purifies the air is in Beijing. There a Smog-Free-Tower is used to clean 30 000 cubic meters of air every hour. However this tower does use 1 170 watts of energy to clean the polluted air (Bane, 2017).

Photo-catalytic materials can also be used to remove pollution from the ambient air, but need the presence of sunlight to function. Photo-catalytic pavement tested in Belgium has shown to reduce pollutants such as nitrogen oxide and volatile organic compounds (Boonen and Beeldens, 2014).

Large scale application of photo-catalytic materials is still being researched (Boonen and Beeldens, 2014). Photo-catalytic treatments can be applied to roofs, pavements or roads.

Increasing green areas in cities is also another way to reduce air pollution. The plants can filter and purify the air already polluted. Cities can increase their green fraction by planting more trees, creating more public parks, or installing green roofs and walls onto existing and new buildings. In France, a study on the ability of urban trees to remove air pollutants concluded that the trees had the potential to reduce air pollutants, specifically particulate matter (Selmi et al., 2016). In Paris it is mandatory for all new commercial buildings to have either solar panels, or green roofs, or both on the rooftop in order to provide habitat for birds, absorb pollutants and retain rainwater (Lawson, 2015). In Denmark, the City of Copenhagen has a mandatory green roof policy to promote the City to become the world's first carbon neutral capital (Leipzig and Mohr, 2012). The policy requires green roofs on all new buildings with a slope less than 30°.

The UHIE and air pollution are closely related as the UHIE increases as the air quality decreases, which is discussed in more detail in the following section. Figure 4 gives a summary of strategies being used to reduce air pollution.

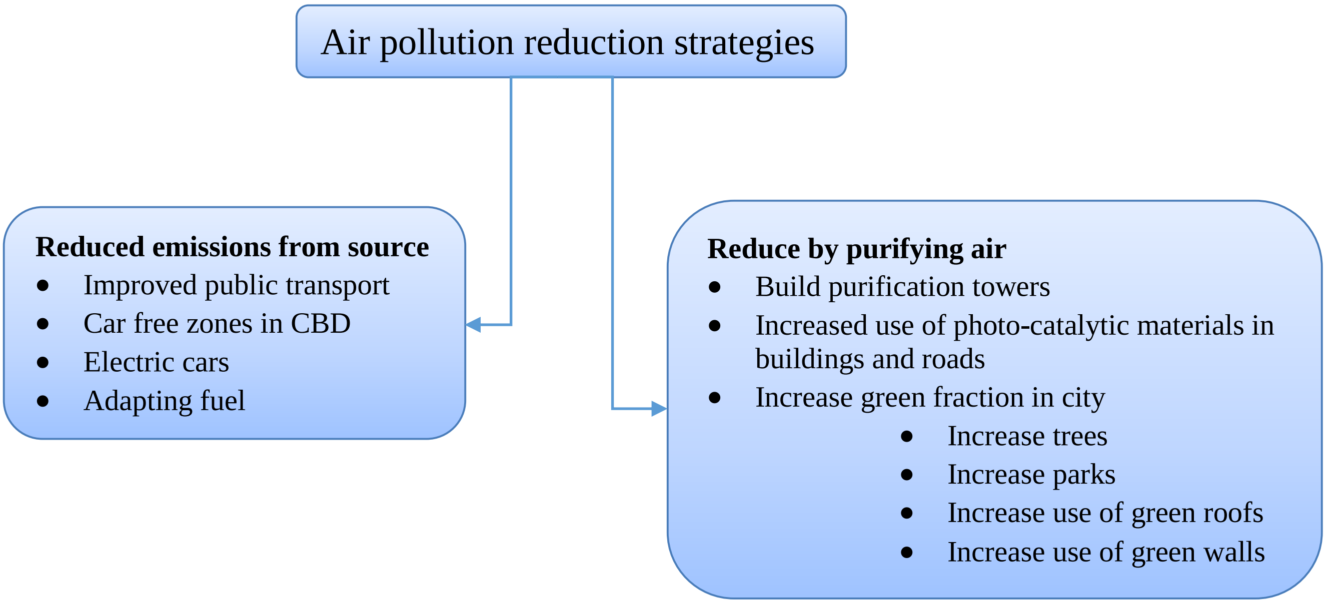


Figure 4 Air Pollution Reduction Strategies

2.1.3 Urban Heat Islands

UHIs occur due to the formation of heat plumes over urbanised or high-density residential areas. The extensive use of man-made materials such as asphalt and concrete in urban areas has been shown to be the cause of UHIs (Li, Bou-Zeid and Oppenheimer, 2014).

During the day, buildings are warmed due to solar and other anthropogenic heat. At night the heat does not simply escape, but is stored within the city, which increases night temperatures as well. A heat plume forms over each building within the urban area. These heat plumes merge into a large urban plume.

Due to the buoyancy effect, air is lifted up and a lower pressure exists within the centre of the urban area. This drives an inward flow through the urban edges, which eventually develops into an Urban Heat Island. Solitary building's heat plume would flow directly upwards, but within an urban area only the buildings within the centre would have upward plumes. The plumes of the buildings at the edges would bend towards the urban centre. Figure 5 illustrates the formation of an UHI (Wang and Li, 2016). Thus, by reducing the heat plumes over individual buildings, theoretically the UHI can be reduced.

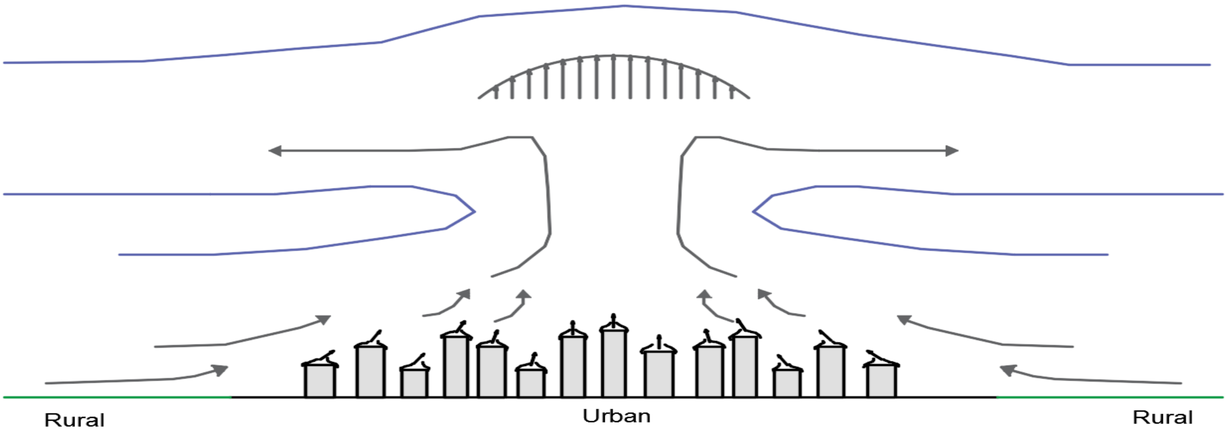


Figure 5 Illustration of Urban Heat Island phenomenon (adapted from Wang & Li 2016)

Typical characteristics of an urbanised area, such as the high density of people and buildings and the reduced amount of vegetated areas within populated urban areas, increase the UHIE (Hardy and Nel, 2015). The extent of the temperature differences varies in time and place as a result of the meteorological, locational and urban characteristics of an urban environment (Kleerekoper, Esch and Baldiri, 2012).

UHIs are a natural phenomenon seen in cities all over the world. The UHIE increases the ambient air temperatures of an urban area and traps pollutants within the city (Oke, 1987). Studies concerned with the formation of influence of UHI have shown that in a city where UHIE is apparent, the city's air temperature will be several degrees higher than that of its surrounding rural areas (Oke, 1987; Mirzaei and Haghighat, 2010; Wang and Li, 2016). Figure 6 is an illustration of the increased air temperatures in urban centres compared to nearby rural areas.

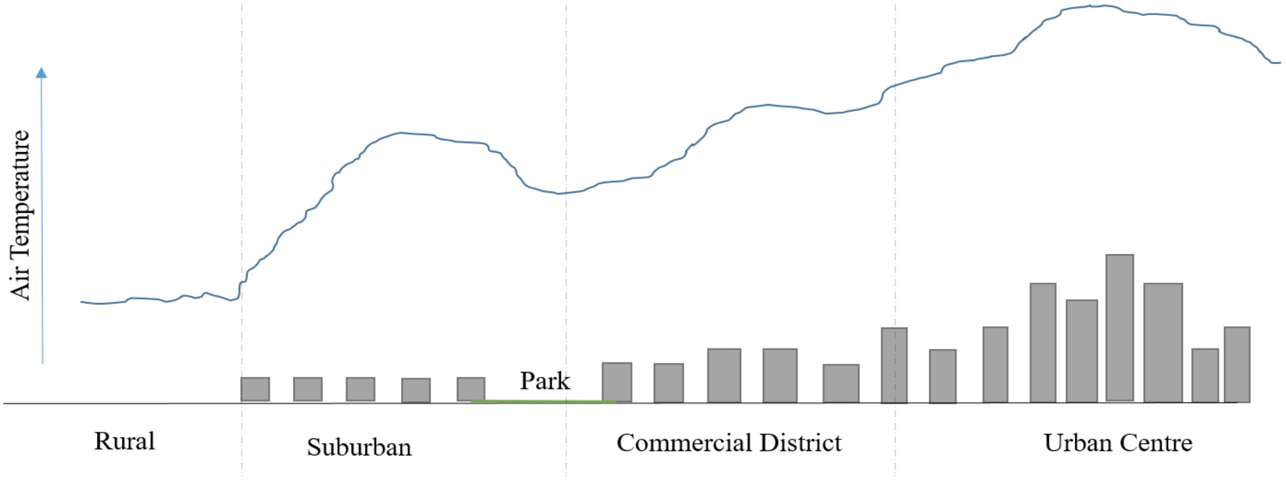


Figure 6 Generalised cross-section of UHI (Oke, 1987)

Factors contributing to the UHIE are interlinked and affect each other. Figure 7 shows a causal loop diagram considering the typical relationship between energy consumption, pollution and UHI of a city. In this figure the 'S' represents the word same, indicating that the next effect will react the same as the previous effect did. This diagram shows the reinforcing loop effect of the UHIE. The scenario depicted in Figure 7 will typically occur in an existing city that is polluted.

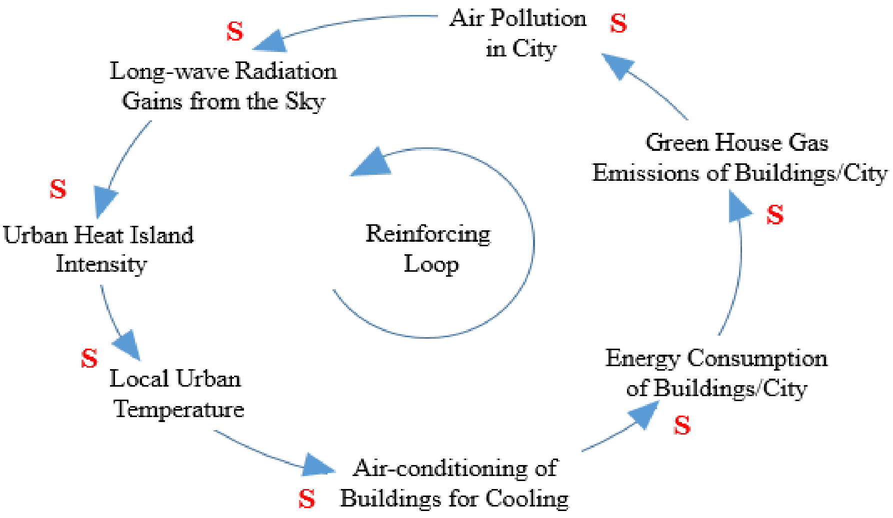


Figure 7 Causal Loop Diagram: Compilation of UHIE

The diagram in Figure 7 shows that long wave radiation gains from the sky increases the UHI intensity or effect. This is due to additional radiation loads due to the pollutants in the air above the city (Oke, 1987; Asimakipoulos et al., 2001). This figure shows that the presence of the UHIE increases the UHIE and that the UHIE results in more pollution and more building energy usage.

More factors contributing to the UHIE are discussed in Table 1. This table briefly discusses the possible mitigation strategies for each cause listed. Figure 8 is a graphical representation of causes 1 to 7 in Table 1.

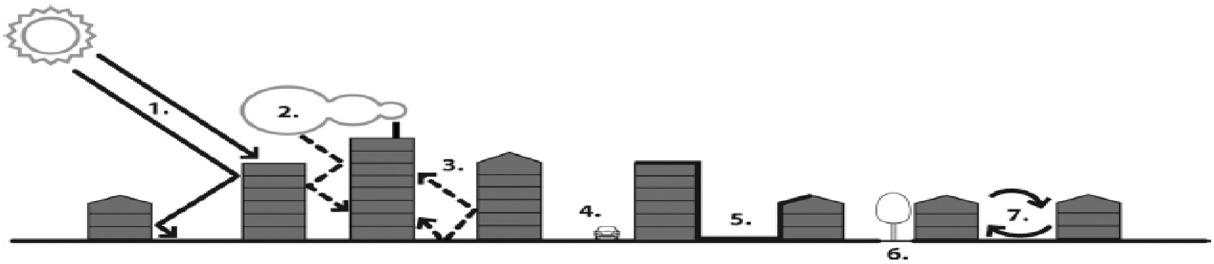


Figure 8 Causes of Urban Heat Islands (Kleerekoper et al. 2012)

The main strategy that can be used to mitigate the UHIE in the urban environment is to reduce energy consumption in cities and GHG emissions into the atmosphere (Gago et al., 2013).

A study by Hirano & Fujita (2012) evaluates the impact of the heat island effect. The study mainly focused on the energy consumption for heating and cooling of buildings and water in the commercial and residential sector. The study found that energy consumption was increased due to UHI in the commercial sector, but reduced in the residential sector. Their conclusion was that measures to mitigate the UHIE should be applied to city centres where commercial buildings are more common than residential buildings.

Proven ways of cooling the urban environment, thereby reducing the UHIE, include altering the urban microclimate by modifying its heat absorption and emission. This is possible through urban greening such as green roofs and walls and the use of high-reflectivity surfaces such as cool roofs. Cool roofs are roofs painted with highly-reflective white paint. This paint has a low albedo, thus it reflects rather than absorbs solar radiation.

Table 1 Causes of Urban Heat Island (Oke, 1987; Asimakipoulos et al., 2001; Grimmond, 2007; Kleerekoper, Esch and Baldiri, 2012)

Cause no.	Urban Heat Island effect cause	Cause description	Possible Mitigation Strategy
1	Increased short-wave radiation gain	Increased absorption of solar radiation due to multiple reflection in the urban environment.	High reflection paint, building and road materials.
2	Amplified long-wave radiation gain from the sky	Additional radiation load due to air pollution	Increased green space to reduce air pollutants. Other measures to reduce GHG emissions
3	Decreased long-wave loss	Buildings act as obstructions which keeps part of the long-wave emissions within street canyons	Better urban planning and spacing of buildings
4	Anthropogenic heat sources inside urban areas	Heat generated from human activity such as cars, industry etc.	Reduce transport needs
5	Increased heat storage within urban environment due to impervious surfaces	The use of construction materials such as concrete, asphalt etc. which have a large thermal capacity	Reduce surface temperatures by changing albedo and emissivity of materials. Use of porous pavements. Improved roof insulation. Install green roof, cool roof, green walls
6	Less evapotranspiration	Due to a lack of vegetation and an increase in less permeable materials	Increase green space. Increased use of green roofs and green walls.
7	Decreased turbulent heat transfer	A lower wind velocity in courtyards and street canyons results in a decreased convective heat transfer and urban ventilation	Better urban planning, spacing of building and different building heights.
8	Increased energy consumption	Buildings consume more energy for cooling due to increased local or micro climate.	Reduce microclimate by reducing impervious surfaces and increase green spaces to increase evapotranspiration

Increasing openness of a city to allow for cooling winds can also reduce the UHIE. Buildings can also be modified with facades, glazing and ventilation designs (Smith and Levermore, 2008).

The effectiveness of cool and green roofs as UHI mitigation strategies was studied by Li et al. (2014). The study concluded that the two approaches are about equally effective in reducing the surface and near surface UHIs. It was also suggested that cool roofs are a more cost-effective approach to mitigating the city-scale UHIE. Danko (2014) suggests that cool roofs should be used when it is not possible to use green roofs and that these roof types should not be seen in opposition to each other. Unlike cool roofs however, green roofs can help with stormwater management and provide more environmental, social and economic benefits.

Gago et al. (2013) reviewed recent literature on strategies to mitigate adverse effects of UHIs in cities. Some of the conclusions of the study are listed, where:

1. The three main elements to consider in urban planning are buildings, green spaces and pavements. These elements have a major impact on temperature variation in a city.
2. The formation of UHI is affected by the distribution of buildings and urban structures in a city.
3. The combination of high buildings and narrow streets encourages the UHIE.
4. Vegetation cover improves the environmental conditions of the surrounding area as well as building energy consumption.

These strategies are mostly helpful to use in the planning stage. Figure 9 shows a summary of the strategies to consider during planning stages to reduce or prevent UHI formation in the city, as well as strategies to reduce the UHIE in existing cities.

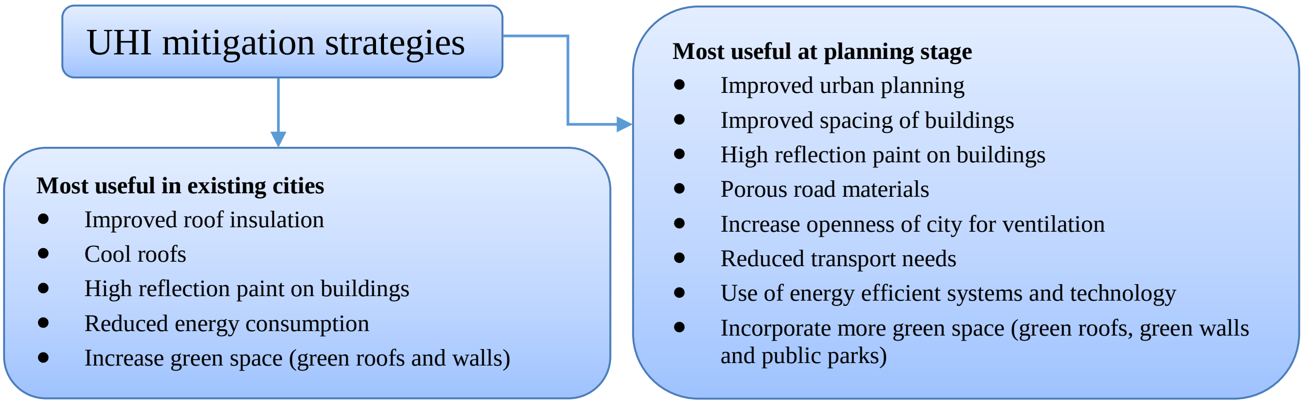


Figure 9 UHI Mitigation Strategies

2.1.4 The Existing City

In an existing city where population and building density are increasing, environmental concerns such as air pollution, stormwater pollution and the formation of Urban Heat Islands are inevitable. This is true since anthropogenic activity increases as the population grows and building density increases. This results in a reduced amount of green space and an increase in impervious surfaces. In order to reduce the adverse effects of urbanisation significantly more than one type of mitigating strategy and technology will have to be implemented in an existing city (Booysen, 2013; Selmi et al., 2016). However, a strategy that can be implemented to start to reduce the environmental concerns mentioned is to increase the amount of vegetated areas in a city.

Greening in a city can be done by increasing the number of green areas, such as parks, and by planting more trees. However, space is needed in order to do this. In densely built up cities space is limited. An alternative way to green cities is to retrofit green walls and roofs on existing buildings. When a green roof or wall is retrofitted onto an existing building, the impervious surface of the rooftop or wall is effectively replaced with vegetation.

Green roofs can be used to mitigate the UHI effect. Green roofs are known to reduce air pollution, the UHIE and are used as a stormwater BMP, as shown in Figures 3, 4 and 9. For the purpose of this study the use of green roofs to increase vegetation in a city is considered. Green walls were not considered.

According to Gago et al. (2013) green roofs are a feasible solution when applied to multi-story buildings as well as low-rise commercial buildings in order to combat the UHIE within a city, as green roofs improve a building’s energy performance and the environmental conditions of its surroundings. The benefits of green roofs and the implementation of them in cities are discussed in detail in the following section of this chapter.

Considering the scenario depicted in Figure 7, implementing measures that reduce GHG emissions will lead to reduced air pollution, which in turn can lead to lowered UHI effects and a reduction in the energy usage of buildings for cooling purposes. As previously mentioned, greening a city can help to filter and purify the air in the city, thereby reducing the GHG emissions. Figure 10 shows a causal loop diagram of the possible spin-off effects of increasing the green fraction in a city, through the implementation of green roofs on a large scale in an area where the UHIE is apparent.

This figure shows that implementing green roofs can theoretically have a fourfold influence on the UHIE regarding energy consumption and air pollution. The reinforcing loop is a simplified version of the causal loop diagram in Figure 7. In this figure the 'O' and 'S' represents the word opposite and same respectively, indicating that the next effect will react the opposite to the previous effect.

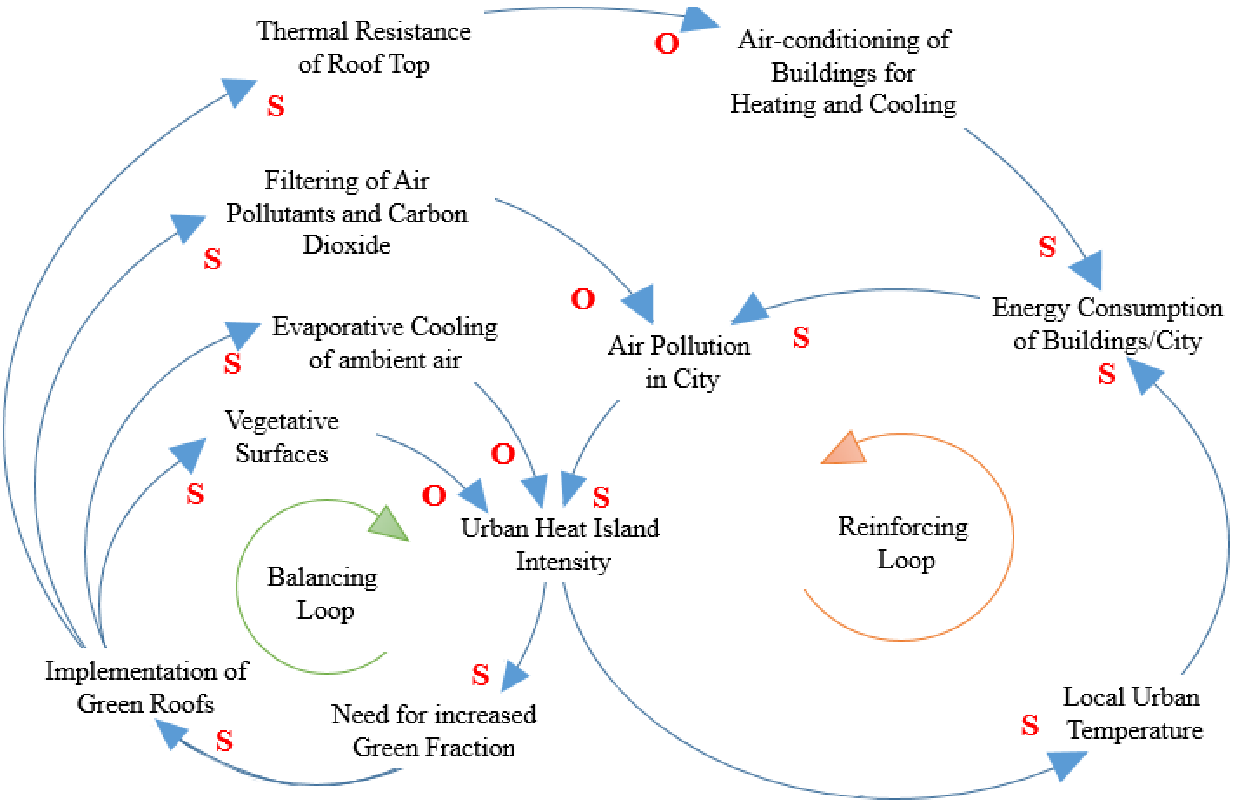


Figure 10 Casual Loop Diagram: Compilation of Effect of Increasing the Green Fraction

Figure 10 shows that the increase in UHIE results in an increased need for green space in the city. In the scenario depicted in this figure, green roofs are chosen as a means to increase the green fraction of the city. This scenario assumes large scale implementation of green roofs. The effects of implementing green roofs by retrofitting them onto existing buildings are as follows:

1. The impervious surfaces of the rooftops are replaced with vegetative surfaces. Reducing impervious surfaces leads to reduced absorption of solar radiation, reduced heat storage of the building and reflected heat within the urban environment, leading to reduced UHIE.

2. The vegetation on the rooftops cools down the ambient air on the roof through evaporative cooling which leads to a lowered microclimate, which leads to reduced UHIE.

3. The vegetation filters and purifies the air around it thereby reducing the air pollution in the city. This leads to a reduction in UHIE since the heat that would previously have been trapped in the city due to air pollution, can escape.

4. The thermal resistance of the rooftop is increased due to the soil and vegetation layer on the roof. Consequently less radiation is absorbed by the building during the day and less heat escapes the building during the night. The heat within the building is better regulated, thereby reducing the heating and cooling needs, which reduces the building's energy consumption. Reducing the energy consumption of the buildings will lead to reduced GHG emissions both within the city and at the electricity plants providing the electricity. Reduced GHG emissions lead to less air pollution which leads to a reduction in the UHIE.

   In addition to the reduction in building energy consumption, the reduced use of air conditioners can directly contribute to reducing the UHIE. A study done by Ohashi et al. (2007), looked at the effect of air conditioner waste heat from office buildings on local air temperature. The study area was in Tokyo. The results indicated that the air conditioners' waste heat caused an increase of 1°C to 2°C.

The overall reduction in UHIE as described and depicted in Figure 10, can theoretically lead to an ongoing reduction in air pollution and energy consumption. The reduction in UHIE will reduce the need to increase the green fraction of a city. This is considered a balancing loop as shown in Figure 10.

The layout of a city has a great effect on the way heat moves through the city. Therefore the location of a building retrofitted with a green roof within a city could hold some significance. Planning where to place green roofs and how many buildings to retrofit may influence the success of the green roofs to mitigate the UHI and reduce runoff during rainfall conditions.

Different approaches are used to simulate, predict and investigate the UHIE, such as Computational Fluid Dynamics (CFD) simulations (either meso- or micro-scale), or Urban Canopy Models (UCM). However, these tools have major limitations due to the complexity and characteristics of an urban environment. Improving on these models can help to better simulate and understand how urban planning and building design influence the urban environment (Mirzaei and Haghighat, 2010).

CFD and UCM could provide better insight into the ability of green roofs to mitigate the UHIE, reduce air pollution and reduce stormwater runoff when implemented on a large scale (Li, Bou-Zeid and Oppenheimer, 2014; Toparlar et al., 2014; Wang and Li, 2016). However the use of CFD or UCM is not investigated in this study.

Li et al. (2014) investigated the ability of cool and green roofs to mitigate the UHIE when implemented on a large scale, using UCM and a weather forecasting model. The Weather Research and Forecasting (WRF) and Princeton Urban Canopy Model (PUCM) were used to model the cooling impact of cool and green roofs over a metropolitan area during a heat wave. The investigation looked at the surface UHIE, defined as the urban-rural surface temperature difference and the near surface UHIE, defined as the urban-rural temperature difference 2 meters above the surface. The results showed that surface UHIE is reduced more than the near surface UHIE. Furthermore, the study found that as the cool or green roof fraction increased, the surface and near surface UHIE reduced almost linearly.

Costanzo et al. (2016) compared the use of green and cool roofs. The comparison showed that cool roofs are the most suitable solution for reducing the external roof surface temperature in any climate. Cool roofs are also less expensive than green roofs. However cool roofs do not offer a wide range of benefits, as discussed in the following section, compared to green roofs. Resultantly, cool roofs will not be considered in this report.

2.1.5 Hypothetical Effects of Implementing Green Roofs

This section looks at what the hypothetical effect of implementing green roofs in a city will be, with respect to UHIE, air pollution and building energy consumption for heating and cooling. This section forms the background study for the investigation conducted in Chapter 9.

The causal loop diagram shown in Figure 10 was used to evaluate the effects of implementing green roofs. Figure 11 shows the factors and their effects on each other. The ‘S’ shows that the factor will have the same effect as the previous one and the ‘O’ means that the factor will have the opposite effect.

In this hypothetical scenario it is assumed that a densely built-up urban area in a city has an increasing problem with the UHIE. Therefore, the green fraction in this area needs to be increased. As the UHIE increases, so does the need for more green spaces. The city chooses to increase the green fraction by installing green roofs on many of the existing buildings. This option is chosen since the area is densely built up and there is no space to create parks or plant more trees.

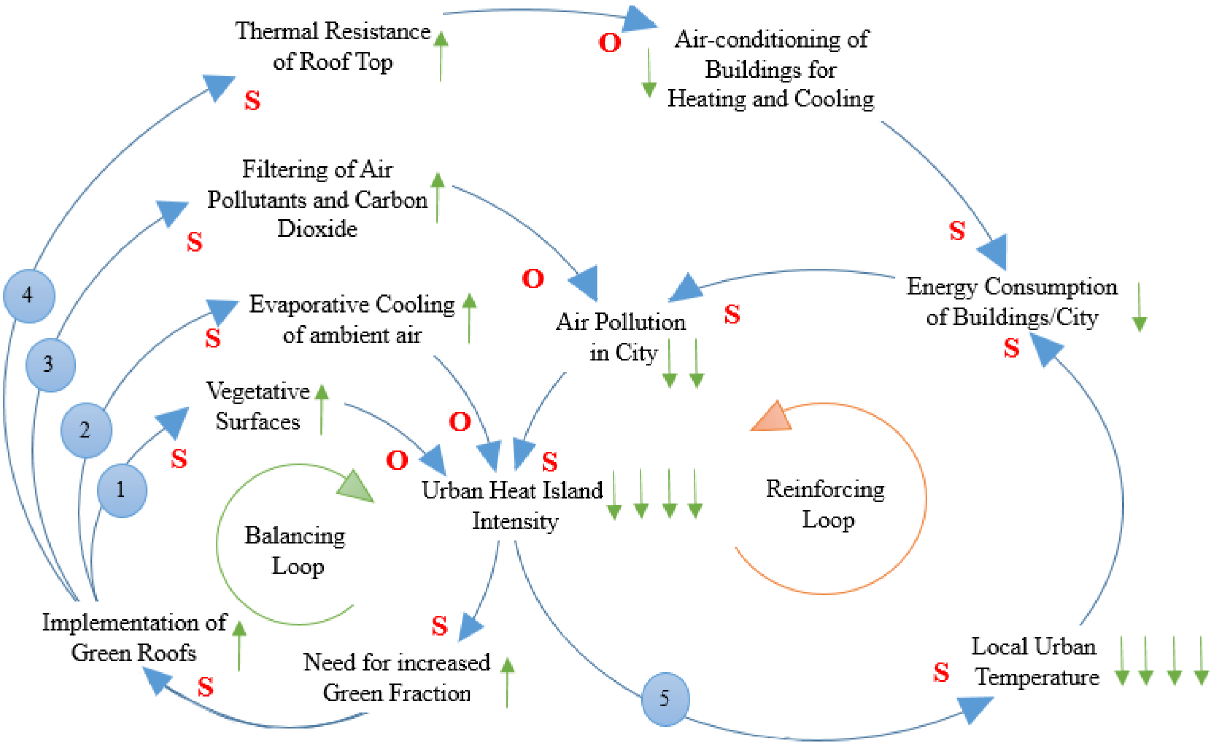


Figure 11 Casual Loop Diagram: Evaluation of Green Roof Implementation

Looking at Figure 11, the effects of this choice have the following results. The green arrows indicate whether the factor is reduced or increased by pointing downwards or upwards respectively.

1. *Consider the balancing loop numbered 1:* The increase in green roofs increases the vegetative surface in the city, which directly reduces UHIE.

2. *Consider the balancing loop numbered 2*: The increase in green roofs results in an increase in evaporative cooling of the ambient air around the roof, which directly reduces UHIE.

3. *Consider the balancing loop numbered 3:* The increase in green roofs increases the amount of plants in the area, which leads to polluted air being filtered and purified. This leads to a direct reduction in air pollution, which leads to an indirect reduction in UHIE.

4. *Consider the balancing loop numbered 4:* The increase in green roofs increases the building's thermal resistance, which means that the building does not need to use the same amount of electricity for cooling and heating purposes. This leads to a direct reduction in the building's energy usage, leading to an indirect reduction in air pollution and UHIE.

At this stage two factors are directly contributing to a reduction in UHIE, one factor is directly contributing to a reduction in air pollution, the other factor is directly contributing to a reduction in building energy consumption, which adds to four factors causing a reduction in UHIE.

5. *Consider the loop numbered 5, the reinforcing loop:* If four factors are reducing the UHIE, it leads to four factors reducing the local urban temperature in the area, leading to a further reduction in building energy consumption since the need for cooling the building is reduced. If the four previously discussed factors can reduce the UHIE enough, the reinforcing loop will also result in a reduction in the UHIE.

In conclusion, if a city has an urban area where the UHIE or pollution is a problem, the implementation of green roofs in that area can theoretically reduce the problem. Figure 12 is a simplification of Figure 11. Figure 12 shows that implementing green roofs has a balancing effect. Thus, when the need to increase the green fraction in an area is high, green roofs can be implemented. As green roofs are implemented in the area, the UHIE, air pollution and building energy consumption of that area reduces. This reduces the need to increase the green fraction in said area until there is no more need to increase the green fraction, which means there is no need to continue to install more green roofs. Therefore, the more green roofs are implemented in an area, the less the need to implement them becomes as shown in Figure 12.

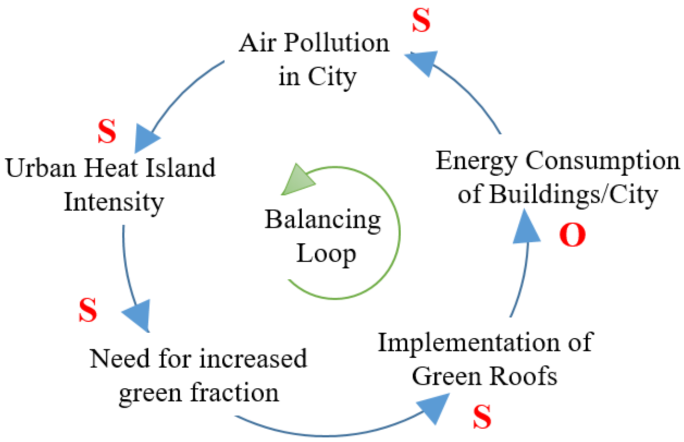


Figure 12 Causal Loop Diagram: Theoretical Effect of Green Roofs

This hypothetical result of implementing green roofs considered the benefits related to green roofs in terms of an urban area’s air temperature, air pollution and the energy usage of the buildings. Other benefits that can be analysed in a similar way is a green roof’s ability to retain stormwater, increase biodiversity and reduce city health care costs due to air pollution.

2.2 Green Roofs

In this section green roof systems are defined in more detail; the different types of green roofs as well as their benefits to the public and private sector especially regarding UHIE, air pollution and stormwater management, are discussed. The use of green roofs for UHI mitigation, reduced air pollution and stormwater management in existing cities are explored and the criteria of a building that can be retrofitted are also discussed.

The use of an extensive modular green roof system was considered for the purpose of this study as it is less expensive to construct and maintain, suitable for retrofitting onto existing buildings and requires less or no structural strengthening of the building. An intensive direct system is typically more expensive and structural strengthening is required. The benefits of modular extensive systems compared to intensive direct systems are discussed in the following sections.

2.2.1 What are Green Roofs?

Green roofs, also referred to as planted, brown, living, eco or vegetated roofs, are roofs which are covered with soil and plants. Green roofs are usually classified into two types, either intensive or extensive roofs. An intensive green roof has a substrate depth thicker than 150 mm, whereas an extensive green roof's substrate depth is between 40 and 150 mm.

Two types of extensive green roofs are used in South Africa. Direct and modular green roof systems. Modular green roofs consist of specially designed containers, trays or modules with the substrate and plants placed into the trays. The trays are placed next to each other to create the green roof system. With a direct green roof system the substrate is placed directly on the underlays required for the green roof. Under layers required for a direct green roof system are an additional protection layer on top of the existing roof membrane and a drainage layer. The drainage layer is not always required for modular systems.

Extensive green roofs are considered the more economically viable option and are easily retrofitted on existing roof surfaces. Extensive green roofs require less maintenance and are perfect for drought tolerant plants that thrive in conditions where only a limited amount of water and nutrients are available. The vegetation selected for the plant layer must be drought resistant and tolerant to harsh weather conditions. It can be very windy on a roof top and the plants will typically receive direct sun for most of the day. Plants selected should also preferably be low growing and self-seeding

(Greenstone, 2011). Most succulents indigenous to South Africa will be suitable. It is important to plant more than one type of plant in order to not create a monoculture and to improve biodiversity. Maintaining a modular extensive green roof requires the least amount of maintenance compared to other green roof systems (Greenstone, 2011; Bianchini and Hewage, 2012a; Labuschagne and Zulch, 2016).

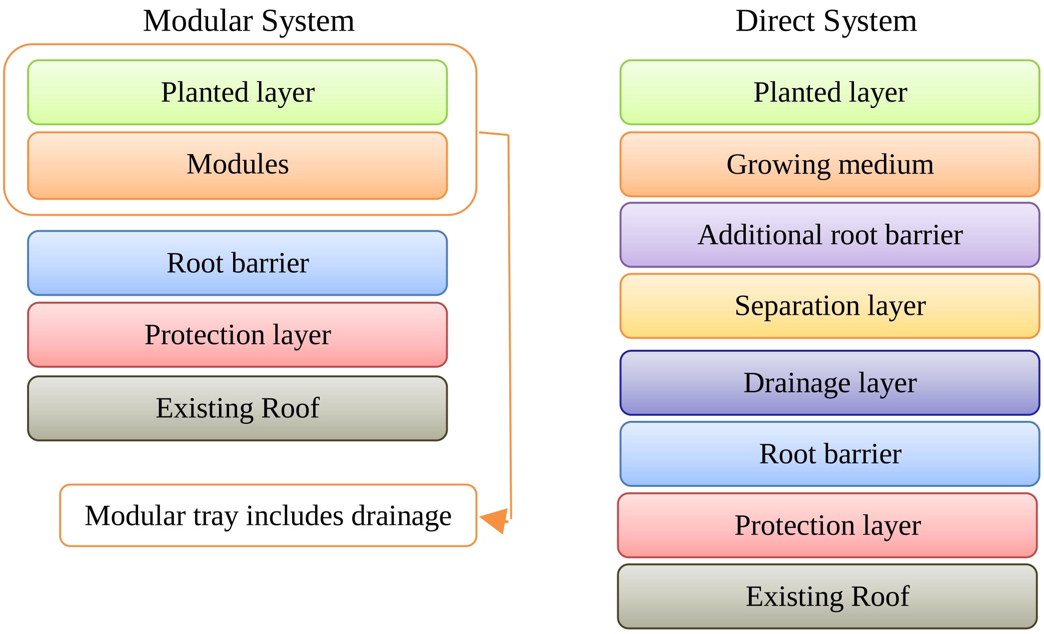


Figure 13 Modular and Direct Green Roof Systems (Adjusted from Niekerk et al. 2011)

Figure 13 shows the different elements for a direct and modular green roof system. As shown in the figure, modular systems can have the drainage layer included in the modular tray. The figure shows that all the layers of the direct green roof system are continuous, whereas only the protection and root barrier layer are continuous for the modular system.

The advantages and disadvantages of a modular green roof system compared to a direct system are as follows (Greenstone, 2011);

- The trays can easily be moved without disturbing the plants or growing medium.
- The green roof can be installed in sections, thus alterations can be made at a later stage or more trays can be added.
- Quick installation is possible since trays can be pre-planted.
- Trays are ‘do it yourself’ friendly
- Trays can be installed on almost any existing roof surface which has the structural capacity to carry the additional load and is in a good condition.

The only disadvantage of modular green roof systems mentioned is that the plants may struggle since there is less space for the roots than in a direct green roof system. Thus plants with shallow root systems must preferably be used in modular systems. This disadvantage can be avoided by making use of advanced modular systems which allow roots to grow through different trays.

In Germany over 80% of green roofs are extensive systems and these types of green roofs are expected to offer the most cost effective approach for roof greening (Harzmann, 2002). Extensive green roofs implemented on a citywide scale have the potential to provide a wider variety of benefits than other vegetative roof systems. These benefits can be realised for both building owners and the public (Booysen, 2013).

Green roofs usually contain plants such as grass and sedum which need less soil and maintenance. A study done at the University of Stellenbosch compared different roof cover alternatives and quantified their performance using a performance score. This performance score was based on the reduction in outdoor surface temperature 1m above the surface, water requirements, maintenance resistance to weather, ecological benefit, carbon sequestration and nutritional value, each parameter having the same weight. The study found that a native succulent plant, Portulacaria afra, which has enormous carbon-storing capabilities, gave the best performance score and reduced the surface temperature of the rooftop by 13.8% (Volkmann, 2016).

Portulacaria afra is locally known in South Africa as “spekboom”. A spekboom thicket is said to be ten times more effective per hectare at carbon fixing, converting inorganic carbon to organic compounds, than any tropical rain forest. Each hectare of spekboom can potentially capture 4.2 tons of carbon annually (The Spekboom Foundation of South Africa, 2014).

2.2.2 Benefits of Green Roofs

Numerous studies write about the advantages of green roofs. Köhler et al. (2002) suggest that green roofs contribute to a better microclimate due to evapotranspiration. Evapotranspiration is the process where plants lose water in the form of vapour released into the air. Evaporation produces the cooling of leaves and the air temperature around them (Dimoudi and Nikolopoulou, 2003). The evapotranspiration process also filters the dust in the air, thus improving the air quality, while lowering the roof temperature.

According to Carter & Keeler (2008) both the private and public sector can benefit from using green roofs as the reduced pollutant loads and the ambient air temperature of the city improves social welfare.

Furthermore green roofs can allow private building owners to receive economic compensation from providing a service for industries looking to offset their polluting activities. Such an incentive can prove beneficial when carbon tax is implemented for buildings, new and existing.

Incentives such as these, that can be used to promote the implementation of green roofs, are discussed in more detail in section 2.4 of this chapter.

The benefits for the public and private sectors when implementing green roofs on a large scale are listed in Table 2. Booysen (2013), determined these benefits form literature and interviews held with national and international specialists in the built environment. Table 2 shows that there are many more benefits to the public sector when green roofs are implemented on a large scale as opposed to benefits for the private sector.

According to Booysen (2013) the cumulative way in which the implementation of green roofs benefit the public sectors is still unknown even in countries that have been implementing green roofs for a number of years. The most important benefits realised when implementing green roofs on a large scale are better stormwater management, reduced air pollution, UHI mitigation, job creation and the production of food to increase food security.

Table 2 Benefits of implementing green roofs (City of Waterloo, 2005; Booysen, 2013)

Public Benefits (Benefits realised when implemented on a large scale)		**Private Benefit** (Benefits realised when implemented on single building)	
1	UHI mitigation	1	Increased property value due to aesthetic appeal
2	Improved air quality		
3	City scale stormwater management		
4	Food security through production possibilities in cities	2	Energy efficiency, resulting in savings
5	Economic growth and job creation specifically in construction and maintenance		
6	Increased physical and physiological health for people living in the city	3	Increased lifespan of roof water proofing membrane
7	Wider scale energy savings. Energy savings are not influenced by individuals		
8	Conservation of areas biodiversity	4	On-site stormwater management
9	Better living environment for local population		
10	City infrastructure savings		
11	Cultural preservation in terms of aesthetics		
12	Reduced landfill waste due to less frequent roof and waterproofing replacements		

As mentioned, green roofs also help with the retention of rainwater, which results in a significant reduction in rainwater input in sewage systems during rainfalls. Extensive green roofs are highly effective at retaining stormwater for small storm events with recurrence intervals of 1 to 2 years, but are less effective at retaining significant portions of runoff from larger 25 to 100 year storms (Carter and Fowler, 2008).

Green roofs increase the lifespan of the waterproofing membrane: research suggests that the lifespan of a waterproofing membrane is doubled when placed under a green roof (Niekerk, Greenstone and Hickman, 2011; Breuning, 2012). A report that reviewed application strategies of green roof considered the lifespan of a green roof to be between 40 and 55 years (Saadatian et al., 2013). Green roofs are aesthetically pleasing and thus increase the marketability of a building, and can act as a habitat for urban wildlife and insects. Green roofs also have the potential for food production and can create reliable jobs, which with training can be made available to local low-income individuals. The local economy can also be stimulated by creating local “green collar” jobs (Dunn, 2010). These green collar jobs consist of construction, maintenance and installation of green roofs.

In a study by (Li, Bou-Zeid and Oppenheimer, 2014), the ability of green roofs to reduce the surface temperatures were analysed for three different urban areas: low density residential, high density residential and industrial/commercial. The study was done to determine the impacts of city-scale green roof implementation on the different urban areas. Different fractions of green roofs were simulated for each urban area. The results of the simulations showed that the surface temperature reductions are most noticeable when implemented in industrial/commercial areas. These results show that the implementation of green roofs on a city-scale is most viable for urban centres such as CBDs. The results of the study showed that when 100% of the roofs in an industrial/commercial area were vegetated, a reduction in surface temperature of up to 7°C was measured, at peak temperatures. Contrary to this study, other literature suggests that the ambient temperature of a city can be reduced by as much as 2°C with only 8% of the roofs in the city retrofitted with green roofs (Gunnell et al., 2009). Research findings suggest that the reduction in ambient are due to the increase of green roofs are very locality-specific.

Graphical representations of the results for the three different types of urban areas are shown in Appendix A, Figure A-1. In conclusion, green roofs can be a useful tool for UHI mitigation, but the effect of green roofs can only really be seen when a specific area implements green roofs on a large scale (van der Walt, 2012).

2.2.3 Urban Heat Island Mitigation

Wong et al., (2003), evaluated the mitigation potential of green roofs by performing measurement of the ambient air temperature at various heights over a vegetated and a conventional roof in Singapore. The study indicated that the cooling effect of the green roof is restricted by the amount of floors in a building. The study concludes that green roofs may be effective when the building height is lower than 10m.

The influence of a green roof is more important during the day time, as it has a larger impact on the ambient air temperatures in the day time (Coutts et al., 2013). The study by (Li, Bou-Zeid and Oppenheimer, 2014), as previously discussed, showed similar results. They studied the effectiveness of cool and green roofs as UHI mitigation strategies, using an urban canopy model. The model simulated the effect of increasing the fraction of green or cool roofs on the UHI in the city. The fraction of green and cool roofs increased from 0% to 100%.

The results of the simulation showed that increasing green roof fractions can significantly reduce the daytime surface temperature by approximately 4 °C. However the night time surface temperature only reduced by approximately 1°C. Similar results were seen for the near-surface temperature. The reason for the difference in surface temperature reduction seen for day and night times is due to the increased evapotranspiration during daytime as a result of increased vegetation i.e. the green roofs. Evapotranspiration has little effect during night times. The green roofs' ability to reduce the UHI during daytime results in reduced heat storage in the urban canopy. The fact that the surface temperature is still reduced during night time suggests that the cooling effects can probably last through the night (Li, Bou-Zeid and Oppenheimer, 2014). The results of the reduction in surface temperature, when temperature peaks, suggest a linear relationship between the maximum reductions in UHIE and the green roof fractions, Figure A-2 in Appendix A shows this relationship.

The linear relationship suggests that the study area must have 30% of its roofs covered with green roofs to have a 1.1 °C reduction in surface temperature. The surface temperature can be reduced by a maximum of about 3.8°C if all the roofs were to be covered with green roofs. The study's results of the analysis are shown in Figure A-2 in Appendix A, the data in Figure 14 corresponds with this data.

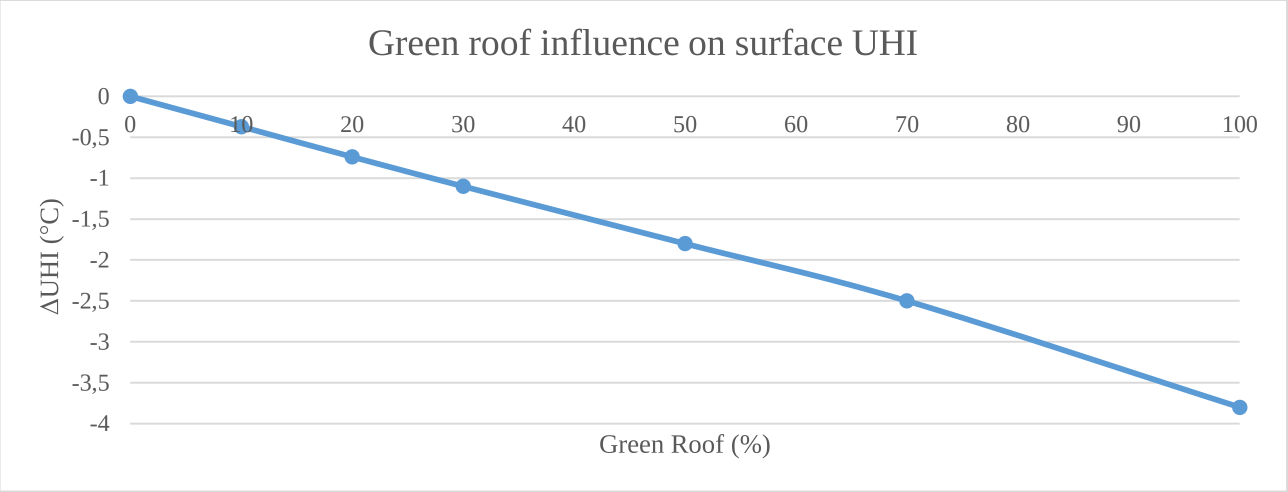


Figure 14 Corresponding reduction in surface temperatures when surface temperatures reach their maximum (Li, Bou-Zeid and Oppenheimer, 2014)

The performance of green roofs is closely related to the soil moisture conditions of the green roof (Li, Bou-Zeid and Oppenheimer, 2014). Altering the soil moisture conditions affects the performance of a green roof, as soil moisture has a significant influence on its performance. A higher soil moisture value will lead to more efficient evaporation (Sun, Bou-Zeid and Ni, 2014), thus increasing the green roof's ability to reduce surface heat. Soil moisture also affects the green roof's ability to retain rainwater.

The impacts of altering soil moisture on green roofs were also evaluated by Li et al. (2014). Their study analysed the change in reduction in surface and near surface temperatures when altering the soil moisture in green roofs. For this analysis 50% of the city's roofs were covered with vegetation and the results compared to the case where 0% of roofs are covered with vegetation. The default soil moisture value was set to be $0.33\mathrm{m}^3\mathrm{m}^{-3}$, which was equal to the rural grass top level soil moisture of the surrounding areas.

With the green roof fraction being 50%, results showed a maximum reduction in surface and near-surface UHIs of 1.81°C and 0.26°C respectively compared to the 0% green roof fraction case. Two other cases were analysed, one in order to determine the performance of green roofs under very dry conditions, the other to determine the performance of irrigated green roofs. A figure showing the results from the analysis can be seen in Appendix A, Figure A-3. The results of the analysis are shown also in Table 3. The values in °C in this table are the reduction in surface and near surface UHI temperature for a city 50% green roofed, compared to 0%. The results shown in Table 3 are graphically shown in Figure 15. This figure shows that green roofs have a much larger effect on the UHI at a surface level, compared to 2m above the surface (near surface level).

Table 3 Change in temperatures when changing green roof soil moisture (value at times of peak temperatures) (Li, Bou-Zeid and Oppenheimer, 2014)

Case	**Default**	**Very Dry**	**Dry**	**Irrigated**	**Extensively Irrigated**
Green roof soil moisture (m^3m^{-3})	0.33	0.15	0.25	0.35	0.45
Changes in surface temperature (°C)	1.81	0.25	1.30	2.10	2.40
Changes in near-surface temperature (°C)	0.26	0.01	0.19	0.31	0.38

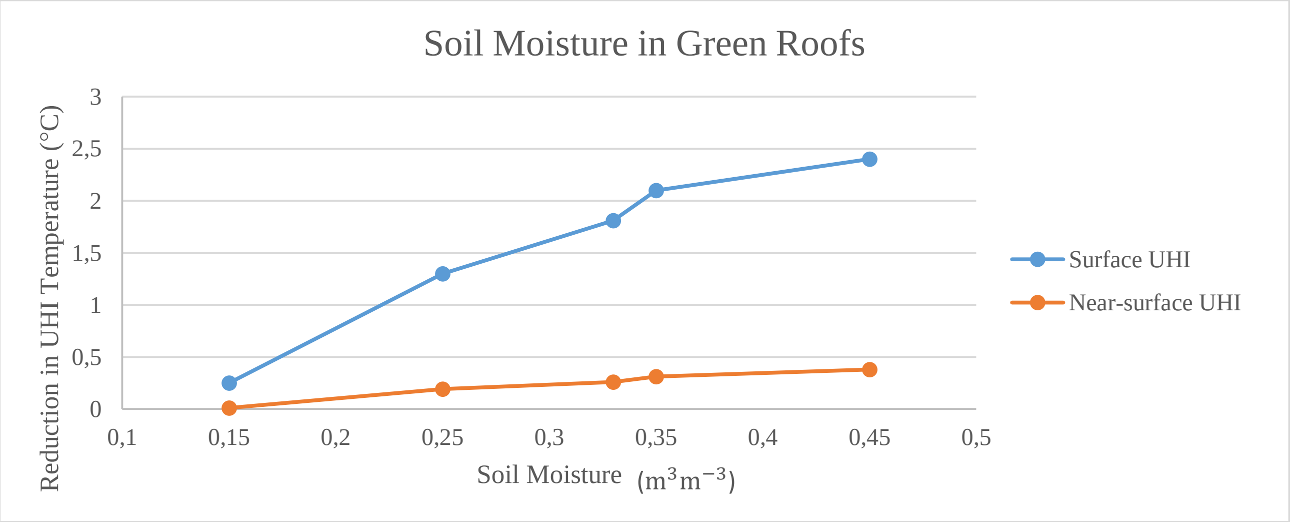


Figure 15 Effect of soil moisture content on green roof's UHI mitigation ability

Maintenance of green roofs and irrigation is a very important part of implementing green roofs according to best management practices. The study by Li et al. (2014) discussed the simulation of green roofs that use grass as the vegetation. Making use of water efficient plants such as succulents may lead to reduced irrigation and maintenance needs and increased performance of green roofs under dry conditions.

2.2.4 On-Site Stormwater Management

Green roofs have the capacity to retain stormwater and can be implemented anywhere that there is a building, theoretically claiming back already used land. Thus in densely developed urban centres where other BMPs, such as stormwater or detention ponds, are impossible to use or cost-prohibitive, green roofs can be implemented.

Green roofs are seen as a stormwater best management practice especially in urbanised areas (Lawlor et al., 2006). Green roofs, having vegetated surfaces, can absorb a percentage of the precipitation during rain showers, whereas impervious surfaces, such as traditional roofs, cannot. Furthermore, green roofs provide on-site stormwater management. A study on the use of green roofs for urban drainage applications by Locatelli et al. (2014), found that extensive green roofs can reduce the mean annual runoff by up to 20% compared to a traditional roof. The study concluded to say that green roofs have the potential to play an important role in future urban stormwater management plans. Due to the fact that green roofs can be used to retain stormwater, irrigation systems should not be placed onto extensive green roofs. Irrigating a green roof will reduce its ability to retain water and would require the application of fertilisation which would pollute the runoff water due to increased nutrients (Breuning, 2013).

Zhang et al. (2015) researched the ability of green roofs to reduce stormwater runoff and pollution. The study found that the annual retention rate of a green roof is 68% better than that of a traditional roof. The study also found that green roofs may reduce pollutants in the runoff water such as Total Suspended Solids (TSS) concentration as well as reduce the pH level, while increasing others such as the Total Nitrogen (TN), NH_4^+-N and NO_3^--N. These increases in pollutants may be due to the soil characteristics and nutrients added to the soil during maintenance as well as the types of vegetation used. In Wisconsin, USA, the Milwaukee Metropolitan Sewage District offers to fund the retrofitting of buildings with modular green roofs in order to capture rainwater on the region’s rooftops and keep that rainwater out of the sewer system (Leipzig and Mohr, 2012). Many other cities have similar incentives to promote on-site stormwater management and to reduce the system’s load.

The temperature of the water also has an effect on the health of the aquatic ecosystem. Lowered water temperatures enhance water quality by reducing the potential for algae formation; higher water temperatures cause the formation of algae, which reduces the water clarity and results in anoxic conditions (City of Waterloo, 2005). As mentioned, green roofs are a stormwater source control measure or on-site stormwater management system and are considered a stormwater best management practice (Lawlor et al., 2006). On-site stormwater management is beneficial since the rain that falls on the site is temporarily stored and released slowly, which reduces the run-off, controls the peak flow and reduces the risk of downstream flooding.

2.2.5 *Existing Roof's Structural Capacity*

When retrofitting a green roof system to an existing roof, the type, size and design of a green roof will be restricted to the load-bearing capacity of the existing roof (Niekerk, Greenstone and Hickman, 2011). Before retrofitting a building with a green roof it is recommended to consult a structural engineer to determine the load-bearing capacity of the existing roof. For an extensive green roof system, additional structural support may not be necessary. Retrofitting of extensive green roofs is often possible without additional structural reinforcement (Dunnett and Kingsbury, 2004). An extensive green roof system has a thin substrate depth, between 40mm and 150mm, whereas an intensive green roof system has a thicker substrate depth. Therefore less structural reinforcement is required to carry an extensive green roof's imposed loads (van der Walt, 2012). Furthermore, extensive systems are usually designed to require minimal maintenance (GSA 2011; Whittinghill & Rowe 2012) making the roof's accessibility requirements less.

According the South African National Standards (SANS 10160-2:2011) an accessible flat roof is a roof designed to carry additional access as well as access required for maintenance (SABS, 2011). An accessible flat roof is designed to carry an imposed load of 2kN/m^2, together with the roof's dead load, which is the roof's own weight (SABS, 2011). Furthermore SANS 10160-2:2011 requires the use of a loading factor of 1.6 and 1.2 for imposed loads and dead loads respectively. An existing commercial building with a flat roof will generally have the following capacity, assuming the roof is designed according to the South African building regulations:

$$\begin{aligned} \textit{Structural capacity of accessible flat roof} &= 1.6 \times \textit{Imposed load} + 1.2\ \textit{Dead load} \\ &= 1.6 \times 2 + 1.2 \times \textit{Roof self-weight} \\ &= 3.2 + 1.2 \times \textit{Roof self-weight kN/m}^2 \end{aligned}$$

When retrofitting an existing building with an extensive green roof, the dead load of the roof increases. Green roofs have the ability to retain rainwater due to the substrate layer. The dead load of this substrate layer varies depending on whether the soil is saturated or dry. The maximum load exerted by the green roof will be when the soil is fully saturated. A planted, fully saturated modular green roof system with a substrate depth of 100mm weighs 80 kg/m^2, which is 0.785kN/m^2 (Greenstone, 2011).

Suppose an extensive modular green roof system with a substrate depth of 100mm is retrofitted onto an existing flat roofed commercial building. It is assumed that the building is designed to have the structural capacity of an accessible flat roof. The dead load of the retrofitted roof would be as follows:

$$\text{Retrofitted roof dead load} = \text{Roof self-weight} + \text{Saturated green roof system load}$$

$$= \text{Roof self-weight} + 0.785\ kN/m^2$$

It is notable that minimal maintenance is necessary for the green roof system, since it is an extensive system. As such, once the roof is retrofitted the roof needs to be considered inaccessible, since only minimal maintenance is required and additional access will no longer be provided. According to SANS 10160-2:2011 the imposed design load for an inaccessible roof, designed for normal maintenance and repair is 0.50 kN/m^2(SABS 2011). The retrofitted roof's imposed load is assumed to be 0.50 kN/m^2. The structural maximum loading exerted on an inaccessible green roof is as follows:

$$\text{Inaccessible green roof load} = 1.6 \times \text{Imposed load} + 1.2 \times \text{Retrofitted roof dead load}$$

$$= 1.6 \times 0.50 + 1.2 \times (\text{Roof self-weight} + 0.785)$$

$$= 0.8 + 1.2 \times (\text{Roof self-weight} + 0.785)$$

$$= 1.742 + 1.2 \times \text{Roof self-weight}\ kN/m^2$$

The structural capacity of a typical flat roof building is compared to the structural capacity required to carry the load of an inaccessible green roof:

- $\text{Structural capacity of accessible flat roof} = 3.2 + 1.2 \times \text{Roof self-weight}\ kN/m^2$
- $\text{Inaccessible green roof load} = 1.742 + 1.2 \times \text{Roof self-weight}\ kN/m^2$
- $\text{Structural capacity of accessible flat roof} > \text{Inaccessible green roof load}$
- $\text{Residual capacity} = \text{Structural capacity of accessible roof} - \text{Inaccessible green roof}$

$$= 3.2 + 1.2 \times \text{Roof self-weight} - 1.742 - 1.2 \times \text{Roof self-weight}$$

$$= 3.2 - 1.742 = 1.46\ kN/m^2$$

Thus the load capacity required for an extensive green roof system, with minimal maintenance requirements is 1.46 kN/m^2 less than the structural capacity provided by an accessible flat roof. Therefore, it can be assumed that invariably no additional structural reinforcement is required when retrofitting a commercial building's rooftop with an extensive modular green roof system with a 100mm substrate thickness.

2.2.6 Construction and Maintenance Standards

Guidelines for construction and maintenance of green roofs are a very important factor in the successful implementation of essentially all the possible policies and incentives that promote green roofs (Booysen, 2013).

Basic guidelines for designing green roof habitats on existing buildings, written for the environmental planning and climate protection department of eThekwini municipality, list the following as important to consider (Niekerk, Greenstone and Hickman, 2011):

1. *Structure of the building, structural capacity:*

   The building must be deemed structurally strong enough to accommodate the additional weight from the green roof. A structural engineer must be consulted to determine the carrying capacity of the existing roof top.

2. *Location of building, shadowing of surrounding buildings, climate of area:*

   The location of the roof, as well as the different micro-climates on the roof, are also important to consider. Wind conditions, as well as the amount of sun and shade on the roof top, should be taken into consideration when choosing plant types.

3. *Roof slope of the exiting building:*

   A roof with a pitched or roof slope more than 10^{o} is considered too steep, as the substrate materials tend to slip or slump and water tends to run-off too quickly. A roof with a slope between 3^{o} and 10^{o} is recommended, as a roof that is too flat can lead to degradation of the plants since water tends to pool which results in root rotting.

4. *Safety in terms of construction and maintenance of green roof:*

   Strict safety considerations must be accounted for during planning and construction; fire hazards and fire preventative measures should be considered. Fire can be prevented by using succulent plants on the green roof as well as ensuring adequate maintenance.

Construction and maintenance guidelines and standards should be specific to the area where green roofs are implemented, which is why it is important to construct a demonstration project when introducing a new technology such as green roofs in an area.

The guidelines provide a list of elements that must be considered when identifying micro-climatic zones on a roof top. These elements are listed in Table 4:

Table 4 Elements of micro-climatic zones on roof tops (Niekerk, Greenstone and Hickman, 2011)

Element	Description
Regional Climate	Plants should be accustomed to the general climate of the region, for example inland or coastal. Using plants indigenous to a specific region.
Aspect	Sloped roofs which face south or west experience less direct sunlight and are therefore cooler and wetter. Sloped roofs which face north or east experience more direct sunlight and are therefore warmer and drier.
Wind	Plants in exposed areas of a rooftop experience higher wind influence. Wind stresses plants by increasing evaporation off their leaves and damaging foliage and branches.
Shading	Some areas of the rooftop may be permanently or periodically shaded by surrounding buildings.

The green roofs must also comply with the requirements of the National Building Regulations if the roof will be accessible to the public. It is recommended that the perimeter of a flat roof be fenced off to prevent people from falling from the building.

As previously discussed, there are two types of green roofs available, direct and modular green roofs. The City of Cape Town Smart Building Handbook, which is a guide for green buildings in Cape Town, recommends the use of modular systems rather than direct green roofing systems (City of Cape Town, 2012).

The Green Building Council of South Africa (GBCSA) is a non-profit company formed in 2007. They are the leaders in greening South Africa’s commercial property sector. The GBCSA has different rating tools. The existing building performance tool is one of the tools available. This rating tool gives a maximum of twenty-four credits towards developments that install green roofs.

The maximum credit score that can be obtained is one hundred credits which will rate the building with six green stars (Booysen, 2013). To promote the implementation of green roofs it is important for a city to lead by example. Sustainability tools such as the green star rating system can influence a city to retrofit its buildings.

There are no criteria specified for the implementation and/or construction of green roofs, which results in isolated green spaces on buildings that have no cumulative effect on any of the benefits realised when implementing green roofs on a large scale (Booysen, 2013).

The Green Building Council of the United States uses the Leadership in Energy and Environmental Design (LEED) green building certification system to rate buildings. The LEED system is a stringent design guideline and measuring tool for designing, constructing and certifying the world’s greenest buildings. The certification includes four levels namely: LEED certified, Silver level, Gold level and Platinum Level (Leipzig and Mohr, 2012). A building with six green stars as rated with the GBCSA green star rating system will not qualify for a LEED Platinum level (Booysen, 2013).

In Germany the FFL 2000 guidelines are used for the construction and maintenance of green roofs. Many specialists consider the FFL guidelines as the best example of guidelines available and that most guidelines almost always incorporate some of the guidelines into their own (Booysen, 2013). The FFL guidelines also specify the criteria of green roofs to be eligible for subsidies (Carter and Fowler, 2008).

The National Building Regulation used for the design of roofs and buildings in South Africa is the South African Bureau of Standards (SABS) 0400 code. These codes however do not include any specification on the designs of green roofs. South African guidelines for green roofs should incorporate the FFL guidelines as far as possible.

2.3 Environmental Aspects in South Africa

This section discusses the current and future environmental concerns in South Africa in general, and considers Johannesburg specifically. The main environmental aspects that were apparent are the need for improved stormwater management and increased green spaces. Increasing the green space contributes to reduced air pollutants and impervious surfaces. Air pollution is increased by the UHIE and impervious surfaces promote the UHIE.

2.3.1 South Africa in General

Operation of the building sector in South Africa produces 23% of the Greenhouse Gas (GHG) emissions (Gunnell et al., 2009). The increasing level of air pollution is mainly due to industrial emissions, domestic use of wood, coal and paraffin, emissions from vehicles, the burning of biomass and energy production (Department of Environmental Affairs South Africa, 2012). The Government of South Africa is aiming to reduce GHG emissions by 34% by 2020 and by 42% by 2025. To achieve this, carbon tax will be introduced. However, when this tax will be introduced is not certain. According to the Carbon Tax Bill of South Africa (2017) the government believes that implementing a tax on GHG emissions and measures such as providing tax incentives for rewarding the efficient use of energy, will steer the economy towards a more sustainable growth path (National Treasury of South Africa, 2017b).

The Global Burden of Disease (GBD) report of 2012 showed that ambient air pollution is the cause of three million premature deaths around the globe annually (World Health Organization, 2014). Furthermore, the developing countries that mainly rely on fossil fuels, such as South Africa and China, contributed to the largest part of these premature deaths. A recent study by the International Growth Centre (IGC) researched the economic impact of air pollution in South Africa, specifically the concentration of fine Particulate Matter (PM) (Winkler, Altieri and Keen, 2016). The study determined that 7.4% of all deaths in South Africa were due to chronic exposure to fine PM. The study also showed that cities such as Johannesburg, Pretoria, Cape Town and Durban, which are densely populated, contributed to the largest part of this estimate. Data on population, air quality, heath of population and value of a statistical life from 2012 was used to determine the economic impact of deaths due to air pollution. The cost of these deaths due to fine PM was estimated to be 20 billion USD, which was approximately 6% of the GDP of South Africa in 2012 (Altieri and Keen, 2016).

This figure is consistent with the estimated annual cost of air pollution in developing countries, which was 5% of the GDP according to (Ksenija, 2016).

The State of Environmental Reports (SOER) of the City of Cape Town, Johannesburg and Tshwane stated that polluted stormwater has a significant contribution to the deterioration of a country's water quality (Fisher-Jeffes and Armitage, 2013). Furthermore, the increase in the volume of stormwater runoff can damage stormwater infrastructure and result in the increased need for maintenance and repairs. According to the SOER, sewage treatments works become overloaded with stormwater which flows from urban areas into sewer networks, which results in failure of the sewage treatment works (Fisher-Jeffes and Armitage, 2013).

Municipalities in South Africa are obligated to provide a safe and healthy environment, to ensure economic development and to make provision for services in an ongoing and sustainable manner (Boshoff and Childs, 2009). Stormwater management in South Africa generally falls short of these goals and does not receive the funding needed for maintenance and capital expenditures for stormwater systems (Boshoff and Childs, 2009).

Funding for stormwater management in South Africa comes from general municipal rates and not from service charges such as for potable water or electricity. In most cases funding available is a tenth of what is required (Fisher-Jeffes et al., 2012). This lack of funding means that municipalities are unable to afford the stormwater management needed, which results in damages to the environment and loss in ecosystem benefits (Fisher-Jeffes and Armitage, 2013).

2.3.2 The City of Johannesburg

(Brooker, 2002) described the climate characteristics of the Johannesburg City as follows: the City lies on the watershed between the Atlantic and Indian Oceans, at an altitude between 1400m and 1900m AMSL. The climate is temperate continental: summer temperatures range from 10°C to 30°C and winter temperatures range from 0°C to 18°C. The City gets summer rainfall, with 90% of the rain falling in the summer months, which are from October to April. The average annual rainfall ranges from 600 to 700mm. Rainfall is typically from convective storms that are intense and short. The one hour storm precipitation is about 80% of the one day rain for the same recurrence interval.

The population of Johannesburg is estimated to be around 4.5 million, with a population density of about 2 900 people per square kilometre. The population is predicted to grow to 11.5 million in 2030

(World Population Review, 2017). Johannesburg has the highest amount of fine PM in South Africa, estimated to be around 98 $\mu g/m^3$ (World Health Organization, 2014).

The following information was extracted from the City of Johannesburg's CDP report (CDP, 2014):

- The City will double in size by 2040.
- No provision is made for incentives to manage climate change issues.
- The City is currently experiencing more frequent rainfall, more hot days, more frequent heat waves and more intense rainfall. All these increased natural events are considered a serious physical risk to the City.
- The City of Johannesburg hopes to attract private sector involvement for climate change related projects such as green roofs, food gardens and retrofitting of municipal buildings among others.
- Flooding is considered a serious and long-term risk. Climate model projections shows that the City will experience temperature rises and flooding in the future.
- Stormwater management systems will be reviewed and updated to account for effects of climate change. Sustainable urban drainage systems such as green roofs, among others, will be considered.

The stormwater systems in Johannesburg were designed to drain as rapidly and efficiently as possible. This results in severe degradation of the stormwater systems downstream (Brooker, 2002), which leads to the need for increased maintenance and repair. Reducing the runoff upstream will reduce the tension on the downstream stormwater systems.

According to the CDP report (CDP, 2014), the City is most at risk of flooding and heating. The City of Johannesburg is rated as one of the cities with the most air pollution in the world (Kings, 2015). The CDP report states that the main sources of air pollution are domestic fuel burning, vehicles, mining operations, industrial activities and waste disposal via incineration.

Johannesburg has the highest amount of pollution in the winter months, approximately from May to September. This pollution is mainly particulate matter and nitrous oxides. The main sources of the pollution is coal fires used to make food in poor areas, vehicle exhausts, veld fires, dust and industry (Momberg and Grant, 2008). Policies to reduce air pollution may be a way to manage and reduce the pollution in cities in South Africa.

(Hardy and Nel, 2015) studied the UHIE in Johannesburg and found that the UHIE exists within the central business district of Johannesburg. Land surface temperature maps used to study the UHIE indicated that the UHIE is the strongest over the northern suburbs of Johannesburg during night time and in areas where the building density is high. Thus, zoning districts can be established in the northern suburbs of Johannesburg, as well as in the areas where building density is high. Policies and incentives to promote green roof implementation can be implemented for these districts to reduce the UHE. Policies promoting increased green space will be suitable for these districts.

Green roofs have proven effective at reducing air pollutants by filtering diesel residuals out of the air (Armstrong, 2010). Thus, incentives that promote green spaces will contribute to improved air quality, reduced UHI effects as well as reduced impervious surfaces,

Policies and incentives related to reduced stormwater runoff and increased green space, can be used to promote green roofs in the City of Johannesburg. Increased green spaces will result in reduced UHIE, which will result in reduced air pollution.

In conclusion, the City of Johannesburg was considered in this study to determine the feasibility of retrofitting buildings, in an existing city, with green roofs. Johannesburg was chosen specifically since it is the city with the highest concentration of air pollution, specifically fine PM and UHIE is apparent in the City (Hardy and Nel, 2015). Furthermore, research on the use of green roofs in cities in South Africa suggests that many of the rooftops in Johannesburg CBD are suitable for retrofitting with green roofs (Labuschagne and Zulch, 2016).

2.4 Policies Supporting Green Roof Retrofits

Policies that encourage green roofs can help with the implementation of green roofs especially in countries where it is uncommon (Carter and Keeler, 2008). According to Godfrey & Zhao (2016), the investment decisions taken today, especially in critical urban infrastructure, will shape tomorrow. Recent research by Godfrey & Zhao (2016) shows that the urban infrastructure investment decisions taken just over the next five years will determine up to a third of the remaining global carbon budget. Countries in Europe are investing in green infrastructure such as green roofs. In Germany, France, Austria and Switzerland among others, the legislative and financial support from the European state and municipal governments has resulted in a multi-dollar market in the green roof industry (Leipzig and Mohr, 2012).

Although there are many environmental, social and economic benefits to implementing green roofs, as discussed, not all these benefits contribute towards the direct personal gain for developers or building owners. The economic cost related to the installation and maintenance of green roofs is high, especially if there is no green roof industry. Many cities have overcome this barrier to some extent by implementing policies, regulations or incentives which promote the use of green roofs.

Policies and incentives need to be established in order for developers and building owners to firstly, support green roof retrofits and secondly, be willing to invest time and money into the construction of green roofs (Booysen, 2014). Financing for more sustainable urban infrastructure in the transport, energy, buildings, waste and water sectors is an immense challenge due to the long-term nature, large upfront investment requirements and high risk of such projects. This is particularly true in emerging and developing countries (Godfrey and Zhao, 2016).

Green roof policies either directly or indirectly encourage the installation of green roofs, by using performance or technology standards, tax incentives or government subsidies (Carter and Fowler, 2008).

Technology standards include specific technical requirements for buildings and can be integrated into building codes. Performance standards may specify the amount of stormwater a site should retain. This requirement can then be met by installing a green roof. The different forms of green roof policies being used globally are direct and indirect regulations, and/or direct and indirect financial incentives (Carter and Fowler, 2008; Danko, 2014).

The need for and different types of policies, regulations and incentives are discussed in this section.

2.4.1 Policy Development

During the Department of Trade and Industry’s economic policy dialog on South Africa’s economic outlook for 2017, the World Bank has urged South Africa to consider changing some investment tax incentives to attract the private sector investors. They propose changing incentives towards more labour-intensive sectors such as construction, manufacturing, agriculture and trade (Odendaal, 2017). This change may encourage private investment and help with job creation.

In the economic policy dialog a World Bank senior economist, Dr Marek Hanusch, stated that investment tax incentives should shift towards the sectors with high productivity and comparative advantage in South Africa’s economy. According to him this shift in investment tax will stimulate growth, increase job opportunities and help with alleviating poverty (Odendaal, 2017). Considering this, the development of policies and incentives to promote the construction of green roofs will be socially, economically and environmentally beneficial to South Africa.

Lawlor et al. (2006) identified six phases that can be used by municipal policy makers for establishing a green roof policy. The six phases are listed and briefly discussed:

1. *Introduction and awareness*: During this phase a municipality looks at the benefits of green roofs, being of an environmental, social and economic nature. Existing green roof policies should also be considered in this phase.
2. *Community engagement:* This phase helps to gain support from community leaders, architects, building owners, building environment professionals, environmental groups and landscape professionals. Meetings should be held to determine funding sources that can be used and to outline the opportunities, threats, strengths and weaknesses of green roof development within the specific municipality.
3. *Action plan development and implementation*: Various existing policies and policy opportunities should be identified and reviewed in this phase. It is also recommended to launch a green roof demonstration project.
4. *Technical research:* During this phase the benefits of green roofs should be investigated and quantified. This phase helps to create green roof policies and design guidelines. Typical research will include assessing the effectiveness and ability of green roofs to mitigate the UHIE and manage stormwater.
5. *Program and policy development:* The way in which incentives should be offered to contractor, developers and building owners should be established during this phase by using the research done in previous phases to create policy options and tools.
6. *Continuous improvement:* Once the municipality is familiar with green roof technology and the possible steps that can be taken to implement green roofs, the research can be refined. This phase involves further research to refine the existing policies and programs.

Carter & Keeler (2008) identified three environmental issues that are typically used to justify a green roof policy. These environmental issues are, the effect of stormwater runoff in urban areas, thermal impact of traditional roof tops otherwise known as the UHIE and the lack of greenspace or biodiversity in urban areas. Reducing outside air pollution by increasing greenspace can also be used as a policy.

2.4.2 *Direct and Indirect Regulations*

Mandatory legislation is usually structured as mandatory by-laws that require green roofs to be installed on both private and public buildings that have a gross floor area larger than a specified area (Danko, 2014). As roof size increases so does the portion of roof that must be covered. These mandatory by-laws are direct policy technology standards and mainly target major developers who have large construction budgets and buildings with high energy demands.

Other examples of technology standard policies are mandates that require all renovated and new public buildings to have green roofs. This is a "setting an example" initiative that shows support for green roofs from the public sector, which influences the private sector perception and allow public buildings to set a precedent.

A direct policy performance standard used in Berlin, Germany and in Malmo, Sweden is the Biotope Area Factor (BAF). This policy places economic value on biodiversity and ecosystem service concerns. Other policies that may influence building owners' perception of the economic value of installing a green roof are policies to limit the pollution (air or water) and climate change. Such policies are likely to bring about significant increases in the price of electricity.

Policies that can be utilised for improved air quality include the cap-and-trade emissions credit or nitrogen oxide emission credit system (Carter and Fowler, 2008).

Stormwater management requirements and zoning are both indirect regulations. This is a public benefit which reduces stormwater runoff and increases water quality. Therefore it is justifiable to use public funds to encourage private building owners to use green roofs for stormwater mitigation (Carter and Keeler, 2008). Green roofs become a highly practical option when the requirements for green features are large enough (Danko, 2014).

2.4.3 *Direct and Indirect Incentives*

Financial policies that can help to overcome the barrier of introducing and adopting the new technology are direct financial incentives. According to Danko (2014), direct financial incentives help with the start-up costs of green roofs which are often the key concern of building and property owners. These incentives are however the most difficult type of policy to implement, as the government must have the financial resources to support these incentives. Mullen et al. (2013) suggest the use of a targeted subsidy to reduce the costs of direct financial incentives. Targeted subsidies are subsidies which are only provided to buildings with negative net private benefits and positive net public benefits. Direct financial incentives are considered the most effective as the quality of green roofs and methods used when constructing green roofs are governed by strict criteria (Danko, 2014). In order for building owners to receive the incentive or subsidy they must meet the specified criteria. Other alternatives for direct financial incentives are grant programs, which offer lump sum payments under a competitive selection process (Carter and Fowler, 2008).

A study on the public and private incentives to invest in green roofs (Claus and Rousseau, 2012), considered an investment project in Dilbeek, Belgium. The study found that private incentives without subsidies are insufficient to convince investors to install a green roof. The results indicated that subsidies for green roofs are socially desirable and are needed to convince potential private investors to construct green roofs. The study compared cost benefit analyses for different scenarios and found that without subsidies, the private costs of constructing an extensive green roof exceed the private benefit for the investor.

In support of these findings, a study conducted by Booysen (2013) found that industry specialists did not think there is any reason for developers or building owners to implement or even consider the use of green roofs if the green roof industry has not been established.

In this study the industry specialist concluded that, without some form of compensation, developers and building owners will have no reason to retrofit their buildings, especially considering the high cost of retrofitting.

Carter & Fowler (2008)evaluated the existing international and North American green roof policies that exist on a federal, municipal and community level. The authors proposed the use of multi-face and spatially focused policy instruments. The three main policy instruments that the study recommend are:

1. The identification of problem zones where the potential benefits of green roofs are needed. It is important to identify areas where green roofs can function most effectively.
2. Provide financial incentives such as density credits or stormwater utility fee credits. These incentives may help building owners and developers to accept the new technology. Such financial incentives will be area specific.
3. Public authorities should construct a demonstration project (pilot project) to establish constriction and maintenance standards. This project can also help to educate the public on the new technology.

Indirect financial incentives are the most common form of policy for the construction of green roofs. A popular indirect financial incentive is a stormwater retention rebate programme, otherwise referred to as credit towards a municipality's stormwater utility fee. As stormwater utilities are usually based on the amount of impervious surface found on a property, property or building owners receive credit towards a portion of the stormwater utility fee if they take measures, such as retrofitting with green roofs, to decrease the amount of impervious surface (Carter and Fowler, 2008).

The City of Waterloo (2005) conducted a feasibility study for the implementation of green roofs on a large scale. They identified problem zones to determine where green roofs will function best. Problem zones can be any area within a city where there is a need for improved stormwater management, reduced air and/or water pollution, reduced UHIE, increased green space or energy efficiency.

Problem zones in need of improved stormwater management will typically have old stormwater systems, high amount of impervious surfaces, not enough space for typical stormwater management techniques, or areas with poor water quality. Zones in need of improved air quality would typically be industrialised areas or areas with high traffic.

Such areas are prone to have higher pollution levels. Areas with a high concentration of older buildings are typically zones that need to become more energy efficient.

Another example of a direct incentive is in the City of Toronto in Canada. The City adopted a Green Roof incentive pilot program (Lawlor et al., 2006). This program granted money to building owners who retrofitted their existing building with a green roof or installed a green roof in a new building. Converted to Rand, the city offered R105 per square meter of eligible green roof area, with a maximum of approximately R210 000 granted per building.

The criteria used to determine if the green roofs were eligible for the grant are as follows; the green roof must be extensive if retrofitted with a minimum soil depth of 80mm, the roof slope cannot be more than 10%. Applicants had to show that at least 50% of the roof was covered in vegetation, that a mixture of vegetation was used and that the runoff coefficient was no more than 0.5.

Various green roof incentives exist in Germany and the rest of Europe. Some examples of which are listed below (City of Waterloo, 2005):

- In Munster building owners can get a reduction of up to 80% on rainwater tax.
- In Nordrhein-Westfalen the state pays approximately R230 per meter of green roof.

- In Darmstadt the costs of green roofs are covered up to R78 000.
- In Bonn individuals receive reduced water fees by R10 per meter of green roof installed.
- In Cologne and Mannheim water fees are reduced by 50%
- In Stuttgart and Esslingen the City pays 50% of the green roof cost. This incentive resulted in the installation of 100 000 green roofs on public owned buildings and 46 000 on private owned buildings in Stuttgart.
- In Switzerland regulations require the relocation of the area of green space that is covered by a new construction, to a roof top, to counter for the new building footprint.

Germany is the leader in the green roofing industry. Much of the success of the green roof industry is due to the use of policies and incentives to promote the installation of green roofs.

Density bonuses and fee waivers are other forms of financial incentives which do not require substantial financial investment (Lawlor et al., 2006). A density bonus allows developers to increase the built floor area or building height beyond the zoning by-law, depending on the portion of green roof installed on the building (Carter and Fowler, 2008; Danko, 2014).

Other types of policies that can be used to encourage the implementation of green roofs are fast-tracking and low interest loans.

2.4.4 Incentives for South Africa

Urban agriculture, or inner city farming can be used to boost employment and food security (Sunday, 2016). The need for food security and increased job opportunities can be used as incentives to promote green roof implementation on a large scale within South African cities.

The City of Johannesburg started an urban agriculture pilot project to produce fresh food for the local community, generate income to participants of the project and donate some of the produce to the homeless. This project makes use of hydroponic systems, instead of green roofs, to grow fresh produce. Hydroponic systems do not make use of soil; the plants get their nutrients form a nutrient rich solution. The advantage hydroponic systems have over green roofs for urban agriculture is the increased growth and production rate of the plants (Burger, 2017). However hydroponic systems do not have any influence on Urban Heat Islands or stormwater retention.

Green roofs have the potential to be used for urban agriculture. Although the plant growth and production rate are slower, the other benefits of green roofs can still be realised. Incentives to create urban farms on roof tops which stimulate food production and create jobs may be a way to help the green roof industry. However, this option will not be considered in this research thesis.

Carbon emission tax is becoming a large possibility in South Africa. Many industries are already paying carbon emission tax to the government. In the near future the construction industries will be billed for their nitrogen oxide emissions. Rather than the private industry paying the government emission tax, the private sector can benefit from coming to an agreement with the public sector to credit building owners with economic compensations for their buildings retrofitted with green roofs, since green roofs have the potential to reduce air pollutants. Furthermore green roof warranties may help institutionalize the benefit of green roofs' protecting the roofing membrane (Carter and Keeler, 2008).

Godfrey & Zhao (2016) mention that cities can leverage the value of existing assets, mainly land and property, to generate revenues for smarter, more sustainable infrastructure investment. The value of buildings within urban centres can be leveraged by retrofitting the buildings with green roofs. But large amounts of capital are required upfront to fund such retrofits. Godfrey & Zhao (2016) and Carter and Fowler (2008), propose land-based financing for raising such large amounts of capital upfront.

Booysen (2013) studied which aspects encourage the successful integration of green roofs in cities. Her study (1) determined the policies and incentives that have been used in cities internationally; and (2) investigated what the perceptions of both national and international green roof specialists are about policies and incentives needed in South Africa to implement cc The main findings and recommendations of the study conducted by Booysen (2013) are listed:

1. Formulate construction and maintenance standards and guidelines for the specific area. These guidelines and/or standards must be specific to the issues, needs and climate of the area under consideration. In a country such as South Africa these standards may differ among regions.
2. Obtain support from local authorities through policies and incentives to help developers and building owners to be less hesitant.
3. The government must lead by example.
4. Technology policies with regard to the government leading by example is the most popular strategy.
5. Indirect financial incentives are the least popular, but could be used to retrofit existing buildings once the green roof market has been established.

6. Direct financial incentives should be used to start implementing green roofs.
7. Policies and incentives should be used together in a multi-beneficial way.

2.5 Cost Benefit Analysis

The use of a Cost Benefit Analysis (CBA) was considered for this study to determine whether it is viable to retrofit an existing building with a green roof system. This section discusses the different aspects of a CBA, how to conduct such an analysis and the type of results obtained from the analysis. Findings and concerns from literature about the costs associated with green roof installations are also discussed.

2.5.1 What is a Cost Benefit Analysis?

With a Cost Benefit Analysis (CBA) the benefits and costs of an investment are estimated to determine if the investment is good or bad. A CBA can also be used to compare one investment or project to another, thereby determining which is more feasible (Dietz, 2015).

The input data for the CBA is based on the costs and benefits associated with the project or investment in question. Certain assumptions will have to be made in order to have the data required for the analysis. It is important that all the data used has the same baseline in order to ensure that the data is comparable.

Due to inflation, the value of money decreases over time. To accommodate for this decrease in purchasing power of money over the period of the CBA, a discount rate factor is used. The discount rate converts the value of the future returns into a present value (Dietz, 2015). The lower the discount rate, the higher the return value of future costs and benefits.

2.5.2 Methods and indicators

Different types of analytical methods and economic indicators are available to determine the projects feasibility or how economically efficient a project is. The different types are as follows; Benefit Cost Ratio (BCR), incremental BCR, Net Present Value (NPV), Internal Rate of Return (IRR) Return on Investment (ROI) and the payback period. For the purpose of this study only the NPV and payback period were considered. These two indicators are discussed:

Net Present Value

The NPV is the difference between the present value of the cash inflow and outflow over the duration of a project. The NPV can be calculated using a few different methods.

1. The NVP function in Microsoft (MS) excel can be used. The input of this function is the discount rate used and the cash flow of each year. The cash flow of a year is the benefits minus the costs of that year.
2. The NPV is equal to the sum of the present values of each year. The present value is calculated by multiplying the cash flow of each year with the discount factor of that year. This is how the NPV function in MS excel calculates the NPV.
3. The NPV is equal to the total discounted benefits minus the total discounted costs.

When using the NPV function in MS excel and the cash flow at present time is not zero, that cash flow needs to be added to the NPV separately and not be added into the NPV function. The MS excel equation is as follows; MS Excel NPV Function = NPV (Discount rate; Present value years 1 to n) + Cash flow year 0. Equation 1 shows the equation for the NPV using the difference in discounted costs and benefits.

$$NPV = \sum_{n=0}^{i} \left[{}^{B_n}\!/_{(1+d)^n} \right] - \sum_{n=0}^{i} \left[{}^{C_n}\!/_{(1+d)^n} \right] \qquad \textit{Equation 1}$$

Where;

B	is Benefits
C	is Costs
d	is Discount rate
NPV	is Net Present Value

The NPV of a project can be positive, negative or zero. In the case where the NPV is positive, it means that the present value of the benefits is larger than the present value of the costs and the project is deemed acceptable. A project with a negative NPV is not acceptable, as the present value of the costs is more than the present value of the benefits. When the present value of benefits is equal to the present value of costs the NVP would be zero.

Payback Period

The payback period gives an indication of how long it will take the investment to pay for itself, thus how long it takes for incoming returns to cover the costs associated with a project, and/or how long it will take for the investor to break even. The payback period considers the timing of cash inflow and outflow.

Payback period is the amount of time needed for the total discounted benefits to become more than the total discounted costs. Thus, the year when the project has a positive net value is when the payback period ends. For an even cashflow the payback period can be calculated as the cost of the investment divided by the annual net cash flow.

When the cash flow is uneven, as it would be for most projects, MS excel would typically be used to calculate the payback period since the cumulative value of the discounted cash flow of each year is used. Typically, the cumulative value for the discounted benefits minus the discounted costs (the cumulative discounted cash flow) would be negative for the first few years on an investment. The payback period is equal to the year n, plus the absolute value of the cumulative cash flow value of year n, divided by the discounted cash flow of the following year. The formula used is as follows;

$$\text{Payback Period} = \text{Year } n + |\text{Cumulative cash flow year } n| \div \text{Cash flow year } (n+1) \qquad \text{Equation 2}$$

Year n is the last year when the cumulative discounted cash flow is negative.

2.5.3 CBA for Green Roof Projects

There are many misrepresentations of cost in the conventional cost benefit analysis when analysing a green roof system. Most lifecycle analyses show that the installation of green roofs is less cost-beneficial compared to conventional roofs. However most of these lifecycle analyses do not take building lifetime costs and the cost of environmental degradation into account (De Groot, Wilson and Boumans, 2002; Langdon, 2009).

The initial days of a roof greening industry are the most costly and problematic. Initial green roof developments are delivered at a premium cost. This is due to a lack of industry efficiency, local material suppliers, local developers' skills, experience and acceptance of the technology by developers and urban designers (Armstrong, 2010). Germany's green roof industry has about 30 years of experience and delivers green roofs at a cost as much as 50% less than the cost of green roofs in the United States during the industry's initial years (Carter and Keeler, 2008). In Germany the reduction in usage fees can compensate for as much as 50% of the additional capital cost over a 36-

year period (Leipzig and Mohr, 2012). Estimates show that the lifetime cost of an extensive green roof (based on a 36 year service life) in Germany is 15% lower than a comparable bituminous roof with gravel ballast (Lawlor et al., 2006).

When future trends are considered, it is expected that environmental benefits from greening cities will increase even more due to climate change, and energy savings associated with green roofs will become more important (Claus and Rousseau, 2012). These benefits are usually not taken into account when conducting a cost benefit analysis and are not easily quantifiable.

A lifecycle net benefit-cost analysis done by Bianchini & Hewage (2012b), considering the social-cost benefits generated by green roofs over their lifetime, demonstrated that green roofs are short-term investments in terms of net return. This analysis also indicated that the probability of profits out of green roof technology are much higher than the potential for financial losses. According to (Bianchini and Hewage, 2012b), installing green roofs is a low risk investment.

2.6 Summary of Literature Review

A summary of the literature review, which highlights the key findings is given in this following subsection. This is followed by a justification for the proposed research of this thesis.

2.6.1 Overview of Key Findings of Literature Review

Cities across the world generally have the same environmental problems due to urbanisation and the increase in the cities' population and building density. Of the environmental problems documented the UHIE, air and water pollution, and stormwater management seem to be the most prominent.

The City of Johannesburg is no exception, especially considering that it is the most polluted city in South Africa. Late afternoon rain showers are common in the summer months in Johannesburg. However the City is experiencing more frequent and intense rainfall as well as more frequent heat waves. This, together with the projections of increased flooding in the future, poses great risk to the City's stormwater infrastructure and wellbeing of its inhabitants.

Green roofs offer numerous benefits, but most of these benefits can only be realised if green roofs are implemented on a large scale. Large scale implementation of green roofs in existing cities can help in alleviating the potential risk mentioned since they have the ability to reduce air pollution and mitigate the UHI, whilst providing on-site stormwater management. Since green roofs function best when implemented on a large scale it would be in the interest of municipal and governmental bodies to invest in the implementation of green roofs in areas where air pollution, the UHIE or stormwater is a problem. Extensive modular trays are recommended when considering the type of green roof to retrofit to an existing building since they are the least expensive in terms of design, installation and maintenance. It is also more likely that additional structural strengthening will not be needed when using extensive modular trays and less layers are required than for a direct system.

South Africa is currently in the initial stages of its green roof industry and the use of green roofs is generally uncommon. The main reason is that green roofs are very expensive. In the initial stages of a green roof industry, the construction of green roofs will be the most expensive. Building owners or developers do not receive direct benefit from constructing a green roof on a building and therefore will not consider the use thereof.

Incentives, regulations and policies can however be used to stimulate the use of green roof and help the green roof industry to grow. Direct subsidies are considered the most effective incentive to use, however the local authority must have access to funding for this incentive to be implemented.

Lastly, most lifecycle and cost-benefit analyses do not take all the benefits of green roof design into account. A more realistic approach to a life cycle or cost benefit analysis, that can take into account the spin-off benefits of green roofs, will give a different answer to whether or not green roofs are cost-beneficial. It is however hard to quantify all the benefits of a green roof into such analyses. Indicators used to determine the feasibility of a project or to compare projects to each other are the NPV and payback period.

2.6.2 Justification of Research

Considering the predictions on increasing ambient temperature in cities around the world, as well as the Paris Agreement made at COP21 which South Africa agreed to, the need for cities to adapt is undisputable. According to the Intergovernmental Panel on Climate Change (IPCC 2014), global warming of more than 2 degrees Celsius would have serious consequences, such as an increase in the number of extreme climate events. At COP21, 195 countries, including South Africa, agreed to limit the rise in temperature to below 2 degrees Celsius. Retrofitting existing cities with green roofs poses an opportunity to help achieve this goal.

The building sector, which includes non-residential and residential buildings, accounts for 23% of the total GHG emissions. Furthermore the manufacture of building materials accounts for 5% of the building sector’s emissions (Truitt, 2015). Retrofitting existing buildings with green roofs may be a solution to limiting the increase in temperature, as well as reducing the building sectors' contribution to GHG emissions, especially when applied on a large city scale.

The unemployment rate of South Africa went up to 27.1% in the third quarter of 2016 from 26.6%. This unemployment rate is the highest it has been since 2004 (Trading Economics, 2017). The green roof industry can stimulate the local economy through job creation (Dunn, 2010) in the construction and maintenance of green roofs.

Currently not much research is available on the implementation of green roofs in South Africa. The research in this report considers the costs of retrofitting a green roof on a commercial office building situated in Johannesburg, to determine the feasibility thereof. Johannesburg was considered since it is the most polluted city in South Africa, where UHIE is a known problem and the building rooftops in the City have space available for green roof systems.

3 Policies and Incentives from Literature

This chapter discusses the use of incentives and policies available to promote the green roof industry. The aim of this chapter is twofold, to:

1. Identify incentives and policies generally used to promote the implementation of green roofs. Literature was studied to collect data concerning the best management practices when implementing policies or incentives to promote the use of green roofs.
2. Determine which incentive or policy would be best suited for Johannesburg where there is no green roof industry. Data collected was used to determine which incentive or policy should be considered in a cost benefit analysis of a typical building retrofitted with a green roof.

3.1 Best Management Practice

The following section provides a discussion on the policies, incentives and funding mechanisms that have been or are being used successfully in other countries. When considering which policies are most suitable for South Africa it is important to consider which sector will benefit from implementing a specific policy, the public or private sector. In South Africa incentives and regulations that would help the green roof industry the most are; incentives that benefit developers and building owners (see Section 2.2.7) and regulations promoting the use of green roof on municipally owned buildings.

3.1.1 Literature

It is unlikely that investors or building owners will consider retrofitting buildings with green roofs unless they are given a subsidy to help with the initial installation costs. The primary barrier to the green roof industry is the greater initial cost of installing a green roof rather than a conventional roof (City of Waterloo, 2005). This is especially true if there is no green roof industry. This is mainly because there are not enough direct private benefits, as most of the benefits realized with green roof systems are not easily quantifiable.

Direct financial incentives are the most effective way of starting a green roof industry in a country. Such incentives enforce a standard on the construction of green roofs and sets strict specifications for the green roof in order to obtain the financial incentive.

Policies that have resulted in a large increase in the use of green roofs in developed countries such as Germany and different states in the USA were policies related to tax deductions and direct and indirect financial subsidies (Lawlor et al., 2006; Leipzig and Mohr, 2012).

According to the literature reviewed, establishing a green roof industry is mainly done by: the Government leading by example, offering direct and indirect financial incentives as a start-up and establishing construction and maintenance standards by means of a pilot project (Carter and Fowler, 2008; Armstrong, 2010; Booysen, 2014). Offering direct and indirect financial incentives is beneficial for the private sector. The benefits for the public sector will only be seen once there are enough buildings retrofitted with green roofs. These benefits are as listed in Table 2 in Section 2.2.2 of this paper.

Priority zones where air pollution, UHIE or stormwater pose a problem should be identified within urban areas. Policies and incentives used to promote green roof implementation should be based on stormwater management, reduced UHIE and reduced air pollution. Such policies or incentives should be implemented in priority zones and can increase the use of green roof systems.

It is important to establish green roof policies and design guidelines specific to South Africa. Guidelines that can be used as a reference are the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) guidelines for green roof design, construction and maintenance used in Germany. The FLL guidelines set standards for the individual components of the system, construction techniques and outline the maintenance of different roof types (Lawlor et al., 2006).

The sustainable building rating systems used in the USA is LEED (Leadership in Energy and Environmental Design). This rating system can also be used to rate the quality of a green roof and provides specification on the construction and standard of green roofs. The LEED rating system is used globally (Leipzig and Mohr, 2012), and can be used in South Africa to ensure that all green roofs installed are at the same and accepted standard.

3.1.2 Incentives Identified

The incentives that were identified in the literature reviewed are listed:

- Reduction in stormwater tax or credit for stormwater tax. (A)
- Municipality or government provides subsidies for a percentage of the total cost of installing a green roof. Costs covered range from 30 to 80% of the total cost. (B)
- Regulations require developers to relocate the green space used for a new construction, by retrofitting a green roof either on the new building or on an existing building. (C)
- Density bonus which allows developers to construct taller or larger buildings if a percentage of the building rooftop is covered with a green roof. (D)
- Local municipalities fund the development of demonstration sites which can provide insight into the construction procedures and standards that should be used when retrofitting a building with a green roof. (E)
- Rating systems are used to promote sustainable buildings. Included in most rating systems are standards for the use of green roofs for new and existing buildings. The rating system mostly used is LEED. Use of the rating systems are mostly voluntary, but are becoming regulation in some cities in France and the United States of America. (F)
- Building owners who retrofit their buildings with green roofs or solar panels do not pay property tax for one year. (G)
- Insurance companies cover the costs of retrofitting a green roof on an existing roof that needs to be replaced. The costs to hire an accredited green consultant for design and construction is also covered. (H)
- Municipalities or governments are obligated to retrofit a green roof on municipal or government owned buildings when roof replacement is due. (I)
- Building permit processes are accelerated and the service fee waivered if developers install green roofs on the new building. (J)

Each incentive listed is labelled A to J. These label corresponds to Table 5 which shows the incentives used in different cities globally. Table 5 indicates how many countries make or made use of the incentive to promote the green roof industry. This table provides a brief description of the incentives used in the specified country.

3.1.3 Suitable Incentives for Johannesburg

The incentives that were considered most suitable for Johannesburg and for the purpose of this study are subsidies for the initial costs of installing a green roof, and the reduction of an annual tax such as stormwater or property tax.

These incentives were considered suitable as it can be used for existing buildings, will benefit the private sector or building owner, and are depended on source being the public sector. As previously discussed, the public sector will receive the majority of benefits realised when implementing green roofs on a large scale, this is discussed and considered in Chapter 9. Furthermore, both these incentives are quantifiable and can be used in the cost benefit analysis to determine the economic effect of implementing the incentives.

Other incentives identified are either not as easily quantifiable, not applicable for the use of existing buildings owned by the private sector or are deepened on uncertain sources and were therefore not considered for the purpose of this study.

The data in Table 5 indicates that the percentage of the construction cost that is typically subsidised by the local municipality ranges between 30% and 80% with 50% most commonly offered, or the subsidy is based on a flat rate per square meter of green roof installed. This data also shows that the percentage by which stormwater tax is typically reduced is between 50% and 80%. For the purpose of this study reductions in stormwater tax was not considered, however reductions in property tax was.

Table 5 Incentives used (Lawlor *et al.*, 2006; Carter and Fowler, 2008; Claus and Rousseau, 2012; Booysen, 2014)

Country	**City**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**Description of Incentives Used**
Germany	Munster	1										80% reduced rainwater tax to building owner
	Nordrhein-Westfalen		1									City pays approximately R230 per square meter of green roof
	Darmstadt		1									Green roof costs covered up to approximately R78 000
	Bonn	1										Reduced fees by R10 per square meter of green roof installed
	Cologne	1										50% reduced stormwater fees
	Mannheim	1										50% reduced stormwater fees
	Munich		1									Municipality paid subsidy up to 50% of green roof installation
	General	1										Thirteen Cities allow stormwater fee reduction between 50% and 80%
	General		1									Twenty-nine Cities pay subsidy to developers who use green roofs
Switzerland	General			1								Regulations require reallocation of green space used, by installing a green roof on a rooftop
Austria	Linz		1									Subsidise 30% of green roof construction cost and 50% once vegetation is established.
North America	Portland	1	1		1	1	1					Grants for installing green roof on existing office building, discount on stormwater utility to residents with green roofs, funds are provided for demonstration sites, LEED
	Atlanta	1										Stormwater utility credits for green roofs
	Vancouver					1	1					City publicizing green roofs through installation of demonstration sites, using LEED certification as incentive
	Ottawa					1						City publicizing green roofs through installation of demonstration sites
	Toronto		1			1				1		City publicizing green roofs through installation of demonstration sites, installation of green roof on existing municipal buildings when roof must be replaced.
North America	Ontario	1										Reduced stormwater tax to building owners with green roofs
	General								1			Insurance company covers additional cost to replace damaged roofs with green roofing systems and cost to hire accredited green consultants for design & reconstruction

Table 5 Incentives used (Lawlor *et al.*, 2006; Carter and Fowler, 2008; Claus and Rousseau, 2012; Booysen, 2014) *continued*

Country	**City**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**Description of Incentives Used**
Denmark	Copenhagen		1									When old roofs are retrofitted building owners can receive public financial support
United Kingdom	London		1				1					Direct financial incentive for retrofitting with a green roof to mitigate stormwater management. Use of BREEAM rating tool
United states of America	New York							1				Building owner with Green roof and or solar electricity generating systems receives one year property tax abatements
	Annapolis	1										Tax credit to building owners who try to reduce stormwater pollution on their property through the use of green roofs and other measures
	Chicago, Illinois				1		1				1	Developers receive service fee waivers and expedited building-permit process when installing a green roof. The city requires buildings to have LEED certification
	Washington						1					The city requires buildings to have LEED certification
	Michigan						1					The city requires buildings to have LEED certification
	Wisconsin, Milwaukee		1									The metropolitan sewage district funds retrofitting of modular green roofs to capture rainwater.
Canada	General					1						Allowance for the construction of taller buildings permitted that building has a green roof
Asia	Singapore		1									Municipality funds up to 50% of installation cost of green roof
Total		**9**	**10**	**1**	**2**	**5**	**6**	**1**	**1**	**1**	**1**	

3.2 Green Roofs in South Africa

The concept of green roofs is new in South Africa (van der Walt, 2012; Booysen, 2013). Green roofs therefor come at a premium cost, as the green roof industry is still at the initial stage. One of the main reasons why the green roof industry is underdeveloped is the lack of knowledge concerning the construction and benefits of green roofs (Labuschagne and Zulch, 2016). This statement was confirmed in an interview with the Head of Energy and Climate Change Environmental Resource Management Department of Cape Town (Interviewer 1), who also confirmed that there are currently no incentives to promote energy efficiency or sustainability in the urban environment.

eThekwini Municipality is the first municipality in South Africa to initiate a green roof pilot project in Durban, as a part of the city's Climate Protection Programme (Niekerk, Greenstone and Hickman, 2011). The goal of the project was to research the use of green roofs as a form of urban management from a South African perspective (Armstrong, 2010). The research in this project can help overcome some of the barriers of the green roof industry, such as the development of construction standards and improve the knowledge on green roof retrofits in South Africa. Improving this knowledge will be beneficial to building owners and policy makers (Armstrong, 2010).

Labuschagne & Zulch (2016) researched the perspective of professionals working in the built environment as well as citizens within Johannesburg, on the use of green roof systems in the City. The study indicated that extensive green roofs are considered feasible whereas intensive green roofs are not. According to the study, improved air quality, better insulated buildings, increased work opportunities and aesthetics are the main elements that will help to encourage the development of green roofs in Johannesburg. The study also showed that there are many roofs in Johannesburg CBD that have the potential to be retrofitted with a green roof system. However, the use of green roof systems are still very limited. The study concluded to say that the cost of construction of green roof systems is a great barrier that is hindering the development of green roof systems in South Africa.

This statement was confirmed during an interview held with a professional property developer (Interviewer 2), who stated that developers and building owners in South Africa are reluctant to use green roofs, as the initial costs are too high. According to her, the lack of knowledge and experience in the construction of green roofs means developers and building owners consider green roofs as a risky investment. Furthermore, she concluded to say developers and building owners are only interested in short term paybacks on investments.

Barriers that hinder the implementation of green roofs are a lack of knowledge and awareness, a lack of incentives, the increased cost related to retrofitting with a green roof, unknown technical issues and risks associated with green roofs and a lack of an established market (Zhang et al., 2012; Wong and Lau, 2013). All these barriers are applicable to South Africa. According to Booysen (2013), a lack of knowledge and awareness and a lack of incentives are the largest barriers.

Considering the current phase of the green roof industry in South Africa it is recommended by the author that direct financial incentives such as a subsidy be offered by the local municipality to reduce the initial cost of the green roof to promote the green roof industry. Three reasons why this incentive is recommended for South Africa, and Johannesburg CBD specifically, are listed:

1. Developers and building owners usually do not consider retrofitting with green roofs due to their high initial costs. Reducing the cost can make them less reluctant.
2. Reducing the initial cost will help reduce the payback period. Considering that most building owners and developers prefer to invest in projects with short paybacks, such an incentive may increase the interest in retrofitting with green roofs.
3. Incentives such as a subsidy offered by the local municipality helps to establish and enforce a high standard for the construction and maintenance of green roofs in that area (Booysen, 2013). The developer or building owner will only be able to receive the subsidy if the green roof is constructed to the specified standard. In order to know which construction and maintenance standards are best suited for the specific area the local municipality should initiate a green roof pilot project within that area.

The use of this incentive was investigated and discussed in Chapter 7 of this study.

3.3 Recommendations from Literature

The best management practices when implementing policies or incentives that should be considered for South Africa are as follows:

- Local municipalities should provide direct incentives such as a monetary subsidy for building owners to retrofit their roofs with green roofs according to specified standards. The subsidy should typically provide 30%, 50% or 80% of the initial costs of installing a green roof. This incentive is the most widely used and recommended in literature. This incentive will also suit the needs of building owners and developers in South Africa. Such an incentive is investigated in Chapter 7 of this study.
- The retrofitting of municipal buildings and the municipality funding demonstration sites, are highly recommended and seen as a government leading by example. This can help educate people on green roofs and help to create standards for green roof construction.
- Local municipalities should reduce certain taxes such as stormwater tax and carbon emission tax for building owners who have retrofitted the building rooftop with a green roof. In the event where building owners are taxed for stormwater runoff or carbon emissions, a typical reduction in that tax would be 50%. The use of such incentives was not investigated in this study.
- Rating systems such as LEED can be used, but will mostly influence large companies to retrofit their buildings as it is good for their image.
- Implementing all of these incentives simultaneously may accelerate the growth of the green roof industry. However, the incentives implemented must be related to the environmental problems specific to the area where they are implemented.

4 Feasibility Study Parameters

A feasibility study was conducted where the cost associated with the installation and upkeep of a green roof retrofitted on an existing building was compared to the costs associated with the same building without a green roof. Cost Benefit Analyses (CBA) were used to compare the costs and determine whether or not it is financially feasible to expect a building owner to retrofit an existing building with a green roof. Different scenarios were considered to determine conditions needed for it to be financially feasible to retrofit an existing building with a green roof. The CBA was done over a 40 year period. Analyses were based on the costs and benefits associated with a typical commercial office building situated in the central business district of Johannesburg in the study area shown in Figure 17. An overview of this chapter's content is shown in Figure 16.

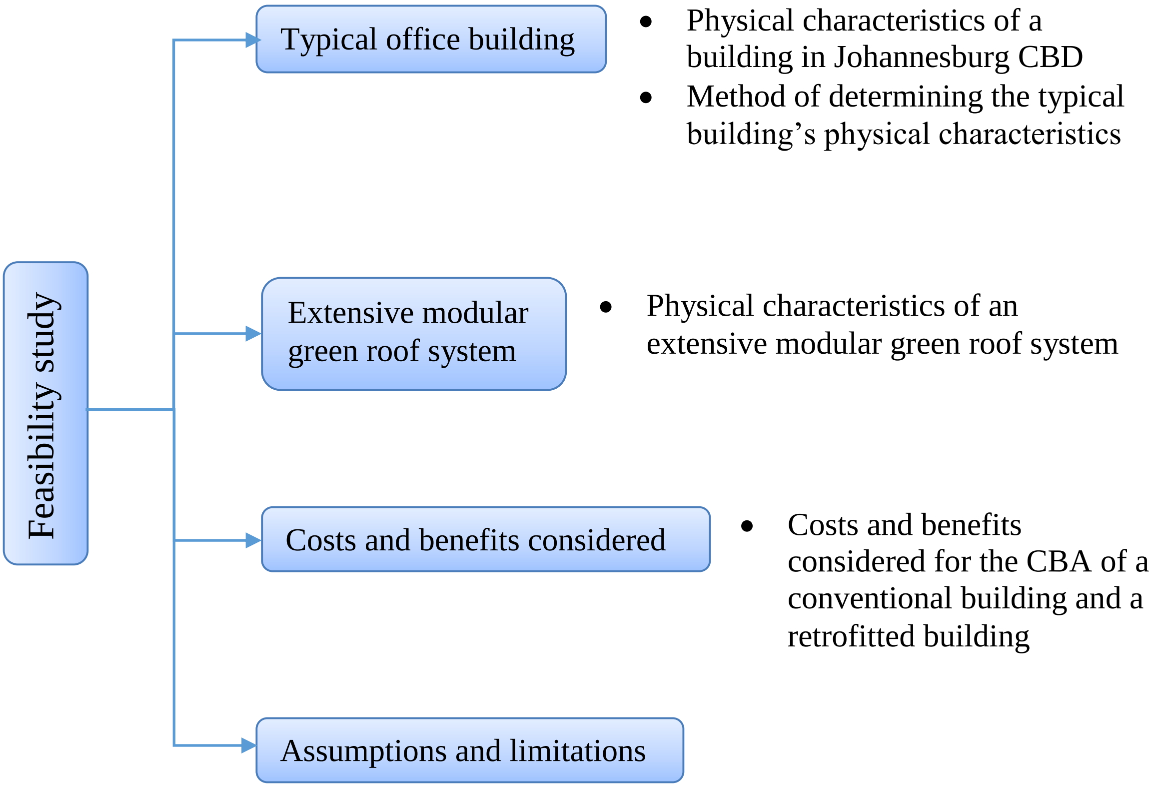
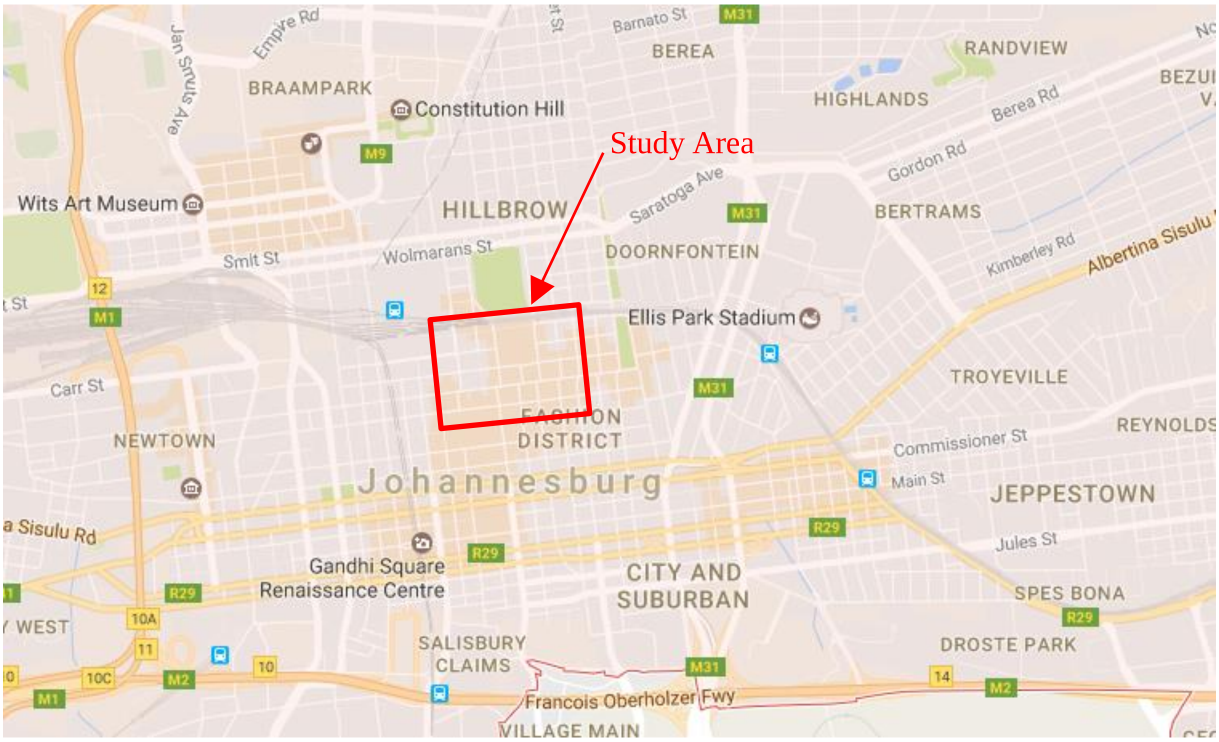


Figure 16 Chapter 4 Overview

4.1 The Typical Office Building

To perform the CBA it was necessary to know what a typical office building in the CBD of Johannesburg looks like. In order to determine this, a study area was selected within the CBD of Johannesburg, which is one of the dense built up urban areas in Johannesburg. The study area selected is shown in Figure 17.



Study Area

Figure 17 Study Area in Johannesburg CBD

In determining the characteristics of a typical building in the study area, six sample areas were chosen at random. Figure 18 shows the location of the six sample city blocks randomly chosen (B1 to B6). These sample areas are situated inside the study area shown in Figure 17. Each sample city block covers an area of approximately 5330m^2. The number of buildings within a sample city block varies, with the minimum and maximum number of buildings in a block being four and seven respectively.

To determine the floor area and number of floors of each building in the sample city blocks, each building within each sample city block was measured. The x and y directions are defined as shown in Figure 18, the North direction is also shown in this Figure. The x and y lengths of each building were measured in the respective directions. These measurements in meters were used to calculate the footprint floor area of each building. Google Maps was used to measure these lengths.

Figure 18 Sample Area

The study area, as shown in Figures 17 and 18, consists of a total area of 1.42km^2. The average number of buildings per block was calculated as 6. There are 204 city blocks within the study area. Using the average number of buildings per block and the number of blocks in the study area it was calculated that the study area has approximately 1224 buildings.

The number of floors for each building in the sample blocks (B1 to B6) was counted using Google Street Viewer. Based on the sample city blocks, the average number of floors of the buildings in the study area was 7, see Figure 19. The number of floors for the different buildings varies considerably. However, a linear trend line shows the average number is 7 floors. Therefore, it was assumed that a typical building will have 7 floors.

Figure 20 shows the results of the analysis. Thirty-four buildings were analysed. The minimum and maximum roof areas calculated are 122m^2 and 2188m^2 respectively. The overall average roof area is 685m^2. It was assumed that a typical building has a footprint floor area of 685m^2. The roof area of the typical building was considered to be equal to the footprint floor area. The perimeter of the typical building was determined to be 105.5m. Figure 20 shows that 4 out of the 34 buildings, which is 13% of the buildings, had relatively larger roof areas then the other 30 building: these four results are considered to be outliers. 88% of the buildings' roof areas fell within the range of 122m^2 to 1117m^2.

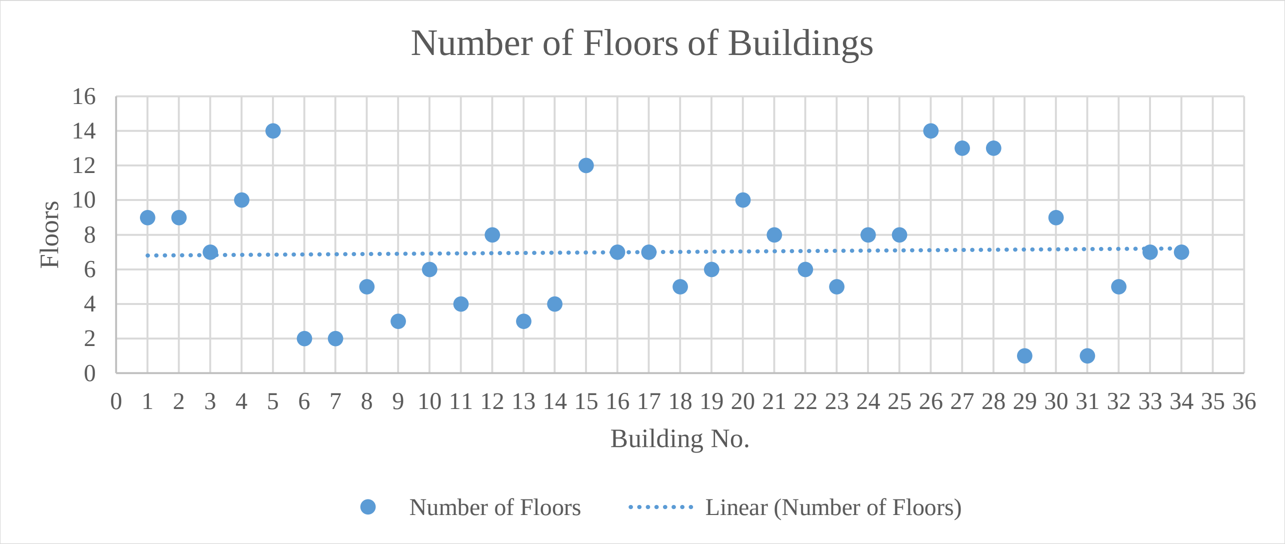


Figure 19 Number of Floor for Buildings in Sample Area

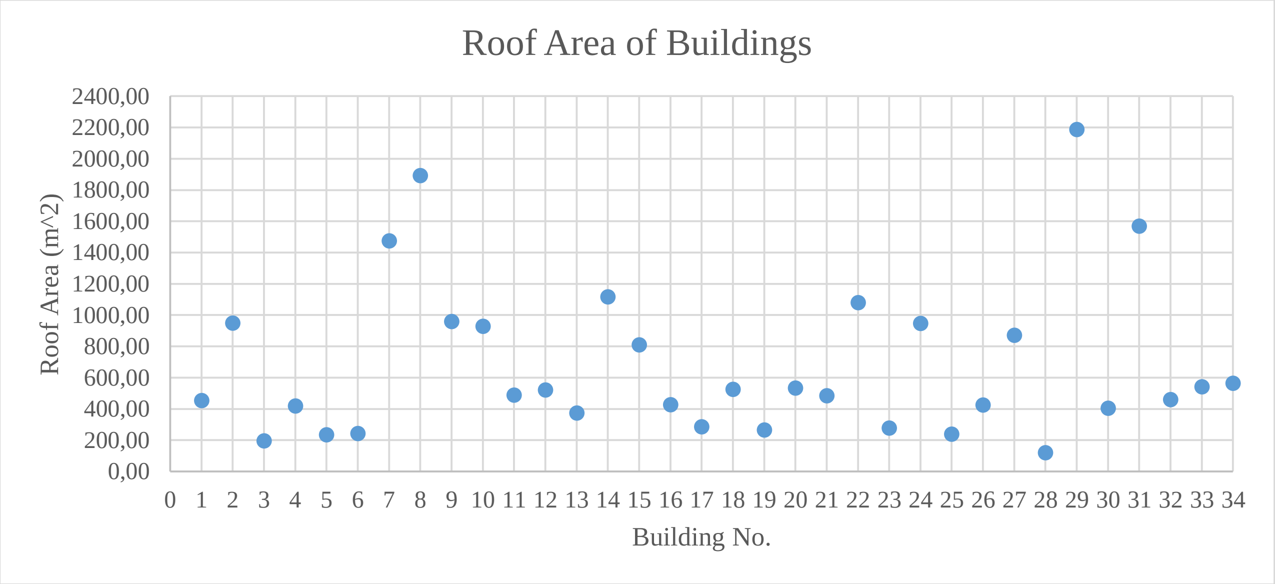


Figure 20 Roof Areas in Sample Area

Table 8 gives a summary of the characteristics of a typical office building located in the study area shown in Figures 17 and 18. All data concerning costs and benefits for the CBA was based on a building with these characteristics. The building is assumed to be rented out as an office building.

The height of the building was calculated based on the assumption that the distance between floors is 2.4m, based on the SANS C-10400 building dimensions code (SABS 2010), the ground floor ceiling is 2.8m from the ground floor.

Table 6 Typical Office Building

Characteristics of building	**Calculated data**
Building Type	Office
Roof type	Flat
Approximate width	25.8 m
Approximate length	26.5 m
Roof and floor area footprint	685 m^2
Perimeter	105m
Number of floors	7
Height	$2.4 \times 7 = 16.8$m
Gross Lettable Area (GLA) = Floor Area × Floors	4797m^2

4.2 The Extensive Modular Green Roof System

The green roof system considered was an extensive modular system. As previously discussed, there are two different types of green roofs, direct and modular. The advantages related to modular green roofs outweigh the advantages of direct green roofs especially regarding the retrofitting of existing structures. The substrate depth was chosen as 100mm. No irrigation systems will be considered as they are not considered environmentally friendly, nor economically feasible (Breuning, 2013). The physical characteristics associated with modular trays that can be purchased in South Africa are as follows (Greenstone, 2011):

- Dimensions: length × breadth × height = 800mm × 600mm × 100mm.
- Made of recyclable high density polyethylene
- UV resistant
- Built-in drainage system, including a water reservoir for water storage
- Fully planted, fully saturated tray weighs $\pm$ 80 kg/m^2

Typically a multi-storey building roof top will not be completely empty. Therefore it is assumed that at least 20% of the roof area cannot be used for the green roof. The green roof area was assumed to be 80% of the building roof top, which is 548m^2.

4.3 Costs and Benefits Considered

The CBA was based on the costs and benefits associated with the general upkeep of an existing office building. It was assumed that the existing building is at least 20 years old and the roof's waterproofing needs to be replaced. In the CBA it was assumed that the building owner has two different options available:

1. Waterproof the roof with standard waterproofing, referred to as the conventional roof.
2. Retrofit the roof with an extensive modular green roof system, referred to as the retrofitted roof. This includes improved waterproofing.

The costs and benefits related to each of these two options are compared to each other. The costs and benefits considered for the CBA of the two different options are shown in Table 9. The costs over each year are considered at the end of the year. In the first year of analysis only the cost of the investment (i.e. waterproofing and green roofing) are considered. The running costs are considered from the second year of the analysis and onwards.

The conventional roof's waterproofing will be replaced twice during the analysis period, once every 20 years, thus in the first year and 20th year of the analysis.

The retrofitted roof's waterproofing will only be considered in the first year of analysis. The life time of a waterproofing layer is at least twice as long when placed underneath a green roof system, as previously discussed. Furthermore, it is assumed that a green roof will have a life span of 40 years, therefore the cost of installing a green roof system is only applicable in the first year. The CBA was done for a 40 year period since.

The benefits listed for the retrofitted building will be considered based on the assumptions of the CBA, which is explained in Chapters 6, 7 and 9. The reduced energy usage, when assumed, will be applicable for each year of the study period. The incentives shown in Table 9 are only applicable in the CBA when it is assumed the government or municipality of the city, offers incentives to promote the use of green roofs. The subsidy will only be for the initial installation costs of the green roof system. The reduced property tax will be a reduction in tax applicable over the 40 year study period.

Table 7 Costs and Benefits Assumed

Retrofitted Building	**Conventional Building**
Costs	
Replacement of waterproofing	Replacement of waterproofing
Green roof installation	
Electricity usage	Electricity usage
Water usage	Water usage
Operation and maintenance	Operation and maintenance
Property tax	Property tax
Stormwater tax	Stormwater tax
Green roof maintenance	
Benefits	
Income for renting office space	Income for renting office space
Reduced energy consumption	
Incentive: Subsidy for green roof installation costs	
Incentive: Reduced property tax due to green roof	

These costs and benefits considered for the CBA are discussed in more detail and the estimated values of each cost and benefit given in Chapter 5 of this report.

4.4 Assumptions and Limitation

Assumptions made with regards to the cost benefit analyses are as follows:

All cost benefit analyses assume that there is no additional capital from previous years available for replacing the waterproofing or installing a green roof.

The discount rate assumed for all CBA is 6%. This is based on South African inflation research from the Bureau for Economic Research (BER), as well as the South African National treasury's economic overview for 2016, 2017 and 2018. According to the inflation expectations of 2016 and 2017 (BER (Bureau for Economic Research), 2017; National Treasury of South Africa, 2017a), the average inflation fluctuates between 5.8% and 6.2%. Thus an average inflation of 6% is assumed.

Stormwater tax is not currently implemented in South Africa and is not taken into account in the CBA. However, there is a possibility that stormwater tax can be implemented in the future. Potential stormwater tax associated with a building in Johannesburg CBA was determined and has a very small effect on the outcome of the analysis. In the event where stormwater tax is implemented and the amount taxed per plot is more than anticipated in this report the impact of the tax will be more evident and can possibly be used as an incentive to promote green roof retrofits.

Carbon tax was not considered in the CBA. Although there is much talk about implementing carbon tax in South Africa to reduce carbon emissions, the manner in which carbon emissions are taxed is still relatively uncertain. If carbon tax is implemented however, it can serve as a future incentive and a reduction in the tax can serve as an additional benefit in a CBA for a retrofitted building, assuming that a retrofitted building would receive a reduction in tax since the green roof can reduce air pollution.

All results from the CBA presented in Chapters 6, 7 and 9 are based on the assumptions and building characteristics as defined in this chapter, as well as the costs defined in Chapters 5.

5 Costs and Benefits Data

In this chapter the costs and possible benefits assumed for the Cost Benefit Analyses (CBA) are discussed. It is explained how these costs were determined and how they will be considered in the CBA. The five costs and two possible benefits discussed in this chapter are as follows:

- Electricity.
- Green roof maintenance.
- Green roof watering.
- Waterproofing.
- Green roof system and installation.
- Reduction in energy consumption due to the green roof.
- Possible reduction in the cost of the green roof system and installation.

The feasibility of retrofitting an existing building with a green roof, when the building's waterproofing needs to be replaced was determined with an incremental CBA. For this analysis, the annual costs and benefits of the conventional and retrofitted building were subtracted from each other.

Most of the annual costs and benefits for the two buildings were the same. The difference in annual costs are the green roof maintenance and additional watering costs and the possible reduction in energy consumption discussed in Section 5.2.1 of this chapter. All other typical building costs and benefits such as building water usage, operation and maintenance, property tax and the monthly income from renting out the office space are the same for both buildings. Thus, these annual costs had no influence on the outcome of the incremental analysis.

Although these identical costs and benefits have no influence on the outcome of the incremental CBA analysis, the costs and benefits were determined and are discussed in Appendix B. These costs, were used to estimate the impact of each annual cost over the 40 year period of the analysis. This estimation gives an indication of which annual costs should be reduced, in order to have the most significant effect on the outcome of the analysis.

Figure 21 shows how the contribution of each cost to the total cost of a year changes over the 40 year analysis period. This graph shows the operation and maintenance costs were initially the largest, but in year 40 electricity costs accounted for the largest part of the total costs. Thus, reducing the energy usage of a building becomes more important in the later stage of the analysis.

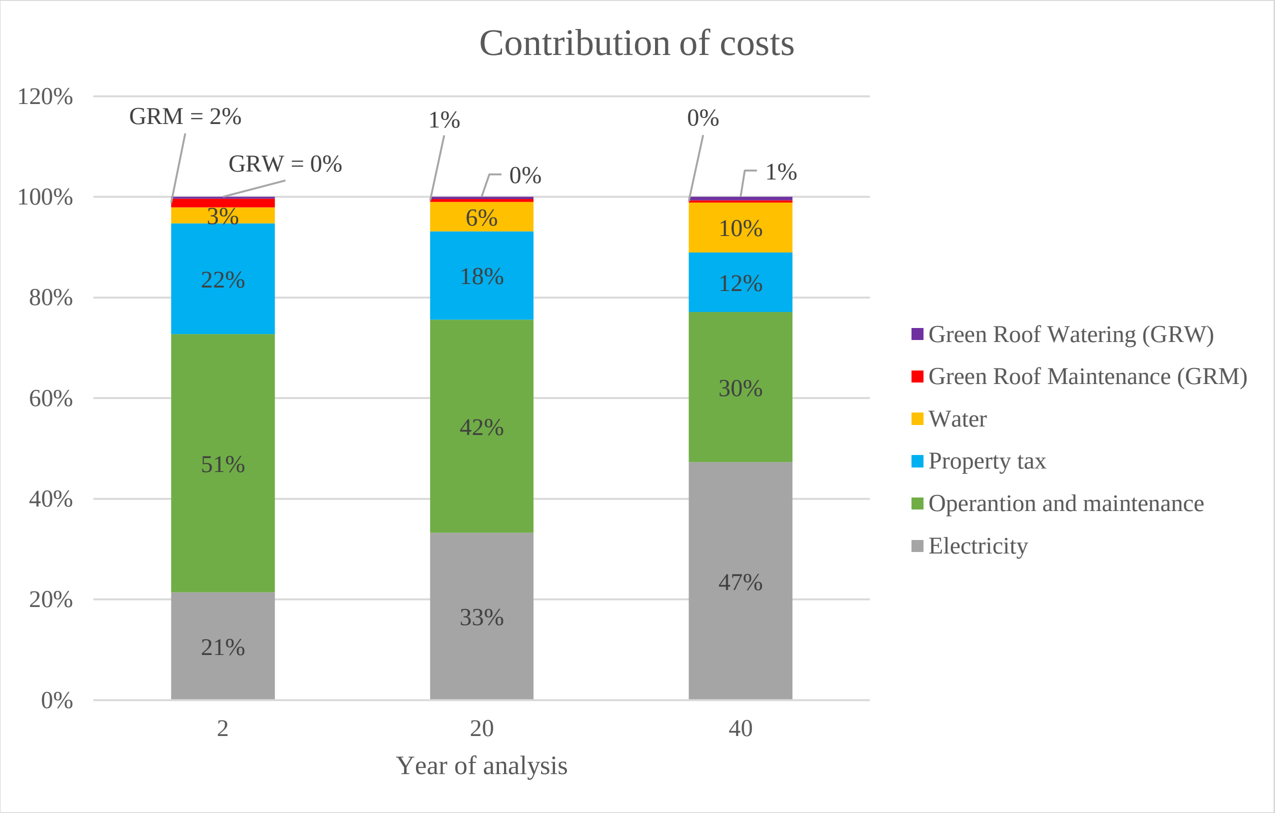


Figure 21 Change in costs over time

5.1 Costs

The costs that were considered for both the conventional and retrofitted buildings were as follows:

- Recurring costs was energy usage.
- Non-recurring costs were for waterproofing of the conventional building, the waterproofing costs were applicable for year 0 and year 20.
- Additional costs for the retrofitted building were as follows:
    - Recurring costs were green roof maintenance and the additional water usage for the green roof.
    - Non-recurring cost was the cost of the extensive modular green roof system.

These costs and how they were determined are discussed in the following sections;

5.1.1 Energy Consumption

The annual costs associated with a typical building's energy usage was determined by using the energy consumption and the energy cost of a typical building. The energy usage data for the Cost

Benefit Analysis (CBA) was based on the GBCSA Energy and Water Benchmark Methodology report (Bannister and Chen, 2012). This report gives a performance-based benchmark for South African office buildings.

The benchmark model aims at predicting the expected energy and water consumption of a building. Building location, building size and year of construction or refurbishment did not have a significant influence on the energy or water usage intensity of a building.

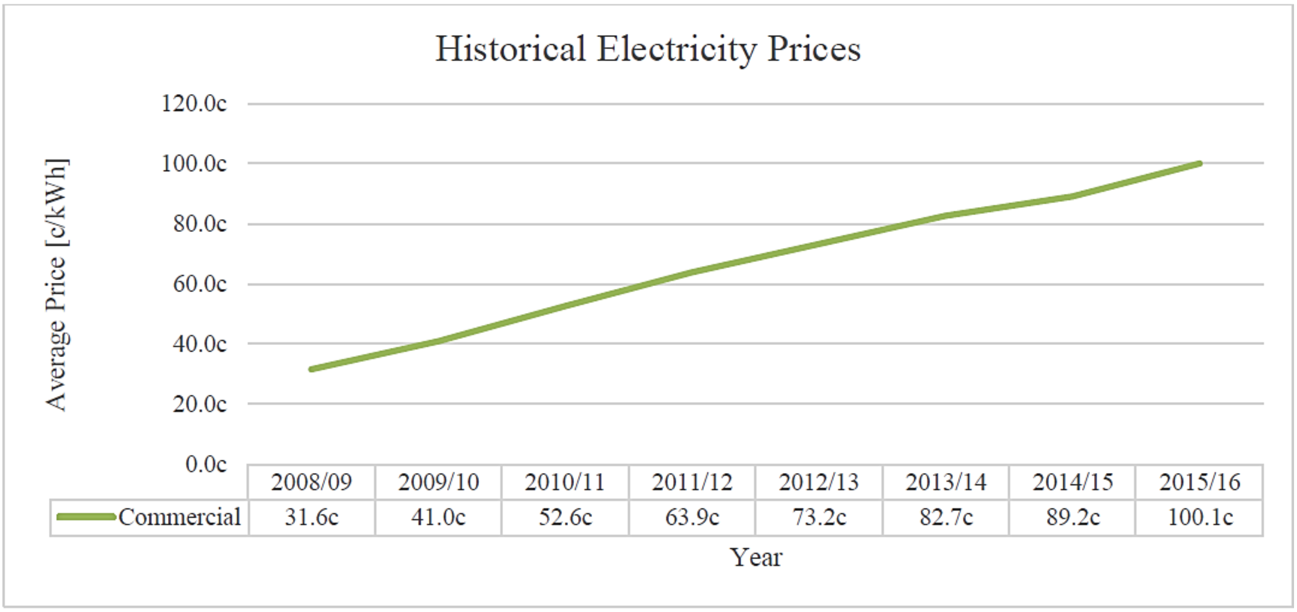
The following information regarding Energy Use Intensity (EUI) and energy consumption was obtained from the GBCSA report (Bannister and Chen, 2012):

- Average EUI of an office building is $219\mathrm{kWh/m^2}$
- $\mathrm{EUI}\ (\frac{\mathrm{kWh}}{\mathrm{m^2}}) = \frac{\text{Annual Energy Consumption (kWh)}}{\text{Building Area }(\mathrm{m^2})}$
- Building area is the Gross Lettable Area (GLA) of the whole building.
- Non-office spaces do not necessarily consume more or less energy per square meter than standard office spaces.
- Buildings with higher computer density have higher EUI.
- The most significant factors influencing the EUI of a building is computer and occupant density.
- Occupancy density is closely related to computer density, thus only computer density is factored into the energy benchmark model, since it is easier to measure.
- Occupancy-hours directly influence a building’s energy and water consumption.
- The impact of climate on a buildings’ EUI is approximately $2.42\mathrm{kWh/m^2}$/year per °C above or below the annual wet bulb temperature of 12.3°C.

The EUI was used to determine the energy consumption of the office building with the specifications as discussed in Chapter 4. The GLA was calculated by multiplying the floor area of $685\mathrm{m^2}$ and number of floors in the building, which is 7. The GLA of the office building was thus $4797\mathrm{m^2}$.

5.1.2 Electricity Tariffs

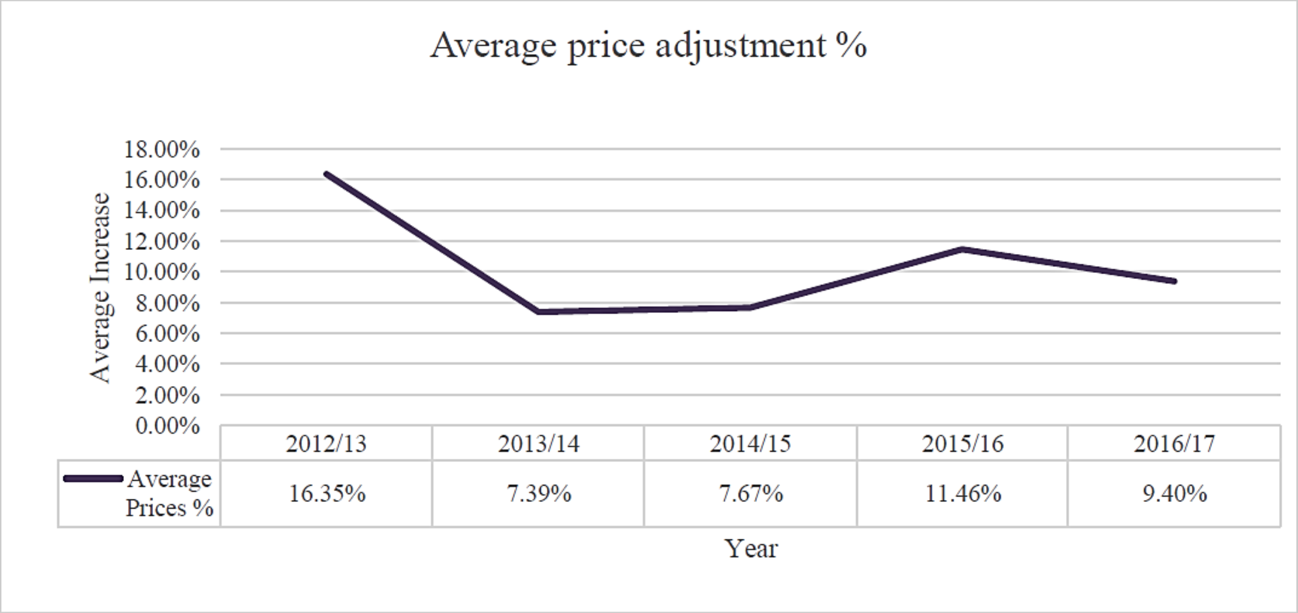
The annual electricity cost was based on the historical data shown in Figure 22. The data displayed in this figure is the average price of electricity sold by Eskom in cents/kWh from 2008 to 2016. The data in Figure 22 shows that electricity prices increase by 10 cents per year on average.



	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
🟩 Commercial	31.6c	41.0c	52.6c	63.9c	73.2c	82.7c	89.2c	100.1c

Figure 22 Electricity Rates (Eskom 2016)

The annual increase in electricity was based on the average increase over the past 5 years. Figure 23 shows the average annual increase in electricity costs for year 2012 to 2017 (Eskom, 2016; Fripp, 2016). Using this data it was determined that electricity increased with 10.45% per year on average. Sources report that Eskom intends to increase electricity rates by 19.9% in 2018 (Financial News South Africa, 2017). However, this increase has not been approved and will not be taken into account. An annual electricity increase of 10% was assumed for the CBA.



	2012/13	2013/14	2014/15	2015/16	2016/17
Average Prices %	16.35%	7.39%	7.67%	11.46%	9.40%

Figure 23 Annual Electricity increase (Eskom, 2016; Fripp, 2016)

5.1.3 Electricity

The initial electricity rate for year 0 of the Cost Benefit Analysis (CBA) was taken as the electricity rate for 2016, which is R1.001/kWh as shown in Figure 22, this is the electricity rate used to calculate the electricity cost in Equation 3. The GLA of the building is 4797m^2, the EUI is 219 kWh/m^2, as previously discussed.

This data was used to determine the cost of energy consumption for year 0 of the CBA. The electricity cost for year 0 was therefore taken to be R1 051 594 as shown in Equation 3 and was calculated as follows:

$$EUI\left({}^{kWh}/_{m^2}\right) = Annual\ energy\ consumption\ (kWh) \div Average\ GLA\ (m^2)$$

$$219 = Annual\ energy\ consumption \div 4797$$

$$Annual\ energy\ consumption = 219 \times 4797$$

$$= 1\ 050\ 543\ kWh$$

$$Electricity\ cost = Electricity\ rate\ (R/kWh) \times Annual\ energy\ consumption\ (kWh) \qquad Equation\ 3$$

$$= 1.001 \times 1\ 050\ 543$$

$$= R\ 1\ 051\ 594$$

5.1.4 Green Roof Maintenance

The green roof system proposed is an extensive modular system, which requires very little maintenance. The costs associated with maintaining a modular green roof system are the most expensive in the first year since the plants need to be watered three times a week for the first three months to become established (Niekerk et al. 2011). Additional maintenance and watering costs were considered for year 1 of the analysis. After the green roof has been established, the maintenance will consist of the following activities as discussed in the green roof maintenance guide (Columbia Green Technologies, 2014): Annual fertilizing preferably during the spring season, removing vegetation in unwanted places such as drain systems in order to keep the roof's drainage functioning properly, removal of debris and dead plants from the green roof, removal of weeds or tree seedlings, trimming the vegetation in order to keep the roof neat and aesthetically pleasing and watering the green roof. The cost of water the plants is discussed in the following section. In general a green roof needs to be maintenance every 2 to 3 weeks and requires annual inspection (Columbia Green Technologies, 2014), to ensure that the plants are healthy, that adequate nutrients are available, that the plant coverage is as needed and that the plants are not showing any signs of wilting or stress. The trays also need to be inspected to ensure they are fitted together as installed. It is assumed that maintenance will be done on a biweekly basis, twice a month, during the study period.

No maintenance costs are considered in year 0. For year 1 of the analysis period maintenance will be done 59 times, this accounts for the additional maintenance required for the first three months, Maintenance will be 26 times per year for the remaining years, year 2 to 40, of the study period.

Maintenance fees were based on the assumption that 6 labourers will work for half a day, thus 4 hours, during a maintenance day. This assumption is speculative, but is based on the size of the green roof and the type of maintenance that will be done. The green roof area is 548m^2. Thus there will be little over 1 person maintaining a 100m^2 area of the roof. The influence of increasing and reducing the number of labourers were tested using Monte Carlo analyses, and is discussed in Chapter 8.

The labour fee was based on the general worker rates of R24.02/hour (Alexanders et al., 2016), and supervisor rates were assumed to be double that of the labour rate which is R48.04/hour. The weekly cost of maintenance was calculated using Equation 4. The overhead cost was assumed to be the same as that of the overhead cost for consultants (Department of Public Service and Administration South Africa, 2003), which is 1.9.

Weekly maintenance cost was calculated as follows:

$$\text{Weekly maintenance} = (LF \times L + SF) \times OF \times h \qquad \text{Equation 4}$$

$$= (R24.02 \times 6 + R48.04) \times 1.9 \times 4$$

$$= R1\ 460/week$$

Where;

h	is hours of work per week
L	is number of Labourers
LF	is Labour Fee
SP	is Supervisor Fee
OF	is Overhead Factor

The annual maintenance cost for year 1 and the remaining years of the analysis is as follows:

- *First year maintenance cost (Year 1) = R1 460 × 59 = R86 145*
- *Annual Maintenance cost (Year 2 -40) = R1 460 × 26 = R 37 971*

The maintenance costs for year 1 amounts to R157/m^2, and for the remainder of the analysis period the cost is R69/m^2. According to the U.S. Environmental Protection Agency (2008), extensive green roof maintenance costs between \$0.75 - \$1.50/ft^2 annually. Whilst the Minnesota Pollution Control Agency (2016), states that annual maintenance costs between \$0.1 - \$1.0/ft^2. These costs amount to an average of R112/m^2, which is 38% more than the maintenance cost assumed. However, these annual maintenance costs from the U.S. resources are not necessarily comparable to the maintenance costs of South Africa.

The annual increase is assumed to be 6%. For the CBA the annual maintenance cost was converted to the present value for each year.

5.1.5 Green Roof Water Usage

Water usage of the building was not considered in the CBA however, the additional water usage for watering the plants on the green roof were considered. Water usage of the green roof was based on the study by Volkmann (2016), which compared different roof cover alternatives for green roofs. The study considered the water requirements of the alternative roof covers during the months of September and October, in this period the average rainfall was 0.9 mm/day. The average rainfall for the Johannesburg region is 1.65 mm/day, indicating that a green roof situated in Johannesburg would requires less water than determined in the study. The study found that 'spekboom' and other succulents typically found in South Africa require 1.875 l/m^2/day.

The water requirement data from the study was used to determine the monthly water requirements of a green roof containing succulent plants. The calculations were done as follows:

$$\begin{aligned} \textit{Monthly water requirements} &= 1.875\ l/m^2/day \times 30.42\ days/month \\ &= 57.04\ l/m^2/month \\ &= 0.057\ kl/m^2/month \end{aligned}$$

For the purpose of this study it is assumed that the green roof's water requirements are 0.057 kl/m^2/month. As previously mentioned, the green roof requires additional maintenance for the first three months, during these months the green roof uses 0.171 kl/m^2/month, for the remainder of the year the green roof requires 0.057 kl/m^2/month. Note that no water is used for the green roof in year 0. The green roof covers an area of 548m^2, using this area the annual additional water consumption of the green roof was determined as follows:

- *First year water consumption (Year 1)* $= (0.171\times3 + 0.057\times9)\times548 = 562$ *kl/year*
- *Annual additional water consumption (Year 2 -40)* $= 0.057\times12\times548 = 375$ *kl/year*

The water tariff was assumed to be R27.47/kl, with an annual increase of 11%, this is based on the water tariffs as discussed in Appendix B. The annual cost of watering the green roof for year n=1 and the remained of the study, year n=2 - 40 was determined as follows:

- *Additional water consumption year 1 (n= 1)* $= 562\times R27.47\,(1+0.11)^n = 15\,445\,(1+0.11)^n$

  $= R\ 17\,144$

- *Annual additional water consumption (n= 2 - 40)* $= 375\times R27.47\,(1+0.11)^n$

  $= 10\,297(1+0.11)^n$

  $= R12\,687$ *when* $n = 2$

  $= R\ 669\,314$ *when* $n = 40$

5.1.6 Waterproofing

The costs associated with waterproofing were material, labour and installation costs. A conventional building's roof waterproofing has to be replaced every 20 years. As previously mentioned, once a roof has been retrofitted with a green roof system the waterproofing will last up to twice as long, thus 40 years. The material costs associated with waterproofing include the cost of the sealants and membranes used for typical waterproofing. The prices used in the CBA for the waterproofing were based on the prices provided in the annual building and pricing guide for the construction industry which was published in 2016 (Alexanders et al., 2016). Therefore none of these prices were adjusted to present value. Labour costs were also determined using the building and pricing guide. Waterproofing is considered to need skilled workers. The labour rates for skilled workers are R36.65 per hour. Considering waterproofing will take about three working days and up to three workers, working approximately eight hours a day (Ross & Son, 2017), labour will thus cost R2639 in total.

Waterproofing membranes used beneath green roofs are covered grade membranes with a 4 mm thickness. For a reinforced concrete flat roof or boarded roof that is exposed to the open air a superior quality special polyester membrane is used. The exposed grade membrane must have a thickness of 4 mm. The costs per square meter for water proofing a regular roof and a green roof are shown in Table 8. The waterproofing costs of a green roof include the additional material costs associated with waterproofing a roof for retrofitting. The roof area is 685m^2.

Waterproofing costs for the retrofitted building in Table 8, are more expensive because a higher quality waterproofing is used to ensure that the roof does not leak due to the green roof.

Table 8 Waterproofing Pricing (Alexanders et al., 2016)

	Conventional Roof	Green Roof
Materials	R103.17/m^2 = R70 671	R103.17/m^2= R70 671
Labour	R2 639	R2 639
Preparation Cost	R 35.00 /m^2 = R23 975	R 750.00/m^2 = R513 750* *Includes preparation and additional material costs
Waterproofing Cost	R 265.00/m^2 = R181 525	
Total Cost	**R 278 810**	**R 587 060**

5.1.7 Green Roof System

Costs typically associated with retrofitting a building with a green roof are:

- A consultant engineer to do a structural analysis of the building. This analysis will determine if it can support the additional load of the green roof system.
- Structural modifications if deemed necessary by the structural engineer.
- A green roof specialist to design the green roofing system.
- Materials, which include the costs of the protection layer, root barrier, modular trays, soil, plants, edge restraints and balustrading.
- Installation of the green roof system.
- Planning and building permits.
- Permits for the lifts and cranes.
- Inspecting the water proofing system and verification of the roof's water tightness.
- Demolition and relocation of the existing infrastructure on the roof.
- Labour.

These costs and how they were calculated are discussed in the following paragraphs:

Consulting Engineers

The cost of a consulting engineer to do a structural analysis and green roof specialist to design the green roof, was based on the fees given in the Guide on Hourly Fee Rates for Consultants (Department of Public Service and Administration South Africa 2003).

The guide lists all the factors used in calculating the hourly fees for consulting engineers and specialist consultant engineers. The factors used are as follows;

- Average total package, which is the average salary of a consultant.
- Overhead factor, which accounts for the basic administration and auditing needs and costs of the company the consultant works for.
- Mark-up for profit, which provides for taxation and profit depending on the tax status of the consultant as provided by SARS.

- Utility rate, which allows for time to generate income that cannot be attributed to a specific project or consultancy work

The fees were converted to present value and the calculation based on a short-term employment of both these specialists. The Guide proposes how the hourly fees should be calculated and provides the values for the factors based on whether the engineer is a specialist and the duration of the work.

Structural Engineer

Average salary of a specialist is R1 158 832 per year (Department of Public Service and Administration South Africa 2003), which was adjusted to present value. Other factors used to determine the hourly fee were the overhead factor of 1.90, mark up of 1.30, utilisation rate of 0.7 and available hours are 1760 per year. It was assumed that a structural analysis of the building will take approximately 3 days to complete and that the specialist works 8 hours per day, thus the specialist works 24 hours in total.

The total cost of the structural engineer was calculated as R55 759. This total cost is based on the hourly fee, the hourly fee for the structural engineer was calculated as follows:

$$Hourly\ Fee = \frac{Average\ total\ package}{Available\ hours} \times \frac{Overhead\ Factor\ \times Mark-up}{Utilisation\ rate}$$

$$= \frac{R1\ 158\ 832}{1760} \times \frac{1.9 \times 1.3}{0.7}$$

$$= R2\ 323/hour$$

Green Roof Specialist

The average salary of a green roof specialist was based on the salary of a general consulting engineer. The average salary is R793 940 per year (Department of Public Service and Administration South Africa, 2003), which was adjusted to present value.

Other factors used to determine the hourly fee were overhead factor of 1.90, mark up of 1.30, utilisation rate of 0.7 and available hours of 1760 per year.

The green roof specialist will design the green roof, be present during installation and inspect the green roof once it is installed. It was assumed that the green roof specialist will be employed for a duration of 8 working days, 8 hours per day. Thus, the green roof specialists works 64 hours in total.

The total cost of the green roof specialist was calculated as R101 872. This total cost is based on the hourly fee, the hourly fee for a green roof specialist was calculated as follows:

$$Hourly\ Fee = \frac{Average\ total\ package}{Available\ hours} \times \frac{Overhead\ Factor\ \times Mark - up}{Utilisation\ rate}$$

$$= \frac{R793\ 340}{1760} \times \frac{1.9 \times 1.3}{0.7}$$

$$= R1\ 592/hour$$

Materials

A modular system requires the installation of a protection layer and a root barrier underneath the trays. The root barrier and protection layer is placed between the roofing membrane and the modular trays.

The protection layer considered is a woven fabric and costs $\mathrm{R6.46/m^2}$ (Alexanders et al., 2016). The root barrier considered is a Safeguard Root Barrier, designed for green roofs, which is available in South Africa. The root barrier present value is $\mathrm{R7.30/m^2}$ (Safeguard, 2010). The costs of the protection layer and root barrier were calculated as R4 427 and R5 002 respectively.

Generally edge restraints and balustrades also need to be installed onto a green roof. Edge restraints are used to restrain the green roof's substrate, especially when the roof is sloped. Edging is only used for direct green roof systems and not for modular systems, since the modular tray itself restrains the substrate. Thus the cost of edge restraints is not considered for the purpose of this study. Stainless steel balustrades cost R1300 per meter (Kanew, 2016). The perimeter of the roof is 105.5m. Therefore, the cost of balustrading was taken as R137 150. Due to the building regulations of older buildings in Johannesburg not all roofs may need balustrades however, for the purpose this study balustrading is taken into consideration.

It is assumed that a new waterproofing layer will be installed together with the green roof system. The cost of inspection of the waterproofing layer and verification of the roof's water tightness will therefore not be considered. The cost of installing a waterproofing layer will however be included in the CBA as previously discussed.

Extensive modular green roof system

As mentioned, an extensive modular green roof system will be considered in the CBA. The substrate depth for the extensive green roof system was chosen as 100mm thick. Modular trays with a substrate depth of 100mm can be purchased fully planted, at a cost of R923/m^2 (Greenstone 2011), which was adjusted to present value. This cost includes the cost of the soil and plants.

It is assumed that the entire roof will not be retrofitted, but that at least 20% of the roof surface will be used for existing infrastructure on the rooftop. Therefore only 80% of the roof will be used for the modular trays. The total cost of the planted trays for the roof area is R506 197.

Building permit

In order to be allowed to construct the green roof it is necessary to have a building permit issued by the City of Johannesburg. A construction permit takes about 141 days to be issued and there are 19 procedures to follow in obtaining this permit. The costs associated with the permit add up to approximately R20 775 (National Treasury of South Africa, 2016).

Crane

A crane will be needed to lift the materials onto the roof top. The typical building's rooftop is 19.6m above the ground, therefore a crane that can reach higher than 19.6m is needed. A truck-mounted lattice boom crane with the capacity to lift 40 tons and a boom length of 23.5m was considered. Such a crane has a working height higher than 20m (Manitex International, 2017).

The cost associated with the hire of such a crane, is an hourly rate of R927/hour (Contractors Plant Hire Association, 2017). It was assumed that the crane will be hired for a total of four days and that the crane will be used for nine hours a day. This is a conservative assumption. The total cost of hiring the crane is R33 372.

Labour

Skilled labourers are needed for the installation of the green roof. The cost of such a labourer is R36.65 per hour (Alexanders et al., 2016). Most commercial installations of green roofs take a few days up to a week, depending on the complexity and size of the design. It is assumed that it takes five days for five specialist labourers to install the green roof. Therefore the labour cost for installing the green roof was taken as R7330.

It is possible that the existing infrastructure on the roof will have to be relocated. The cost of relocating the existing infrastructure was based on the cost of specialist labour, since this will be a very conservative assumption. It is furthermore assumed that it will not take more than two days, which is also a conservative assumption, for the relocation of the existing infrastructure. Therefore it will cost R2932.

Green roof costs summary:

A summary of all the costs taken into account for the green roof system is listed in Table 9. The total cost of installing an extensive modular green roof system was determined to be R 874 772.

Table 9 Green Roof Installation Costs

Component	Cost
Structural Engineer	**R55 759**
Green Roof Specialist	**R101 872**
Materials - Root Barrier - Protection Layer - Balustrading	**R146 534** - R5 002 - R4 427 - R137 105
Extensive modular system	**R506 197**
Building Permit	**R20 775**
Site equipment (Crane)	**R33 372**
Labour - Installation of Green Roof - Relocation of existing infrastructure	**R10 262** - R7330 - R2932
Total Cost of System	**R874 772**
Cost of Waterproofing	**R587 060**
Total Green Roof Cost	**R1 461 832**

5.2 Benefits

The benefit considered for both the conventional and retrofitted buildings is the annual income a building owner receives for renting out the office space. This benefit will have no influence on the outcome of the incremental CBA and is therefore not discussed in this section. Possible benefits that were considered for the retrofitted building are a reduction in energy usage and the subsidy a building owner can receive, which reduces the initial costs of the green roof. No additional benefits were assumed for the conventional building.

5.2.1 Reduced Electricity Usage

The potential reduction in electricity usage of a building with seven floors, retrofitted with a green roof, was considered. This section discusses the method used and assumption made to estimate the reduction in electricity usage considered in the CBA. Data concerning the reduction in energy usage of a building, due to the increased thermal resistance of a building retrofitted with a green roof, is limited. This is especially true for buildings with more than three to four floors.

Table 10 Building energy savings data from literature

Number of floors	Energy Savings	City, Country	Average Temperature (°C)		Literature Reference
			Summer	**Winter**	
2	73%	Toronto, Canada	21	-3	Sustainable Technologies Evaluation Program 2007
3	29%				
4	18%				
5	5.9%				Berardi 2016
2	11%	Athens, Greece	29	10	Spala et al. 2008
2	11%				Santamouris et al. 2007
8	4.88%	Madrid, Spain	25	6	Saiz et al. 2006
10	3.7%				

Table 10 shows the possible building energy savings for buildings with green roofs. The table presents the energy savings with regards to the number of floors of different buildings in three different cities, namely Toronto in Canada, Athens in Greece, and Madrid in Spain. The energy savings data in Table 10 was used to create the graphs in Figures 24 and 25. These figures were used to estimate the potential energy saving of a building with seven floors such as the building considered in this study. It was assumed that the reduction in energy consumption of the typical building in Johannesburg is related to the energy reduction estimated using these figures. This is assumed since no research concerning the reduction in energy usage of a building, retrofitted a green roof is available for buildings situated in Johannesburg.

Figure 24 shows the trend line for the potential energy savings data presented in Table 10. Using this trend line, and the equation thereof as shown on the figure, a potential reduction in energy usage of 3.2% was estimated.

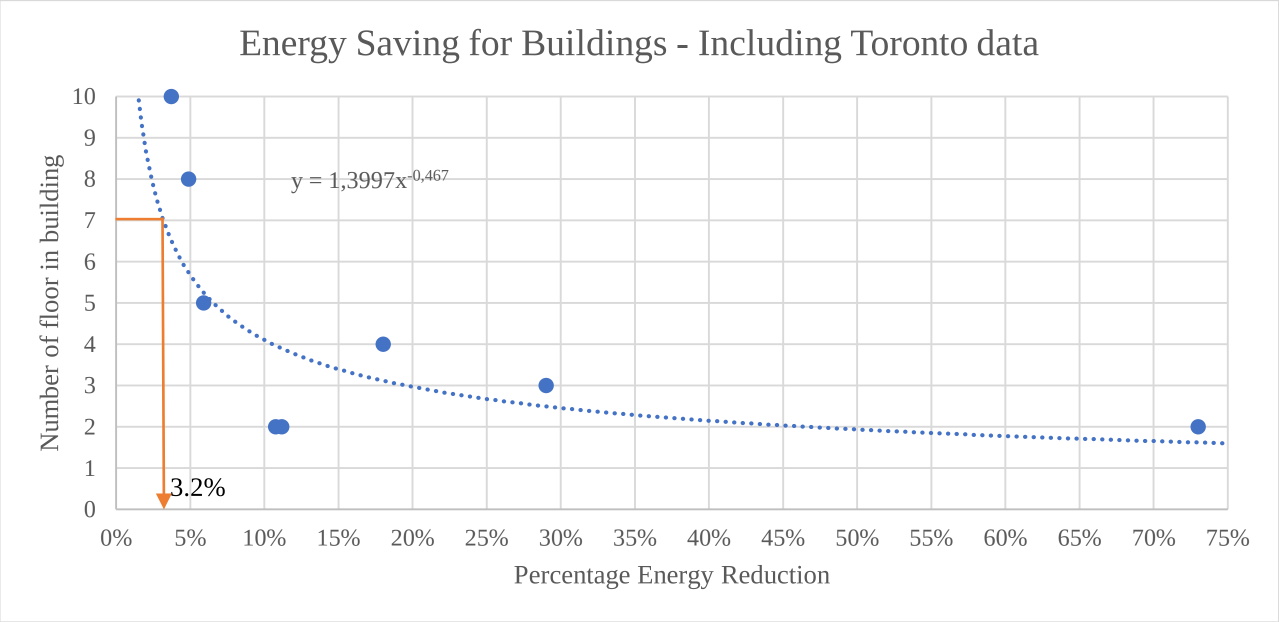


Figure 24 Estimated energy savings - including Toronto data

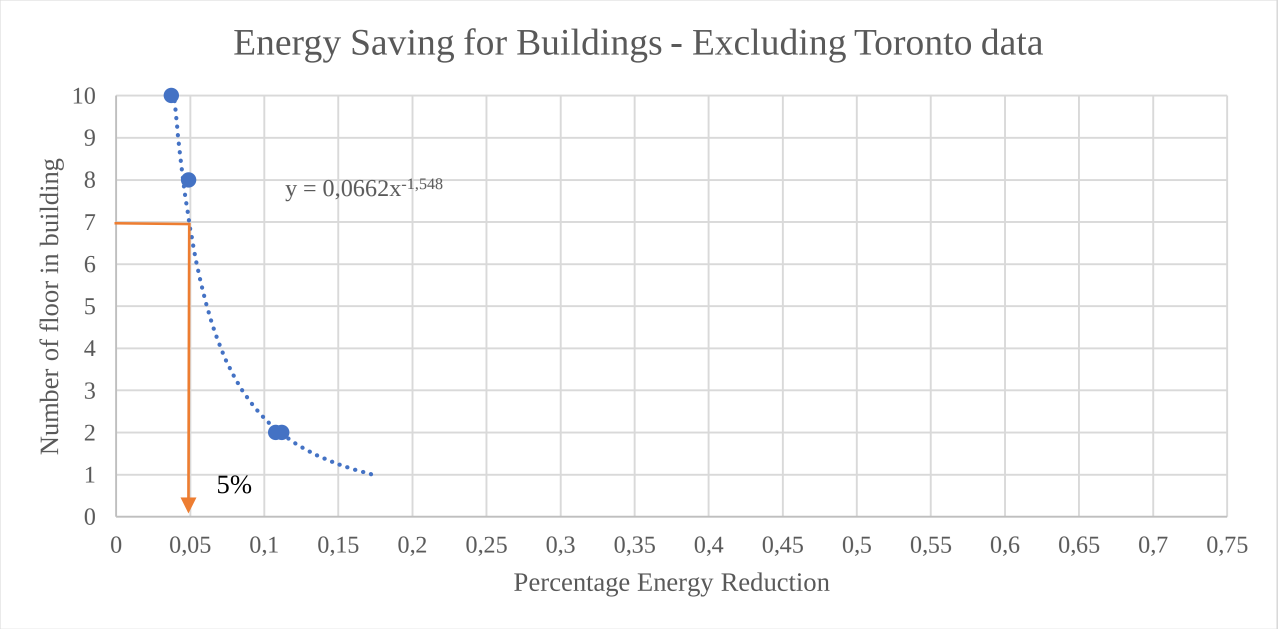


Figure 25 Estimated energy savings - excluding Toronto data

The average summer and winter temperatures of Johannesburg is 21°C and 10°C respectively. Table 10 shows the average summer and winter temperatures of the different cities. The average annual winter and summer temperatures of Athens and Madrid are relatively similar to that of South Africa, compared to the average annual temperatures of Toronto. In order to determine whether the Toronto data will have a significant influence on the predicted energy savings it was excluded from the graph shown in Figure 25. This figure shows the trend line using the data for Athens and Madrid. Using this trend line a potential reduction in energy usage of 5% was estimated.

Figures 24 and 25 show that excluding the data from Toronto results in a less conservative prediction of the energy savings. Therefore, the data from Toronto was included in the energy savings considered in the CBA of a building retrofitted with a green roof. For the purpose of this study it was assumed that the annual electricity usage will reduce by a maximum of 3%.

The effect of the reduction in annual electricity usage was analysed in sensitivity analyses presented in Chapter 7. The percentage reduction ranged from 0.5% to 3%. The Electricity Cost of the Retrofitted building (ECR) was calculated using Equation 5.

$$ECR = \text{Annual electricity cost} \times (1 - \text{Reduced energy usage}) \qquad \textit{Equation 5}$$

Thus the ECR ranged between R1 020 046 and R1 046 336. The calculations are as follows;

- Assuming 0.5% reduced electricity usage;

$$ECR\ (\text{retrofitted building}) = R1\ 051\ 594 \times (1 - 0.005) = R1\ 046\ 336$$

- Assuming 3% reduced electricity usage;

$$ECR\ (\text{retrofitted building}) = R1\ 051\ 594 \times (1 - 0.03) = R1\ 020\ 046$$

Note that the buildings considered in the data presented in Table 10 may have either intensive or extensive green roofs and their roofs may be insulated or uninsulated. The wall to roof ratio of the building walls and green roofs of these buildings are also unknown. These aspects could have significant effects on the reduction in energy consumption of a building. Furthermore, results presented here are purely theoretical. Field research is needed to establish the potential savings in building energy usage of buildings retrofitted with green roofs in South African cities.

5.2.2 Subsidies

Sensitivity analyses were done to determine the influence of subsidies on the NPV and discounted payback period of the retrofitted building. These analyses assume that the local municipality or government provides a subsidy of a percentage of the initial cost of a green roof, to a building owner who installs a green roof system. The subsidy is a benefit to the building owner, but is considered as a reduction in the initial cost. The discounted costs will therefore be reduced, whereas the discounted benefits will not increase. This is explained in Chapter 7.

The percentages of reduction in initial cost that were considered were 30%, 50% and 80%. The rand values of these subsidies are R438 550, R730 916 and R1 169 465 respectively. This reduction in cost is only considered in the first year of the analysis. This is discussed in more detail in Chapter 7.

5.3 Total Costs and Benefits

A summary of the costs taken into account for the CBA of the conventional and retrofitted buildings for the first and second year of the analysis is shown in Table 11. This table shows the total annual, recurring and non-recurring costs for both roofs, as well as the cash flow at the end of the first and second year (years 0 and 1). The interest rates assumed for the each of the different cost or benefit are also shown in the table. The costs and benefits in Table 11 are based on a typical office building in Johannesburg CBD as determined in Chapter 4, Table 6. This typical building has 7 floors, a floor footprint of 685m^2 and a roof perimeter of 105.5m.

The difference in cost for the first and second year of the analysis is shown in the last row in Table 11. This value is the difference in the discounted cash flow for each year. The costs and benefits shown for year 1 of the analysis are the future costs and benefits. These costs and benefits were discounted at a 6% discount rate to determine the difference in the discounted cash flow of the retrofitted and conventional building for the first and second year of the analysis. The discounted cash flows over the 40 year period are shown in Table C1 in Appendix C.

The discounted cash flows for each of the 40 years in the CBA, discussed in the following chapters, was calculated in this manner. All results were based on the difference in the discounted costs and benefits of the retrofitted and conventional building.

The CBA assumes that the building is in need of replacing its roofs’ waterproofing membrane. The cost of waterproofing is considered for year 0 and year 20 of the CBA for a conventional roof. For the retrofitted rooftop, the waterproofing and green roofing is only considered for year 0.

The initial costs associated with retrofitting the existing building's rooftop with a green roof being R1 461 832, is R1 183 022 more expensive than the option to just waterproof the building which costs R278 810, as shown in Table 11.

Table 11 Summary of costs and benefits – first year of CBA

Cost/Benefit Type	Retrofitted	Conventional	Retrofitted	Conventional	Growth rate
Year	0	0	1	1	
Costs					
Waterproofing	R587 060	R278 810			6%
Green roofing	R874 772				N.A
Operation and Maintenance			R2 689 851*	R2 689 851*	6%*
Property tax			R1 151 291*	R1 151 291*	6%*
Water			R166 746*	R166 746*	11%*
Electricity			R1 156 753	R1 156 753	10%
Green roof maintenance			R91 334		6%
Green roof water			R17 144		11%
Total Costs	R1 461 832	R278 810	R5 273 119	R5 164 641	
Benefits					
Total Benefits = annual rent			R7 220 901*	R7 220 901*	7%*
Net income	- R1 461 832	- R278 810	R1 947 782	R2 056 260	
Difference = Retrofitted - Conventional	-R 1 183 022		-R108 478		
Discounted at a 6% discount rate					
Discounted Net Income	- R1 461 832	- R278 810	R 1 837 530	R 1 939 868	
Difference = Retrofitted - Conventional	**-R1 183 022**		**-R102 338**		

*Note that assumptions and calculations for the operation and maintenance, property tax, water and annual rent costs and annual growth rates, shown in Table 11, are discussed in Appendix B.

The data in Table 11 (see also Appendix C) was used as the input data for the CBA discussed in Chapters 6, 7 and 9. These chapters consider the cost, discussed in Chapter 3, under different circumstances to determine which benefits and incentives are required to ensure retrofitting a building with a green roof is affordable for a building owner.

6 Cost Benefit Analysis

Cost Benefit Analyses (CBA) were used to determine the feasibility of retrofitting a building with an extensive modular green roof system. The feasibility was determined based on the Net Present Value (NPV) and the payback period. For these analyses it was assumed that the building is at least 20 years old and the roof's waterproofing is in need of replacement.

The CBA compared the costs of retrofitting the building with a green roof to the costs of replacing the waterproofing the building. Replacing the waterproofing of the building was considered to be the "do nothing" option. This option is referred to as the "conventional building". The option to retrofit the building with a green roof is referred to as the "retrofitted building". The costs and benefits discussed in Chapter 5 were assumed. The CBA discussed in this chapter assumed that there are no additional benefits received when retrofitting the building. A CBA that considered additional benefits is discussed in Chapter 7.

The alternative buildings were compared using the difference in discounted cash flows over a 40 year analysis period. The results of this difference in discounted cash flows are presented in this chapter. The data used to create Figures 26 and 27 are shown in Appendix C, Table C 1.

6.1 Discounted Cash Flow

Discounted cash flow of a year is the difference between the discounted benefits and discounted costs of that year. The difference in discounted cash flows for each year of the analysis is the retrofitted building's discounted cash flow minus the conventional building's discounted cash flow. A discount rate of 6% is assumed.

Table 12 shows the CBA data of the discounted costs for the retrofitted and the conventional building. The costs of the first three years are shown, as well as the costs in year 20. The difference in discounted cash flows for each of these years is shown, as well as the accumulated cash flow.

The difference in discounted cash flows in Table 12, is graphically shown in Figure 26. In the first year of the analysis the cost of waterproofing the conventional building and the costs of installing a green roof system on the retrofitted building are the only costs considered. No running costs are considered in the first year.

The difference in discounted cash flow for this year is –R1 183 022, calculated as shown in Table 12. This is the additional cost a building owner will pay for installing an extensive green roof system.

Table 12 Discounted Costs

Year	0	1	2	20
R = Retrofitted building				
Discounted costs				
Green roof installation	R 1 461 832			
Green roof maintenance		R 86 165	R 37 971	R 37 971
Green roof water		R16 173	R 11 291	R25 884
C = Conventional building				
Discounted costs				
Waterproofing replacement	R 278 810			R 278 810
Difference in discounted cash flow (R – C)	-R 1 183 022	-R 102 338	-R 49 262	R 214 955
Cumulative	-R 1 183 022	-R 1 285 360	-R 1 334 621	-R 2 063 260

Year 1 of the analysis has a lower discounted cash flow, than that of the years that follow, due to the additional green roof maintenance and water requirement for the first year of the green roof's lifetime. This is discussed in Chapter 5, Sections 5.1.4 and 5.1.5.

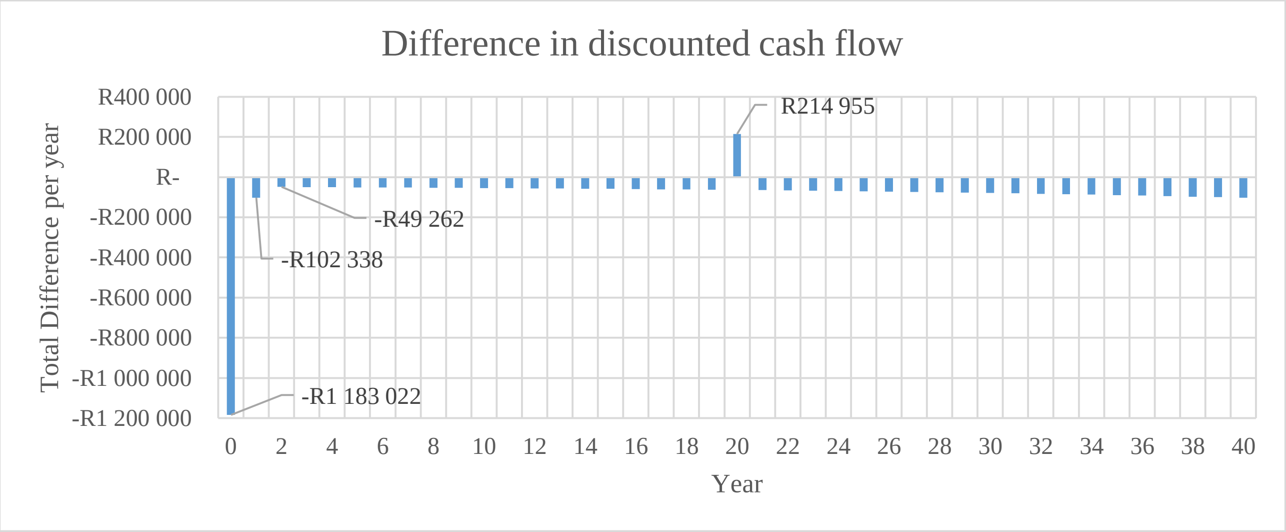


Figure 26 Discounted Cash flow

This annual maintenance cost of the green roof and the additional water used for the green roof are the additional costs for the retrofitted building after year 0 of the analysis. The sum of these costs accounts for approximately 1% of the annual costs for the retrofitted building over the 40 year period (see Figure 21, Chapter 5). This annual cost makes the retrofitted the less attractive option in terms of NPV and discounted payback period.

In year 20 of the analysis the conventional building has a lower discounted cash flow than that of the retrofitted building. This is due to the waterproofing that needs to be replaced again in year 20, as the waterproofing on a conventional building needs to be replaced every 20 years.

6.2 Cumulative Discounted Cash Flow

The cumulative difference in discounted cash flow of the conventional and retrofitted building is shown in Figure 27. This figure shows that the costs associated with the retrofitted building always outweigh the costs of the conventional building. This means that a building owner retrofitting with a green roof will never receive a return on his investment, unless he receives an incentive or other benefits.

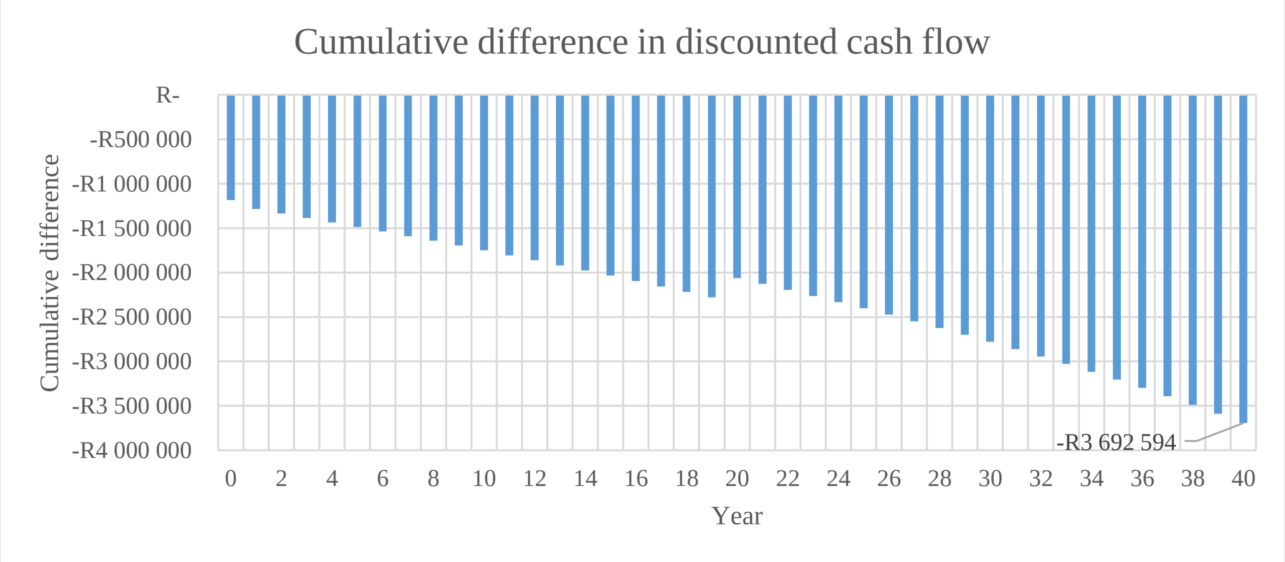


Figure 27 Cumulated discounted cash flow

The cumulative value of the difference in the discounted cash flows for each year is the difference in NPV for this analysis, which is –R3 692 594, as shown in Figure 27.

The NPV for each building is the sum of the discounted cash flow of each year. Equation 1 is used to calculate the NPV. Thus the difference in NPV is the difference in cash flows of the retrofitted and conventional buildings over the 40 year period.

The difference in NPV, being –R3.7 million as shown in Figure 27, means that the future value of the retrofitted building considered in the present is R3.7 million less than the conventional building. Thus, over a 40 year period, the additional costs associated with the green roof amount to R3.7 million. The difference in NPV can be calculated as shown in Equation 6. The discount rate was assumed to be 6%.

Equation 6

$$NPV\ difference = Retrofitted\ NPV - Conventional\ NPV$$

$$= \sum_{n=0}^{40} \frac{B_n - C_n}{(1+d)^n} - \sum_{n=0}^{40} \frac{B_n - C_n}{(1+d)^n}$$

$$= \frac{-GRI_{n=0}(1+6\%)^{n=0}}{(1+6\%)^{n=0}} + \sum_{n=1}^{40} \frac{-GRM_n(1+6\%)^n}{(1+6\%)^n}$$

$$+ \sum_{n=1}^{40} \frac{-GRW_n(1+11\%)^n}{(1+6\%)^n} - \left[\frac{-W_{n=0}\,(1+6\%)^{n=0}}{(1+6\%)^{n=0}} + \frac{-W_{n=20}\,(1+6\%)^{n=0}}{(1+6\%)^{n=20}}\right]$$

$$= -R\,1\,461\,832 - R\,1\,567\,026 - R\,1\,221\,357 + R\,278\,810 + R\,278\,810$$

$$= -R\,3\,692\,594$$

Where;

B	is Benefit
C	is Cost
GRI	is Green Roof Installation cost
GRM	is Green Roof Maintenance cost
GRW	is Green Roof Water cost
W	is Waterproofing replacement cost

The difference in NPV was used to evaluate the feasibility of retrofitting an existing building with a green roof assuming different conditions and benefits, which is discussed in the following chapters.

Figure 27 shows that the there is no payback period, as the cumulated cash flow will continue to be negative indefinitely. These results show that without any benefits received when retrofitting a building with a green roof there is no incentive for a building owner to do so. The benefits related to a building retrofitted with a green roof are investigated and discussed in Chapter 7.

7 Sensitivity Analyses

Green roofs have many benefits to offer. This chapter considers two different sensitivity analyses. These analyses investigate how the benefits influence the annual and initial costs of the retrofitted building. Benefits considered were as follows;

- The ability of a green roof to reduce the building's annual energy consumption. This is a direct, annual benefit towards the building owner.
- An incentive offered by the city's municipality to subsidise a percentage of the initial green roof installation costs. This benefit will only be applicable in the first year of the analyses.

7.1 Benefits Considered

This section discusses the reasons why these benefits were considered and the limitations of these benefits.

7.1.1 Reduced Energy Consumption

Energy savings due to green roofs are limited as the largest exposed surface of a building is the vertical walls. The potential energy savings alone due to green roofs are not necessarily enough to justify the implementation thereof, however energy savings were considered.

With respect to the characteristics of the typical building considered in the CBA, the contribution of the annual electricity costs towards the total running costs, over the study period of 40 years are 34% (see Figure 21, Chapter 5).

This means that over the 40 year study period, electricity costs account for 34% of the running costs on average. Even a small reduction in annual electricity costs therefore can have a significant impact on the total running costs of the building over the 40 year study period.

A non-linear relationship is assumed between the building height and the corresponding reduction in energy consumption. The taller a building, the less a green roof reduces the electricity usage, as previously discussed in Chapter 5. The building considered in the CBA has 7 floors. The reduction in energy consumption of a retrofitted building with 7 floors was estimated to be 3% (See Chapter 5.2.1). Thus it is assumed that energy consumption can be reduced by a maximum of 3% if a building is retrofitted with a green roof.

7.1.2 *Subsidised Installation Costs*

Literature suggests that a municipality, which strives to create a sustainable and resilient city, through the implementation of green roofs, should start by offering some form of incentive. Results from Chapter 3 indicates the incentive most commonly used is municipal subsidies for the initial green roof installation costs. Subsidies provided ranged from 30% to 80% of the initial costs. Most cities offer to subsidise 50%. Reasons why such incentives could be offered are discussed in Chapter 9.

7.2 Sensitivity Analysis: Building Energy Consumption

The significance of reducing the energy consumption of the building was investigated by conducting a sensitivity analysis. This was investigated by reducing the energy consumption of the retrofitted building by increments of 0.5%, starting form 0% and leading to 3%, while the energy consumption of the conventional building remains unchanged.

Table 13 Discounted Costs – 3% Reduced Energy Consumption

Year	0	1	2	20
R = Retrofitted building				
Discounted costs				
Green roof installation	R 1 461 832			
Green roof maintenance		R 86 165	R 37 971	R 37 971
Green roof water		R 16 173	R 11 291	R 25 884
ECR		R 1 058 538	R 1 098 483	R 2 139 716
C = Conventional building				
Discounted costs				
Waterproofing replacement	R 278 810			R 278 810
ECC		R 1 091 276	R 1 132 457	R 2 205 892
Difference in discounted cash flow (R – C)	-R 1 183 022	-R 69 600	-R 15 288	R 281 132
Cumulative	-R 1 183 022	-R 1 256 654	-R 1 285 466	-R 1 068 499

Table 13 shows the discounted costs data for years 0, 1, 2 and 20 of the CBA, the data in this table assumes a 3% reduction in the retrofitted building’s energy consumption. ECR and ECC refer to Energy Cost of the Retrofitted and Conventional building, respectively.

The difference in discounted costs and the accumulation of the difference, shown in Table 13, were used to calculate the difference in NPVs and payback periods discussed in this section.

The difference in NPV for each incremental reduction in energy consumption was calculated using Equation 7, which is an adjusted version of Equation 6.

Equation 7

$$NPV\ difference = Retrofitted\ NPV - Conventional\ NPV$$

$$= \frac{-GRI_0 - (-W_0)}{(1+0.06)^0} + \frac{-GRM_1 - GRW_1 - ECR_1 - (-ECC_1)}{(1+0.06)^1}$$

$$+ \cdots + \frac{-(-W_{20}) + \left(-GRM_{20} - GRW_{20} - ECR_{20} - (-ECC_{20})\right)}{(1+0.06)^{20}} + \cdots$$

$$+ \frac{-GRM_{40} - GRW_{40} - ECR_{40} - (-ECC_{40})}{(1+0.06)^{40}}$$

The terms are as follows,

GRI $_0$	is Green Roof Installation	= *R1 461 877 ×(1- Subsidy),* with Subsidy = 0
W $_0$	is Waterproofing replacement	= *R278 810*
W_{20}	is Waterproofing replacement	$= R\,278\,810 \times (1+0.06)^{20}$
GRM $_n$	is Green Roof Maintenance	$= (R24.02 \times 6 + R48.04) \times 1.9 \times 4 \times (1+0.06)^{n}$
GRW $_n$	is Green Roof Water	$= R27.47 \times 375 \times (1+0.11)^{n}$
ECR $_n$	is Electricity Cost of Retrofitted building, as previously shown in Equation 4	$= R1.001 \times 219 \times 4797 \times (1+0.1)^{n} \times (1 - \text{Reduced energy usage})$
ECC $_n$	is Electricity Cost of Conventional building	$= R1.001 \times 219 \times 4797 \times (1+0.1)^{n}$

The results of the difference in NPV for each incremental reduction in energy consumption are shown in Figure 28. This figure shows that the energy usage must be reduced by more than 3% in order for retrofitting to be feasible.

The minimum reduction in energy consumption needed to obtain a NPV for the retrofitted building that is equal to the NPV of the conventional building was determined to be 3.76%. Reducing the energy consumption by 3.76% will make the difference in NPVs equal to zero. Any reduction larger than this will result in the retrofitted building having a higher NPV than that of the conventional building. Combining solar panels with green roofs to create a Photovoltaic (PV) green roof may help to reduce the energy consumption even more since the solar panels will produce energy whilst the green roof improves the solar panels effectivity (Köhler, M., 2007; Hui and Chan, 2011; Tomazin, 2016). However, the use of a PV green roof is not considered in this study.

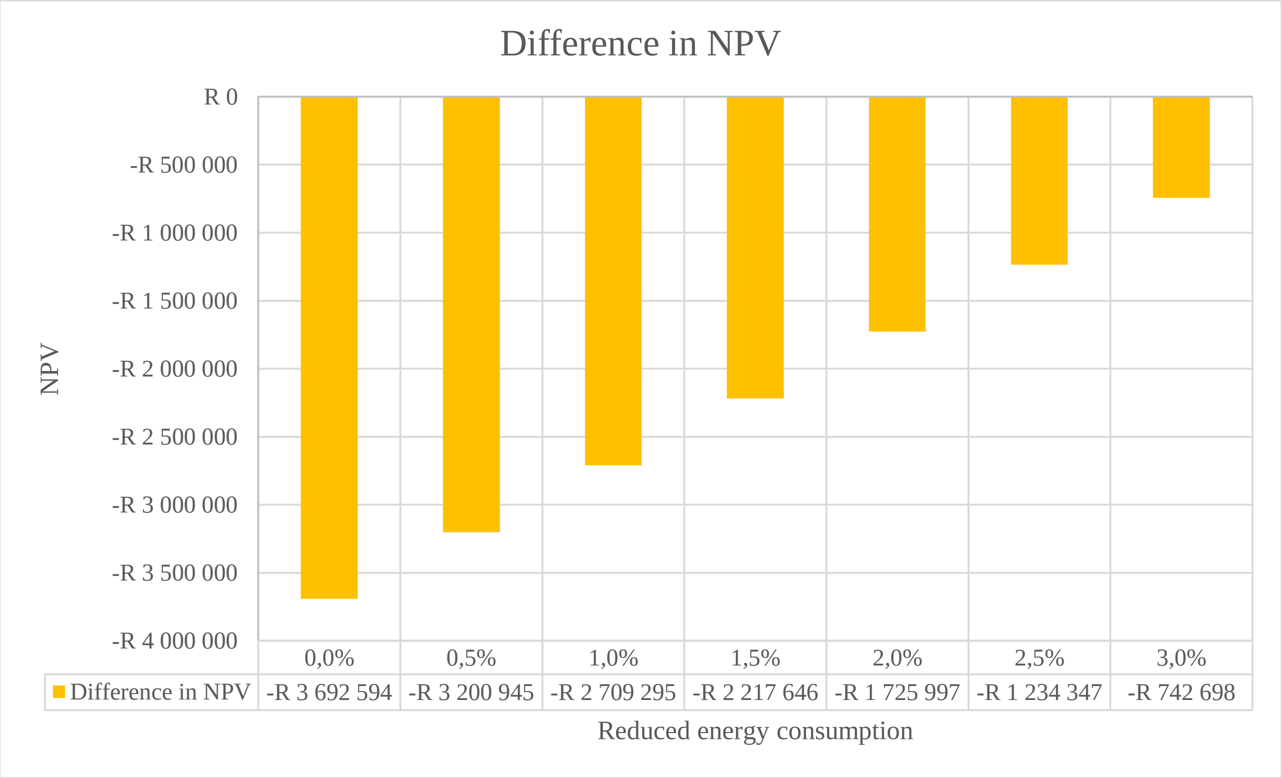


Figure 28 Energy Consumption Sensitivity Analysis: NPV

Table 14 shows the discounted payback period related to each incremental reduction in energy consumption. The payback period was calculated using Equation 2, as discussed in the literature review, since the annual cash flows are uneven. The data in Table 14 shows that the building owner will only have a positive cumulative cash flow in year 40 if the energy consumption is reduced by 3.76%.

Table 14 Reduced Energy Consumption: Discounted Payback Period

0%	**0,5%**	**1%**	**1,5%**	**2%**	**2,5%**	**3%**	**3,5%**	**3.76%**
>40								40

The sensitivity analysis shows that reducing the energy consumption has a significant influence on the NPV. A reduction of 3% results in an 80% increase in the difference in NPV, from –R3.7 million to –R0.7 million. However, this increase is not enough, additional incentives are needed to make retrofitting feasible. This is considered in a following chapter.

7.3 Sensitivity Analysis: Subsidies

The influence of a reduction in the initial cost of installing an extensive modular green roof system was investigated by conducting a sensitivity analysis. The analysis assumes that there are incentives to promote the use of green roofs. It is assumed there is no reduction in energy usage as a result of the green roof. The incentives are in the form of subsidies offered to reduce the initial green roof installation costs. The influence of three different subsidies, 30%, 50% and 80% were analysed.

Table 15 Subsidies offered

	Subsidy for retrofitting	Analysis year	Subsidy per building (cost to city)	Cost to building owner
Extensive modular green roof installation and waterproofing	0%	0	R0.00	R 1 461 832 (Table 13)
	30%	0	R 438 550	R 1 023 282
	50%	0	R 730 916	R 730 916
	80%	0	R 1 169 465	R 292 366
Conventional Roof Waterproofing	-	0	-	R 278 810 (Table 13)
	-	20	-	R 278 810 (Table 13)

Table 15 shows the rand value of the different subsidies offered, as well as the initial cost the building owner would pay for installing the green roof system instead of just replacing the waterproofing in the first year of the CBA. Table 15 also shows the costs for waterproofing a conventional building rooftop, shown as the conventional roof for year 0 and year 20 in the table. These costs are the same since the cost in year 20 is the discounted cost.

The subsidies, which reduce the initial cost of the green roof system are presented as a direct benefit to the building owner, in the first year of analysis. Table 16 shows the discounted costs and benefits for years 0, 1, 2 and 20 for the CBA when an 80% subsidy is assumed.

Table 16 Discounted Costs – 80% Subsidy

Year	0	1	2	20
R = Retrofitted building				
Discounted costs				
Green roof installation	R 1 461 832			
Green roof maintenance		R 86 165	R 37 971*	R 37 971*
Green roof water		R 16 173	R 11 291	R 25 884
Discounted benefit				
Subsidy	R 1 169 465			
C = Conventional building				
Discounted costs				
Waterproofing replacement	R 278 810*			R 278 810*
Difference in discounted cash flow (R–C)	-R 13 556	-R 102 338	-R 49 262	R 214 955
Cumulative	-R 13 556	-R 115 894	-R 165 156	-R 893 795

*Note that these costs are the same for each year since the discount rate is the same as the rate of inflation.

The NPVs for the different subsidies were calculated using Equation 7, where the reduced energy usage is 0% or 3% and the subsidy varies, being either 0%, 30%, 50% or 80%. Figure 29 shows the NPVs that were calculated for each subsidy given the two different reductions in energy consumption.

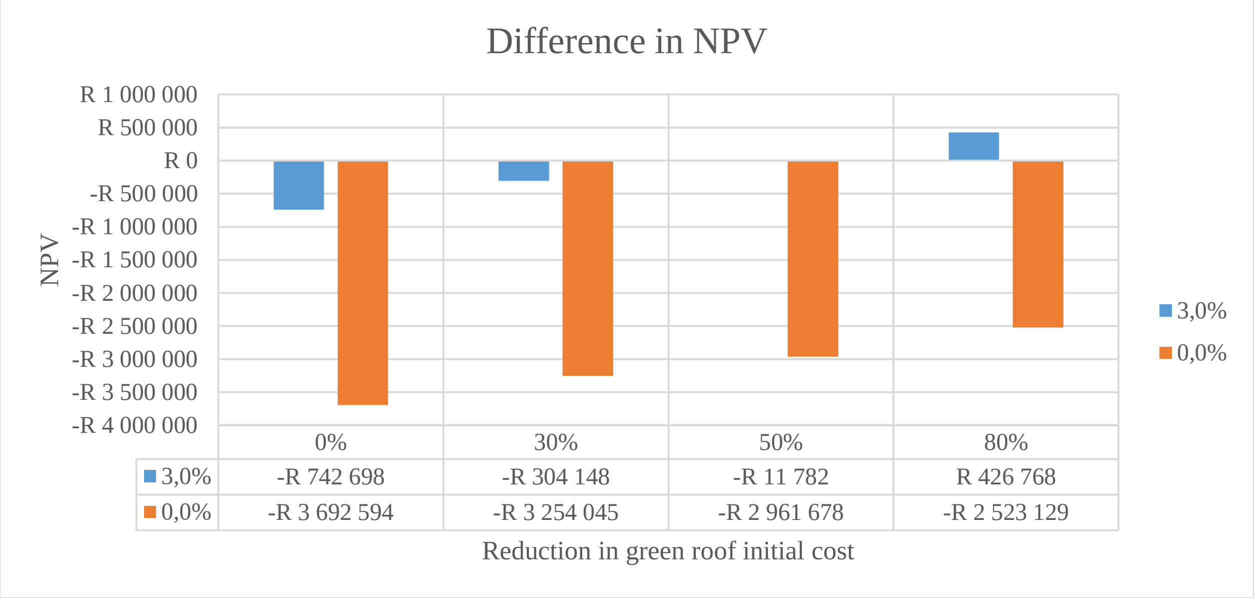


Figure 29 Subsidy Sensitivity Analysis: NPV

Figure 29 shows that the NPV of the conventional building will always exceed that of the retrofitted building regardless of any reduction in the initial installation costs of the green roof system. This is due to the annual green roof maintenance and green roof watering costs that are additional costs for the retrofitted building. The figure also shows that if a reduction of 3% in energy consumption is assumed and given an 80% subsidy, retrofitting can become feasible. This combination of benefits will result in a payback period of 20 years.

Reducing the initial cost of the green roof system had no influence on the discounted payback period when 0% reduction in electricity usage is assumed. Thus no reduction in initial cost will help in reducing the payback period, which will always be more than 40 years. This is due to the additional annual costs of the green roof. Without an annual benefit, the costs of a retrofitted building will always exceed the costs of a conventional building. A reduction in annual costs is needed to make up for the additional annual green roof maintenance and water costs.

Any form of a subsidy, either 30%, 50% or 80%, for retrofitting a building in the City of Johannesburg is optimistic. There are currently no initiatives to either promote the use of green roofs, or increase the green fraction of urbanised areas in South Africa. Thus, the assumption that a municipality in South Africa will offer subsidies at this stage is unrealistic.

However, motivations for why a municipality would offer subsidies are presented and discussed in Chapter 9. Furthermore, the possibility of offering additional incentives to reduce the payback period for the building owner is also investigated and discussed.

7.4 Combined Benefits Analysis

The previous sensitivity analyses showed that a reduction in of 3% in electricity consumption together with a subsidy of 80% is not enough to reduce the discounted payback period to an acceptable period. In an interview a Development Manager stated that projects that require initial capital, but provide reduced operation costs, are accepted when the estimated payback period is between 5 and 7 years (Interviewer 3). In another interview a director of a property development firm, stated that 7 years is an acceptable payback period in terms of properties especially considering that the retrofitted roof will last longer than 10 years (Interviewer 4). Considering the perceptions of the interviewees it was assumed that a 7 year payback period is acceptable for an investment such as retrofitting with a green roof, which is a long term investment.

Cost benefit analyses were performed combining the different subsidies and different reductions in energy consumption. These analyses were conducted to determine how much energy consumption should be reduced for the different subsidy to reduce the discounted payback period of the building owner to 7 years.

Table 17 shows the reduction in energy consumption needed to reduce the discounted payback periods of the building owner to 7 years, given the different subsidies. Table 17 also shows the corresponding difference in NPV. The difference in NPV is the NPV of the retrofitted building minus the NPV of the conventional building, these values show how much more profitable retrofitting is given the subsidies and corresponding reduced energy consumption.

Table 17 Required reduction in energy consumption

Discounted payback period	Subsidy	Reduced energy consumption	Difference in NPV
7 years	0%	19%	R 14 990 085
	30%	14%	R 10 512 140
	50%	11%	R 7 854 610
	80%	5%	R 2 393 366

The data in Table 17 shows that the difference in NPV increases as the reduction in energy consumption is increased, as would be expected. Furthermore, the data shows that the reduction in energy consumption required is much more than would realistically be possible, especially for the

0%, 30% and 50% subsidy. However, an 80% subsidy and 5% energy reduction might be possible and retrofitting would be feasible given these benefits. This analysis shows that a 5% reduction is required however, it is assumed that the green roof can reduce energy consumption by 3% at most as discussed in Chapter 5.2.1.

7.5 Comparison of Results

The results of the CBA discussed in Chapter 6 are compared to the results of the CBA that assumes the local municipality offers an 80% subsidy to building owners to retrofit their building with a green roof and that this green roof reduces the energy consumption by 3%.

The discounted payback period for the building owner for retrofitting the building is 20 years when the above benefits are assumed. When no benefits are assumed there is no discounted payback period. There is thus a significant reduction in the discounted payback period if benefits are considered, however, the payback period is still a long term payback period.

Table 18 Discounted Costs - 3% Reduced Energy Consumption, 80% Subsidy

Year	0	1	2	19	20
R = Retrofitted building					
Discounted costs					
Green roof installation	R 1 461 832				
Green roof maintenance		R 86 165	R 37 971*	R 37 971	R 37 971*
Green roof water		R 16 173	R 11 291	R 24 718	R 25 884
ECR		R 1 058 538	R 1 098 483	R 2 061 908	R 2 139 716
C = Conventional building					
Discounted costs					
Waterproofing replacement	R 278 810*				R 278 810*
ECC		R 1 091 276	R 1 132 457		R 2 205 892
Difference in discounted cash flow (R – C)	-R 13 556	-R 69 600	-R 15 288	R 1 081	R 281 132
Cumulative	-R 13 556	-R 83 156	-R 98 444	-R 222 630	R 58 502

*Note that these costs are the same each year since the discount rate is the same as the rate of inflation.

Table 18 shows the discounted costs, when the two benefits are combined. The cumulative difference in discounted cash flow shown in year 20 is positive, showing that the payback period is 20 years for the building owner. The cost of waterproofing the conventional building in year 20 does help to reduce the payback period for the retrofitted building. Without the additional costs of waterproofing in year 20 the payback period for the retrofitted building would be 36 years instead of 20 years.

The accumulated difference in discounted cash flow is shown in Figure 30. The results of a retrofitted building without any benefits and the same building with benefits are compared in this figure.

The accumulated difference in cash flows for the retrofitted building when benefits, the subsidy and reduced energy consumption, are assumed is R0.4 million. The retrofitted building that assumes no benefits has an accumulated difference in cash flows of –R3.7 million. The difference in these values is R4.1 million. These accumulated values are the NPVs of the two different incremental CBAs. Figure 30 shows that savings of 3% in electricity costs and 80% in the initial costs result in savings up to R4.1 million (i.e. R3.7 million + R0.4 million) over the 40 year analysis period.

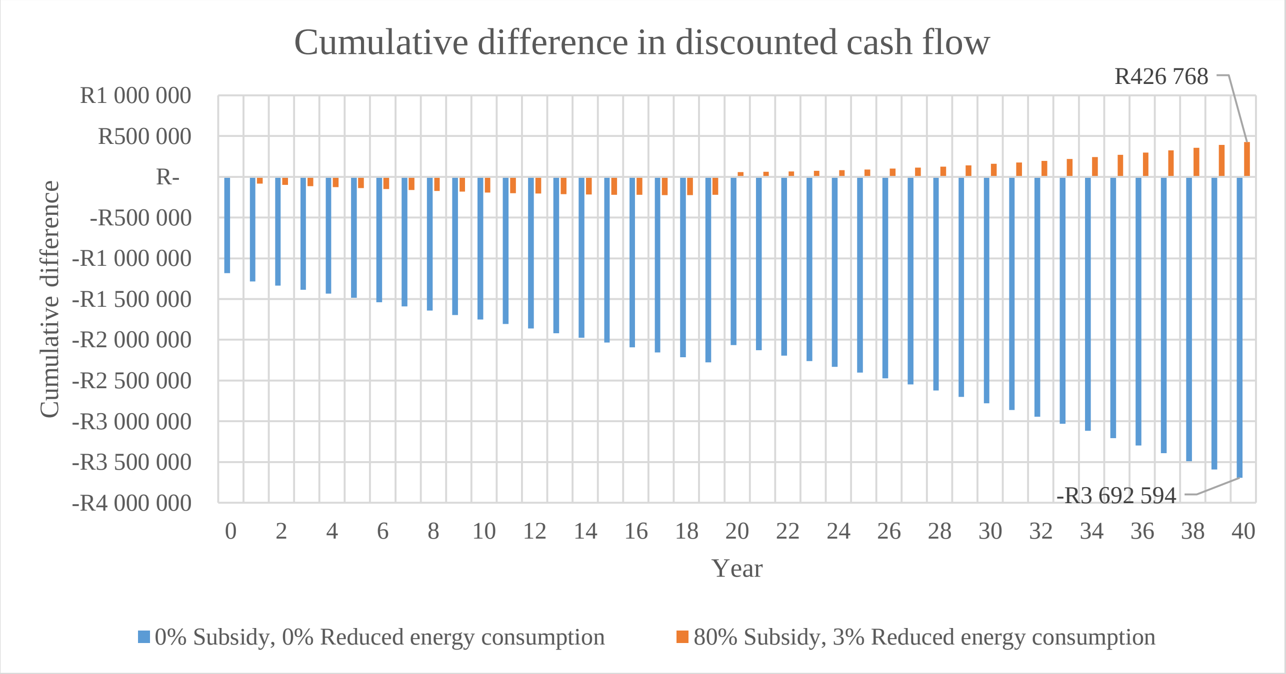


Figure 30 Comparison of cumulative difference assuming different benefits

See an enlarged version of Figure 30 in Figure D2 in Appendix D. The data used to create these figures are shown in Tables C1 and C2 in Appendix C.

7.6 Discussion of Results

The results of the sensitivity analyses showed that reducing energy consumption has a significant impact on the NPV of the building and reducing the initial cost of the green roof has no significant influence on either the NPV or discounted payback period. However, the NPV is reduced when the initial cost is reduced.

The NPV to the building owner of the retrofitted and conventional building will be equal if a green roof can reduce the energy consumption by at least 3.76%. Thus, any reduction more than 3.76% will result in the retrofitted building having a better NPV than that of the conventional building.

Assuming that a green roof can reduce the building energy usage by 3%, the optimal case for a building owner would be if the local municipality or city offers an 80% subsidy to building owners who retrofit their buildings with green roofs. In this case reducing the initial cost of the green roof can reduce the discounted payback period to 20 years. The CBA showed that this incentive and reduction in energy consumption will result in a profit of R0.4 million more, in today's terms, for the retrofitted building, compared to the conventional building.

However, expecting the municipalities in South Africa to offer such an incentive is unrealistic considering that there are currently no plans for any energy efficiency or sustainable urban development incentives in South Africa. Furthermore, even this significant reduction in the initial cost of the green roof will still result in a relatively long payback period. As previously discussed building owners and developers are reluctant to invest in projects with long payback periods.

All the results showed that annual costs have the most significant influence on the overall costs of the buildings over the 40 year analysis period. Thus, reducing annual costs through additional incentives such as a reduction in property and/or stormwater tax could help to reduce the payback period.

The data for the CBA, and thus the NPV's, depend on the assumptions made when determining how the costs and benefits were calculated. The true value of some of the variables used in calculating the costs were uncertain. Monte Carlo analyses were done to determine the possible range of NPV's when the uncertain variables changed. This is discussed in Chapter 8.

7.7 Conclusion

Retrofitting a building with a green roof is 81% more expensive than just replacing the waterproofing of the building. The results from the sensitivity analyses, investigating different combinations of subsidies and reductions in energy consumption, showed that retrofitting a building with a green roof is an expensive investment which with no payback period if no incentives are offered. This is assuming that the energy consumption of the building's energy consumption is reduced by 3%.

However, assuming that an 80% subsidy is offered to reduce the initial costs of the green roof, the discounted payback period is reduced to 20 years, also assuming a 3% reduction in energy consumption. This combination would result in the retrofitted building having a NPV that is R0.4 million more than the conventional building. Furthermore, investing in technology that reduces annual costs, especially a cost such as energy consumption will become more beneficial in the long term if the current state of energy supply continues.

The results show that if the City of Johannesburg is in the financial position to offer a subsidy of at least 80%, building owners will have more reason to consider the option of retrofitting their building. However, the likelihood that a building owner will choose to retrofit is slim due to the long payback period. Additional incentives would be needed to reduce the payback period for the building owner in order to make the retrofitting of an existing building with a green roof more feasible. Reasons why the City would consider offering incentives to increase the green fraction in an urban area are considered and discussed in Chapter 9.

8 Monte Carlo Analysis

Monte Carlo analyses were conducted to determine the range of NPVs given that some of the variables in calculating the NPV were uncertain. The data used for the CBA in Chapters 6 and 7 were used for these analyses. In these analyses, the green roof maintenance and the electricity costs varied. This chapter explains the calculations used and provides the input data for the Monte Carlo analyses. The results are provided and discussed. First a short explanation of a Monte Carlo analysis is provided.

Monte Carlo analyses can be used for countless applications, for example, to estimate the probability of cost overruns in large projects, to assess risks and uncertainties in projects, or to estimate the likelihood that an investment will result in a certain outcome. The Monte Carlo analysis is used, for example, when there are uncertainties about some of the factors influencing the outcome of a project, investment or assessment. In the analysis, the uncertain variables are given a range of possible answers in the form of a distribution such as uniform, normal, triangular and so forth. Using these distributions, the Monte Carlo analysis simulates a range of possible answers.

8.1 Data and Calculations

Companion Monte Carlo Simulation software by Minitab was used to conduct the analyses presented in this chapter. Three uncertain variables were considered, namely the number of labourers and the annual increase in electricity and water costs. Different distributions were assumed for the uncertain variables. A triangular distribution was used for the number of labourers, to calculate the green roof maintenance cost. This distribution was assumed since 5 labourers were considered to be the most likely due to the size of the green roof. A normal distribution for the annual increase in electricity and water was used to calculate the electricity and water cost. This distribution was assumed since there is a range of annual increase data available and the input data can consist of decimal values.

The input data for the uncertain variables, namely: number of labourers; annual electricity increase; and annual water increase is shown in Table 19. Data required for a triangular distribution for the software was the best, worst and most likely case data. Data required for a normal distribution was the mean and standard deviation, this data which is based on annual increase in electricity and water costs over the past 5 years shown in Table 19.

Data in the "most likely" and 'mean" columns in Table 19 are the values that were used to determine the green roof maintenance, electricity and water costs in the CBA presented in Chapters 6 and 7.

Table 19 Monte Carlo Analysis: Input Data

Variable	Input Data Depending on Distribution						
Number of labourers	**Triangular Distribution**						
	Best Case	**2**					
	Most Likely	**5**					
	Worst Case	**7**					
Electricity increase	**Normal Distribution**						
	2012	2013	2014	2015	2016	Mean	Standard Deviation
	16.35%	7.39%	7.67%	11.46%	9.40%	**10.45%**	**3.7%**
Water Increase	**Normal Distribution**						
	2014	2015	2016	2017	2018	Mean	Standard Deviation
	8.5%	13,4%	15%	8.9%	8.4%	**10.76%**	**3.05%**

The inflation and discount rate was assumed to be 6%, the same as for the CBA in Chapters 6 and 7. Equation 7 used to calculate the difference in Net Present Value (NPV), the equation is repeated;

$$NPV\ difference = Retrofitted\ NPV - Conventional\ NPV$$

$$= \frac{-GRI_0 - (-W_0)}{(1 + 0.06)^0} + \frac{-GRM_1 - GRW_1 - ECR_1 - (-ECC_1)}{(1 + 0.06)^1}$$

$$+ \cdots + \frac{-(-W_{20}) + \left(-GRM_{20} - GRW_{20} - ECR_{20} - (-ECC_{20})\right)}{(1 + 0.06)^{20}} + \cdots$$

$$+ \frac{-GRM_{40} - GRW_{40} - ECR_{40} - (-ECC_{40})}{(1 + 0.06)^{40}}$$

The terms used are as follows, note that the values used to calculating the electricity cost and green roof maintenance cost are as discussed in Chapter 5.

$GRI_{n=0}$ Green Roof Installation = *R1 461 877×(1- Subsidy)*

$W_{n=0}$ Waterproofing replacement = *R278 810*

$W_{n=20}$ Waterproofing replacement = *R 278 810 × (1+0.06)*^{20}

$GRM_{n=0}$ Green Roof Maintenance

= *(R24.02 ×Number of labourers+R48.04) ×1.9×4 × (1+0.06)*^{n}

GRW_{n} is Green Roof Water = *R27.47×375× (1+Water increase)*^{n}

$ECR_{n=0}$ Electricity Cost Retrofitted building

=*R1.001×219×4797×(1+Electricity increase)*^{n} *×(1- Reduced energy usage)*

$ECC_{n=0}$ Electricity Cost Conventional building

= *R1.001×219×4797×(1+Electricity increase)*^{n}

8.2 Results

Three analyses were performed, the first assumes no subsidy is offered and no reduction in energy usage. The second and third assumes an 80% subsidy is offered and energy usage is reduced by 3% and 5% respectively. These assumptions correspond to that of the assumptions made to obtain the results presented and discussed in Chapters 6 and 7.

The results of the range of answers for the difference in NPV from the two analyses are shown in Table 20. The analyses were done for a 40 year period. This table also shows the results for the difference in NPV from the CBA in Chapters 6 and 7. The complete results from the simulation software is available in Appendix C; the results also show the distribution for the difference in NPV for each analysis.

The percentile data in Table 20 shows that there is a 90% certainty (10th percentile) that the difference in NPV falls within –R12.2 million and –R2.4 million, when no benefits are assumed. The NPV calculated in the CBA is within the upper limits of this range. These results depend only on the 'number of labourers' variable, which has a triangle distribution.

When benefits are assumed the range of answers for the analysis becomes very wide, which shows that the change in electricity and water increase has a significant influence on the results.

Table 20 Monte Carlo Analysis Results

Benefits	0% Subsidy, 0% Reduced Energy usage	80% Subsidy, 3% Reduced Energy usage	80% Subsidy, 5% Reduced Energy usage
Incremental CBA Results from Chapters 6 and 7			
NPV	-R 3 692 594	R 426 768	R 2 393 366
Monte Carlo Analysis Results			
Difference in NPV Summary Statistics			
Mean	-R 6 507 807	-R 1 561 276	R 1 740 498
Standard Deviation	R 5 373 120	R 8 578 037	R 12 353 837
Minimum	-R 244 544 610	-R 164 515 762	-R 153 645 477
Median	-R 4 967 637	-R1 751 678	-R94 313
Maximum	-R 675 907	R 358 663 845	R 641 383 970
Difference in NPV Percentiles			
10th	-R 12 220 261	-R 8 859 369	-R 7 341 505
90th	-R 2 373 949	R 5 394 154	R11 940 873

The difference in NPV's of the analyses which assumed a 3% and 5% reduction in energy usage and an 80% subsidy are within the range of results of the Monte Carlo analysis. However, this is expected since the range of answers is wide. These results depended on the electricity and water increase, as well as number of labourers.

The results of this Monte Carlo analysis show that the assumption that the annual increase in electricity and water is 10% and 11% respectively, for the CBA, is too conservative an assumption. Furthermore the results show that the effect of reducing the energy consumption becomes more significant the higher the annual increase in electricity becomes.

8.3 Conclusion

The Monte Carlo analysis indicated that the difference in NPV of a CBA, comparing a conventional building to a building retrofitted with a green roof over a 40 year period, will favour a building owner who retrofitted his building. This is if the green roof reduces the energy consumption by 5%, the initial green roof installation costs are reduced by 80% and the annual increase in electricity and water cost is more than 10% and 11% respectively. The Monte Carlo analysis shows that the higher the annual increase in electricity, the more significant the effect of a reduction in electricity consumption becomes.

9 Large Scale Green Roof Implementation

The benefits of green roofs can only truly be realised when green roofs are implemented on a large scale (City of Waterloo, 2005; van der Walt, 2012; Booysen, 2014). This is especially true regarding the benefits towards the public sector, such as:

- Mitigation of the Urban Heat Island Effect.
- Wider scale energy savings. Energy savings are not only influenced by individuals.
- Improved air quality, thus reduced air pollution.
- Increased health for people living in the city.
- Better living environment for local population.
- Conservation of area's biodiversity.
- Cultural preservation in terms of aesthetics.
- City scale stormwater management.
- City infrastructure savings.
- Economic growth and job creation, specifically in construction and maintenance.
- Food security through production possibilities in cities.

Considering these benefits, a city experiencing environmental concerns such as air pollution, UHIE and an increased demand in energy usage will benefit from implementing green roofs on a large scale. This chapter discusses the possibility of implementing green roofs on a large scale in Johannesburg CBD and why this implementation should partly be funded by the city.

9.1 Johannesburg City Health

Air pollution in a city has a significant impact on the economy of a city, as deaths and illnesses caused by urban air pollution are estimated to cost 5% of the GDP in developing countries (Ksenija, 2016).

Research concerning the cost of deaths due to air pollution, specifically Particulate Matter (PM), estimated that 6% of South Africa's GDP went to deaths due to air pollution (Altieri and Keen, 2016). Johannesburg has the highest amount of PM in South Africa, estimated to be around 98µg/m^3 (WHO, 2014). PM refers to suspended particulate matter smaller than 10µm and 2.5µm in diameter.

Urban greening is used to combat air pollution in many cities. Numerous studies have qualitatively assessed the ability of urban greening to reduce air pollution, specifically PM in the ambient air. Studies have shown that PM concentrations in an area decrease with the increase in vegetation in that area (Freiman, Hirshel and Broday, 2006; Yin et al., 2011; Cohen, Potchter and Schnell, 2014; Irga, Burchett and Torpy, 2015). However, not many studies give quantitative data showing the relationship between urban greenery and air pollution. Irga, Burchett and Torpy (2015)preformed a study to quantify the effects of urban greenery on air pollutants. The study considered monthly air samples over a period of a year in eleven different sites in central Sydney, Australia. The study found there was a negative correlation between greenspace cover and PM levels. The results of the correlation between the percentage greenspace in an area and the PM levels in the ambient air are shown in Figure 31. The study by Irga, Burchett and Torpy (2015)also mentioned that the PM levels of an area were influenced by wind speed, the amount of rain in an area and the time since it last rained in that area. However, greenery was found to be the biggest contributor in reducing the PM levels in the ambient air.

A trend line was plotted, based on Irga, Burchett and Torpy (2015)data, which shows the logarithmic relationship between the concentration of PM in the ambient air and greenspace cover of that area. This logarithmic relationship shows that the PM levels will increase as the percentage of greenspace cover reduces. The greenspace cover will never reach 0%. The relationship shows that the increase in greenspace cover can significantly reduce the PM levels in areas with little greenspace cover. As the percentage of greenspace cover increases, the fraction by which the PM levels are reduced becomes less significant.

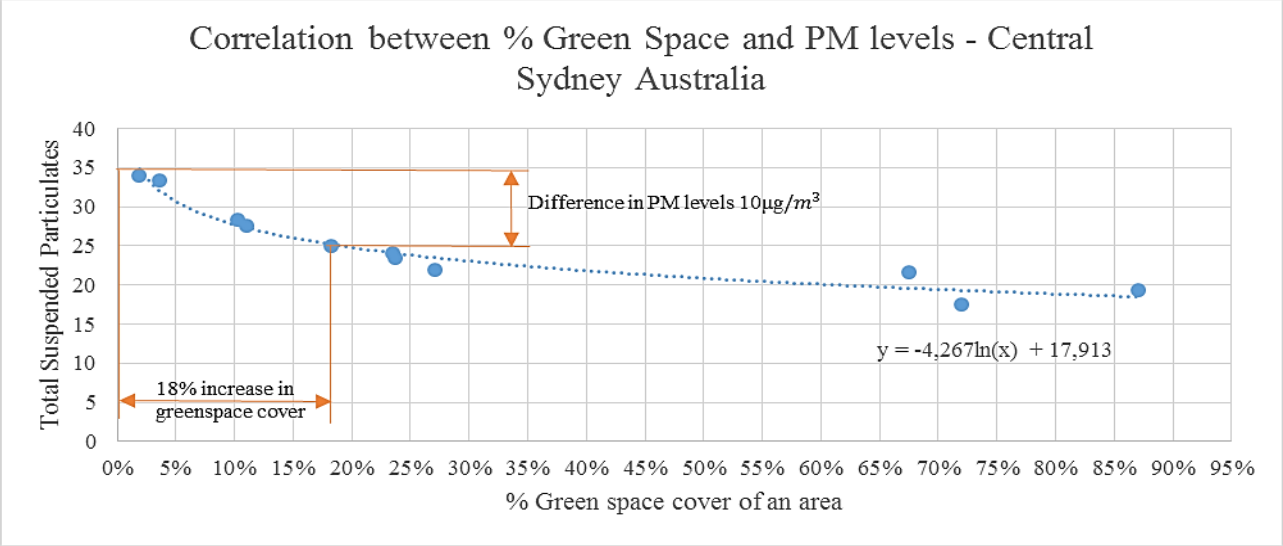


Figure 31 Green fraction and PM levels (Irga, Burchett and Torpy, 2015)

It was assumed that the PM levels are approximately $35\mu g/m^3$ if the greenspace cover of an area is 0%. Figure 31 shows that an area of 18% greenspace cover will have a PM level of $25\mu g/m^3$. Thus, increasing the green space cover by 18% leads to a reduction in PM levels of approximately 10$\mu g/m^3$ (i.e. 35$\mu g/m^3$-25$\mu g/m^3$). For the purpose of this study it was assumed that the approximate reduction in PM levels, corresponding to an increase in greenspace cover of 18%, is 10$\mu g/m^3$. The reason why an 18% increase in greenspace cover is considered is explained in the following section.

9.1.1 Air Pollution and City Health

Improving the air quality in a city directly effects the health costs associated with air pollution in a city. Air pollution in Johannesburg is a known problem (Momberg and Grant, 2008; CDP (Carbon Disclosure Project), 2014; Kings, 2015). One option to consider for improving air quality, by reducing urban air pollution, is to increase the green fraction of the city (see Figure 11 Casual Loop Diagram: Evaluation of Green Roof Implementation).

According to the state of air report of South Africa, PM is the greatest national cause of concern with regard to air quality in South Africa (Department of Environmental Affairs South Africa, 2013). Figure 32 shows recorded data concerning the annual number of deaths and the PM levels for years 1997 to 2012 (Department of Environmental Affairs South Africa, 2013; Statistics South Africa, 2017). This figure shows the relationship between annual deaths and annual recorded PM levels. As the annual PM levels increase per year, the number of deaths also increases. This shows a strong correlation between annual deaths and annual PM levels in the ambient air. This data is for the whole of South Africa and not specifically for Johannesburg. Note that the annual number of deaths due to all causes is taken into account, not only deaths specifically due to PM concentrations.

The study done by Altieri & Keen (2016), concerning the economic cost of urban air pollution, determined that 7.4% of all deaths in South Africa are due to chronic exposure to PM. Cities such as Johannesburg, Pretoria, Cape Town and Durban account for most of these deaths due to PM. In order to find a correlation between the annual deaths and annual PM levels, data of the annual deaths due to chronic exposure to PM and annual PM levels were plotted in Figure 33.

Data from Figure 32 were used to create Figure 33. The annual deaths due to PM data in Figure 33 is 7.4% of the total annual deaths shown in Figure 32.

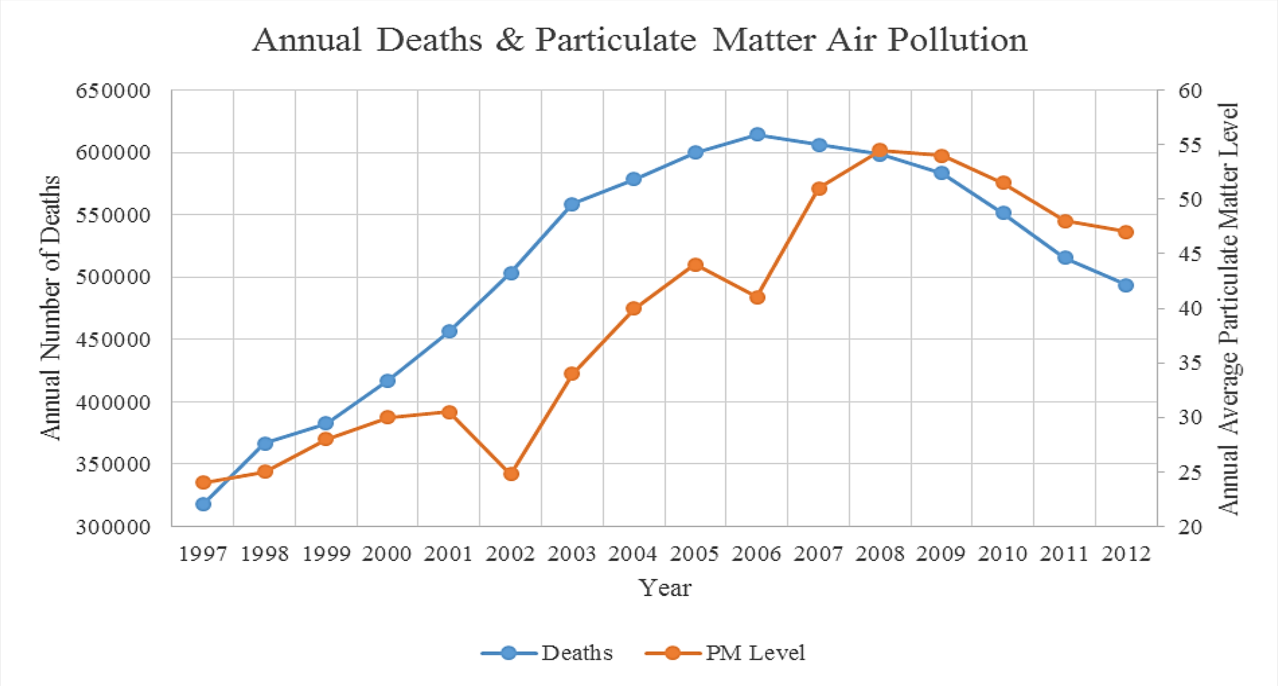


Figure 32 Annual Deaths and PM Data (Department of Environmental Affairs South Africa, 2013; Statistics South Africa, 2017)

The correlation shown in Figure 33 was used to determine the influence of reducing the PM level in an area on the annual number of deaths in that area. The figure shows the trend line for the data. The data used to plot Figures 32 and 33 are shown in Appendix F, Table F1.

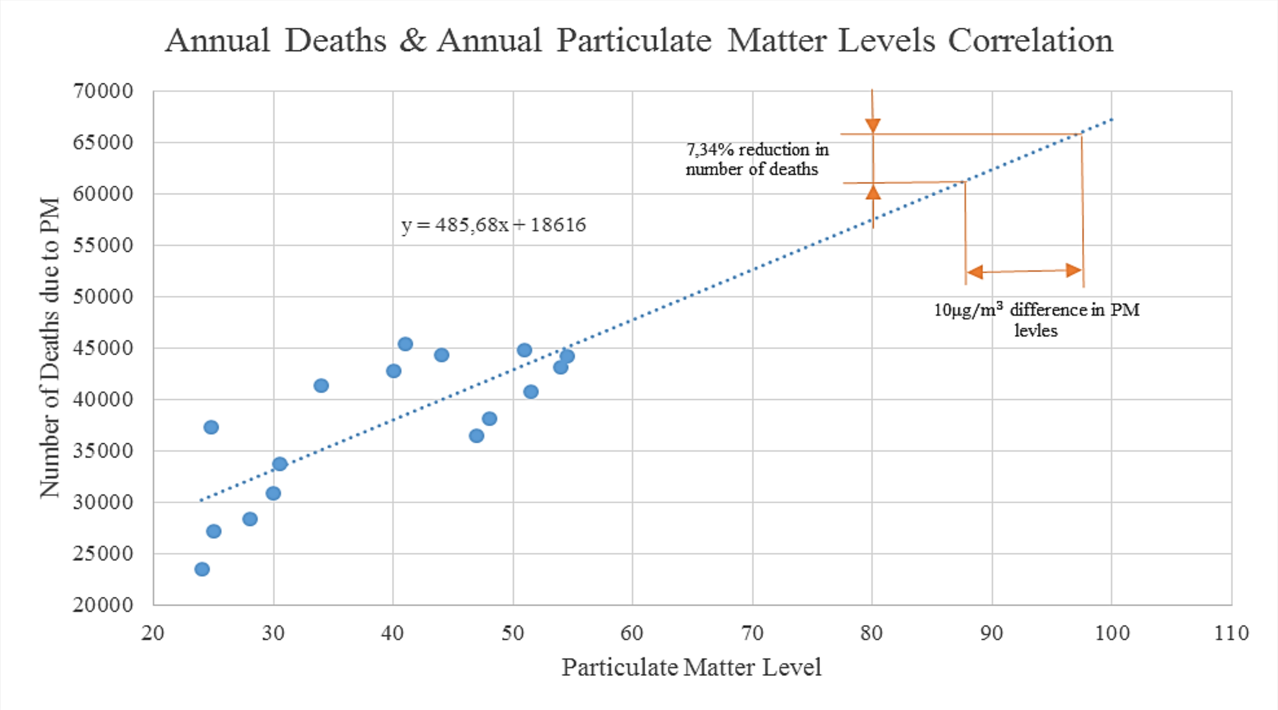


Figure 33 Correlation between Annual Deaths due to PM and PM Levels

Considering the trend line shown in Figure 33, which shows a linear relationship between the annual number of deaths and PM levels, it was determined that a reduction of 10μg/m^3 in PM levels will lead to a 7.34% reduction in annual deaths due to PM levels in the ambient air. The equation of the linear trend line (i.e. $y = 485.68x + 18616$), shown in Figure 33, was used to determine the reduction in annual deaths as follows:

The PM levels in the city of Johannesburg were estimated to be 98μg/m^3, the number of deaths corresponding to this PM level are 66213. Reducing the PM level by 10μg/m^3 means the PM level is reduced to 88μg/m^3 and the number of deaths are reduced to 61356. Thus, the number of deaths is reduced by 7.34%.

The annual PM and deaths data in Figures 32 and 33 are for the whole of South Africa and PM levels in the City of Johannesburg are much higher than that of the whole of South Africa. There is thus a significant chance that the number of deaths due to PM levels in the City of Johannesburg, is more than 7.4% of all deaths in the City, than is estimated for South Africa. Thus, it is assumed conservative that the same relationship as in the whole of South Africa, exists between the number of deaths due to PM levels and the PM levels in Johannesburg.

9.2 Funding for a Healthy City

This section considers the possible costs and effects of increasing the green fraction in a study area in Johannesburg. This is done by evaluating whether the City can afford subsidies for the initial cost of installing green roofs on 80% of the buildings in a study area. Funds available were based on annual health cost of urban air pollution.

9.2.1 The Funds

Urban air pollution results in a cost of 6% of the GDP of South Africa. Urbanised areas account for a larger percentage of the GDP and population than the rural areas, thus assuming that urban air pollution costs 6% of the GDP of a city such as Johannesburg is conservative.

This assumption was made since the results of this assumption will show the worst case scenario, thus the least possible savings for the City. Assuming that air pollution costs the City more than 6% in GDP will results in larger savings in health costs for the City if air pollution is reduced. It was assumed that air pollution costs 6% of the GDP of the study area.

The City of Johannesburg had a GDP per capita of R95 000 in 2016 (Gauteng Provincial Government, 2016). To evaluate the impact of using City funds to help with the implementation of green roofs the following is assumed; the average occupancy density in office buildings is 0.05/m^2 (ASHRAE American National Standards Institute, 2017), and the study area has 1224 buildings, with the average GLA of each building being 4797m^2 (see Chapter 4). The occupancy density and GLA were used to determine the population of the study area, which was calculated to be 293 576.

The GDP of the study area is R28 billion, which was calculated by multiplying the GDP per capita and the study area's population (i.e. R95 000 × 293 576). The cost of air pollution in the study area is thus R1.67 billion (i.e. 6% of R28 billion). If a portion of this money is used on strategies to reduce air pollution, the percentage of GDP spent on health-related problems due to urban air pollution can be reduced.

9.2.2 The Study Area

The evaluation is based on the study area shown in Chapter 4, Figure 17. A three dimensional perspective of the study area is shown in Figure 34. The following costs and characteristics associated with the buildings in the study area in the CBD of Johannesburg were assumed: a typical building has 7 floors and a height of 16.8m; a floor area footprint of 685m^2; and a width and length of approximately 25.8m and 26.5m (see Table 8, Chapter 4). The cost of retrofitting a green roof onto a typical building in the study area was determined to be R1.46 million (see Table 13, Chapter 5). The study area covers an area of 1.35km^2 and has 1224 buildings. It is assumed that 80% of the building are retrofitted. Furthermore, it is assumed that all buildings have the same dimensions.

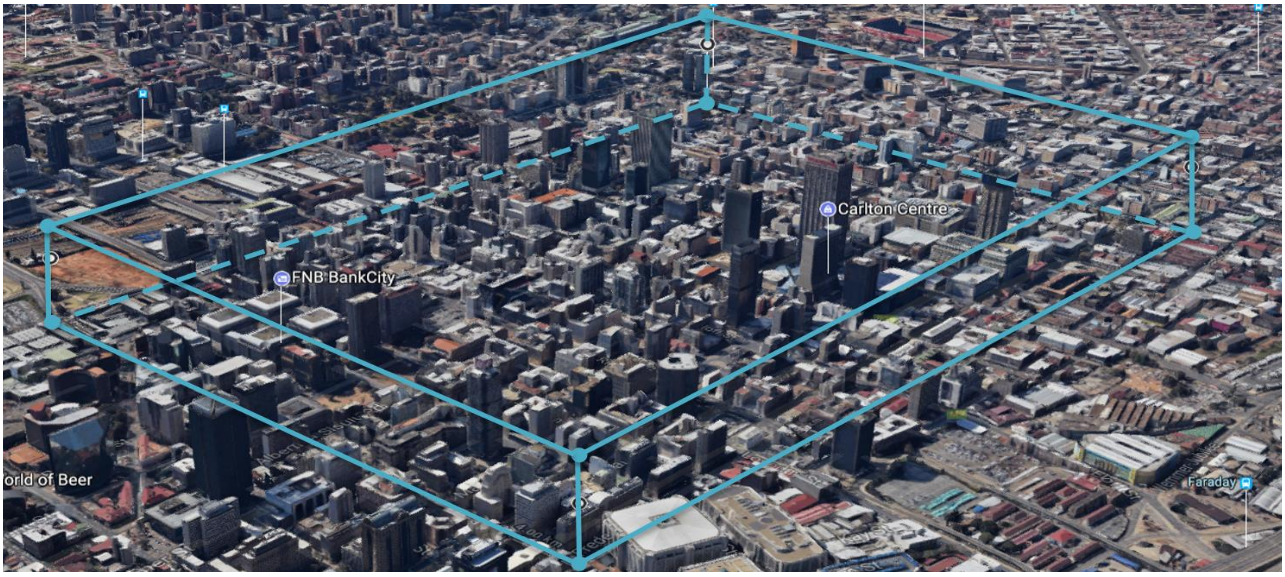


Figure 34 Study Area - 3D Perspective

The greenspace cover in the study area will increase by 18%, if 80% of the buildings are retrofitted with green roofs. It is assumed that a green roof covers 80% of a roof's area. This was determined by dividing the total exposed surface area of the study area, by the total exposed surface area covered by the green roofs. It was assumed that not all the walls of a building will be exposed, due to the buildings being built directly next to each other. The exposed wall area was assumed to be 75% (¾) of the total wall area, this assumption is conservative as it is possible that less wall area is exposed since urban centres are typically densely built up. However, assuming a smaller exposed wall area does not significantly influence the green fraction, unless the exposed wall area is approximately 40% or less of the total wall area.

$$
\begin{aligned}
\text{Exposed surface area} &= \text{Total building roof area} + \text{Total exposed wall area} + \text{Total pavement area} \\
&= \text{Number of buildings} \times (\text{Roof area} + \text{Wall area} \times 3/4) + \text{Total pavement area} \\
&= 1224 \times (685 + (25.8 \times 16.8 \times 2 + 26.5 \times 16.8 \times 2) \times 3/4) + 1\,350\,000 - 1224 \times 685 \\
&= 1224 \times 1\,318 + 1\,350\,000 \\
&= 2\,963\,183 \;\; m^2
\end{aligned}
$$

$$
\begin{aligned}
\text{Total green roof area} &= (80\% \times \text{Number of buildings}) \times (80\% \times \text{Roof area}) \\
&= (0.8 \times 1224) \times (0.8 \times 685) \\
&= 536\,602 \; m^2
\end{aligned}
$$

$$
\begin{aligned}
\text{Total increase in greenspace cover} &= \text{Total green roof area} \div \text{Total surface area} \\
&= 536\,602 \div 2\,963\,183 \\
&= 0.18
\end{aligned}
$$

Thus, the green fraction of the study area is increased by 18%. This is a percentage of the total surface area of the study area, which includes the total road, building walls and roofs surface areas. As shown in Figure 31, increasing the greenspace cover by 18%, will result in a reduction in PM levels of 10μg/m^3. Figure 33 shows that reducing the PM levels by 10μg/m^3, reduces the annual number of deaths due to PM levels in the ambient air by 7.34%. It is assumed that there is a linear relationship between the annual number of deaths and the annual health costs. Thus, a 7.34% reduction in annual deaths due to air pollution, results in a 7.34% reduction in annual health costs due to air pollution.

Health costs due to air pollution in the study area were determined to be R1.67 billion. This cost becomes R1.54 billion when reduced by 7.34%. Thus, the savings in costs due to air pollution, for the study area, is R122 million (i.e. 7.34% of R1.67 billion), when the green fraction in the area is increase by 18%.

9.2.3 The Evaluation

The assumptions made and method used in evaluating how the City will benefit from offering an 80% subsidy for the initial cost of installing green roofs on the existing buildings in the study area are discussed in this section. The possibility of the City offering an additional incentive to building owners who retrofitted their buildings is also investigated. The assumptions for the evaluation are listed, when a 40 year period is considered:

1. The city offers to subsidise 80% of the initial cost of installing a green roof.
2. 80% of the 1224 buildings (i.e. 979 buildings) in the study area are retrofitted with green roofs.
3. The initial cost of retrofitting a building with a green roof is R1.46 million (refer to Table 13, Chapter 5). The subsidies for retrofitting 979 buildings in the study area cost the City R1.4 billion.
4. The population of the study area is 293 576 and the GDP is R95 000/capita, thus the GDP of the study area is R28 billion (refer to Section 9.2.1).
5. The cost of deaths due to urban air pollution is 6% of the GDP, thus R1.67 billion is spent on deaths due to air pollution in the study area (refer to Section 9.2.1).
6. Retrofitting 80% of the buildings in the study area results in an 18% increase in the green fraction of the study area. (refer to Section 9.2.2)
7. Increasing the green fraction by 18% reduces the PM levels in the ambient air by $10\mu g/m^3$. The PM levels in Johannesburg are $98\mu g/m^3$, thus the PM levels are reduced to $88\mu g/m^3$ (see Figure 31, Section 9.1).
8. A $10\mu g/m^3$ reduction in annual PM levels results in a 7.34% reduction in the annual number of deaths due to PM levels in the ambient air (see Figure 33, Section 9.1.1).
9. The percentage reduction in annual deaths is equal to the percentage reduction in annual health costs. The reduction in annual health costs is thus 7.34% (refer to Section 9.2.2).

The assumptions listed were used to determine how much the City will save per square meter per year. The methodology used to determine the saving is shown in Table 21.

The letter column in this table shows the letter of each entity in the table, which were used to show how the values in the value column was calculated using the calculation shown in the calculation column.

Table 21 Savings due to increased green fraction in study area

Letter	Entity	Calculation	Value
A	GLA of each building (m^2)		4797
B	Number of retrofitted buildings in study area		979
C	Study Period (years)		40
D	Annual health cost due to air pollution		R1.67 billion
E	Cost to subsides 80% of buildings in study area		R1.4 billion
F	Reduction in health costs		7.34%
G	Annual savings in health cost due to air pollution	$D \times F$	R122 million
H	Payback period (years)	$E \div G$	12
I	Savings over study period	$(C-1) \times G - E$	R3.36 billion
J	Savings to area/ year	$I \div C$	R84 million
K	Savings to area/m^2/year	$J \div (A \times B)$	R17.90

Table 21 shows that the City will save R17.90/m^2/year. The initial cost of subsidising the retrofits is R1.4 billion. This cost has a payback period of 12 years, where after the City will save R3.36 billion due to the reduction in health costs over the 40 year study period.

This evaluation assumes that 80% of the building owners will retrofit their buildings. However, the likelihood of this is slim, since the payback period for retrofitting an existing building is 20 years given an 80% subsidy and a 3% reduction in energy consumption. Thus, an additional incentive is needed to encourage building owners to retrofit, which is discussed in the following section.

9.2.4 Additional Incentive Required

Additional incentives are needed to encourage building owners to retrofit with a green roof, as building owners prefer to invest in projects with short term payback periods. This section investigates the use of a reduction in property tax as an incentive offered to building owners who retrofit their buildings with green roofs.

The effect of reducing the annual property tax over the 40 year period of the CBA considered in Chapters 6 and 7 was analysed. This was done to determine the reduction needed to reduce the discounted payback period of 20 years to 7 years.

Different reductions in property tax were analysed to determine the reduction needed to reduce the discounted payback period to 7 years. The analysis showed that a 2% reduction in property tax is enough to reduce the discounted payback period to 7 years. The results of the analysis are shown in Figure 35. This figure shows the first 15 years of the CBA comparing the retrofitted and conventional building. The cumulative difference in discounted cash flows for two CBA is shown. The additional incentives case assumes a 3% reduction in energy consumption, an 80% subsidy for the green roof installation costs and an additional incentive which reduces the annual property tax by 2%. Figure 35 shows that the cumulative difference in cash flow in year 7 becomes positive, thus the building owner starts to make a profit in year 7. The other CBA has a discounted payback period of 20 years.

The difference in NPV when considering the additional incentive in the CBA shown in Figure 35 amounts to R1.39 million over the 40-year study period (see Figure D4 in Appendix D). The difference in discounted cash flow and the accumulation of this cash flow over the 40-year period are shown in Appendix D, Figures D3 and D4. The CBA data is shown in Appendix C, Tables C2 and C3.

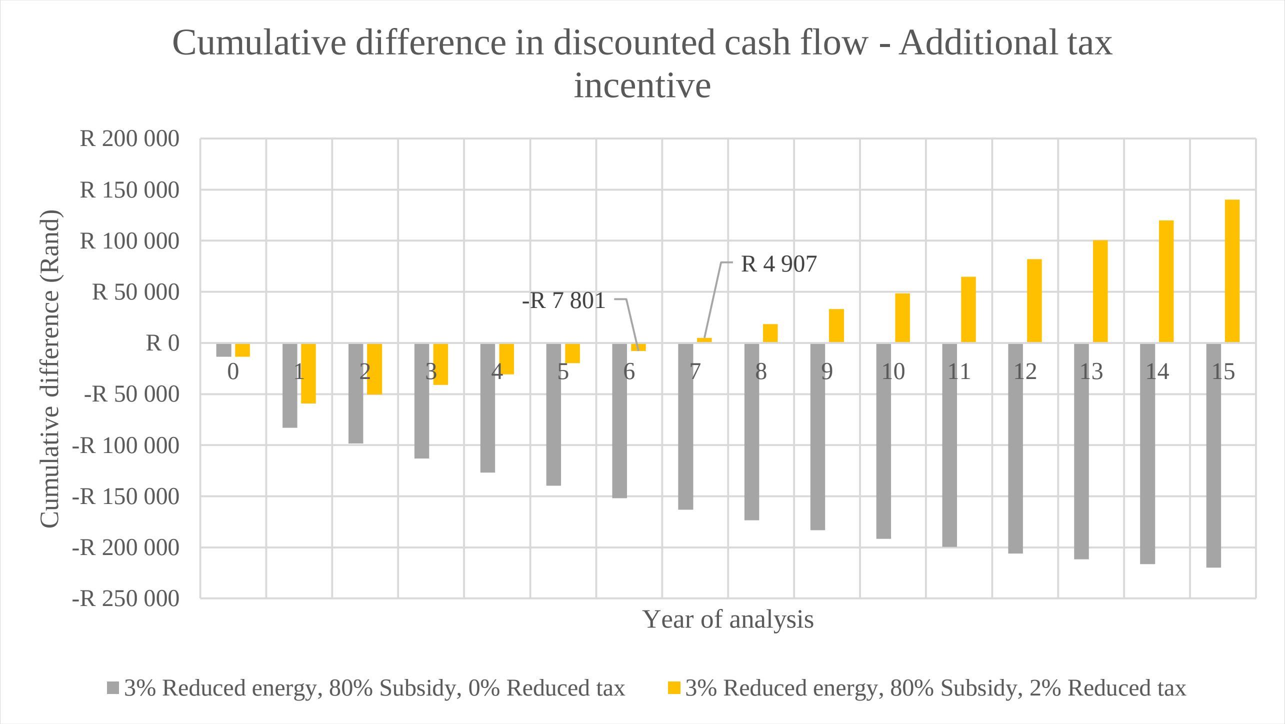


Figure 35 Additional Incentive- Cumulated difference in discounted cash flow

9.2.5 Funding for Additional Incentive

The evaluation of the effect of increasing the green fraction in the study area previously discussed, showed that the City can save up to R17.90/m^2/year if 80% of the buildings in the study area are retrofitted with green roofs. Table 22 shows the methodology used to determine how much a 2% reduction in property tax for the retrofitted buildings will cost the city. The letter column in this table shows the letters of each entity in the table, which were used to show how the values in the value column was calculated using the calculation shown in the calculation column.

Table 22 Additional Incentive - Reduced Property Tax

Letter	Entity	Calculation	
A	Savings to area/m^2/year		R 17.90
B	Savings to area/year		R84 million
C	Tax discount for each building/year as a percentage of property tax		2%
D	Property tax per year (see Appendix B Section B.3)		R1.1 million
E	GLA of each building (m^2)		4797
F	Number of buildings in study area		1224
G	Number of retrofitted buildings in study area	$F \times 80\%$	979
H	Original income from property tax of study area	$D \times F$	R1.33 billion
I	Adjusted income from property tax	$H-(C \times H)$	R1.30 billion
J	Tax discount for each building/year	$C \times D$	R 24 011
K	Tax discount for each building /m^2/year	$J \div E$	R 5
L	Actual savings for area/m^2/year	$A-K$	R 12.90
M	Actual savings for area/year	$L \times E \times G$	R60 million
N	Savings for city as a percentage of the income from property tax from study area	$M \div I$	5%
O	Cost to subsides 80% of buildings		R1.4 billion
P	Annual savings in health cost due to air pollution		R122 million
Q	Annual health cost savings – Annual tax deduction	$P-J \times G$	R99 million
R	Payback period (years)	$O \div Q$	15

Table 22 shows that if the city offers a reduction in property tax of 2% to building owners who retrofitted their buildings, the City still saves R12.9/m^2/year. These annual savings are equivalent to the city receiving an additional 5% in property tax annually, from all the buildings in the study area. However, this additional incentive increases the payback period of the R1.4 billion the City will spend on subsidies in the study area.

The payback period increases from 12 years to 15 years. Thus, reducing the payback period for the building owners to 7 years, increases the payback period for the City with 3 years.

Different combinations of incentives were considered to determine if it would be more beneficial for the City to reduce the initial expense, thus offering a smaller subsidy, such as 30% or 50%, but still allow for a 7-year payback period for the building owner. The same methodology used to determine the savings and payback periods in Tables 22 and 23 was used to determine the tax deduction required when subsidies of 30% or 50% are offered.

Table 23 shows the different tax deductions required to reduce the building owners' payback period to 7 years given different subsidies for the installation cost of the green roof.

Table 23 Additional Incentive - Different Subsidies

Letter	Entity	Calculation	Subsidy		
			30%	**50%**	**80%**
A	Cost to subsidise 80% of buildings		R537 million	R895 million	R1.4 billion
B	Original payback period for cost of subsidies (years)		5	8	12
C	Percentage tax discount required per year for 7-year building owner payback period		12%	8%	2%
D	Annual health cost savings – Annual tax deduction		-R2.6 million	R 38 million	R99 million
E	New payback period (years)	A÷D	None	24	15

Subsidising 30% of the initial cost, means the building owner requires a reduction in property tax of 12%. The City will not be able to afford this tax deduction as this cost exceeds the savings and will cost the City R2.6 million. Subsidising 50% means the building owner will receive a reduction in property tax of 8%, which increases the payback period for the City to 24 years from 8 years. An 80% subsidy will require a 2% tax deduction and has a 15-year payback period for the City.

The data in Table 23 shows that it is in the best interest of the City to offer an 80% subsidy and a 2% reduction in annual property tax, as this will result in the shortest possible payback period and largest annual savings for the City.

9.3 Additional Effects of Implementing Green Roofs

The investigation conducted in this chapter considered the implementation of green roofs on a large scale. Section 2.1.5 (see pages 20 and 21) of this thesis considered the hypothetical effects of implementing green roofs on a city scale. The causal loop diagram shown in Figure 11 describes these hypothetical effects. Figure 11 shows that implementing green roofs on a large scale can reduce the UHIE fourfold, thereby reducing the energy consumption of all the buildings in the area of implementation fourfold. The energy consumption of a building in a green roofed area will be reduced regardless of whether the building has a green roof or not. In the analyses previously discussed it was assumed that a green roof reduces a building's energy consumption by 3%. If the spin-off effects of large scale green roof implementation are taken into account, a building's energy consumption will theoretically be reduced by more than 3%.

A reduction in a building's energy consumption of 5% is required to reduce the discounted payback period for a building owner who retrofits to 7 years. Thus, if a building's energy consumption is reduced by an additional 2% (i.e. 5% - 3%), there will be no need for the additional incentive offered by the City as discussed in the previous section. The quantification of this additional effect needs further investigation.

In conclusion, if the UHIE in the study area previously considered is reduced so much so that the energy consumption of all the buildings in said area is reduced by 2%, the City will be able to pay off the cost of the subsidies (80% of initial green roof installation costs) within 12 years and no additional incentives will be required. However, the actual reduction in building energy consumption due to the reduction in UHIE is unknown.

9.4 Conclusion

The City can afford to offer incentives to increase the green fraction in areas where urban air pollution is a concern. Increasing the green fraction of the study area considered results in savings in the health costs due to air pollution. The City will be able to save up to 0.2% (i.e. R60 million) of the GDP of the study area each year, when the following incentives are offered in order to increase the green fraction; an 80% subsidise for the initial cost of retrofitting a building with a green roof and a 2% reduction in the property tax of the retrofitted buildings. The savings in health costs are equivalent to the City receiving 105% in property tax from all the buildings in the study area for a 40 year period. The payback period for these incentives is 15 years for the City.

If the City offers these two incentives, a building owner retrofitting with a green roof will have a 7 year payback period, instead of never having a payback period, without the tax and subsidy incentive. Building owners will thus be more inclined to retrofit. This is assuming that the green roof reduces the building's energy consumption by 3%.

Increasing the green fraction of the City by giving incentives such as these will be an expensive investment for the city. However, this investment has the potential to reduce future health costs due to air pollution in the City, by improving the health of the city's inhabitants, reducing infrastructure costs with regards to stormwater infrastructure, providing improved stormwater management, reducing the UHIE and reduce energy usage in the area of implementation. These are all benefits gained by the City.

9.5 Assumptions and Limitations

The assumptions and limitations of the evaluation and analyses discussed in this chapter are discussed in this section. The assumptions made are listed and the limitations explained.

- The GDP per capita considered in this study is R95 000
- A building's occupancy density is 0.05/m^2
- The population in the study area is 293 576
- All buildings in the study area have the same dimensions
- The building dimensions are as follows;
    - 7 floors,
    - 16.8m high, 25.8m wide, 26.5m long,
    - 105m circumference,
    - And a 685m^2 floor area footprint.
- 80% of the building owners in the study area retrofit their buildings with green roofs
- All green roof systems are extensive modular tray systems with a substrate depth of 100mm
- A green roof covers 80% of the roof area

- A building retrofitted with a green roof will have a reduction in energy consumption of 3%
- Increasing the green fraction in the study area by 18% reduces particulate matter air pollution in the study area by 10µg/m^3
- A reduction of 10µg/m^3 in particulate matter levels result in a 7.34% reduction in health cost due to air pollution, specifically particulate matter
- Health costs are reduced by 7.34% in the study area
- Urban air pollution costs 6% of the GDP of the study area

In this chapter, a direct financial incentive is proposed, namely subsidising the initial cost of the green roof. This type of incentive is the most difficult type of incentive to implement, as the government must have the financial resources to support the incentives. The other incentive proposed, a reduction in annual property tax, is an indirect financial incentive, which is the most common form of incentive used to promote the construction of green roofs.

The results presented in this chapter do not take the other spin-off effects of increasing the green fraction in an area into account. The effect of reducing the UHIE was not considered. The study done by Li et al. (2014), as discussed in Chapter 2, showed the UHIE can be reduced by approximately 3°C if 80% of the buildings in the area under consideration are retrofitted with green roofs (see Figure.A-2 in Appendix A). This reduction in UHIE can lead to reduced energy usage in the area.

Reducing the UHIE in an area will also reduce the pollution in that area. Thus, saving in health cost can be more than expected due to the reduction in UHIE. The extent to which the pollution will be reduced due to a reduction in UHIE is unknown.

The study by Irga, Burchett and Torpy (2015) provided quantitative data that showed the CO_2, SO_2 and NO_2 concentrations reduced as the greenspace cover in an area increased. According to the study, these results are yet to be evaluated, however other studies support these results (Yin et al., 2011; Pugh et al., 2012). The effect of the reduction in CO_2, SO_2 and NO_2 on the cost of urban air pollution was not taken into account.

10 Summary of Findings

The findings from the CBA presented in Chapters 6, 7 and 9 are summarised in Table 24. The assumptions and benefits for each analysis are shown as well as the difference in NPV, the discounted payback period for the standard building owner and the City for providing the incentives.

Table 24 Summary of CBA Results

Analysis	Assumptions	NPV		Discounted payback period (years)	
		Building owner	City	Building owner	City
Chapter 6	No incentives, no benefits	-R3.7 million	N.A.	>>40	0
Chapter 7	3% reduced energy consumption	-R 742 689	N.A.	>40	0
Chapter 7	80% subsidy 3% reduced energy consumption	R426 768	R3.5 billion	20	12
Chapter 8	80% subsidy 3% reduced energy consumption 2% property tax deduction	R1.4 million	R2.5 billion	7	15

The results in Table 24 show that retrofitting a building with a green roof is not affordable if no incentives are provided, or the green roof provides no benefits to the building owner. Assuming that the green roof can reduce the annual energy consumption of the building by 3%, the payback period will not be reduced enough to have any payback period. Thus, the reduction in energy consumption alone is not enough to make retrofitting feasible.

Retrofitting becomes more feasible but still a poor investment in terms of discounted payback period if a subsidy of 80% of the installation cost is offered and the green roof reduces the building's energy consumption by 3%. The City will have to use the savings in health costs in the study area for 12 years to fund this incentive.

Retrofitting becomes feasible if the green roof can reduce the building's energy consumption and the City gives incentives, such as an 80% subsidy and a 2% reduction in property tax. In this case the City will have to use the savings in health costs in the study area for 15 years to fund these incentives.

The final conclusions made with regard to the summary of the results shown in Table 24 and other results from this study are discussed in the following chapter. Refer to Appendix C, Tables C1 to C3 and Appendix D, Figures D1 to D4, for the CBA data used to determine the NPV and discounted payback period for the building owner.

11 Final Conclusions

Green roofs have the ability to reduce and mitigate many environmental concerns apparent in the major cities of South Africa. However, the causes and effects of most of the environmental concerns in cities are complex and interlinked. The use of green roofs alone is thus not enough: more than one strategy and sustainable technology should be used to make a city more sustainable and resilient. How the aim and objectives of this study were met are discussed in this chapter and recommendations for future research are also presented.

11.1 Significance of Results

The aim of this study was to determine whether large-scale implementation of green roofs can be economically beneficial for both the City and the building owners. The results of the study showed that large scale implementation of green roofs can be economically beneficial to both. The City can save in health costs due to air pollution and a building owner will be able to pay off the green roof within 7 years, subject to certain incentives from the City.

The research objectives were;

1. *Identify the policies that can help in establishing the green roof industry in South Africa.*

Policies have been identified that require all municipal owned buildings, deemed structurally capable to support a green roof, to be retrofitted with a green roof when the roof's waterproofing needs replacement. Such policies should be used to help establish the green roof industry.

Furthermore, local municipalities should use municipal buildings as green roof pilot projects to help increase the knowledge of green roofs specific to the different climatic areas in South Africa. This will also help in establishing the construction and maintenance standards required for green roofs in the different climatic areas in the country.

2. *Identify incentives that will encourage developers and building owners to retrofit an existing building with a green roof.*

Two incentives were identified; the City can offer an 80% subsidy to all building owners who retrofit their building with a green roof and the City can give a tax deduction of approximately 2% of a building's property tax to all building owners who retrofit their building with a green roof.

3. *Investigate and determine the costs and benefits associated with retrofitting an existing building with a modular extensive green roof.*

The costs and benefits were investigated. Additional costs associated with the retrofitting of a green roof are; the green roof system, design and installation, additional waterproofing and the annual green roof maintenance.

The additional benefit of a green roof is a reduction in electricity usage. The study showed that a reduction of at least 3.76% in electricity usage is required for the retrofitted building to have a NPV equal to that of the conventional building. This benefit becomes more significant if the annual increase in cost of electricity is higher than 10%.

4. *Determine the feasibility of retrofitting a building with a green roof with the use of cost benefit analyses.*

Retrofitting an existing building's roof with a green roof is 81% more expensive than replacing the waterproofing. Without any benefit considered as a result of retrofitting the additional expense will never by payed off.

Unless incentives are offered, it is unlikely that building owners or developers will invest in retrofitting an existing building with a green roof.

Retrofitting an existing building in the City of Johannesburg is only feasible under the following conditions listed:

- The City provides an 80% subsidy for the initial cost of the green roof.
- The City reduces an annual cost such as property tax by at least 2%.
- The green roof reduces the building's energy consumption by at least 3%.

If these conditions are met, the payback period for installing the green roof will be 7 years for the building owner. The subsidy and reduction in property tax will result in a 15 year payback period for the City.

Furthermore, these incentives and the reduction in the building's energy consumption will make retrofitting a building with a green roof more profitable than only waterproofing the building's roof. Over a 40 year period, the NPV of the retrofitted roof was determined to be R1.4 million more than that of the conventional building, given the conditions listed.

5. *Determine how increasing the green fraction of an urban environment can be beneficial towards both the private and public sector.*

The City of Johannesburg is experiencing environmental concerns such as air pollution and the UHIE with Johannesburg's air being the most polluted in South Africa. Increasing the green fraction in polluted areas in the City can reduce the air pollution, as fine particulate matter is the governing air pollutant in Johannesburg's air and green areas are able to reduce the concentration of fine particulate matter in the ambient air.

The City of Johannesburg needs to create incentives to improve the ambient air quality of the City. The City should start by improving the air quality in areas within the City where air pollution and the UHIE are the worst.

The City should start by offering subsidies to building owners, within the identified areas, to retrofit their building with a green roof. Retrofitting the existing buildings with green roofs will increase the green fraction in that area.

It is proposed that the City increases the green fraction by offering an 80% subsidy and a reduction of 2% in property tax to building owners who retrofit their buildings with green roofs. Such incentives will make retrofitting an existing building with a green roof beneficial to the private sector.

Due to the savings in annual health costs as a result of a reduction in air pollution when the green fraction is increased, the City will be able to afford to offer the proposed incentives to increase the green fraction. However, the City will need 15 years to make up these expenses, after which the City will have annual savings of 7% in health costs related to urban air pollution.

The net annual savings amount to R12.9/m^2 of office building per year in the area where the green roofs are implemented. Thus, the use of City funds to increase the green fraction is beneficial to both the public and private sector.

11.2Future Research

The data used to determine the reduction in energy consumption of a building due to a green roof was based on data form Canada and Spain. Research on the ability of a green roof to reduce the building energy usage in South Africa is needed. This research should look at the reduction in energy based on the number of floors of the building as well as the area of the green roof on the building. Using this data it might be possible to determine a correlation between the total wall area to green roof area ratio and the reduction in energy usage.

The effect of green roofs to reduce the ambient air temperature has been studied in numerous cities, however, research on the effect of a building retrofitted with a green roof on the buildings around it is lacking. Such research could give insight into the influence of the placement of green infrastructure such as green roofs or green walls and the minimum amount of green roofs or walls needed in an area to optimise mitigating effects.

Urban air pollution and the UHIE are interlinked; research suggests that the UHIE worsens the air pollution, which worsens the UHIE. Quantitative research on the relationship between the UHIE and air pollution in cities is needed to determine if the relationship between the two environmental problems is as qualitative research suggests.

The use of solar panels is becoming more and more common in South Africa. Research suggest that green roofs can increase the effectiveness of the Photovoltaic (PV) panels due to the green roof's ability to reduce the ambient air temperature (Hui and Chan, 2011; Tomazin, 2016) . The reduction in ambient air temperature improves the voltage output of PV cells. Studies in Germany have shown that a green roof can boost the energy output of the solar panels by approximately 6% (Köhler et al. 2007). Furthermore, the vegetation beneath the solar panels is usually more diverse since the plants are not exposed to such harsh conditions. Research concerning the ability of green roofs to increase the effectiveness of the solar panels is suggested.

Furthermore, research on a hybrid roof which combines solar panels and green roofs is also suggested. Such a roof, referred to PV green roofs in literature, could potentially reduce the long-term payback period of a green roof through the direct electricity savings due to the solar panels. The cost benefit analysis presented in this thesis did not consider the use of a PV green roof. Research on the costs related to such a roof could show that combining these technologies is beneficial since the green roof improves the solar panel's effectiveness and this increase in effectiveness offsets the cost of the green roof. The use of a PV green roof may also reduce the need for incentives to reduce the annual and initial costs of a green roof system.

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Interviewer 1: Ward, S. (2016) Telephone conversation, 19 June.

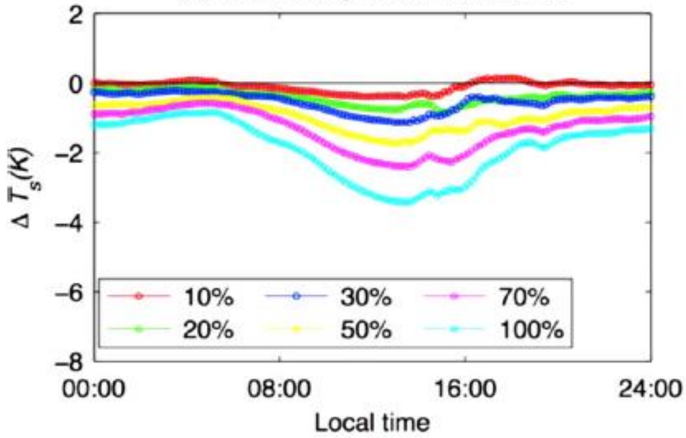
Interviewer 2: Burger, K. (2016) Personal communication, 24 July.

Interviewer 3: du Plessis, A. (2017) Email correspondence, 11 December.

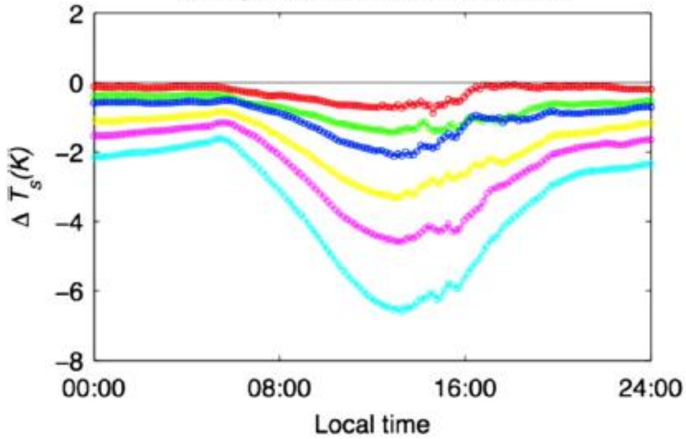
Interviewer 4: Kleynhans, C. (2017) Telephone conversation, 8 December.

Appendix A Simulation Results from Literature

(a) Low Density Residential Urban



(b) High Density Residential Urban



(c) Industrial/Commercial Urban

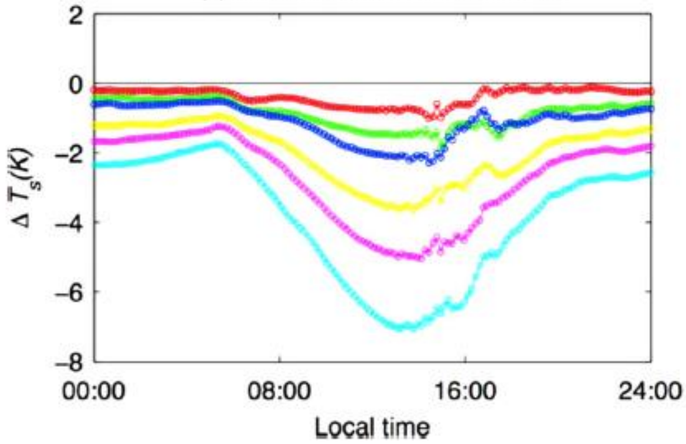


Figure A1 City scale impact of green roof mitigation strategies on surface temperatures in different urban areas (Li et al. 2014)

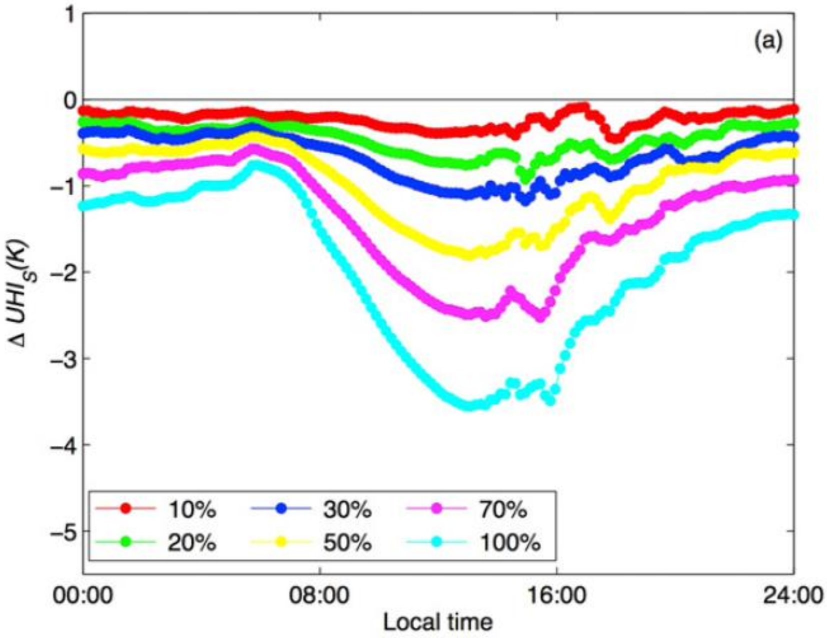


Figure A2 Change in surface UHI due increased green roof fractions (Li et al. 2014)

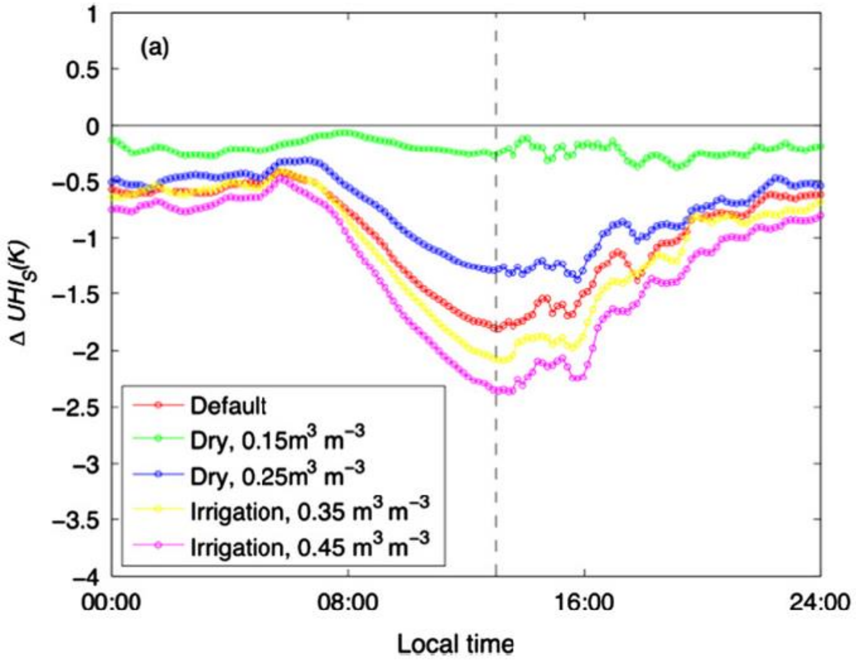


Figure A3 Change in surface UHI due to alternating soil moisture (Li et al. 2014)

Appendix B Building Costs and Benefits

B.1 Cost: Water Consumption

The annual costs associated with a typical building's water usage were determined by using the water consumption and water cost of a typical building. The water usage data for the Cost Benefit Analysis (CBA) was based on the GBCSA Energy and Water Benchmark Methodology report (Bannister & Chen 2012). This report gives a performance based benchmark for South African office buildings.

The benchmark model aims at predicting the expected energy and water consumption of a building. Building location, building size and year of construction or refurbishment did not have a significant influence on the energy or water usage intensity of a building.

The following information regarding Water Use Intensity (WUI) and water consumption was obtained from the GBCSA report (Bannister & Chen 2012):

- Average WUI of an office building is 1.14kL/m^2
- $WUI\left(\frac{kL}{m^2}\right) = \frac{Annual\ Water\ Consumption\ (kL)}{Building\ Area\ (m^2)}$

The WUI was used to determine the water consumption of the office building with the specifications as discussed in Chapter 4. The GLA was calculated by multiplying the floor area of 685m^2 and number of floors in the building, which is 7. The GLA of the office building was thus 4797m^2.

__Water Tariffs__

The water tariffs for a commercial building were obtained from Johannesburg water, sewerage and sanitation services reports (City of Johannesburg 2013; City of Johannesburg 2015). The annual water tariffs are shown in Table B1, being the historical and proposed water tariffs for years 2013 up to 2018.

Table B 1 Current and Expected Water Tariffs

Year	2013	2014	2015	2016	2017	2018
Tariff (R/kl)	R19.60	R21.72	R23.78	R27.47	R29.80	R32.33

The data in Table B1 was used to estimate the increase in water tariffs over the 40 year analysis period. The trend line in this figure is based on the water tariffs from 2013, and the expected tariffs for 2018. The predicted increase is shown in Figure B1. From Figure B1 it was determined that the annual water tariffs will increase by approximately 11% per year. The 2016/2017 water, sewerage and sanitation services reports (The City of Johannesburg 2016) proposes a tariff increase of 15% for commercial buildings using more than 200kl per month, and an average increase of 8.9% and 8.4% for 2018 and 2019. The initial annual cost used for the CBA is R27.47 /kl.

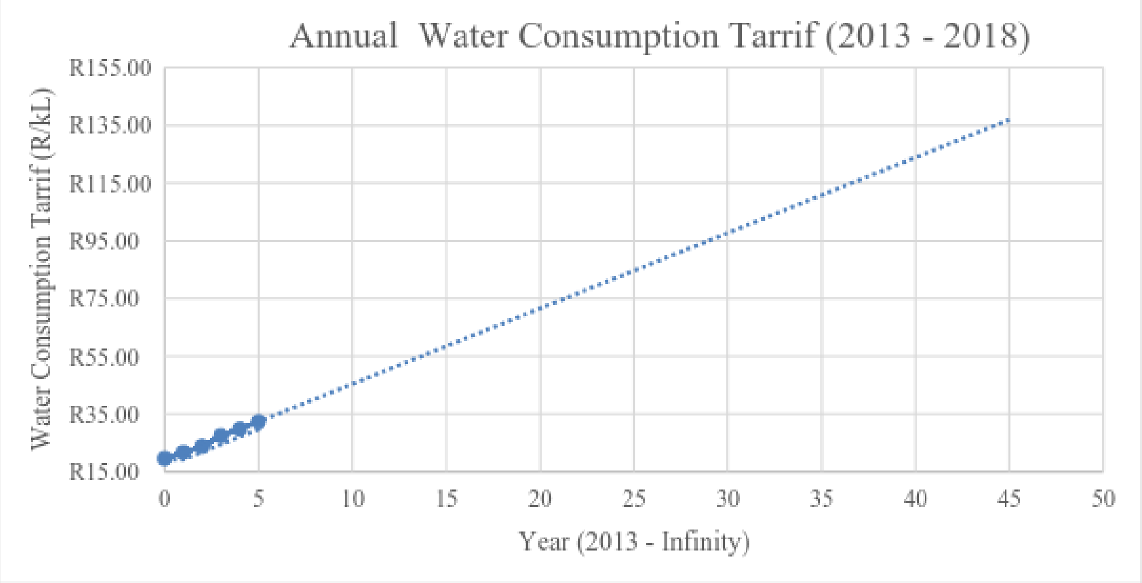


Figure B 1 Predicted Water Tariff Data

Water Cost

The initial water tariff for year 0 of the Cost Benefit Analysis (CBA) was taken as the water tariff for 2016, which is R27.47/kl, as shown in Table B1. The GLA of the building is 4797m^2, the WUI is 1.14 kl/m^2, as previously discussed. This data was used to determine the cost of water consumption for year 0 of the CBA. The water cost for year 0 was taken as R150 222, and was calculated as follows;

$$WUI\ (kl/m^2) = Annual\ water\ consumption\ (kl) \div Average\ GLA\ (m^2)$$

$$1.14 = Annual\ water\ consumption\ (kl) \div 4797$$

$$Annual\ water\ consumption = 1.14 \times 4797$$

$$= 5\ 469\ kl$$

$$\text{Annual water cost} = \text{Water Tariff (R/kl)} \times \text{Annual water consumption (kl)}$$

$$= 27.47 \times 5\,468.58$$

$$= R\ 150\ 222$$

B.2 Cost: Building Operation & Maintenance

The Operations and Maintenance (O&M) costs associated with a typical office building in Johannesburg, was included into the CBA of both the conventional and retrofitted building. The cost of maintaining the green roof was considered for the retrofitted building.

An investment service company in Johannesburg did a study on the operating costs associated with buildings in Johannesburg (Hean & Montaung 2011). The study was based on data provided by building owners in Johannesburg. Costs that are typically included in the operating cost, and paid by the building owner are; cleaning, security, repairs and maintenance of the building, building management, leases and administrative expenses and building insurance. According to the study the average monthly operating cost of an office building in Johannesburg is approximately R33/m^2.

The average operating costs were converted to a present value for 2016 which is year 0 of the study period. The year 2016 is 5 years after the study was done in 2011. Assuming the rate of inflation is 6%, the average monthly operating cost was determined to be R44/m^2 for the year 2016.

The GLA of the building is 4797m^2, therefore the initial operating cost in 2016, year 0 of the analysis was taken as R 2 532 816. It was assumed that the building operating cost will increase with inflation, which is assumed to be 6%.

B.3 Cost: Property Tax

The property tax rates for a business or commercial space in the City of Johannesburg are based on the market value of the property as well as the property rates. The property rates for 2016 are R0.017982/m^2 of commercial property (The City of Johannesburg 2017).

The increase in property tax between years 2016 to 2017 was 6.2% (The City of Johannesburg 2017). Property tax is assumed to increase with inflation, which is a 6% annual increase.

According to a development trend report the market value of a building situated in Johannesburg CBD was R6 618.20/m^2 in year 2007 (DEMACON 2009). The market value of such a building in 2016, year 0 of the analysis, was determined to be R11 181.30/m^2, assuming the value increased with inflation. The report also indicated that the price of renting office space in the CBD was R59.80/m^2 per month in 2007. According to these values, the rental price was a 9th of the market value in 2007. Broll Propertry Group (2011) reported that office space in the CBD was R8 100/m^2 in 2011, thus R10 840/m^2 in 2016. Other sources reported that the market value and rental price was R11 920/m^2 and R110/m^2 per month in 2015, thus R12 363/m^2 and R117/m^2 per month in 2016 (Jones Lang Lasalle 2015) The 2016 report showed that rental prices were R123/m^2 per month and the market value was R15 981/m^2 in 2016 (Jones Lang Lasalle 2016), these prices were for grade A office buildings. The rental prices were an 8th and 10th of the price of the building market value in 2015 and 2016 respectively. The market value was taken as the average of the four values discussed for year 2016. Furthermore the rental price was considered to be a 9th of the building market value.

The Gross Lettable Area (GLA) of the building used for the study is 4797m^2 as previously discussed. The property tax for year 1 of the building was calculated as follows:

$$\begin{aligned} \text{Property Tax} &= \text{Building Market Value in 2016} \times (1+6\%) \times \text{GLA} \times \text{Property Tax Rate} \\ &= R\ 12\,591.33 \times (1+0.06) \times 4797 \times 0.017982 \\ &= R\ 1\,151\,291 \end{aligned}$$

B.4 Cost: Stormwater Tax

Stormwater utilities fees are not currently implemented in South Africa. As previously mentioned there is a lack in funding available for stormwater management. Also previously mentioned is that stormwater needs to be reduced in the major cities of South Africa. Therefore there is a possibility of municipalities implementing stormwater tax in the future. Stormwater tax would typically be collected as a usage fee, and be used to cover the construction, maintenance and replacement of stormwater management facilities.

According to Fisher-Jeffes & Armitage (2013) a typical residential plot, with an impervious area of 160m^{2}in the City of Tshwane, will have to pay R60.00 – R87.00 per month on Stormwater utility fees. The predicted fees are based on the climate zone and level of treatment needed in the area.

In order to determine what the fees for a commercial office building situated in Johannesburg will be, the runoff coefficients of a typical residential flat or suburban area, and a city centre were compared. The runoff coefficients of a suburban area and a city centre are between 0.5 - 0.7 and 0.7 - 0.95 respectively (Kruger 2013 B-4 s assumed that the monthly fees aligned with the runoff coefficient. Thus a suburban plot with a runoff coefficient of 0.5 would pay R60 per month, similarly a suburban plot with a runoff coefficient of 0.7 would pay R87 per month. Assuming that a plot in the city centre with a runoff coefficient of 0.7 would pay R87 per month, and using linear extrapolation, the monthly cost that would be paid for a plot in the city centre with a runoff coefficient of 0.95 is R120.75. This monthly payment is the highest payable fee for the City of Tshwane. There is no data for predicted stormwater utility fees for the City of Johannesburg, therefore the fees for the City of Johannesburg were based on data for the City of Tshwane. The stormwater utility fee for 2013 for a plot in the city centre of Johannesburg is R120.75/month, which amounts to R1449 for the entire year.

Stormwater tax in comparison to property tax, and the other general building costs, is small, including or excluding this cost in the CBA will not have much of an influence on the results. Therefore stormwater tax was not included.

B 5 Benefit: Renting Office Space

The commercial rate for office space in the CBD of Johannesburg can vary significantly based on whether the building is A+, A, B or C grade. The commercial rate of the typical building was based on the building market value used to calculate the property tax for the typical building. It was assumed that the monthly rent is a 9th of the building's market value, as previously discussed. The area of each floor is 685m^2, and there are seven floors in the building. The income that can be received from rent for year 0 was determined as follows:

$$Monthly\ commercial\ rate = \frac{Building\ market\ value}{9 \times 12}$$

$$= \frac{R\ 12\ 591.33}{9 \times 12}$$

$$= R\ 116.59\ /month/m^2$$

$$Annual\ Rent = Monthly\ commercial\ rate \times Floor\ Area \times Floors \times 12\ months$$

$$= R116.59 \times 685 \times 7 \times 1$$

$$= R\ 6\ 708\ 381$$

The monthly rent for year 1 was taken as the future value of the annual rent calculated, which is R7 110 884. It is assumed that the rent will increase with 7% per year, which is the weighted average of all the different annual increases of all the costs assumed. The weighted average was determined as follows: The weights of the costs were determined by using the costs of year 2 as shown in Figure 21, only considering the conventional building costs:

$$Annual\ Increase = 6\% \times O\&M + 6\% \times Property\ tax + 11\% \times Water + 10\% \times Electricity$$

$$= 6\% \times 52\% + 6\% \times 22\% + 11\% \times 3\% + 10\% \times 22\%$$

$$= 7.06\%$$

Appendix C CBA Data

Table C 1 CBA Data Chapter 6

Year	0	1	2	3	4	5	6	7	8
Discount rate	6%								
Discount factor	1	0,943	0,890	0,840	0,792	0,747	0,705	0,665	0,627
A = Retrofitted Building									
Costs									
Waterproofing	R 587 060								
Green Roofing	R 874 772								
Green Roof Maintenance		R 91 334	R 42 664	R 45 224	R 47 937	R 50 814	R 53 862	R 57 094	R 60 520
Green Roof Water		R 17 144	R 12 686	R 14 082	R 15 631	R 17 350	R 19 259	R 21 377	R 23 729
B = Conventional Building									
Costs									
Waterproofing	R 278 810								
Comparison of building costs									
Cash flow A- B	-R 1 183 022	-R 108 478	-R 55 350	-R 59 306	-R 63 568	-R 68 164	-R 73 121	-R 78 472	-R 84 249
Discounted cash flow A - B	-R 1 183 022	-R 102 338	-R 49 262	-R 49 794	-R 50 352	-R 50 936	-R 51 548	-R 52 188	-R 52 859
Cumulated discounted cash flow	-R 1 183 022	-R 1 285 360	-R 1 334 621	-R 1 384 416	-R 1 434 768	-R 1 485 704	-R 1 537 251	-R 1 589 439	-R 1 642 298

9	10	11	12	13	14	15	16	17	18	19	20
6%											
0,592	0,558	0,527	0,497	0,469	0,442	0,417	0,394	0,371	0,350	0,331	0,312
A = Retrofitted Building											
Costs											
R 64 151	R 68 000	R 72 080	R 76 405	R 80 989	R 85 848	R 90 999	R 96 459	R 102 247	R 108 382	R 114 884	R 121 778
R 26 339	R 29 236	R 32 452	R 36 022	R 39 985	R 44 383	R 49 265	R 54 684	R 60 700	R 67 377	R 74 788	R 83 015
B = Conventional Building											
Costs											
											R 894 182
Comparison of building costs											
-R 90 490	-R 97 236	-R 104 532	-R 112 427	-R 120 974	-R 130 231	-R 140 264	-R 151 144	-R 162 946	-R 175 758	-R 189 672	R 689 390
-R 53 561	-R 54 296	-R 55 066	-R 55 873	-R 56 717	-R 57 601	-R 58 527	-R 59 497	-R 60 512	-R 61 576	-R 62 689	R 214 955
-R 1 695 859	-R 1 750 155	-R 1 805 222	-R 1 861 095	-R 1 917 812	-R 1 975 413	-R 2 033 941	-R 2 093 438	-R 2 153 950	-R 2 215 526	-R 2 278 215	-R 2 063 260

21	22	23	24	25	26	27	28	29	30	31	32
6%											
0,294	0,278	0,262	0,247	0,233	0,220	0,207	0,196	0,185	0,174	0,164	0,155
A = Retrofitted Building											
Costs											
R 129 084	R 136 829	R 145 039	R 153 741	R 162 966	R 172 744	R 183 108	R 194 095	R 205 741	R 218 085	R 231 170	R 245 040
R 92 146	R 102 282	R 113 533	R 126 022	R 139 885	R 155 272	R 172 352	R 191 310	R 212 355	R 235 714	R 261 642	R 290 423
B = Conventional Building											
Costs											
Comparison of building costs											
-R 221 230	-R 239 112	-R 258 572	-R 279 763	-R 302 850	-R 328 016	-R 355 460	-R 385 405	-R 418 095	-R 453 799	-R 492 812	-R 535 463
-R 65 076	-R 66 355	-R 67 694	-R 69 096	-R 70 564	-R 72 101	-R 73 711	-R 75 397	-R 77 162	-R 79 011	-R 80 947	-R 82 974
-R 2 128 336	-R 2 194 691	-R 2 262 385	-R 2 331 480	-R 2 402 044	-R 2 474 145	-R 2 547 856	-R 2 623 253	-R 2 700 415	-R 2 779 426	-R 2 860 373	-R 2 943 347

33	34	35	36	37	38	39	40	Year
6%								Discount rate
0,146	0,138	0,130	0,123	0,116	0,109	0,103	0,097	Discount factor
A = Retrofitted Building								
Costs								
								Waterproofing
								Green Roofing
R 259 743	R 275 327	R 291 847	R 309 358	R 327 919	R 347 594	R 368 450	R 390 557	Green Roof Maintenance
R 322 369	R 357 830	R 397 191	R 440 882	R 489 379	R 543 211	R 602 964	R 669 290	Green Roof Water
B = Conventional Building								
Costs								
								Waterproofing
Comparison of building costs								
-R 582 112	-R 633 157	-R 689 038	-R 750 240	-R 817 299	-R 890 805	-R 971 414	-R 1 059 847	Cash flow A- B
-R 85 097	-R 87 320	-R 89 647	-R 92 085	-R 94 638	-R 97 311	-R 100 110	-R 103 041	Discounted cash flow A - B
-R 3 028 444	-R 3 115 763	-R 3 205 411	-R 3 297 496	-R 3 392 134	-R 3 489 444	-R 3 589 554	-R 3 692 594	Cumulated discounted cash flow

Table C 2 CBA Data Chapter 7

Year	0	1	2	3	4	5	6	7	8
Discount rate	6%								
Discount factor	1	0,943	0,890	0,840	0,792	0,747	0,705	0,665	0,627
A = Retrofitted Building									
Costs									
Waterproofing	R 587 060								
Green Roofing	R 874 772								
Green Roof Maintenance		R 91 334	R 42 664	R 45 224	R 47 937	R 50 814	R 53 862	R 57 094	R 60 520
Green Roof Water		R 17 144	R 12 686	R 14 082	R 15 631	R 17 350	R 19 259	R 21 377	R 23 729
Electricity (reduced 3%)		R 1 122 050	R 1 234 255	R 1 357 681	R 1 493 449	R 1 642 794	R 1 807 073	R 1 987 781	R 2 186 559
Benefits									
Subsidy (80%)	R 1 169 465								
B = Conventional Building									
Costs									
Waterproofing	R 278 810								
Electricity		R 1 156 753	R 1 272 428	R 1 399 671	R 1 539 638	R 1 693 602	R 1 862 962	R 2 049 258	R 2 254 184
Comparison of building costs									
Cash flow A- B	-R 13 556	-R 73 776	-R 17 178	-R 17 316	-R 17 379	-R 17 356	-R 17 232	-R 16 994	-R 16 623
Discounted cash flow A - B	-R 13 556	-R 69 600	-R 15 288	-R 14 539	-R 13 766	-R 12 969	-R 12 148	-R 11 302	-R 10 430
Cumulated discounted cash flow	-R 13 556	-R 83 156	-R 98 444	-R 112 983	-R 126 748	-R 139 718	-R 151 866	-R 163 168	-R 173 597

9	10	11	12	13	14	15	16	17	18	19	20
6%											
0,592	0,558	0,527	0,497	0,469	0,442	0,417	0,394	0,371	0,350	0,331	0,312
A = Retrofitted Building											
Costs											
R 64 151	R 68 000	R 72 080	R 76 405	R 80 989	R 85 848	R 90 999	R 96 459	R 102 247	R 108 382	R 114 884	R 121 778
R 26 339	R 29 236	R 32 452	R 36 022	R 39 985	R 44 383	R 49 265	R 54 684	R 60 700	R 67 377	R 74 788	R 83 015
R 2 405 214	R 2 645 736	R 2 910 310	R 3 201 340	R 3 521 475	R 3 873 622	R 4 260 984	R 4 687 083	R 5 155 791	R 5 671 370	R 6 238 507	R 6 862 358
B = Conventional Building											
Costs											
											R 894 182
R 2 479 603	R 2 727 563	R 3 000 319	R 3 300 351	R 3 630 386	R 3 993 425	R 4 392 767	R 4 832 044	R 5 315 248	R 5 846 773	R 6 431 450	R 7 074 596
Comparison of building costs											
-R 16 102	-R 15 410	-R 14 523	-R 13 416	-R 12 062	-R 10 429	-R 8 481	-R 6 182	-R 3 489	-R 355	R 3 271	R 901 628
-R 9 531	-R 8 605	-R 7 650	-R 6 668	-R 5 655	-R 4 613	-R 3 539	-R 2 434	-R 1 296	-R 124	R 1 081	R 281 132
-R 183 128	-R 191 733	-R 199 383	-R 206 051	-R 211 706	-R 216 319	-R 219 858	-R 222 291	-R 223 587	-R 223 711	-R 222 630	R 58 502

21	22	23	24	25	26	27	28	29	30	31	32
6%											
0,294	0,278	0,262	0,247	0,233	0,220	0,207	0,196	0,185	0,174	0,164	0,155
A = Retrofitted Building											
Costs											
R 129 084	R 136 829	R 145 039	R 153 741	R 162 966	R 172 744	R 183 108	R 194 095	R 205 741	R 218 085	R 231 170	R 245 040
R 92 146	R 102 282	R 113 533	R 126 022	R 139 885	R 155 272	R 172 352	R 191 310	R 212 355	R 235 714	R 261 642	R 290 423
R 7 548 593	R 8 303 453	R 9 133 798	R 10 047 178	R 11 051 896	R 12 157 085	R 13 372 794	R 14 710 073	R 16 181 080	R 17 799 188	R 19 579 107	R 21 537 018
B = Conventional Building											
Costs											
R 7 782 055	R 8 560 261	R 9 416 287	R 10 357 915	R 11 393 707	R 12 533 077	R 13 786 385	R 15 165 024	R 16 681 526	R 18 349 679	R 20 184 647	R 22 203 111
Comparison of building costs											
R 12 231	R 17 696	R 23 916	R 30 974	R 38 961	R 47 977	R 58 131	R 69 545	R 82 351	R 96 692	R 112 727	R 130 630
R 3 598	R 4 911	R 6 261	R 7 650	R 9 078	R 10 546	R 12 055	R 13 605	R 15 198	R 16 835	R 18 516	R 20 242
R 62 100	R 67 010	R 73 272	R 80 921	R 89 999	R 100 545	R 112 600	R 126 205	R 141 403	R 158 238	R 176 754	R 196 996

33	34	35	36	37	38	39	40	Year
6%								Discount rate
0,146	0,138	0,130	0,123	0,116	0,109	0,103	0,097	Discount factor
A = Retrofitted Building								
Costs								
								Waterproofing
								Green Roofing
R 259 743	R 275 327	R 291 847	R 309 358	R 327 919	R 347 594	R 368 450	R 390 557	Green Roof Maintenance
R 322 369	R 357 830	R 397 191	R 440 882	R 489 379	R 543 211	R 602 964	R 669 290	Green Roof Water
R 23 690 720	R 26 059 792	R 28 665 771	R 31 532 348	R 34 685 583	R 38 154 141	R 41 969 555	R 46 166 511	Electricity (reduced 3%)
B = Conventional Building								
Costs								
								Waterproofing
R 24 423 422	R 26 865 765	R 29 552 341	R 32 507 575	R 35 758 333	R 39 334 166	R 43 267 583	R 47 594 341	Electricity
Comparison of building costs								
R 150 591	R 172 816	R 197 532	R 224 987	R 255 451	R 289 220	R 326 613	R 367 983	Cash flow A- B
R 22 014	R 23 833	R 25 700	R 27 615	R 29 580	R 31 594	R 33 659	R 35 776	Discounted cash flow A - B
R 219 010	R 242 844	R 268 544	R 296 159	R 325 738	R 357 332	R 390 992	R 426 768	Cumulated discounted cash flow

Table C 3 CBA Data Chapter 9

Year	0	1	2	3	4	5	6	7	8
Discount rate	6%								
Discount factor	1	0,943	0,890	0,840	0,792	0,747	0,705	0,665	0,627
A = Retrofitted Building									
Costs									
Waterproofing	R 587 060								
Green Roofing	R 874 772								
Green Roof Maintenance		R 91 334	R 42 664	R 45 224	R 47 937	R 50 814	R 53 862	R 57 094	R 60 520
Green Roof Water		R 17 144	R 12 686	R 14 082	R 15 631	R 17 350	R 19 259	R 21 377	R 23 729
Electricity (reduced 3%)		R 1 122 050	R 1 234 255	R 1 357 681	R 1 493 449	R 1 642 794	R 1 807 073	R 1 987 781	R 2 186 559
Benefits									
Subsidy (80%)	R 1 169 465								
Property tax reduced 2%		R 25 451	R 26 978	R 28 597	R 30 313	R 32 132	R 34 060	R 36 103	R 38 269
B = Conventional Building									
Costs									
Waterproofing	R 278 810								
Electricity		R 1 156 753	R 1 272 428	R 1 399 671	R 1 539 638	R 1 693 602	R 1 862 962	R 2 049 258	R 2 254 184
Comparison of building costs									
Cash flow A- B	-R 13 556	-R 48 324	R 9 801	R 11 281	R 12 934	R 14 776	R 16 827	R 19 110	R 21 646
Discounted cash flow A - B	-R 13 556	-R 45 589	R 8 723	R 9 472	R 10 245	R 11 041	R 11 863	R 12 709	R 13 581
Cumulated discounted cash flow	-R 13 556	-R 59 145	-R 50 422	-R 40 950	-R 30 705	-R 19 664	-R 7 801	R 4 907	R 18 489

9	10	11	12	13	14	15	16	17	18	19	20
6%											
0,592	0,558	0,527	0,497	0,469	0,442	0,417	0,394	0,371	0,350	0,331	0,312
A = Retrofitted Building											
Costs											
R 64 151	R 68 000	R 72 080	R 76 405	R 80 989	R 85 848	R 90 999	R 96 459	R 102 247	R 108 382	R 114 884	R 121 778
R 26 339	R 29 236	R 32 452	R 36 022	R 39 985	R 44 383	R 49 265	R 54 684	R 60 700	R 67 377	R 74 788	R 83 015
R 2 405 214	R 2 645 736	R 2 910 310	R 3 201 340	R 3 521 475	R 3 873 622	R 4 260 984	R 4 687 083	R 5 155 791	R 5 671 370	R 6 238 507	R 6 862 358
Benefits											
R 40 566	R 43 000	R 45 580	R 48 314	R 51 213	R 54 286	R 57 543	R 60 996	R 64 655	R 68 535	R 72 647	R 77 006
B = Conventional Building											
Costs											
											R 894 182
R 2 479 603	R 2 727 563	R 3 000 319	R 3 300 351	R 3 630 386	R 3 993 425	R 4 392 767	R 4 832 044	R 5 315 248	R 5 846 773	R 6 431 450	R 7 074 596
Comparison of building costs											
R 24 464	R 27 590	R 31 057	R 34 898	R 39 151	R 43 857	R 49 062	R 54 813	R 61 167	R 68 180	R 75 918	R 978 634
R 14 480	R 15 406	R 16 360	R 17 343	R 18 356	R 19 398	R 20 472	R 21 577	R 22 715	R 23 886	R 25 092	R 305 143
R 32 969	R 48 375	R 64 735	R 82 078	R 100 434	R 119 832	R 140 304	R 161 881	R 184 596	R 208 482	R 233 574	R 538 717

21	22	23	24	25	26	27	28	29	30	31	32
6%											
0,294	0,278	0,262	0,247	0,233	0,220	0,207	0,196	0,185	0,174	0,164	0,155
A = Retrofitted Building											
Costs											
R 129 084	R 136 829	R 145 039	R 153 741	R 162 966	R 172 744	R 183 108	R 194 095	R 205 741	R 218 085	R 231 170	R 245 040
R 92 146	R 102 282	R 113 533	R 126 022	R 139 885	R 155 272	R 172 352	R 191 310	R 212 355	R 235 714	R 261 642	R 290 423
R 7 548 593	R 8 303 453	R 9 133 798	R 10 047 178	R 11 051 896	R 12 157 085	R 13 372 794	R 14 710 073	R 16 181 080	R 17 799 188	R 19 579 107	R 21 537 018
Benefits											
R 81 626	R 86 524	R 91 715	R 97 218	R 103 051	R 109 234	R 115 788	R 122 735	R 130 100	R 137 906	R 146 180	R 154 951
B = Conventional Building											
Costs											
R 7 782 055	R 8 560 261	R 9 416 287	R 10 357 915	R 11 393 707	R 12 533 077	R 13 786 385	R 15 165 024	R 16 681 526	R 18 349 679	R 20 184 647	R 22 203 111
Comparison of building costs											
R 24 464	R 27 590	R 31 057	R 34 898	R 39 151	R 43 857	R 49 062	R 54 813	R 61 167	R 68 180	R 75 918	R 978 634
R 14 480	R 15 406	R 16 360	R 17 343	R 18 356	R 19 398	R 20 472	R 21 577	R 22 715	R 23 886	R 25 092	R 305 143
R 32 969	R 48 375	R 64 735	R 82 078	R 100 434	R 119 832	R 140 304	R 161 881	R 184 596	R 208 482	R 233 574	R 538 717

33	34	35	36	37	38	39	40	Year
6%								Discount rate
0,146	0,138	0,130	0,123	0,116	0,109	0,103	0,097	Discount factor
A = Retrofitted Building								
Costs								
								Waterproofing
								Green Roofing
R 259 743	R 275 327	R 291 847	R 309 358	R 327 919	R 347 594	R 368 450	R 390 557	Green Roof Maintenance
R 322 369	R 357 830	R 397 191	R 440 882	R 489 379	R 543 211	R 602 964	R 669 290	Green Roof Water
R 23 690 720	R 26 059 792	R 28 665 771	R 31 532 348	R 34 685 583	R 38 154 141	R 41 969 555	R 46 166 511	Electricity (reduced 3%)
Benefits								
R 164 248	R 174 103	R 184 549	R 195 622	R 207 359	R 219 800	R 232 988	R 246 968	Property Tax reduced 2%
B = Conventional Building								
Costs								
								Waterproofing
R 24 423 422	R 26 865 765	R 29 552 341	R 32 507 575	R 35 758 333	R 39 334 166	R 43 267 583	R 47 594 341	Electricity
Comparison of building costs								
R 314 838	R 346 918	R 382 081	R 420 609	R 462 810	R 509 020	R 559 602	R 614 951	Cash flow A- B
R 46 025	R 47 844	R 49 711	R 51 626	R 53 590	R 55 605	R 57 670	R 59 787	Discounted cash flow A - B
R 1 011 365	R 1 059 209	R 1 108 920	R 1 160 546	R 1 214 136	R 1 269 741	R 1 327 411	R 1 387 198	Cumulated discounted cash flow

Appendix D CBA Figures

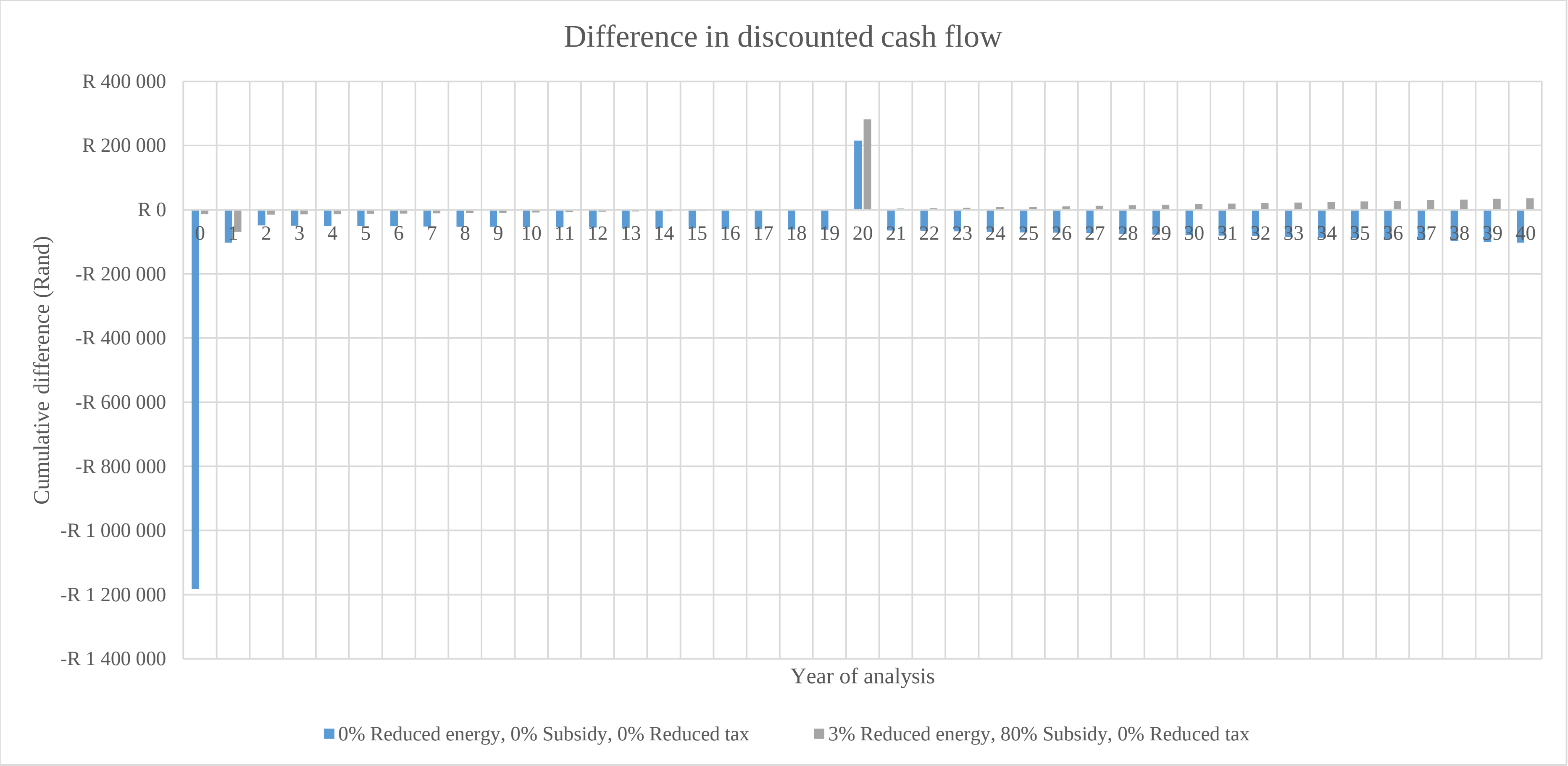


Figure D 1 Difference in Discounted Cash Flow

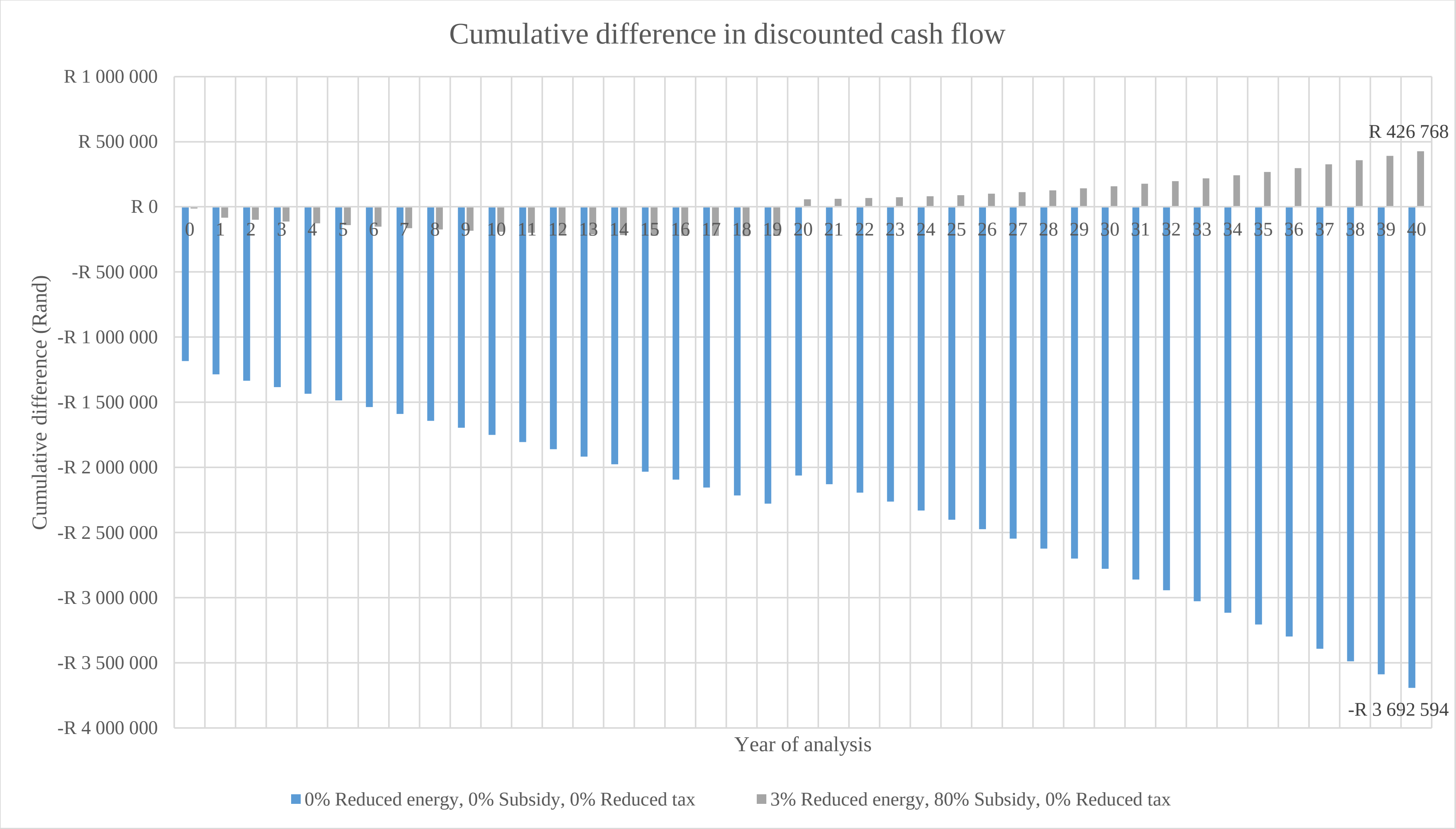


Figure D 2 Cumulated Difference in Discounted Cash Flow

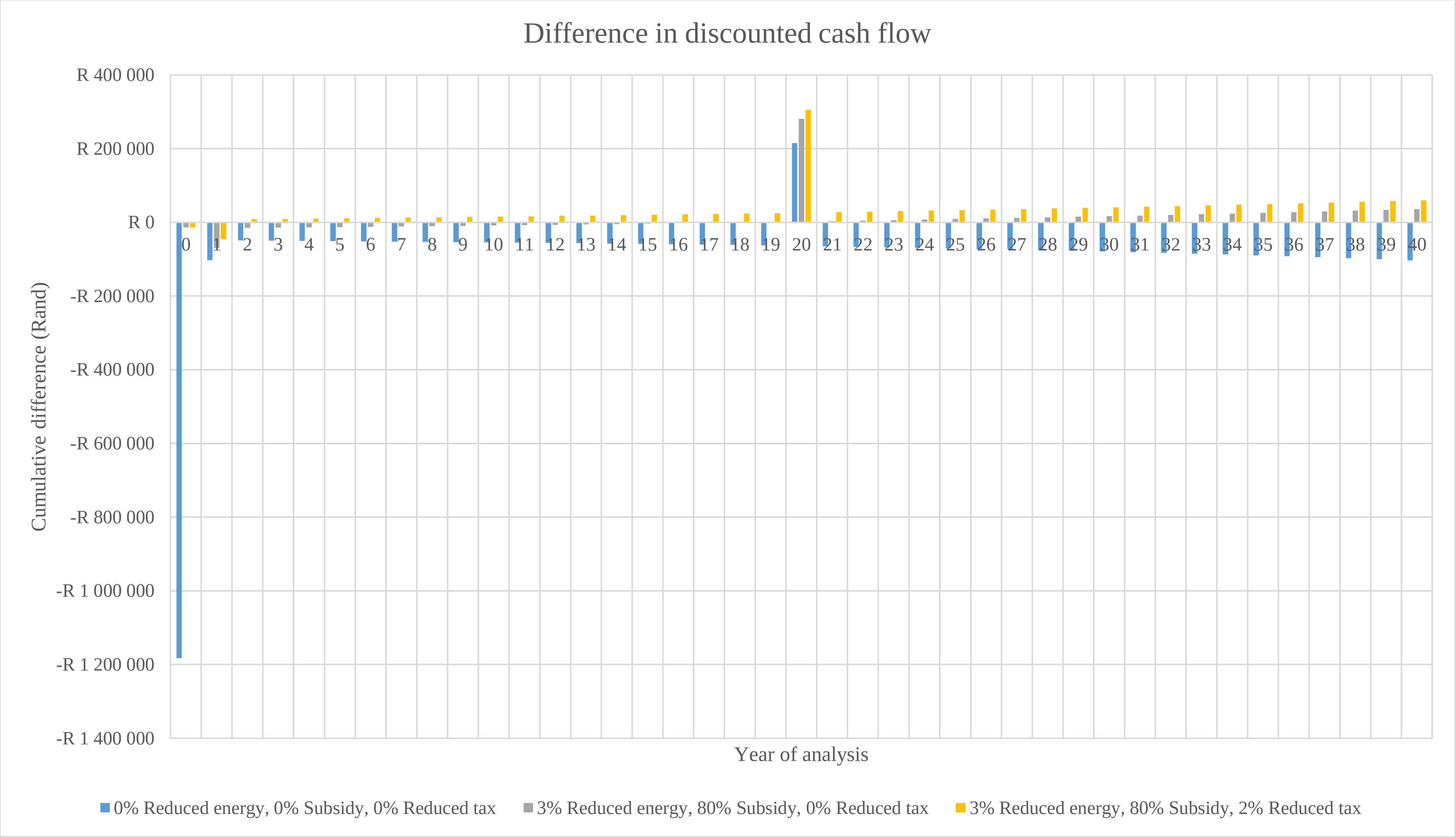


Figure D 3 Additional Incentives- Difference in Discounted Cash Flow

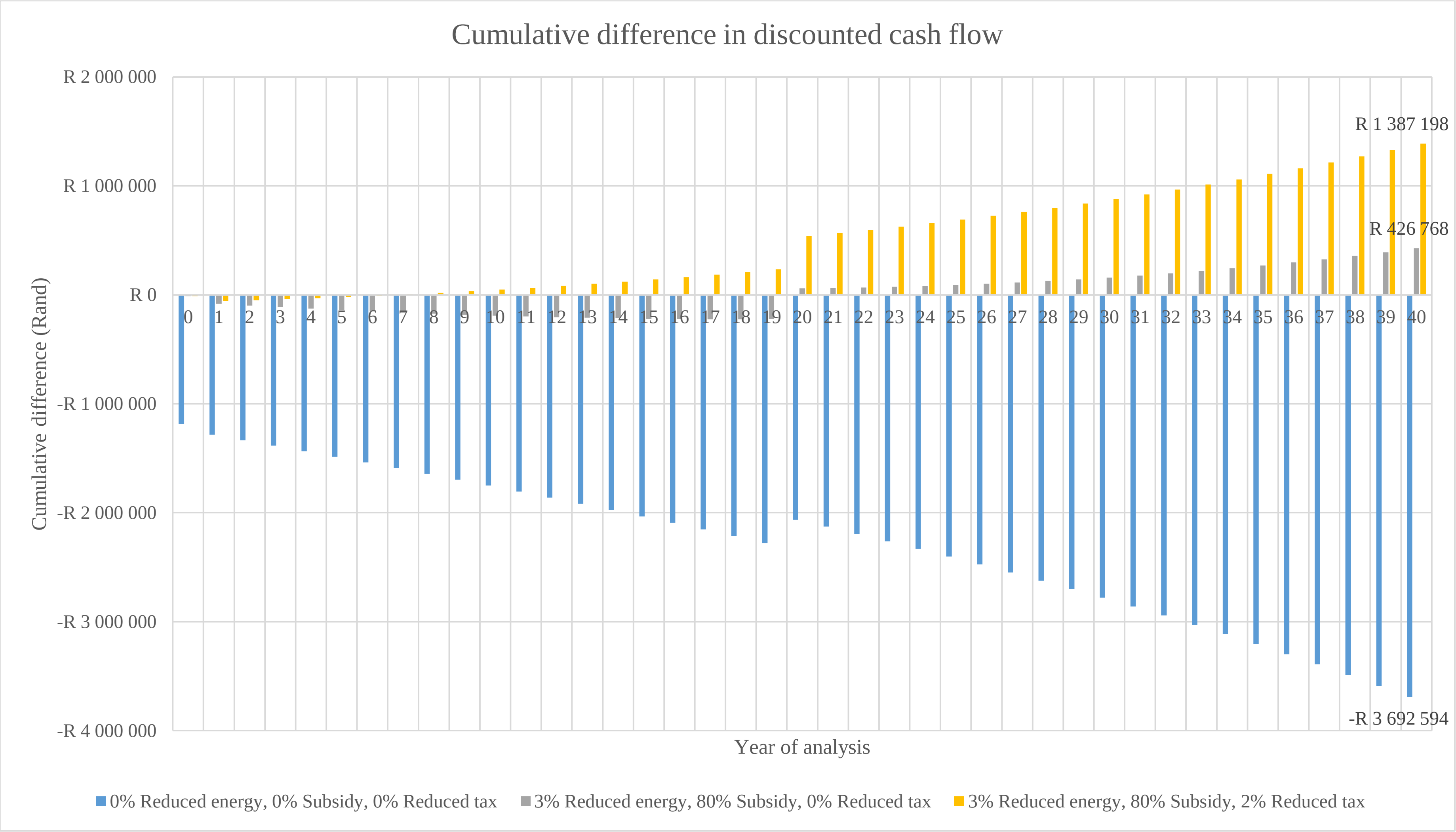


Figure D 4 Additional Incentives - Cumulated Difference in Discounted Cash Flow

Appendix E Monte Carlo Simulation

E.1 Analysis Results: 0% Subsidy, 0% Reduced Energy Usage

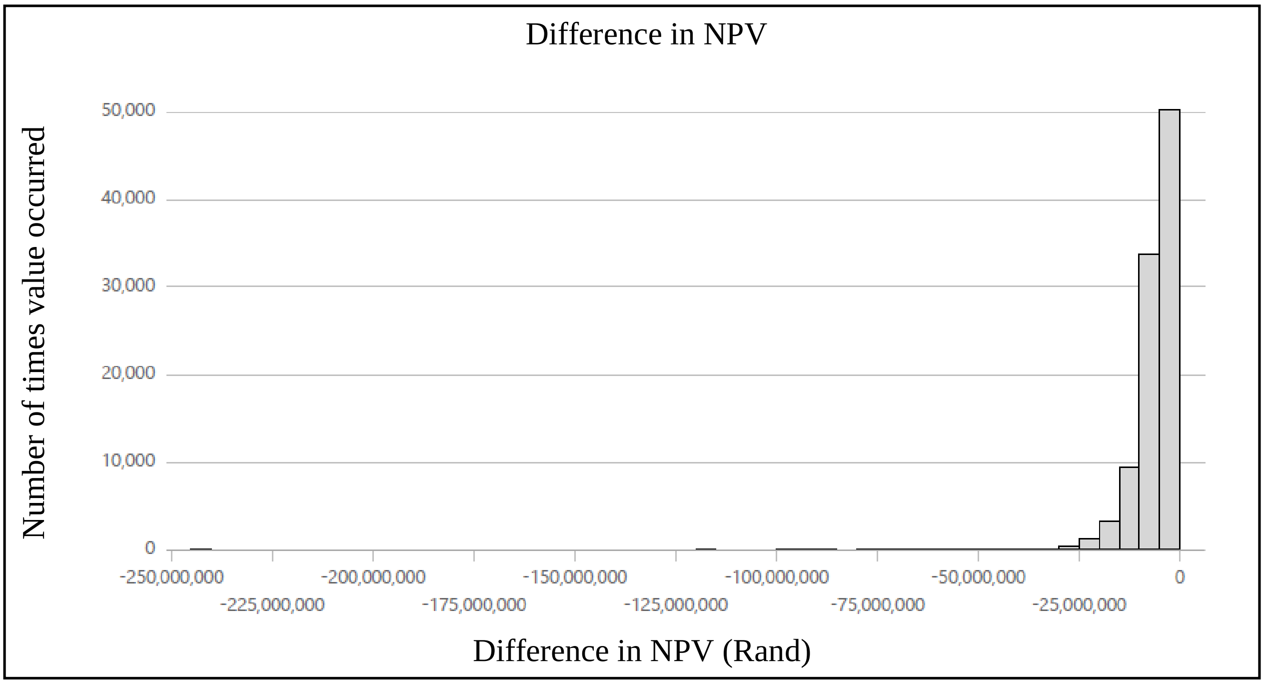
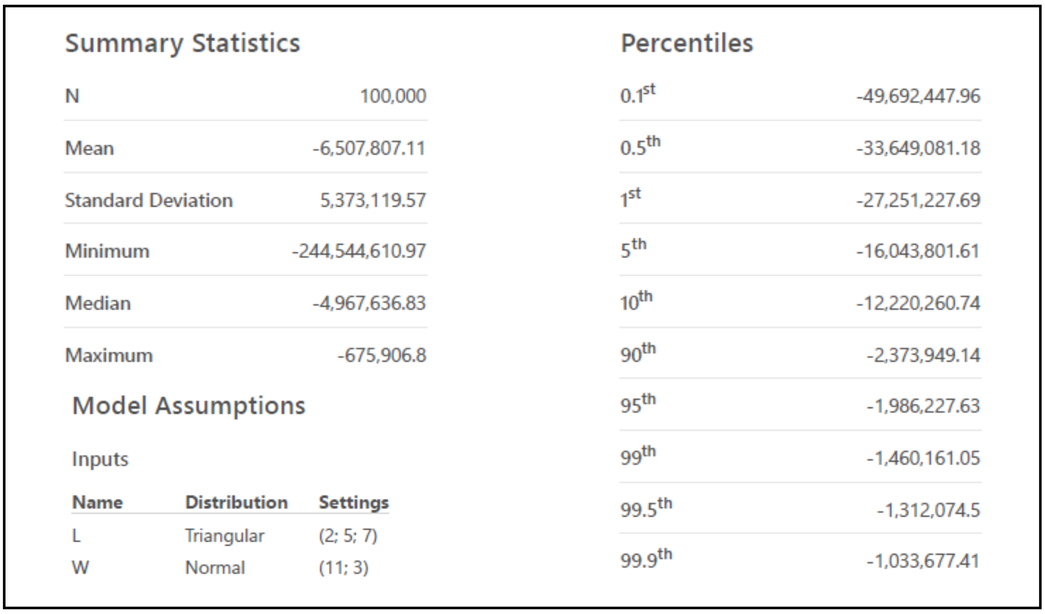


Figure E 1 Monte Carlo analysis distribution of difference in NPV assuming no benefits



Summary Statistics

N	100,000
Mean	-6,507,807.11
Standard Deviation	5,373,119.57
Minimum	-244,544,610.97
Median	-4,967,636.83
Maximum	-675,906.8

Model Assumptions

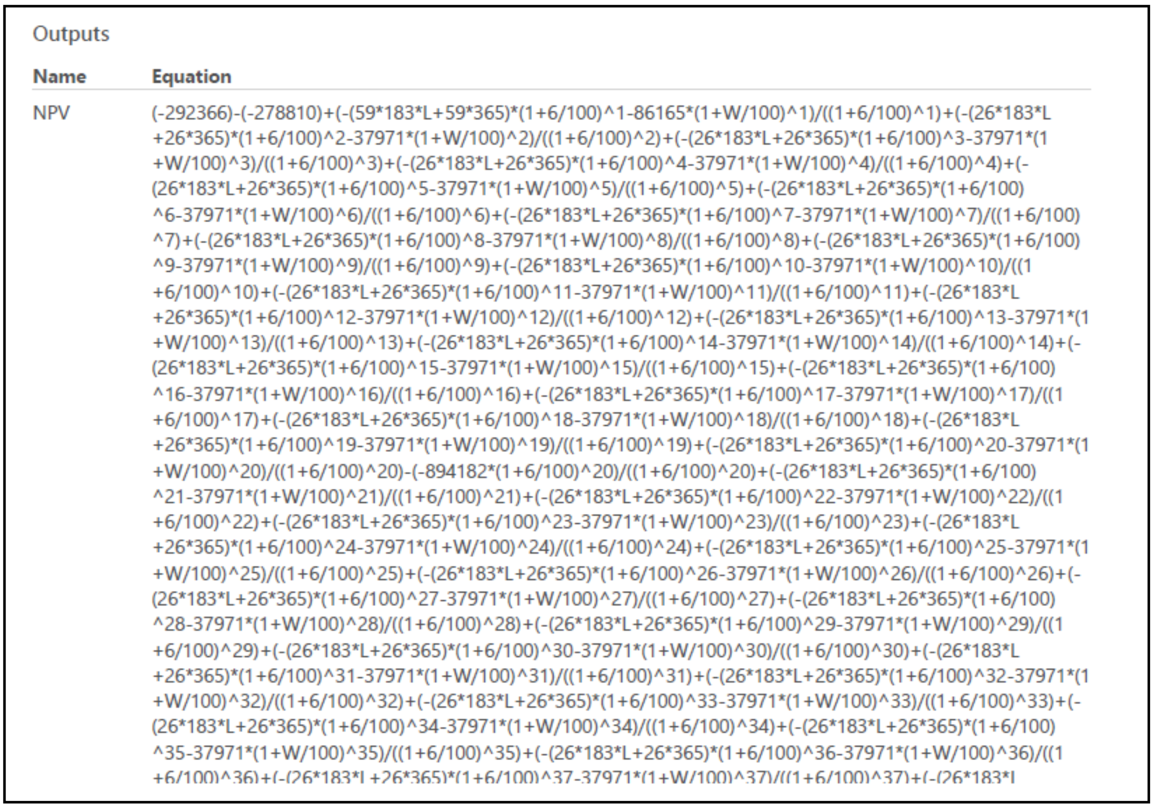
Inputs

Name	Distribution	Settings
L	Triangular	(2; 5; 7)
W	Normal	(11; 3)

Percentiles

0.1st	-49,692,447.96
0.5th	-33,649,081.18
1st	-27,251,227.69
5th	-16,043,801.61
10th	-12,220,260.74
90th	-2,373,949.14
95th	-1,986,227.63
99th	-1,460,161.05
99.5th	-1,312,074.5
99.9th	-1,033,677.41

Figure E 2 Simulation Output – no benefits



Outputs

Name	Equation
NPV	(-292366)-(-278810)+(-(59*183*L+59*365)*(1+6/100)^1-86165*(1+W/100)^1)/((1+6/100)^1)+(-(26*183*L+26*365)*(1+6/100)^2-37971*(1+W/100)^2)/((1+6/100)^2)+(-(26*183*L+26*365)*(1+6/100)^3-37971*(1+W/100)^3)/((1+6/100)^3)+(-(26*183*L+26*365)*(1+6/100)^4-37971*(1+W/100)^4)/((1+6/100)^4)+(-(26*183*L+26*365)*(1+6/100)^5-37971*(1+W/100)^5)/((1+6/100)^5)+(-(26*183*L+26*365)*(1+6/100)^6-37971*(1+W/100)^6)/((1+6/100)^6)+(-(26*183*L+26*365)*(1+6/100)^7-37971*(1+W/100)^7)/((1+6/100)^7)+(-(26*183*L+26*365)*(1+6/100)^8-37971*(1+W/100)^8)/((1+6/100)^8)+(-(26*183*L+26*365)*(1+6/100)^9-37971*(1+W/100)^9)/((1+6/100)^9)+(-(26*183*L+26*365)*(1+6/100)^10-37971*(1+W/100)^10)/((1+6/100)^10)+(-(26*183*L+26*365)*(1+6/100)^11-37971*(1+W/100)^11)/((1+6/100)^11)+(-(26*183*L+26*365)*(1+6/100)^12-37971*(1+W/100)^12)/((1+6/100)^12)+(-(26*183*L+26*365)*(1+6/100)^13-37971*(1+W/100)^13)/((1+6/100)^13)+(-(26*183*L+26*365)*(1+6/100)^14-37971*(1+W/100)^14)/((1+6/100)^14)+(-(26*183*L+26*365)*(1+6/100)^15-37971*(1+W/100)^15)/((1+6/100)^15)+(-(26*183*L+26*365)*(1+6/100)^16-37971*(1+W/100)^16)/((1+6/100)^16)+(-(26*183*L+26*365)*(1+6/100)^17-37971*(1+W/100)^17)/((1+6/100)^17)+(-(26*183*L+26*365)*(1+6/100)^18-37971*(1+W/100)^18)/((1+6/100)^18)+(-(26*183*L+26*365)*(1+6/100)^19-37971*(1+W/100)^19)/((1+6/100)^19)+(-(26*183*L+26*365)*(1+6/100)^20-37971*(1+W/100)^20)/((1+6/100)^20)-(-894182*(1+6/100)^20)/((1+6/100)^20)+(-(26*183*L+26*365)*(1+6/100)^21-37971*(1+W/100)^21)/((1+6/100)^21)+(-(26*183*L+26*365)*(1+6/100)^22-37971*(1+W/100)^22)/((1+6/100)^22)+(-(26*183*L+26*365)*(1+6/100)^23-37971*(1+W/100)^23)/((1+6/100)^23)+(-(26*183*L+26*365)*(1+6/100)^24-37971*(1+W/100)^24)/((1+6/100)^24)+(-(26*183*L+26*365)*(1+6/100)^25-37971*(1+W/100)^25)/((1+6/100)^25)+(-(26*183*L+26*365)*(1+6/100)^26-37971*(1+W/100)^26)/((1+6/100)^26)+(-(26*183*L+26*365)*(1+6/100)^27-37971*(1+W/100)^27)/((1+6/100)^27)+(-(26*183*L+26*365)*(1+6/100)^28-37971*(1+W/100)^28)/((1+6/100)^28)+(-(26*183*L+26*365)*(1+6/100)^29-37971*(1+W/100)^29)/((1+6/100)^29)+(-(26*183*L+26*365)*(1+6/100)^30-37971*(1+W/100)^30)/((1+6/100)^30)+(-(26*183*L+26*365)*(1+6/100)^31-37971*(1+W/100)^31)/((1+6/100)^31)+(-(26*183*L+26*365)*(1+6/100)^32-37971*(1+W/100)^32)/((1+6/100)^32)+(-(26*183*L+26*365)*(1+6/100)^33-37971*(1+W/100)^33)/((1+6/100)^33)+(-(26*183*L+26*365)*(1+6/100)^34-37971*(1+W/100)^34)/((1+6/100)^34)+(-(26*183*L+26*365)*(1+6/100)^35-37971*(1+W/100)^35)/((1+6/100)^35)+(-(26*183*L+26*365)*(1+6/100)^36-37971*(1+W/100)^36)/((1+6/100)^36)+(-(26*183*L+26*365)*(1+6/100)^37-37971*(1+W/100)^37)/((1+6/100)^37)+(-(26*183*L

Figure E 3 Simulation Formula for difference in NPV – no benefits

E.2 Analysis Results: 80% Subsidy, 3% Reduced Energy Usage

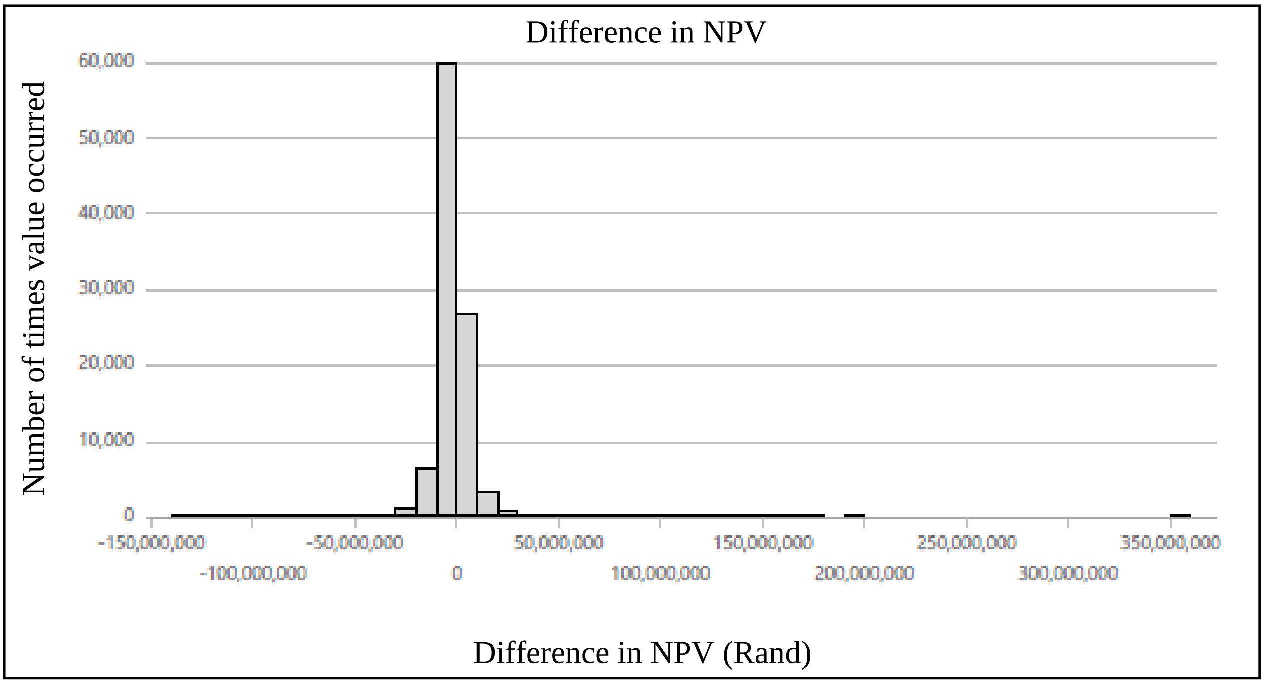
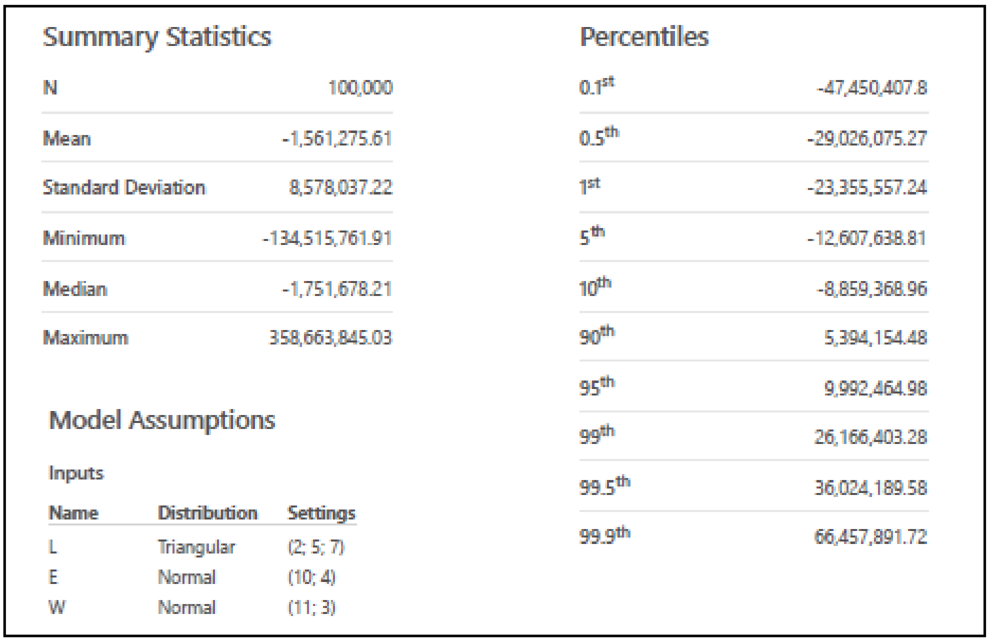


Figure E 4 Monte Carlo analysis distribution of difference in NPV assuming benefits



Summary Statistics

N	100,000
Mean	-1,561,275.61
Standard Deviation	8,578,037.22
Minimum	-134,515,761.91
Median	-1,751,678.21
Maximum	358,663,845.03

Percentiles

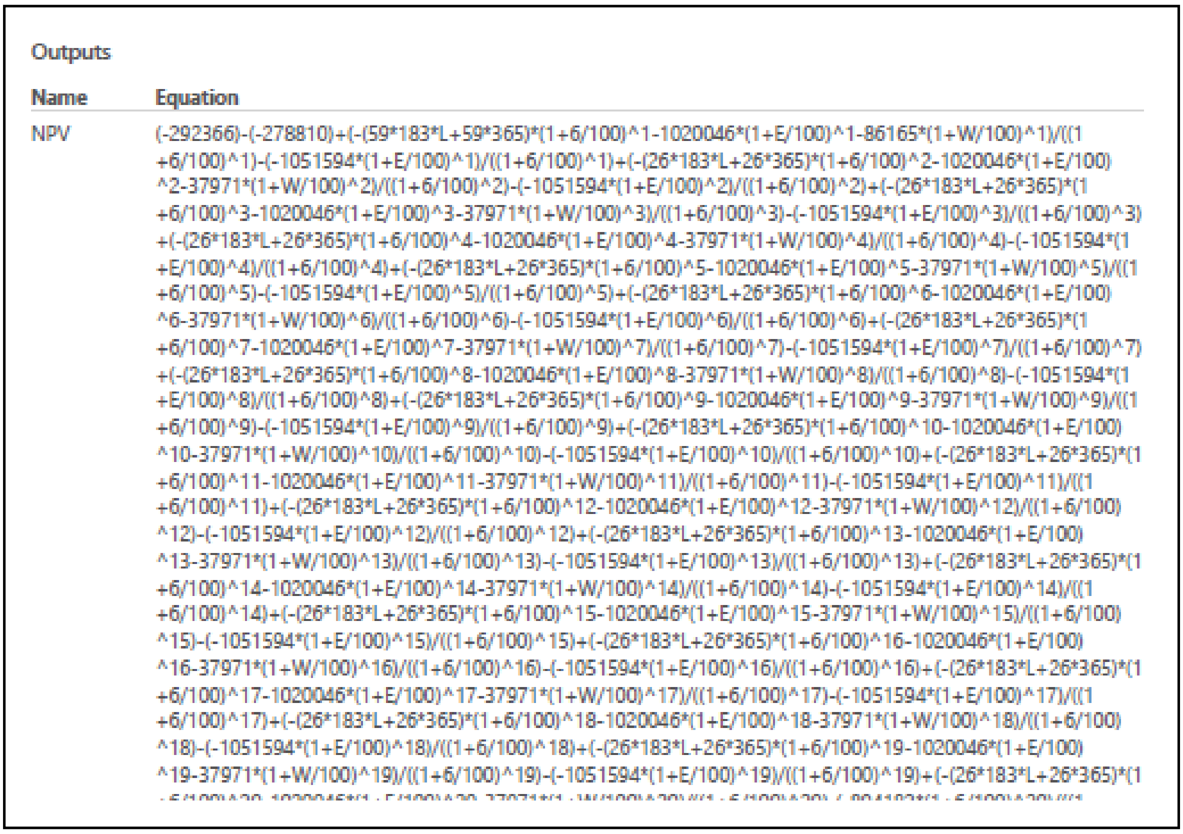
0.1st	-47,450,407.8
0.5th	-29,026,075.27
1st	-23,355,557.24
5th	-12,607,638.81
10th	-8,859,368.96
90th	5,394,154.48
95th	9,992,464.98
99th	26,166,403.28
99.5th	36,024,189.58
99.9th	66,457,891.72

Model Assumptions

Inputs

Name	Distribution	Settings
L	Triangular	(2; 5; 7)
E	Normal	(10; 4)
W	Normal	(11; 3)

Figure E 4 Simulation Output - benefits



Outputs

Name	Equation
NPV	(-292366)-(-278810)+(-(59*183*L+59*365)*(1+6/100)^1-1020046*(1+E/100)^1-86165*(1+W/100)^1)/((1+6/100)^1)-(-1051594*(1+E/100)^1)/((1+6/100)^1)+(-(26*183*L+26*365)*(1+6/100)^2-1020046*(1+E/100)^2-37971*(1+W/100)^2)/((1+6/100)^2)-(-1051594*(1+E/100)^2)/((1+6/100)^2)+(-(26*183*L+26*365)*(1+6/100)^3-1020046*(1+E/100)^3-37971*(1+W/100)^3)/((1+6/100)^3)-(-1051594*(1+E/100)^3)/((1+6/100)^3)+(-(26*183*L+26*365)*(1+6/100)^4-1020046*(1+E/100)^4-37971*(1+W/100)^4)/((1+6/100)^4)-(-1051594*(1+E/100)^4)/((1+6/100)^4)+(-(26*183*L+26*365)*(1+6/100)^5-1020046*(1+E/100)^5-37971*(1+W/100)^5)/((1+6/100)^5)-(-1051594*(1+E/100)^5)/((1+6/100)^5)+(-(26*183*L+26*365)*(1+6/100)^6-1020046*(1+E/100)^6-37971*(1+W/100)^6)/((1+6/100)^6)-(-1051594*(1+E/100)^6)/((1+6/100)^6)+(-(26*183*L+26*365)*(1+6/100)^7-1020046*(1+E/100)^7-37971*(1+W/100)^7)/((1+6/100)^7)-(-1051594*(1+E/100)^7)/((1+6/100)^7)+(-(26*183*L+26*365)*(1+6/100)^8-1020046*(1+E/100)^8-37971*(1+W/100)^8)/((1+6/100)^8)-(-1051594*(1+E/100)^8)/((1+6/100)^8)+(-(26*183*L+26*365)*(1+6/100)^9-1020046*(1+E/100)^9-37971*(1+W/100)^9)/((1+6/100)^9)-(-1051594*(1+E/100)^9)/((1+6/100)^9)+(-(26*183*L+26*365)*(1+6/100)^10-1020046*(1+E/100)^10-37971*(1+W/100)^10)/((1+6/100)^10)-(-1051594*(1+E/100)^10)/((1+6/100)^10)+(-(26*183*L+26*365)*(1+6/100)^11-1020046*(1+E/100)^11-37971*(1+W/100)^11)/((1+6/100)^11)-(-1051594*(1+E/100)^11)/((1+6/100)^11)+(-(26*183*L+26*365)*(1+6/100)^12-1020046*(1+E/100)^12-37971*(1+W/100)^12)/((1+6/100)^12)-(-1051594*(1+E/100)^12)/((1+6/100)^12)+(-(26*183*L+26*365)*(1+6/100)^13-1020046*(1+E/100)^13-37971*(1+W/100)^13)/((1+6/100)^13)-(-1051594*(1+E/100)^13)/((1+6/100)^13)+(-(26*183*L+26*365)*(1+6/100)^14-1020046*(1+E/100)^14-37971*(1+W/100)^14)/((1+6/100)^14)-(-1051594*(1+E/100)^14)/((1+6/100)^14)+(-(26*183*L+26*365)*(1+6/100)^15-1020046*(1+E/100)^15-37971*(1+W/100)^15)/((1+6/100)^15)-(-1051594*(1+E/100)^15)/((1+6/100)^15)+(-(26*183*L+26*365)*(1+6/100)^16-1020046*(1+E/100)^16-37971*(1+W/100)^16)/((1+6/100)^16)-(-1051594*(1+E/100)^16)/((1+6/100)^16)+(-(26*183*L+26*365)*(1+6/100)^17-1020046*(1+E/100)^17-37971*(1+W/100)^17)/((1+6/100)^17)-(-1051594*(1+E/100)^17)/((1+6/100)^17)+(-(26*183*L+26*365)*(1+6/100)^18-1020046*(1+E/100)^18-37971*(1+W/100)^18)/((1+6/100)^18)-(-1051594*(1+E/100)^18)/((1+6/100)^18)+(-(26*183*L+26*365)*(1+6/100)^19-1020046*(1+E/100)^19-37971*(1+W/100)^19)/((1+6/100)^19)-(-1051594*(1+E/100)^19)/((1+6/100)^19)+(-(26*183*L+26*365)*(1

Figure E 5 Simulation Formula for difference in NPV – benefits

E.3 Analysis Results: 80% Subsidy, 5% Reduced Energy Usage

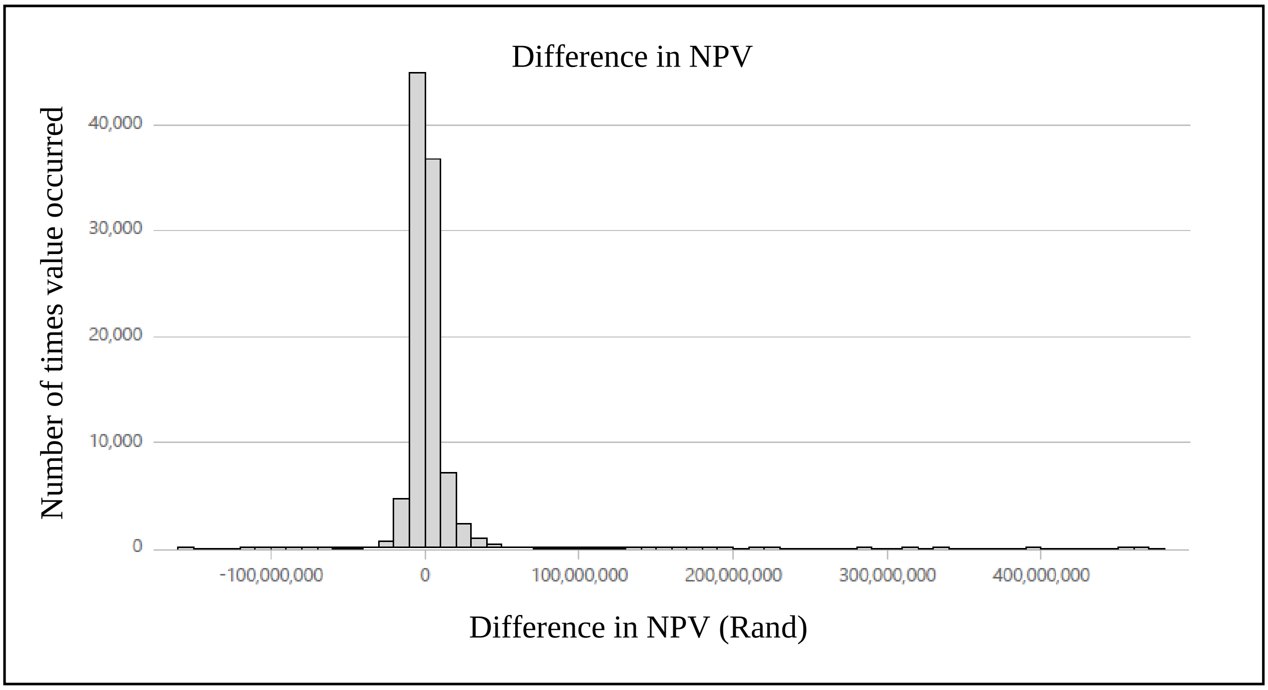
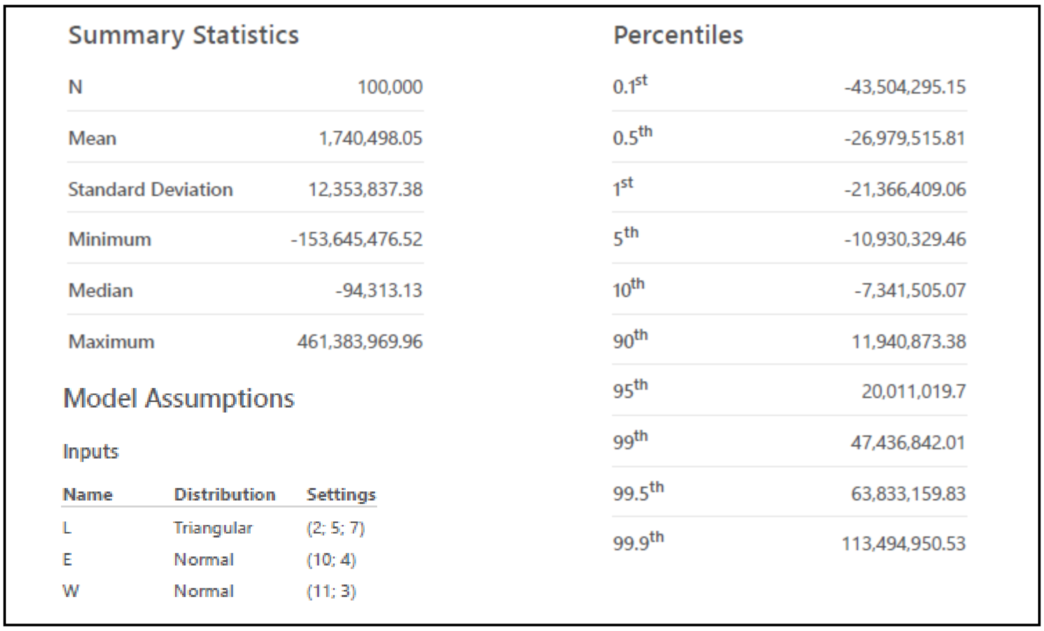


Figure E 7 Monte Carlo analysis distribution of difference in NPV assuming benefits



Summary Statistics

N	100,000
Mean	1,740,498.05
Standard Deviation	12,353,837.38
Minimum	-153,645,476.52
Median	-94,313.13
Maximum	461,383,969.96

Percentiles

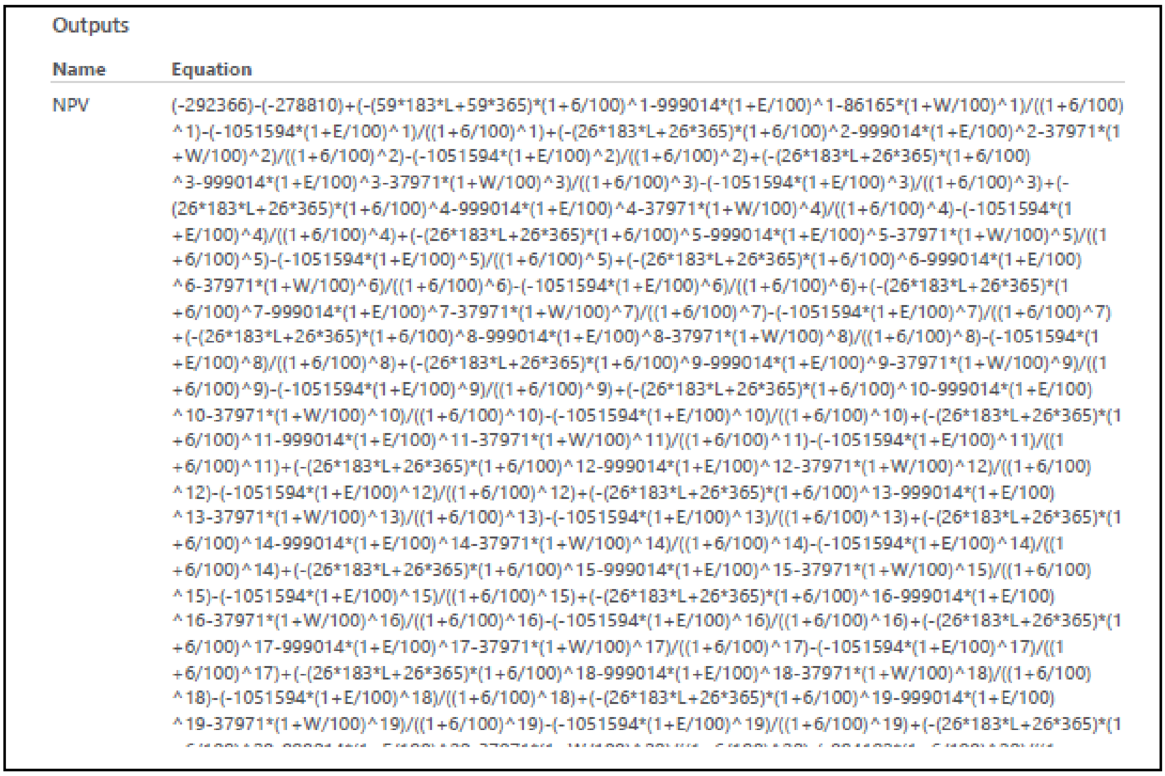
0.1st	-43,504,295.15
0.5th	-26,979,515.81
1st	-21,366,409.06
5th	-10,930,329.46
10th	-7,341,505.07
90th	11,940,873.38
95th	20,011,019.7
99th	47,436,842.01
99.5th	63,833,159.83
99.9th	113,494,950.53

Model Assumptions

Inputs

Name	Distribution	Settings
L	Triangular	(2; 5; 7)
E	Normal	(10; 4)
W	Normal	(11; 3)

Figure E 8 Simulation Output - benefits



Outputs

Name	Equation
NPV	(-292366)-(-278810)+(-(59*183*L+59*365)*(1+6/100)^1-999014*(1+E/100)^1-86165*(1+W/100)^1)/((1+6/100)^1)-(-1051594*(1+E/100)^1)/((1+6/100)^1)+(-(26*183*L+26*365)*(1+6/100)^2-999014*(1+E/100)^2-37971*(1+W/100)^2)/((1+6/100)^2)-(-1051594*(1+E/100)^2)/((1+6/100)^2)+(-(26*183*L+26*365)*(1+6/100)^3-999014*(1+E/100)^3-37971*(1+W/100)^3)/((1+6/100)^3)-(-1051594*(1+E/100)^3)/((1+6/100)^3)+(-(26*183*L+26*365)*(1+6/100)^4-999014*(1+E/100)^4-37971*(1+W/100)^4)/((1+6/100)^4)-(-1051594*(1+E/100)^4)/((1+6/100)^4)+(-(26*183*L+26*365)*(1+6/100)^5-999014*(1+E/100)^5-37971*(1+W/100)^5)/((1+6/100)^5)-(-1051594*(1+E/100)^5)/((1+6/100)^5)+(-(26*183*L+26*365)*(1+6/100)^6-999014*(1+E/100)^6-37971*(1+W/100)^6)/((1+6/100)^6)-(-1051594*(1+E/100)^6)/((1+6/100)^6)+(-(26*183*L+26*365)*(1+6/100)^7-999014*(1+E/100)^7-37971*(1+W/100)^7)/((1+6/100)^7)-(-1051594*(1+E/100)^7)/((1+6/100)^7)+(-(26*183*L+26*365)*(1+6/100)^8-999014*(1+E/100)^8-37971*(1+W/100)^8)/((1+6/100)^8)-(-1051594*(1+E/100)^8)/((1+6/100)^8)+(-(26*183*L+26*365)*(1+6/100)^9-999014*(1+E/100)^9-37971*(1+W/100)^9)/((1+6/100)^9)-(-1051594*(1+E/100)^9)/((1+6/100)^9)+(-(26*183*L+26*365)*(1+6/100)^10-999014*(1+E/100)^10-37971*(1+W/100)^10)/((1+6/100)^10)-(-1051594*(1+E/100)^10)/((1+6/100)^10)+(-(26*183*L+26*365)*(1+6/100)^11-999014*(1+E/100)^11-37971*(1+W/100)^11)/((1+6/100)^11)-(-1051594*(1+E/100)^11)/((1+6/100)^11)+(-(26*183*L+26*365)*(1+6/100)^12-999014*(1+E/100)^12-37971*(1+W/100)^12)/((1+6/100)^12)-(-1051594*(1+E/100)^12)/((1+6/100)^12)+(-(26*183*L+26*365)*(1+6/100)^13-999014*(1+E/100)^13-37971*(1+W/100)^13)/((1+6/100)^13)-(-1051594*(1+E/100)^13)/((1+6/100)^13)+(-(26*183*L+26*365)*(1+6/100)^14-999014*(1+E/100)^14-37971*(1+W/100)^14)/((1+6/100)^14)-(-1051594*(1+E/100)^14)/((1+6/100)^14)+(-(26*183*L+26*365)*(1+6/100)^15-999014*(1+E/100)^15-37971*(1+W/100)^15)/((1+6/100)^15)-(-1051594*(1+E/100)^15)/((1+6/100)^15)+(-(26*183*L+26*365)*(1+6/100)^16-999014*(1+E/100)^16-37971*(1+W/100)^16)/((1+6/100)^16)-(-1051594*(1+E/100)^16)/((1+6/100)^16)+(-(26*183*L+26*365)*(1+6/100)^17-999014*(1+E/100)^17-37971*(1+W/100)^17)/((1+6/100)^17)-(-1051594*(1+E/100)^17)/((1+6/100)^17)+(-(26*183*L+26*365)*(1+6/100)^18-999014*(1+E/100)^18-37971*(1+W/100)^18)/((1+6/100)^18)-(-1051594*(1+E/100)^18)/((1+6/100)^18)+(-(26*183*L+26*365)*(1+6/100)^19-999014*(1+E/100)^19-37971*(1+W/100)^19)/((1+6/100)^19)-(-1051594*(1+E/100)^19)/((1+6/100)^19)+(-(26*183*L+26*365)*(1

Figure E 9 Simulation Formula for difference in NPV – benefits

Appendix F Annual Number of Deaths & Particulate Matter Levels Data

Table F 1 Annual Deaths and Particulate Matter levels in South Africa

Year	Number of Deaths	Annual PM level (μg/m^3)	Number of Deaths due to PM levels (7.4% of Number of Deaths)
1997	317860	24	23522
1998	366585	25	27127
1999	382624	28	28314
2000	417191	30	30872
2001	456238	30,5	33762
2002	503335	24,8	37247
2003	558388	34	41321
2004	578355	40	42798
2005	599593	44	44370
2006	614158	41	45448
2007	606112	51	44852
2008	598165	54,5	44264
2009	583419	54	43173
2010	551320	51,5	40798
2011	515427	48	38142
2012	493493	47	36518