Maintenance Practices —
Improving Sustainability Performance of Existing Office Buildings: An Australian Case Study

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ACT	Australian Capital Territory
A_0	Annual amount
AIQS	Australian Institute of Quantity Surveyors
AMCA	Air Conditioning and Mechanical Contractors Association
AP	Acidification potential
API	Australian Property Institute
AR4	Fourth Assessment Report
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
AS/NZS	Australia/New Zealand Standards
ASTM	American Society for Testing and Materials Publications
Australia ICOMOS	Australia International Council of Monument and Site
AWC	Available Water Capacity
BAU	Business as Usual
BEEC	Building Energy Efficiency Certificate
BMCS	Building management and control systems
BMRC	Bureau of Meteorology Research Centre
BOMA	Building Office and Managers Association
BPI	Building price index
BWRO	Brackish water reverse osmosis
CAR	Cause, Action, and Result
CBD	Commercial Building Disclosure
CBDs	Central business districts, e.g. Sydney CBD
CEC	Commission for Environmental Cooperation
CEO	Chief executive officer
CEPA	Commonwealth Environment Protection Agency
CFCs	Chlorofluorocarbons
CH_4	Methane
CIE	Centre for International Economics
CIOB	Chartered Institute of Building
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent

COAG	Council of Australian Governments
COP21	21st Conference of the Parties
COP	Coefficient of Performance
CPI	Consumer Price Index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EE	Energy efficiency
ERI	Energy Recovery Inc.
ESCOs	Energy service companies
ESD	Ecologically sustainable development
FMA	Facility Management Association of Australia
GFA	Gross floor area
GHG	Greenhouse gas
GL	Gigalitre
GST	Goods and services tax
Gt	Gigatonne
GWh	Gigawatt hour
GWP	Global warming potential
H_2O	Water vapour
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HVAC	Heating, ventilation, and air conditioning
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEQ	Indoor environment quality
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal rate of return
ISO	International Organisation for Standardisation
kWh	Kilowatt hour
LCA	Life cycle assessment
LCC	Life cycle costing
LCE	Life cycle energy
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LE	Lighting efficiency
LED	Light-emitting diode
LPP	Litres per person

MEPS	Minimum efficiency performance standards
MF	Microfiltration
MJ	Megajoule
MIT	Massachusetts Institute of Technology
ML	Megalitre
MPa	Megapascal
MR	Materials and resources
NABERS	National Australian Built Environment Rating System
NASA	National Aeronautics and Space Administration
NF	Nanofiltration
NLWRA	National Land and Water Resources Audit
NP	Nutrification potential
NPV	Net present value
NS	Norway standards
NSW	New South Wales
NT	Northern Territory
N_2O	Nitrous oxide
OEH	Office of Environment and Heritage (NSW)
OECD	Organisation for Economic Co-operation and Development
ODP	Ozone depletion potential
PCA	Property Council of Australia
PECC	Special Program on Climate Change
PFCs	Perfluorocarbons
PJ	Petajoule
PVC	Polyvinyl chloride
QLD	Queensland
RH	Relative humidity
RICS	Royal Institute of Chartered Surveyors
SA	South Australia
SADPTI	South Australia Department of Planning Transport and Infrastructure
SBS	Sick building syndrome
SD	Standard deviation
SIR	Savings to investment ratio
SMOB	Sustainable Maintenance of Office Buildings
SPSS	Statistical Package for the Social Sciences
SPV	Single present value

SVOCs	Semi volatile organic compounds
SWRO	Sea water reserve osmosis
T5	Fluorescent lamps T5
T8	Fluorescent lamps T8
TAS	Tasmania
TBL	Triple bottom line
UF	Ultrafiltration
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
UPV	Uniform present value
US	United States of America
VAV	Variable air volume
VIC	Victoria
VCT	Vinyl composition tile
VOCs	Volatile organic compounds
VSD	Variable speed drives
WA	Western Australia
WD	Waste disposal management
WE	Water efficiency
WWR	Window to wall ratio

Abstract

The purpose of this thesis is to establish a method to analyse the interaction between the environment and existing buildings, to examine how the impact of existing buildings on the environment can be reduced and to suggest strategies by which any negative effects can be minimised. The investigation is focused on the development of a strategic framework to maintain and improve existing office buildings performance through sustainable maintenance strategies. It concentrates on reducing emissions generated within office buildings over their life cycle. The developed framework is a model for sustainable maintenance of office buildings entitled SMOB: an Australian case study.

Over many decades, office buildings have been recognised as a significant area contributing to the negative impacts on the environment over their life cycle, hastening climate change or global warming. In return, climate change also impacts on buildings with extreme heatwaves occurring more frequently and raising the earth's temperature. Increased temperatures make many advanced techniques as applied in buildings ineffective, which then require more energy to provide indoor comfort. The operation and maintenance phase is the longest period of operation over a building's life span. In this period, office buildings consume the highest rates of energy and water; and consequently, emit the highest rates of greenhouse gas pollution, especially CO_2, into the environment.

The framework of SMOB includes four indicators and 23 criteria for scheduling sustainable building maintenance through routine, ad hoc and upgrading practices which are derived from analysis of data collected through questionnaire survey, focus group discussion and a Delphi study. Case studies were used to verify the SMOB and results show that when using the model, energy and water consumption, and in particular CO_2 emissions in the buildings are significantly reduced, and that the buildings will satisfy environmental protection requirements. The research shows that the SMOB is well suited for assessing the costs and returned benefits against economic and environmental criteria in sustainable office building maintenance.

1. Introduction

1.1 Research Background

This research aims at establishing sustainable maintenance practices as mainstream approaches to improve environmental performance of existing office buildings. This research will develop a framework to examine the interaction between the environment and existing office buildings so as to lessen the environmental impacts by reducing energy consumption and associated carbon dioxide (CO_2) from existing office buildings through improving maintenance practices toward sustainability. It is believed from the literature that energy and water consumption, and CO_2 emissions have an effect on accelerating global climate change, ozone depletion, acidification, eutrophication, resource depletion and human health (Simonen 2014).

Climate change, which has been observed for several decades, has captured people's attention because of the increase in the earth's average temperature (Lindinger 2009). Attention has been placed on its strongest and most comprehensive impacts to the natural systems (IPCC 2014). The effects of climate change have certainly influenced the living environment throughout Australia (Cleugh et al. 2011; Kentwell 2007; Lindinger 2009). However, the most significant impact of climate change on buildings is extreme heatwaves that have caused Australia's annual average temperature to increase significantly (Australian Department of Climate Change 2010; Clarke 2009; Cleugh et al. 2011; Lindinger 2009). The increased temperature makes new technologies applied to buildings ineffective, which in turn requires more energy to provide indoor comfort (Hinnells et al. 2008; Ürge-Vorsatz et al. 2007a).

The main substance that contributes to climate change is CO_2 (Li & Yao 2009; Lynas 2007). The existing building stock is one of the major sectors responsible for emitting high levels of CO_2 into the environment (Gluch & Stenberg 2006; Madew 2007; Ürge-Vorsatz et al. 2007b; Ürge-Vorsatz, Koeppel & Mirasgedis 2007b). The main problems that cause buildings to produce high levels of CO_2 are the ways in which natural resources are being used, such as energy and water consumption, and the methods in which the buildings are operated and maintained during the operating phase of a building's life cycle (Kohler & Yang 2007; Wilson & Tagaza 2006).

Furthermore, most existing office buildings in Australia are decades old, and due to existing energy inefficiency operations, they currently consume excessive rates of energy and produce high rates of CO_2 (Taylor 2009). Even though there are a number of new office buildings on the market annually, the number is small compared to the many largely old and outdated buildings in the stock. Therefore, the general condition of office buildings seems to be unimproved, and the impacts between office buildings and the environment have not decreased (Wilkinson & Reed 2006b).

The main target for the interaction between office buildings and the environment is the reduction of CO_2 emission (Li & Yao 2009; Lynas 2007). Research has shown that an integrated method of sustainable maintenance can satisfy this target and in turn can improve the value of buildings (Wilkinson 2013, 2014). However, currently, the approach used in maintaining these buildings is ineffective. Many barriers remain that may hinder stakeholders' opportunities to make their office buildings become sustainable. The main barriers are the constraints in stakeholders' budgets used for improving their office buildings, the lack of knowledge of and confidence in new technologies in sustainable maintenance, and the lack of a framework used for assessing the improvements over long-term performance (Elmualim et al. 2010; Wilson & Tagaza 2006).

According to Elmualim et al. (2010); Hinnells et al. (2008); and Miller and Buys (2008), the lack of knowledge and confidence in new technologies in sustainable maintenance can lead stakeholders to have ineffective views about sustainable development. Financial concerns can pressure stakeholders to avoid or delay improving office buildings due to the capital outlays required.

So, the office buildings retain an existing management method, which may not comply with the environmental protection requirements. Also, the lack of a framework used for long-term assessment can influence stakeholders to waive expenditures for improving environmental performance of existing office buildings. Mostly, restricted maintenance budgets and lack of framework for the long-term assessment of sustainable maintenance prevent stakeholders from designing and performing a strategy of efficient maintenance of office buildings, which may not satisfy economic and environmental performances over the building life cycle (Ellison & Sayce 2007; Sev 2009).

Developing a framework for an integrated sustainable maintenance method to improve environmental performance of existing office buildings is included in the aim of this research. Such a framework can improve existing office buildings to become more environmentally friendly, to reduce the use of resources, energy and water, thereby reducing the emission of CO_2 and savings on utility bills. The framework of sustainable maintenance of office buildings is based on the assessment of the performance of an office building over the long-term. The benefit is that the assessment process balances the measures of economic prosperity and environmental quality. It will assist stakeholders in making a more informed decision. It will also provide stakeholders opportunities to reduce risk while contributing to environmental protection and achieving economic growth.

The research will collect data with regards to various current methods of maintenance applied to office buildings and their impacts on the environment. The research will examine and analyse the applications of sustainable maintenance practices of office buildings which would satisfy environmental protection requirements. The collected data and analysed information will then be used to establish an efficient framework model for the maintenance of office buildings to be more sustainable over their life cycle.

1.2 Research Significance

Since 1950, the average temperature in Australia has increased by about 1 °C because of the potential impact of global warming (Australian Department of Climate Change 2010; Clarke 2009; Cleugh et al. 2011; Lindinger 2009). However, according to the Australian Bureau of Meteorology (2014a), during the period from January 2011 to October 2014, the trend of the national mean temperature was mostly more than 1 °C above average. This trend may further rise if there is no action to reduce climate change. The increase of earth’s temperature has been directly linked to the frequency of extreme heatwaves. Consequently, indoor climate conditions have become uncomfortable, and buildings will consume more energy to satisfy indoor comfort levels.

The key substance responsible for raising the earth's temperature is the CO_2 concentration in the environment (Li & Yao 2009; Lynas 2007). Research has found that the building sector contributed around 7.85 gigatonnes of CO_2 emissions or 33% of the global sum of energy related emissions (ürge-Vorsatz et al. 2007c; ürge-Vorsatz, Koeppel & Mirasgedis 2007a). Commercial buildings contribute approximately 10% of greenhouse gas (GHG) emissions alone, of which office buildings and hospitals contribute almost 40% (Wilson & Tagaza 2006). The annual new office buildings addition to the building stock is approximately 2% (The New South Wales Resource Centre 2009) whereby majority of the buildings in the building stock do not comply with environmental requirements (Taylor 2009). Based on this rate, it would take approximately 50–100 years to replace the current building stock (Bullen 2007).

To protect the environment, existing office buildings should be maintained to be more environmentally friendly via sustainable maintenance practices. To keep functioning, an office building generally requires a major refurbishment every 20–25 years (Wilkinson & Reed 2006b). However, buildings in Sydney average 28 years since construction or last refurbishment, whereas in other states it varies from 25 to 31 years (Adelaide City Council 2007; Wilkinson & Reed 2006b). Therefore, most buildings are now in need of refurbished to improve their energy and water efficiency to meet green standards and regulations (Bullen 2007; Connelly & Adam 2009; Langston et al. 2008; Pfaehler 2008).

Another factor is that building maintenance management is a major determinant in balancing economic and environmental requirements of a building's life cycle (Elkington 2002; Proctor & Straton 2009). It is a strategic commitment within an affordable budget to maintain the functions of a building and its equipment to avoid any unexpected breakdown (Wild 2008; Witt 2004). However, research has found that there are not many methods used to predict malfunction or schedules for preventative maintenance of buildings (Takata et al. 2004). Research has also identified that a system for routine maintenance associated with regular inspection will provide significant savings over unexpected repair work for a building and building services. Therefore, building maintenance is needed to change from unplanned ad hoc to well-planned practices to maintain the function of the buildings (Pitt, Goyal & Sapri 2006). A sound plan of sustainable maintenance practices for buildings is necessary because it can be used to maintain the buildings in good condition, reduce downtime by around 80%, lower actual operating cost, lessen stress over systems breakdown and decrease the examining time of systems by about 50% (Huber 2004).

Research has also established that sustainable buildings will create a healthy built environment by using resources efficiently and apply ecologically based principles (Kilbert 1994b; cited in Hill & Bowen 1997). These principles can increase building value, reduce vacancy rates, improve rental levels and mitigate obsolescence (Wilkinson & Reed 2006a). Significantly, they will reduce the negative interaction with the environment (Henderson 2006) because a green building can reduce energy usage by 85%, potable water by 60% and building waste to landfill by 69% (Madew 2007).

1.3 Research Gaps

Currently, the tools used for the assessing sustainable performance of existing office buildings include life cycle assessment (LCA) and life cycle costing (LCC). These methods and tools can be used to evaluate a building under construction for an affordable cost and assist in informed choices of material used, efficient use of energy and water, qualification of indoor environment and green labelling equipment. However, research has found a number of problems:

- Traditionally, most methods are concerned with the design and construction phase of a building, whereas other phases, such as operation, maintenance and disposal phases, are not given much consideration. Significantly, the operation and maintenance of buildings are identified as the most expensive phases both financially and environmentally in terms of energy and water usage. An integrative method of sustainable maintenance can improve the function, increase the value, expand the lifetime, and reduce the energy and water consumption and CO_2 emissions of an office building.

- Buildings with a long-term performance are commonly evaluated with either LCA or LCC. LCA is a tool used to assess environmental matters, whereas LCC is a tool used to assess buildings financially. The current problem is that in appraising a building, one tool can be used at a time, but not both simultaneously, due to different processing methods (Bierer et al. 2014; Goh & Sun 2015; Langdon 2007; Ristimäki et al. 2013). Therefore, this research will develop a framework that combines LCA and LCC in assessing performance of existing office buildings. This can be used to evaluate economic value and benefits both before and after improving/upgrading an office building. The outcome is an integrated evaluation.

- Commonly, there is a certain inconsistency between building regulations and building markets. A high requirement from building regulations increases pressure on sustainable building developments and operations, and decreases the existing value of buildings. Another factor is that the improved/upgraded value of a building may not satisfy its valuation on the market. For example, a government's ongoing environmental taxes, such as taxes on energy, water and waste services, may exert pressure on businesses and building operations, but the market requires more high-performance buildings.

Following these identified problems, the research will fill these gaps with:

- An integration of maintenance strategy for existing office buildings towards sustainable long-term performance.

- An assessment method merging LCA and LCC for the purpose of balancing economic and environmental performances.

- A way that would balance regulations and the market.

1.4 Research Aims and Objectives

This research aims at examining and analysing the issues in the maintenance of office buildings which effect the environment, and to develop a strategic model for sustainable maintenance of office buildings (SMOB) over their life cycle. Based on this aim, the study will investigate interactions in the application of sustainable maintenance of office buildings and the environment, and examine the strategies for existing office building to reduce resource consumption in terms of energy and water, whereby reducing CO_2 emissions in the long-term. The development of the SMOB will provide a framework to assess environmental performance of existing office buildings.

The specific aims and objectives of this research are to:

- Review traditional practices in the maintenance of office buildings.
- Investigate sustainable maintenance practices.
- Identify stakeholders' views in the design and performance of maintenance strategies for office buildings to satisfy environmental protection.
- Examine costs and benefits to stakeholders from the design and performance of sustainable maintenance in long-term performance.
- Identify stakeholders' responses to the maintenance of non-green office buildings through case studies.
- Develop a strategic model for sustainable maintenance over the whole life of office buildings, balancing economic and environmental concerns.
- Verify the effectiveness and usefulness of the SMOB.

1.5 Research Questions

This research concentrates on identifying and integrating environmental issues into establishing a whole life approach SMOB. The SMOB will be developed to encompass stronger awareness of environmental protection for the purpose of maintaining office buildings via maintenance practices.

A comprehensive investigation of the current maintenance practices performed in the building industry will be incorporated into the SMOB, which will be used to improve sustainable maintenance practices for office buildings. The investigation is in three key areas:

- A literature review to identify impacts between office buildings and the environment.

- Findings from the literature as a foundation for extensive processes of industry survey, focus group discussion and Delphi study to identify sustainable maintenance criteria.

- The development of the SMOB based on identified sustainable maintenance criteria found from the outcomes of this research.

Three high-rise office buildings located in Sydney, Australia are examined as case studies to verify the SMOB. Data will be collected and analysed to find the gaps between the case study buildings current maintenance practices and the sustainable maintenance criteria forming the SMOB. Finally, the SMOB will be tested to determine its robustness and validity.

The purpose of the questionnaire survey is to gather the opinions and experiences of industry professionals about current maintenance practices towards sustainability. Focus groups are used to verify and consolidate outcomes from the survey and organised into sustainable maintenance criteria. Lastly, the Delphi study will be used to rank sustainable maintenance criteria in order to come up with a consensus from a panel of experts. The SMOB is a strategic model of sustainable maintenance of office buildings that is compiled from the outcomes of the questionnaire surveys, focus group discussions and the Delphi study. The prime role of the SMOB is a framework used to improve an office building to become environmentally friendly by using sustainable maintenance criteria found through the research.

The research plan forms the reference point for the literature review. The work for this research is expressed as:

> The use of sustainable maintenance practices can significantly improve an existing office building's sustainability over its life cycle.

Current and future sustainable maintenance practices for office buildings that are available in the field are investigated for this research. Their strengths and weaknesses are examined to provide the principal work for the development of the SMOB to assess the sustainability of an existing office building. The findings in the literature review and the processes of the questionnaire survey, focus group discussion and Delphi study increase the understanding of the level of environmental awareness in the building industry.

In proceeding with this research, the following questions have been formulated:

- How does the application of sustainable maintenance interact with existing office buildings?

- What are the costs and benefits in improving/upgrading existing office buildings with a sustainable maintenance strategy?

- What are the behaviours of stakeholders in applying sustainable maintenance to existing office buildings for today and tomorrow?

These questions underpin the study; addressing these questions will determine the answer to the core question of this research project, that is:

> Will the model developed in this project be a contribution to the reduction of the impacts of office buildings on the environment over their whole of life cycle?

1.6 Research Methodology

The process plan for this research project is outlined in Figure 1.1. The process includes two main themes described as follows:

Theme 1

Interactions between existing office buildings and the environment: Are there any solutions?

Theme 2

Sustainable maintenance practices: Is this research a solution for environmental impacts?

To carry out the first main theme, a review of related literature from journals, books and reports will be conducted and will establish solutions to this problem. Significantly, there is no project that has a clear singular solution for environmental impacts. Literature will be collected to develop strategies for in-depth data gathering for the questionnaire survey, focus group discussion, Delphi study, and case studies to find solutions to the research questions.

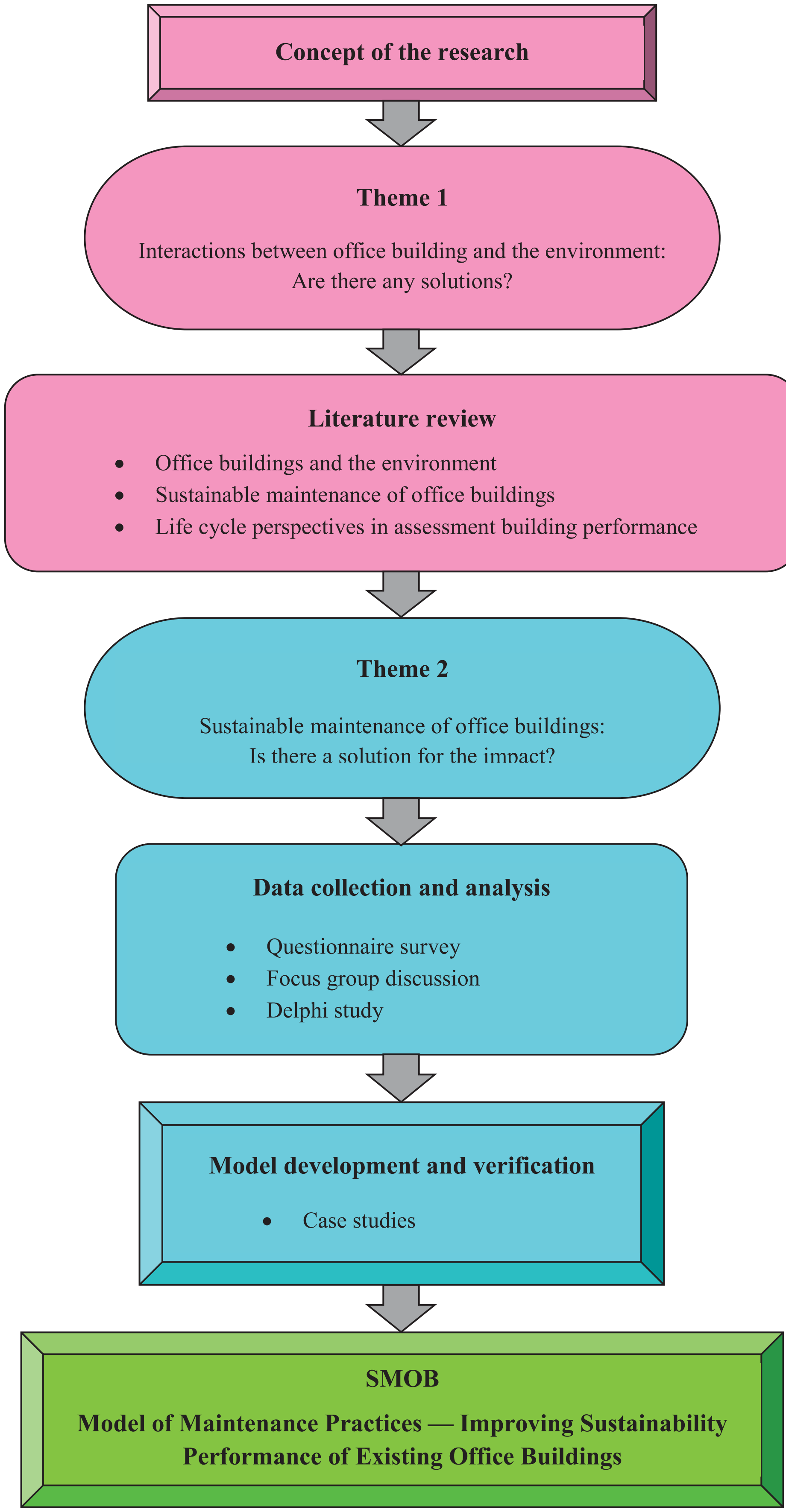
The second main theme will be conducted using a questionnaire survey, focus group discussion and Delphi study. Data collected from these studies will be analysed, and the outcome will be used to develop a strategic SMOB. Case studies are used to verify the workability of the developed SMOB.

In carrying out the data collection for this research, mixed methods research, a combination of quantitative and qualitative research methods, is selected. The essence of quantitative methods is on measurements and amounts of behaviours expressed by people and characteristics conveyed by events (Thomas 2003). To carry out quantitative methods, a survey process is preferably conducted through means of closed questions (ACAPS 2012; Jonker & Pennink 2010). Quantitative methods can lead researchers to know the degree to which something might or might not happen by amount, number, frequency and so forth (Jonker & Pennink 2010). For example, the number of times the heating, ventilation, and air conditioning (HVAC) systems are cleaned and/or serviced per month; how frequently the servicing/repairing of lifts and plant occur per year; and so forth.

Qualitative methods, in contrast, are processes through which researchers express types of characteristics of people and events without measurements or amounts (Thomas 2003). The conduction of qualitative methods relies on text and image data, has distinctive stages in data analysis, and draws on different strategies of query (Creswell 2009). Qualitative methods research is used when researchers wish to have answers to why and how the problems occur. The results are in-depth knowledge (ACAPS 2012; Jonker & Pennink 2010). An example is discovering intangible factors relating to current maintenance programs of existing office buildings.

Mixed methods research is used to collect or analyse both quantitative and qualitative data in which data are collected either simultaneously or consecutively and are integrated at one or more stages in the process (Creswell et al. 2003 cited in Lund 2012). Mixed methods research can be conducted by either single or multi-research studies that include a blending of the two methods, approaches or other paradigm characteristics within a coordinated group of different studies (Creswell & Clark 2011; Polit & Beck 2004 cited in Lund 2012).

Figure 1.1 Research plan



As illustrated in Figure 1.1, the methods involved in data collection in this research include a questionnaire survey, focus group discussion, Delphi study, and case studies. Data analysis from these processes is integrated into establishing the SMOB. The developed SMOB is then verified using case studies. The outcomes of the prior method will provide information for the next method to be conducted. Participants involved in the survey are invited through their email addresses, and their responses are via the online survey. Participants involved in the focus group and Delphi study are volunteers who accept the invitation in the survey process. Collected data will be refined and classified into a coding system of documentary groups that includes setting up a computer database. Data will also be analysed by using statistical techniques with computer software, such as SPSS, and non-statistical mean calculation. Following statements of Leedy and Ormrod (2001); and Oluwoye (1996), data analysis will be integrated and interpreted into statistical tables, figures, graphs and distributions.

The aim of the survey questionnaire is to identify the subjective views and practices of professionals in the industry about the maintenance of office buildings. The study will establish the most important factors in relation to improving the current maintenance practices for office buildings. The focus group discussion aims to affirm these important factors, and the Delphi study aims to obtain a consensus from the experts in ranking the most important factors (critical factors). The ranked critical factors are then compiled into a strategic model of sustainable maintenance of office buildings.

Case studies will be used to investigate the current maintenance practices for three high-rise office buildings located in the Sydney CBD, which aim to verify the practicality of the SMOB. The study is to identify unexploited improvements in current maintenance practices for office buildings compared to the SMOB. The test outcome derived from case studies is the answer to the questions of this research project. Details of the data collection and analysis are discussed in Chapter 6, the development of the SMOB is discussed in Chapter 7, and case studies in verifying the SMOB are discussed in Chapters 8. The robustness and usefulness of the SMOB should then open up opportunities for further research to be conducted.

1.7 Thesis Structure

The thesis structure is presented in Figure 1.2. The outline of each chapter is described as follows:

Chapter 1: Introduction

This chapter presents the background information for this research. It also introduces the reason this research has been undertaken. It explains why this research is conducted: to develop a SMOB – on a whole life approach to be used to improve maintenance practices for office buildings. Knowledge of theories and practices of sustainable maintenance of existing office buildings is explained. It also explains the main themes and stages for the study.

Chapter 2: Office Buildings and the Environment

This chapter reviews the literature and previous research regarding the impacts between existing office buildings and the environment. This research shows how the significance of non-green existing office buildings contributes high level environmental impacts and vice versa. The review examines the nature and effect of climate change and environmental degradation due to inefficient use of resources, energy and water when maintaining office buildings, particularly, the high level of emission of CO_2 from non-green office buildings due to conventional maintenance practices. The study investigates the concept of how green buildings with sustainable maintenance could produce high-performing buildings and the techniques available for improving building maintenance in order to attain major CO_2 emission reductions. The responses from governments toward climate change are also investigated in this chapter.

Chapter 3: Sustainable Maintenance of Office Buildings

This chapter reviews the literature to gather information and data from previous research on strategic maintenance of office buildings. The chapter starts by investigating current maintenance practices for office buildings and sustainable development available for improving strategic practices for building maintenance. The study presents and discusses the consideration of performance in maintaining and upgrading an existing building to achieve reduction of CO_2 emissions by implementing maintenance practices. It includes the "what", "why" and "how" factors required to achieve the best practice in maintenance performances, and drivers and barriers in accelerating sustainable maintenance practices in the industry.

Chapter 4: Life Cycle Perspectives in Assessment of Building Performance

This chapter reviews the literature to study the robustness and effectiveness of LCA and LCC in evaluating sustainable maintenance of office buildings. It explains the problems of the current applications of each method in assessing sustainable maintenance due to the principal characters of each method. Particularly, there are limitations in the use of LCA in appraising costs of buildings and equipment employed in office buildings; and limitations in the use of LCC in assessing environmental impacts of office buildings. The study examines significant performances of building maintenance over long-term assessment in order to reduce energy and water consumption and CO_2 emissions within existing office buildings. It also demonstrates a combination of LCA and LCC in assessment costs and impacts of maintenance office buildings on long-term performance to satisfy the environmental burden.

Chapter 5: Research Design

This chapter establishes the conceptual framework for in-depth studies into strategic practices of sustainable maintenance of office buildings based on literature reviews of improving our environment. It provides information and discussion on research methodologies, research methods and data collection methods. It explains the framework in studying the practical design and performance of sustainable building maintenance. It discusses in-depth data collection via most common research methods such as questionnaire survey, focus group discussion, Delphi study and case studies to establish and verify the developed SMOB for this research. It also discusses and demonstrates the mixed methods approach which combines quantitative and qualitative research methods that help to identify big gaps between conventional and sustainable maintenance practices for office buildings and bridgeable ways to fill these gaps.

Chapter 6: Data Collection and Analysis

This chapter establishes the research structure and approaches for the questionnaire survey, focus group discussion, Delphi study, and case studies to be conducted. Participants involved in the survey are key stakeholders and professionals who currently work in office buildings, and members of professional building institutions. Respondents who have voluntarily agreed to help in further investigation on sustainable maintenance practices for office buildings are selected to participate in the focus group discussion and Delphi study. Data collection and analysis provides details in examining advantages and disadvantages, costs and benefits of the current theoretical and practical performances, and future trends of maintenance management towards sustainability in the building industry. It also explains the preliminary organisation and analysis of data collected from the questionnaire survey, focus group discussion and Delphi study for a provisional outcome in developing the SMOB for this research.

Case studies are used to verify the SMOB. The chapter then clarifies the initial outcome including discussion on the current practices and future trends in maintenance strategies in the industry. The chapter also draws on collected and analysed data from the processes of the literature review, questionnaire survey, focus group discussion, Delphi study and case studies to ensure answers to the questions of this research. It provides details of the analysed processes of collected data by the application of both statistically analysed techniques and by statistical programs such as SPSS, and non-statistical mean calculation for an observational result. It makes clear an integrated outcome from analysis and the range of tabulated distribution, interpretation and comments.

Chapter 7: Model Development

This chapter develops a strategic SMOB, based on the integrated outcome from quantitative and qualitative data collected from the questionnaire survey, focus group discussion and Delphi study. The process of integration of data analysis and development of the SMOB will be explained in this chapter. The SMOB is a benchmark platform that comprises a number of main important factors or critical issues used to improve maintenance practices for office buildings based on the assessment of return on investment costs and benefits that the SMOB can provide. The SMOB may satisfy the necessary requirements needed to improve/upgrade a non-green office building to meet the level of green standards. It will also explain whether the SMOB will provide an answer to the research questions.

Chapter 8: Case Studies and Model Verification

This chapter details the case studies of each particular non-green office building and the necessary requirements that are needed to improve/upgrade the building. It provides current details in examining the advantages and disadvantages of recent design and practices in the building industry to improve/upgrade existing office buildings. It identifies gaps between the SMOB and current maintenance practices for each case study building. It also explains the preliminary organisation and analysis of data collected from case studies for the provisional outcome. It clarifies the initial outcome and includes comments on recent green practices that are used to improve/upgrade existing office buildings in the industry by using the SMOB. The effects and practicality of the SMOB to satisfy environmental protection practices are also explained and discussed in this chapter.

Chapter 9: Summary and Conclusions

This chapter summarises the research process used to address the research problem and its targeted answer. It makes clear the general recommendations and formulations in the approach to the design and performance of sustainable maintenance of office buildings. Throughout this chapter, contributions and limitations of this research are discussed; along with recommendations for future research.

Figure 1.2 Thesis structure

Stage 1: Concept of the research

Chapter One: Introduction to the research to be conducted

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Stage 2: Review the views and practices undertaken by industry professionals on maintenance of office buildings for environmental protection (**Theme 1**)

Chapter Two: Office building and the environment
Chapter Three: Sustainable maintenance of office buildings
Chapter Four: Life cycle perspectives in assessment building performance

↓

Stage 3: Establish conceptual framework for studies through questionnaire survey, focus group discussion, Delphi study and case studies

Chapter Five: Research design

↓

Stage 4: Investigate and analyse how innovation in maintenance can improve/upgrade an office buildings to be sustainable (**Theme 2**)
Identify stakeholders behaviour in design and performance of maintenance strategies for office buildings

Chapter Six: Data collection and analysis

↓

Stage 5: Investigate and analyse costs and savings that stakeholders would suffer/gain from design and performance of sustainable maintenance in the long-term, balancing environmental and economic measures

Chapter Seven: Model development

↓

Stage 6: Verify the robustness and practicality of the model of maintenance practices – improving sustainability performance of existing office buildings

Chapter Eight: Case studies and model verification

↓

Stage 7: Deliver the outcome of this research

Chapter Nine: Summary and conclusions

2. Office Buildings and the Environment

2.1 Introduction

This chapter reviews the literature and previous research regarding the impacts of existing office buildings on the environment under global and local climate change, particularly in the Sydney area. The literature review concentrates on non-green existing office buildings that have high impact on the environment due to the inefficient use of energy and water. The review examines the inefficient use of energy and water in maintaining office buildings that produce high emissions of CO_2 in the environment.

The study investigates the concept of green buildings or sustainable buildings and the techniques available for improving building maintenance in order to reach major CO_2 emission reductions. The findings presented range from the interaction between buildings and the environment due to increasing climate conditions, the contribution of buildings that account for global warming, and a discussion of appropriate methods that the building industry must consider to reduce the detrimental climatic impact. The responses of government to climate change are also investigated in this chapter.

2.2 An Environmental Crisis

In recent years, the rapidly increasing average temperature on earth has become known as climate change or global warming (Anderson, Hawkins & Jones 2016; Lindinger 2009). The effects of climate change have certainly influenced our living environment, as people are affected by the increased need for cooling to accommodate daily higher environmental temperature (Kentwell 2007; Lindinger 2009). Across most of Australia, the frequency of warm weather has risen since 1960 (Australian Bureau of Meteorology 2014a; Australian Department of Climate Change 2010). As a direct result of climate change, in particular to address the continual and extreme heatwaves, people adapt by increasing the use of indoor climate modifiers such as HVAC systems. This requires increased use of energy and the burning of fossil fuels, which makes ineffective the new techniques applied for cooling buildings, such as the building's passive ventilation and natural breeze, and low-energy evaporative cooling or night ventilation (Ürge-Vorsatz et al. 2007a).

Many substances can contribute to greenhouse gas (GHG) emissions, which include contaminated gases which may change the nature of the GHG effect, that lead to climate change; however, carbon dioxide (CO_2) is recognised as the main substance (Li & Yao 2009; Lynas 2007). The existing building stock worldwide is one of the major sectors accounting for the production of high levels of CO_2 in the environment (Gluch & Stenberg 2006; Madew 2007; Ürge-Vorsatz, Koeppel & Mirasgedis 2007b). The manner of using natural resources and the methods of operating and maintaining buildings are major problems that as buildings facilitate high levels of CO_2 (Kohler & Yang 2007; Wilson & Tagaza 2006). Furthermore, according to Taylor (2009), most existing office buildings are many decades old; therefore, energy efficiency and the consideration of energy consumption that impacts the environment were not considered during their design and construction. Overall, the reduction of energy consumption and CO_2 emissions of office buildings seems not to have been effective; thus, their impact on climate change has not decreased.

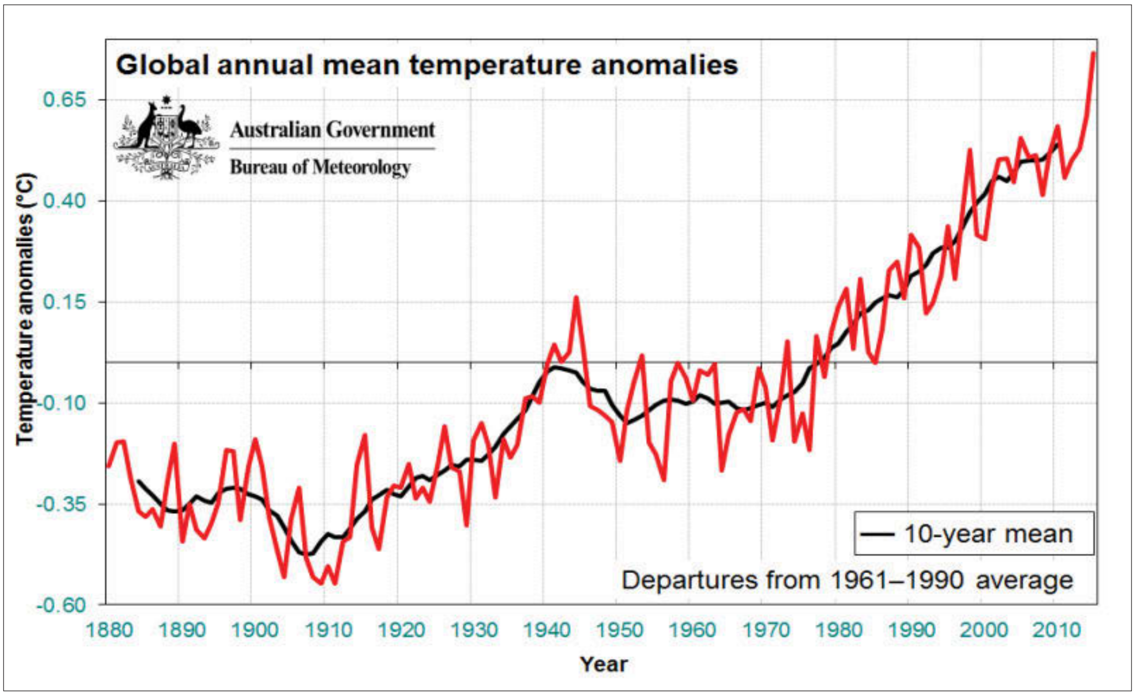
2.2.1 Global Climate Change

Global climate change has contributed to an increase in the earth's average temperature (Lindinger 2009). The consequences of climate change are experienced over regions as an increase in extreme events, such as heatwaves, droughts, resource depletion, air quality deterioration and increase in human sickness (Kentwell 2007; Lindinger 2009; Yau & Hasbi 2013). Climate change has been observed since about 1950, and its impacts are strongest and most comprehensive on natural systems (IPCC 2014).

Throughout the United States (US), climate change impacts many regions through heatwaves, heavy downpours, and a rise in sea level. Significantly, the effects of climate change affect people's health, energy use, air and water quality (NASA 2014). Across Europe, heavy rain and other extreme weather events are occurring more frequently. European countries are observing more frequent heatwaves, droughts and human health problems (European Commission 2014). In Asia, the annual average temperatures, flash floods and extreme weather events are increasing regularly. For instance, current annual temperatures have increased by approximately 1 ^{o}C or more over many regions in Asia (Yau & Hasbi 2013).

Figure 2.1 presents the global annual mean temperature anomalies for the period from 1880 to 2010. The black line denotes the 10-year moving average and the red line graph shows the annual mean temperature, which has had a greater above average increase since the period of 1961–1990. Since 1985 there was no year which observed a below average global mean temperature. All of the ten hottest years have occurred from 1998 to the present.

Figure 2.1 Global annual mean temperature anomalies

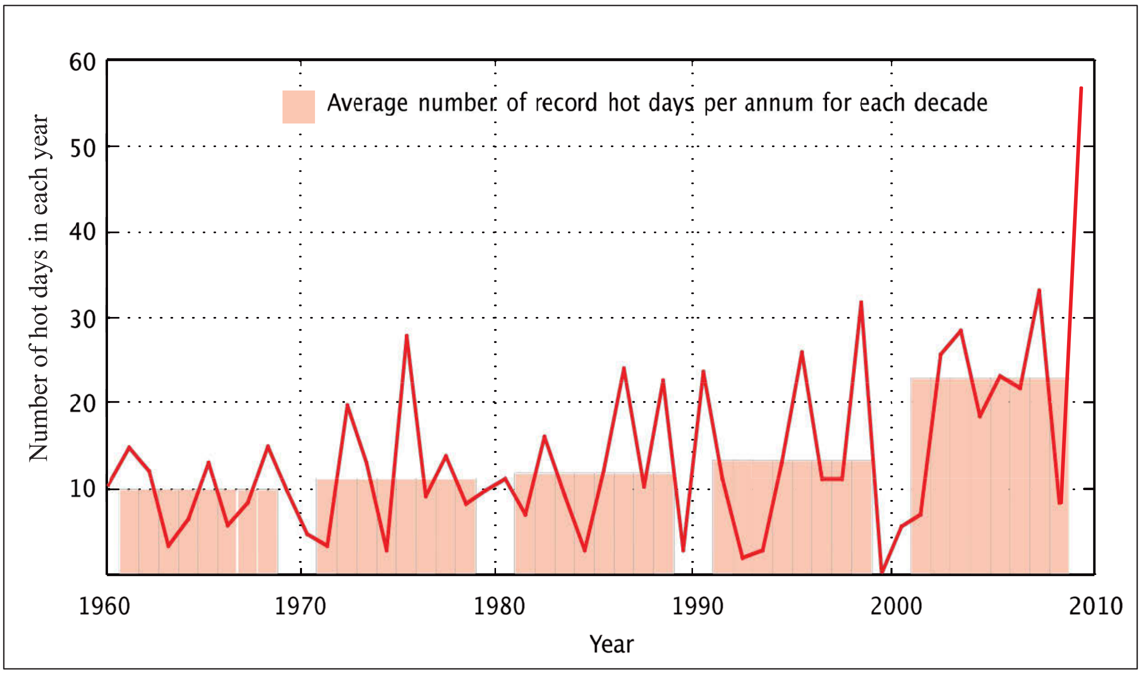


Source: Australian Bureau of Meteorology (2016a)
Notes: Black line: moving average temperature per 10-year period
Red line: annual anomaly means temperature

In Australia, the effects of the exponential change in temperature have been more visible (Höhne et al. 2017). Since 1950, the annual average temperature has increased by approximately 1 °C (Australian Department of Climate Change 2010; Clarke 2009; Cleugh et al. 2011; Lindinger 2009). However, according to the Australian Bureau of Meteorology (2014a), through the period from January 2011 to October 2014, the trend of the national mean temperature was mostly more than 1 °C on average. Consequently, the frequency of heatwaves has clearly increased, whereas the number of days of frost and cold has declined. Long periods of drought have been apparent and have affected many regions. Over the last 50 years, the rainfall in the north-west has increased, but in the east and the far south-west it has decreased (Australian Bureau of Meteorology 2014a; Australian Department of Climate Change 2010; Cleugh et al. 2011; Kentwell 2007; Lindinger 2009).

Figure 2.2 shows that Australia has suffered from an increased frequency of heatwaves and hot days recorded for the period from 1960 to 2010. The bar columns indicate the Australian annual average number of hot days per decade, while the line graph presents the actual hot days per year. It shows that over the past 50 years Australia has significantly experienced warmer temperatures, and 2010 was the hottest year for this period. The annual average temperature has increased and will continue to increase over the coming decades; up to the present, 2015 was recorded as Australia's fifth-hottest year when the annual national mean temperature reached up to 0.8 ^{o}C above average as reported by the Australian Bureau of Meteorology (2016a).

Figure 2.2 Australian annual average number of hot days per decade for the period 1960 to 2010



Source: Cleugh et al. (2011)
Notes: Bar columns: annual average number of hot days per decade
Line graph: the actual hot days per year

Due to the impact of rising temperature, the river flows of the Murray-Darling Basin have decreased by approximately 15% (Clarke 2009). However, according to a project of CSIRO (2001 cited in Karoly, Risbey & Reynolds 2003), the stream flow in the Murray-Darling Basin will decrease up to 45% by 2070 if the trend of increasing temperature continues to escalate. At that time, most areas of eastern Australia would suffer extreme drought, because the Murray-Darling Basin provides around 66% of surface water in Australia (NLWRA 2001 cited in Kingsford 2009).

Climate change will continue if strategies for the reduction of GHG emissions are not implemented (Australian Bureau of Meteorology 2014b; Australian Department of the Environment 2014a; Höhne et al. 2017).

2.2.2 Resource Depletion

The depletion of the world's natural resources are mostly affected by human activities (Boryczko, Hołda & Kolenda 2014). Natural resources include air, land, water, fossil fuel, minerals, fauna and flora (Dixon 2010; Langston 1997). According to Nematollahi et al. (2016), the natural environment consists of two types of natural resources: renewable and non-renewable.

Renewable resources include living organisms and non-living resources. The benefits of renewable resources are they exist and emerge continuously; and they are recognised infinite resources (Nematollahi et al. 2016). Sunlight can be categorised as a renewable resource; while water is sometimes considered a renewable resource; it cannot be generated anew (Behboodi et al. 2016; Friedl 2016).

Non-renewable resources, once consumed, cannot be used again. Fossil-based fuels, for instance, are classified as exhaustible non-renewable resources because they become depleted as they are consumed. Non-renewable resources are classified as renewable when they can provide renewable services to support human activities, such as fertile land. Resources that can be reused with cautious recycling through a course of action are recyclable non-renewable natural resources, such as tin, copper, gold, iron and so forth (Boryczko, Hołda & Kolenda 2014; Grimaud & Rougé 2003).

Products, which are made up from renewable raw materials, can be considered as green and environmentally friendly products (Geldermann et al. 2016; Meier, Metzger & Schubert 2007). Replacing the use of non-renewable resources by renewable resources is preferable to the use of natural resources. Consuming renewable resources will reduce the depletion of the natural resources (Silva, Soares & Afonso 2013). The depletion of natural resources, particularly non-renewable resources, is hazardous for the future survival of humankind (Boryczko, Hołda & Kolenda 2014). Therefore, the consumption of non-renewable resources should be minimised to an acceptable level for the protection of the natural environment.

2.2.3 Environmental Degradation

Environmental degradation is possibly caused by GHG emissions in the environment. The greenhouse effect is defined as:

> … a natural process that plays a major part in shaping the earth's climate. It produces the relatively warm and hospitable environment near the earth's surface where humans and other life forms have been able to develop and prosper. It is one of a large number of physical, chemical and biological processes that combine and interact to determine the earth's climate (Australian Bureau of Meteorology 2014b, p. 1).

GHG, which includes water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone and some artificial chemicals such as chlorofluorocarbons (CFCs), acts as a blanket in absorbing both the sun's energy and heat from human activities to warm the atmosphere and the earth's surface (Abdallah & El-Rayes 2015; U.S. Environmental Protection Agency 2014a). The process is the effect which provides the earth with warmth or cold as is its nature to allow life on earth to exist (U.S. Environmental Protection Agency 2014a). The GHG effect will be changed when its nature is changed due to greenhouse emissions (U.S. Environmental Protection Agency 2014a).

According to Chau, Leung and Ng (2015); the US Environmental Protection Agency (2014a); and the Australian Bureau of Meteorology (2014b), there are many factors contributing to greenhouse effect. These factors are both natural, and the results of human activities such as the consumption of energy in producing, operating and maintaining buildings (Lindinger 2009).

According to Zwick (2008), humans produce about 32 gigatonnes of CO_2 per year. As a result, the average amount of CO_2 in the atmosphere has increased by about 40% since the beginning of the industrial revolution. The global volume of CO_2 emission could double by 2080 (Australian Bureau of Meteorology 2014b).

Table 2.1 summarises the main GHG emissions influenced by human activities. The CO_2 lifetime in the atmosphere is up to 200 years. Its lifetime is less than CFCs, which is up to 50,000 years; however, its atmospheric concentration is 365 ppmv (parts per million by volume), whereas CFCs vary from 14 to 268 pptv (parts per trillion by volume). These figures show that the volume of CO_2 is normally many times greater than CFCs concentrated in the GHG. Furthermore, the annual rates of growth and proportional contribution to global warming of CO_2 are 0.4% and 60% (in 1998). CH_4 is 0.4% and 20%, CFCs are -0.5% to +4% and 14%, and N_2O is 0.3% and 6%. Comparing these gases, CO_2 in the atmosphere is the main gas that has contributed to climate change and is responsible for 60% of the global warming. This is greater than the combined rate of the rest of the gases. In the aim to reduce climate change and environmental impact, the emissions of CO_2 made by human activities is targeted by national emissions strategies at international and national levels (Australian Bureau of Meteorology 2014b).

Table 2.1 Greenhouse gas emissions influenced by human activities

Greenhouse Gases	Human Activities	Lifetime in Atmosphere	Atmospheric Concentration (1998)	Annual Rate of Growth (from 1998)	Proportional Contribution to Global Warming
Carbon dioxide (CO_2)	Fossil fuel burning, deforestation, biomass burning, gas flaring, cement production	5 to 200 years	365 ppmv	0.4%	60%
Methane (CH_4)	Natural wetlands, rice paddies, ruminant animals, natural gas drilling, venting and transmission, biomass burning, coal mining	12 years	1745 ppbv	0.4%	20%
Halocarbons (includes CFCs, HFCs, HCFCs, perfluorocarbons)	Industrial production and consumer goods (e.g., aerosol propellants, refrigerants, foam-blowing agents, solvents, fire retardants)	2 to 50,000 years e.g., CFC-11: 45 years HFC-23: 260 years CF_4: >50,000 years	Varies e.g., CFC-11: 268 pptv HFC-23: 14 pptv CF_4: 80 pptv	Varies Most CFCs now decreasing or stable, but HFCs and perfluorocarbons growing e.g., CFC-11: -0.5% HFC-23: +4%, CF_4: +1.3%	14%
Nitrous oxide (N_2O)	Biological sources in oceans and soils, combustion, biomass burning, fertilisers	114 years	314 ppbv	0.25%	6%

Source: Australian Bureau of Meteorology (2014b)

Notes: ppmv: parts per million by volume
ppbv: parts per billion by volume
pptv: parts per trillion by volume

2.3 International Collaboration in Climate Change

Climate change may vary from region to region, and adapting, measurements and assessments that help to reduce its impact depend on global and local changes (Kentwell 2007). Under the pressures of climate change and following the information of the Intergovernmental Panel on Climate Change (IPCC), governments around the world have developed initiatives to address climate change in an effort to reduce CO_2 emissions. They include, for example, the 2008 Climate Change Act of the United Kingdom, the Climate Change Mitigation Strategy 2020PLUS of Germany, the Special Program on Climate Change (PECC) of Mexico, and the Business as Usual (BAU) of Indonesia.

The measurements and assessments are guided by the Kyoto Protocol depending on the changes and requirements of each national emissions target. The targets are aimed at reducing energy use in all industries and hence at reducing CO_2 emissions in the future compared with agreed base years. To increase internationally responsive to climate change, a global climate agreement, known as The Paris Agreement, was agreed under the United Nations Framework Convention on Climate Change (UNFCCC) at the 21st Conference of the Parties (COP21) which was held in Paris from 31 November to 12 December 2015 (Australian Department of the Environment and Energy 2016). The Paris Agreement has been ratified by 115 out of 197 parties to the convention, in those Australia signed on 22 April 2016, and the Paris Agreement entered into force on 4 November 2016 (UNFCCC 2016). The Paris Agreement was internationally bound and supported (Christoff 2016).

According to the UNFCCC (2016):

> The Paris Agreement's central aim is to strengthen the global response to the address climate change by keeping a global temperature rise to below 2 ^{o}C at pre-industrial levels and pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

Table 2.2 summarises the commitments of countries in reducing emissions. As shown in the table, following the Paris Agreement, the Australian government is committed to reducing CO_2 emissions by 26–28% by 2030 below the 2005 levels based on the target of 5% reduction by 2020 below 2000 levels from 1 July 2011. The target would support the world agreement of stabilising levels of GHGs in the atmosphere at 450 ppm (parts per million) carbon dioxide equivalent (CO_2-e) or lower. To further commit to reducing carbon emission, some counties, such as Canada, Mexico, Russia and Australia, have established two or more targets rather than one. Australia's second target for reducing CO_2 emissions is by 80% by 2050 below 2020 levels.

Table 2.2 Commitments of countries in reducing emissions

Continent	Country	Base Year	Reduction Target (%)	Target Year	Reference
North America	Canada (1)	2005	17	2020	Saint-Jacques (2012)
	Canada (2)	2006	60	2050	Torney and Gueye (2009)
	Mexico (1)	2000	20	2020	Sopher and Mansell (2013)
	Mexico (2)	2000	50	2050	
	US	2005	17	2020	US Department of State (2014)
Europe	Denmark	1990	40	2020	The Ministry of Climate (2013)
	Germany	No record	30	2020	Ecology Institute Germany (2014)
	Iceland	1990	50–75	2020	Ministry for the Environment (2007)
	Ireland	1990	20–30	2020	Department of the Environment Heritage and Local Government (2012)
	Netherlands	1990	40	2020	Ministry of Infrastructure and the Environment (2014)
	Sweden	1990	40	2020	Wallhagen, Glaumann and Malmqvist (2011)
	United Kingdom	1990	80	2050	Williams et al. (2012); Lockwood (2013)
	Russia (1)	1990	15–25	2020	Yale Center for Environmental Law and Policy Webinar Series (2014)
	Russia (2)	1990	50	2050	
Asia	China	2005	45–50	2020	Hilton and Kerr (2017); Leung (2014)
	Hong Kong	2005	50–60	2020	
	Japan	1990	25	2020	Torney and Gueye (2009)
	India	2005	20–25	2020	Pahuja et al.(2014)
	Indonesia	No record	26–41	2020	Yusuf (2010)
Australia and New Zealand	Australia (1)	2005	26–28	2030	Australian Department of the Environment and Energy (2016)
	Australia (2)	2020	80	2050	Australian Department of the Environment (2014b)
	New Zealand	2001	30	2020	Environment and Sustainable Development (2012)

Notes: (1): National emissions reducing target 1
(2): National emissions reducing target 2

According to the Australian Department of Climate Change (2010); and the Australian Department of the Environment (2014b), Australia accounts for about 2% of global CO_2 emissions. Globally, Australia is classified as one of the top 20 polluting countries that generate the most CO_2 per capita at approximately 30 tones CO_2 per person per year (Australian Department of the Environment and Energy 2016). Therefore following calls for improvement of the government's policies in mitigating GHG emissions, according to the Australian Department of the Environment and Energy (2016), Australia signed the Paris Agreement on 22 April 2016 and ratified on 19 November 2016 and contributed the target of reduction of emissions to 26–28% on 2005 level by 2030 that represents a 50–52% reduction in emissions per capita and a 64–65% reduction in the emissions intensity of the Australian economy between 2005 and 2030 (UNFCCC 2016). The target will be accomplished through a policy suite; of which emissions is already decreasing, technological innovation is boosting and the clean energy sector is enlarging. The target will be updated every five years (UNFCCC 2016).

Stevenson (2009) states that the Australian government has not done enough to satisfy the international benchmark for CO_2 reduction to address climate change compared to the methods and efforts from China, the US or India. For example, as studied by Morrison, Duncan and Parton (2013), the support for climate change policy in Australia has been split, and the level of support has decreased in the years since the release of the Garnaut Report on climate change in 2008. However, the Garnaut Climate Change Review in 2008 also indicates that Australia support global efforts to achieve a target for GHGs of 450 ppm CO_2-e in the atmosphere, the commitment within Australia for climate change policies was recommended at high levels (Morrison, Duncan & Parton 2013). Spash (2016) points out that the GHGs of 450 ppm was stablished by the UNFCCC in associating with the 2 ^{o}C for global warming target.

To reduce the effects of climate change with the aim of environmental protection, CO_2 emissions should be decreased (Höhne et al. 2017; Lindinger 2009; Lynas 2007; Stenberg & Räisänen 2006). The actions should concentrate on energy efficiency in all sectors (Clarke 2009). An emissions reduction target is a way to reduce global climate change. It should be followed and monitored to ensure it is achieved or improved on. All government policies and incentives are needed to focus on promoting "green energy", such as solar power and other renewable energy sources (Butcher & Stilwell

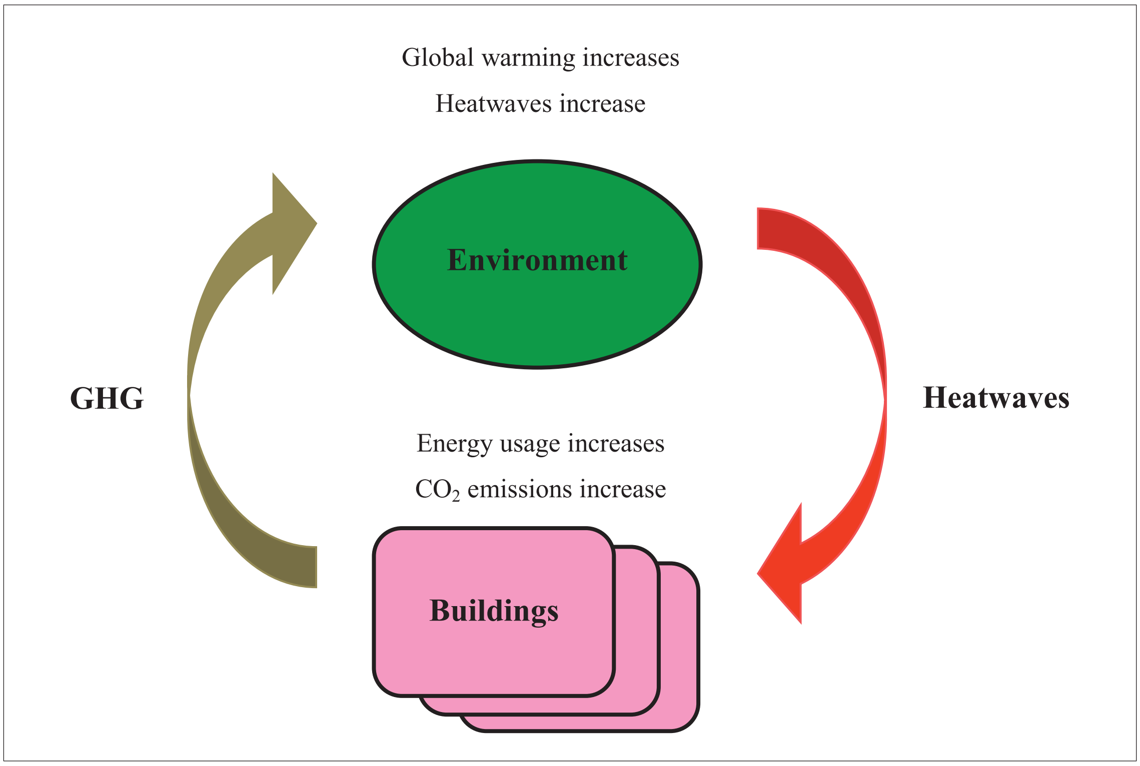
2009). Improving buildings with new technologies to become more environmentally friendly that use less energy is also a challenge (Clarke 2009). According to Balaban and Puppim de Oliveira (2016); and Brennan (2009), government should provide more incentive schemes to the industry to subsidise the upfront costs of sustainable technologies and additional costs in improving/upgrading existing office buildings to be greener. The urgency to accelerate a green movement in the building industry should also be addressed in order to mitigate CO_2 and other substances contributing to GHG emissions to satisfy the Paris Agreement.

2.4 Impacts of Office Buildings on the Environment

2.4.1 Interactions between Buildings and the Environment

As stated, since 1950, the average temperature in Australia has increased by around 1°C because of climate change (Australian Bureau of Meteorology 2014a; Australian Department of Climate Change 2010; Clarke 2009; Cleugh et al. 2011; Lindinger 2009). The key substance responsible for raising the earth's temperature is CO_2 (Li & Yao 2009; Lynas 2007). The earth's atmospheric absorption of CO_2 reinforces the production of heatwaves. Under heatwaves, buildings consume even more energy to provide cooling to occupants. That leads to buildings emitting more CO_2 into the environment. Therefore, buildings and the environment are caught in a vicious cycle as shown in Figure 2.3.

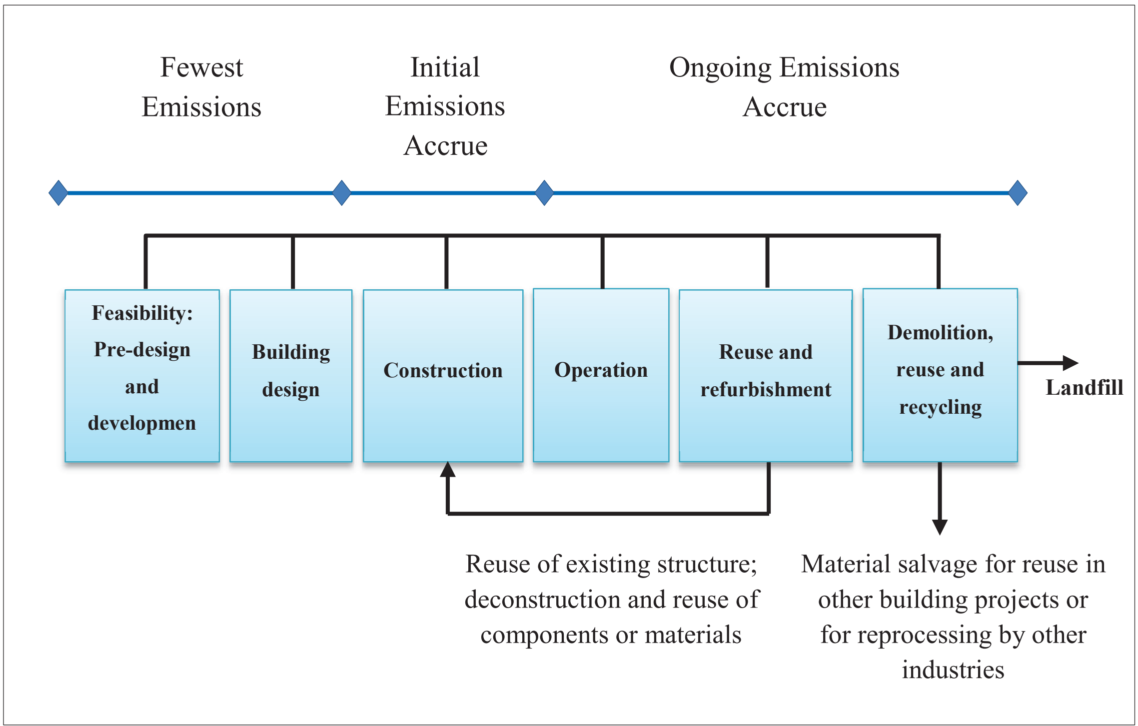
Figure 2.3 Interactions between buildings and the environment



The effects of the interaction between buildings and the environment occur during all phases of the building's life cycle. However, the strongest influence is the building's operational and maintenance phase. This phase is the longest period of the building's life cycle. The greatest proportion of energy and water consumption and the greatest rate of CO_2 emissions are in this phase (Huovila et al. 2009; Ibn-Mohammed et al. 2013). Figure 2.4 summarises buildings' links to emissions over life cycle phases based on energy and water uses. The highest amounts of energy and water are used during the building's operational and maintenance phase to meet the requirements for building services such as HVAC systems, water heating and lighting.

The operational and maintenance phase of buildings accounts for 80–90% of CO_2 emissions, while the construction and demolition phases account for around 10–20% (Junnila 2004; Suzuki & Oka 1998; Adalberth et al. 2001 cited in Huovila et al. 2009). This also includes embodied energy and embodied emissions of maintenance of the building's systems. When the building services are to be refurbished and/or replaced, the embodied energy and embodied emissions of these new systems will be added to the operational and maintenance phase of a building's life cycle. Therefore, the operation and maintenance phase of buildings has been the main target of research studies into ways to reduce energy use and CO_2 emissions (Huovila et al. 2009).

Figure 2.4 Summary of buildings links to emissions over life cycle phases



Source: Graham 2003 cited in Huovila et al. (2009)

Table 2.3 summarises the distribution of the life cycle environmental burden for five impact categories of buildings. They include global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), nitrification potential (NP) and waste generation. The operation and maintenance phase of a building contributes the greatest impacts on the environment. These impacts include the use of energy and water for HVAC systems and lighting. Significantly, in a building's operation and maintenance, the impacts of GWP account for 94% of energy and 3% of water uses; ODP accounts for 83% of energy and 3% of water uses; and waste generation accounts for 62% of energy and 3% of water uses. GWP and ODP comprise the main GHG, such as CO_2 and CFCs that mostly affect climate change.

Table 2.3 Summary of distribution of life cycle environmental burden for five impact categories of buildings

Impacts	(%)					
	Material Production	Transportation	Construction	Operation		Decommissioning
				HVAC/ Lighting	Water Services	
GWP	3.0	0.1	0.1	93.5	3.1	0.2
ODP	13.5	0	0.2	82.9	3.4	0
AP	7.4	0.4	0.4	89.5	1.5	0.8
NP	4.7	0.7	0.5	89.5	3.3	1.3
Waste	22.4	0.1	5.8	62.0	2.8	6.9

Source: Scheuer, Keoleian and Reppe (2003)

Notes: GWP: Global warming potential
ODP: Ozone depletion potential
AP: Acidification potential
NP: Nutrification potential
Waste: Waste generation

The building sector, particularly existing office buildings, has been the key target for public policy addressing climate change (Kentwell 2007; Lyth & Chastel 2007). Compared to other types of commercial buildings, office buildings have the greatest potential to save energy in terms of HVAC, lighting and electronics, and reduce water consumption, particularly (Higgins et al. 2014). It should also be noted that existing building stock should not only reduce energy consumption requirements but also boost energy effectiveness in accordance with the environmental protection requirements.

A policy for the commitment of a CO_2 abatement target can be efficient when it can also provide information on how to increase consumer access to information, responsiveness and knowledge (Ürge-Vorsatz et al. 2007a). However, climate change is a global problem requiring a global solution along with the cooperation of nations in the world aiming to protect our environment (Australian Department of Climate Change 2010). To deal with these problems, national and international government policies and the creation of funds for climate change are necessary strategies to readdress these issues (Butcher & Stilwell 2009). Countries should also record what they do so that these actions can be further studied (Brennan 2009). Moreover, it's very important that data and information on green buildings should be internationally interchangeable (Lomas 2010).

2.4.2 Resources Consumption

The building sector is one of the main sectors affecting the environment in consuming resources. Globally, buildings consume almost 30% of the world's resources (OECD 2003 cited in Wilson & Tagaza 2006), which includes the destruction of rainforest by 25% (Dixon 2010). Significantly, resources are extracted for the production of products and sub-products and the process also generates pollution, such as CO_2 (Hyde et al. 2007; Kohler & Yang 2007). Table 2.4 summarises the impacts of buildings on global resource depletion and pollution. From the table, globally, buildings consume 50% of the total energy, 42% of water, 50% of materials, and destroy agricultural land by 48% since the 1990s. Consequently, buildings contribution to air pollution is 24%, global warming gases by 50%, fresh water pollution by 40%, landfill waste by 20%, and ozone depleting gases by 50%.

Table 2.4 Impacts of building on global resources and pollution

Global Resource	Building Use (%)	Global Pollution	Building Related Emissions (%)
Energy	50	Air quality (cities)	24
Water	42	Global warming gases	50
Materials by bulk	50	Drinking water pollution	40
Agriculture land loss	48	Landfill waste	20
Coral reef destruction	50 (indirect)	CFCs/HCFCs	50

Source: Hyde et al. (2007)

In considering environmental protection, recycling of resources will reduce the consumption of virgin materials. According to Zero Waste SA (2014), as reported by the Recycling International, recycling can save energy by 95% for aluminium, 85% for copper, 80% for plastics, 74% for steel and 64% for paper. Therefore, reducing the use of virgin materials should be a key target when aiming to reduce energy and water consumption and CO_2 emissions from existing buildings. It will decrease significantly the impact of buildings on climate change.

a) Buildings and Energy Use

The building sector is the main area consuming energy for occupants' activities, facilities, comfort and lighting. Kwok and Rajkovich (2010 cited in Wan et al. 2012) reported that in the US the building sector is responsible for around 39% of the total primary energy requirements, of which 35% was used for HVAC systems. This rate represents 80% of buildings in the US equipped with air conditioning systems (Nicol 2009). In Canada, buildings account for 54% of energy for space heating and 6% for space cooling; while equipment, lighting and hot water systems account for 20%, 13% and 7% respectively (Ürge-Vorsatz et al. 2007a).

In Europe, Ürge-Vorsatz et al. (2007a) found that energy used for space heating accounted for 52% and for space cooling accounted for 4%. In Greece, Asimakopoulos et al. (2012 cited in Berger et al. 2014) found that because the earth's temperature would continue to increase severely, the energy required for heating buildings could decrease by around 50%, but the energy required for cooling could increase by up to 248% by 2100.

In China, energy use in the building stock has been steady increased since 1980s. Buildings consumed around 24% of the total national energy use in 1996, rose to around 28% in 2001 and the growth was projected to rise to about 35% in 2020 (Yao, Li & Streemers 2005; Wang et al. 2011 cited in Wan et al. 2012).

In Australia, office buildings account for 33.6 PJ (petajoule) or 25% of the total energy consumed by all types of building in 2009. It is projected to increase by 38.1 PJ or 29% in 2020 (Higgins et al. 2014; Pitt & Sherry 2012). Table 2.5 summarises the breakdown for Australian office buildings in the end use of energy and CO_2 emissions. Cooling systems, contribute the highest rate of emissions at 28%, ventilation systems at 22% and lighting systems at 21%. The indoor environment is identified as the main space which accounts for the highest rate of energy consumption. From a global perspective, the current consumption of energy to maintain human indoor comfort and outdoor environment is unsustainable, and adopting more efficient methods for indoor comfort will have a major effect on the overall state of global warming (Shove et al. 2008).

Therefore, HVAC and lighting systems are essential in energy and emissions savings for the whole life of buildings throughout the design, construction, operation, and particularly, in the maintenance phase of existing office buildings (Nicol 2009; Wilkinson & Reed 2006a).

Table 2.5 The shared end use of energy and greenhouse gas emissions of Australian office buildings

Use	Energy Share by End Use (%)	Rank	Greenhouse Gas Emission Share by End Use (%)	Rank
Heating	33	1	13	4
Cooling	21	2	28	1
Ventilation	16	3	22	2
Lighting	15	4	21	3
Office equipment and other	9	5	12	5
Cooking and hot water	6	6	4	6

Source: AGO 1999 cited in Wilkinson and Reed (2006a)

Moreover, in the maintenance of office buildings, materials are used for repair, refurbishment and replacement at regular intervals over the building's life. Building materials contain embodied energy and have caused CO_2 emissions (Ding 2004). The extent and choice of materials use will impact on the amount of embodied energy and emissions in buildings (Ibn-Mohammed et al. 2013; Williams et al. 2012).

There are two forms of embodied energy used in buildings:

- Initial embodied energy in building components represents the energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site and installation.

- Recurring embodied energy in buildings represents the energy consumed to maintain, repair, restore, refurbish, or replace materials, components or systems during the life of the building (SA Department of Planning Transport and Infrastructure (SADPTI) 2012).

Maintaining a building over its life cycle requires repair, refurbishment and replacement of building and service systems within the building. It may include reorganising the floor layout; internal and external decorations and ornaments; landscaping; repainting walls and ceilings; changing doors and/or windows; changing carpets and/or tiles; repairing, refurbishing and replacing HVAC systems, lighting systems and others; using cleaning agents and paper. The life expectancy of a building may expand up to 100 years, but the life expectancy of materials may range from 5 to 80 years. For example, the expected lifetime of solid internal doors is 80 years, aluminium windows is 40 years, toilet suites is 35 years, water taps is 30 years, carpets is 12–20 years, ceiling paint is 20 years, and wall paint is 7–10 years (Ding 2004; Ibn-Mohammed et al. 2013).

The use of recycled materials in the maintenance of an office building will reduce energy consumption and decrease CO_2 emissions. Table 2.6 summarises the embodied energy intensity and embodied GHG emissions of common building materials. It shows that the use of recycled materials will save embodied energy compared to the use of virgin materials. For example, the embodied energy of recycled aluminium is 8 MJ/kg and recycled steel is 9 MJ/kg, whereas for the original aluminium, it is 227 MJ/kg and for original steel it is 32 MJ/kg.

Table 2.6 Embodied energy content and embodied emissions of common building materials

Material	Embodied Energy [1]		Embodied GHG Emissions [2]
	MJ/kg	MJ/m^3	CO_2/kg
Concrete (30 MPa)	1.30	3,180	0.11
Aluminium (recycled)	8.10	21,870	No record
Steel (recycled)	8.90	37,210	No record
Plywood	10.40	5,720	2.57
Glass	15.90	37,550	0.69
Steel	32.00	251,200	2.12
Zinc	51.00	371,280	2.82
Brass	62.00	519,560	2.60
PVC	70.00	93,620	1.97
Copper	70.60	631,164	3.60
Aluminium	227.00	515,700	12.30

Sources: 1: Canadian Architect Magazine cited in SADPTI (2012)
2: Williams et al. (2012)

b) Buildings and Water Use

Due to climate change, global fresh water is becoming scarce, with pollution increasing rapidly worldwide (Cheng 2003; Kingsford 2009). The growth of population, particularly in urban areas, increases the demand for drinkable water (Krishnamurti, Biswas & Wang 2012). As Krishnamurti, Biswas and Wang (2012) found, based on a US Geological Survey, around 167.3 billion litres of water withdrawals were for supplying users in urban areas. This is an increase from 62% in 1950 to 86% in 2005. Globally, the commercial sector typically accounts for 10–20% of total water required in an urban water supply system (Chanan et al. 2003).

Even though Australia has 12 major water basins, the country is lacking fresh water (Kingsford 2009). The water levels stored in dams throughout Australia have been recorded and are shown in Table 2.7. A further concern, as mentioned, is that around 66% of surface water use in Australia is extracted from the rivers of the Murray-Darling Basin (National Land and Water Resources Audit 2001 cited in Kingsford 2009). However, because the earth's average temperature has increased by 1 °C, rainfall has changed over many of Australia's regions, leaving the river flows of the Murray-Darling Basin decreased by approximately 15% (Clarke 2009). Significantly, in November 2016, according to the Australian Bureau of Meteorology (2016b), the total water catched from rainfall into the Murray-Darling Basin was reduced by 46% compared to the period from 1980s to 2015. This contributes to further shortage of fresh water supply in Australia, and the shortage of water would increase the impact to the water end-users. Towards a healthy and working Murray-Darling Basin, as reported by the Murray-Darling Basin Authority (2016), the Murray-Darling Basin plan came into effect in November 2012 to control water flows and improve the environment of Basin's rivers. However, it is still debatable around the amounts of water being allowed to be extracted from the Basin under the plan between the Federal and State Governments (Environment Victoria 2016; Hart 2016; Kirby et al. 2014).

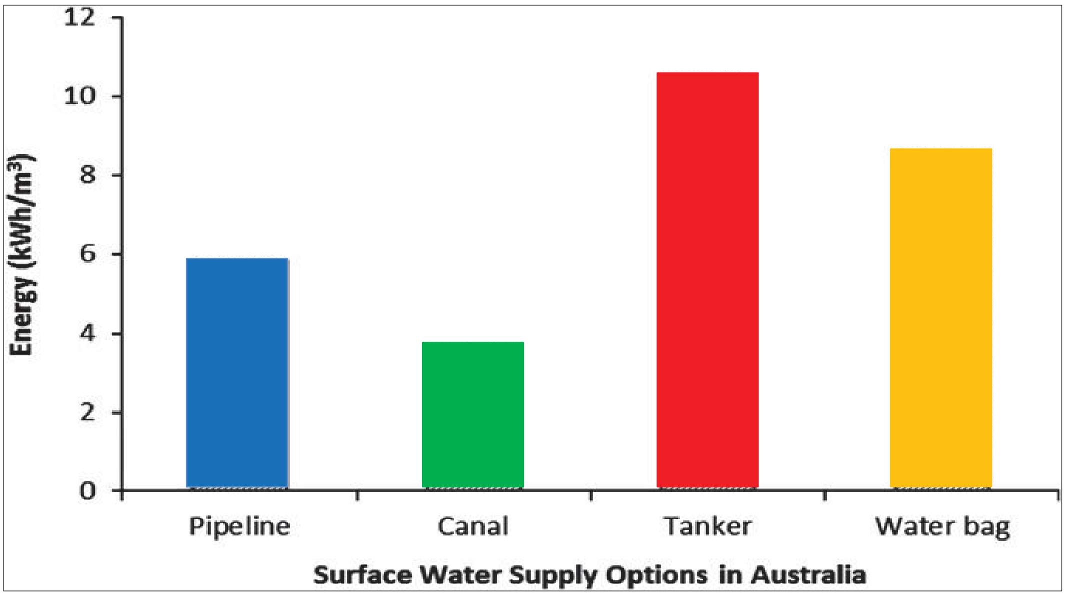
Table 2.7 Water levels stored in dams in Australia's capital cities in May 2007

Capital City	%
Brisbane	19
Perth	21
Melbourne	30
Canberra	31
Sydney	38
Adelaide	59
Hobart	67
Darwin	95

Source: Hurlimann (Source: 2007)

Production and purification of water for consumption requires energy for extraction, treatment, transportation, distribution, use and disposal and the process generates CO_2 emissions. Energy consumption associated with water supply is computed by kWh per cubic metre (kWh/m^3) of drinkable water which will depend on the specific technologies applied at each stage of the water cycle (Plappally & Lienhard 2012; Shrestha et al. 2012). In Australia, water related energy consumption required for the treatment of conventional water ranges from 0.01 to 0.2 kWh/m^3 (Plappally & Lienhard 2012). Energy intensities of delivering 200 GL (gigalitres) per year of surface water using pipeline, canal, tanker, and water bag distribution are shown in Figure 2.5. The study is based on the calculations as studied by Plappally and Lienhard (2012) that include: the pipeline is a proposed distance of 1,900 km long with a rise of 700 m above the sea level; the canal is 3,700 km long; there are eight pumping stations with a cumulative lift of approximately 500 m with a rise of 127 km; there are fourteen shipping tankers of 500,000 dead weight tonnage to deliver water to a distance of around 3,000 km; and a towing of 0.5 GL water bag using a large tug boat along the same shipping route.

Figure 2.5 **Energy used in delivering surface water supply in Australia**



Source: Plappally and Lienhard (2012)

The building sector currently accounts for 15% of the world's water consumption caused by human activities taking place inside buildings (Gluch & Stenberg 2006; Madew 2007). According to the Australian Department of the Environment and Heritage (2006), the commercial office sector in Australia accounts for 10% of capital city water consumption. This is significant for urban water supply. For example, typically, the average size office building of 10,000 m^2 consumes more than 20,000 litres per day, or greater than 7 million litres per year. Commonly, water use in a typical Australian office building is as follows: amenities (toilets, kitchenettes, showers) 37%, HVAC systems 31%, leakage (taps, urinals, cisterns, piping, valves, pumps, etc.) 26%, retail (primarily food outlets) 3%, irrigation (landscaping) 1%, and others (cleaning, car wash) 2%. Therefore, decreasing the use of water in order not only to reduce water consumption in buildings but also to reduce water-related energy consumption and CO_2 emissions is the key to reducing the impact in the use of buildings on the environment. Significantly, an office building could achieve 30–40% in water savings (Australian Department of the Environment and Heritage 2006).

2.4.3 Generation of Emissions

The building sector is said to be the main area emitting a high rate of CO_2 in the environment. In 2002, the building sector contributed 8 Gt (gigatonne) of CO_2 emissions or 33% of the global total energy related emissions; and it is predicted that the contributions will increase from 8 to 11–16 $GtCO_2$ or approximately from 46 to 63% by 2030 (de Wilde & Coley 2012; Ibn-Mohammed et al. 2013; Ürge-Vorsatz et al. 2007a; Ürge-Vorsatz, Koeppel & Mirasgedis 2007b; Wan et al. 2011; Wan et al. 2012; Yau & Hasbi 2013). In office buildings alone, the growth of CO_2 emissions has been calculated to have increased at a rate of 3% per year between 1971 and 2004 (Huovila et al. 2009). If no action is taken for sustainable building development, the rate of CO_2 emissions would increase up to 3–5% per year, from 2015 to 2050 (Langdon 2008; Odón de Buen 2009).

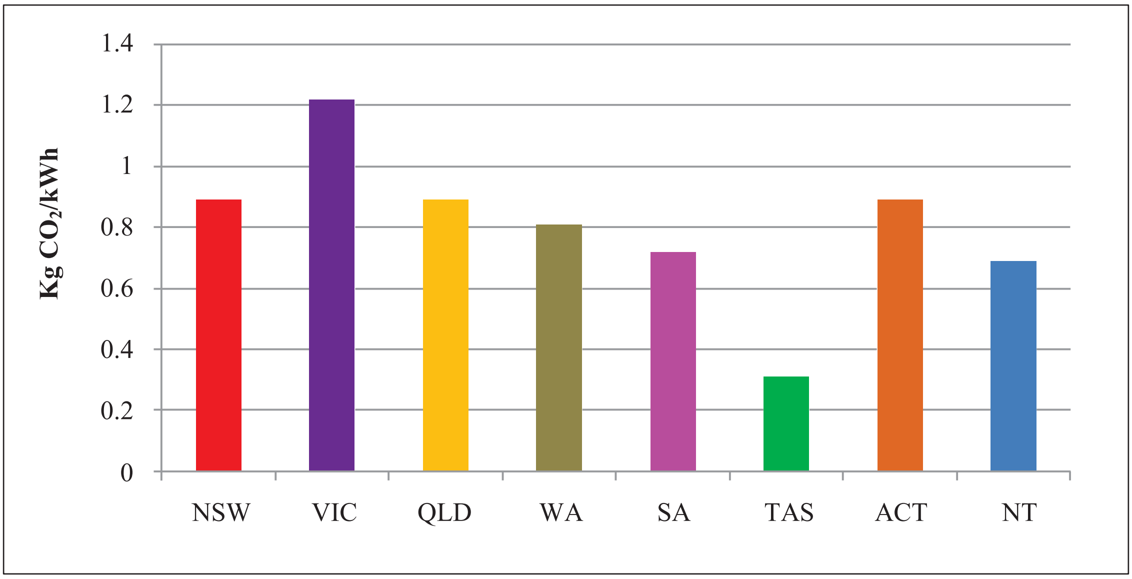
Buildings are also responsible for approximately 2 Gt of CO_2 emissions from fluorinated gases such as fluorochlorohydrocarbons, which are commonly used in air conditioning systems to provide indoor comfort. These gases contribute to ozone depletion (Huovila et al. 2009).

In addition, as studied by Ürge-Vorsatz et al. (2007a), buildings in the Organisation for Economic Co-operation and Development (OECD) accounted for around 35–40% of global CO_2 emissions. That percentage of emissions is attributed to the direct use of fossil fuels, which include natural gas and oil, for provision of heating and cooling, and for the production of electricity consumed in buildings. Buildings use around 50% of total electricity use in OECD countries, and the consumption of fossil fuels in the generation of electricity produces a higher rate of CO_2 emissions than do other sources of energy (Ürge-Vorsatz et al. 2007a). For example, as projected by Ürge-Vorsatz et al. (2007a), in the regions of North America and the Pacific ocean only, advanced countries would produce 3 Bt (billion tonnes) of CO_2 emissions; while developing countries in these regions account for 5 Bt in 2020. Therefore, de Wilde and Coley (2012) state that developed countries could take more responsibility in mitigating emissions.

In Australia, the Emissions Report by the government in 2005 found that the building sector alone accounted for 130 Mt (million tonnes) or around 23% of CO_2 emissions per year due to energy consumption in buildings. It is also projected that CO_2 emissions in the building sector will grow to 280 Mt or an increase of 110% by 2050 compared with 2005 levels if no action takes place in reducing the energy use (CIE 2008; Höhne et al. 2017). Commercial buildings alone contribute about 10% of CO_2 emissions. Collectively, office buildings and hospitals contribute almost 40% (Wilson & Tagaza 2006). In aiming to decrease the cost of reducing emissions to run the Australian economy for the very long-term, as suggested by the CIE (Centre for International Economics) (2008), the CO_2 emissions of the buildings sector could be reduced by 30–35% by 2050. Stronger incentives for emissions reduction strategies are needed to be included in the government's policy.

Significantly, the building sector is a major contributor to pollution in Australia. The building sector could play a major role in reducing CO_2 emissions within the government's strategy of abatement of emissions in the framework of a target for emissions reduction. Figure 2.6 indicates GHG intensity by one kilogram of CO_2 per kWh of electricity supply by Australian states in 2009. Of which, VIC has the highest (1.2 kg CO_2 per kWh) and followed by NSW, QLD and ACT (around 0.9 kg CO_2 per kWh).

Figure 2.6 Greenhouse gas intensity of electricity supply by Australian states in 2009



Source: Pitt and Sherry (2012)

2.4.4 Generation of Waste

Industrial waste emissions contribute to the environmental crisis. Significantly, the national volume of waste to landfill resulting from industrial production is 40–45% in the US, 33% in the UK and 50% in Australia (Moore 2009). Solid waste from buildings is produced throughout their lifetime from construction, operation and maintenance, to demolition. According to the OECD (2003 cited in Terry & Moore 2008), buildings account for approximately 40% of waste to landfill.

In Australia, waste from the building sector accounts for 40% of landfill (Gluch & Stenberg 2006; Madew 2007). That classifies Australia as one of the top ten solid waste producers in the OECD (DEH 2001; OECD 2003 cited in Terry & Moore 2008). In the operation and maintenance over a building's life span, renovation and refurbishment generate approximately 5–10% of building waste to landfill (Miller et al. 2005 cited in Terry & Moore 2008). Most of which is generated by tenants day-to-day business operations and building maintenance management activities including fix-out churn and maintenance produces (Terry & Moore 2008).

Reducing waste to landfill will certainly reduce energy use and therefore reducing as much as possible CO_2 emissions. Waste can be managed by avoiding, reducing, reusing, recycling, recovering, treating and disposing (Zero Waste SA 2014). Recycling and reusing are the preferred ways. For instance, as audited by Peter Hoskins, Great Forest Australia, up to 75% of office waste is paper and cardboard-based generated by tenants during their day-to-day business activities; and building management activities account for 25%. Of the total waste, approximately 90% produced within a building can be recycled. This waste is mainly paper, cardboard, glass, metal and electronics (Terry & Moore 2008). Therefore, more conscious efforts for the disposal of waste to landfill could be a target to consider in the effort to decrease impacts between buildings and the environment.

2.5 Summary

This chapter has examined and discussed climate change, and the interaction between existing office buildings and the environment that accelerates climate change. It has also examined and discussed ways of mitigating climate change by reducing energy and water consumption in existing office buildings.

The study has identified that the main substance accelerating climate change is CO_2. The study has also found that the operation and maintenance phase of existing office buildings accounts for the highest level of CO_2 emissions in the environment. This is because most existing office buildings are operated and maintained inefficiently. Therefore, to reduce climate change, the rate of CO_2 produced from existing office buildings should be decreased. To satisfy the reduction of CO_2 emissions, existing office buildings must be improved by using better maintenance practices. The improvements can be performed by reducing the use of energy, water, and materials and waste disposed to landfill, as well as by increasing the reuse and recycling of water, materials and waste from existing office buildings.

Other factors that can speed up sustainable development in office buildings are the government's policies and incentives. The policies encourage and the incentives support sustainable development for office buildings. The next chapter reviews the literature relating to strategies for sustainable maintenance of office buildings. It examines and discusses why and how maintenance practices can be improved for existing office buildings to become sustainable.

3. Sustainable Maintenance of Office Buildings

3.1 Introduction

Green buildings or sustainable buildings are a possible solution to improve building functionality and reduce environmental impacts. The concept of sustainable development based on "Our Common Future", one of the most popular definitions, is that buildings should meet present-day needs and the ability of future generations needs without compromising between them (Australian Department of the Environment 2010).

This chapter reviews literature to gather information and data on recent theories and practices from previous research, in order to examine strategic maintenance of office buildings. The study investigates current maintenance practices for office buildings in the industry and sustainable development available for improving strategic practices for building maintenance. It includes "what", "why" and "how" factors to achieve the best practice in maintenance performance, and the drivers and barriers in the development of sustainable maintenance in the industry.

The study also presents and discusses the consideration of performance in maintaining and upgrading an existing building to achieve a reduction of CO_2 emissions by the implementation of maintenance practices. It includes improvements in the building's energy efficiency, lighting efficiency, indoor comfort levels for occupants, water efficiency, materials and resources management, and waste reuse and recycling. These key initiatives are considered to be best practices in the application of new technologies (Jentsch, James & Bahaj 2010). Lastly, the latest maintenance practices for office buildings in Sydney, Australia are discussed.

3.2 Sustainable Development of Existing Buildings

In the past few decades, the concept of sustainable buildings has been developing rapidly worldwide and throughout Australia due to the increased awareness of environmental protection (New South Wales Resource Centre 2009; Taylor 2009). At the First International Conference on Sustainable Construction in Tampa, Florida, in November 1994, the term sustainable building was first defined as “the creation and responsible management of healthy built environment based on resource efficient and ecological principles” (Yin & Cheng 2005, p. 4423). The US Environmental Protection Agency (2014b) states a green building or sustainable building or high performance building is the practice which responds on the environmental performance and uses efficient resources throughout the building’s life cycle from design, construction, operation, maintenance, renovation and deconstruction. This practice also considers concerns for economy, utility, durability, and comfort of the building. The Green Building Council of Australia defines a sustainable building as “one that incorporates design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and occupants” (Henderson 2006, p. 8).

Berardi (2013, p. 72) argues that many difficulties still exist in the definition of sustainable building that are technologically not clear, “a building is sustainable if it contributes to the sustainability through its metabolism and by doing this it favours a regenerative resilience of the built environment among all the domains of sustainability.”

The principle of sustainable development is to improve the human living environment, meet human needs, such as living in comfort, while conserving our natural resources. It is a major objective for the industry to deal with. According to Berardi (2013); and Yin and Cheng (2005), sustainable development should be considered in three crucial constituents, or three pillars of the triple bottom line of green buildings:

> “Sustainable development requires integrating and coordinating environmental, social and economic issues and disciplines. Thus, the decision and assessment of interdependencies and interactions between different aspects of sustainable development is the prime research priority” (Lorenz, Lützkendorf & Panek 2005, p. 427).

The concept of the triple bottom line includes:

- Economic sustainability: aiming to consume resources with more efficiency.
- Environment sustainability: aiming to avoid damaging impacts on the environment.
- Social sustainability: aiming to have reasonable effects in all phases for the requirements of people in the building process and to supply superior stages of contentment to clients, suppliers, employees and communities.

Considering the concept of sustainable development, the study will focus only on the first two aspects of the triple bottom line. The study will investigate the application of new technologies to make existing office buildings greener, and improve sustainability with maintenance practices, which satisfy both economic and environment sustainability. Social sustainability is outside the scope of this study but is suitable for a comprehensive assessment in all phases of a building from design, construction, operation and demolition or a new development.

From these aspects, a greener or more sustainable office building is the target. We reduce the impacts on the environment by reducing the consumption of energy[1] and water in the building, aiming to minimise the contributions of CO_2 of the building (Henderson 2006). These aspects include energy efficiency, GHG emission abatement, water conservation, waste avoidance, recycling, pollution prevention, reduced natural resource consumption, and productive and healthier environments (Henderson 2006). Green building characteristics can be implemented throughout all buildings projects, including maintenance of existing facilities and office buildings (Ding 2004).

[1] The term *energy consumption* used in this research refers to electricity consumption.

3.2.1 Current Situation of Sustainability in Buildings

a) International

The annual rate of new buildings entering the building stock is very low compared to the number of existing buildings; and many of the existing buildings do not satisfy the sustainable requirements (Hassler 2009). According to the US Environmental Protection Agency (2007, 2008), as reported in McGraw-Hill Construction's report in 2006: in the US in 2005 green buildings included approximately 2% of the building market for both new commercial and residential buildings. The rate increased to between 5 and 10% in 2010. In Western Europe, the increase rate in the building stock is only 1% annually (Hassler 2009). The development of greener buildings in the economically developed Asian regions of Hong Kong and Singapore is significantly better; however, other large regions of Asia are still very low (Chan, Qian & Lam 2009). In Australia, approximately 2% of the demand for office buildings is satisfied annually by new construction (Adelaide City Council 2007; New South Wales Resource Centre 2009).

Therefore, the current concern regarding sustainable development is now on improving existing buildings. However, there is a lack of long-term strategies for sustainable building development: data from the registration of modifications to existing buildings appear too low; improving the life of existing buildings is usually based on a short time measurement rather than a long-term assessment which requires massive exchange, renovation and new technology (Hassler 2009).

One of the major barriers is the lack of information on green principles to be delivered to owners and tenants. The shortage of information results in key stakeholders misperceiving the performance, cost, and benefits of the technologies of sustainability (U.S. Environmental Protection Agency 2007, 2008). According to the Secretariat of the Commission for Environmental Cooperation (CEC) (2008), the main barriers in applying the principles of sustainable development for buildings are:

- Higher perceived or actual additional costs of green building strategies and technologies.

- Risk and uncertainty about green building technologies, development costs, economic benefits, and performance over time.

- Lack of experienced workers and therefore increased risk of inexperienced or untrained service professionals.

- Lack of coordination and consistency in government policies potentially harming practices and failing to require environmentally preferable practices.

- Lack of research that leads to misunderstanding the advances of green building development, cost savings, and strong return on investments.

- Lack of understanding of assessment of long-term costs of sustainable building.

Chan, Qian and Lam (2009) support the view and agree that lack of training and environmental awareness in the private sector is particularly important barriers. However, Garman et al. (2011) argue that the biggest barrier to green innovation in buildings is the building codes. Building codes ensure buildings provide health, safety and welfare to building users. Many current codes are prescriptive and based on traditional industry standards and should be amended to include innovative approaches to be environmentally responsible. The other problems are that the public, the building industry, and policymakers do not have concerns for sustainable development, or a very good understanding of it. Several barriers in the building industry to sustainability are contributing reasons the building sector has not performed significantly and that there is minimal public discussion of the issue (Lorenz, Lützkendorf & Panek 2005).

Therefore, the most important factors for the development of greener or sustainable buildings are low operation costs, higher building values and low lifetime costs. Enhanced marketability is considered a good reason for business interests, whereas increased staff productivity and retention, or reduced liability and risk are less important reasons. However, the shortage of detailed data and information about the concepts of green development may make developers unwilling to apply green building principles (Chan, Qian & Lam 2009).

b) Australia

The Australian building sector is a late developer of green buildings (Madew 2007). As mentioned previously, at the current rate of new building/rebuilding at around 2% per year (Adelaide City Council 2007; New South Wales Resource Centre 2009), it would take 50–100 years to replace the current stock (Bullen 2007). Therefore, the major part of building stock consists of older assets that are great consumers of energy and producers of toxic gases (Taylor 2009). According to Häkkinen and Belloni (2011); Hassler (2009); Pitt et al. (2009); and Wilson and Tagaza (2006), reasons why developers/owners are unwilling to invest in sustainable building development include:

- Sensitivity of financial risk including higher initial capital costs compared to conventional buildings.
- Assessment of short-term period rather than long-term costing.
- Lack of tenant demand.
- Lack of perspective of risk linked to change from traditional performances to greener implementations.
- Lengthening the approval process for new technologies and recycled materials.

In addition Häkkinen and Belloni (2011) further state that a lack of technology and methods are not holding back sustainable development, but in practice their implementation entails more risks and unforeseen costs . Similarly, Issaacs (2003) states that an understanding of rating systems in energy assessments is necessary in mitigating CO_2 emissions and making buildings greener.

3.2.2 Drivers for Improving Sustainability in Buildings

According to Wilson and Tagaza (2006), tenant demand for sustainable buildings can speed up the development of sustainable buildings as these buildings will:

- Have strength with the “green” brand.

- Meet standards for the buildings leases and occupations.

- Provide indoor environment quality to improve user’s health and productivity levels.

- Prevent the building from being obsolete by embodying ecologically sustainable development (ESD) standards.

Therefore, tenant demand is an important driver for the movement of green buildings in improving office buildings (Henderson 2006).

The most impact that tenants, especially existing ones, can make on existing office buildings to become more sustainable is to require the performance of these building to be improved prior to entering new leases (Madew 2007), because green buildings will provide lower operation costs on energy and water consumption to occupants (Estates Gazette 2009).

Another factor affecting sustainable building development is the consumer demand from the green market. The building sector is certainly moving towards green buildings, and existing buildings have the majority share in the total building market. When a building is deemed outdated, building owners could consider improving the building so it becomes greener or sustainable prior to re-entering the building market (Chan, Qian & Lam 2009).

Chan, Qian and Lam (2009) argue that the concept of sustainability can satisfy environmental and economic concerns; however, this concept is not widely accepted by the parties involved in the building sector. Additional costs and extra risks to meet green building standards might lead key stakeholders to become reluctant to consider entering the green building market. If the information on green buildings is not methodical and widely accepted everywhere concerning quality standards and mandatory requirements, most market players may choose to retain conventional buildings.

However, when new information, technologies and practices for green buildings are developed and accepted by the green building market, the additional costs and extra risks will decrease, and the barriers to enter will consequently be reduced (Ahn & Pearce 2007; Chan, Qian & Lam 2009).

Therefore, to speed up sustainable development for existing buildings:

- New appropriate regulations are needed to suit the long-lasting effects of the existing building stock.

- New incentive systems should be established for resource preservation or other regulations to ensure intergenerational value preservation to adjust for the effects of historical strategies.

Furthermore, Gottfried and Malik (2009) state that the main drivers for existing buildings to be greener are initiatives of three tiers of federal, state and local governments. Federal and state governments are making green buildings occur with their legislative policies and incentives; and local governments act as drivers through their regulations. Thus, government policies, incentives and regulations will help to speed up the performances for sustainable buildings (Secretariat of the Commission for Environmental Cooperation 2008; Yin & Cheng 2005).

Sustainability has the potential to improve existing buildings to satisfy economic needs on long-term wealth and the requirements of environmental protection. Even though there are many factors that may prevent investors/owners from implementing of new technologies in green buildings (Gerrard 2009); according to Häkkinen and Belloni (2011); and Pitt et al. (2009), there are many drivers that can lead key stakeholders to improve/upgrade their buildings to be sustainable as shown in Table 3.1. The table summarises the most significant drivers for sustainable buildings development. They are also ranked from 1 to 8, 1 being the most important and 8 the least important. The most important driver is financial incentives and the least important driver is lack of labelling/measurement requirements.

Table 3.1 Drivers for sustainable building development

Ranking	Drivers
1	Financial incentives
2	Building regulations
3	Client awareness
4	Client demand
5	Planning policy
6	Taxes/levies
7	Investment
8	Labelling/measurement

Source: Adapted from Häkkinen and Belloni (2011); Pitt et al. (2009)

Furthermore, as shown in Table 3.1, proper policies, experience in previous projects and knowledge of cost-benefits may accelerate the development of sustainable buildings (Garman et al. 2011; Marchman & Clarke 2011). A policy can be efficient when it can go hand-in-hand with information delivered to increase green building performances, responsiveness and knowledge (Ürge-Vorsatz, Koeppel & Mirasgedis 2007b). These factors are further discussed below.

3.2.3 Challenges for Improving Sustainability in Buildings

For existing office buildings, the process is to improve/upgrade buildings so that they are more sustainable (Sustainable Energy Research Group 2006). The main demand for improving/upgrading buildings for sustainability is to ensure energy and water consumption and carbon emission reductions in buildings by commitments to energy effectiveness, water preservation, waste prevention, recycling, decreased natural resource use, and productive and improved environments (Henderson 2006; New South Wales Resource Centre 2009; Taylor 2009). This can be achieved with better maintenance practices and the application of new technologies to upgrade the buildings and improve their energy efficiency, indoor comfort levels for occupants, lighting and air conditioning systems, water efficiency, and waste reusing and recycling (Abdallah & El-Rayes 2015; Jentsch, James & Bahaj 2010).

While almost every new commercial office building is now constructed encompassing green technologies and inventiveness, existing office buildings can also be improved or upgraded to meet sustainability standards (Abdallah & El-Rayes 2015; Madew 2007). The challenge is moving existing buildings from negative to positive impact by the year 2020 (The Green Building Council of Australia 2008). The challenge is not only to limit CO_2 emissions but also to reduce CO_2 emissions with a target level that is high but achievable. Under the “carbon neutral” challenge, buildings will be improved or upgraded with innovative techniques to reach “zero net operating emissions” in their adaptation, operation and embodied energy of building materials. The application of innovation and technical methods for sustainable buildings should reach the carbon neutral level in building operation and maintenance, such as passive indoor comfort and onsite renewable energy generation (The Green Building Council of Australia 2008)

The biggest advantage that existing office buildings gain by being sustainable is that they will stay competitive, increase energy and water effectiveness, reduce vacancy rates, increase rental levels, improve assets and counteract obsolescence (Burton 2001 cited in Wilkinson & Reed 2006a). Sustainable buildings increase in value, gain positive influence in keeping tenants, who will be provided with large savings on energy and water in running their businesses (Madew 2007).

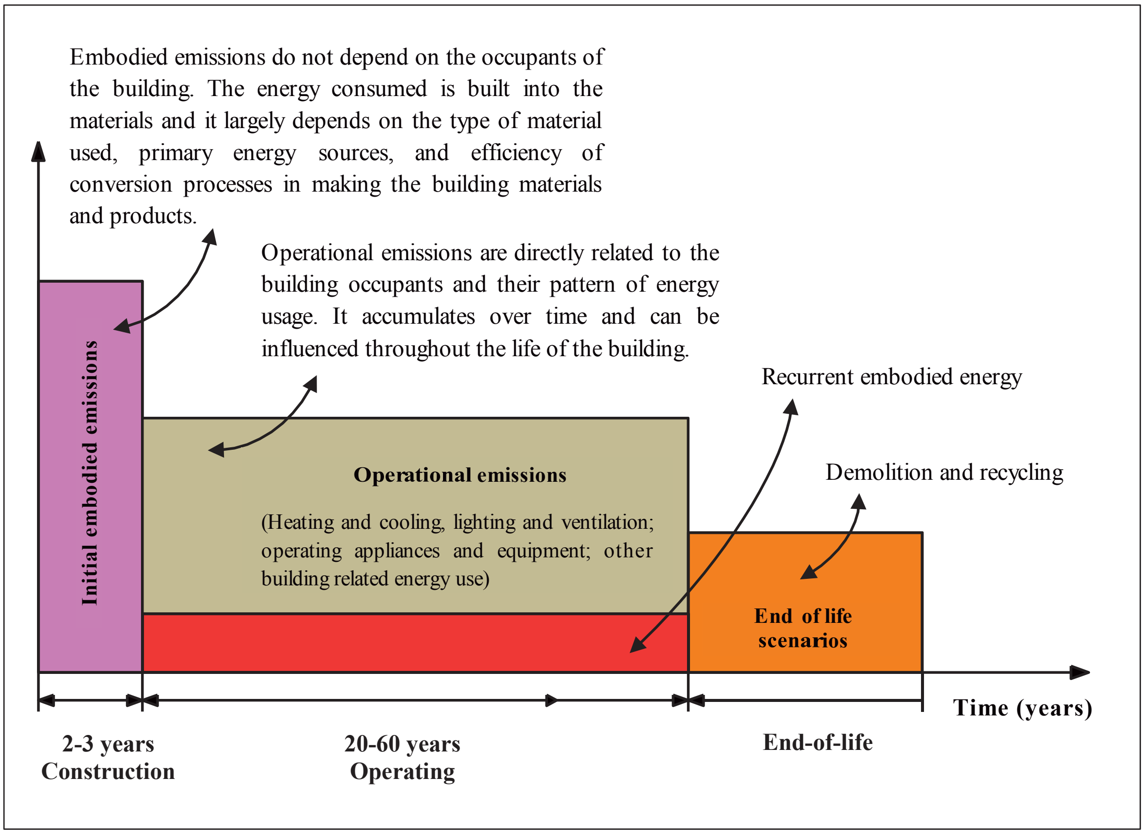
3.3 Office Building Maintenance

3.3.1 Building Maintenance Management

Maintenance management is the process to keep buildings/equipment functional over their life cycle (Pitt, Goyal & Sapri 2006; Witt 2004). The building’s operational phase is the longest period of the life cycle, and building maintenance is required during this period. Building maintenance management is defined as “the preservation of a building so that it can serve its intended purpose” (Arditi & Nawakorawit 1999b, p. 117). Burra Charter defined building maintenance management as “the continuous protective care of the fabric, contents and setting of a place” (Australia ICOMOS Charter for the Conservation of Cultural Significance cited in NSW Heritage Office 2004, p. 1). The greatest portion of energy and water are used in this phase (Huovila et al. 2009; Ibn-Mohammed et al. 2013). As shown in Figure 3.1 the operation and maintenance phase of a typical building is 20–60 years, compared to the construction phase, which is usually 2–3 years. The operational and embodied energy of the materials and equipment in this phase also account for a greater portion of energy and water usage. Consequently, a great rate of emissions is also generated during this period.

Building maintenance management is a key to maintaining the building and equipment functioning effectively over the life cycle (Pati, Park & Augenbroe 2010; Witt 2004; Wood 2009). Maintenance management involves the organisation of resources, such as materials, energy and water, to obtaining maximum benefits from the building (Pitt, Goyal & Sapri 2006). A building in poor condition will decrease in value and the indoor environmental aspects will be downgraded. The poor condition may harm the occupants, threaten production, cost more to operate, and so forth (NSW Heritage Office 2004; Pitt, Goyal & Sapri 2006).

Figure 3.1 Energy components and emissions of a building over its lifetime



Source: Adapted from Ibn-Mohammed et al. (2013)

According to the NSW Heritage Office (2004), the processes in building maintenance include:

- Preparing a budget for expenditure management.
- Inspecting the building.
- Preparing a program.
- Having a maintenance review by feedback and/or surveying at regular intervals.

A strategic maintenance plan can provide advantages such as:

- Maintaining property in a methodical rather than an unplanned way.
- Examining ways to optimise building services.
- Maintaining building standards and building presentation.
- Minimising decision-making about emergency corrective maintenance.

Building maintenance can be performed differently by application of practices that people use to assess it, and by location and region. Son and Yuen (1993 cited in Pitt, Goyal & Sapri 2006) suggest that maintenance of a building can be properly covered by four categories:

- Planning and carrying out of day-to-day maintenance of servicing, cleaning and inspection of facilities and components.
- Rectification work due to any defect in design or improper use of materials.
- Replacement of any items considered high-relative cost.
- Retrofitting or modernisation work for modification, addition, and improvement to existing buildings.

Therefore, the best practice in building maintenance is considered to have a plan which can focus on routine maintenance, ad hoc maintenance and upgrading maintenance. The details of these maintenance performances are further discussed in the next Section 3.3.2.

3.3.2 Definition of Building Maintenance

Commonly, building maintenance will focus on repairing or replacing components and performing periodic maintenance or work according to the requests of the users (Pitt, Goyal & Sapri 2006). Following Arditi and Nawakorawit (1999b); Chanter and Swallow (2007); the NSW Heritage Office (2004); and Pitt, Goyal and Sapri (2006), in this project, maintenance practices for existing office buildings are put into three categories with the aim to achieve energy and water efficiency, and consequently to reduce CO_2 emissions. These categories are covered throughout this research project as follows:

a) Routine Maintenance

Routine maintenance includes:

- Service maintenance such as periodic cleaning and services to systems or equipment.
- Preventive maintenance such as periodical inspections, audits, and services to systems and equipment.

Service maintenance includes common and regular work. This type of strategy can be time-based maintenance, planned maintenance or cyclic maintenance for regular and/or interval performances over the operating time, such as weekly, monthly, quarterly, half-yearly and yearly.

Preventive maintenance can be executed to reduce the breakdown of buildings, components or systems. Preventive maintenance keeps a building operating at peak efficiency through regular inspections and repair/upgrading/replacement. The aim is to catch small problems before they become big and expensive. Preventive maintenance can also follow the recommendation of suppliers or manufacturers. This is in addition to service maintenance or combinative work along with service maintenance.

b) Ad Hoc Maintenance

Ad hoc maintenance comprises works on:

- Repair maintenance such as inspect and repair breakdown of the systems or equipment.

- Corrective maintenance such as inspection, adjustment and correction of the systems or equipment - due to their long service.

Repair maintenance consists of immediate work required for health, safety, security reasons, and so forth. It is necessary due to the wear and tear of the systems or equipment, for example, repairing damage to HVAC systems or motors, lighting systems or leaking water pipes.

Corrective maintenance is work required for restoring a system or equipment to a satisfactory standard, such as treatment of water in cooling towers. This work consists of repairs to systems or components due to natural wear and tear or faulty preventive maintenance. Where system or equipment problems arise, there may be a question about whether the particular item should be repaired or replaced. Corrective maintenance can also be referred to as failure-based or unplanned maintenance.

c) Extraordinary Maintenance or Upgrading Maintenance

Extraordinary maintenance or upgrading maintenance consists of:

- Refurbishment of systems or equipment at the end of service life rather than replacement.

- Replacement of systems or equipment at the end of service life due to it being too old, obsolete, unable to be refurbished or upgraded to a new system.

Extraordinary maintenance is tasks involving major rehabilitation, refurbishment or replacement of systems or equipment. This is the biggest and most expensive type of maintenance.

3.3.3 Problems in Traditional Building Maintenance

The owners and/or facility managers usually face problems in building maintenance management. Most major problems in building maintenance management strategies are unplanned or delayed. According to Dillon (2005), a number of main factors lead to maintenance management strategies being unplanned or delayed.

- There is a lack of resources. Usually, an annual budget for building maintenance may be constrained over time. There is also the absence of maintenance staff or out-of-date maintenance skills of maintenance staff; also, technology, standards, and responsibilities change over time. Modern society also requires buildings to be improved and/or upgraded to new standards, such as indoor conditions and air quality.

- There may be a lack of planning. This can occur in both private and public sectors. Maintenance is often ignored because owners are too busy with their business operations.

- There is a lack of understanding. Maintaining a building in good shape and saving money over time by performing preventive maintenance is not usually identified. For instance, according to the US Department of Energy, the annual costs for lighting, heating, and power for school buildings account for 25% of building operating costs; however, a report claimed that this can be reduced up to 5–20% when proper maintenance strategies are planned (Dillon 2005).

- There is a lack of priority. Within the allowed budget, maintenance strategies should be considered the priority for performance of the plans (Dillon 2005). The most urgent actions should be chosen after the budget has been approved (Taillandier, Sauce & Bonetto 2009), so that "maintenance needs to be recognised as a major need in all states" (Dillon 2005, p. 31).

Over the building's lifetime, the most important cost and biggest difficulty for owners and/or facility managers is equipment maintenance. A study by Arditi and Nawakorawit (1999a) found that the average maintenance costs for equipment of case studied buildings account for almost 79% of total maintenance requirements. Mechanical and electrical systems are the most difficult and costly components to clean, inspect, repair and replace in maintenance practices (Arditi & Nawakorawit 1999a).

The most effective action in building maintenance is risk reduction. To have solutions based on risk-based investment for maintenance management, risks should be identified and addressed with fundamental actions, and then there should be optimisation of a comprehensive investment plan with the longer-term perspective of a multi-year maintenance plan for buildings (Taillandier, Sauce & Bonetto 2009).

Furthermore, there is traditionally a lack of cooperation between parties relating to a building, such as the facility designer, manager, owners and tenants. This lack of cooperation can result in maintenance practices being ineffective (Pati, Park & Augenbroe 2010).

Therefore, traditionally, maintenance is practiced as repair work. There are a few methods used to foresee malfunctions or a plan applied for preventive maintenance (Takata et al. 2004). For example, a system is used until it is broken and then repaired or replaced. A change from unplanned maintenance practices to a sound and strategic maintenance program is required for sustainability to be achieved. A plan for routine maintenance associated with regular inspections is a better way to make big savings by avoiding unexpected repair work. Sustainable maintenance over routine, ad hoc and upgrading maintenance is not commonplace in building maintenance management but provides benefits by supporting learning from errors and adds value to the life of the building (Pitt, Goyal & Sapri 2006; Pitt et al. 2009).

3.4 Improving Office Buildings with Sustainable Practices in Australia

The most complicated and costly period of a building's life cycle is the operation and maintenance phase (Huovila et al. 2009; Ibn-Mohammed et al. 2013; Pitt, Goyal & Sapri 2006; Witt 2004). According to Ive (2006), over a 30-year period the cost of operation and maintenance of office buildings is about 2 times the cost of initial construction. This cost can be estimated to be up to five times the cost of initial construction over the life of the buildings (Evans et al. 1998; McDougall et al. 2002; Snodgrass 2008). The biggest expense is for energy usage in the buildings for internal comfort, lighting and running equipment. Compared with other types of buildings, office buildings are among the highest consumers of energy, and consequently, contribute high levels of GHG emissions (Ibn-Mohammed et al. 2013). The annual energy consumption of office buildings varies between 100 and 1,000 kWh per square metre depending on geographic location, type and use of office equipment, operational schedules, type of envelope, use of HVAC and lighting systems, and so forth (Burton & Sala 2001 cited in Juan, Gao & Wang 2010). The next largest costs are water consumption, materials for maintenance and fit-outs, and waste to landfill.

Pitt, Goyal and Sapri (2006); and Pitt et al. (2009) suggest that sustainable buildings, maintenance is not only a technical consideration but also requires a quality system. The availability of production facilities, and the volume, quality and cost of production will influence the method of maintenance. This innovation can mean effective maintenance management, known as integrated maintenance management systems. The aim of integrated maintenance management is to keep facilities optimally functional and to satisfy environmental protection regulations. Innovation maintenance management of buildings to make them more sustainable will grow and provide adequate competition to keep driving improvements in building maintenance. Building maintenance management is a process of continuous innovation and enhancement to satisfy all requirements.

Improving maintenance practices to bring an existing office building up to satisfactory environmental requirements is the target of maintenance managers. Current and future targets are to reduce the uses of energy, water, conventional materials and waste disposal to landfill during the operation and maintenance of the building. The significance for Australia's existing office buildings under the concept of sustainable buildings is that "everything old is new again" (Larsen 2009).

3.4.1 Sustainable Maintenance Practices for Buildings

The Australian building stock comprises a large number of older buildings which consume great quantities of energy and water, and produce a high rate of toxic gases (Taylor 2009). Traditionally, to maintain its intended function a building has to be well maintained and, particularly, have a major refurbishment every 20–25 years (Wilkinson & Reed 2006b). However, according to Wilkinson and Reed (2006a; 2006b); and the Adelaide City Council (2007), the average age of the office building stock in major Central Business Districts (CBDs) throughout Australia is found to vary from 25 to 31 years since construction or from 13 to 19 years since last refurbishment; and the average age of office buildings in Sydney is 28 years and 19 years respectively. This shows that the Sydney office building market possesses old properties. Existing building stock continues to contribute negatively to the environment and the well-being of users. Therefore, current existing office buildings in Australia and Sydney must be improved to meet environmental standards (Remøy & Wilkinson 2012; Strachan & Banfill 2012; Xu, Chan & Qian 2012).

Another factor is that, according to a study by Nguyen, Ding and Runeson (2013), only 17% of Sydney's office buildings are maintained with sustainable maintenance as general practice by owners/facility managers; 65% considered applying sustainable maintenance in the 6–10 years or more, and another 18% not specified. In addition, 64% against 36% of building owners and facility managers still employ conventional building materials and finishes in building maintenance. This indicates that sustainability is not widely applied in Sydney's office buildings, and most office buildings are still maintained with traditional maintenance methods.

3.4.2 Sustainable Maintenance Practices for Buildings in Australia

According to Lecamwasam, Wilson and Chokolich (2012), best practice maintenance can be carried out with a focus on energy and water efficiency which can provide utility cost savings by 10–40% compared with poor maintenance practices. The following are requirements from the government for achieving sustainable maintenance practices for office buildings.

- Under the Australian policy for energy efficiency, governments have implemented the national Green Lease policy which requires tenant occupied buildings to have low impact on the environment, such as a 4.5 star or higher NABERS energy rating or a 4 star NABERS water rating (New South Wales Government 2014).

- The private sector is also required to ensure buildings reach recommended efficiency levels, and where possible, existing buildings should be upgrading or replacing their systems or equipment. When upgrading, maintenance managers should ensure the system or equipment is produced with high coefficient of performance. When replacing, new systems or equipment must comply with current minimum efficiency performance standards.

- Under the national energy program for Commercial Building Disclosure, from 1 November 2010, when selling or leasing an office space greater than 2,000 m^2 sellers or lessors are required to obtain or disclose an up-to-date NABERS energy rating. Also required from 1 November 2011 is the disclosure of a Building Energy Efficiency Certificate.

Typical targets for buildings, according to Lecamwasam, Wilson and Chokolich (2012); and Sartori and Hestnes (2007), are expressed in $kWh/m^2/year$ or $MJ/m^2/year$ for energy consumption, kg $CO_2/m^2/year$ for GHG emissions and $ML/m^2/year$ or ML/occupant/year for water consumption. The target of energy used in the provision of services in office buildings (Office-Central Service), including air conditioning, lifts, security and lobby lights, domestic hot water and so forth, is 400 $kWh/m^2/year$ for the use of electricity. With better management of systems/equipment and lighting loads, the typical annual energy usage for cooling an office building may be reduced by 60–75% (Jenkins et al. 2008).

3.4.3 Criteria of Sustainable Maintenance

A better way to approach sustainable maintenance to minimise negative environmental impacts is upgrading of building systems or components (Abdallah & El-Rayes 2015). The renovation of an office building to make it more sustainable should consider energy efficiency (EE), lighting efficiency (LE), indoor environment quality (IEQ), water efficiency (WE), environmental materials and resources (EMR) and waste disposal management (WD) (Juan, Gao & Wang 2010). In upgrading, buildings should integrate sustainable measures such as energy efficient lighting, motion sensors, efficient HVAC systems, renewable energy systems, water-saving plumbing fixtures, and solid waste management plans (Abdallah & El-Rayes 2015).

Table 3.2 summarises these criteria and assessment items. The table shows that for enhancing energy efficiency, the upgrading work should consider improvements to windows and shifting to renewable energy sources, such as solar power. For lighting systems, application of technology in integrating mechanical lighting and natural daylight is better for performance. To improve indoor environment quality, recommissioning/tunning or upgrading the HVAC systems and reducing the use of high-impact chemicals can be applied. Water efficiency can be improved with waterless devices and fixtures to reduce water use and recycle wastewater within the buildings. Lastly, in materials and resources management, reused and recycled materials, purchasing green power or the use of solar power are preferred. Materials and resources management can also improve waste disposal.

Table 3.2 Renovation criteria for sustainable maintenance of office buildings

Criteria	Sub-criteria	Assessment items
Energy efficiency (EE)	Thermal and moisture improving	Openings of primary facade orientation; Occupied density
	Openings improvement	Openings area; Solar shading; Windows insulation
	Innovative energy technology	Renewable energy sources e.g. solar, wind energy, etc.
Lighting efficiency (LE)	Electric lighting improving	Overheating condition; Indoor daylight; Electric lighting;
Indoor environment quality (IEQ)	HVAC improving/upgrading	Natural ventilation; Energy-saving HVAC devices
	Outdoor air introduction and exhaustion systems	Air introduction/exhaust system maintenance
	Tobacco smoke control	Smoke control devices
	Indoor chemical and pollutant control	Natural paints; IEQ management plan
	Occupant comfort and IEQ management	Indoor climate control; Chemical/pollutant control devices
Water efficiency (WE)	Water performance measurement	Water measurement devices
	Wastewater technology	Wastewater technologies
	Water use reduction	Waterless urinal and toilet type
	Cooling tower water treatment	Cooling towers treatment
Environmental materials and resources (EMR)	Purchasing policy	Green furniture/materials purchasing
	Storage and collection for recyclables	Storage/collection plan
Wastes disposal management (WD)	Sewage and garbage improvement	Waste management plans; Adaptable design strategies

Source: Adapted from Juan, Gao and Wang (2010)

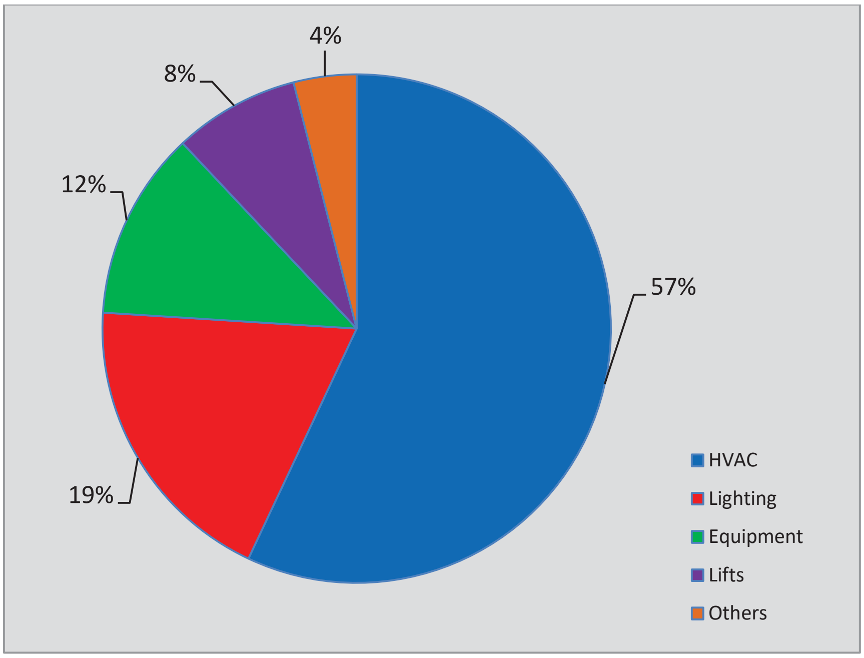
a) Energy Efficiency (EE)

In the life cycle of buildings, most energy is used to provide heating, cooling, lighting and office equipment, such as service systems, HVAC, lighting, equipment and appliances. Together, they account for about 80% of total energy use during the operational and maintenance period (Abdallah & El-Rayes 2015; Juan, Gao & Wang 2010; Santamouris et al. 1994).

Energy is the highest cost item in operating office buildings (Pitt, Goyal & Sapri 2006; Witt 2004). It is also the main source of impact on the environment. Australian office buildings alone accounted for 33.6 PJ (petajoule) or 25% of the total energy consumed by all types of building, and for 8.7 Mt CO_2 or 10% of total GHG emissions in 2009 (Higgins et al. 2014; Pitt & Sherry 2012; Steinfeld, Bruce & Watt 2011). As reported by the Fourth Assessment Report (AR4) of the IPCC (2007), the commercial sectors can save approximately 1.4 billion tonnes of CO_2 by 2020. These GHG emissions can be reduced by approximately 29% or even at zero-net with further commitment (IPCC 2007 cited in Ürge-Vorsatz, Koeppel & Mirasgedis 2007b).

Commonly, the greatest end use of energy in Australia is the use of electricity within the buildings. Nationally, the average electricity end use shares for base office buildings are HVAC systems at 67%, lighting at 15%, equipment at 11%, domestic hot water at 2% and other electrical processes at 4% (Council of Australian Governments (COAG) 2012b). In Sydney, the peak electricity demand in office buildings (both base and tenant loads) is HVAC systems accounting for 57%, lighting for 19%, equipment for 12%, lifts for 8%, and others for 4% (Knight et al. 2006 cited in Steinfeld, Bruce & Watt 2011). Figure 3.2 indicates the energy end use shared in Sydney office buildings.

Figure 3.2 Energy end use shared in Sydney office buildings



Source: Night et al. 2006 cited in Steinfeld, Bruce and Watt (2011)

When a large office building is upgraded with an automation system, such as building management and control systems (BMCS) a savings of 30% can be achieved from energy consumption within the building (Colmenar-Santos et al. 2013). The initial capital outlay for becoming green can be expected to be recovered by decreasing long-term energy costs.

According to COAG (2012b), in the base year 2009, the annual average energy intensity of office base buildings was around 530 kWh/m^2/year. For office tenancies it was less than 60 kWh/m^2/year. However, as found by Steinfeld, Bruce and Watt (2011), an office building having a market average of 2.5 stars NABERS energy rating accounting for 174 kWh/m^2/year can improve to an average 5 star rated building accounting for 75 kWh/m^2/year. The result is reducing the end use of energy by up to 57% per year compared to buildings with average energy performance. In an environmental assessment for NSW and the Australian Capital Territory, according to Lecamwasam, Wilson and Chokolich (2012), when 1 kWh is saved, there is a reduction of 1.06 kg CO_2 emitted into the environment.

Therefore, considering Hinnells' (2008) opinion, the key to green refurbishment and/or upgrading of existing office buildings is actual energy savings. Improving an existing building so it becomes a green building requires new technology where practical in all or parts of the building and depends on the policy of the owners. There is a need to understand new technology and users behaviours so that:

> The combination of green design techniques and clever technology can reduce not only energy consumption and environmental impact, but also reduce running costs, create a more pleasant working environment, improve employees health and productivity, reduce legal liability, and boost property values and returns (Herzog et al. 2004, p. 17).

Additionally, green design in upgrading requires buildings to meet the least critical environmental impact, while improving economic performance (ISO 2005 cited in Hakkinen & Nuutinen 2007). Moreover, Hinnells (2008) said that the right decision-making framework for stakeholders is most important to encourage changes. This would include:

> …information (e.g. labels), incentives (e.g. the governments' proposals for carbon reduction commitment) and know-how and access to capital (e.g. energy services companies or ESCOs). Such a framework can be underpinned by regulation (e.g. the energy-using product directives) to remove the worst products from the market. There is a significant challenge in integrating the engineering and technology issues appropriately with the behavioural, economic and policy issues (Hinnells 2008, p. 4433).

b) Lighting Efficiency (LE)

Improving the lighting load will not only reduce annual energy consumption but also reduce heat gains in buildings. The reduction of electrical consumption in office buildings can be achieved with proper daylighting schemes, which is an integration of daylight and artificial lighting systems. Thus, building energy expenses can be affected by two key climatic factors, solar radiation and outdoor illuminance, which can cool the buildings without the use of electricity where there is a proper strategic plan (Li & Lam 2003; Li et al. 2009; Li, Lam & Wong 2006).

In existing office buildings, the lighting systems that include tubes or fixtures can be retrofitted with more energy effective ones or by decreasing unnecessary lamps, which are the main strategies of building managers due to costs (Zmeureanu & Peragine 1999). Daylighting in office buildings are broadly considered an important design strategy of energy preservation that demanded cautious architectural design to satisfy that optimum benefits are achieved (Ko, Elnimeiri & Clarke 2008). Another factor affecting the effectiveness of the lighting system in office buildings is that the lighting system continuously interacts with the HVAC system. To improve energy efficiency for heating in the winter and reducing energy use for cooling in summer, the refurbishment or upgrading of the lighting systems must be coordinated with HVAC systems (Abdallah & El-Rayes 2015; Juan, Gao & Wang 2010). Moreover, the optimal energy balance used for cooling, heating and lighting can only be achieved by incorporating daylighting and thermal aspects (Bodart & De Herde 2002). Due to daylight constantly being associated with solar heat gain, when design levels exceed the space luminance required, solar heat gains will increase, and consequently the electrical cooling load will also increase (Li & Lam 2003; Li et al. 2009; Li, Lam & Wong 2006).

The design strategy of daylighting, which requires effective space usage, is usually dependent on the lease span measures and an impact of other elements, such as the aspect ratio, floor-to-floor height, total height and total floor area. It is also associated with window types, sizes and glazing methods. As Zain-Ahmed et al. (2002) found, when a strategy of daylighting is performed alone in buildings, the energy savings can reach a maximum of from 10 to 20%, and the sensible heat load on air conditioning systems can be decreased by approximately 25–35% depending on the climate conditions. However, according to Bodart and De Herde (2002), generally, in adapting daylighting, the consumption of electricity for the artificial lighting systems employed in office buildings can be reduced by 50–80% when a connection between daylighting and glazing and/or high-performance glazing is exercised.

In addition, geographic location and outside climate are factors that will affect the daylighting design. Thus, the proper integrated design for daylighting incorporated with the indoor lighting systems will certainly improve energy efficiency for office buildings. The integration can be associated with other retrofitting measures including dimming ballasts and lighting controls, electrochromic window glazing, heat pumps, building integrated photovoltaic systems, building monitoring system for HVAC systems, upsized electrical wiring and changes in users behaviour (Ko, Elnimeiri & Clarke 2008; Madew 2007).

c) Indoor Environment Quality (IEQ)

The HVAC systems are employed in office buildings to provide a comfortable indoor environment. Indoor thermal comfort is a major source of energy consumption (Lecamwasam, Wilson & Chokolich 2012). According to Clarke et al. (2002 cited in Barlow & Fiala 2007), by 2050, buildings which installed conventional HVAC systems to retain comfortable conditions will increase levels of energy use as the interior temperatures could exceed comfort levels in the buildings by over 20% on working days. Consequently, CO_2 emissions and pollution will also increase. Sustainability in indoor environment quality can be categorised into saving energy consumption for indoor thermal comfort and improving indoor air quality. In achieving the efficient use of energy and reducing CO_2 emissions relating to indoor thermal comfort, conventional air conditioned offices have to be retrofitted (Barlow & Fiala 2007). A reliable HVAC system is extremely important in affecting the level of occupants productivity and comfort (Au-Yong, Ali & Ahmad 2014a).

A HVAC system that is well maintained will provide better indoor comfort (Kwon, Chun & Kwak 2011). According to Budaiwi (2007), an acceptable thermal situation for satisfying people’s desire for interior thermal comfort is becoming a major demand for the indoor environment. The balance of a human body through gains and losses in body heat depends on the thermal environment. This includes air temperature, air humidity, air velocity, mean radiant temperature, occupants clothing, and activity rates. The human body through its regulatory system acts as a passive object in exchanging heat within its surrounding in the course of radiation, convection, and conduction. It will also lose heat by evaporation and response to space conditions (Budaiwi 2007). To provide acceptable thermal comfort in offices during summertime, as suggested by Nasrollahi, Knight and Jones (2008), the indoor temperature should be maintained below 26 ^oC when outside temperature is in a range from 25 to 35 ^oC and relative humidity (RH) between 20 and 45%.

However, Tian and Love (2008) recommend that indoor temperatures in buildings with environmental control systems should remain between 20 ^oC and 26 ^oC. The neutral operative temperature is about 24 ^oC in summer and 22 ^oC in winter - a difference of approximately 2 ^oC. As Tian and Love (2008) found, indoor comfort can be acceptable when the measured average indoor operative temperature is around 22 ^oC but varies between 20 ^oC and 24 ^oC in both summer and winter. To receive more on energy savings, Tian and Love (2008) suggested that the average air temperature for indoor comfort can be set at around 22 ^oC in both seasons with a variation of 20–24 ^oC.

The quality of indoor air has certain negative and positive effects on the productivity of office employees and especially occupants' health and safety. The population of occupants in a building with unsatisfactory ventilation and poor indoor air quality can lead to the indoor absorption of CO_2 that can increase the concentration of bacteria and moulds. These may cause Sick Building Syndrome (SBS) and other problems, such as a heterogeneous group of non-specific symptoms which consist of headaches, fatigue, lack of concentration, problems of the mucous membranes, and skin irritation or dryness. These symptoms disappear as soon as people leave the building (Engelhart et al. 1999). The indoor air quality of existing office buildings can be improved by incorporating either mechanical or natural ventilation systems (Lahtinen et al. 2009; Mentese et al. 2009).

For sustainable buildings, indoor thermal comfort should be designed to meet the required needs, such as air conditioning systems designed in conjunction with or without window shading types. Localised zoning comfort spaces should be controlled by the users on demand (Koerth-Baker 2007; Nasrollahi, Knight & Jones 2008). However, the energy consumed in existing office buildings would be significantly reduced if the occupants responded to their environment, such as adjusting their clothing, locality or cooperating; for example, by manually opening windows for natural ventilation, and so forth. Furthermore, today, people are more pleased with their thermal comfort when they can control it, such as by personally controlling individual climate. This explanation is more likely a psychological response (Nasrollahi, Knight & Jones 2008).

A study by Niemela et al. (2006) found that having proper indoor quality would result in an average reduction of general illness symptoms by 10%. Productivity will also increase by 2% and an average level of irritation decrease by 10%. The short-term absenteeism rate will decrease by 1%. Therefore, according to these results, key stakeholders can achieve better interior environments in existing office buildings through green improvements.

d) Water Efficiency (WE)

As discussed in Chapter 2, Australia is a dry country with limited fresh water supplies (Clarke 2009; Kingsford 2009) and office buildings account for 10–20% of urban supplied water (Australian Department of the Environment and Heritage 2006; Chanan et al. 2003). In office buildings, a large component of water use is in toilets, showers and basins (Australian Department of the Environment and Heritage 2006; Chen, Ngo & Guo 2012; Sydney Water 2007). Table 3.3 summarises the end use of water in a typical office building in global, Australia-wide and Sydney areas. The rates are different due to the assessments being carried out using different methods and in different geographic regions. Toilet flushing is the highest water component in office buildings; it represents more than 60% of water usage for amenities (Hills et al. 2002 and Shouler et al. 1998 cited in Chen, Ngo & Guo 2012). This provides many opportunities for achieving possible savings in water schemes for sustainable water management. Traditionally, the average daily water amount required for these usages can be as high as 155 litres per person. This amount of water usage can be reduced by 25–30% in buildings currently managed with an inefficient water operation (City West Water 2014).

Table 3.3 End use of water in a typical office building

End-use	Global [1]	Australia [2]	Sydney [3]
	%		
Amenities	31	37	37
Cooling towers	48	31	25
Leakage	No record	26	28
Shops/retails	No record	3	6
Landscaping/irrigation	18	1	1
Other	3	2	3

Sources: [1] Chanan et al. (2003)
[2] Australian Department of the Environment and Heritage (2006)
[3] Sydney Water (2007)

According to Chanan et al. (2003), a conventional office building can be improved to achieve from 80 to 87% of water savings through best practice water efficiency, such as adopting new technologies in the efficient use of water. Sewage discharge, which is recycled for use as treated water, can reach a limit of 90% in a sustainable building compared to a conventional building. However, the target in reusing and recycling water for Sydney is to reduce 35% of potable water consumption in buildings from 2011 to 2020. This rate of consumption is required to be further reduced by 10% by 2020 (NSW Office of Water 2010; Radcliffe 2006 cited in Chen, Ngo & Guo 2012).

Recycled water consumption in commercial buildings can be a major factor in saving the supply of drinking water. However, it is necessary to be careful with odour problems (Hurlimann 2006, 2007; Hurlimann & Dolnicar 2010). According to Hurlimann (2009) water savings can be also be accounted for with the use of efficient fixtures, such as water flow regulator taps, showerheads, toilets, waterless urinals and closets. However, in office buildings, showerheads are not considered as important in water management due to actual usage levels. Currently, the Australian government has also adopted other technologies to supply water to consumers, such as dual piping water supply, which consists of potable water for drinking and showers, and treated water for toilet flushing and garden watering, desalinated seawater, and so forth. The use of recycled water for drinking is significantly challenging (Hurlimann & Dolnicar 2010; Hurlimann 2009).

Table 3.4 summarises water savings of modelled options for a typical sustainable office building compared to conventional office buildings. When a building is upgraded with water saving devices it can provide savings from 35 to 70% of the total water use within the building. When combined with reused water and rainwater, savings up to 85% can be achieved.

Table 3.4 Water savings of modelled opinions compared to conventional office buildings

No.	Option	Water savings (%)
1	Business as usual: 11 L/minute showerheads; 6/3 L dual flush toilets, 6 L/flush urinals, 12 L/minute tap aerators	0
2	Level 1 Efficiency: AAA 9 L/minute showerheads; 6/3 L dual flush toilets, 2.8 L/flush urinals, 6 L/minute tap aerators	> 35
3	Level 2 Efficiency: 5 L/minute showerheads with user feedback; 5/2 L dual flush toilets, waterless urinals, 2.5 L/minute flow regulated taps with infrared sensors	> 70
4	Effluent reuse in toilets: 5 L/minute showerheads with user feedback; 5/2 L dual flush toilets, waterless urinals, 2.5 L/minute flow regulated taps with infrared sensors	> 80
5	Rainwater supply: as (4) + effluent reuse in toilets and roof garden	> 85
6	Rainwater supply: as (4) + composting toilets+ effluent reuse in toilets and roof garden	> 85

Sources: Adapted from Chanan et al. (2003)

In addition, according to Vince et al. (2008), each potable water supply project needs a kind of water treatment process, such as desalination, nanofiltration, conventional treatment process and so forth. These processes use energy for potable water production. Table 3.5 summarises minimum and maximum values of energy consumption used to produce potable water in kWh per m^3 of water treated in plant life cycle steps. For example, each m^3 of conventional fresh water treatment process accounts for a minimum of 0.1 kWh to a maximum of 0.2 kWh of energy consumption. This energy consumption does not include the energy used to convey potable water from the plant to the buildings. Saving water used in buildings reduces the energy used to produce potable water and consequently reduces CO_2 emissions.

Table 3.5 Energy consumption to produce potable water in plant life cycle steps

Potable water production plant life cycle steps		Energy consumption to produce potable water (kWh/m^3)	
		Min	**Max**
Intake pumping		0.05	1
Water treatment process	Conventional fresh water treatment process	0.05	0.15
	UF/MF membrane fresh water treatment process	0.1	0.2
	Advanced fresh water membrane treatment process	0.4	0.7
	Brackish water desalination (NF, BWRO)	0.6	1.7
	Seawater membrane desalination with ERI (SWRO)	3.5	4.5
	Seawater membrane desalination without ERI (SWRO)	5.5	7
	Thermal desalination (distillation) [1]	6.5	20
	Reuse	0.25	1.2
Chemicals production		0.1	0.4
Potable water distribution		0.2	0.8

Source: Vince et al. (2008)
Notes: 1: Electricity + electrical equivalent of heat

e) Environmental Materials and Resources (EMR)

The use of materials in office buildings is associated with their embodied energy for production, transport and construction. A significant amount of building materials transported onto sites are bedded in landfill (Urie & Dagg 2004). Materials are not only considered in new construction projects but are also considered as a way to improve existing buildings. Particularly, office buildings have common activities in maintenance work, refurbishment or replacement of components or systems, and procedures of fit-out churn (Douglas 2006 cited in Isnin, Ahmad & Yahya 2012). With a new lease, the returned pre-lease condition space is ready for the fit-out for the new tenant. New materials will be demanded and the selection should consider sustainable materials (Florez & Castro-Lacouture 2013). Table 3.6 summarises the contribution of primary energy demand and CO_2 emissions associated with the manufacture of some commonly used materials. The assessment is based on 1 m^2 gross floor area (GFA). As shown in the table, wood has low rates of contribution of primary energy demand at 2%, and 1% of CO_2 emissions. Steel has high rates at 26% and 19%, respectively.

Table 3.6 Contribution of primary energy demand and CO_2 emissions associated with the manufacture of some building materials by 1 m^2 GFA

Material	Contribution of primary energy demand (%)	Contribution of CO_2 emissions (%)
Steel	25.5	18.7
Ceramic	21.5	20.3
Cement	11.7	30.3
Mortar	9.1	6.9
Aluminium	7.7	2.3
Additives	4.0	1.5
Gravel	3.5	2.9
Lime	3.0	7.9
PVC	1.9	1.0
Wood	1.5	1.1
Others	8.8	5

Source: Zabalza Bribián, Valero Capilla and Aranda Usón (2011)

To be sustainable, materials chosen for the maintenance of office buildings should have a low content of embodied energy and should not discharge pollution or other emissions that affect human health and comfort throughout their life cycle (Ding 2014). Both initial and recurrent embodied energy are important for the energy efficiency of building materials. Commonly, sustainable materials selected may be on an environmental claim, eco-labelling benchmark or environmental product declaration. Materials used for a buildings finished areas, such as walls, floors and ceilings, may produce fumes, formaldehyde, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) which may be found in paint, furniture, wallpaper, flooring, carpet, timbers, and other furnishings (Isnin, Ahmad & Yahya 2013). These products are the most commonly used in the maintenance of office buildings and they may all affect occupants health.

However, to provide the function necessary for office buildings while minimising material and energy consumption in sustainable maintenance management, Takata et al. (2004, pp. 643-644) state that the plan for maintenance management should include all phases of the life of a building from design to demolition:

> … a need to change the paradigm of manufacturing from "how to produce products most efficiently" into "how to avoid producing products while still maintaining customer satisfaction and corporate profits"… a need to consider from the perspective of life cycle management is the notion of "production free" rather than "maintenance free".

Their opinion calls for innovation in building maintenance such as maintenance strategy planning, monitoring, and diagnosis for preventing failures rather than carrying out failures of systems (Cunningham 2007). Therefore, preventing a system breakdown is preferred over letting a failure occur and then having to repair or replace the system. This is an expected strategy for sustainable maintenance of buildings.

f) Waste Disposal Management (WD)

Waste to landfill is currently a major problem for human health, the environment, and land and resource use (Guerrero, Maas & Hogland 2013; Marshall & Farahbakhsh 2013). A sustainable practice of waste management should be accomplished to lower pollution and improve the environment (Al-Salem, Lettieri & Baeyens 2009; Hardie, Khan & Miller 2006).

According to Resource NSW (2002); and Hardie, Khan and Miller (2006), many office buildings already have recycling systems in place; however, the rates of recycling are still under the expectation for environmental protection, and the recycling system contains a lot of contamination. Waste disposal management can be planned to avoid, reduce, reuse, recycle, recover, treat and dispose (Zero Waste SA 2014). As shown in Figure 3.3, the preferable waste management method is to avoid generation of waste, and the least is to dispose of waste to landfill.

Figure 3.3 Waste disposal management plan

Source: Zero Waste SA (2014)

The best practice of waste management starts with office building managers providing appropriate facilities for waste to be sorted by paper, cardboard, drinks containers, reusable stationary items, and garbage for reuse, recycling and landfill (Resource NSW 2002). A target of reducing waste to landfill was by 50% per capita from 2000 (Terry & Moore 2008). Significantly, in Australia, the Australian WasteWise construction project reduced the budgeted amount for waste removal by approximately 50% (Miller, Khan et al. 2005 cited in Terry & Moore 2008).

To sum up, existing office buildings can be improved to become environmentally friendly buildings through sustainable maintenance practices that are the expected resolution for the environmental crisis. Buildings which have sustainable maintenance practices can provide big savings of energy and water consumption and especially reduce large rates of CO_2 emissions to the environment. The new targets now for both owners and tenants are to share all benefits in improving building performance. The cost for upgrading traditional buildings to green buildings may be between 3 and 16% of the price of the work (Estates Gazette 2009). To encourage the movement to be green, capital expenditures for the changes should be recaptured in a few years, and the building owners are key stakeholders in determining a proper building maintenance program. The green movement in the building industry is mostly driven by major corporations as they have policies for being green. Nowadays, the sustainability risk has raised more awareness by industry key stakeholders, and legislation is a part of this. Moreover, according to Garris (2009); and Pitt et al. (2009), the levels of sustainability vary over time; the knowledge and technology of sustainable buildings should be updated to understand the changes.

For sustainable maintenance of existing office buildings, best practices and new technologies should be implemented along with energy efficient renovation strategies with the aim to reduce environmental impacts. For a green upgrading and to satisfy the environmental protection requirements, the HVAC systems may be designed with localised zoning comfort spaces controlled by automatic sensors or by the users on demand. That is significant for energy efficiency (Koerth-Baker 2007; Nasrollahi, Knight & Jones 2008). With a proper design strategy for the sustainable maintenance of office buildings, a company's productivity will certainly increase due to the proper design of workplace environments, and it will improve the health of the occupants. Furthermore, accounting for tenants needs and self-concepts in the changed design process of sustainable buildings will improve occupants satisfaction with the environment during occupation after upgrading (Au-Yong, Ali & Ahmad 2014a; Lahtinen et al. 2009; Lecamwasam, Wilson & Chokolich 2012; Mentese et al. 2009; Schwede & Davie 2008).

As found by Kofoworola and Gheewala (2009), energy consumption in office buildings can be saved as follows:

- In temperate areas, such as Sydney, the indoor temperatures can be set at about 24 ^oC in summer and 22 ^oC in winter as suggested by Tian and Love (2008). However, the better setpoint for indoor temperatures can be determined by the building owners or facility managers. The result would be that for a 1 ^oC increase in the setpoint temperature, the mean annual energy consumption would be reduced by around 7%. If the entire office building stock increases the indoor temperature setpoint by 2 ^oC, an energy savings of 978 × 10^6 kWh per year would result.

- By replacing inefficient chillers for air conditioning systems, the energy used in the operation phase can be reduced by around 17%.

- Recycling recovered building materials from refurbishment/replacement at the end of the life of building systems would reduce the life cycle energy assessment and contribute to the reduction of initial embodied energy of building materials. The literature review shows that recycling refurbished/replaced materials could reduce the initial embodied energy by around 9% and a further 2% over its life cycle. Another factor is that the building rubble from refurbishment/replacement can be crushed and reused in place of virgin aggregates in other kinds of construction, such as roads, fill, and as ingredients for concrete and asphalt pavement.

Creating sustainable buildings from existing office buildings is therefore an attractive alternative to demolition and rebuilding as a means to entice tenants. It is argued that sustainability is the expected way forward where retrofitting or upgrading of mature buildings is seen necessary in meeting the environmental protection requirements (Berardi 2013; Bullen 2007; Pfaehler 2008; Yin & Cheng 2005). The sustainable improvement of existing office buildings would help in harmonising the growth of the economy and environmental protection. A balance must be achieved between protecting and improving the natural environment and contributing positively to the economy over the building's life cycle (Berardi 2013; Bullen 2007; Pfaehler 2008; Yin & Cheng 2005). Buildings which offer multiple uses that meet market demands will reduce vacancy rates and thus survive longer and stay competitive, yet, improving the sustainable performance of existing office buildings in a long tern approach has been largely untapped (Carter 2005/6; Lorenz, Lützkendorf & Panek 2005; The Green Building Council of Australia 2008).

Most existing office buildings in Australia, especially in Sydney, are outdated; however, the literature review and previous research indicate that an existing office building can be made to meet environmental protection standards by applying sustainable maintenance. The literature review reveals that even though there are many potential maintenance practices for existing office buildings, there may still be many difficulties in undertaking these practices.

They include:

- Management of the organisation's budget or finances due to the additional cost of sustainability.
- Commitment of owners and/or key stakeholders.
- Inadequate education, knowledge and skills on sustainability among stakeholders.

Significantly, strategies for sustainable maintenance practices can be carried out for the improvement of energy and water in office buildings. However, the review has found that most existing office buildings in Sydney are currently maintained by non-sustainable mainstream practices (Nguyen, Ding & Runeson 2013). The review has also identified a number of key factors and limitations in applying sustainable maintenance. It revealed that sustainability is a relatively new concept for the maintenance of existing office buildings, and that stakeholders are willing to apply sustainable maintenance practices when possible.

3.5 Summary

Based on a review of current literature and previous research, this chapter has examined and discussed the development of sustainable maintenance of office buildings. Currently, most existing office buildings are maintained with conventional practices, and this way they will continue to impact negatively on the environment. Therefore, sustainable maintenance is a strategic way to improve an existing office building to become sustainable in a long term approach. The best practice in sustainable maintenance is adoption of new technologies into maintenance strategies of buildings. This practice provides many savings by reducing energy and water consumption and reducing CO_2 emissions from buildings.

To hasten sustainable maintenance of existing buildings, the main driver for green buildings is the government's policies, and new appropriate regulations to suit the long-lasting effects of existing building stock. More incentive schemes could also be established for resource preservation.

The best practice for sustainable maintenance of office buildings is changing from unplanned or delayed to planned strategies. To do this, resources should be ready, there should be proper planning and improved knowledge in understanding new technologies and standards, and making better decisions about priorities for necessary improvements.

The next chapter reviews the literature relating to life cycle assessment to investigate the appraisal of an office building over its life cycle by balancing environmental and economic measurements.

4. Life Cycle Perspectives in Assessment of Building Performance

4.1 Introduction

The rapid growth of the property industry has accelerated continuous change in the environment, including technologies, standards, policies and regulations. Existing office buildings, particularly older ones, may not be able to keep up with the changes. Under the current environmental protection policies and regulations, older buildings are required to be improved to satisfy environmental protection standards, such as living environment, environmentally friendly building components and service systems with new technologies, environmental strategies for maintenance practices, and so forth.

Key stakeholders may be reluctant to invest money in improving their existing buildings. They face uncertainty about long-term benefit for their investments, particularly in assessments over environmental approaches. Life cycle evaluation is an option for management to address this uncertainty. The current concept of green buildings for sustainable development is the balance between economic, social[1] and environmental measures (the triple bottom line TBL) for a project (product, asset, property, building, system, component, equipment). To assess these measures, there are a number of methods and tools; however, the disadvantage is that each method is based on a different set of factors or dimensions, which are limited in application of the assessment of buildings under sustainable requirements (Jeswani et al. 2010).

Improvements in energy and water efficiency as a result of improvements in building maintenance are the main target areas when improving/upgrading buildings to become environmentally friendly. Questions have been raised for existing office buildings: How can we improve the efficiency of energy and water consumption in buildings? Should investment be in new buildings or in retaining and upgrading existing buildings to become greener? What would the relative cost of greening an existing building be? How can we appraise the improvements?

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[1] As stated in Chapter 3, the social measure is out of the scope of this study. This study concentrates on environmental and economic measures, specifically the application of new technologies to improve an existing office building to be greener or have sustainable maintenance practices.

This chapter reviews the literature and previous research to develop a tool to answer the above questions. It is proposed that the combination of life cycle assessment (LCA) as an environmental assessment approach and life cycle costing (LCC) as an economic assessment approach, is a tool that key stakeholders can use to assess their buildings.

Environmental assessment approach is mostly preferred and required for environmental protection. There are different methods and the most popular one is LCA. In practice, LCA is a useful tool to assist key stakeholders in gaining a greater understanding of environmental performance of building materials, components and products in order to achieve building sustainability performance.

Economic assessment approach is mostly preferred by investors/owners for economic reasons. There are different methods used and the focus here is the LCC approach. In practice, LCC is a valuable tool to assist key stakeholders in making economically based decisions and to weigh up whether to continue to improve/upgrade and retain the existing building, or to rebuild in order to maximise the return on investment.

This chapter discusses:

- *How* to assess sustainability of a building.
- How to *understand* the order and prioritise the work that needs to be done.
- *When* to improve/upgrade based on a suggested assessment using a combined LCA and LCC approach.

4.2 Life Cycle Approach

The lifetime of a product is from cradle, when the raw materials are extracted, to grave, when the product is disposed of (Berardi 2015; Cabeza et al. 2014; Nalewaik & Venters 2009; Qualk & McCown 2009). The building life cycle commonly consists of four major phases: the study phase, the construction phase, the exploitation phase which includes several rehabilitation and maintenance operations, and the end-of-service phase (Arja, Sauce & Souyri 2009). These phases are commonly known as design, construction, operation, and disposal.

Buildings are complex in terms of environmental assessment and economic analysis. LCA is a popular environmental assessment method that can be used to assess building environmental performance (Bribián, Usón & Scarpellini 2009). More than 90–95% of LCA case studies concentrate on assessing environmental impacts within the building sector (Ortiz, Castells & Sonnemann 2009). These case studies assist key stakeholders by concentrating on appraising the total environmental impacts and supporting decision-making regarding environmental performance over a building's life cycle (Chau, Leung & Ng 2015). On the other hand LCC is as economic analysis tool for buildings and is a common method for appraising economic investments over the life of a building (Goh & Sun 2015).

LCA is a method to study environmental impacts while LCC is a tool to estimate financial value. Each assessment method has a distinctive process, each has certain limits, and some areas of assessment overlap. Overall, it is too complex to have a combined method for all assessments (Jeswani et al. 2010) due to LCA and LCC being processed independently or in parallel with few processes common to both methods (Bierer et al. 2014; Gluch & Baumann 2004; Goh & Sun 2015; Pelzeter 2007; Ristimäki et al. 2013).

4.2.1 New Buildings versus Existing Buildings

Environmental crises such as a shortage of natural resources, ozone depletion, emissions of CO_2, climate changes, living and working environments mean the building sector has to be improved to meet sustainability requirements. This is a current major challenge in today's green buildings developed for the building sector (Chan, Wang & Raffoni 2014). The approach to improvement is via strategies for either constructing new buildings or retaining and upgrading existing ones.

As discussed in Chapter 3, in Australia, over the past decade, the average new construction of office buildings across major CBDs is less than 2% per annum (Adelaide City Council 2007; New South Wales Resource Centre 2009). A large number of existing office buildings were built decades ago without considering their impacts on the environment (Taylor 2009). The majority of office buildings, particularly high-rise office buildings, throughout Australia are located in the CBDs of the main cities, and with the current rate of rebuilding, it would take 50–100 years to replace the current stock (Bullen 2007). During this time these buildings will continue to contribute negatively to the environment and the well-being of users. Fortunately, an existing building can retain and improve its performance through sustainable maintenance. Sustainable maintenance can improve building performance to meet green standards and operate in an environmentally friendly way (Larsen 2009). Retaining and improving a building with sustainable maintenance provides many benefits, as building new buildings consumes a mass of energy at the same time as the embodied energy in the old building is wasted (Chau, Leung & Ng 2015; Taylor 2009).

The life cycle energy consumption of a building is the total energy used to produce, maintain, operate and demolish the building. This includes gathering of natural resources to manufacture building materials, components and equipment, delivering them and putting them in place, and demolishing and removing them at the end of the building's life cycle. In a lifetime of 100 years, the embodied energy of buildings is about 10–15% of the total energy consumed in the buildings (Bullen 2007; Pfaehler 2008). Thus, retaining and improving a building with sustainable maintenance rather than knocking it down and rebuilding saves on embodied energy.

Pinder and Wilkinson (2000) argue that changes in technological and economic forces may lead to an increase of a continual problem of obsolescence that shortens buildings' life span and decreases its value. For example, obsolescence was found to reduce the life span of existing office buildings by 5–10 years since the 1980s (Pinder & Wilkinson 2000). However, obsolescence is different from the building's physical deterioration. Obsolescence relates to a building or equipment no longer being usable because of changed technologies, regardless of its condition. Whereas, deterioration is the effects of wear and tear and the counteraction in the performance of maintenance work that is directly related to the use, the services of the components or the passing of time (Buam 1991 cited in Pinder & Wilkinson 2000).

However, Bullen (2007) argues that there are certain potential problems with retained and improved buildings that include the following:

- A retained and improved building may not totally meet the performance of a new building.
- The life expectancy of a retained and improved building may be shorter compared with a new building.
- The life cycle of existing materials may be shorter than that of new ones.
- The maintenance cost of the retained and improved building may be greater than that for a new building.
- The retained and improved building may not meet the desired environmental standards of a new building.
- There are more difficulties in estimating the costs of retaining and improving a building than constructing a new one.

However, retaining and improving through the application of sustainable maintenance to an existing office building will be an important strategy to achieve the goal of the green building movement and improve life expectancy of buildings. Therefore, retaining and improving an existing building with sustainable maintenance may be a more viable solution than demolishing a building and then rebuilding. This practice can provide a number of benefits as shown in Table 4.1.

Table 4.1 Benefits of retaining and improving an existing office building with sustainable maintenance

Benefits	Cost Impacts	References
Improve the effectiveness of energy use and the indoor environment and reduce pollutant emissions and operational waste.	Additional costs for the work involved but annual operational cost will be reduced.	Gene, Flourentzos and Stockli (2000)
Require only half to three-quarters of the time for the process of demolition and building a new building.	The cost may be only from 50 to 80% of the cost of demolition and building a new.	Highfield (2000)
Increase the building's market value and avoid being obsolescence.	Costs from obsolescence will be avoided.	Burton (2001); Pinder and Wilkinson (2000)
Improve the interior and exterior environments which may increase the life of the building.	Improvement costs in retaining the building will be recovered from rental improvement.	Burton (2001)
Extend then building life in conversion and renovation for long-term operation of existing buildings, particularly concentrating on energy and water efficiency innovations.	Annual operational cost is improved by savings on energy and water consumption.	Schittich (2003)
Create a more pleasant working environment, improve employees health and productivity, reduce legal liability, and boost property values and returns.	Annual running costs and energy consumption would be reduced by up to 50%.	Herzog et al. (2004); Kaluarachchi et al. (2005); Riley and Cotgrave (2005)
Conserve the scarcity of usable land in cities, the density in urban planning, the problem of transportation in city areas etc.	N/A	Kaluarachchi et al. (2005); Riley and Cotgrave (2005)
Improve their rental rates, reduce vacancy rates, and retain the occupants.	Cost benefits are factored in over the life of the building extending to financial and environmental measures.	Bullen (2007); Larsen (2009); Mulholland, Hartman and Plumb (2005)

Benefits	Cost Impacts	References
Satisfy the requirements of buyers and/or tenants.	Market value of the building will be improved and costs from obsolescence will be avoided.	Bullen (2007); Kaklauskas, Zavadskas and Raslanas (2005); Larsen (2009)
Conserve the national heritage so it can be evaluated on the grounds of financial and environmental measures.	Cost benefits are factored in over the life of the building extending to environmental and economic approaches. Costs from obsolescence will be significantly reduced.	Langston et al. (2008); Larsen (2009)
Lessen the conflicts between buildings and the environment compared to a new building, due to minimal materials used, low CO_2 emissions, less waste in demolition and rebuilding.	There are cost benefits to the concrete and steel for the new building.	Baker (2009)
Provide inter-exchangeable means. This is the prime area where the industry requires concentration over the next few years, thus allowing existing buildings to compete with green buildings with energy savings performance.	Annual running costs, energy savings and environmental performances will be significantly improved in a short time.	New South Wales Resource Centre (2009)
Existing embodied energy embedded in existing buildings will be retained in the building fabric and equipment, and not contribute to emissions.	Great costs will be saved on existing building materials, components, and waste disposal.	Chau, Leung and Ng (2015); Taylor (2009)

Developing sustainable maintenance practices to retain and improve an existing building is therefore an important commitment as opposed to demolishing and rebuilding. The building can be reused, remain competitive, and perform more environmentally friendly (Bullen 2007; Pfaehler 2008). Retaining and improving with sustainable maintenance are potential ways forward for existing buildings in meeting the environmental and economic measurements (Bullen 2007). The strategy of retaining and improving an existing office building with sustainable maintenance is not difficult to design (Abdallah & El-Rayes 2015; Taylor 2009; Wang et al. 2016). Key stakeholders can see that retaining and improving with sustainable maintenance can generate return on investment through increasing energy efficiency, saving water, improving the indoor environment and implementing new technology and regulations in an existing office building.

4.2.2 Environmental versus Economic Approaches

The most important aspect in the sustainable maintenance of existing office buildings are environmental and economic factors. Nowadays, the consumption of fuels, GHG emissions, global warming, and the shortage of natural resources have impacted on every new and improved/upgraded building (discussed in Chapter 3). Mostly, the principal concern in improving/upgrading an office building is financial; however, the other factor that should be taken into account in decision-making is the environmental impacts.

Within the environmental and economic approaches, a building's maintenance performance must be critically assessed not only economically but also with environmental measures. This ensures that the investors/owners can adapt the entire concern and procedure for their buildings to reduce any damage to the environment and make a decision over financial investment towards sustainability. This also provides a platform to establish annual reporting for environmental and economic achievements for the buildings (Jennifer Ho & Taylor 2007).

According to Colbert and Kurucz (2007), there are three reciprocally apparent concepts of a building's sustainability based on environmental and economic aspects:

- Balanced operational concept: Sustainability is to keep the building going, and value can be maximised. Management would concentrate on conscientiously controlling trade-offs amid stakeholders interests, as the environmental and economic risks to be handled are lessened.

- Integrated operational concept: The current building can be successful when it can be maintained with a sustainability framework which provides an integrative framework for the building, reinforcing the effects in contributing a competitive advantage.

- Integrated strategic concept: Key stakeholders views can be adjusted to establish value on critical concerns. Those problems can be solved within the building's ability, and simultaneously value for the building can be established so that the improvement can be achieved by logically sustainable development.

Significantly, environmental and economic measures provide a platform to assess investment with fewer risk opportunities (Stephenson 2008). They can be broadly applied to assist decision-makers to assess their buildings, systems and equipment sustainability, at any level of a project, and provide an uncomplicated and progressively more general mode to sort out opinions and achievements towards sustainability using environmental and economic approaches (Elkington 2002; Mitchell, Curtis & Davidson 2008).

In Australia, investors/owners and green groups have combined and established a connection relating to environmental and economic improvement and climate change for improving buildings. In operation, maintenance managers can develop the concept of sustainable development in equilibrium of ecological stability and economic expansion (Foran et al. 2005). Towards sustainable practices, office buildings now are required to consider not only financial return but also environmental performance (Tuchman 2004). However, assessment of a building with either economic growths or environmental impacts alone cannot satisfy the environmental requirements, other tools that can assist key stakeholders in evaluating their performances include LCA for an environmental approach and LCC for an economic approach in decision-making of sustainable maintenance of buildings over life cycle assessment (Proctor & Straton 2009).

An environmental approach to sustainable maintenance can make a building greener, satisfy sustainable standards, perform effectively in reducing CO_2, and reduce its ecological footprint. A carbon audit using LCA is an assessment tool used to measure energy and water use, and GHG emissions for buildings. This assessment will assist stakeholders to make decisions about action to take to improve the buildings sustainability (Baggs 2013; Chau, Leung & Ng 2015).

Through an economic approach, sustainable maintenance can support stakeholders in decision-making on costs and savings to make a building greener. The assessment can be performed through the entire operation and maintenance strategy for buildings, systems and components. The assessment can also be accomplished when improving/upgrading the buildings, systems and components. Cost estimates using LCC is an assessment tool used to evaluate costs to be spent and also benefits in return for the action taken to improve the buildings sustainability (Goh & Sun 2015; Pelzeter 2007).

4.2.3 Study Period

The concept of life cycle studies – mainly developed in the 70s and 80s – concentrates on the usage of energy and materials and production of waste into the environment (Sharma et al. 2011 cited in Cabeza et al. 2014). To assess a building or system, the process is to evaluate the effects of the building or system over its service life in relation to building operation, maintenance, repair and replacement (Berardi 2015; Grant & Ries 2013). The study period can be from a few years to hundreds of years for components, systems and buildings (Bierer et al. 2014; Cabeza et al. 2014; Cole & Kernan 1996; Kubba 2010).

a) Study Period of Buildings

The life cycle of a building spans from its design, construction, operation and deconstruction. Even though a building can have a long life expectancy, the assessment of a building based on a 50-year cycle for the cumulative energy savings for materials with high levels of embodied energy is commonly used (Bribián, Usón & Scarpellini 2009; Grant & Ries 2013). Table 4.2 summarises the study period for energy use over the life of office buildings from international research studies. While the assessment periods used in the industry range from 25 to 100 years the results and a study period of 50 years seems to be the most used life span for energy assessment in buildings. The 50 year study period is therefore selected for the research as it indicates the energy consumption distributed for operation and maintenance in comparison with the building's construction and deconstruction phases.

Table 4.2 Study period for energy use in office buildings

Country	Period (years)	References
Canada	25, 50 & 100	Cole and Kernan (1996)
Canada	50	Berardi (2015)
USA	50	Grant and Ries (2013)
USA	75	Scheuer, Keoleian and Reppe (2003)
Belgium	30, 60 & 90	Verbeeck and Hens (2010)
Greece	50	Dimoudi and Tompa (2008)
Finland	50	Cabeza et al. (2014)
Spain	50	Zabalza Bribián, Valero Capilla and Aranda Usón (2011)
Japan	40	Suzuki and Oka 1998 cited in Sartori and Hestnes 2007 (2007); Cabeza et al. (2014)
Thailand	50	Kofoworola and Gheewala (2009)
Australia	50	Dewar (2004)

b) Study Period of Components and Systems

The service life of building components and systems may vary from 5 to 75 years (Kubba 2010; Menzies & Wherrett 2005; Scheuer, Keoleian & Reppe 2003). Table 4.3 summarises the life spans of some commonly used components and systems for the maintenance and upgrading of office buildings. The data range of life span of components and systems present drastic differences with some components having durability of 75 years whereas some only 5 years. The life spans used are the most commonly applied in the industry (e.g. see also Kubba (2010); Menzies and Wherrett (2005); Scheuer, Keoleia and Reppe (2003)). These indicated derived from the average peak usage period of each component's and system's life span. For example, in mechanical, electrical and plumbing the peak usage period of steel air ducts, copper pipes and sewer pipes is 75 years, urinals 50 years, elevators 40 years, HVAC systems 30 years but paint on drywalls is generally 5 years. Commonly, the lifetime of components and systems is shorter than the life span of buildings; and also it may vary depending to the manufacture, installation, use and maintenance schedule.

Components and systems may be refurbished/replaced during the building's lifetime; however, the life cycle study period in assessing and evaluating a building and its components and service systems can be adjusted based on the physical life cycle of the building, or it can be shortened by investors/owners based on its purpose (Bierer et al. 2014). The service life of components and systems can also be applied as advised by the manufacturers and/or suppliers.

Table 4.3 Life span of components and services systems for office buildings

Building services		Building interior and finishes	
Component	**Years**	**Component**	**Years**
Duct liner, acoustic	75	Ceramic floor tile	75
Pipe, copper	75	Door frames	75
Sewer pipes	75	Drywall (gypsum board, steel studs)	75
Steel air ducts (sheet metal)	75	Interior column covers (stainless)	75
Pipe, black steel	50	Stone, base material, interior	75
Pipe, cast iron	50	Wood panelling	75
Pipe, PVC	50	High class insulating glass windows	60
Restroom sinks	50	Metal doors	50
Sprinkler system pipes	50	Wooden doors	50
Toilet fixtures	50	Toilet compartments (stainless steel)	50
Urinals	50	Treatment of wood panelling	35
Elevators	40	Joint sealer	25
Radiators (base board)	40	Acoustical wall panels	20
HVAC system	30	Ceiling tiles	20
Phone and data wiring (copper)	25	Insulating glass windows	20
Sprinkler heads	25	Raised rubber tile	18
Air handling unit, roof	20	Sheet vinyl	18
Fan coils	20	Vinyl composition tile (VCT)	18
Faucets, sink	20	Carpet (tile and broadloom)	12
Faucets, shower	20	Paint on drywall	5
Flush valves toilet	20		
Flush valves urinal	20		
Shower tubs	20		

Source: Adapted from Kubba (2010); Menzies and Wherrett (2005); Scheuer, Keoleian and Reppe (2003)

4.3 Environmental Assessment

In practice, a building's environmental assessment is mostly performed to assess energy and water consumption. This process is part of the current green building assessment for improving building performance (Arpke & Hutzler 2005; Cole & Sterner 2000). LCA is a commonly used technique to evaluate impacts of a building on the environment and the process used to appraise the energy and water consumption, and the level of CO_2 emissions for buildings or building products (Baggs 2013; Dimoudi & Tompa 2008).

The main problem is that each building is a single product, whereas LCA has been developed to assess mass produced industrial products or material. Therefore, there are some difficulties when using LCA for the environmental assessment of buildings (Verbeeck & Hens 2010). Other factors regarding LCA systems are the lack of information, uncertainties in collecting data relating to the building process, and lack of consideration of economic cost estimation (Berardi 2015). There is a need for different life cycle approaches within buildings, and they should be associated with economic assessments (Jeswani et al. 2010).

4.3.1 Definition

LCA has mainly developed since the mid-1980s. Since then, it has rapidly developed into a systematic and robust tool for measuring potential environmental burden and impacts of a product, asset, property, building, system, component, equipment, process or an activity (Finnveden et al. 2009; Jeswani et al. 2010); especially carbon emissions (Baggs 2013).

According to Chau, Leung and Ng (2015, p. 396):

> "LCA is an objective process which aims to evaluate the environmental burdens associated with a product, process or an activity by identifying and quantifying the energy and material uses and releases to the environment, and also aims to evaluate and implement opportunities to affect environmental improvements."

LCA is a useful and important assessment tool to support manufacturers, suppliers, customers, policymakers, and building stakeholders in making decisions about environmental assessment processes (Rebitzer et al. 2004 cited in Baggs 2013; Jeswani et al. 2010).

4.3.2 Aims

According to Taygun and Balanli (2007), the use of LCA aims at assisting in:

- Conserving natural resources.
- Preventing environmental pollution.
- Supporting environmental parity.
- Preserving diverse sustainable ecosystems.
- Developing environmental legislation.
- Developing environmental execution evaluation in environmental management systems.
- Providing the manufacture of environmentally friendly building products.
- Decreasing the environmental impacts and health risks in building operation and maintenance.

As discussed in Chapter 3, the major causes of climate change are emissions of GHG that include gases such as CO_2, CH_4, N_2O, CFCs, HCFCs, and PFCs. Of these CO_2 is the main gas impacting on the environment (Australian Bureau of Meteorology 2014b; Chau, Leung & Ng 2015; U.S. Environmental Protection Agency 2014a).

In the building sector, improved environmental performance of buildings is the main driving force for saving energy and water and reducing CO_2 emissions. An environmental assessment is the evaluation of the environmental effects and from that, possible reduced impacts to the environment may be identified. LCA is a useful tool to compute the quantities of resources demanded, and emissions and waste produced per functional unit, which is "a quantitative description of the service performance (the needs fulfilled) of the investigated product system(s)" (Rebitzer et al. 2004, p. 705).

4.3.3 LCA Framework

The LCA framework has been developed through a series of International Standards Organisation ISO 14040 (Geneva) that includes:

- ISO 14040 (1997–2006) Environmental Management: Life Cycle Assessment – Principles and Framework.

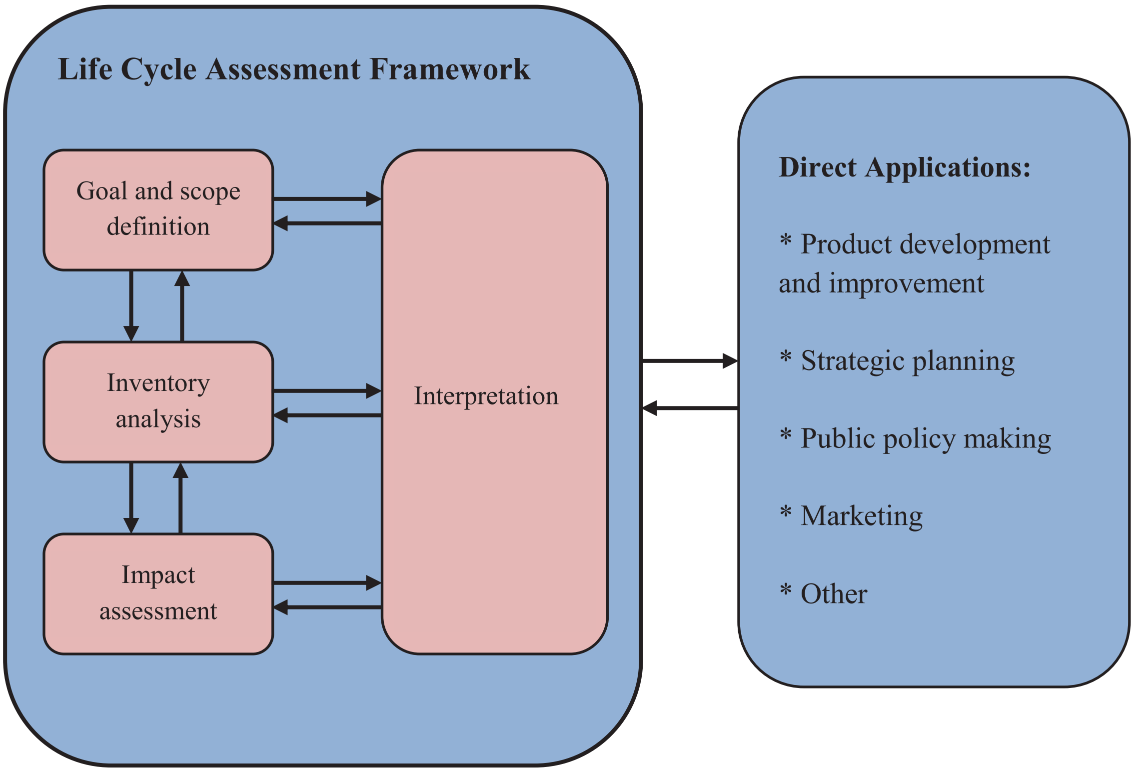
- ISO 14041 (1998–2006) Environmental Management: Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis.

- ISO 14042 (2000–2006) Environmental Management: Life Cycle Assessment – Life cycle Impact Assessment.

- ISO 14043 (2000–2006) Environmental Management: Life Cycle Assessment – Life cycle Interpretation.

Figure 4.1 illustrates the phases and applications of an LCA based on ISO 14040 (1997–2006).

Figure 4.1 An LCA framework



Source: ISO 14040 (2006)

According the Figure 4.1 the process of LCA includes four major stages detailed as the following:

Stage 1: Definition of Objectives and Scope of Application

The purpose of study, the limits or boundaries of the system, the necessary data, audiences, and so forth.

Stage 2: Creating Inventory Analysis or Life Cycle Inventory (LCI)

Collecting, quantifying and calculating all inputs (resources consumed) and outputs (emissions released) of energy and mass flows of the system during its useful life and data on emissions to air, water and land.

Stage 3: Impact Evaluation or Life Cycle Impact Assessment (LCIA)

A classification and evaluation of the results of the inventory analysis, evaluating potential environmental impacts and estimating the resources used, relating the results to observable environmental effects by using a collection of impact categories (climate change, acidification of soils, ozone layer depletion, toxicity, resource depletion, and so forth). This stage comprises three mandatory elements: selection of impact categories, assignment of LCI results (classification) and modelling category indicators (characterisation). In LCIA, all impacts on the environment caused by human activities should be analysed and evaluated, including damage levels to the environment, especially global warming potential, climate change, GHG, the uses of energy and water, waste management, and particularly chemical releases that may affect human health, resulting in respiratory conditions, cancer, cataracts, infectious diseases and so forth. The assessment should have answers to "to what extent?", "under which circumstances?", and "pragmatically how?" The assessment would be compared according to CO_2 equivalent by the use of GWPs. For example, a GWP_{500} of 100 means that 1 kg of the substance will affect the same cumulative climate change as 100 kgs of CO_2 up to 500 years (Pennington et al. 2004).

Stage 4: Interpretation

The results of the preceding phase are evaluated in accordance with the objectives defined in the study, in order to establish conclusions and formulate recommendations for a final report. That is the last component to complete the process of LCA, as directed by ISO 14040. Different techniques are used to do this, including sensitivity analysis on the data, an analysis of the relevance of the different stages of the process and an analysis of alternative scenarios.

4.3.4 Assessment Process

The process of LCA to assess a building or building component concentrates on life cycle energy use and other impacts on buildings. Energy can be assessed to include energy acquired in the production, use, and removal or possible recycling and reuse of a building/equipment (Cole & Kernan 1996; Huberman & Pearlmutter 2008). They include current energy used in buildings during its effective life and embodied energy required for production of a building/component (Chan, Wang & Raffoni 2014; Chau, Leung & Ng 2015; Venkatarama Reddy & Jagadish 2003).

According to Cole and Kernan (1996); and Huberman and Pearlmutter (2008), these types of energy can be categorised into four distinct measures: initial embodied energy (design/pre-use phase, construction phase), recurring embodied energy (use phase), operating energy (use phase), and demolition energy (disposal phase) as outlined in the following:

- Initial embodied energy is needed to produce the materials or components for a building from extraction of raw materials and manufacturing, transportation to site and construction/installation at the building site.

- Recurring embodied energy is needed to upgrade, refurbish and maintain the building and/or equipment over its effective life. The interior partitions, doors, finishes and building services require maintenance, repair, refurbishing and replacement more regularly than do the structure and building envelope. During this period, the number of repairs, refurbishments and upgrades of service will be required upon demand; while, replacement will replace 100 percent of a material or component. Replacements may occur several times during the life of the building. All this periodical work will accumulate and require energy to perform. The work is then also to be included in the life cycle energy analysis of the life of the building.

- Operating energy is consumed to provide interior space conditions to the building that include HVAC systems, lighting, powering equipment, and other services, such as vertical transport. Operating energy will vary according to building use patterns, orientation, local climate and seasons, and the effectiveness of the building and services systems. Over the past 20 years the building industry has concentrated on reducing operating energy by changes in technologies and improvements in the design of the building's components (Cole & Kernan 1996; Huberman & Pearlmutter 2008). Other factors taken into consideration are the working time and length in offices and how this may also affect the level of operating energy.

- Demolition energy is needed to demolish buildings/components, transport waste materials to landfill and/or reuse materials at the end of their effective lifetime. The published figures on the actual amount of energy in the disposal process are limited and have a high degree of uncertainty. Commonly, it is predicted as approximately 1–3% of the initial embodied energy designation (Cole & Kernan 1996; Huberman & Pearlmutter 2008).

Scheuer, Keoleian and Reppe (2003); and Verbeeck and Hens (2010) point out that the evaluation of buildings is very difficult compared to the evaluation of products. Buildings are big in scale, complicated in installed materials and service functions, and have long life spans; whereas the lifetime of some components and service systems is shorter than the building and they require refurbishment/replacement a number of times during the building's life cycle. An LCA on their energy use and environmental impacts can be made when:

- The building is upgraded or refurbished.

- Components/systems are refurbished or replaced.

New technologies used to improve the sustainability of buildings enhance over time but the industry's knowledge is commonly left behind. This means that the industry has more limited information on impacts from extraction of raw materials for manufacturing building materials, transportation to the site, construction, use, and disposal processes at their end-of-life (Berardi 2015; Chan, Wang & Raffoni 2014; Scheuer, Keoleian & Reppe 2003). LCA is a useful tool to assist stakeholders in assessing these impacts of buildings to the environment over the buildings effective life.

4.4 Economic Assessment

Today, most people in the building industry are aware of and support policies that govern the protection of our environment. However, a number of barriers exist and limit environmental protection development (Chan, Wang & Raffoni 2014).

The main concerns for an existing building to become greener to satisfy green standards are:

- What green costs and benefits would be financially feasible for the investment?

- How long would it take for the investment to be recovered?

A financial investment, particularly in building projects, commonly may not yield a good result on short-term projects compared to a longer-term strategy (Ristimäki et al. 2013). The principle of long-term building investments is based on the lifetime of buildings. To determine costs associated with a building/system, life cycle costing (LCC) can be a useful tool in helping the decision-making process (NSW Treasury 2004). However, traditionally, LCC focuses on the profits or the economic return connection to the operation of buildings, but it does not include the damage to the environment (Goh & Sun 2015; Pelzeter 2007).

In managing a strategy and analysis for buildings and service systems over maintenance practices, LCC is the expected solution for decision-making on building investment. Thus, applying LCC to a building will enable the operator to estimate the costs which will assist stakeholders in the decision-making process about the benefits of going green. This can be achieved when green building concepts and financial commitments are appraised at the early stage of the project (Arja, Sauce & Souyri 2009; Kubba 2010; NSW Treasury 2004).

4.4.1 Definition

LCC is not consistently defined. The terminology describing the calculation method of cost, often referred to as the LCC of a product over its lifetime, has changed from “cost in use” to “life cycle costing” and further to “whole life costing”. The latest term is "whole life appraisal" (Flanagan & Jewell 2005 cited in Schade 2007). Other terms to denote the same fundamental nature as LCC are "total life cycle cost", "whole life cycle cost", "life cycle cost analysis", "through life cost", "working life cost", and "lifetime cost" (Sarja 2005 cited in Arja, Sauce & Souyri 2009).

While LCC has a number of names depending on the region or researcher; they describe the same concept. They are similar in usage, but the meaning, particularly for the operation and maintenance period, has not been sufficiently investigated (Arja, Sauce & Souyri 2009). According to Boussabaine and Kirkham (2004, p. 5), the term LCC has been widely used since 1977 as it is:

> "A concept which brings together a number of techniques – engineering, accounting, mathematical and statistical – to take account of all significant net expenditures arising during the ownership of an asset. Life cycle costing is concerned with quantifying options to ascertain the optimum choice of asset configuration. It enables the total life cycle cost and the trade-off between cost elements, during the asset life phases to be studied and for their optimum selection use and replacement."

LCC also has a number of different definitions depending on the use or application for calculating the life cycle cost of a project. According to NSW Treasury (2004, p. 1), the LCC of a building/system is defined as:

> "The total cost throughout its life including planning, design, acquisition and support costs and any other costs directly attributable to owning or using the asset."

However, the definition of LCC used throughout this study will follow that stated by Kubba (2010, p. 325), that LCC is:

> "A technique of combining both capital and operating costs to determine the net economic effect of an investment, and to evaluate the economic performance of additional investments that may be required for green buildings."

4.4.2 Aims

To assist stakeholders in their decision-making on an investment relating to a building/system, LCC aims to determine the cost of acquisition or ownership of the building/system. This cost includes the financial costs of funding, design, construction, operation, maintenance and repair, component replacement, and sometimes disposal of the building/system, which includes reuse and/or demolition (Clift 2003; NSW Treasury 2004). In the case of reuse, the cost estimation would also enable residual life and value. In the case of rented buildings, LCC would include revenues in financial accounting calculations (Cole & Sterner 2000; Jiang, Zhang & Ji 2003).

Based on the opinions of Clift (2003); Kubba (2010); and Pelzeter (2007), LCC is an important tool for meeting economic sustainability in buildings. The calculation method is a key for optimisation in investment projects. The advantage of LCC is that it provides the possibility to logically quantify costs in comparing alternative opportunities on the same economically basis or reference dollar. From this, according to Langdon (2007), benefits of using LCC will be obtained. Firstly, LCC provides a better indicator of value for money of all costs over the building/system assessment. For example, the costs of owning and occupying a typical office building over a 30 year period account for the wide-ranging ratio of 1:5:200 (1 = construction costs, 5 = maintenance costs and 200 = operating and staffing costs) (Langdon 2007). Therefore, concentration on the operating and maintenance costs rather than on capital costs alone will generate significant long-term financial and environmental benefits. Secondly, LCC is also a key element as a tool for economic appraisal of alternative sustainability selections over all of a building's costs, and a method for assessing the cost benefits of including more sustainable practices into buildings/systems.

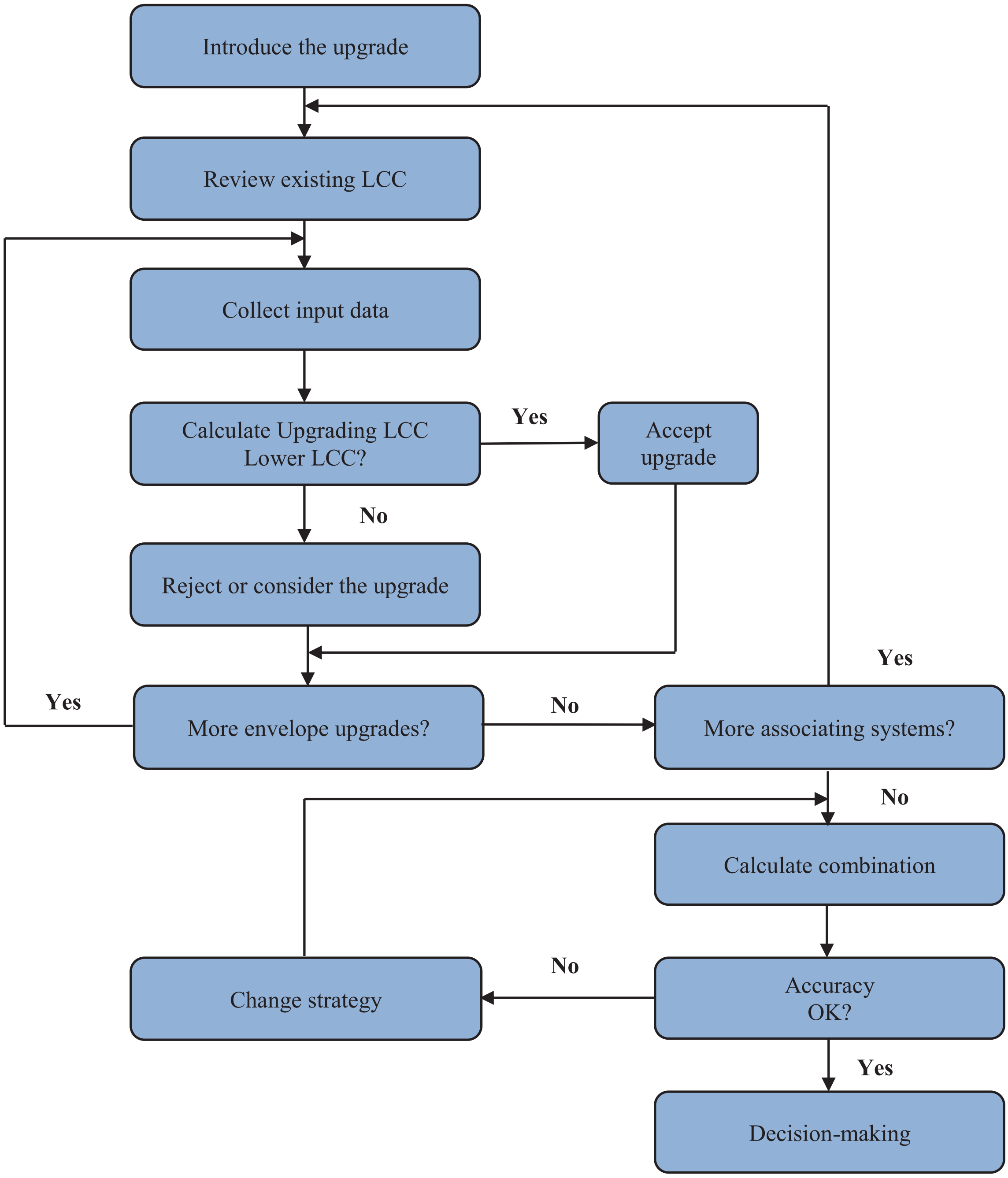
4.4.3 LCC Framework

LCC is widely used worldwide and can potentially contribute as an instrument for accomplishing economic sustainability in property management for building optimisation. However LCC has not yet fully utilised as a management tool in the property management sector (Pelzeter 2007). There is a global principal framework, ISO 15686, and a number of national standards provided as frameworks to undertake LCC assessment. These standards, which include the US Standard ASTM E 917-02 (2002), NS 3454 (2000) used in Norway or AS/NZS 4536 (1999) used in Australia/New Zealand, have been incorporated into the ISO 15686-5 (2008) (Arja, Sauce & Souyri 2009; Pelzeter 2007).

According to Arja, Sauce and Souyri (2009), the conceptual framework of LCC can be applied throughout the four phases of the life cycle of a building/system. However, as stated by Bull (1993), in maintenance, an improvement, refurbishment or upgrade of a building/system, LCC can provide an optimised calculation as shown in Figure 4.2.

Figure 4.2 emphasises an interacted LCC calculation for improvement, refurbishment or upgrade of a building/system. Assuming the existing HVAC system is found to be unprofitable and an upgrade is introduced, then the new LCC calculation is compared to the existing one. If the new LCC is lower, the upgrade will be profitable; otherwise, the upgrade will be unprofitable. However, assuming the upgrade is profitable but that, due to the upgrade, problems have arisen, that makes other components unprofitable. Using incremental steps to examine all problems which are due to the introduction of the upgrade makes it possible to determine if the savings of the upgrade have been overestimated. If the difference between the incremental and the combination of upgrades is very small, the upgrade is preferred. If not, the LCC must be recalculated before decisions are made or the upgrade decision will be adjusted or alternated for the optimal solution.

Figure 4.2 Optimisation LCC for upgrading a building or system



Source: Adapted from Bull (1993)

4.4.4 Assessment Process

a) Reconciling the Theory and Practice of LCC

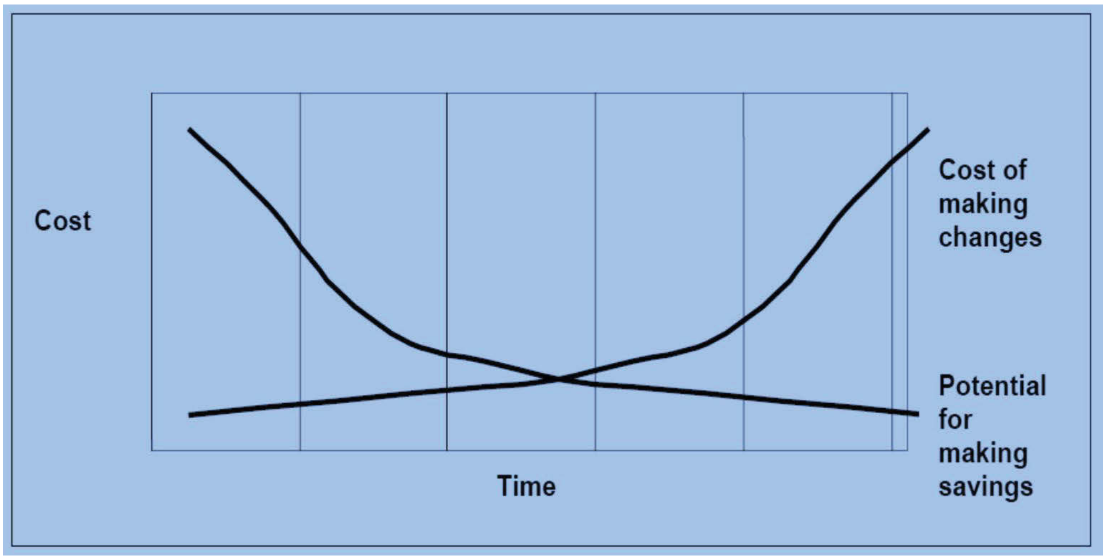
According to Cole and Sterner (2000), theoretically, the LCC techniques are used to judge prior to decision-making on alternative improvement, refurbishment or upgrade of the building, systems, or components throughout their economic or technical life. LCC will have to involve extra contingencies due to the risk involved in the process. In practice, LCC would be applied to budgeting; used for suggesting the structure of the capital and revenue budgets thus helping investors/owners to make choices in key areas while isolating others.

Cole and Sterner (2000) suggest reconciling the theory and practice of LCC in two aspects. The first is by improving communication of the merits of LCC as a strategic choice. To ensure that LCC will be incorporated in the budget it is important to bring together building owners and professionals, first in the design stage and then throughout the project process.

According to Arja, Sauce and Souyri (2009); Kubba (2010); and NSW Treasury (2004), the early use of LCC assists the decision-makers to balance performance, reliability, maintainability, maintenance support and other goals against life cycle costs. As shown in Figure 4.3 early identification of acquisition and ownership costs provide potential savings using the LCC process. Decisions made early in a project's life cycle have a much bigger influence on life cycle costing than those made later. Late changes will increase the costs of making changes, while decreasing the potential for making savings.

The second suggestion by Cole and Sterner (2000) is to improve cost and performance data. Data quality and accessibility are needed to be improved. Otherwise confidence in the outcomes would suffer (Cole & Sterner 2000; Levander, Schade & Stehn 2007; Schade 2007).

Figure 4.3 Potential costs and savings relationship in performing LCC



Source: NSW Treasury (2004)

b) LCC Analysis

Keenan and Georges (2002) suggest the following steps to be used to analyse the LCC of building components and services systems towards sustainable building maintenance to satisfy environmental protection requirements:

- Identify feasible alternatives: Only energy-savings or green alternatives would be taken into account in the practical evaluation. For economic reasons, there are physical or other constraints that may eliminate an alternative.

- Establish parameters: Parameters are the length of the study period, base date, length of planning/construction period, service date, treatment of inflation, operational works for a building or building system, and energy and water price schedules.

- Determine costs: Initial investment costs, capital replacement costs, residual values, such as resale or salvage values or disposal costs, operating, maintenance, and repair costs, energy costs, water costs, taxes (e.g. financial subsidies, property tax laws, sales tax, and income tax laws), non-monetary costs (and benefits). All costs in LCC analysis are necessarily converted to base year dollars. The discount technique is used for measuring the base year present value.

c) Discount Costs to Present Values

The principle in LCC analysis is based on all future costs, such as costs used to measure performances in improving/upgrading a building, system or component. There are three types of future cash flow, expressing a different type of present value factor:

- A one-time amount is multiplied by the single present value (SPV) coefficient.

- A regular cash flow as of the base year is multiplied by the uniform present value (UPV) calculation of a stream of costs throughout the study period.

- An annual amount (A_0) that varies from year to year at some known rate is multiplied by the modified uniform present value (UPV) calculation.

These would be performed at different times in the future and should be converted into present-day value by using a discounting technique to a value of dollars of a special quotation year, that are then preferred over the outcome of present value (PV) dollars. This calculation will give an easy way to compare alternative outcomes prior to engaging in a decision-making process (Clift 2003; Kubba 2010).

According to Bierer et al. (2014); Levander, Schade and Stehn (2007); and Schade (2007), future operating cost savings are traded off in opposition to higher initial capital investment costs. In assessment, net present value (NPV) is commonly used for decision-making. NPV is the result of the application of discount factors, based on a required discount rate of return to each years projected cash flow, so that the cash flows are discounted to present value (Levander, Schade & Stehn 2007; Schade 2007).

Costs borne for improvements/upgrades are carried out for today and in the near future and that the value of an amount of money received at the time *t* will be smaller than the amount received today due to inflation. Thus, for a project to be accepted, the sensitive test for the benefit-cost is especially analysed with the rate at which future benefits are discounted (Arrow et al. 2014). Under the LCC analysis, stakeholders can make a decision based on an NPV resulting from the calculation with a discount rate. The discount rate is the rate that gives the investors/owners accountability between cash flows, which are amounts received or paid now or in the future, by the adjustment of future costs and savings to present value (Bierer et al. 2014; Levander, Schade & Stehn 2007; Schade 2007).

As studied by Arrow et al. (2014), there are two kinds of discounted rates: constant exponential rate and declining discount rate. Constant exponential rates assume other things equal and assign a lower weight to future benefits and costs based on uncertain consumption. While, with declining discount rates, benefits and costs are converted to certain consumption units and discounted to the present using the declining discount rate. Going on to the future, cost growth is an uncertain parameter due to inflation; thus a declining discount rate is robust to a project, particularly projects which are aimed at reducing GHG emissions.

d) Selection Criteria of office upgrading items

In practice, an important factor that is needed to be considered in LCC relates to the improvement or upgrade of a building/component is that it might have an existing LCC. A critical factor for decision-making is the comparison between the existing and new LCCs. According to Bull (1993); Keenan and Georges (2002); and Lu et al. (2000), the selection can be considered as follows:

- When the alternatives have the same life span as the building/component to be assessed, the alternative with the lower LCC would be accepted.

- When the alternatives have a different life span with the building/component to be assessed, the annual costs are considered for the selection. In the case of GHG emissions projects, the selection can be based on the following:

    - If there is not much difference in annual costs between the existing and alternative LCCs but the assessments on CO_2 have big differences, the one with lower CO_2 emissions is accepted.
    - If there is not much difference in CO_2 assessments between the existing and alternative LCCs but the annual costs have big differences, the one with lower annual costs is accepted.

Therefore, a decision on an alternative using LCC can be commonly made on financial appraisal with a lower LCC accepted for a building/component having the same life span. However, the one with lower CO_2 emissions may be accepted.

4.5 Combining Environmental and Economic Approaches for Assessing Performance of Existing Office Buildings

Based on the characteristics of LCA and LCC, the use of each tool alone cannot comprehensively assess an office buildings approach to environmental and economic measures. An assessment combining environmental and economic approaches is expected to assist in assessing performance of existing office buildings.

This section presents the principal differences of characteristics and aspects between LCA and LCC and suggests way to assess an office building by amalgamating the LCA and LCC approaches.

4.5.1 Principal Differences between LCA and LCC

The life cycle evaluation of a building, service system and/or component can be measured using the LCA analysis or the LCC method. However, as mentioned, each method has a different aspect. LCA concentrates on the environmental measures, whereas LCC focuses on an economic assessment. They are commonly processed independently of each other (Gluch & Baumann 2004; Goh & Sun 2015; Norris 2001; Pelzeter 2007; Ristimäki et al. 2013). Table 4.4 outlines the differences in the purpose and approach between LCA and LCC. The table lists out the principal differences in the purpose of the assessment methods; activities considered part of the life cycle; flows considered in assessments; monetary units such as dollars in LCC analysis; units for tracking flows such as energy and water consumption and CO_2 emissions in LCA assessment; and time treatment and scope of assessment such as 100-year time horizon for assessing global warming potentials.

Table 4.4 Differences in purpose and approach between LCA and LCC

	LCA	LCC
Purpose	Compare environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision-maker
Activities considered part of the 'life cycle'	All processes connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps	Cash flows during the economic life of the investment, as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision-maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical units	Monetary units
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time window of impacts (e.g., 100-year time horizon for assessing global warming potentials), but future impacts are generally improved with the effective consumption of energy, resources and materials	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored

Source: Adapted from Norris 2001(2001)

4.5.2 Combined Assessment Using LCA and LCC Approach

An assessment using an LCA and LCC approach can support key stakeholders in decision-making on a long-term basis because both LCA and LCC are used for life cycle evaluation (Bierer et al. 2014; Ristimäki et al. 2013). They are valuable in assessing environmental impacts and economic aspects of green buildings over the life span of an office building/component (Berardi 2015; Chan, Wang & Raffoni 2014).

As suggested by Langdon (2007), for priorities in decision-making, LCA and LCC can be flexibly applied in any sequence to achieve a life cycle evaluation. Therefore, LCA and LCC can be used in conjunction with each other in a larger appraisal process. For example, according to Langdon (2007, p. 8), the range of approaches might include:

- Use of LCA and LCC as two of the criteria in the evaluation of a single investment option (such as the decision to construct an asset), where other evaluation criteria might include functionality, aesthetics, speed of construction, future investment returns etc.

- Use of LCA and LCC as two of the criteria in the evaluation of a number of alternative investment options (either entire constructed assets or specific components, materials or assemblies within them).

- Use of LCC to provide a financial/economic evaluation of those sustainability impacts.

- Use of LCC to provide a financial/economic evaluation of alternative options identified in an LCA assessment.

- Use of LCA as a means of identifying alternative options with good environmental performance and then carrying out a LCC analysis on those options only.

- Use of LCC to select cost-effective options, then making a final decision in the light of a process of LCA carried out on those options only.

Figure 4.4 is a suggestion of a combined assessment using both the LCA and LCC process. The life cycle evaluation is set up by the decision-maker, and LCA and LCC are parts of the process (Bierer et al. 2014). The assessment process includes seven steps, they are:

Step 1: Determination of assessment goal and scope

The first step in the assessment of the goal and scope, specified by the decision-maker, are the systems or components to be assessed; for example, the whole building or base building, a service system, a component or an equipment.

Step 2: Determination of system boundaries and study period

The assessment will be a life cycle evaluation, and the assessment period will be determined by the decision-maker. Suppose the building lifetime is 50 years (see Table 4.2). The life span of a system, component or equipment is physically indicated by the manufacturer; for example the life span of an HVAC system is 30 years (see Table 4.3).

Step 3: Determination of impact assessment and methods

The process includes LCA and LCC methods and any other calculating methods relevant to LCA and LCC analysis that are adjusted or reconciled by the decision-maker over the life cycle evaluation. Impact assessment would be CO_2 emissions for LCA calculation, and net present value (NPV) for LCC calculation, as discussed above.

Step 4: Data compilation

All data needed for and relevant to the assessment should be collected for LCA and LCC calculations. Figure 4.5 indicates types of data that can be collected for LCA.

Step 5: Calculations

For LCC, all costs and incomes have to be accounted for in the assessment. Mostly, NPV is used for the evaluation of annual cash flows in the assessment period. The impact assessment in LCA calculation is focused to savings on CO_2 emissions by effective consumption of energy and water annually over the lifetime of the assessed building or system.

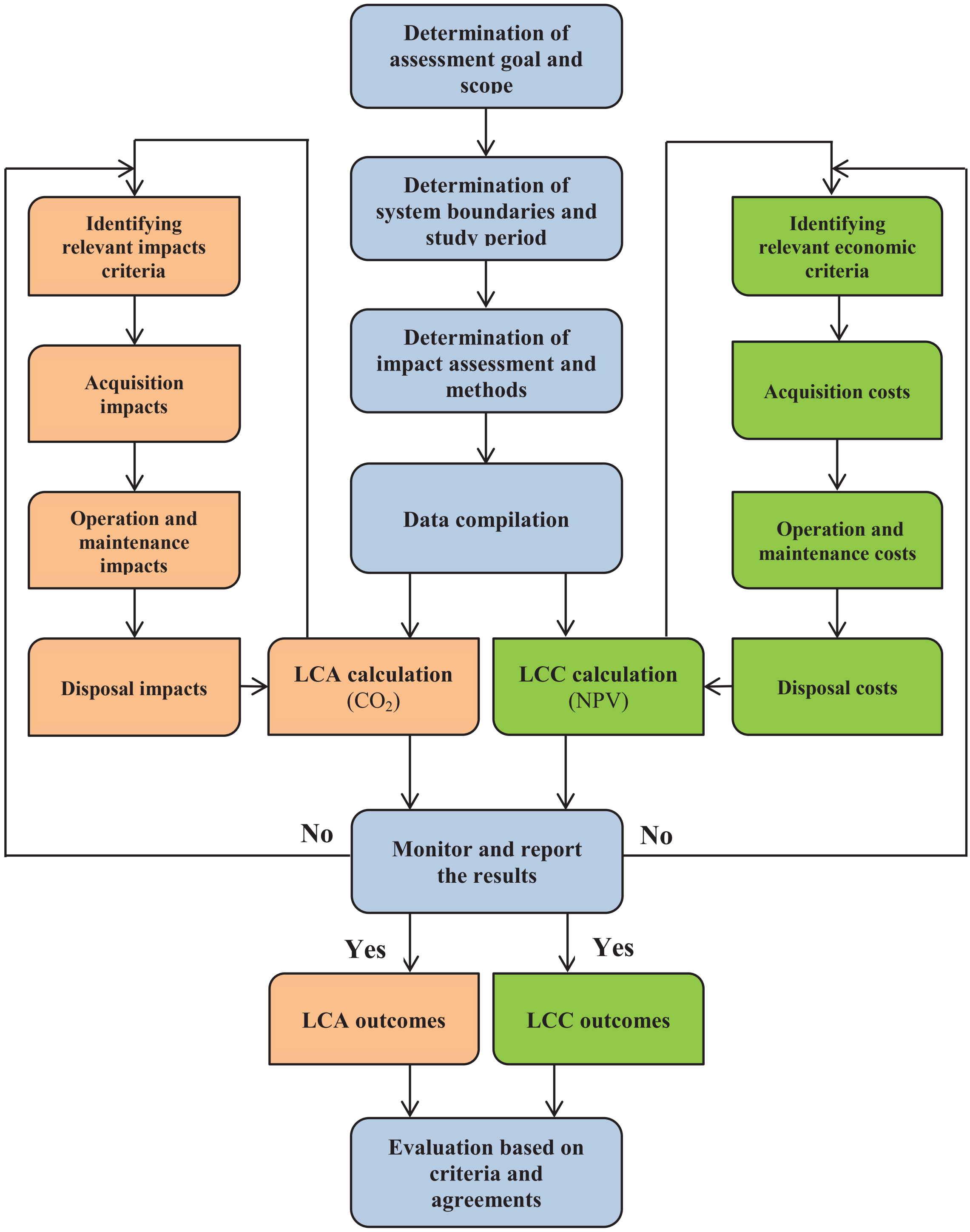
Step 6: Monitor and report the results

This step monitors the results of the calculations. If the calculations indicate that the assessment is satisfactory, they will determine outcomes of LCA with CO_2 assessment value, and LCC with NPV assessment value. If either result of the LCA or LCC is not satisfactory, it will need to be recalculated.

Step 7: Evaluation of outcomes

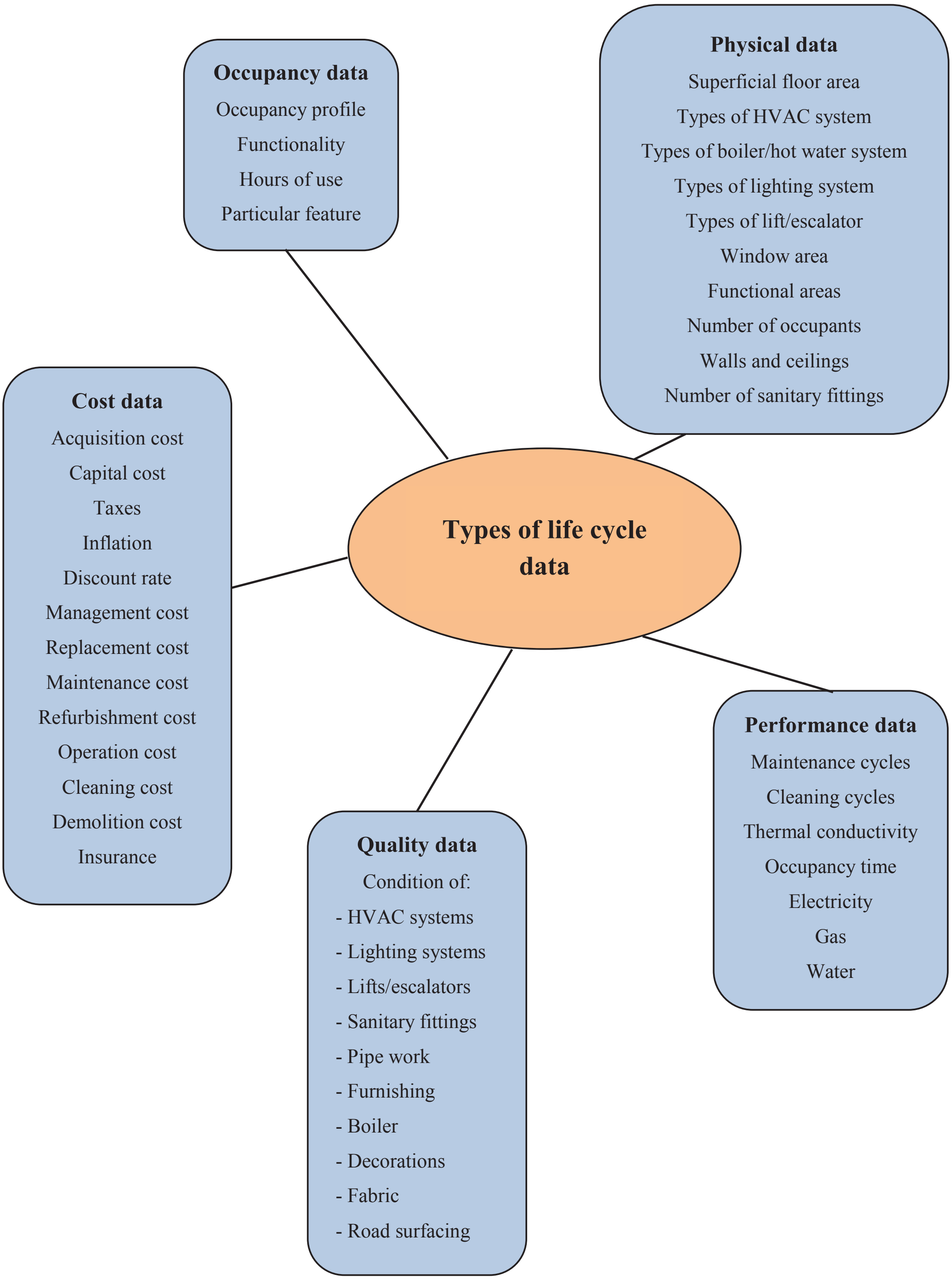
This is the last step of the assessment. The outcomes are evaluated based on established criteria and/or agreements that usually lead to the final decision-making process or another alternative process.

Figure 4.4 A suggestion of combined assessment process using LCA and LCC



Source: Adapted from Bierer et al. (2014); Langdon (2007)

Figure 4.5 Types of data for LCA of existing office buildings



Source: Adapted from Levander, Schade and Stehn (2007); Schade (2007)

To sum up, LCA has significantly developed over the years. It has rapidly developed to be a method for appraising the environmental impacts of a building or a system (Finnveden et al. 2009; Jeswani et al. 2010). It is a useful decision support tool that can be adopted by a building's stakeholders and others (Rebitzer et al. 2004 cited in Jeswani et al. 2010). However, the applications of LCA are still complicated and difficult as follows:

- There are limits on sustainable knowledge, especially the comprehensive information supported in assessment of energy and water consumed in office buildings (Junnila & Horvath 2003 cited in Arpke & Hutzler 2005; Scheuer, Keoleian & Reppe 2003).

- The green valuation of a building may not be easily reflected in the traditional market valuation system (Rebitzer et al. 2004). The improvement of buildings might often be behind the green requirements due to the constraint of budgets. The limitation of budgets may lead owners to leave their buildings with conventional maintenance practices or little performance improvements.

- Under the framework of the International Standards Organisation ISO 14040 (2006), LCA is only concerned with environmental approaches with no connection to the economy (Pelzeter 2007). Therefore, the framework of LCA-related concepts, methods and models are better to focus on sustainability assessments (Jeswani et al. 2010).

- Erlandsson and Borg (2003) stated that LCA for buildings is usually practiced as *linear life cycle* phases from construction, operation, and maintenance, ending with the demolition and waste treatment phases. Using the suggested *sequential life cycle*, a physical building can be divided into different activities that include construction, maintenance, extension, operation, and end-of-life, which includes demolition and material recycling. The different life cycle phases are then treated separately in the life cycle inventory analyses; for example, the building operation and maintenance period can be a continuous process within the actual boundary conditions, and assessed to sufficiently satisfy the goal and scope of sustainable maintenance strategies.

The biggest advantage of LCC is it can indicate a preferred result from calculations, which can be used to monitor the outcome of a project at the design phase. Consequently, project design can be modified or altered to reduce the operation and maintenance costs, such as the height of floors can be reduced to save on energy consumption and CO_2 emissions.

However, according to Nalewaik and Venters (2009), some problems still exit in using LCC. There is a lack of information about costs for green building projects. This lack of information can lead to difficulty in assessing the accurate cost of green buildings using LCC. Other factors that can limit the use of LCC are the uncertainty and risk in LCC evaluation. In the evaluation of the building's life cycle, uncertainties existing in LCC can be considered as errors in the calculation methods, uncertain future costs, escalation of inflation and interest, and uncertain end-of-life value. Other uncertainties in LCC calculations would include taxes, unexpected incidental costs, changes in technologies, changes of building function, changes to regulations, and so forth. Gluch and Baumann (2004) categorise uncertainties in assessment of life cycle of buildings into:

- Physical uncertainty that includes changes in design, materials characteristics and function, and technology (i.e. technologies will improve over time; today's technology management may be obsolete tomorrow), and functional obsolescence.

- Economic uncertainty that includes business operation, market conditions (e.g. downturn), interest and inflation rate changes, revenue changes, and rental obsolescence.

- Standards and regulations uncertainty that includes rezoning, urban and infrastructure development, regulations and law changes, 'rules of the game' changed due to political decisions about building materials, for example, prohibition of asbestos use in construction, environmental taxes, and changes in disposal/recycle costs and taxes.

Arja, Sauce and Souyri (2009) categorise the following factors causing uncertainty in analysing the building's life cycle:

- Internal factors occurring to the building's internal environment which affects the key stakeholders decisions about the maintenance strategy for damage (wear and tear), and regular preventive or corrective maintenance operations to keep the building and/or system functioning.

- External factors occurring outside the building's boundaries or outside the key stakeholders' management. These include regulatory changes, technological changes, and functional evolution, social, urban and economic factors.

The most common problem is that each building is individual and no two buildings have the same conditions for the LCC approach. Another concern is that understanding and managing uncertainty and risk in LCC calculation is more useful in decision-making, rather than a "do nothing" approach, or ignoring management of uncertainties and risks. Kishk et al. (2003 cited in Arja, Sauce & Souyri 2009) point out that when handling uncertainties that exist in LCC calculations, a number of error calculation methods and risk assessment techniques can be used, such as sensitivity analysis, probability-based techniques and a fuzzy approach. Moreover, management techniques are available to minimise uncertainties of future consequences, such as scenario forecasting, decision trees and Monte Carlo simulation (Arja, Sauce & Souyri 2009).

Lu et al. (2000) found from their study with LCC alternative calculations that a new building is preferable to retaining and improving/upgrading an existing office building. The reason is the sustainable market value per square metre (m^2) of the new building was greater than its construction cost per m^2, and the new building is more energy efficient compared to the upgraded existing building. However, the study has shown that this case may not be typical for the building stock in Australia because:

- Consideration of either constructing a new building or retaining an existing building with improvement/upgrading of performance can be based on capital cost and annual cost of operation and maintenance, according to Runeson (1990):

    - When the annual cost of the old building > annualised capital cost + annual cost of the new building, the new build is preferred.
    - When annual cost of the old building < annualised capital cost + annual cost of the new building, retaining the old building is preferred.

  Research has found that, the additional cost (or capital cost) for improving/upgrading to retain an old building is lower than the capital cost for a new build. The cost in operation and maintenance of the building is also significantly reduced in the long-term assessment, particularly the reduction of energy and water consumption and CO_2 emissions within the building (refer to Chapter 7).

- The study of Lu et al. (2000) of assessment through LCC had unclear cost of disposal for the typical new building. LCC is known as a method to assess the economic measures or financial account for a product.

- Under the current environmental protection regulations and in the interest of investors, developers or owners of buildings are required to assess the building according to environmental and economic measures. However, LCC is a tool involved in assessment buildings/components which have a monetary value only.

- Some projects may be suitable as a construction of a new building, but the local conditions where the building will be built require further investigation for the suitability of the development. In Australia, large numbers of existing office buildings are located in major CBDs. It will be significantly difficult to replace all of them with new buildings based on the current rate of rebuilding. It would take 50–100 years to replace all the current existing buildings (Bullen 2007). Therefore, the improvement/upgrade of existing buildings to improve their services and to satisfy environmental regulations is often more efficient than to demolish and rebuild.

4.6 Summary

This chapter has presented and discussed the theories and practices of LCA and LCC in improving an existing office building to be more sustainable via sustainable maintenance practices. The study has also distinguished between the LCA and LCC processes in assessing a building/system over its lifetime.

In the life cycle evaluation of a building, system components and equipment, LCA is a useful tool for decision makers in deciding the environmental performance, whereas LCC is a valuable tool to assist decision makers in economic decisions. Each method has a different way of assessing, and the processes take different approaches. That can mean the assessment has some difficulties in analysing environmental burden, and costs and benefits with either LCA or LCC alone.

A combination assessment on the environmental and economic aspects using LCA and LCC methods for the decision-making process can satisfy the environmental burden, and the cost and benefit of a building, system, components and equipment. However, this kind of process has not been extensively used in the office building assessment. Therefore, the integration of LCA and LCC should be investigated further.

The next chapter presents the research design for this project. It will discuss the conceptual framework for in-depth studies into strategic practices for sustainable maintenance of office buildings.

5. Research Design

5.1 Introduction

The aim of this research is to develop a framework for the lessening of CO_2 emissions from existing office buildings into the environment. The framework is an integrated sustainable maintenance method to improve/upgrade office buildings to be more sustainable.

This chapter discusses the gathering of quantitative and qualitative data for the framework including research methods such as questionnaire surveys, focus groups, Delphi studies and case studies. Lastly, there is a discussion of the research design and process for data collection to systematically establish an efficient framework or strategic model for Maintenance Practices – Improving Sustainability Performance of Existing Office Buildings (SMOB). The SMOB including outcomes from these studies can be used to improve an office building to be environmentally friendly over the rest of its life span and satisfy environmental protection requirements.

The chapter focusses on the presentation of studies for establishing the research framework from research methodology to research design for the data collection process; while data analysis and results presentation will be discussed in later chapters.

5.2 Research Methodology

As discussed in Chapter 1, this project aims at reducing CO_2 emissions by decreasing energy and water consumptions in existing office buildings. The development of sustainable maintenance practices is the expected solution for the project aim. It can improve the long-term environmental and economic performance of office buildings. The results from analyses of data collected are used to develop the SMOB in a long-term approach. From this, the consumption of energy and water in the buildings will be reduced.

A research project is effective when the research scope can be thoroughly investigated (Runeson & de Valence 2015). To satisfy these objectives and for the research to be successful, it requires the right methodology or methodologies (Creswell 2009; Johnson & Christensen 2014; Runeson & Skitmore 1999). There are many types of research methodologies for collecting data or information (Kumar 2011); however, following the opinions of Johnson and Christensen (2014), three methodologies were studied for this research: quantitative, qualitative and mixed methods. The quality of each methodology is distinguishable in its approach, and each methodology carries significant strengths and weaknesses.

Quantitative research is principally based on the collection of quantitative or numerical data. Qualitative research is principally based on the collection of qualitative data or non-numerical data such as words or images. Mixed methods is a combination of quantitative and qualitative methods (Johnson & Christensen 2014). For this project, methods based on all three types of research methodologies have been employed for data collection.

5.2.1 Quantitative Methods

Quantitative methods concentrate on measurements and amounts of behaviour expressed by people and features exhibited by events (Thomas 2003). According to Jonker and Pennink (2010) a frame of theory is the essence of quantitative research in 'quantities', which also denotes measuring and counting, that can lead researchers to know the degree to which something might or might not happen in the form of amount, number, frequency and so forth. An example is a specific kind of behaviour, such as the number of times a month the HVAC system is cleaned and/or serviced, or the service/repair of lighting systems and lifts and escalators per year.

The framework of a theory will also assist a researcher in understanding the research problem. A quantitative method may be conducted with a survey through means of closed questions. The collected information can be systematically classified and numerically analysed, for example by using computing software such as SPSS. The results can be used to test the theory (Jonker & Pennink 2010) and can be presented by statistics, tables, and graphs (ACAPS 2012).

Quantitative methods have clear starting and finishing points. They can be easily adopted by researchers because they are focused on establishing a hypothesis and a theory, and are then followed by testing the hypothesis and the theory. However, the process should have a strictly methodical approach by which the accurate operation is determined and bias avoided (Johnson & Christensen 2014; Jonker & Pennink 2010). Thomas (2003) presents three kinds of quantitative study: survey, correlation analyses and experiments.

Table 5.1 summarises the strengths and weaknesses of quantitative methods. From the table, it can be observed that a survey is useful in disclosing the present status of select characteristics, correlation analyses to show degrees of relationship amongst characteristics, and experiments to deliver information about obvious effects of variation in characteristics. However, the methods have significant weaknesses; for example, surveys fail to show the unique way of target variables, correlation analyses are only beneficial depending on the data quality they are based on, and experiments findings may not be generalised into real-life conditions and some may not be able to be conducted, due to ethical and human concerns. Based on the characteristics of these methods, surveys are the most suitable for this research project, as it is as they are an effective method for collecting information about selected characteristics of an individual or a group.

Table 5.1 Strengths and weaknesses of quantitative methods

Type	Contents	Strengths	Weaknesses
Survey	A method used to collect information about the current and future status of some target variables in a particular entity based on sample sizes.	Useful in revealing the current and future status of a target variable within a particular entity, such as an individual or a group.	Fails to show the unique way that the target variable fits into the pattern of the individual units within the entity because the results are based on averages and percentages outcomes.
Correlation analyses	A scientific study in which a researcher investigates associations between variables, ranging in precision from very general verbal to highly specific statistical.	Uses statistical techniques for calculating the degree of relationship between phenomena and provides more precise information.	To reveal a relationship of variables without determining the cause of the relationship and how variables influence each other.
Experiments	A method to help researchers decide and evaluate the hypotheses concept and the outcomes explanation.	Capacity to demonstrate cause-and-effect relationships and useful in testing theories and hypotheses about how physical processes work under particular conditions.	Findings may not be generalised into real-life conditions; for example, cloning experimental results may not be utilised to human life due to the ethical and human concerns.

Source: Adapted from Liu (2014); Thomas (2003)

5.2.2 Qualitative Methods

Qualitative methods in research express types of characteristics of people and events without occurrences in terms of measurements or amounts (Thomas 2003). Qualitative methods rely on text and image data, possess distinctive stages in data analysis, and draw on different strategies of query (Creswell 2009). According to Jonker and Pennink (2010), recognising the features and construction of phenomena and occurrences assessed in their ordinary perspectives is the essence of qualitative research. Qualitative research can be carried out with an 'open' questionnaire to understand how people experience their circumstances.

ACAPS (2012); and Jonker and Pennink (2010) point out that qualitative research is used when researchers wish to have answers for "why" and "how' the problems occur. It is based on empirical investigation and evidence to discover the characteristics, construct of phenomena and examine events in their natural context. It explores information from the standpoints and experiences of both individuals and groups in situations that are observational and include informal conversation, in-depth interviews and case studies. The results of qualitative research are summaries of in-depth knowledge obtained rather than lists of numeric data as in quantitative research. Qualitative methods of research and analyses deliver extra value in recognising and discovering non-numeral factors, such as an investigation why and how the current programs of building maintenance practices to find suggested ways to improve it if possible for the application of current and future building maintenance strategies.

According to Fowler (2009); Liu (2014); Rowe and Wright (2011); and Thomas (2003), the most effective qualitative methods for collecting the views and experiences of an individual or a group are ethnography and experience narratives, focus group discussions, Delphi studies and case studies. This is shown in Table 5.2, which summarises the strengths and weaknesses of qualitative methods. From the table, it is clear that even though all these methods have strengths, such as allowing more open and flexible participation and disclosing the range of ways that researchers conduct their research, each method also contains some weaknesses that researchers should consider. For example, conclusions drawn from the ethnographic study of one group can not necessarily be applied to other groups, because of the unique conditions that may determine the pattern of life in each setting; experience narrative is not an effective device for revealing how characteristics are distributed throughout a population. The limitations of the case study are that it allows application of generalisations, principles or situations drawn from one case to others at considerable risk of error. The selection could depend mainly on qualitative decision-making that a researcher can rely on in distinguishing what to use rather than amounts, errors and risks about the research results. Based on characteristics of these methods, the last three methods, focus group discussions, Delphi studies and case studies are considered the most suitable for this research project.

Table 5.2 Strengths and weaknesses of qualitative methods

Type	Contents	Strengths	Weaknesses
Ethnography	A special kind of case study, the chief method used by cultural anthropologists to understand the structure and inner workings of a group.	It can reveal characteristics shared among members of groups, characteristics that render the group's culture distinctive, thereby helping consumers of the research understand how and why one group differs from another.	Conclusions drawn from the ethnographic study of one group can not necessarily be applied to other groups, because of the unique conditions that may determine the pattern of life in each setting.
Experience narrative	An account of an event or of several related events as described by a person who was involved in the described episode, either as an active participant or as an observer.	It enables readers to participate vicariously in other people's thoughts and emotions that are associated with events the readers would never directly experience in their own lives.	It is not an effective device for revealing how characteristics are distributed throughout a population.
Focus group discussion	Based on face-to-face discussions with a special research area to collect information from a few selected participants. It can be used in addition to survey methods.	It is almost always useful in evaluating the reality about which respondents answer questions among the study objectives.	The outcomes need to be evaluated due to the opinions of a small number of involved participants.
Delphi study	Relies on a consensus from the involved experts. It is a stronger mechanism used to collect accurate information from the professionals and stakeholders on an expert panel.	It provides a less costly process, more accurate in enhancing judgement than other group techniques, such as face-to-face committee meeting. It is a more appropriate process to bring experts together.	It is tremendously time-consuming. It should be managed in a reasonable period for each designed round. Participants may drop out over rounds.
Case study	Typically consists of a description of an entity and the entity's actions and offers explanations of why the entity acts as it does.	It may reveal the multiplicity of factors that has interacted to produce the unique character of the entity that is the subject of the research.	It allows application of the generalisations, principles or situations drawn from one case to others only at considerable risk of error.

Source: Adapted from Fowler (2009); Liu (2014); Rowe and Wright (2011); Thomas(2003)

5.2.3 Mixed Methods of Quantitative and Qualitative Research

As discussed in Sections 5.2.1 and 5.2.2, each method of quantitative research and qualitative research has its own strengths and weaknesses, and each one is suitable for answering certain kinds of question (Thomas 2003). Data collected from both methods are empirical and are different kinds of information; neither type of data is superior to the other (ACAPS 2012). Conducting a study with only quantitative or qualitative research might not satisfy an in-depth investigation for comprehensive research needs. Therefore, a combination of quantitative and qualitative methods, known as mixed methods, is a good way to solve these kinds of problems (Jonker & Pennink 2010).

Mixed methods research is:

> "A study that involves the collection or analysis of both quantitative and qualitative data in a single study in which data is collected concurrently or sequentially, given a priority, and involve the integration of the data at one or more stages in the process of research" (Creswell et al. 2003 cited in Lund 2012, p. 156).

In mixed methods research, the appropriate consideration of the research questions and the conditional and conductional issues facing a researcher will determine the exact mixture of quantitative and qualitative research (Johnson & Christensen 2014). Mixed methods is commonly used in some types of social science research by using triangulation methods as convergence across quantitative and qualitative methods (Liu 2014; Mengshoel 2012). However, it has been noted that the triangulation concept interacting between quantitative and qualitative research would be very effective when it lies in the principle that the weaknesses of each single method being compensated by the counterbalancing strengths of another (Jick 1979 cited in Liu 2014; Mengshoel 2012; Östlund et al. 2011; Zou, Sunindijo & Dainty 2014). Moreover, Östlund et al. (2011, p. 371) state that "the triangulation metaphor represents the logical relationships between theoretical propositions of quantitative data and empirical findings of qualitative data".

According to Östlund et al. (2011), the outcomes from the analysis are based on the use of the triangulation metaphor:

> Whether that be *convergent*, where qualitative and quantitative findings lead to the same conclusion; *complementary*, where qualitative and quantitative results can be used to supplement each other; or *divergent*, where the combination of qualitative and quantitative results provides different (and at times contradictory) findings.

Data collected from quantitative and qualitative methods can be blended into one large database, or the outcomes can be handled side-by-side to strengthen each other (Crewell & Clark 2007; cited in Liu 2014). Liu (2014) also found, as reported by the US AID Evaluation Special Study Series (1989), the outcomes of more than 60 projects has shown how quantitative and qualitative data can be combined, and how researchers can combine direct fieldwork, secondary data, project documents, interviews, and observations to draw conclusions. Table 5.3 summarises the way mixed methods combine quantitative and qualitative methods based on the triangulation metaphor. From the table it is seen that mixed methods research may be used widely due to its flexibility in applying both quantitative and qualitative methods. The benefit of mixed methods research is that it provides the full range of possibilities of data collection and organisation for researchers to consider. For example, it combines the characteristics of quantitative and qualitative methods: the use of close-ended questioning and open-ended questioning, and the concentration on numeric and nonnumeric data analysis. Therefore, data, including audio-visual data, can be collected and analysed using multi-forms from surveys, focus groups, Delphi studies, case studies and others. The results can deal with both the statistical interpretation and text patterns, or interpretation across databases.

Table 5.3 Features of quantitative, qualitative and mixed method

Quantitative Methods →	Mixed Methods	← Qualitative Methods
• Pre-determined	• Both pre-determined and emerging methods	• Emerging methods
• Instrument-based questions	• Both open- and close-ended questions	• Open-ended questions
• Performance data, altitude data, observational data, and census data	• Multiple forms of data drawing on all possibilities	• Interview data, observation data, document data, and audio-visual data
• Statistical analysis	• Statistical and text analysis	• Text and image analysis
• Statistical interpretation	• Interpretation across databases	• Themes, patterns interpretation

Source: Creswell (2009)

5.3 Research Design

This section presents a framework for the research design including methods used for the data collection process aimed at developing and verifying the SMOB. This research project utilises a mixed methods approach for the data collection process combining the techniques of quantitative and qualitative methods.

The following sections present an analysis of studies on the maintenance of office buildings done by previous researchers; instruments used for data collection; and the research process designed for data collection for this research project.

5.3.1 Research Studies on the Maintenance of Office Buildings

A literature review found a large number of research studies conducted in the building industry relating to the maintenance of office buildings. The methods used for these studies are largely questionnaire surveys, focus groups, Delphi studies, and cases studies. These research studies provide an important insight into the application of these methods in research which are within the areas investigated by this project. Of which they provide useful knowledge in enhancing the establishment of this research's framework.

a) **Questionnaire surveys**

- Liang et al. (2014) studied improving indoor environment quality under certified green performance to satisfy occupants of office buildings in Taiwan.

- Isa et al. (2013) investigated factors that affect developing green office buildings in Malaysia.

- van de Wetering and Wyatt (2011) investigated the views of occupiers perceptions and actions on sustainability issues and drivers for existing UK office buildings.

- Hurlimann (2006) investigated workers attitudes in using recycled water in Melbourne, Australia, office buildings.

- Property Council Research (2012) analysed operating and maintenance costs for office buildings in Australia.

- Wilkinson and Reed (2006a) studied the upgrading of Australian office buildings to satisfy the environment by increasing applications of ESD.

b) **Case studies**

- Juan, Gao and Wang (2010) studied the development of an integrated decision support system to assess existing office building conditions with optimal sustainable renovation actions improving building quality and cost-benefits over environmental impacts in advanced countries.

- Wang et al. (2013) studied the recommissioning of HVAC systems for energy efficiency and cost-effective operations and maintenance of existing office buildings in the US.

- Guan et al. (2014) investigated the responses key stakeholders of office buildings on electricity consumption in South Australia.

- Wilkinson (2014) studied the improvement and upgrading of existing office buildings in Australia.

- Wilkinson (2012) analysed applying sustainable retrofit for Sydney's existing office buildings.

c) Delphi studies, focus groups and case studies

- Hardie, Khan and Miller (2006) investigated benchmarks for recycling practices in improving and upgrading Australian commercial office buildings.

However there are only a few studies about sustainable maintenance of office buildings and they are:

- Lewis, Riley and Elmualim (2010) studied through literature review high-performance buildings with a specific focus on operations and maintenance on both building and systems, such as HVAC systems and others, and organisational systems that are necessary to achieve the successful high performance of buildings. The findings interoperability and integration are key needs for true implementation of high-performance buildings in operations, maintenance technologies, practices, skills to operate and the ways maintenance of high-performance buildings must be improved.

- Au-Yong, Ali and Ahmad (2014b) used a mixed methods approach that includes a literature review, questionnaire survey, semi-structured interviews, and case study to find characteristics of cost maintenance of office buildings based on condition-based maintenance. The findings reveal that the characteristics of condition-based maintenance are significantly important and directly influenced cost performance in the maintenance process from planning to the outcome of maintenance. They include skill and knowledge of management, availability of monitoring equipment and techniques, capability to adopt monitoring technology, as well as reliability of maintenance data and information.

- Au-Yong, Ali and Ahmad (2014c) used a case study to investigate and identify the maintenance characteristics and aspects of preventive maintenance towards good performance in maintenance of components in office buildings. They found that significant maintenance characteristics must be taken into consideration to achieve optimal maintenance performance. These include skill and knowledge of maintenance labour, quality of spare parts and materials, length of predetermined maintenance intervals, skill and knowledge of the maintenance manager, capability to adopt maintenance equipment and techniques, budget allocation for acquisition of maintenance data, reliability of maintenance data, and frequency of monitoring and inspection.

Therefore, many researchers use a variety of methods such as questionnaire surveys, focus groups, Delphi studies and case studies to find facts and events occurring during the building life span. However, research on the sustainable maintenance of office buildings is still limited.

5.3.2 Data Collection

a) Data collection instruments

Data collection is an important part of research projects and the quality of collected data will depend on suitable methods selected for data collection (Harrell & Bradley 2009). When conducting research, researchers have to carry out processes and use instruments in collecting information or data. The three important instruments are questionnaires, inventories, and case studies (Liu 2014; Thomas 2003).

Questionnaires provide researchers with an instrument to collect a large quantity of data in a relatively short time; however, if the researcher is unable to manage the process or is not present to supervise the participants as they complete the questionnaire, participants can easily avoid responding. Case studies can be on a single case or on multi-cases. It allows for a lot of in-depth information to be collected that would not usually be gathered by other methods. It may be biased in data collection and analysis due to an individual's experience, and the outcomes can be generally applied from one case to another, but at considerable risk of error.

Based on the scope of this research project, time and financial considerations, four instruments were adopted for data collection and they are: questionnaire survey, focus group discussion, a Delphi study, and multiple case studies.

b) Four stages of data collection

These adopted methods were designed as four stages of data collection for this research project as shown in Table 5.4. The table outlines the availability or suitability of each method for achieving the aims and objectives of the study as discussed in Chapter 1.

Table 5.4 Four stages of data collection

Aim/Objective	Methods			
	Questionnaire Survey	Focus Group	Delphi Study	Case Studies
Understanding current practices in maintenance of office buildings with a large sample size of participants to establish the most important issues, including advanced and difficult issues, used to improve maintenance practices for office buildings	√	x	x	x
Evaluating the reality in which respondents answer questions, the most important issues in the survey process in establishing the most critical issues used to improve maintenance practices for office buildings	x	√	x	x
Obtaining a consensus in ranking the most critical issues in improving maintenance practices for office buildings	x	x	√	x
Investigating to discover and obtain current maintenance practices in particular office buildings in verifying the SMOB resulting from the survey, focus group and Delphi studies	x	x	x	√

Notes: √: Indicates the method is available or suitable to conduct
x: Indicates the method is not available or difficult to conduct for this research due to its circumstance

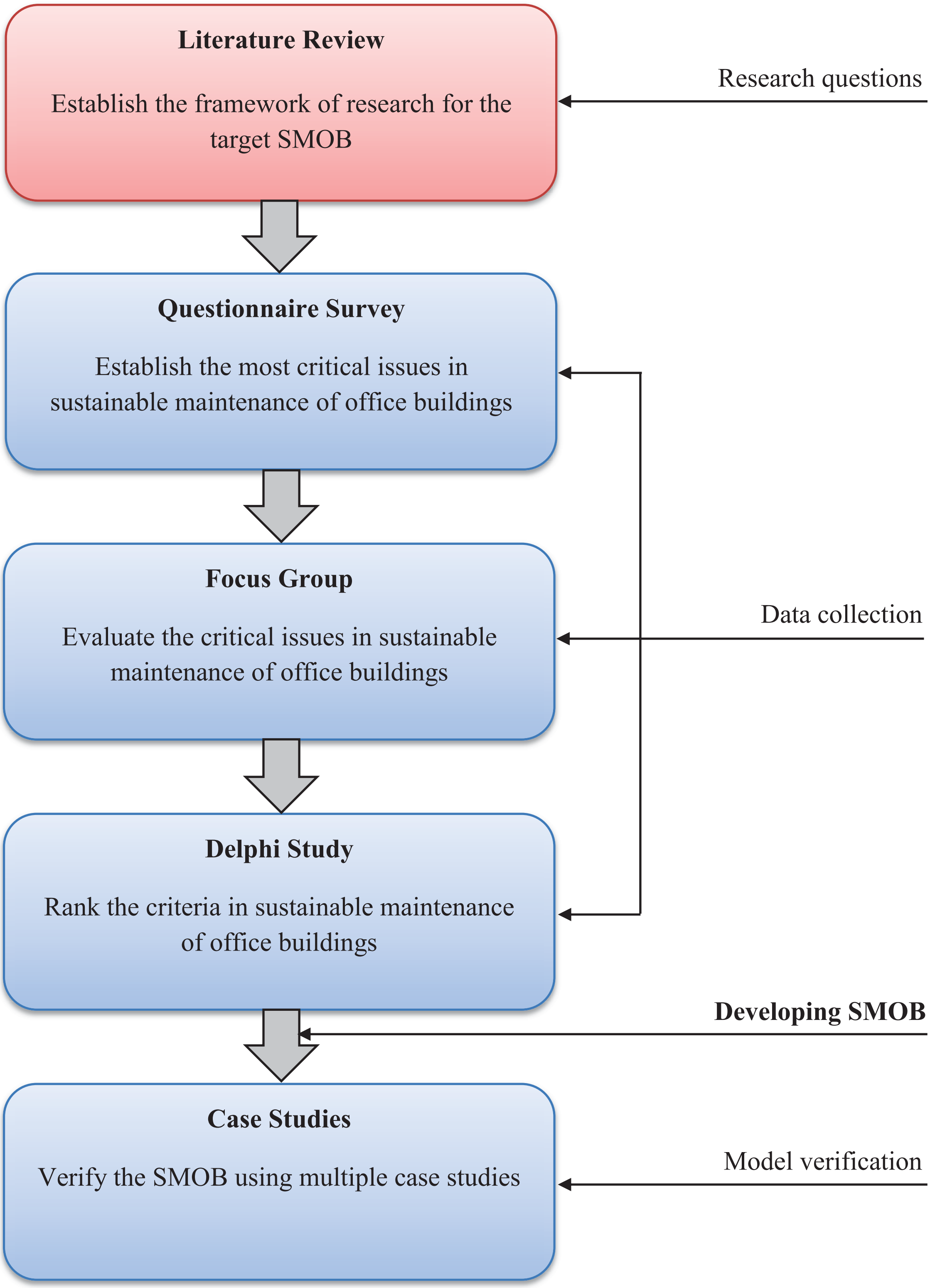
The aim of these processes is to gather opinions and experiences of participants in office buildings about current and future maintenance practices towards sustainable building development. Lastly, case studies of selected office buildings are undertaken to study their current maintenance practices are to verify the SMOB. The preceding method will contribute its outcomes for data collection for the next method.

5.3.3 Research Process

A comprehensive literature review, as discussed in Chapters 2–4, investigated maintenance practices, which include traditional and sustainable maintenance practices, for existing office buildings over the long-term performance. The analyses and discussions included negative impacts between buildings and the environment, sustainable building development to reduce these impacts under the concept of balancing environmental and economic measures, and assessment of sustainable maintenance of buildings.

Based on these findings, a process for this research was established with the aim to develop and verify the SMOB. The research process for data collection is shown in Figure 5.1. Throughout this section, each method used is reviewed with a discussion on their characteristics and methods of data collection. It will also discuss the use of case studies to verify the developed SMOB.

Figure 5.1 Research process



a) Questionnaire survey

The data collection for this research project starts with a questionnaire survey. A questionnaire survey method with a set questionnaire is a popular and powerful means to obtain large amounts of data from large numbers of people in a relatively short time (McNeill & Chapman 2005).

Like other areas, the survey method is commonly used by researchers in the building industry (as discussed in Section 5.3.1). The major effect of surveys is often based on the results of data collection and analysis. These analyses are not error free. According to Fowler (2009), there are two types of errors which are usually correlated in conducting a survey. The first error is associated with 'who' answers, whereby results are different when obtained from a large population and from which data are drawn due to the selection of samples. This type of error includes random selection that affects the true characteristics of the population, called sampling error; and error of bias that is influenced by the relationship between a sample of respondents and of the target population. The second error is associated with 'answers' to survey questions. Respondents need to understand what is being measured: objective facts or subjective states. Objective facts include personal characteristics while subjective states are personal views and experiences in the respondent's profession. This type of error can be caused by: misunderstanding the question, lack of information needed to answer, and distorting answers. However, the outcomes will be accurately derived from the analysis when collected data are cautiously filtered, cleaned, thoroughly investigated, and systematically analysed (Fowler 2009).

According to Fowler (2009) there are two main components of surveys. The first is sampling of a small subgroup of a population to represent the whole population relating to the objectives of the survey. A sample for the survey process can be conducted with simple random sampling, stratified sample or cluster sampling. The second is questionnaire design. Questions should be simple and easily understood by the respondents, so answers can be meaningful. Most importantly, the wording of the questions should be objective rather than subjective. A good question yields answers that are reliable and provides valid measures of something embedded in the objectives of the research (Fowler 1995).

The questionnaire designed for the survey was based on the comprehensive literature review, tested, and then amended by comments received from a pilot survey (as discussed in Chapter 6). Sampling for the questionnaire survey is adapted the stratified sampling technique; however, participants involved in maintenance office buildings are selected for invitation to avoid sampling error, bias, and misinterpretation. The result is a range of critical issues for improving maintenance of office buildings to become sustainable. These critical issues are discussed and confirmed in the focus group discussion.

b) Focus group discussion

A focus group discussion is established after having the analysed the outcome from the survey. The primary purpose of these discussions is to affirm and consolidate the most critical issues established from the survey.

Focus groups are a suitable method for a full range of qualitative research studies (Gray-Vickrey 1993 cited in Webb & Kevern 2000). This is the method that taps human attitudes and perceptions relating to research topics by interaction between people (Krueger 1994 cited in Webb & Kevern 2000). Focus group methods require an initial meeting with a confirmed agreement for weighting key attributes (Wilkinson, James & Reed 2009). According to Fowler (2009), the best way to carry out focus group discussions is with six to eight people. From a group of that size, participants perceptions, experiences and possible feelings related to what is to be measured in the research can be effectively achieved. However, as Wilkinson, James and Reed (2009), argue, because of the small number of people in the focus group discussion, the opinions expressed in the meeting may not reach the real-life situations as expected. Therefore, there is a need to evaluate the participants opinions in data analysis.

The outcomes from the questionnaire survey and focus group discussion are compiled to become the questionnaire for participants to answer in the Delphi study.

c) Delphi study

The Delphi study is conducted after the outcomes of the focus group discussion have been analysed. It aims to obtain a consensus from the involved participants on the rating of criteria used to establish the SMOB.

The Delphi method is an economical and specific type of survey method in research (Chan et al. 2001) and an appropriate method in establishing a precise set of questions for the experts involved (Okoli & Pawlowski 2004) to accumulate the right answers and comments (Rowe & Wright 2011). This method of research is a process that allows experts access to a self-validating mechanism and to have an opportunity to re-evaluate their answers in response to the answers offered by other experts. It also provides a mechanical platform to minimise the amount of bias and gather objective information from a panel of experts. In turn, the Delphi technique can provide a number of benefits in setting a benchmark for measuring the policies within the building industry (Critcher & Gladstone 1998) and the performances of the projects (Yeung, Chan & Chan 2009).

The principle of the Delphi method is to obtain a group judgement or decision on a specific studied area, so that the outcomes are based on a qualitative measure or result (Yeung, Chan & Chan 2009). Therefore, new areas, such as a study of sustainable maintenance practices for office buildings, which are normally themed to variable forces, is the most suitable for using the Delphi technique, because in most cases sustainable maintenance practices are not easily quantifiable (Manoliadis, Tsolas & Nakou 2006). A major advantage of the Delphi method is that it can be carried out without group meetings. Participants can give responses to their answers via an electronic platform, such as a survey website or email address.

The characteristics, strengths and weaknesses of the Delphi method are summarised in Table 5.5. The table illustrates the main characteristics of anonymity, iteration, controlled feedback and statistical combination of group answers. Even though this method has some weaknesses, it provides a number of benefits. In short-term forecasting, the Delphi method provides more accurate judgements and avoids any counterproductive problems such as face-to-face committee meetings. It will provide a positive opportunity that facilitates different views by contributors. It can accept a larger number of participants, who will design the Delphi study according to their available time and individually respond within the timeframe. Therefore, it is widely used by researchers.

Table 5.5 Characteristics, strengths and weaknesses of the Delphi method

Characteristics	Strengths	Weaknesses
• Anonymity: participants are allowed to respond in privacy, avoid undue social pressure, and respond at their convenience. • Iteration: the questionnaire is constructed and presented over many rounds, so participants are allowed to change their opinions between rounds. • Controlled feedback: is carried out within survey rounds so that each participant keeps up-to-date with other members opinions. Usually, feedback is formed with a simple statistical summary of the group reply, such as mean or median. • Statistical group response: is achieved at the completion of the process when a consensus is observed through participants' opinions, and group judgment is presented with a median.	• For short-term forecasting, the Delphi method provides more accurate judgement than face-to-face committee meetings. • It provides significant superior predictions over a normal interacting group. • It provides a structured group with comfortable and confidential environment compared to other types, such as an 'estimate-talk-estimate' procedure or the nominal group technique. • It provides a less costly process in providing enhanced judgmental performance than does other group techniques, such as the meeting of a committee or the nominal group technique. • It is from subjective judgment on a collective basis.	• The process is tremendously time consuming. It should be managed in a reasonable period for each round. Specifically, the follow- up, for instance reminder letters and reminder calls, should be properly managed throughout each round. • The selection of the panel experts is significant; participants must be 'willing and able' to complete the process. Anyone who does not do this would lead the Delphi study into a problem such as time expansion or a consensus not being reached. • It is tremendously important that questionnaires and the presentation format for all Delphi studies must be strategically designed. Any misunderstanding from a question will lead to inefficient effort. Therefore, illumination of the criteria questions is necessary because of indirect communication between the experts.

Characteristics	Strengths	Weaknesses
	• When a process is not practical or desirable to bring experts together, the Delphi method is appropriate. • It will avoid any counter-productive problems that may arise from a face-to-face meeting of a group of experts. It also prevents embarrassment to participants over arguments in meetings that can result in an inaccurate outcome. • It will provide a positive opportunity that facilitates different views and makes certain equal contribution by contributors. • It can accept a larger amount of participants. • Participants will decide their available time and individual way in responding within the timeframe.	• It is very important to keep the panel of experts responding at each round of the process. Any dropout of the panel would be very undesirable for the Delphi study, and a consensus might not be achieved.

Source: Adapted from Ananth, Nazareth and Ramamurthy (2011); Rowe, Wright and Bolger (1991); Yeung, Chan and Chan (2009)

To gather the in-depth thoughts, opinions and expertise of experts about current and future maintenance of office buildings, the three-round Delphi method was chosen instead of personal interviews because it is a stronger mechanism to collect accurate information that is not likely to be collected from round-table meetings and focus groups (Critcher & Gladstone 1998).

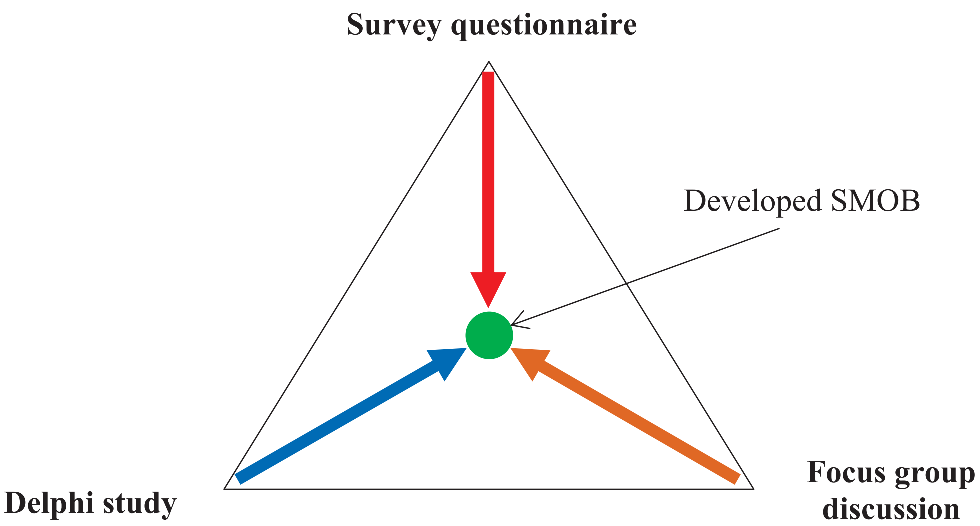
Principally, the result of the Delphi method is based on the judgement of selected experts. A judgement or view on certain areas is naturally planned for in the process rather than observing a quantifiable measure or result (Manoliadis, Tsolas & Nakou 2006; Yeung, Chan & Chan 2009). The Delphi method allows experts to create a self-validating mechanism. They also have an opportunity to re-evaluate their scores in regard to the mean scores assessed by other experts (Rowe & Wright 2011). Whereas nominal surveys aim to detect "what is" questions, the Delphi method makes an effort to find "what could be" or "what should be" questions (Miller 2006 cited in Hsu & Sandford 2007). The Delphi method is a qualitative research method with a systematic and interactive research technique for obtaining the judgement of a panel of independent experts on a specific topic (Hallowell & Gambatese 2010).

Currently, there are a number of methods which can be used to gather participants' in-depth thoughts, opinions and experiences in achieving solutions for a research project; however, they may have more problems than the Delphi method has (Gordon 2008). For example, interviews are costly and time-consuming, not everyone is equally articulate and perceptive, and the researcher's presence may create biased responses during the interviews (Thomas 2003). Thus, the Delphi method is selected to be used as an alternative research technique when traditional methods, such as interviews, cannot be carried out because of economic and time restraints, or the technical organisation of the research. The consensus achieved in the Delphi method is considered suitable for the development of the SMOB because the consensus of expert opinions is specific to a real-world problem (Hsu & Sandford 2007).

d) Model development

The outcomes from the questionnaire survey, focus group discussion and Delphi study are compiled for the development of the SMOB as shown in Figure 5.2. The SMOB contributes important criteria which can assist the industry stakeholders in improving/upgrading existing office buildings using a strategic sustainable maintenance practice to reduce the impacts of buildings on the environment. Details on the development the SMOB and its applications will be further discussed in Chapter 7.

Figure 5.2 Three stages of outcomes for the development of the SMOB



e) Model verification using case studies

Case studies are the last stage for this research process. They aim to verify the developed SMOB. Case studies are the most popular method used by many researchers (Easton 2010). They allow researchers to investigate more deeply into qualitative research (Tsang 2013); and they can provide a great deal of qualitative data. Case studies are mostly suited to finding "how" and "why" occurrences which can be explanatory (Easton 2010). In addition, in seeking to understand the problem being investigated, case studies provide a chance for deep examination and for obtaining the specific fullness of organisational behaviour (Choy 2014); for example, the performance of office building maintenance by facility managers.

There are a large number of case studies used in the building industry (discussed in Section 5.3.1). The purpose of case studies is to explain why the entity acts as it does. Entities can include various categories such as individuals, groups, organisations, or events (Thomas 2003). It is an in-depth method and a suitable form of quantitative and qualitative analysis. It involves a careful and complete observation from small to large numbers of social units, such as office buildings. The principal objective of case studies is to investigate particular unit/s to discover the factors which explain the behaviour patterns of the given unit/s as an integrated totality (Kothari 2004). Case studies can be conducted as a single or a group of studies in a sample; however, entities of either process can supply a huge allocation of qualitative data which can provide understanding into the nature of the phenomena (Easton 2010).

For this research project, the case studies are selected using multi-case studies of existing office buildings in the Sydney CBD. Observed information from these buildings is studied as evidence to compare and evaluate the developed SMOB. To reduce the risk of error in case studies, Thomas (2003) recommends that the process be carefully designed so that conclusions drawn on the knowledge derived from the case studies can then be used to verify the SMOB (refer to Chapter 8).

To sum up, the design of this research project is based on mixed methods, which combine quantitative and qualitative research methods. The research questions are developed based on the study of the comprehensive literature review, to find the gaps between traditional and sustainable maintenance practices for office buildings. The gaps lead to the design of the research project to develop the SMOB. The SMOB may be used to improve performance of an office building over the long-term in balancing environmental and economic measurements. Data collected for the study include:

- Closed form, linear or one-way communication, and quantitative or numerical data as in the survey process.

- Open form, non-linear or two-way communication, and qualitative or non-numerical data as in the focus group discussion and Delphi study.

They are designed to be carried out consecutively. The triangulation metaphor is used for convergence across and between them. Mixed methods research is used to help in gathering enough data to develop the SMOB. The collection is wide-ranging and provides in-depth data from quantitative and qualitative methods. The mixed methods process can compensate for the weaknesses of each other to provide adequate means in analysing and avoiding bias. Due to the broad range of data to be collected, they will have to be cautiously filtered, cleaned, and systematically analysed to derive an accurate result. Collected data is then coded to ensure confidentiality. Lastly, case studies are conducted to verify the developed SMOB.

5.4 Summary

This chapter has discussed research methodologies and research methods designed for data collection. The discussions have analysed various common research methods used by researchers for conducting a research project to find out characteristics of people, facts and events. They include quantitative, qualitative and mixed research methods.

In this research project, quantitative research will be conducted with a questionnaire survey; qualitative research carried out with a focus group discussion; and a Delphi study and case studies as mixed methods research, which is the combined processes of quantitative and qualitative research for the outcomes. The characteristics, strengths and weaknesses of each were carefully considered in selecting mixed methods for this research project.

The next chapter discusses the process of data collection and data analysis will utilise both statistical and non-statistical methods. The detailed investigations for the development of the SMOB will be further discussed in Chapter 7, and the case studies in Chapter 8.

6. Data Collection and Analysis

6.1 Introduction

As discussed in Chapter 5, the development of a model for sustainable maintenance of office buildings (SMOB) is based on information derived through a questionnaire survey, focus group discussions and a Delphi study.

This chapter presents details of the advantages and disadvantages, costs and savings of the current theory and practice performances and future trends of maintenance management towards sustainability in office buildings. It also outlines the preliminary organisation and analysis of data collected for the provisional outcomes that will contribute to the development of the SMOB. It then clarifies the initial outcomes including expressions of and comments on current practices and the future of maintenance strategies in the industry.

6.2 Questionnaire Survey Process

A questionnaire survey was designed for property professionals, and was conducted in the Sydney CBD from 01 June 2012 to 30 November 2012. It was restricted to this area due to timeframes and manageability. These manageability factors include survey planning, survey process, data collection, and data analysis (McNeill & Chapman 2005).

The questionnaire design is based on the review of the literature. A series of questions was created to gather the opinions and experiences of participants in the property industry, specifically office buildings, on the negative impacts between existing office buildings and the environment, the existing performance of maintenance of office buildings and the expected future practices in improving the maintenance of office buildings. Benefits and difficulties that key stakeholder could face in the building maintenance. The core questions concentrate on the strategies and practices of professionals in maintenance work. They include the current maintenance practices and the applying sustainable maintenance in the property management sector. The future perspective in managing for improving maintenance of buildings is also explored.

Before the main questionnaire survey could be carried out, a pilot study was conducted for the preliminary questionnaire. The outcomes and comments of the pilot study were incorporated in the testing and provided guidance for amendments to the finalised survey.

6.2.1 Pilot Questionnaire Survey

The pilot study was conducted from 1 March 2012 to 31 March 2012. The aim of the pilot study was to obtain professional opinions and comments on how to improve the questionnaire. Outcomes from literature review in Chapters 2–4 were compiled to establish questionnaire for the pilot survey process. A copy of the questionnaire of pilot survey is included in Appendix 1.1.

A total of 17 people, 14 professionals working in the property industry and three academics, were invited to participate in the pilot study via email. Ten responses were received, seven from professionals and three from academics, including a total of four comments were received. Thus, the study reached 59% in returns.

Following the analysis of the pilot study, the original meaning of the questions for the survey process remains; but responses and comments were incorporated to finalise the questionnaire. Part 1 was altered to include participants classified into six categories (as discussed in Section 6.2.3). Three questions were added to Part 2 about the efficiency of the current legislation regarding practices of sustainable maintenance, and usages of sustainable materials and products. This part was also rewritten to consider both the views of building owners and service professionals.

6.2.2 Survey Overview

In the main survey, the participants were mainly professionals in property management and from professional institutes such as AIQS, API, CIOB, FMA and RICS. The participants were invited to participate in the survey online via an emailed request with a survey link. The survey took approximately 15 to 20 minutes to complete. The period for responses was four weeks. Data collected included knowledge and experiences of current practices in the maintenance of office buildings. Future trends in managing office buildings were also identified.

The survey was intended to collect the following data:

- Knowledge about the environmental situation.
- Practical views and experiences on designing and managing systems in maintaining office buildings, particularly:
    - Method applied for maintenance
    - Reasons for the selection of these methods
    - Advantages and disadvantages of the selection
    - Constraints in the execution
- Impacts of the practices on environmental and economic assessments.
- Future trend for incorporating sustainable concepts in the maintenance of office buildings.

Data collected from the survey were systematically organised into electronic coding files for analysis. Data were also refined and cleaned to reduce sources of errors and to align with the research aims (Fowler 2009).

6.2.3 Survey Participants, Sampling and Sampling Errors

A total of 600 professionals currently employed in the maintenance of office buildings were invited to participate in the survey. Following the opinions of Leedy and Ormrod (2001) and Fowler (2009), the number of participants selected was considered an appropriate sample size for this research project.

According to Fowler (2009), to reduce errors in a survey, the process should take into consideration:

a) **Characteristics of population**: only professionals who are working in maintenance of office buildings would be invited.

This study aims to improve the maintenance of office buildings; so the sampling is designed around a population which will provide information regarding current maintenance practices within the property management sector and important factors which can be used to improve the maintenance practices.

b) **Sample of population**: using stratified sampling method

Participants were classified into six categories and 100 participants were selected for each category. The categories are: owners/developers, asset/property managers, sustainability managers, tenants, building services professionals (e.g. builders, building consultants, engineers, etc.) and others (e.g. project managers, valuers, quantity surveyors, etc.).

c) **Answers respondents give**: the answers are assumed to be accurate reflections of participants' knowledge and experience.

The gathered information about building maintenance is expected to achieve the aim of the research because the participants were selected from within the property management sector. Their experiences in the maintenance of office buildings will provide specialised information to be used to improve the maintenance practices for office buildings. Each selected participant was also encouraged to providing individual opinions, knowledge and experiences without being influenced by another. Thus, the gathered information is assumed to be a more reliable measure.

6.2.4 Structure of the Survey Questionnaire

Based on the literature review and the pilot study, the survey questionnaire contains three parts with a total of 21 questions (a copy of the questionnaire of main survey is included in Appendix 1.2).

Part 1: General

This part comprises ten questions. It is a general information compilation including participants background, work experience and expertise. The aim of these questions is to gather the opinions and experiences of participants in the property management sector, particularly office buildings, and to investigate impacts between existing office buildings and the environment. The core questions are on "what", "why" and "how" a building impacts the environment, how to make the building greener to reduce these impacts, and which sustainable maintenance practices are implemented in the property industry. These include the main drivers, such as financial incentives, building regulations, owners awareness, tenants demand and so forth. The analysed results will be a study of "what" and "how" the industry responds to environmental protection requirements and what problems and barriers currently exist.

Part 2: Sustainable maintenance of office buildings

This part includes nine questions. It is a compilation of existing performances of maintenance of office buildings. The aim of these questions is to gather opinions and experiences of participants in the property management sector on the maintenance of office buildings. The core questions concentrate on the current strategies and practices of key stakeholders on maintenance work done. These include "what" are the major considerations, "why" are difficulties experienced with their strategies and practices on maintenance responsibilities, and "how" they overcome these difficulties.

Part 3: Invitation to participate in the focus group and Delphi study

Participants are invited to take part in focus group discussions and the Delphi study at the later stage of the study. These processes allow further investigation of thoughts about details in office building maintenance practices.

6.2.5 The Survey Process

The main survey was conducted in June 2012 and was open for participation for four weeks. However, only about 10% of responses were received. A follow-up email was sent out to remind people to respond to the survey, and then around 12% additional responses were received. A third email reminder was sent out and the survey was closed in November 2012. A total of 219 usable responses were received, equivalent to a response rate of 37%.

There were also a number of responses which were either answered questions outside the scope of the maintenance of office buildings or incomplete. They were filtered out prior to analysis.

6.2.6 Survey Discussions and Analysis

a) Background of respondents

A total of 219 participants or a total of 37% returned usable responses to the main survey. The respondents were 179 males and 40 females between six categorised industry groups of sample (as discussed in Section 6.2.3). The respondents of each group of sample are summarised in Table 6.1.

Table 6.1 Responses by category of respondents

Category of Respondents	Male	Female	Sub-Total	%
Owner/Developer	13	1	14	6
Asset Manager/Property Manager	48	25	73	33
Sustainability Manager	46	4	50	23
Tenant	7	2	9	4
Building Service Professional	37	2	39	18
Others (Project Managers, Valuers, Quantity Surveyors, etc.)	28	6	34	16
Total:	**179**	**40**	**219**	**100**

As shown in Table 6.1, Asset/Property Managers were the largest group of respondents that about 73% of the group participated in the survey, accounting to approximately 33% of the total returned survey. Tenants (non-owners and they are defined as current users of the existing office building) were the smallest group and only about 9% in the group participated, accounting to approximately of only 4% of the total returned survey. The significant groups of professionals who were most concerned and expressed their opinions about maintenance management were collectively the Asset/Property Managers, Sustainability Managers, and Building Service Professionals. The total number of these three groups is 131 males and 31 females (74%). Overall, the number of responses returned fulfilled the purpose of the survey.

The characteristics of the respondents are summarised in Table 6.2. The age range is from 25– to 65+ years old. The number of respondents between 25– and 35 was 71 (46 males and 25 females) or 32%. The number of respondents between 36 and 65+ years old was 148 (133 males and 15 females) or 68%. The mean age of the respondents was 43 (SD = 11.62). This indicates the building workforce has a high number of mature professionals.

Approximately 72% of respondents hold a bachelor's degree or higher, and 28% of respondents academic qualified were not specified. The findings also show that approximately 52% of respondents have been in the workforce for more than five years. The mean was 13 years (SD = 5.18).

Table 6.2 Characteristics of respondents

Description		Numbers of Responses			%
		Male	Female	Sub-Total	
Gender		179	40	219	100
Age groups	25 years and under	8	5	13	6
	26–35 years	38	20	58	26
	36–45 years	46	8	54	25
	46–55 years	51	5	56	25
	56–65 years	31	1	32	15
	Over 65 years	5	1	6	3
	Total:	**179**	**40**	**219**	**100**
Academic qualification	PhD	2	0	2	1
	Master	32	4	36	16
	Bachelor	94	25	119	55
	Not specified	51	11	62	28
	Total:	**179**	**40**	**219**	**100**
Years as professionals	5 years and under	78	28	106	48
	6–10 years	40	9	49	22
	11–15 years	19	1	20	9
	16–20 years	13	2	15	7
	Over 20 years	29	0	29	14
	Total:	179	40	219	100
Not working in maintenance of office buildings		60	10	70	32
Working in maintenance of office buildings		119	30	149	68
	Total:	**179**	**40**	**219**	**100**

Results also show that 149 respondents (119 males and 30 females) or 68% are currently working directly in the maintenance of office buildings, as shown in Table 6.3. There are approximately 72% of respondents who have been working directly in the maintenance of office buildings (107/149 respondents) for more than five years. The mean was 15 years (SD = 7.45).

Based on the large number of respondents who have continuously worked in the same career for more than five years (see Table 6.3), it can be said that the respondents represent a group of professionals having work experience in office building maintenance.

Table 6.3 Respondents working directly in the maintenance of office buildings

Description		Numbers of Responses			%
		Male	Female	Sub-Total	
Years of experience in maintenance of office buildings	5 years and under	29	13	42	28
	6–10 years	34	11	45	30
	11–15 years	20	2	22	15
	16–20 years	11	1	12	9
	21–25 years	12	2	14	8
	26–30 years	9	1	10	7
	Over 30 years	4	0	4	3
	Total:	**119**	**30**	**149**	**100**

b) Difference of mean test of survey participating groups

Before detail analysis was used, four mean different tests were carried out to examine whether there is a significant difference of the survey participating groups using SPSS. Table 6.4 illustrates outcomes of these tests and details of the analysis have been included in Appendix 2 at the end of the thesis

Table 6.4 Outcomes of mean different tests between groups of respondents

Test No.	Test Between Survey Questions	One-way Subjects ANOVA		Result
1	1.7.1–1.7.6	$p > 0.05$	$[F(3, 20) = 0.68, p = 0.58]$	No significant difference
2	1.7.1, 1.7.3 and 1.7.4	$p > 0.05$	$[F(3, 8) = 157.64, p = 0.87]$	No significant difference
3	1.8.2, 1.8.5, 1.8.8, 1.8.9, 1.8.10 and 1.8.12	$p < 0.05$	$[F(5,30) = 2.64, p = 0.04]$	Significant difference
4	1.9.1, 1.9.2, 1.9.5, 1.9.6, 1.9.9 and 1.9.10	$p > 0.05$	$[F(5,30) = 0.62, p = 0.68]$	No significant difference

As shown in the Table 6.4, the tests were conducted on the six categories of respondents participated in the survey questionnaires. They are owners, asset/property managers, sustainability managers, tenants, building services professionals (e.g. builders, building consultants, engineers, etc.) and others (e.g. project managers, valuers, quantity surveyors, etc.). The first test was between questions of 1.7.1 to 1.7.6. The results indicate that there is no significant difference in the respondents' opinions that the existing office building impacts to the environment caused by inefficient use of energy and water, and sustainable maintenance strategies should be developed for maintenance practices. The second test was the same as the first test undertaken to the three questions of 1.7.1, 1.7.3 and 1.7.4. Similarly, the results of the test indicate that there is no significant different in the opinions of the groups. The third test was between six questions, 1.8.2, 1.8.5, 1.8.8, 1.8.9, 1.8.10 and 1.8.12. The results indicate the respondents have their own opinions independently on main factors that influence to sustainability initiatives for existing office buildings depending on their age, profession and position. Lastly, the fourth test was between six questions of 1.9.1, 1.9.2, 1.9.5, 1.9.6, 1.9.9 and 1.9.10. The results indicate that there are no different opinions of respondents on main factors that can be used to achieve sustainable maintenance practices for existing office buildings

c) Perceived maintenance practices in existing office buildings

This part aims to identify and explore the current maintenance practices in relation to office buildings. The questions are Likert 5-point scale questions ranging from strongly disagree/very unimportant to strongly agree/very important. It focuses on three significant aspects. The first aspect is an examination of current strategies for sustainable maintenance of existing buildings. About 72% of the respondents agreed or strongly agreed that building stock is a leading source impacting on the environment due to current inefficient use of energy and water in these buildings. Table 6.5 summarises the ratings of respondents on six issues regarding strategies for sustainable maintenance practices. The table indicates that sustainability is the biggest concern in maintenance practice for stakeholders in the industry.

Table 6.5 Rating of issues regarding strategies for sustainable maintenance practices

Issues	Responses					
	Disagree or Strongly Disagree		Neutral		Agree or Strongly Agree	
	Frequency	%	Frequency	%	Frequency	%
Sustainability strategies need to be developed and incorporated into building maintenance practices.	8	4	10	5	201	91
Further growth in sustainable maintenance practices is desirable.	5	2	18	8	196	90
Sustainability initiatives are important in the maintenance of buildings.	10	5	19	9	190	86
Sustainable maintenance practices will gain momentum over the next five years.	9	4	35	16	175	80
Existing buildings impact the environment because they are energy and water inefficient.	26	12	35	16	158	72
The current practices of building maintenance do not support sustainable maintenance of buildings; changes may be required.	45	21	70	32	104	47

From the table, the survey identified that 91% of the respondents agreed or strongly agreed that sustainable strategies must be developed and incorporated into building maintenance. It was also confirmed by 90% of respondents who agreed or strongly agreed that further growth in sustainable maintenance practices is desirable. Approximately 86% of respondents agreed or strongly agreed that sustainability initiatives are important in the maintenance of buildings. There were approximately 80% of respondents who agreed or strongly agreed that sustainable maintenance practices will gain momentum over the next five years. Furthermore, approximately 72% of respondents agreed or strongly agreed that existing buildings impact the environment because they are energy and water inefficient. Approximately 47% of the respondents agreed or strongly agreed that the current practices of building maintenance do not support sustainable maintenance of buildings; and that changes may be required.

This aspect identifies the main factors which influence the present acquisition of sustainability initiatives for building maintenance (as presented in Table 6.6). The most significant factor is the expected costs in carrying out sustainable maintenance, as rated by 91% of respondents. Another factor was the commitment of property owners to sustainable maintenance practices, as rated by 89%. Furthermore, the issue of potential government incentives for sustainable development was rated by 86%. The fact that knowledge and expertise of key stakeholders in the industry should be improved so that newer technologies can be used in sustainable development and the disclosure of performance data of sustainable technologies in the industry was agreed upon by 83% and 82% respectively. Another area explored were the needs to improve current government policies/legislation; 82% agreed or strongly agreed. These factors and others are summarised in Table 6.6. The responses indicate the most significant factors affecting the performance of sustainable maintenance practices were expected costs for sustainability and building owners considering bearing the cost with the support of government incentives. It is assumed and anticipated that when these factors become accessible, the application of sustainability in buildings would be expedited.

Table 6.6 Rating of factors that influence the current uptake of sustainability initiatives in office buildings

Issues	Responses					
	Disagree or Strongly Disagree		Neutral		Agree or Strongly Agree	
	Frequency	%	Frequency	%	Frequency	%
Cost	8	4	10	5	201	91
Commitment of property owners	7	3	17	8	195	89
Potential government incentives	6	3	24	11	189	86
Professional knowledge and expertise	7	3	30	14	182	83
Performance data of sustainable technologies	6	3	33	15	180	82
Current government policies/legislation	8	4	31	14	180	82
Corporate social responsibility policies	7	3	34	16	178	81
Demands from property tenants	10	5	39	18	170	77
Availability of environmentally friendly materials	13	6	39	18	167	76
Community perception	14	6	41	19	164	75
Time	16	7	50	23	153	70
Pre-existing maintenance practices	23	11	64	29	132	60

The third aspect was the identification of significant factors that can be adapted to apply sustainable maintenance practices for existing buildings (see Table 6.7). Results show 92% agreed or strongly agreed that owners/developers should consider replacing existing systems with energy efficient devices. The need to develop sustainable management strategies for building maintenance practices was agreed or strongly agreed by 89%. The need to improve indoor air quality to provide indoor comfort to occupants, reducing sick building syndrome and increasing workers productivity, was agreed or strongly agreed by 80%. Improving/developing legislation to accelerate sustainable maintenance practices for office buildings was agreed or strongly agreed by 77%. The need to use low environmental impact building materials in building maintenance had 74% agreement. The suggestion of using specified cleaning products/paints was supported by 62%. Both suggestions of using recycled building materials and harvesting rainwater to reduce the use of potable water in buildings were supported by 61%. These votes by respondents are summarised in Table 6.7.

Table 6.7 Rating of factors in performing sustainable maintenance of office buildings

Issues	Responses					
	Disagree or Strongly Disagree		Neutral		Disagree or Strongly Disagree	
	Frequency	%	Frequency	%	Frequency	%
Replace existing system with energy efficient devices	3	1	15	7	201	92
Develop sustainable management strategies for the building	1	1	21	10	197	89
Enhance occupants health and productivity by improving indoor air quality and comfort	8	4	36	16	175	80
Develop legislation for sustainable maintenance of office buildings	14	6	37	17	168	77
Use low environmental impact building materials	9	4	48	22	162	74
Use specified cleaning products/paints	16	7	68	31	135	62
Use recycled building materials	10	5	74	34	135	61
Harvest rainwater	23	11	61	28	135	61
Recycle grey or black water	26	12	67	31	126	57
Examine the impact of building sustainability management committees	29	13	81	37	109	50
Purchase green energy	49	22	65	30	105	48

From the Table 6.7, the important factors in performing sustainable maintenance practices are upgrading existing systems or equipment with new technology systems or equipment; developing strategic maintenance management for sustainability; improving indoor climate and comfort for occupiers; using environmental materials and finishes, harvesting rainwater and/or recycling black/grey water. Also, a suggestion is that to accelerate sustainable maintenance of office buildings legislation is needs to be developed.

The survey reveals that professionals in the property management sector are aware that the negative impact of existing buildings on the environment is significant, and therefore sustainability should be developed for maintaining existing office buildings. Certainly, outdated devices or systems, such as HVAC and lighting systems, consume extremely high rates of energy. The usage of water in buildings is also significant. The response indicates that inefficient systems need to be replaced by energy efficient devices or systems with well-managed plans. These improvements/upgrades will not only reduce the consumption of energy but also increase the indoor air quality, provide wellness to occupiers and increase the productivity of personnel. In achieving sustainable maintenance of existing office buildings, the most influential factors that key stakeholders should be concerned with are replacing old devices or systems with energy- or water-efficient ones, planning strategic maintenance management, enhancing occupants health and productivity by improving indoor air quality and comfort, using environmentally friendly materials and finishes, reusing and recycling materials, harvesting rainwater and reusing/recycling grey and/or black water.

d) Current maintenance practices in existing office buildings

The aim of this part is to identify and investigate the current practices by industry professionals who are directly working on the maintenance of existing office buildings. This area also focuses on critical factors that would improve existing office buildings to have more sustainable maintenance practices. There were 149 responses (119 males and 30 females) or 68% of respondents, working directly in the maintenance of office buildings. Approximately 72% of respondents have been working directly in the maintenance of office buildings (107/149 respondents) for more than five years. The mean was 15 years (SD = 7.45). Based on the large number of respondents who worked continuously in the same career for more than five years (see Table 6.3), it can be said that the respondents represent a group of professionals having work experience in office building maintenance.

The first deciding factor is the establishment of difficulties that respondents faced when practicing sustainable maintenance of office buildings. The questions in this part required participants to express their opinions/experiences in short statements about their perception of difficulties they have confronted in applying sustainable maintenance of the buildings. Approximately 72% of respondents addressed their experiences with difficulties in practicing sustainable maintenance, a total of 251 statements. The analysis of these issues found that a common constraint was the experience in managing budgets/finances, as expressed by 89% of respondents. Another problem was the commitment of key stakeholders to sustainable maintenance practices, as expressed by 88%. Furthermore, the dilemma of managing and monitoring energy efficiency within the buildings due to capital expenditures and/or operational expenditure was expressed by 72%. Table 6.8 summarises the difficulties that key stakeholders face in applying sustainable practices.

Table 6.8 Summary of difficulties perceived by key stakeholders

Difficulty in applying sustainable maintenance practices	%
Budget/Financial	89
Commitment of key stakeholders	88
Energy efficiency	72
Government policies, legislation and incentives	67
Scheduling and planning maintenance program	64
Education, training and knowledge	63
Time management	60
Sustainable maintenance skills	56
Building service systems	53
Sustainable technologies	47

The results indicate that when a budget is constrained or is not properly managed, key stakeholders might delay or avoid applying sustainable maintenance in their buildings.

The literature review indicates that energy consumption is identified as the greatest source that impacts the environment (as discussed in Chapters 2 and 3). This was also agreed by 72% of respondents as found in Table 6.5, Section 6.2.6 (c). Thus, energy efficiency is an appropriate way to reduce these negative impacts. Usually, additional costs for sustainability are greater than the costs for traditional practices. Therefore, due to circumstances such as investment conditions, organisation policies, and facility management strategies, the commitment of key stakeholders may also be delayed, or they may avoid applying strategies that facilitate sustainability. However, as established in the literature review, it is evident that in the long-term, the initial extra cost of sustainability may be recouped over time from the savings of operating and maintaining costs. In addition, the lack of knowledge about sustainability can lead key stakeholders to delay or avoid applying sustainable practices. Developing and applying new technologies is not as problematic; therefore, accumulation of knowledge and updating real data for applying sustainable technologies would accelerate the employment of strategies for maintenance practices that would improve and/or upgrade office buildings to be more sustainable.

In current maintenance practices in existing office buildings, approximately 64% of respondents stated that their organisations had an organisational sustainability policy. However, only 17% of respondents stated that sustainable maintenance schedules are already part of their mainstream practices, 65% of respondents would consider it within six to 10 years or more, and 18% of respondents had not specified as shown in Table 6.9. Approximately 14% of respondents stated that they 'always' apply sustainability initiatives as part of the mainstream practices, 57% stated that they 'mostly' apply them, 29% did not specify. The table shows that most existing office buildings in the industry are currently maintained by non-sustainable practices (or traditional maintenance practices). It is significant that the rate of current practices for sustainability is very low. Even though the buildings have a mainstream practice policy, they do not always apply sustainability practices. The use of non-toxic materials and employ efficient systems, equipment and materials are of 36%; while, the use of toxic materials, conventional systems, equipment, and building materials is still high at approximately 64% each category. Service professionals encouraging clients to use non-toxic materials in maintenance are stated by 50%.

Table 6.9 Current maintenance practices in office buildings

Issue	(%)		
	Currently	Applying in 6-10 Years	Not applying or Not Specified
Mainstream practices in sustainable maintenance	17	65	18
Using non-toxic materials	36	-	64
Employing efficient systems, equipment and materials	36	-	64
Service professionals encouraging clients to use non-toxic materials in maintenance	50	-	50

To affirm in ‘always’ applying sustainability in maintenance, there was greatest performance was based on the management of energy consumption within office buildings, expressed by 59%. Key stakeholders would commit to sustainable maintenance of their buildings and work towards sustainability, expressed by 21%. The management of efficient use of water was expressed by 20%.

In ‘mostly’ performing sustainability in maintenance, the most critical issue was the management of energy consumption within buildings, expressed by 63%. The management of efficient water use was expressed by 24%. Improving and upgrading the buildings and/or building systems, particularly the building management and control systems (BMCS), was expressed by 13%.

Following these statements, the key to sustainable maintenance is in improving energy efficiency for HVAC systems and lighting systems, using efficient products, devices and automatic switching-off service systems when the room is not occupied or equipment is not in operation. Next is the expectation of the commitment of key stakeholders towards sustainability. The efficient use of water is also a critical issue in applying sustainable practices. In water management, efficient water fixtures and devices, recycling grey and black water, and harvesting rainwater are good ways to implement sustainable practices. In addition, properly designing and upgrading building service systems and BMCS are efficient ways to apply sustainability.

Finally, 26% of respondents agree or strongly agree that sustainable maintenance practices are currently encouraged and supported by government incentives for stakeholders commitment. However, 22% of respondents agree or strongly agree that the current legislation is not strong enough to make key stakeholders perform sustainable maintenance practices. Table 6.9 regarding responses on the use of non-toxic materials in maintenance practices, 36% of building owners and facility managers agree or strongly agree to use them, and 50% of building service professionals state that they will provide advice to their clients. Therefore, existing office buildings are still maintained with non-sustainable maintenance methods as the mainstream practice, identified by approximately 83% (including 18% of responses were not specified) of the total responses. In addition, approximately 64% of responses confirmed that building owners and facility managers still employ ineffective systems, equipment, building materials and finishes in maintenance practice. Approximately 50% said that building service professionals would encourage their clients to use non-toxic materials in maintenance.

Therefore, enforcing legislation to facilitate applying sustainable practices to satisfy environmental protection requirements is one way towards more sustainable office buildings. The most significant factors in carrying out sustainable maintenance of office buildings are effective energy and water management. The appropriate key factors include the use of environmentally friendly materials, reused and recycled building materials, waste management and up-to-date education to impart sustainable knowledge and skills to professionals. To compensate for additional costs in performing sustainability, government incentives are needed to support sustainable development. Table 6.10 summarises the most critical issues that can be used in achieving sustainable maintenance of office buildings. Saving energy consumed in the buildings and replacing outdated or energy inefficient systems and equipment with energy efficient devices is the first consideration, suggested by 92%. Developing strategies of sustainable maintenance is the second, suggested by 89%. Commitment of property owners to sustainable maintenance is the third, suggested by 89%. Enhancing occupants health and productivity by improving indoor air quality and comfort is the fourth, suggested by 80%. The rest are developing legislation, using low-environmental impact or recycled materials, harvesting rainwater and recycling grey or black water. These suggestions are from 57 to 77%.

Table 6.10 Critical issues in achieving sustainable maintenance of office buildings

Critical Issue	Disagree (%)	Neutral (%)	Agree (%)
Replacing existing system with energy efficient devices	1	7	92
Developing sustainable management strategies for the building	1	10	89
Commitment of property owners	3	8	89
Enhancing occupants health and productivity by improving indoor air quality and comfort	4	16	80
Developing legislation for sustainable maintenance of office buildings	6	17	77
Using low environmental impact building materials	4	22	74
Using specified cleaning products/paints	7	31	62
Using recycled building materials	5	34	61
Harvesting rainwater	11	28	61
Recycling grey or black water	12	31	57

To sum up, environmental improvements of existing office buildings attract tenants because green buildings typically denote lower operation costs for them. New targets for both building owners and tenants are needed to cooperate in the improvement of building services. Sustainability is important, so sustainable maintenance practices seem necessary to meet the requirements in maintaining existing building stock. Sustainability will improve existing buildings and balancing environmental protection and economic growth. Sustainability will lead the property industry to achieve a balance between protecting and improving the natural environment, and contributing positively to the economy.

Even though most of the respondents agreed with the statements on developing sustainable maintenance of existing office buildings, a number of respondents disagreed. This might be due to:

- The circumstances for their buildings.
- They think developing sustainable maintenance is complex and costly.
- Their budget does not allow for sustainable changes and/or is not available.
- They are satisfied with the current maintenance practices.
- They have limited knowledge of or lack new technologies.
- Legislation is not suitable for encouraging development of sustainable maintenance of existing office buildings.

The survey found that a large number of existing office buildings in the property management sector is currently maintained by non-sustainable practices (or traditional maintenance practices). The survey also found that sustainability is a relatively new concept in maintenance practice; however, key stakeholders are eager to consider sustainable maintenance and may apply it to mainstream practices in maintenance strategies for their existing office buildings when possible.

As a result the survey revealed that there are many significant factors relative to applying sustainable maintenance practices to existing office buildings. They include advantages and difficulties that follow the application as summarised in Table 6.11.

The table lists three groups of critical issues from the survey analysis:

- Critical issues that can be adapted to achieve sustainable maintenance practice.
- Critical issues that affect the current uptake of sustainability.
- Critical issues that make it difficult to undertake sustainable maintenance practice.

Each group has a number of activities relating to developing sustainable maintenance practices for existing office buildings. These critical issues are used as information for the focus group discussion in Section 6.3.

Table 6.11 Critical issues in developing sustainable maintenance practices

Critical Issues	Activities
Critical issues that can be adapted to achieve sustainable maintenance practice	• Managing energy and water efficiently • Developing sustainable maintenance strategies • Improving indoor air quality • Developing appropriate policies/legislation • Using low-environmental impact materials and finishes • Improving/upgrading BMCS
Critical issues that affect the current uptake of sustainability	• Additional cost in applying sustainability • Commitment of building owners and key stakeholders • Government incentives and policies and legislation • Sustainable technologies, knowledge and skills • Corporate social responsibility policies • Availability of environmentally friendly materials and finishes
Critical issues that make it difficult to undertake for sustainable maintenance practice	• Managing the organisation's budget and finance • Committing owners and key stakeholders • Updating education, knowledge and skills on sustainability • Improving and/or upgrading energy and water efficiency • Planning strategies of sustainable maintenance practice • Enforcing governments policies and legislation

6.3 Focus Group

A focus group discussion was conducted after having analysed the data from the questionnaire survey. The primary purpose of the discussion was to affirm and consolidate the most critical issues established from the survey. The focus group discussion was selected because it can be used to provide an environment for participants to discuss questions and important issues in establishing the most critical issues to improve maintenance practices for office buildings (as discussed in Chapter 5). The focus group discussion was held for three hours on 22 May 2013 in the Boardroom of the RICS Oceania Head Office in Sydney, and participants were invited via email. The outcomes from the survey were compiled into five questions for participants in the focus group to discuss (details are in Section 6.3.2).

6.3.1 Focus Group Participants

Participants from the questionnaire survey who voluntarily accepted to further support the research through Part 3 of the questionnaire were invited by email to join the focus group discussion. The invitation to participate in the focus group was sent by email to 17 professionals on 30 April 2013. Eight replied, however, two were unable to attend due to unexpected work commitments. In total, there were six professionals in the focus group discussion, approximately 35% of responses, as shown in Table 6.12.

Table 6.12 Categories of participants in the focus group discussion

Participants	Invitation	Acceptation	Attendant
Asset Manager	1	0	0
Project Manager	2	0	0
Facility Manager	3	3	1
Engineer	2	1	1
Sustainability Manager	4	2	2
Builder/Contractor	1	0	0
Quantity Surveyor	1	1	1
Valuer	3	1	1
Total:	**17**	**8**	**6**

6.3.2 Focus Group Discussion

The focus group was managed and chaired by a professional external to the research study. Notes were taken of the participants' discussion. The face-to-face discussion lasted approximately three hours. There were five questions generated from the survey responses for the participants to discuss. Each participant was given a paper that listed the questions and asked to spend about five minutes writing down their opinions. This was followed by an open discussion. The prepared discussion questions for the focus group were to enable the session to be a relatively informal chat. In addition, there were five discussion issues in line with the five questions to help participants express their opinions and to avoid any discussion beyond the scope of the research.

Question 1

How sustainable outcomes are incorporated within current maintenance practices?

Question 2

How could sustainable outcomes be improved within current maintenance practices?

Question 3

What barriers exist to improving sustainable outcomes within current maintenance practices?

Question 4

What strategies could be implemented to overcome these barriers?

Question 5

How does/could government impact on sustainable maintenance practices?

6.3.3 Focus Group Discussion and Analysis

A total of 46 issues were raised and discussed by participants during the focus group. They include 11 issues for Questions 1 and 3, 8, and 14; and 10 issues for Questions 2, 3, 4 and 5 respectively. The outcomes of the focus group discussion are summarised in Table 6.13. Participants said that even though many barriers still exist, sustainable maintenance of office buildings can be developed. The most critical issues in sustainable maintenance development are improvement of energy and water efficiency, lighting systems, indoor environment, environmentally friendly materials, and waste management through a sustainable maintenance strategy with government legislation and support. The outcomes of the focus group support the conclusions derived from the questionnaire survey.

Table 6.13 Outcomes of focus group discussion

Question No	Discussion Issues	Issues
1	Current maintenance practices should incorporate sustainable development	• Submetering to tenancy and separated areas • Training of operating staff • Reporting/achieving of NABERS/Green Star ratings by national commitments and ratings • Reviewing life cycle of the elements/components • Replacing items/equipment/plant with sustainable products • Replacing lighting, water fittings with energy efficient ones • Refurbishing common areas, tenancy spaces and fitting out tenant areas • Using environmentally friendly cleaning materials • Developing waste management strategies • Increasing spending on energy and water • Performing mandatory disclosure
2	Current maintenance practices could be improved with sustainable development	• Understanding paybacks • Providing carbon tax incentives for buildings to upgrade • Reviewing the life cycle of the elements/components

Question No	Discussion Issues	Issues
3	Barriers to the development of sustainable maintenance practices	• Cost of performing sustainability • Lack of legislation • Financial constraint • NABERS threshold • Access to funds and assessing value added after work • Owners incentives • Lack of knowledge of key stakeholders • Lack of data/analysis; fragmented industry; lots of sub-calculating
4	Sustainable maintenance strategies could be implemented to overcome these barriers	• Enforcement legislation/mandatory • Providing better training • Providing help from carbon tax • Increasing government incentives • Increasing tax on energy to improve stakeholders behaviour • Committing to NABERS • Developing an industry-wide embodied energy/life cycle costing method of assessment • Informing people of the guidance on energy prices • Standardising requirements for property owners to keep records and projecting maintenance • Industry wide/government accepted projection for 10 years of PCA outgoing categories that Valuer could use • Having dynamic and compulsory Green Star ratings to get re-rated annually • Re-commissioning/tuning working hours on HVAC • Having manufacturers and suppliers commit to products (such as taking back/replacement defective products) • Accessing data of payback

Question No	Discussion Issues	Issues
5	Governments could support development of sustainable maintenance practices	• Pass legislation to greatly affect development • Have an incentive scheme • Change regulations: tax law to encourage better maintenance practices • NABERS energy and water mandatory disclosure • Report waste stream • Expand NABERS to include more office spaces and other building uses • Standardise regulation and enforcement of recycling • Extend mandatory disclosure to water and waste • Be consistent in national and state legislation; have state-wide legislation • Assess risk to board in performing sustainability

6.4 Delphi Study

To achieve the aims and objectives set for this research project, a Delphi study via email was used for data collection. The aim of using the Delphi method is to gather the in-depth opinions and expertise of experts who have experience working directly in the maintenance of office buildings (as discussed in Chapter 5). The participants were selected from the survey's respondents, who accepted to further assist in this research project.

According to Schmidt (1997), for the Delphi method to be a sound process, the facilitator should:

- Conduct a number of rounds.
- Monitor feedback thoroughly and carefully.
- Control when the poll should stop.
- Design a clear and transparent questionnaire for the process.
- Detail items or issues to carry out in each round.
- Apply statistical techniques or a straightforward method in analysis.
- Use nonparametric statistics to analyse and report on the result.

Furthermore, to avoid any problem that may make the Delphi study unsuccessful or cause participants to misunderstand and/or respond beyond the scope of the topic, an appropriate definition of the method of the study and the outcome results from the focus group discussion were provided. There were also clear explanations on how the Delphi study might operate and how participants respond.

6.4.1 Delphi Study Timeframe

To retain the subjects for the duration of the study in achieving a consensus, the process was organised into three rounds. To provide an appropriate period for participants to respond and the study coordinator to analyse collected data, each round was conducted over five weeks. The responses spanned three weeks and the analysis two weeks. Table 6.14 summarises the timeframe of the Delphi study. Details and discussion follow in Section 6.4.2.

Table 6.14 Timeframe of the Delphi study

Round	Tasks	Platform	Response	Analysis	Outcomes
1	Each participant expresses five issues on maintenance practices to make office buildings more sustainable	Email	3 week	2 week	Compilation of 16 critical issues for participants to rate in Round 2
2	Participants rate 16 critical issues compiled from Round 1	Email	3 week	2 week	Compilation of the 12 most critical issues for participants to rate in Round 3
3	Participants rate the 12 most critical issues compiled from Round 2	Email	3 week	2 week	Achievement of a consensus on ranking the 12 most critical issues for establishing criteria in sustainable maintenance

6.4.2 Design of Delphi Study Questions

Following the instructions of Gordon (2008); McGeary (2009); and Rowe and Wright (2011), the questionnaire for the Delphi study was as follows:

Round 1

The question for Round 1 was "open-ended" or unstructured. The "what should/could be" format for the question was used. It is a single question to encourage participants to express their opinions. Each participant is required to contribute five critical opinions relating to the topic area and if possible, provide reasons for each opinion.

The opinions were then compiled into a set of critical issues based on the frequency (mode) of opinions contributed by participants. The critical issues were then sent to participants for rating in Round 2.

Round 2

Participants were required to rate the set of critical issues. Each was rated by a 5-point scale, in which 1 is the least important and 5 the most important. To avoid raising any bias, these issues were arranged randomly.

In the analysis of Round 2, each selected answer was treated as a mostly critical issue for the panel to rate in the next round and had to be rated more than 50% of participants in the panel (Okoli & Pawlowski 2004; Yeung, Chan & Chan 2009). All selected answers were then put into a list of the most critical issues. The list was then sent to participants for rating in Round 3.

Round 3

According to Okoli and Pawlowski (2004); and Yeung et al. (2009), the following was considered for Round 3.

- If the list consists of up to 10 critical issues, Round 3 can be kept going without fine-tuning.

- If the list is more than 10 critical issues, the coordinator could consider a number of critical issues for Round 3.

According to the analysis from Round 2, a modified set of critical issues were then put in a random list for participants to rate in Round 3 in order to arrive at a consensus for the most critical issues. The rating was done with the 5-rating scale in the same way as in Round 2.

There is no restricted judgment process, and this allows participants the freedom to contribute opinions and judge issues from their own point of view. Participants can review, rejudge or change their judgment in previous rounds with or without providing reasons.

6.4.3 Participants in the Delphi Study

Voluntary participants were recruited from Part 3 of the questionnaire survey. Other participants were introduced to the research with the help of professional institutes. Participants were invited to participate voluntarily by email. They were also informed that they could withdraw from the Delphi study at any time without providing a reason. However, to keep a high rate of success and ensure the quality of the process, participants should satisfy a set of requirements for selection. The requirements for participants in the Delphi study are:

- Selected participants are directly working in the maintenance of office buildings.

- Selected participants have experience of 5 years or more in maintenance of office buildings.

- Selected participants are encouraged to respond to all questions, complete all rounds, and reply within the timeframe.

The Delphi study was conducted in three rounds. Each round included 18 professionals. The number of participants in each professional category who participated in the Delphi study are summarised in Table 6.15.

Table 6.15 Participants in the Delphi study

Participants	No
Asset Manager	1
Building Advisor	1
Engineer	2
Facility Manager	7
Project Manager	1
Quantity Surveyor	1
Sustainability Consultant	4
Valuer	1
Total:	**18**

Participants who dropped out of Round 2 included a project manager and two valuers; from Round 3 two property managers. However, the total number of participants for each round was 18 professionals as new participants were recruited. Participants who joined in Round 2 were a sustainability consultant and two facility managers. Round 3 included two facility managers.

The number of facility managers increased from three to five in Round 2 and to seven in Round 3. Sustainability consultants increased from three to four from Rounds 2 to 3. As the study is on sustainable maintenance of office buildings, contributions from facility managers who are directly involved in the performance of the maintenance of office buildings and sustainability consultants who are directly involved in sustainable development were highly regarded and significant to the study. However, all opinions expressed by professionals in the Delphi study are treated as the main concerns in improving sustainability in office buildings.

6.4.4 Discussions and Analysis of the Delphi Study

Data analysis was computed statistically based on the achieved frequency for Round 1 and the achieved mean from participants rating for Rounds 2 and 3. At Rounds 2 and 3, each issue considered critical should reach a mean of more than 50% from participants rating, following the opinions of Okoli and Pawlowski (2004); and Yeung, Chan and Chan (2009). They are also considered from the relevant comments from participants.

In approaching a consensus, the rank of each critical issue is weighted on its mean achieved through Rounds 2 and 3. The outcomes of these rounds are directly rated by participants. The highest weighted issue is ranked as the highest rank or first class and vice versa. Round 3 is the final round to reach a consensus in ranking the most critical issues. These issues are then listed as a result of the Delphi study.

These results will be used to identify the most criteria that will be part of developing the SMOB to make office buildings more sustainable.

Round 1 Outcome

A total of 152 opinions were recorded in Round 1. This number is a result of most participants contributing more than five opinions required. These opinions were directly related to maintenance practices for office buildings. In the analysis, 16 critical issues were compiled according to their frequency or the same opinions being expressed from participants. They were then inserted into a random list without identification of their frequencies and ranks to avoid leading participants in their ranking in Round 2.

Table 6.16 ranks the 16 critical issues compiled from participants opinions in Round 1. The first critical issue is auditing and measuring energy consumption to improve the efficiency of systems, plant, equipment or devices, etc. expressed by 94%. The two issues ranked second were improving and/or upgrading energy efficient lighting systems, and upgrading, tuning or recommissioning HVAC systems and/or chillers to be more energy efficient, expressed by 83% each. The fourth and fifth issues were monitoring annual feedback and adjustment to maintenance management programs for immediate, medium- and long- term action as part of the overall plan; and installing new or upgrading BMCS to automatically control plant in balancing heat and cold air, expressed by 61% and 56% respectively. Using low environmental impact materials, finishes and paints for maintenance was the least critical issue, expressed by 28%.

Table 6.16 16 critical issues compiled from Round 1

Critical Issues	Frequency	%	Rank
Auditing and measuring energy consumption to improve efficiency of systems, plant, equipment or devices, etc.	17	94	1
Improving and/or upgrading energy efficient lighting systems	15	83	2
Upgrading, tuning or recommissioning HVAC systems and/or chillers to be more energy efficient	15	83	2
Monitoring annual feedback and adjustment to maintenance management programs for immediate, medium- and long-term actions as part of an overall plan	11	61	4
Installing new or upgrading BMCS to automatically control plant in balancing heat and cold air	10	56	5
Enhancing health and productivity of occupants by improving indoor air quality and comfort	10	56	5
Auditing and measuring water consumption to improve water efficiency of systems, plant, equipment or devices, etc.	9	50	7
Considering all construction and replacement of assets, systems or equipment upon their life cycle	9	50	7
Enforcing legislation/regulations in building maintenance	9	50	7
Reusing and recycling materials, components and all kinds of waste	8	44	10
Education or training programs for maintenance staff/workers, owners and tenants	7	39	11
Collaboration between owner and tenants in performing sustainable maintenance practices	7	39	11
Managing better ways of using CAPEX (capital expenditure) and OPEX (operational expenditure)	7	39	11
National commitments of ratings to existing buildings such as NABERS	7	39	11
Improving thermal comfort by upgrading the facade and insulating western walls	6	33	15
Using low environmental impact materials, finishes and paints for maintenance	5	28	16

Round 2 Outcome

In Round 2, participants were required to rate 16 critical issues, compiled from participants opinions in Round 1. The rating of the 16 issues in Round 2 is summarised in Table 6.17. The rating is based on a 5-point scale, in which 1 is the least important and 5 is the most important.

Adapted from Stapel (2012), the Round 2 outcomes listed in Table 6.17 are based on a mean of total points recorded by participants rating for each issue within the 5-point scale. The mean was computed by the formula below:

$$\text{Mean} = \frac{(A1 \times n1) + (A2 \times n2) + (A3 \times n3) + (A4 \times n4) + (A5 \times n5) \times 100}{B \times N} \qquad (6.1)$$

Where:

Mean = Weight by percentage (%)

A = Numbers in 5-point rating scale as 1, 2, 3, 4 and 5

n = Frequency achieved by participants' rating relating to A1 to A5

B = Highest number in 5-point rating scale or 5

N = Number of participants involved

For example: the mean of Issue 1 (see Table 6.17) is calculated as below:

$$\text{Mean (Issue 1)} = \frac{(1 \times 0) + (2 \times 0) + (3 \times 2) + (4 \times 7) + (5 \times 9) \times 100}{5 \times 18}$$

$$\text{Mean (Issue 1)} = \frac{79 \times 100}{90}$$

Mean (Issue 1) = 88%

Based on the calculated weighted mean, each critical issue is ranked upon its achievement of mean (%). The issue which achieves the highest mean is ranked as first, followed by second, third and so forth for other issues as summarised in Table 6.17. When two or more critical issues have the same mean, their rank is considered according to the frequency achieved and the highest results from the 5-point scale (number 5). The consideration is then downwards to the next number (4, 3, 2 and 1) if their rating frequencies achieve the same number as the highest number in the 5-point scale. For instance, issues ranked from 4 to 7 (see Table 6.17) have the mean as 76%. However, their ranks are considered 4, 5, 6 and 7 because their rating frequencies that achieved the highest number in the 5-point scale are 7 of 5, 4 of 5, 3 of 5; and 2 of 5. It is the same consideration for issues 10 and 11 as their mean achieved was the same rate, 69%.

The table reveals that auditing and measuring energy consumption for improving efficiency of systems, plant, equipment or devices, etc. is still the first critical issue rated by 88%. Upgrading, tuning or recommissioning HVAC systems and/or chillers to be more energy efficient moved to second, rated by 86%. Installing new or upgrading BMCS to automatically control plant in balancing heat and cold air is third, rated by 79%. Enforcing legislation/regulations in building maintenance is fourth, rated by 76%. Improving and/or upgrading energy efficient lighting systems, and monitoring annual feedback and adjustment to maintenance management programs for immediate, medium- and long-term action as part of an overall strategy were fifth and seventh, respectively. The last is improving thermal comfort by upgrading the façade and insulating western walls, rated by 54%.

Table 6.17 16 critical issues rated from Round 2

Critical Issues	Rating Frequency					Total Points Achieved	%	Rank
	1	2	3	4	5			
Auditing and measuring energy consumption for improving efficiency of systems, plant, equipment or devices, etc.	0	0	2	7	9	79	88	1
Upgrading, tuning or recommissioning HVAC systems and/or chillers to be more energy efficient	0	0	2	9	7	77	86	2
Installing new or upgrading BMCS to automatically control plant in balancing heat and cold air	0	1	5	6	6	71	79	3
Enforcing legislation/regulations in building maintenance	0	4	3	4	7	68	76	4
Improving and/or upgrading energy efficient lighting systems	0	1	6	7	4	68	76	5
Education or training programs for maintenance staff/workers, owners and tenants	0	1	5	9	3	68	76	6
Monitoring annual feedback and adjustment to maintenance management programs for immediate, medium- and long- term action as part of an overall strategy	0	1	4	11	2	68	76	7
Collaboration between owners and tenants in performing sustainable maintenance practices	1	1	4	9	3	66	73	8
National commitments of ratings of existing buildings such as NABERS	2	1	5	6	4	63	70	9
Considering all construction and replacement of assets, systems or equipment for their life cycle	0	3	7	5	3	62	69	10
Auditing and measuring water consumption to improve water efficiency of systems, plant, equipment or devices, etc.	0	3	6	7	2	62	69	11
Enhancing health and productivity of occupants by improving indoor air quality and comfort	0	4	7	5	2	59	66	12
Reusing and recycling materials, components and all kinds of waste	0	5	5	8	0	57	63	13
Managing better ways of using CAPEX (capital expenditure) and OPEX (operational expenditure)	1	2	10	4	1	56	62	14
Using low environmental impact materials, finishes and paints for maintenance	1	6	6	3	2	53	59	15
Improving thermal comfort by upgrading the facade and insulating western walls	3	4	6	5	0	49	54	16

Round 3 Outcome

Round 3 is the final round of the process in approaching a consensus. According to participants ratings and comments from Round 2, 12 critical issues were established for participants to rate in Round 3. As participants commented, four issues in the list of Round 2 (Table 6.17) were removed to be more manageable in Round 3. The removed issues included enforcing legislation/regulations in building maintenance; education or training programs for maintenance staff/workers, owners and tenants; collaboration between owners and tenants in performing sustainable maintenance practices; and improving thermal comfort by upgrading the facade and insulating western walls.

The process of Round 3 was performed in the same way as described in Round 2. The rating is also based on a 5-point scale, whereby 1 is the least important and 5 is the most important. The weighted mean was computed using the same formula (Formula 6.1) as for Round 2.

A consensus would identify the most critical issues, based on the outcomes of Round 3. The highest-ranking critical issue is the highest weighted mean and so on. They would be identified as the most critical issues which could be used for maintenance practices to improve office buildings to be environmentally friendly. Table 6.18 summarises the 12 critical issues as established by the Delphi study. The consensus confirms that the first critical issue in achieving sustainable maintenance practices for office buildings is auditing and measuring energy consumption for improving efficiency of systems, plant, equipment or devices, etc., ranked 88%. The second critical issue is upgrading, recommissioning or tuning HVAC systems and/or chillers to be more energy efficient, ranked 84%. The third critical issue is improving and/or upgrading to more energy efficient lighting systems, ranked 78%. Installing new or upgraded BMCS to automatically control plant in balancing heat and cold air, and national commitments to ratings by instruments such as NABERS are fourth and fifth critical issues, ranked 78% and 76%, respectively. The last critical issue is reusing and recycling materials, components and all kinds of waste, ranked 51%.

Table 6.18 12 most critical issues rated from Round 3

Critical Issues	Rating Frequency					Total Points Achieved	%	Rank
	1	2	3	4	5			
Auditing and measuring energy consumption for improving efficiency of systems, plant, equipment or devices, etc.	0	0	2	7	9	79	88	1
Upgrading, tuning or recommissioning HVAC systems and/or chillers to be more energy efficient	0	0	2	10	6	76	84	2
Improving and/or upgrading energy efficient lighting systems	0	1	6	5	6	70	78	3
Installing new or upgrading BMCS to automatically control plant in balancing heat and cold air	0	0	6	8	4	70	78	4
National commitments to ratings of existing buildings such as NABERS	2	0	3	8	5	68	76	5
Monitoring annual feedback and adjustment to maintenance management programs for immediate, medium- and long-term action as part of an overall strategy	0	3	6	7	2	62	69	6
Considering all construction and replacement of assets, systems or equipment for their life cycle	1	3	6	5	3	60	67	7
Enhancing health and productivity of occupants by improving indoor air quality and comfort	1	5	4	4	4	59	66	8
Auditing and measuring water consumption to improve water efficiency of systems, plant, equipment or devices, etc.	0	4	7	5	2	59	66	9
Managing better ways of using CAPEX (capital expenditure) and OPEX (operational expenditure)	1	3	6	7	1	58	64	10
Using low environmental impact materials, finishes and paints for maintenance	4	6	1	7	0	47	52	11
Reusing and recycling materials, components and all kinds of waste	3	7	3	5	0	46	51	12

To sum up, according to participants opinions in Round 1, to improve existing office buildings to be more sustainable, energy efficiency is the most important factor. Secondary factors are improving and/or upgrading lighting systems and particularly re-commissioning/tuning up HVAC systems. The third factor is improving maintenance management programs. The fourth factors are installing or upgrading BMCS and indoor environment. The fifth factors are efficiency of water consumption by reusing and recycling rainwater, grey and black water, replacing devices and systems at the end of their life cycle and enforcing legislation to speed up the application of sustainability for office buildings (see Table 6.16).

Round 2 categorises 16 critical issues, which are ranked the same as the outcomes of Round 1: efficiency of energy consumption ranked 1; HVAC systems 2; BMCS 3; enforcing legislation 4; efficiency of lighting systems moved from rank 2 to 5 (see Table 6.17).

In achieving a consensus as a result of the Delphi study, in Round 3 the weighted means of all 12 critical issues were above 50% rated in Round 2. The result identifies the highest-ranked issue, auditing and measuring energy consumption to improve the efficiency of systems, plant, equipment or devices was 88% and the lowest-ranked issue, reusing and recycling materials, components and all kinds of waste, was 51% as summarised in Table 6.18.

6.5 Outcomes of Studies

Table 6.19 summarises the 12 critical issues relating to sub-activities in maintenance practices to improve an existing office building to be more sustainable resulting from the questionnaire survey, focus group discussion and Delphi study. From the collected data reducing energy consumption in office buildings is the first concern. Significantly, energy consumption accounts for the highest expenditure in existing office buildings. Therefore, the overall efficient energy consumption of all building systems will decrease the annual costs of operation and maintenance and reduce the impacts of office buildings on the environment.

Table 6.19 12 critical issues in sustainable maintenance of office buildings resulting from survey, focus group and Delphi study

Critical Issues		Sub-criteria
1	Energy efficient systems	• Auditing and measuring energy consumption for improving efficiency of systems, plant, equipment or devices, etc. • Controlling or monitoring the efficient installation or use of lift systems • Installing automatic switch-off devices for unused equipment • Selecting energy efficient plant when upgrading • Installing or upgrading solar water heating systems • Striving for synergy between mechanical systems and controls and implementing tri-generators • Benchmarking diagnosed changes in energy efficient performance for buildings • Metering of main plant and equipment
2	Tuning/Upgrading HVAC systems	• Upgrading, tuning or recommissioning HVAC systems and/or chillers to be more energy efficient • Turning HVAC systems for efficient use with critical working hours and temperatures • Ensuring the HVAC system has a fresh air economy cycle • Installing VAV and VSDs on all pumps and fans, and link to controls system • Employing chilled beam technology, automated controls • Changing occupants behaviour when operating HVAC systems
3	Efficient lighting systems	• Improving/upgrading energy efficient lighting systems that comply with Australian standards • Increasing the use of natural light • Replacing energy efficient lighting fittings • Using LED lights and/or T5 tubes • Installing automatic on/off sensor lighting in all common areas, fire stairs and tenants areas • Removing enclosed offices

Critical Issues		Sub-criteria
4	Improving/upgrading BMCS	• Installing new or upgrading BMCS to automatically control plant in balancing heat and cold air • Calibrating systems to run efficiently to prevent conflicts between heat and cold • Optimising operation of plant software that will monitor service systems and alert the facility managers if a system is malfunctioning or operating abnormally • Upgrading existing system to achieve maximisation of service • Allowing off-site and flexible control of the building and zones therein, including car park CO_2 monitoring
5	Commitment to national building ratings	• National commitment to ratings of existing buildings such as NABERS • Developing national commitments on building ratings • Developing an industry-wide embodied energy and life cycle costing method of assessment • Informing guidance on energy prices on sustainability and life cycle costing assessment • Expanding NABERS assessment to include more office spaces and other building uses • Maintaining the NABERS rating for the building and implementing energy monitoring • Considering performance of Green Stars on all refurbishments and upgrading

Critical Issues		Sub-criteria
6	Improving maintenance management programs	• Monitoring annual feedback and adjustment to maintenance management programs for immediate, medium- and long-term actions as part of an overall strategy • Programming or monitoring strategic, regular, basic maintenance performance plan • Monitoring the operation of the plant and machinery independently • Retrofitting, commissioning and reviewing or streamlining operations of the plant and machinery • Scheduling regular maintenance and calibration of equipment • Selecting maintenance-free or minimum-maintenance components and finishes
7	Replacing systems upon completion of the life cycle	• Considering all construction and replacement of assets, systems or equipment for their life cycle • Reviewing the life cycle of the elements and components based on their lifetime age • Upgrading old plant and equipment with more efficient plant and equipment • Identifying the steps (or products) which would add value and extend the length of the life cycle • Benchmarking major replacements in achieving greener and sustainable outcomes
8	Improving indoor health and environment	• Enhancing health and productivity of occupants by improving indoor air quality and comfort • Satisfying occupants or tenants comfort by regular monitoring of maintenance performance • Ensuring that buildings maintain natural ventilation through the use of breezeways if possible • Applying mixed method ventilation including natural, mechanical and operable windows • Providing areas to complement other facilities and activities including bike parking • Optimising designing open plans to increase the efficient use of space • Using layout changes, ergonomically designed furniture

Critical Issues		Sub-criteria
9	Efficient water systems	• Auditing and measuring water consumption to improve water efficiency of systems, plant, equipment or devices • Upgrading water efficient systems, devices, fixtures and waterless urinals • Harvesting rainwater for plant watering • Recycling grey and black water from all catchments within the building site for urinal use • Metering water usages
10	Improving budget management	• Managing better ways of using CAPEX and OPEX in the correct performance of maintenance • Scheduling and monitoring regular maintenance performance to improve management of cost/budget • Avoiding selecting the lowest price when carrying out a maintenance upgrade or setting up a maintenance contract • Increasing spending on energy and water use and understanding paybacks • Increasing resources for maintenance practices • Seeking external financing for sustainable approaches
11	Using low environmental impact materials	• Using low environmental impact materials, finishes and paint for maintenance • Using environmentally friendly cleaning materials • Refurbishing and upgrading with sustainable materials, paint, etc.
12	Improving/upgrading waste management	• Reusing and recycling materials, components and all kinds of waste • Managing waste systems should be implemented • Clearly labelling and having appropriately sized recycling bins with smaller general waste bins to encourage recycling behaviour • Breaking up all kinds of waste such as building materials, solid waste, office waste and household waste for reuse and recycling • Reporting waste stream

From the table, recommissioning/tuning HVAC systems by resetting their working hours and internal temperatures, balancing the temperature and quantity of fresh air, and turning off the systems when a room is unoccupied are the best ways of reducing energy consumed by HVAC systems. In some cases, upgrading the HVAC system with a new technology system, such as chilled beam technology, combined with automated controls is a better choice.

Improving lighting systems by using a mixture of natural and artificial lighting systems (automatic dimming lighting systems) is also an important part of reducing energy consumption. To ensure that building service systems have correct working and monitoring systems, the building management control systems (BMCS) should also be installed and/or upgraded.

Other critical issues to consider include: planned maintenance management practices for buildings, improved the indoor environment to maintain the well-being of occupants, reduce water consumption by reusing and recycling rainwater, grey and black water within buildings and reduce all kinds of waste produced in buildings. Buildings should achieve and maintain national building performance standards such as NABERS.

6.6 Summary

This chapter has discussed data collection and analysis for the questionnaire survey, focus group discussion and Delphi study. Data collection and analysis have been through closed form, linear or one-way communication, and quantitative in the questionnaire survey; open form, non-linear or two-way communication and qualitative as in-depth thought in the focus group discussion; and the three-round Delphi study.

The study reveals that most existing office buildings in Sydney are currently maintained with traditional maintenance practices including the use of conventional systems, equipment and materials with high rates of toxic materials and finishes. However, the study has confirmed that existing office buildings can be improved sustainably via sustainable maintenance practices. The study has found that even though there are still some barriers, a large number of practices can be used to improve existing office buildings. The study also found that sustainability is a relatively new concept in maintenance practice in the building industry; key stakeholders are willing to consider applying sustainable maintenance to mainstream practices in maintenance strategies for existing office buildings when possible.

The most critical issues identified in improving maintenance practices for office buildings include improving energy consumption by upgrading HVAC systems, lighting systems, electrical controlling and monitoring systems (BMCS); improving water consumption by employing water-efficient fixtures/devices and harvesting rainwater and recycling grey/black water; using low environmental impact materials and finishes in maintenance work; and reducing waste to landfill by providing a waste disposal space.

The next chapter discusses the development of the SMOB based on the integrated outcomes from the questionnaire survey, focus group discussion and Delphi study. It also discusses the costs and savings that the SMOB can provide.

7. Model Development and Testing

7.1 Introduction

As discussed in Chapter 6, the questionnaire survey, focus group discussions and Delphi study have revealed that most existing office buildings in Sydney are currently maintained using conventional maintenance practices. The research has identified some difficulties that still exist in the development of sustainable buildings. However, despite this, many strategies can be used to improve an existing office building to become sustainable via strategic sustainable maintenance practices.

There are still many questions about the improvement of maintenance practices in office buildings: How can maintenance practices be improved? How much does it cost to make the improvements? What benefits are received from the improvements?

This chapter is a discussion of the development and testing of a strategic model to answer these questions. The model is called Sustainable Maintenance of Office Buildings (SMOB). It is based on the integrated outcomes of the questionnaire survey, focus group discussion and Delphi study. The chapter also discusses the process of integrating the collected data; development and testing of the SMOB; and the reduced costs, and the savings that the SMOB can provide.

7.2 Development of the Model of Sustainable Maintenance of Office Buildings (SMOB)

The questionnaire survey, focus group discussion and Delphi study have identified that improving maintenance practices can transform an existing office building to meet environmental requirements. Improvements can be done through reducing the use of energy, water, traditional materials and disposal of waste to landfill during operation and maintenance. From the collected data the SMOB model was developed to suggest ways for improvement. The SMOB includes four indicators and 23 criteria derived from survey, focus group and Delphi processes to improve maintenance practices in office buildings.

7.2.1 Developing the SMOB

Results from the questionnaire survey, focus group discussion and Delphi study are shown in Table 6.19. The 12 critical issues have been consolidated into the following crucial factors in improving maintenance practices in office buildings in the development of the model in Figure 7.1:

- Improving energy efficiency by upgrading HVAC systems (Issues 1 and 7);
- Lighting efficiency (Issues 3 and 7);
- Electrical controlling and monitoring systems via BMCS (Issues 2, 4, 7 and 8);
- Reducing water consumption by employing water-efficient fixtures/devices and harvesting rainwater, recycling grey/black water (Issues 1 and 9);
- Using low environmental impact materials and finishes in maintenance work (Issues 7 and 11);
- Reducing waste to landfill by providing a waste disposal space to sort waste for reuse, recycle or landfill (Issue 12);
- Routine maintenance (Issue 6);
- Ah hoc maintenance (Issue 6); and
- External factors (Issues 5 and 10).

These factors were therefore integrated to establish the SMOB which is based on three main parts denoted as: Cause, Action and Result, as illustrated in Figure 7.1 and discussed as follows.

a) Cause: Identification of Problems

This part assesses the impacts of existing office buildings on the environment and vice versa. The measurement of impacts depends on the current situation of the building. The study considers: What causes impact between the building and the environment? Why do they impact each other? How do they impact each other? What levels and effects resulted from the impacts? How can the impacts be reduced? When these questions have been answered, the next step is identifying and establishing ways to reduce the impacts.

b) Action: Ways to Improve the Building and Reduce Impacts

This part explores ways to improve a building and reduce impacts on the environment using sustainable maintenance. Mostly, a building can be improved by upgrading work. Upgrading includes reduction in the use of energy, improvement of indoor climate and lighting, a decrease of water consumption within the building, better ways to dispose of waste, and the use of low environmental impact materials. Improvement is also needed in the practice of routine and ad hoc maintenance. Lastly, external factors are necessary to accelerate the move towards sustainability. These factors are formed into four indicators and six sub-indicators. These indicators and sub-indicators are extended into a number of criteria. The extension is illustrated in Figure 7.2. The details are further discussed in the next sections.

c) Result: Resolution

The impact between buildings and the environment will be reduced when sustainable maintenance practices are used for maintaining existing office buildings.

Figure 7.1 Model of sustainable maintenance of office buildings (SMOB)

7.2.2 Extension of the SMOB

The extension of the SMOB is illustrated in Figure 7.2 and it is categorised into three levels: model, indicators and criteria.

a) Level 1: The Model

The SMOB is developed to indicate ways to improve building maintenance towards sustainability, particularly to save on energy and water consumption and reduce CO_2 emissions from buildings into the environment.

b) Level 2: Indicators

The level 2 of the SMOB contains four indicators based on results from the questionnaire survey, focus group discussion and Delphi study viz:

- Upgrading maintenance,
- Routine maintenance,
- Ad hoc maintenance and
- External factors.

Upgrading maintenance is arguably the most important way to improve maintenance practices towards sustainability. Upgrading maintenance is upgrading or replacing old systems with technologically more advanced systems. The research identified that if existing systems or equipment are upgraded to a new technology, it will provide significant annual savings in operation and maintenance.

There are six sub-indicators that are crucial in upgrading the service systems or equipment in the buildings viz.

- Energy efficiency,
- Indoor climate,
- Lighting efficiency,
- Environmentally friendly materials,
- Water efficiency and
- Waste management

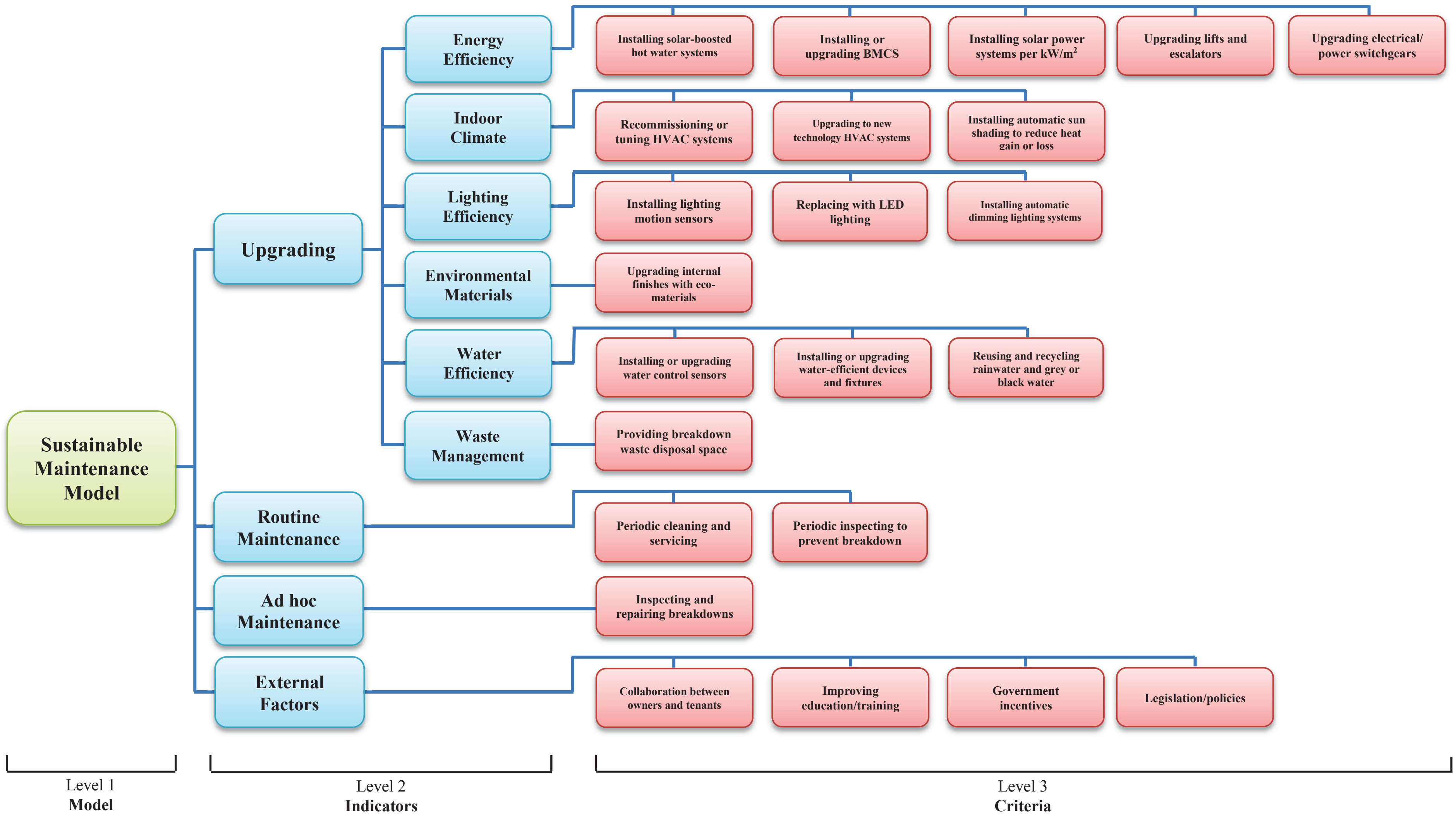
Routine maintenance are tasks performed regularly, and ad hoc maintenance is work to correct or repair the breakdown of systems or equipment. Systems or equipment having good routine maintenance means breakdown times are reduced, which result in large savings in operation and maintenance. This maintenance may also move the buildings towards a strategy on sustainable maintenance, noting that external factors, such as building regulations, incentives, etc., are necessary to accelerate this move towards sustainable maintenance for office buildings.

External factors include providing sustainability education and training to key stakeholders in building maintenance practices, strengthening collaboration between owners and tenants, and issuing government regulations and policies to toughen the sustainability requirements of existing buildings.

c) Level 3: Criteria

There are 23 criteria within these indicators or sub-indicators. Each criterion represents an action for a system or equipment and plays a role in improvement and cost savings in maintenance practices. When applied as mainstream practice for buildings, these criteria will accelerate sustainable maintenance.

Figure 7.2 Extension of the SMOB



7.3 Explanation of the SMOB

This section explains the information used for applying the SMOB through upgrading maintenance, routine maintenance, ad hoc maintenance and external factors (see Figure 7.2). The savings on energy and water consumption of systems and equipment employed in the buildings is the main focus of the explanation. Savings, denoted by %, in this study are distinguished between energy and water savings on building services, and estimated savings in applying the SMOB. The results from these kinds of savings may be different. Savings on building services are derived from the literature review.

7.3.1 Upgrading Maintenance

Upgrading maintenance includes modification, recommission, refurbishment, addition or replacement of existing systems or equipment with a more efficient system or equipment (Arditi & Nawakorawit 1999b; Chanter & Swallow 2007; NSW Heritage Office 2004; Pitt, Goyal & Sapri 2006). Upgrading existing systems and equipment is the most expensive work in office building maintenance. However, it may provide great savings on CO_2 emissions and utility costs through savings on energy and water consumption. Upgrading can be done by:

- Refurbishing systems or equipment at the end of its service life.
- Replacing systems or equipment that are old, obsolete or unsuitable for refurbishment with new technology.
- Replacing systems or equipment with new technologically advanced systems or equipment, regardless of stage of life cycle.
- Installing new systems or equipment.

The SMOB contains upgrading in six areas of building maintenance and they include enhancing building performance during operation stage through improving energy, lighting and water efficiency, indoor climate, using environmentally friendly materials and achieving waste management.

a) Energy Efficiency (A1)

In the operation of a building, the greatest expenditures are for energy used for running service systems and equipment in the buildings (Lecamwasam, Wilson & Chokolich 2012). Energy used in buildings includes electricity and gas. However, in the SMOB, energy assessment will concentrate only on the use of electricity because:

- Electricity is still the main type of energy used in buildings.
- The main target in reducing electricity consumption is to reduce CO_2 emissions.
- Gas is considered an efficient energy source compared to electricity (Tian et al. 2017; Xu & Chen 2016).

Reducing energy consumption will result in reduced CO_2 emissions and this is the greatest concern for both owners and tenants. According to the Fourth Assessment Report (AR4) of the IPCC (2007), CO_2 emissions can be reduced by approximately 29% by 2020 when buildings are running with energy efficiency (IPCC 2007 cited in Ürge-Vorsatz, Koeppel & Mirasgedis 2007b).

Compared to other types of buildings, in Australia, office buildings are the one of the highest consumers of energy, and consequently they contribute the highest level of CO_2 emissions to the environment (Sherry 2008 cited in Steinfeld, Bruce & Watt 2011; IEA 2008 cited in Tuominen et al. 2014). The annual energy consumption in office buildings varies from 100 kWh/m^2 to 1,000 kWh/m^2 depending on the geographic location, type and use of office equipment, operational schedules, type of envelope, and use of HVAC and lighting systems (Burton & Sala 2001 cited in Juan, Gao & Wang 2010).

Commonly, energy consumption in office buildings can be reduced by 26% at peak load and a better maintenance practice can provide cost savings on energy of 10–40% (Lecamwasam, Wilson & Chokolich 2012). However, as studied by the Council of Australian Governments (COAG 2012b) in 2009, under conventional maintenance practices, the annual average energy consumption of office base buildings was around 530 $kWh/m^2/year$; while for the tenancy areas it was less than around 60 $kWh/m^2/year$. When a building is improved for energy efficiency, the total end-use of energy is potentially less than 100 kWh/m^2/year and it is categorised as a green building (Hestnes & Kofoed 2002; Steinfeld, Bruce & Watt 2011). Therefore, improving the maintenance of systems and equipment would provide a significant savings on energy.

Based on the SMOB the following criteria can be applied to achieve energy efficiency at an affordable cost:

- Upgrading/installing efficient solar-boosted water heating to supply hot water within a building can reduce the consumption of electricity, providing energy savings of about 30% (Cabeza et al. 2014).

- Upgrading/installing BMCS to control, monitor service systems and alert facility managers when malfunction of a system has occurred. It can automatically turn on or off systems and equipment when necessary or upon the ambient climate; monitor and report the working of systems and equipment on breakdown; alert facility managers of the malfunction or incorrect running of systems and equipment to prevent conditions from getting worse. This upgrading/installing can provide a savings on energy use by about 20% (Steinfeld, Bruce & Watt 2011).

- Installing solar power with photovoltaic panels to generate electricity onsite can give savings from the main power supply by up to 26% (Bondanza 2011; Steinfeld, Bruce & Watt 2011).

- Refurbishing/upgrading lifts/escalators reduces waiting and transporting times, reduces the use of electricity, and decreases operation and maintenance expenditure. In certain situations, this refurbishing/upgrading can provide a savings of energy of approximately 30% (Australian Building Code Board 2004; De Almeida et al. 2012).

- Upgrading/replacing electrical switchgears can be performed at major upgrading of electrical/power supply to reduce the demand on the electricity systems at peak times, such as replacing mains and sub-mains, switching gears and so forth. Installing automatic switch-off or motion sensors can turn off the systems or equipment when they are not required or at off-peak times. Installing sub-metering can be used to audit energy use of services systems. For example, sub-metering will provide more control in BMCS, and/or allow for a more accurate understanding of where, when, and how much energy is being used. The records of sub-meters on energy consumption show that improvements can be made. This installation can provide a savings on energy use by approximately 26% (Jenkins, Liu & Peacock 2008; Lecamwasam, Wilson & Chokolich 2012; Steinfeld, Bruce & Watt 2011).

b) Indoor Climate (A2)

The occupant comfort in office buildings is commonly provided by HVAC systems. These systems include many kinds of equipment that can meet the requirements of internal temperatures over varying weather conditions. HVAC systems consume approximately 50% of energy in a building, and older or less efficient systems can consume up to 75% of a building's energy supply (Air Conditioning and Mechanical Contractors' Association (AMCA) 2014). Indeed, HVAC systems in older buildings can waste approximately 20 to 40% of total energy consumed (Lecamwasam 2014). Upgrading existing HVAC systems can provide savings on energy consumption. Improving the indoor climate can be achieved by performing the following work:

- Recommissioning is the first consideration in saving energy consumed by HVAC systems, due to its low cost. This can provide a 10% savings on energy (Lecamwasam 2014). Recommissioning can mean resetting the air temperature according to the season. Traditionally, air conditioned spaces are set to supply air at 22 ^{o}C and 50% RH for all seasons. However, according to the Commercial Buildings Committee (2014) the following can be used to recommit HVAC systems:

  - Public holidays could be programed to eliminate wasteful operation.

  - After-hours operation could be restricted to those areas requiring operation.

- In consultation with the end-users, temperatures for winter operation could be set at 20–21 °C and for summer at 24–25 °C.

- RH can vary from 35 to 60%, without significant impact on occupant comfort.

- Transient areas where occupants spend relatively short periods can be set to 17–26 °C.

Additionally, when the required internal temperature is the same as the outside air temperature, the air conditioning can be turned off and supplied with fresh air only. For example, air conditioned spaces require supply air of 25 ^{o}C. While the ambient temperature is also 25 ^{o}C, the air conditioning can be automatically switched off and only supply fresh air.

- Upgrading HVAC systems can mean minor upgrades by replacing some components, such as boilers for heating, chillers for cooling, air handling systems for air conditioning, pumps, fans, electrical, controls and cooling towers. Such minor upgrading can provide savings on energy use from 5 to 9% (Jenkins, Liu & Peacock 2008; Lecamwasam 2014; Lecamwasam, Wilson & Chokolich 2012; Steinfeld, Bruce & Watt 2011).

- In major upgrading, the entire HVAC system can be replaced with a new energy efficient system. This can provide the greatest savings on energy consumption and lower cost in operation and maintenance annually. Major upgrading can avoid waste of energy and provide savings on system energy of 30% (Jenkins, Liu & Peacock 2008; Lecamwasam 2014; Lecamwasam, Wilson & Chokolich 2012; Steinfeld, Bruce & Watt 2011).

c) Lighting Efficiency (A3)

Lighting systems are ranked second in energy consumption in buildings (Council of Australian Governments (COAG) 2012b; Steinfeld, Bruce & Watt 2011). According to COAG (2012b), Australian office buildings consume 16% of the end-use energy for base building lighting and 26% for both base and tenant building lighting. As studied by Knight et al. (2006 cited in Steinfeld, Bruce & Watt 2011), at peak times, the lighting systems in Sydney offices account for 19% of the end-use energy in buildings. Lighting efficiency can be achieved by performing the following work:

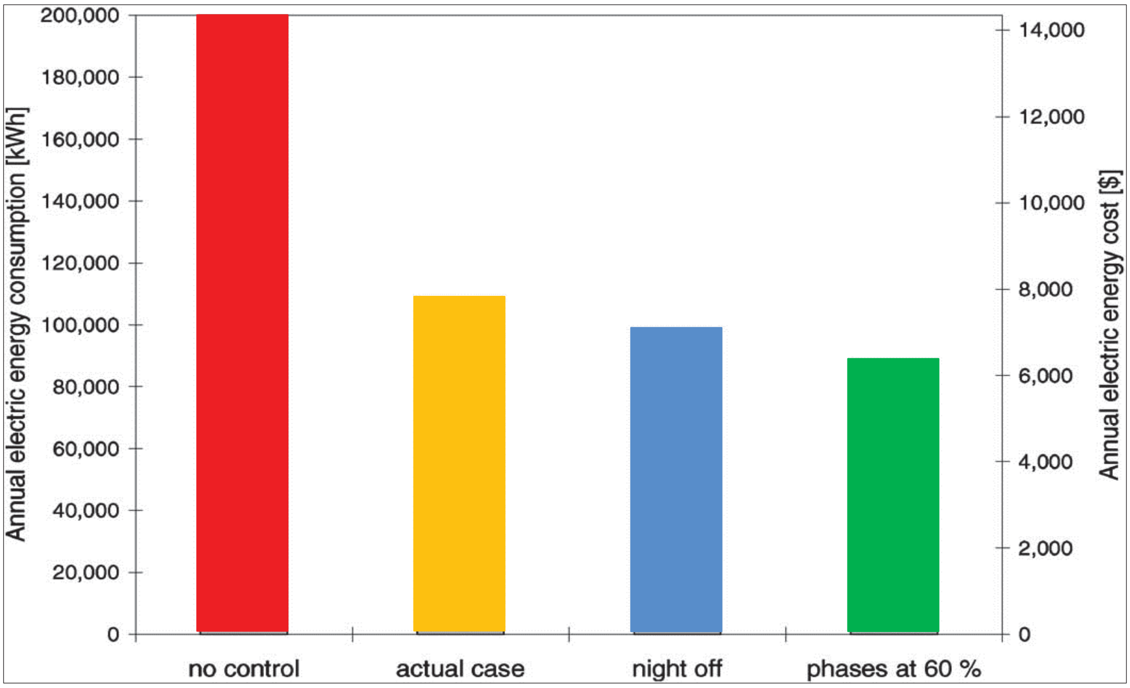
- The lowest cost upgrading starts with installing motion sensors that automatically turn lights on when someone is in the room and off when there is no one in the room. This upgrade can provide savings between 11 and 17% on systems energy consumption.

- Upgrades of lighting systems can be either minor or major. Minor upgrades can be performed by just replacing some existing lighting with T5 or LED lighting to common areas such as external security lighting, street lighting, main entry, lifts, lobbies and plant rooms. This upgrading may provide savings on energy by about 5 and 6% respectively (Zografakis, Karyotakis & Tsagarakis 2012). However for further improvements in lighting efficiency, major upgrading is necessary. This can provide greater savings on energy consumption (Bodart & De Herde 2002; Roisin et al. 2008). Major upgrading means the entire lighting system in the buildings are replaced with T5 or LED lighting systems. That can provide a system savings of up to 20% on energy consumption (Jenkins, Liu & Peacock 2008; Lecamwasam, Wilson & Chokolich 2012; Steinfeld, Bruce & Watt 2011).

- Upgrading lighting efficiency can be achieved with a mixed mode of mechanical and daylighting systems for which automatically continuous dimming control can be considered. A continuous dimming lighting control system can automatically dim artificial lighting when the day lighting is enough for the rooms and the lighting system is kept dimmed as long as day lighting is still sufficient. This kind of system can provide about 46% savings on energy (Atif &

Galasiu 2003). However, in a case studied by Atif and Galasiu (2003), atrium lighting installed with an automatic dimming control will provide more cost savings on energy when operated at 60% load after dusk and completely shut-down overnight than does normal daylight dimming control and no control at all. The cost impact is illustrated in Figure 7.3. Furthermore, a combination of window glazing, shading, insulation and natural ventilation can achieve up to 43% savings on system energy (Omer 2008).

Figure 7.3 Impact of automatic dimming control lighting on annual energy consumption for atrium lighting



Source: Atif and Galasiu (2003)

d) Environmentally Friendly Materials (A4)

Materials are not only considered in new building projects but also in the rising requirements of maintenance in existing buildings. Particularly, office buildings are regularly maintained with maintenance activities, refurbishment or replacement of systems and components, and fit-out churn (Douglas 2006 cited in Isnin, Ahmad & Yahya 2012). For example, materials will be demanded for the new lease tenants fit-out to pre-lease condition spaces, and for walls, floors and ceiling finishes. Selection of sustainable materials used for maintenance has to be considered (Florez & Castro-Lacouture 2013).

For sustainability, materials chosen for maintenance of office buildings should be of low embodied energy meaning a low level of GHG emissions (Bribian et al. 2011 cited in Ding 2014; Florez & Castro-Lacouture 2013). Both initial and recurrent embodied energy play an important role in the energy efficiency of building materials. Materials used in buildings should not discharge pollution or emissions that affect human health and comfort throughout their life cycle (Ding 2014). Commonly, sustainable materials may be selected from eco-labelling benchmarks or environmental product declarations. Materials mostly used in building maintenance include cleaning agents; paints; furniture; wall, floor and ceiling finishes; and other furnishings. They may produce fumes, formaldehyde, VOCs and SVOCs when used in buildings (Isnin, Ahmad & Yahya 2013).

In upgrading maintenance environmentally friendly materials can be used for wall, floor and ceiling finishes. The upgrading work includes:

- New tiling in toilets and tea rooms, redecoration of existing painted surfaces, upgrading finishes in lift lobbies, new finishes to main entry and lobby.

- New carpets to lettable areas, new tile finishes to main entry and lobby.

- Making good and redecorating ceilings in service core areas; new suspended ceilings to lettable areas, main entry and lobby, and lift lobbies on upper floors. These upgrades can provide energy savings of 20% on each upgrading work (Bondanza 2011; Steinfeld, Bruce & Watt 2011).

e) Water Efficiency (A5)

Office buildings consume water at a high rate. A large component of water use is for toilets and basins. According to Chanan et al. (2003), typically, office buildings account for 10–20% of total water demand in urban water supply systems. Toilet flushing accounts for the highest water component in office buildings, representing over 60% of water usage (Hills et al. 2002 cited in Chen, Ngo & Guo 2012). This provides many opportunities for achieving savings in schemes for sustainable water management. Traditionally, average daily water required for these uses can be as high as 155 litres per person. This amount of water can be readily reduced by about 25–30% in office buildings (City West Water 2014). As studied by Chanan et al. (2003), conventional office buildings can be improved to achieve up to 87% of water savings through best practice water efficiency such as waterless fixtures and recycling stormwater for various usage. However, the future target in reusing and recycling water for Sydney, Australia, is to reduce 35% of water consumption from 2011 and to increase water recycling up to 10% by 2020 (NSW Office of Water 2010; Radcliffe 2006 cited in Chen, Ngo & Guo 2012). Water efficiency can be achieved by performing the following work:

- Upgrading can be done at a low cost by installing water control sensors to minimise water use for toilets, urinals and tapware. The best practice is that water flushes for toilets and urinals can be set at 1–2 litres per flush, or flushing time can be approximately 5 seconds and automatic flush time between 6–8 minutes. While, for tapware, sensors can automate shut-off taps when the handle is released and be set that tapware can deliver a flow rate of 3 litres per minute. Upgrading can provide water savings of about 22% (Australian Department of the Environment and Heritage 2006; Sydney Water 2007; Terry & Moore 2008).

- Major upgrades for water efficiency strategies are the replacement of entire plumbing systems with efficient devices/fixtures that include hand basins, sensor tapware, waterless urinals, dual flush WC suites and water sub-meters. These upgrades can provide systems water savings of up to 82% (Australian Department of the Environment and Heritage 2006; Sydney Water 2007; Terry & Moore 2008).

- The best practice in water efficiency is reusing stormwater and/or recycling grey/black water onsite to provide savings on water use. Capturing and reusing stormwater can achieve water savings of over 50% or up to nearly 87% for toilet and urinal flushing (Chanan et al. 2003). Recycling grey/blackwater can provide up to 80–90% of blackwater discharged to waste recoverable for use in toilet flushing or irrigation through simple filtration (City West Water 2014). However, in installing treatment facilities for recycling grey/blackwater, maintenance managers should consider the high cost of operation and maintenance of these facilities (Australian Department of the Environment and Heritage 2006; Sydney Water 2007; Terry & Moore 2008).

There are some significant problems that may be ignored in maintenance practices, but waste water is not one of them. The first problem is leakage from taps, urinals, cisterns, piping, valves, pumps, and cooling towers. One leaking toilet or urinal can waste up to 3,000 litres of water per year (City West Water 2014). Leakage in offices can waste up to 26% of end-use water (Australian Department of the Environment and Heritage 2006; Chen, Ngo & Guo 2012). Stopping leakage would prevent waste of water. The second problem is testing water from the sprinkler systems at half-yearly and/or yearly intervals. Traditionally, after a test, testing water will be disposed into sewer lines. Installing storage for sprinkler testing water for reuse would provide an annual systems water savings of up to 50% on water consumption in the buildings (Australian Department of the Environment and Heritage 2006; Sydney Water 2007; Terry & Moore 2008).

f) Waste Management (A6)

Waste disposed to landfill is currently a major problem for the land environment. The building industry is the main source of waste to landfill. The construction and demolition of buildings in Australia generates up to 50% of all waste going to landfill (Moore 2009). With sustainable practices, waste to landfill can be reduced through increased reuse/recycling of materials. This can lead to lower environmental impact, lower consumption of energy resources and lower economic costs. However, most waste in the operation of office buildings are paper, cardboard, plastic containers and garbage. Reused and recycled paper and cardboard will reduce logging, and recycled plastic containers will replace virgin plastic. Paper used in office buildings can also be reduced by using both sides rather than a single side for ordinary documents.

According to Resource NSW (2002), many office buildings already have recycling systems in place. However, the rate of recycling is still quite low, and the recycling system contains a lot of contamination. Normally, paper accounts for 55% of waste generated in office buildings; cardboard accounts for 10%; drinks containers and reusable stationary items account for 5% each; and garbage waste accounts for 25%.

A target set by the Australian Commonwealth Environment Protection Agency in 2000 has been set to reduce waste to landfill by 50% per capita (Terry & Moore 2008). Significantly, for example in Australia, the Australian WasteWise construction project reduced the budgeted amount for waste removal by approximately 50% (Miller, Khan et al. 2005 cited in Terry & Moore 2008).

In the best practice of waste management, the most effective option is for office building managers to provide appropriate space for waste to be sorted by paper, cardboard, drinks containers, reusable stationary items and garbage for reuse, recycling and landfill respectably. A waste disposal space can be equipped with following containers and bins:

- Paper bins: for reducing, reusing or recycling paper.

- Cardboard baler: for recycling cardboard.

- Drinks container bins: for recycling plastic drinking containers.

- Stationery bins: for reusable stationery items.

- Garbage bins: for disposing of all kinds of household waste and waste that cannot be reused and/or recycled to landfill.

7.3.2 Routine Maintenance

Routine maintenance is regular maintenance work. It can include periodic inspecting, testing and calibrating the service systems or equipment to prevent breakdown. Routine maintenance can be carried out by monthly, quarterly, half-yearly and yearly periods.

In routine maintenance, preventive maintenance is a way to improve the reliability of systems and equipment by keeping them from problems, failure and breakdown. Preventive maintenance can be performed during basic inspection, such as once a month; and detailed inspection periods or regular inspection and measurement, such as once every six months or once a year (Australian Department of the Environment and Heritage 2006; Budaiwi 2007; Kwak et al. 2004). In addition, preventive maintenance can follow the recommendation of suppliers/manufacturers. It may be done separately or in combination with service maintenance.

7.3.3 Ad Hoc Maintenance

Ad hoc maintenance is inspection and repair of breakdown of services systems and equipment to return them to working condition. The need to repair broken-down systems and equipment cannot be avoided in maintenance. It can occur at any time even if the system or equipment is in good order. However, having better maintenance practices can reduce breakdowns.

7.3.4 External Factors

External factors included in the SMOB are providing education and training to improve key stakeholders knowledge in sustainable building maintenance, collaboration between owners and tenants in improving the performance of buildings, encouraging development of sustainable building maintenance with government incentives and legislation/policies. They are important factors in accelerating the development of sustainable maintenance practices in office buildings.

The external factors comprise four criteria and they are discussed in detail as the following issues:

- The questionnaire survey has revealed that a large number of key stakeholders in the industry lack knowledge about new technologies in the development of sustainable buildings. The application of sustainability is still not widely exercised. Only 17% of survey respondents apply sustainability in mainstream maintenance practices (discussed in Chapter 6). Therefore, improving key stakeholders' knowledge about new technology in sustainability is critical.

- Cooperation between owners and tenants may accelerate moves towards sustainability for buildings. Owners can upgrade their buildings to be greener to avoid obsolescence, to keep the existing tenants longer and/or to attract new tenants and to provide more convenience to occupiers. Tenants who lease greener building spaces would accept paying more rent, allowing the owners to recover their expenditures on improving the buildings. In return, tenants will acquire savings on energy usage in running their businesses. Both owners and tenants could collaborate to accelerate the development of sustainability for buildings.

- Existing office buildings in the private sector are encouraged to improve their performance to meet environmental protection regulations. However, the improvement might be delayed or avoided due to budget limitations and the additional costs for achieving sustainability.

- Government regulations, policies and incentives may be increased to speed up the application of sustainability as the standard in maintenance practices for office buildings. The incentives can be increased with a higher threshold and/or more money to the owners who improve their buildings. The incentives can also be in the form of a reduction of taxes on developing sustainability for existing office buildings.

7.4 Estimating Annual Costs and Potential Savings in the SMOB for Existing Office Buildings

In assessing the costs and savings provided by the SMOB, the improvement of maintenance practices concentrates on calculating the additional costs and savings of work done for upgrading and maintaining office buildings. This assessment is based on how maintenance service could satisfy three objectives:

- Improving the environment by reducing CO_2 emissions with sustainable maintenance practices in effective uses of energy and water in the buildings.

- Improving office buildings with sustainable maintenance practices to minimise operation and maintenance costs.

- Keeping systems and equipment functioning with sustainable maintenance practices to prevent downtime of systems and equipment.

The estimated costs and savings in the SMOB are based on the data from researched sources and published data. Where assessed data cannot be collected because they are considered confidential or unavailable, they are assumed.

7.4.1 Estimating Annual Costs and Potential Savings on Energy Consumption

Estimating annual costs in upgrading and maintaining the systems are calculated in cost per square metre ($/m^2), and savings are by percentage (%) on energy and water consumptions and CO_2 emissions. Commonly, the end-use shares of energy consumed in a building are computed for electricity and gas use. However, the energy calculation in this project only considers electricity use in buildings as gas consumption is only minor in office buildings (see Section 7.3.1). The energy savings are based on savings on building services running on normal and peak loads. The energy savings calculated will be the end-use of energy consumption per annum. Table 7.1 summarises the annual costs and potential savings as derived from the implementation of the SMOB.

Table 7.1 Annual costs and savings in SMOB over a 30-year period

SMOB Issues		Life Span [1] (Years)	Potential Annual Savings on Energy Use & CO_2 emission [2] (%)	$/m²			Reference	
				Capital Cost	Annualised Capital Cost (at 30 Years)	Additional Annual Maintenance Cost [3]	Capital Costs	Energy Savings
A. Upgrading								
A.1 Energy Efficiency	A.1.1 Installing solar-boosted hot water systems	30	6.00	9.91	0.47	0.20	[2, 4, 27]	[17]
	A.1.2 Installing or upgrading BMCS	15	2.40	0.93	0.08	0.02	[2, 21, 30]	[5]
	A.1.3 Installing solar power systems per kW/m²	30	3.12	1.09	0.05	0.05	[2, 4, 28]	[5, 19]
	A.1.4 Upgrading lifts and escalators	30	2.40	57.93	2.77	0	[4]	[1, 6]
	A.1.5 Upgrading electrical/power switchgears	15	3.12	146.95	11.87	0	[2, 3, 4]	[5, 8, 11]
A.2 Indoor Climate	A.2.1 Recommissioning or tuning HVAC systems	10	8.44	2.65	0.30	0	[2, 4]	[5]
	A.2.2 Upgrading to new technology HVAC systems	30	17.10	319.29	15.25	1.00	[3, 29]	[5, 8, 11, 20]
	A.2.3 Installing automatic sun shading to reduce heat gain or loss	15	8.55	392.81	31.73	1.96	[2, 4, 30]	[5, 7, 9, 10, 18]
A.3 Lighting Efficiency	A.3.1 Installing lighting motion sensors	15	2.66	5.31	0.43	0.05	[2, 4, 30]	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	A.3.2 Replacing with LED lighting	20	1.01	129.58	6.19	0	[2, 4]	
	A.3.3 Installing automatic dimming lighting systems	30	3.80	128.09	6.12	1.28	[2, 4, 30]	
A.4 Environmental Materials	A.4.1 Upgrading internal finishes with eco materials	30	0.80	135.68	6.48	0	[4]	[5, 19]
A.5 Water Efficiency	A.5.1 Installing or upgrading water control sensors	15	8.17	20.46	1.65	0.20	[4, 30]	[23, 24, 25]
	A.5.2 Installing or upgrading water-efficient devices and fixtures	50	30.34	83.42	3.99	0	[4]	
	A.5.3 Reusing and recycling rainwater and grey or black water	30	19.50	141.22	6.75	1.41	[4, 30]	
A.6 Waste Management	A.6.1 Providing breakdown waste disposal space	30	37.50	3.24	0.15	0.03	[4, 26, 30]	[25, 26]
B. Routine Maintenance								
B.1 Periodic cleaning and servicing	B.1.1 Electrical systems	-	3.18	-	-	-	[2, 3, 4]	[5, 8, 11]
	B.1.2 HVAC systems	-	7.94	-	-	-		[5, 8, 11, 20]
	B.1.3 Lighting systems	-	2.12	-	-	-	[2, 4]	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	B.1.4 Interior	-	0.53	-	-	-	[4]	[5, 19]
	B.1.5 Water systems	-	0.71	-	-	-	[4]	[23, 24, 25]
	B.1.6 Waste disposal space	-	0.53	-	-	-	[4, 26]	[25, 26]
B.2 Periodic inspecting to prevent breakdown	B.2.1 Electrical systems	-	2.12	-	-	-	[2, 3, 4]	[5, 8, 11]
	B.2.2 HVAC systems	-	5.29	-	-	-		[5, 8, 11, 20]
	B.2.3 Lighting systems	-	1.41	-	-	-	[2, 4]	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	B.2.4 Interior	-	0.35	-	-	-	[4]	[5, 19]
	B.2.5 Water systems	-	0.47	-	-	-	[4]	[23, 24, 25]
	B.2.6 Waste disposal system	-	0.35	-	-	-	[4, 26]	[25, 26]

SMOB Issues		Life Span [1] (Years)	Potential Annual Savings on Energy Use & CO_2 emission [2] (%)	$/m²: Capital Cost	$/m²: Annualised Capital Cost (at 30 Years)	$/m²: Additional Annual Maintenance Cost [3]	Reference: Capital Costs	Reference: Energy Savings
C. Ad Hoc Maintenance								
C.1 Inspecting and repairing breakdowns	C.1.1 Electrical systems	-	2.07	-	-	-	[2, 3, 4]	[5, 8, 11]
	C.1.2 HVAC systems	-	5.17	-	-	-		[5, 8, 11, 20]
	C.1.3 Lighting systems	-	1.38	-	-	-	[2, 4]	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	C.1.4 General repairing/restoring to interior	-	0.34	-	-	-	[4]	[5, 19]
	C.1.5 Water systems	-	0.57	-	-	-		[23, 24, 25]
	C.1.6 Waste disposal system	-	0.46	-	-	-	[4, 26]	[25, 26]

	Capital Cost	Annualised Capital Cost (at 30 Years)	Additional Annual Maintenance Cost
Upgrading:	**1,578.56**	**94.28**	**6.21**
Routine maintenance:	**0**	**0**	**0.00**
Ad hoc maintenance:	**0**	**0**	**0.00**
Total:	**1,578.56**	**94.28**	**6.21**

Notes:
[1]. The systems' life spans are adapted from Kubba 2010; Menzies & Wherrett 2005; and Scheuer, Keoleian & Reppe 2003
[2] Costs and Savings are adapted from literature review materials (see following references)
[3]. Annual maintenance costs of Routine (B) and Ad Hoc (C) are included in Upgrading (A).

Reference
[1] Australian Building Code Board (2004)
[2] City of Melbourne (2007)
[3] CostWeb (2014) (www.costweb.com.au)
[4] Rawlinsons (2016)
[5] Steinfeld, Bruce and Watt (2011)
[6] De Almeida et al. (2012)
[7] Omer (2008)
[8] Jenkins, Liu and Peacock (2008)
[9] Medrano et al. (2008)
[10] Zain-Ahmed et al. (2002)
[11] Lecamwasam, Wilson and Chokolich (2012)
[12] Zografakis, Karyotakis and Tsagarakis (2012)
[13] Bourgeois, Reinhart and Macdonald (2006)
[14] Galasiu and Veitch (2006)
[15] Ihm, Nemri and Krarti (2009)
[16] Li, Lam and Wong (2006)
[17] Cabeza et al. (2014)
[18] Burton (2001)
[19] Bondanza (2011)
[20] Lecamwasam (2014)
[21] Commercial Buildings Committee (2014)
[22] Atif and Galasiu (2003)
[23] Australian Department of the Environment and Heritage (2006)
[24] Sydney Water (2007)
[25] Terry and Moore (2008)
[26] Resource NSW (2002)
[27] WePowr (2017)
[28] Blanch (2013)
[29] Price (2017)
[30] Wu (2010)

a) Estimating potential savings on energy use

The potential annual savings on energy use in Table 7.1 refers to the percentage savings on various building services as derived from the literature and published data on a typical office building (COAG 2012b; Steinfeld, Bruce & Watt (2011).

Table 7.2 presents the calculation of the percentage savings on various building services. In Table 7.2 the second column summarises the energy consumption distribution of a typical office building and it indicates that the HVAC system consumes the most energy and followed by lighting. The fourth column shows the expected savings in percentage should these systems be upgraded (COAG 2012b; Steinfeld, Bruce & Watt 2011).

Table 7.2 Calculation on savings of some major systems in the SMOB

System	Energy consumption distribution in typical office building	Upgrading	Savings on system upgrading	Estimated annual savings on energy use in the SMOB
HVAC	57%	Major upgrade to HVAC systems	30%	17.1%
Lighting	19%	Major upgrade to lighting systems with T5 light fittings and lighting sensors	20%	3.8%
Equipment	12%	Major upgrade to electrical/power switchgears	26%	3.1%
Lifts	8%	Refurbishing/upgrading lift/escalators	30%	2.4%
Others	4%	Replacing with new tiles finish to main entry and lobby, toilets, etc.	20%	0.8%

Source: Adapted from COAG (2012b); Steinfeld, Bruce and Watt (2011)

The last column in Table 7.2 shows the calculation of estimated annual savings on utility cost and CO_2 emissions in the SMOB which is based on the Formula 7.1 below:

Estimated annual savings in the SMOB per system upgrade (%) = Energy consumption of system (%) x savings on system upgrade (%) (7.1)

For example, an upgrade to the HVAC systems provides a savings of 17.1%. The HVAC energy consumption in office buildings are 57% to give an energy savings for the buildings of 30% of 57%. Therefore the potential annual savings was calculated at 17.1% (see Table 7.2). This is the estimated annual savings on energy consumption and CO_2 emissions related to an upgrade to the HVAC systems in the SMOB. This calculating method is applied for the calculation of all other systems and equipment. Details of all the calculations for savings on energy consumptions and CO_2 emissions are included in Table A3.1 and A3.2, Appendix 3. The potential savings for upgrading (A), routine maintenance (B) and ad hoc maintenance (C) are shown in Column 4 in Table 7.1. The estimated percentage savings on energy consumption and CO_2 emissions is considered the same in the SMOB[3].

b) Estimating Upgrading Costs

The estimation of upgrading costs has also been summarised in Table 7.1 and included in Columns 6 and 7 in the table.

The upgrading costs of systems or equipment in the SMOB include initial capital cost and additional annual maintenance cost[4]. The capital costs in upgrading are priced at 2016 in terms of $\$/m^2$ of GFA (excluding GST). The life span of each system or equipment is shown in Table 7.1 and it is expected that each system or equipment may need to be upgraded several times over the building's life cycle. To simplify the calculation the capital cost is annualised on a 30 year study period at discount rate of 3% (Nominal rate/inflation). The annualised capital costs are included in Column 6 of Table 7.1. Therefore the total cost of upgrading is the capitalisation of annualised capital cost (Column 6) and additional annual maintenance cost (Column 7) for each upgraded system or equipment.

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[3] It is assumed that in the development of the SMOB, the estimated rates of savings on energy consumption is considered the same as the rates of savings on CO_2 emissions in buildings; however, when measuring, energy consumption is calculated by kWh, while CO_2 emission is by kg CO_2.

[4] Additional annual maintenance cost refers to extra cost incurred due to installing new systems or equipment. For replacing existing systems or equipment with new there will be no additional maintenance cost in most cases.

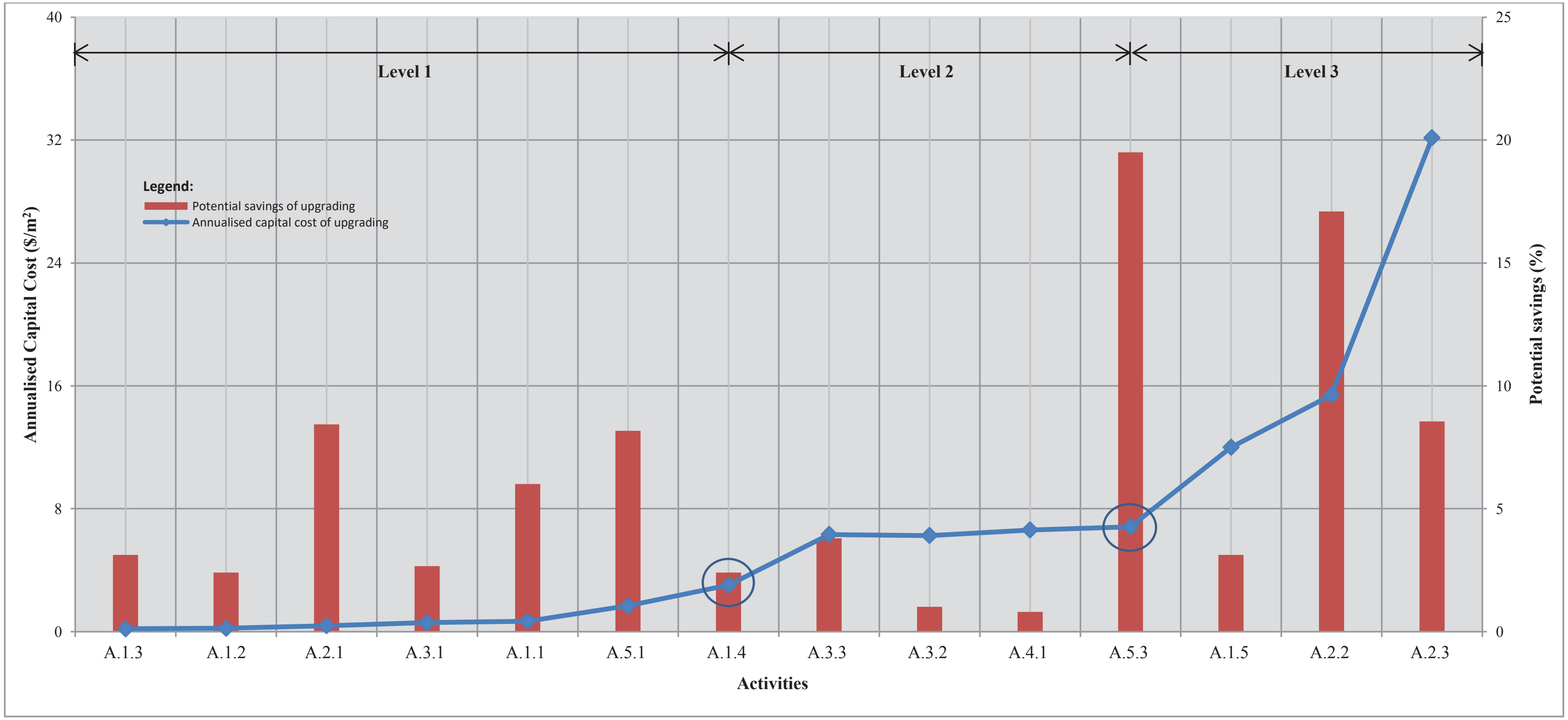
The annual maintenance costs were developed from journal articles, building maintenance websites and facility managers. The collected cost data were adjusted in the SMOB. However according to Nalewaik and Venters (2008); and Wu (2010), there is no fixed costs in maintenance of building service system. Annual maintenance costs may vary depending on frequency in schedules, the size and operation of systems. In building upgrading, an existing system may be upgraded or a new technology system may be installed the new or upgraded system may require less frequent maintenance or require no maintenance compared with existing systems. For example if traditional lighting system is replaced with LED lighting (A.3.2), it may require less maintenance as LED lighting has longer life span compared with traditional incandescent light bulbs. Therefore the SMOB only considers maintenance costs that are over and above the cost of the systems that are replaced.

In Table 7.1 the highest annualised capital cost is the installation of automatic sun shading (A.2.3) to reduce heat gain and loss in the building of approximately \$32/m^2 and an additional annual maintenance cost of \$2/m^2. This upgrade will give approximately 9% saving on annual energy consumption and CO_2 emission. While, upgrading the entire of HVAC system (A.2.2) has an annualised capital cost of approximately \$15/m^2 and additional annual maintenance cost of \$1/m^2. This will provide a savings on annual energy consumption and CO_2 emissions of 17%. The lowest upgrading cost is the installation of a solar power system (A.1.3) with an annualised capital cost of \$0.1/m^2 and additional annual maintenance cost of \$0.05/m^2 for a potential savings of 3%. The lowest rate of potential savings on energy consumption and CO_2 emissions is the improvements/upgrades floors with eco finishes (A.4.1) by only 1%.

c) Analysing Upgrading Costs and Potential Savings in Three Levels

Figure 7.4 presents the annualised capital cost of upgrading from the lowest to highest (\$/m^2) and the associated potential savings of upgrading (%) systems and equipment in the SMOB. The horizontal axis represents upgrading activities in the SMOB. The vertical axis on the left is the annualised capital cost (\$/m^2), ranging approximately from \$0.1–32/m^2. The vertical axis on the right shows the percentage of potential savings on energy consumption and CO_2 emissions, which is ranged approximately from 1–20%.

Figure 7.4 Annualised capital costs and savings in upgrading over a 30-year period based on SMOB



<u>Notes:</u>

- A.1.1: Installing solar-boosted hot water systems
- A.1.2: Installing or upgrading BMCS
- A.1.3: Installing solar power systems per kW/m^2
- A.1.4: Upgrading lifts and escalators
- A.1.5: Upgrading electrical/power switchgears
- A.2.1: Re-commissioning or tuning HVAC systems
- A.2.2: Upgrading new technology HVAC systems
- A.2.3: Installing automatic sun shading to reduce heat gain/loss
- A.3.1: Installing lighting motion sensors
- A.3.2: Replacing with LED lighting
- A.3.3: Installing automatic dimming lighting system
- A.4.1: Upgrading internal finishes with eco materials
- A.5.1: Installing or upgrading water control sensors
- A.5.3: Reusing and recycling rainwater and grey or blackwater

The Figure 7.4 also presents the annualised capital costs and potential savings in three levels. The three levels were established to suit the appropriate work for the budget allowed in improving a building. The improving/upgrading work for systems and equipment can be carried out with one, two or all three levels depending on the building's maintenance strategy or budget allowance. Works listed in a level do not include works in other levels. They are as follows:

Level 1: Upgrading with the Lowest Costs

In the figure work having annualised capital cost varies from approximately $0.1/m^2 to $3/m^2. Upgrading work at Level 1 is basic. It can be simply upgrading/installing BMCS (A.1.2), tuning/recommissioning HVAC systems (A.2.1), installation of solar power systems (A.1.3), and so forth. Recommissioning/tunning the HVAC systems (A.2.1) will provide the highest rate of annual savings on energy consumption and CO_2 emissions.

For example, in Level 1, the best value is recommissioning/tunning the HVAC systems (A.2.1) to have necessary running times on normal and peak loads, and adequate air balance so that the right air quantity and temperature is delivered to each space. The annualised capital cost of only $0.3/m^2 but it can provide a savings up to 8% on energy consumption and CO_2 emission. Installation of a solar power system (A.1.3) is the lowest annualised capital cost in this level. It costs $0.1/m^2 and provides a potential savings of approximately 3% on energy consumption and CO_2 emissions.

Level 2: Upgrading with Intermediate Costs

This work having annualised capital cost that varies from approximately $3/m^2 to $7/m^2. Work done in Level 2 can be upgrading finishes with eco materials (A.4.1), upgrading lifts and escalators (A.1.4), installing automatic dimming lighting system (A.3.3), and so forth.

In Level 2, upgrading lifts and escalators (A.1.4) costs of $3/m^2 and provides a savings of 2%. The most effective savings in Level 2 is installing automatic dimming lighting system (A.3.3). This costs of $6/m^2 and provides potential savings of 4% on energy consumption and CO_2 emissions annually.

Level 3: Upgrading with the Highest Costs

Level 3 works have annual cost ranged at $7/m^2$ to $32/m^2$. Upgrading work in Level 3 is major. This can include major upgrading to HVAC systems (A.2.2), electrical/power switchgears (A.1.5) and installing automatic solar light sun shading (A.2.3), such as external louvres to reduce heat gain and loss through the building. Major upgrades to HVAC systems can be by refurbishing or replacing the existing HVAC system with a new high-tech system.

In this level, the major upgrade to electrical/power switchgears (A.1.5) costs of $12/m^2$ and provides a savings of 3%. While installation of automatic sun shading (A.2.3) would cost $32/m^2$ and provide savings at 9%. The major upgrade to HVAC systems (A.2.2) would provide the most effective savings in Level 3. The cost is $15/m^2$ and savings is 17%.

7.4.2 Estimated Annual Costs and Potential Savings on Water Consumption

Annualised capital costs on systems or equipment of water consumption (A.5 in Table 7.1) are estimated using the same approach as for the energy consumption. Potential savings on water consumption in the SMOB can be performed to all water devices/fixtures including insulating piping system and replacing existing fixtures with more water efficient ones. The estimation of potential savings is presented in water related energy consumption and CO_2 emission in Table 7.1. The calculation of a system's water and CO_2 savings (using Formula 7.2 below) is based on percentages on building services of water savings obtained from the literature review. Therefore the estimated rates of savings on water consumption and CO_2 emissions are calculated according to the following formula:

$$\text{Estimated annual savings in the SMOB per system upgrade (\%)} = \text{Water consumption of system (\%)} \times \text{savings on system upgrade (\%)} \qquad (7.2)$$

The percentage of water consumption for categorised water systems or devices in office buildings in Sydney (Column 2), is adapted from the data of Sydney Water (2007) as shown in Table 7.3.

Table 7.3 Calculation on savings of water systems in the SMOB

System	Water consumption distribution in typical office building	Upgrading	Savings on system upgrading	Estimated annual savings in the SMOB per system
Toilets, kitchenettes & showers	37%	Installing or upgrading water control sensors (A.5.1)	82%	30.3%
		Installing or upgrading water efficient devices and fixtures (A.5.2)	22%	8.1%
Landscaping, cooling towers for HVAC	26%	Reusing or recycling rainwater, grey or blackwater (A.5.3)	75%	19.5%

Source: Adapted from Australian Department of the Environment and Heritage (2006); Sydney Water (2007); and Terry and Moore (2008)

Same principle applies in the calculation of water consumption related CO_2 emissions. Upgrading water systems can be performed through either minor or major upgrades. Minor upgrades can be executed by upgrading/replacing some plumbing devices and fixtures, whereas major upgrades will be performed by upgrading/replacing the entire existing plumbing system with an efficient one including pipework. This includes water efficient hand basins, tapware and sensor taps, WC floor-mounted suites with standard dual flush system (halfway and full flushing), waterless urinals, and sub-metering to audit and monitor water use for bathrooms, cooling towers, irrigation, recycled water systems, and hot water systems (A.5.1 & 2).

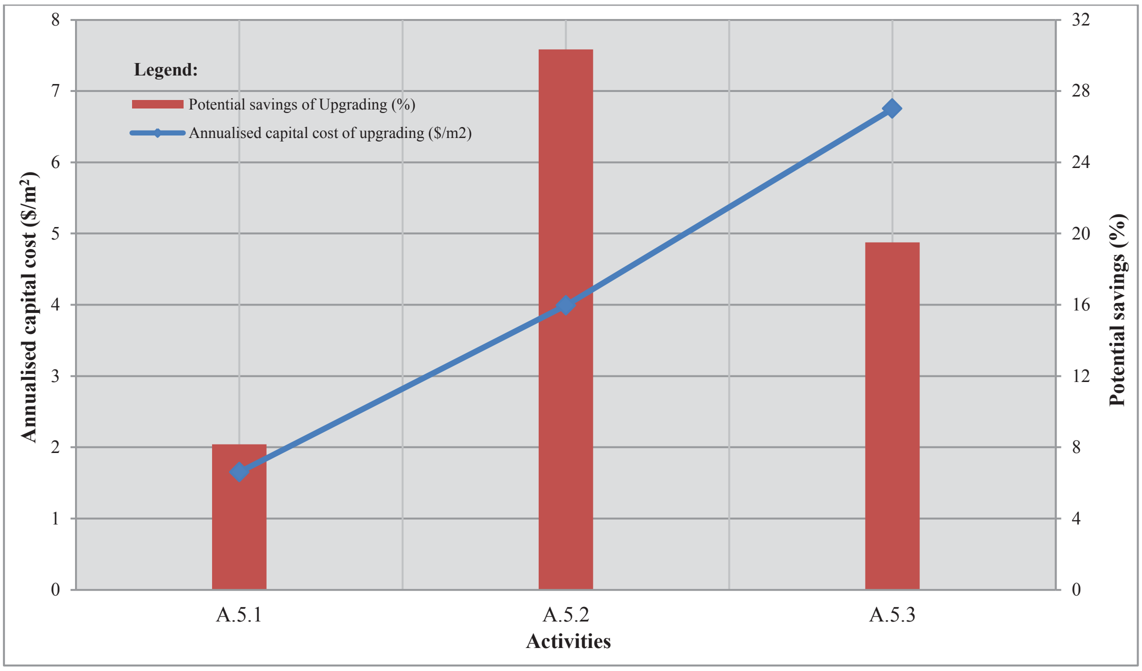
Further consideration for upgrading can include installing stormwater harvesting system and grey/black treatment systems (A.5.2) for recycling wastewater. However, grey/black treatment systems are expensive to install and have high ongoing maintenance costs with little savings on water as the treated grey/blackwater is currently only suitable for gardening or toilet flushing. That might not be economical in office buildings. Table 7.1 summarises the estimated annualised capital costs in upgrading and potential savings on water related energy consumption and the associated CO_2 emission (detail calculations refer to Table A3.1, Appendix 3).

The table shows that the most suitable ways of saving water are major upgrades to the existing system with water-efficient or waterless devices/fixtures including pipe work (A.5.2). This will provide high rates of savings of approximately 30% on water related energy consumption and CO_2 emissions with an annualised capital cost of approximately \$4/m^2. This system requires no additional maintenance cost as it has already been required in the existing maintenance expenses.

Installation of a rainwater harvesting system and/or treatment system to recycle grey or blackwater (A.5.3) can save up to 20% on water related energy consumption and CO_2 emission with an annualised capital cost of 7/m^2. Installing or upgrading water control sensors (A.5.1) will provide as savings of 8% with an annualised capital cost of \$2/m^2.

Figure 7.5 presents the annualised capital cost (\$/m^2) from the lowest to the highest with associated potential savings (%). The horizontal axis presents upgrading activities on water efficiency in the SMOB. The vertical axis on the left is the annualised capital costs relating to improved/upgraded systems or equipment. The vertical axis on the right is presented rates of potential savings on utility cost, water consumption and CO_2 emissions. As revealed in the figure upgrading to plumbing system (A.5.2) is the second most expensive option but it can generate the most savings on water consumption and CO_2 emissions. Nevertheless the installation of waste water treatment system (A.5.3) is the most expensive upgrading activity but it generates the least savings among all.

Figure 7.5 Annual costs and savings in upgrading for water efficiency based on SMOB



Note: A.5.1 Installing or upgrading water control sensors
A.5.2 Installing or upgrading water efficient devices and fixtures
A.5.3 Reusing and recycling rainwater and grey or black water

7.4.3 Estimated Upgrading Costs and Savings on Waste Management

Waste disposed of in operating office buildings is mostly paper, cardboard, drinks containers, stationary items and household waste. To reduce waste to landfill, a better way is to provide a waste disposal space to sort waste including solid, office and household waste to reuse/recycle where possible. In addition, paper used in office buildings can be reduced by using both sides rather than a single side for ordinary documents.

In upgrading, estimated costs and savings on waste disposal in the SMOB are calculated in the same way as discussed previously. However, the potential savings from reduced waste to landfill by half the normal waste amount per capita is as set by the Australian Commonwealth Environment Protection Agency (Terry & Moore 2008). Therefore, the annual savings on waste disposal and CO_2 from an office building is calculated using the following formula:

$$\text{Estimated waste savings (\%)} = \text{Savings on building services (\%)} \times 50\% \tag{7.3}$$

The estimated cost in upgrading and savings on waste disposal is included in Table 7.1. The table shows that the annualised capital cost in providing a garbage compactor, cardboard baler, and mobile waste paper bins for waste disposal is approximately $0.2/m^{2,} but can save up to 38% of energy use and CO_2 emission on waste disposal (detail calculations refer to Table A3.1, Appendix 3).

7.4.4 Contribution of SMOB in Improving Sustainability Performance of Existing Office Buildings

To sum up, in improving an existing office building to meet environmental requirements by reducing CO_2 emissions, the most suitable consideration is reducing energy and water consumption. The SMOB has been developed to provide ways to satisfy these reductions through improving maintenance practices.

A building does not have to apply upgrades to all systems as set out in the SMOB. Each building can be independently assessed and upgrading criteria selected depending on its geographic location, type, use of equipment, operational and maintenance schedules. Improvements can start with Level 1 upgrading then go to the next levels where possible. For major upgrading, the facility managers can perform improvement to one, two or more parts of a system rather than upgrading or replacing the entire system, unless it is necessary.

For energy efficiency, upgrading or installing BMCS and solar power are generally cost effective with good savings. To address indoor climate, HVAC systems can be improved by upgrading or by replacing cooling towers, chillers or air handling units where possible. In most cases, recommissioning HVAC systems would prove useful. To address lighting systems, the upgrade approach could be replacing either LED or T5 lighting on some floors or the entire building where necessary. The lowest cost in upgrading the lighting systems is the installation of automatic motion sensors, which is low cost and provides good savings. Regarding water efficiency, the fixtures that consume the highest rates of water are urinals and WCs. Therefore, replacing sanitary fixtures and installing rainwater systems would provide good savings on water consumption with lower upgrading costs.

As Lecamwasam, Wilson and Chokolich (2012) state, the best maintenance practice can be found by concentrating on energy and water efficiency. Juan, Gao and Wang (2010) argue that sustainable maintenance would also include sustainable site uses of materials and resources, and indoor environment quality. The SMOB covers both of these issues, and also includes the disposal of waste to landfill as part of the model. To improve waste management, the best practice is having garbage compactors, cardboard balers, mobile paper bins and garbage bins for reusing or recycling potential waste; they are considered as having lower upgrading costs but provide better savings.

Additionally, energy savings in operating and maintaining the building can be achieved by regularly cleaning and servicing the systems. Servicing the systems could keep them functioning and reduce breakdown times. Cleaning the components could keep the systems in normal working condition, leading to great savings. When a component is mud-covered, it would consume more energy than usual. For example:

- When HVAC filters are cloudy, they block the supply air and rooms cannot reach the set temperature. This means the system consumes excess electricity by continuously running rather than automatically turning on/off at set points.

- When a pump motor is muddy, it is hotter than in normal running conditions due to obstruction of ambient air. That causes the pump motor to use more electricity, and its life span will be shortened.

- When a motor fan is dusty, it becomes heavy and runs slowly. That makes the fan motor use more electricity and burn out quicker.

Furthermore turning off plant, equipment and lights when they are not required could save on energy consumption without additional cost. This includes turning off HVAC systems and equipment at night and breaks; switching off lights in plant rooms when they are not being inspected or repaired.

Regular auditing and inspection of service systems is also good practice in routine maintenance of a building. These services could test the working condition of systems and calibrate the systems to prevent breakdowns. The audit and inspection could record the systems energy consumption which could lead to ways to reduce energy consumption. It can also record the breakdown times of the systems, which could be helpful in planning to reduce breakdown times.

The questionnaire survey (see Chapter 6) revealed that a large number of key stakeholders in the industry lack knowledge of new technologies in sustainably maintaining buildings. The application of sustainability to their buildings is still not widely exercised. Only 17% of key stakeholders apply sustainable practices in their maintenance. Therefore, improving key stakeholders' knowledge about new technology for sustainability is very important. The next concern is the cooperation between owners and tenants. Owners can upgrade their buildings to be greener and provide more comfort to tenants. In return, tenants who lease greener spaces may accept paying more rent in order to facilitate the owners recovering their expenditures on building improvements. Whereas, the tenants would recover part of the higher rent in the form of lower running costs and better indoor environment. Therefore, both owners and tenants could collaborate to accelerate the development of sustainability for buildings.

Currently, the owners of existing office buildings are encouraged to improve them to meet environmental protection standards. Government regulations, policies and incentives will help to speed up the application of sustainability as the mainstream maintenance practice. When the incentives are increased with a higher threshold or an amount of money to compensate owners for expenditures, the sustainable maintenance of office buildings would be increased. Incentives can also be in the form of a reduction of taxes on the development of sustainability for existing office buildings.

As shown in Table 7.1, estimated annualised capital costs of some typical systems and equipment, and savings on annual expenditures in maintenance of upgrading for improving the maintenance of an office building using the SMOB are presented. The presentation aims to demonstrate annual costs and annual savings that key stakeholders can obtain in improving or upgrading systems or equipment in a long term strategy.

7.5 Summary

This chapter has discussed the development of the SMOB, which includes four indicators and 23 criteria used to improve maintenance practices in office buildings via upgrade, routine and ad hoc maintenance. The explanation of the SMOB, assessment, costs and savings provided from the model are also discussed. Significantly, the research has found that impacts between buildings and the environment can be reduced by improving maintenance practices in buildings.

The SMOB shows that for sustainable maintenance practices in office buildings, improvements can be applied to energy efficiency, lighting efficiency, water efficiency, use of environmental materials and a segregated and organised waste disposal space. The improvements can be applied as minor or major upgrading/installing existing systems or equipment with energy efficient systems or equipment. Each improvement provides a certain cost and benefit depending on the type of building, geographic location, type and use of systems or equipment, operational and maintenance schedules, and the systems requiring upgrades. The best way to improve maintenance practices is to replace existing systems or equipment with ones that uses new technologies. This approach will not only reduce annual expenditures in operation but will also provide more savings on maintenance work.

The next chapter discusses three case studies verifying the SMOB. These studies are of existing high-rise office buildings located in the Sydney CBD. The chapter thoroughly discusses the variants between the case studies when applying the SMOB, and the costs and benefits in improving each building.

8. Case Studies and SMOB Verification

8.1 Introduction

This chapter aims to verify the SMOB using case studies. The case studies include three commercial office buildings in the Sydney CBD. Collection of data involved meetings with the facility managers and visits to the site to examine building conditions under current maintenance practices. In addition, utility bills for electricity and water consumption were collected for the three buildings for the period of 2010–13.

Throughout this chapter the current maintenance practices for the three buildings are analysed to identify activities and costs and to examine maintenance of systems or equipment over routine, ad hoc and upgrading maintenances. The results from these case studies are then compared to the SMOB to identify:

- Whether the current maintenance practice reveals any potential gaps for improvement.
- What has been missed?
- How much has been missed.
- How to improve.

It also discusses maintenance costs of the case study buildings and the potential savings to be achieved in applying the SMOB. The results from these case studies indicate that the developed SMOB can be applied to actual buildings to identify hot spots for improvement. They also enhance the confidence that it can be applied in improving an existing office building to be environmentally friendly.

8.2 The Case Studies

8.2.1 Reasons for Using Case Studies

To verify the SMOB, case studies were selected because they were most suited to canvas and investigate current maintenance practices. Case studies provide the chance to examine and capture the specific details of organisational behaviour on building maintenance (Choy 2014), for example, investigating the current maintenance practices for the case study buildings to discover in-depth information on the scheduling of performances, method of practices, results obtained and improvements required.

Using the SMOB, the investigation can examine the current strategies and practices of maintenance work performed in the buildings being studied. Studying the buildings maintenance strategies means investigating current and future plans for maintenance practices. We can observe advantages and disadvantages between the case buildings maintenance strategies. Studying the maintenance practices means examining the current performances of routine maintenance, ad hoc maintenance and upgrading maintenance of the service systems.

8.2.2 Case Study Method

Data of three years' utility bills were obtained from facility managers of the three buildings with the consent of the building owners. Additional data were collected during site visits and meetings with the facility managers. Further information about the three buildings was also collected from the annual *Energy Efficiency Opportunities Reports* for the three buildings. Data collection concentrates on the current maintenance practices to find out:

- What maintenance practices are currently used?
- What are the advantages and/or disadvantages in current maintenance practices?
- What are the possible gaps compared with the SMOB?
- How can systems and equipment be improved?
- What are the costs of improvements?
- What benefits are returned from the potential improvement?

Collected data were tabulated and analysed to identify current practices to systems or equipment in routine, ad hoc and upgrading maintenance. These data were analysed, categorised and presented in a similar format of the SMOB to facilitate comparative studies at the later stage.

The analysis examined the areas of maintenance currently carried out by facility managers in the three buildings. The study also examined the savings achieved and squandered in current maintenance practices when the SMOB is applied.

8.3 Case Study Buildings

The case studies are three commercial office buildings located in the Sydney CBD, referred to as Buildings 1, 2 and 3. There are numerous office buildings in the Sydney CBD; however, these three were considered the best suited for this study due to:

- Their current maintenance strategies and practices are available for examination, while the information on the operation and maintenance of most office buildings is significantly limited and highly confidential.

- These buildings range from 22 to 31 years old and are within the range of ages this research investigates (see Table 8.1). As studies in the literature review suggest, a building may need to be refurbished/upgraded when it has 20–25 years of service from construction or last refurbishment (Wilkinson & Reed 2006a; 2006b). This is necessary to keep up with the change in technology in reducing energy and water consumption, to keep the building functional, and particularly, to satisfy the environmental protection regulations in minimising CO_2 emissions. However according to the maintenance records of the three case study building, these buildings have not had any major upgrades in the past ten years. This is a rare but the situation makes them good case studies for the research.

- They are medium and high-rise office buildings having GFAs from 17,000 m^2 to 45,000 m^2 (see Table 8.1). These sizes are considered within the scope of this research project.

- According to Hestnes and Kofoed (2002); and Steinfeld, Bruce and Watt (2011), a building that uses 75 kWh/m^2/year, may achieve energy efficiency in assessment. The annual energy consumption per GFA of the three case study buildings is still high at 128, 103 and 135 kWh/m^2 for Buildings 1, 2 and 3 respectively (see Table 8.1). Based on these studies, these buildings have opportunities for improvements in annual usage, and savings on energy and the environment by using the SMOB.

- The current maintenance practices in the case study buildings are similar and all have achieved A-grade status in according to the Property Council of Australia (PCA) commercial building grading. The study identifies whether their current maintenance strategies satisfy environmental protection regulations or not. Works not performed in the current maintenance practices for buildings are identified by using the SMOB.

The current maintenance records of the three buildings were collected for this study. The analysis found that the maintenance practices in the buildings concentrate on savings on energy and water consumption through HVAC systems and equipment, energy efficient lighting systems, water efficient water fittings. The analysis found that there were some upgrades done in previous years. However, upgrades to other service systems and equipment, such as installing solar power systems, upgrading lifts and escalators, upgrading lighting systems, installing/upgrading water control sensors and providing a waste disposal space, were not performed (see Table 8.2). Lastly, the analysis also found that the three buildings can further improve maintenance practices using the SMOB. The improvements can be further concentrated on potential savings of energy and water consumption in improvements/upgrades of other service systems and equipment and waste management in buildings, as well as reducing CO_2 emissions.

8.3.1 Characteristics of the Case Study Buildings

The characteristics of the three case study buildings have been summarised in Table 8.1

Building 1

This building was built in two stages, the first beginning in 1990 and the second in 1997. The building comprises a ground floor retail area and entrance foyer, 18 upper floors of office space and two levels of basement car parking with the GFA of 17,682 m^2. The average annual energy consumption was 2,256,933 kWh, and emissions were 2,528,224 kg CO_2. The average annual water consumption was 22,888 kL. The building energy intensity was 128 kWh/m^2, 143 kg CO_2/m^2 emissions and 1.3 kL/m^2 of water consumption per year of GFA.

Building 2

This building was completed in 1986. It comprises a ground floor with an entrance foyer and café, 32 upper floors of commercial office space, and three levels of basement car parking and the GFA is 40,089 m^2. The average annual energy consumption was 4,125,003 kWh and emissions were 4,501,961 kg CO_2. The average annual water consumption was 34,302 kL. The building's energy intensity was 103 kWh/m^2, 112 kg CO_2/m^2 emissions and 0.9 kL/m^2 of water consumption per year per GFA.

Building 3

This building was completed in 1995. It comprises an upper ground floor of retail stores, an entrance foyer, a lower ground floor for specialised retail and loading dock, 31 upper floors of commercial office space, and five levels of basement car parking. The GFA is 45,356.5 m^2. The average annual energy consumption was 6,134,401 kWh and emissions were 6,649,808 kg CO_2. The annual water consumption was 39,516 kL. The building's energy intensity was 135 kWh/m^2, 147 kg CO_2/m^2 emissions and 0.9 kL/m^2 of water consumption per year per GFA.

Significantly, the GFA of Building 2 is 2.3 times that of Building 1, and its average annual energy consumption and CO_2 emissions are approximately 25% and 31% lower than Buildings 1 and 3 respectively. It also clearly shows that the average annual energy consumption (kWh/m^2) per year of Building 2 is far less than that of Building 1. Building 3 has the biggest GFA of the three buildings, however annual energy consumption (kWh/m^2) was not much higher than Building 1 due to it having had an upgrade of electrical/power switchgears, recommission/tuning HVAC system and installation of internal blinds to windows to reduce heat gains or losses compared to Building 1. In water usage, Building 3 had the same annual water consumption per GFA as Building 2 at 0.9 kL/m^2 because it had upgraded with water-efficient devices and fixtures (see Section 8.4).

Table 8.1 Characteristics of the three case study buildings

Detail	Building 1	Building 2	Building 3
Age (years)	27	31	22
GFA (m^2)	17,682	40,089	45,356
Hours of occupancy (hours/week)	52.1	No record	52.9
Average annual energy consumption (kWh)	2,256,933	4,125,003	6,134,401
Average annual energy consumption per GFA (kWh/m^2)	128	103	135
Average annual emissions (kg CO_2)	2,528,224	4,501,961	6,649,808
Average annual emissions per GFA (kg CO_2/m^2)	143	112	147
Average annual water consumption (kL)	22,888	34,302	39,516
Average annual water consumption per GFA (kL/m^2)	1.3	0.9	0.9

8.3.2 Comparison of the SMOB with the Current Maintenance Practices in the Three Case Study Buildings

The current maintenance practices of the three case study buildings were analysed using the SMOB framework to identify what have been done and the savings achieved. The analysis of the three case study buildings has been done according to the three tier maintenance framework of the SMOB: upgrading maintenance, routine maintenance and ad hoc maintenance. The results are summarised in Tables 8.2.

From Table 8.2 some of the areas in the SMOB have already been dealt with in according to the maintenance records of the three projects. The table presents the realised savings according to the SMOB in terms of annual savings in cost, usage and CO_2 emissions for the three case study buildings.

With regards to upgrading (A) the maintenance records show that the three buildings have undertaken major upgrading of the HVAC systems only. Other upgrades include installation of BMCS, installation of light-motion sensors, and replacement of some energy efficient fittings and lighting in common areas. Only Building 3 had two minor upgrades to water-efficient devices and fixtures in 2010. However there have not been any other upgrades since then for the three buildings.

In routine maintenance (B), the three buildings satisfy almost all issues in the SMOB: maintenance schedules for monthly, quarterly, half-yearly and yearly performances. Routine maintenance includes regular cleaning, servicing and inspection of systems and equipment to prevent breakdown. Mostly, routine maintenance is on electrical systems, HVAC systems, water systems, waste disposal, and some work on lighting systems.

Ad hoc maintenance (C) for the three buildings includes inspection and repairs of breakdowns of systems and equipment. All three buildings have repair work on systems and equipment. Data analysis of the maintenance records for the three projects revealed that the electrical systems, HVAC systems, lighting systems and water systems commonly break down and require repairs.

Table 8.2 Annual savings realised by the SMOB from current maintenance practices for the three case study buildings

SMOB Issues		SMOB (Table 7.1) Annualised Capital Cost ($/m²)	SMOB (Table 7.1) Additional Annual Maint. Cost ($/m²)	Building 1 Annualised Capital Cost ($/m²)	Building 1 Additional Annual Maint. Cost ($/m²)	Building 1 Achieved Annual Savings in Upgrading/Improving Using the SMOB on Energy Cost [1] ($/m²)	Building 1 Achieved Annual Savings: Energy Uses [2] (kWh/m²)	Building 1 Achieved Annual Savings: CO_2 [3] ($kgCO_2/m^2$)	Building 2 Annualised Capital Cost ($/m²)	Building 2 Additional Annual Maint. Cost ($/m²)	Building 2 Achieved Annual Savings in Upgrading/Improving Using the SMOB on Energy Cost [1] ($/m²)	Building 2 Achieved Annual Savings: Energy Uses [4] (kWh/m²)	Building 2 Achieved Annual Savings: CO_2 [5] ($kgCO_2/m^2$)	Building 3 Annualised Capital Cost ($/m²)	Building 3 Additional Annual Maint. Cost ($/m²)	Building 3 Achieved Annual Savings in Upgrading/Improving Using the SMOB on Energy Cost [1] ($/m²)	Building 3 Achieved Annual Savings: Energy Uses [6] (kWh/m²)	Building 3 Achieved Annual Savings: CO_2 [7] ($kgCO_2/m^2$)
A. Upgrading																		
A.1 Energy Efficiency	A.1.1 Installing solar-boosted hot water systems	0.47	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A.1.2 Installing or upgrading BMCS	0.08	0.02	0.08	0.02	1.07	3.06	3.43	0.08	0.02	0.86	2.47	2.70	-	-	-	-	-
	A.1.3 Installing solar power systems per kW/m²	0.05	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A.1.4 Upgrading lifts and escalators	2.77	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A.1.5 Upgrading electrical/power switchgears	11.87	0	-	-	-	-	-	11.87	0	1.12	3.21	3.50	11.87	0	1.48	4.22	4.57
A.2 Indoor Climate	A.2.1 Recommissioning or tuning HVAC systems	0.30	0	0.30	0	3.77	10.77	12.06	-	-	-	-	-	0.30	0	3.99	11.41	12.37
	A.2.2 Upgrading to new technology HVAC systems	15.25	1.00	15.25	1.00	7.64	21.83	24.45	15.25	1.00	6.16	17.60	19.20	15.25	1.00	8.09	23.13	25.07
	A.2.3 Installing automatic sun shading to reduce heat gain or loss	31.73	1.96	-	-	-	-	-	-	-	-	-	-	31.73	1.96	4.05	11.56	12.54
A.3 Lighting Efficiency	A.3.1 Installing lighting motion sensors	0.43	0.05	0.43	0.05	1.19	3.40	3.80	0.43	0.05	0.96	2.74	2.99	0.43	0.05	1.26	3.60	3.90
	A.3.2 Replacing with LED lighting	6.19	0	6.19	0	0.45	1.29	1.45	6.19	0	0.36	1.04	1.14	6.19	0	0.48	1.37	1.49
	A.3.3 Installing automatic dimming lighting systems	6.12	1.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A.4 Environmental Materials	A.4.1 Upgrading internal finishes with eco materials	6.48	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A.5 Water Efficiency	A.5.1 Installing or upgrading water control sensors	1.65	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A.5.2 Installing or upgrading water-efficient devices and fixtures	3.99	0	-	-	-	-	-	-	-	-	-	-	3.99	0	0.07	0.21 [8]	0.23 [9]
	A.5.3 Reusing and recycling rainwater and grey or black water	6.75	1.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A.6 Waste Management	A.6.1 Providing breakdown waste disposal space	0.15	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B. Routine Maintenance																		
B.1 Periodic cleaning and servicing	B.1.1 Electrical systems	-	-	-	-	1.42	4.05	4.54	-	-	1.14	3.27	3.57	-	-	1.50	4.30	4.66
	B.1.2 HVAC systems	-	-	-	-	3.55	10.14	11.35	-	-	2.86	8.17	8.92	-	-	3.76	10.74	11.64
	B.1.3 Lighting systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.00	2.86	3.10
	B.1.4 Interior	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.1.5 Water systems	-	-	-	-	0.32	0.90	1.01	-	-	0.25	0.73	0.79	-	-	0.33	0.95	1.03
	B.1.6 Waste disposal space	-	-	-	-	0.24	0.68	0.76	-	-	0.19	0.54	0.59	-	-	0.25	0.72	0.78
B.2 Periodic inspecting to prevent breakdown	B.2.1 Electrical systems	-	-	-	-	0.95	2.70	3.03	-	-	0.76	2.18	2.38	-	-	1.00	2.86	3.10
	B.2.2 HVAC systems	-	-	-	-	2.37	6.76	7.57	-	-	1.91	5.45	5.95	-	-	2.51	7.16	7.76
	B.2.3 Lighting systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.2.4 Interior	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.2.5 Water systems	-	-	-	-	0.21	0.60	0.67	-	-	0.17	0.48	0.53	-	-	0.22	0.64	0.69
	B.2.6 Waste disposal system	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

SMOB Issues		SMOB (Table 7.1)		Building 1					Building 2					Building 3				
		Annualised Capital Cost	Additional Annual Maint. Cost	Annualised Capital Cost	Additional Annual Maint. Cost	Achieved Annual Savings in Upgrading/Improving Using the SMOB on			Annualised Capital Cost	Additional Annual Maint. Cost	Achieved Annual Savings in Upgrading/Improving Using the SMOB on			Annualised Capital Cost	Additional Annual Maint. Cost	Achieved Annual Savings in Upgrading/Improving Using the SMOB on		
						Energy Cost [1]	Energy Uses [2]	CO_2 [3]			Energy Cost [1]	Energy Uses [4]	CO_2 [5]			Energy Cost [1]	Energy Uses [6]	CO_2 [7]
		$/m²		$/m²			kWh /m²	$kgCO_2$ /m²	$/m²			kWh /m²	$kgCO_2$ /m²	$/m²			kWh /m²	$kgCO_2$ /m²
C. Ad Hoc Maintenance																		
C.1 Inspecting and repairing breakdowns	C.1.1 Electrical systems	-	-	-	-	0.92	2.64	2.96	-	-	0.75	2.13	2.32	-	-	0.98	2.80	3.03
	C.1.2 HVAC systems	-	-	-	-	2.31	6.60	7.40	-	-	1.86	5.32	5.81	-	-	2.45	7.00	7.58
	C.1.3 Lighting systems	-	-	-	-	-	-	-	-	-	0.50	1.42	1.55	-	-	0.65	1.87	2.02
	C.1.4 General repairing/ restoring to interior	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C.1.5 Water systems	-	-	-	-	0.26	0.73	0.82	-	-	0.21	0.59	0.65	-	-	0.27	0.78	0.84
	C.1.6 Waste disposal system	-	-	-	-	0.21	0.59	0.66	-	-	-	-	-	-	-	-	-	-
	Upgrading:	**94.28**	**6.21**	**22.25**	**1.07**	**14.12**	**40.35**	**45.20**	**33.82**	**1.07**	**9.47**	**27.05**	**29.53**	**69.76**	**3.02**	**19.43**	**55.50**	**60.16**
	Routine maintenance:	**0**	**0**	**0**	**0**	**9.04**	**25.83**	**28.93**	**0**	**0**	**7.29**	**20.82**	**22.72**	**0**	**0**	**10.58**	**30.23**	**32.77**
	Ad hoc maintenance:	**0**	**0**	**0**	**0**	**3.70**	**10.56**	**11.83**	**0**	**0**	**3.31**	**9.46**	**10.33**	**0**	**0**	**4.35**	**12.44**	**13.48**
	Total:	**94.28**	**6.21**	**22.25**	**1.07**	**26.86**	**76.74**	**85.96**	**33.82**	**1.07**	**20.07**	**57.34**	**62.58**	**69.76**	**3.02**	**34.36**	**98.17**	**106.42**
	% of SMOB	**100**	**100**	**23.60**	**17.22**	**60.30**	**60.12**	**60.12**	**35.87**	**17.22**	**55.29**	**55.72**	**55.72**	**73.99**	**48.57**	**73.13**	**72.59**	**72.59**

Note:
[1] $0.35 (Energy price adapted from Synergy 2016) x Annual savings on energy consumption of buildings (kWh/m²)
[2] 2,256,933kWh/year (total of annual energy consumption of Building 1) x Percentage (%) of savings (Table 7.2) / 17,682m² (GFA of Building 1)
[3] 2,528,224 kg CO_2/year (total of emissions of Building 1) x Percentage (%) savings (Table 7.2) / 17,682m² (GFA of Building1)
[4] 4,125,003kWh/year (total of annual energy consumption of Building 2) x Percentage (%) of savings (Table 7.2) / 40,089m² (GFA of Building 2)
[5] 4,501,961 kg CO_2/year (total of emissions of Building 2) x Percentage (%) savings (Table 7.2) / 40,089m² (GFA of Building 2)
[6] 6,134,401kWh/year (total of annual energy consumption of Building 3) x Percentage (%) of savings (Table 7.2) / 45,356m² (GFA of Building 3)
[7] 6,649,808 kg CO_2/year (total of emissions of Building 3) x Percentage (%) savings (Table 7.2) / 45,356m² (GFA of Building 3)
[8] 32,008kWh (Table 8.3) x Percentage (%) of savings (Table 7.2) / 45,356m² (GFA of Building 3)
[9] 33,928 kg CO_2 (Table 8.3) x Percentage (%) of savings (Table 7.2) / 45,356m² (GFA of Building 3)

In the SMOB to establish the annual savings achieved by the three case study buildings in their current maintenance practices, it is assumed that when a system or component has been improved or upgraded, it has achieved a savings which is denoted by a 'number' in Table 8.2. For example, all three case study buildings had upgraded to new technology of HVAC systems (A.2.2) that lead to a savings of 17.1% (refer to Table 7.1). Other systems or components which have not been improved or upgraded under current maintenance practices will be considered as not having achieved any savings, and are shown by the symbol '–'.

As presented in Table 8.2, in upgrading (A), there are three maintenance activities currently undertaken by all three buildings: upgrading to new technology for HVAC systems (A.2.2), installing lighting motion sensors (A.3.1) and replacing with LED lighting (A.3.2). The other upgrading includes:

- Buildings 1 upgraded BMCS (A.1.2) and recommissioning or tuning HVAC systems (A.2.1)

- Building 2 also upgraded BMCS (A.1.2) and electrical/power switchgears (A.1.5)

- Building 3 upgraded electrical/power switchgears (A.1.5) and has installed internal shadings to windows to reduce heat gain or loss through the building (A.2.3).

With regards to improving Water Efficiency (A.5), none of the three buildings have performed any major upgrades to water systems. Only Building 3 has installed flux valves to water closets (A.5.2) that has incurred an annual water savings of about 30% (see Table 7.1). With regards to Waste Management (A.6) no record of upgrading was obtained from the three buildings.

In routine (B) and ad hoc maintenance (C), all three buildings are similar. They mostly concentrate on servicing the HVAC systems, electrical/power switchgears, water systems, and waste disposal systems. In operation, equipment breakdown cannot be avoided; however, it can be reduced when a good maintenance program is in place to save large costs in operation and maintenance.

Table 8.2 also summaries estimated additional annual maintenance costs per square metre of GFA ($/m^2) and savings of energy cost ($/m^2), energy uses (kWh/m^2), and CO_2 emissions (kg CO_2/m^2) of the three buildings in the current maintenance practices as compared to the SMOB. These costs and savings presented as achievements realised by the SMOB in the current maintenance practices of the three case study buildings.

In assessing the three case study buildings, the additional annual maintenance costs ($/m^2) for keeping the systems/equipment function were obtained from Table 7.1 in Chapter 7. As discussed in Section 7.4.1(a), Chapter 7 the annual maintenance costs established in the Table 7.2 are additional costs when upgrading in according to the SMOB.

The potential annual savings on annual energy cost ($/m^2) is calculation from a current energy price approximately $0.35 per kWh adapted from Synergy (2016) multiplied with annual savings on energy consumption of the case study buildings (kWh/m^2) as shown in Table 8.2.

The estimated annual savings on energy costs and consumptions, and CO_2 emissions were computed in according to the current annual energy and water consumptions, and CO_2 emissions of the three year record from the three case study buildings and has been expressed per GFA of each building (refer to Table 8.1).

Water consumption incurs the use of energy and emits CO_2. The work of Plappally and Lienhard (2012) has been used to estimate energy consumptions relating to water usages (A5) in the buildings. According to Plappally and Lienhard (2012) to supply 1 kL of water there is a need of approximately 0.8 kWh of energy to treat and convey the water to the end user. This figure was adapted to convert the water consumptions into kWh on water-related energy consumptions in the study. To calculate the CO_2 emissions, according to Lecamwasam, Wilson and Chokolich (2012), 1 kWh of energy generation/usage emits approximately 1.1 kg CO_2 emission. Therefore, for calculating savings on equivalent energy consumptions and CO_2 emissions on water usage in the buildings, the following figures are used:

- 1 kL of water consumption ≈ 0.8 kWh of energy consumption
- 1 kWh of energy consumption ≈ 1.1 kg CO_2 emissions

Table 8.3 summaries the conversion of water usages to water-related energy consumptions and CO_2 emissions of the three case buildings. From the table, Building 1 consumed 22,888 kL of water annually. This figure was converted to be approximately 18,539 kWh on water-related energy consumption and 19,652 kg CO_2 emissions. Building 2 consumed 34,302 kL of water per year that was converted to be approximately 27,785 kWh water-related energy consumption and 29,452 kg CO_2 emissions. Building 3 consumed 39,516 kL of water per annum that was converted to be approximately 32,008 kWh water-related energy consumption and 33,928 kg CO_2 emissions. These figures were used to calculate the savings on energy consumptions and CO_2 emissions related to water usages in Table 8.3.

Table 8.3 Convert of water usages to energy consumptions and CO_2 emissions of the three case study buildings

Building ID	Water Usages [1] (kL)	Water-related Energy Consumptions [2] (kWh)	Water-related CO_2 Emissions [3] (kg CO_2)
Building 1	22,888	18,539	19,652
Building 2	34,302	27,785	29,452
Building 3	39,516	32,008	33,928

Notes: [1] Annual water usage of buildings derived from Table 8.1
[2] Column 2 x 0.81kWh (Adapted from Plappally & Lienhard 2012)
[3] Column 2 x 1.06 kg CO_2 (Adopted from Lecamwasam, Wilson & Chokolich 2012)

In the calculation for savings on energy consumptions and CO_2 emissions relating to waste generation (A6), the process is adapted data from Resource NSW (2002) and Terry and Moore (2008). Generally, office buildings generate 4 kg/m^2 of waste annually. This is equivalent to approximately 16 kWh/m^2 of energy consumption and approximately 17 kg CO_2/m^2 emissions per annum (Resource NSW 2002; Terry & Moore 2008). These figures are adopted for the calculation of savings on waste-related energy consumptions and CO_2 emissions related to waste disposal of the three case study buildings in Table 8.3.

From Table 8.2, in upgrading Building 3 provides highest savings of approximately \$19/m^2 on energy costs, 56 kWh/m^2 on energy consumptions and 60 kg CO_2/m^2 on CO_2 emissions. While Building 1 is approximately \$14/m^2, 40 kWh/m^2 and 45 kg CO_2/m^2; and Building 2 is approximately \$9/m^2, 27 kWh/m^2 and 30 kg CO_2/m^2 respectively for energy costs, energy use and CO_2 emissions.

In improving efficient uses of water, Buildings 1 and 2 have not performed by upgrading; while Building 3 has installed flux valves to water closets that produce savings on annual water costs of approximately \$0.1/m^2, 0.2 kWh/m^2 on energy cost and consumption, and 0.2 kg CO_2/m^2 emissions. In routine and ad hoc maintenances, there are similar savings achieved by the three case study buildings.

Table 8.2 also compares the total costs and savings realised for each building with the SMOB (Columns 5 to 19). The achievements realised by the SMOB of current annual maintenance costs are approximately 17% for both buildings 1 and 2, and 49% for Building 3. With regards to achieving savings on energy costs Building 3 has the highest of 73% of the SMOB, followed by Building 1 of 60% and Building 2 of 55%. The achieved savings on energy consumptions and CO_2 emissions Building 3 has the highest of 73% and next are Building 1 of 60% and Building 2 of 56%. As derived from Table 8.2 there are further potential savings yet to be maximised as presented in the SMOB which will be analysed and discussed in the next section.

8.4 Further Potential Savings for the Case Study Buildings Using the SMOB

This section presents further potential annual savings on energy costs and consumption, and CO_2 emissions if the SMOB is adopted to improve the maintenance practices demonstrated using the three case study buildings. Throughout the section, all calculations are based on figures developed in Table 7.1 (Chapter 7). As per the estimates in Section 8.3.2 Table 8.2, the estimated annual savings on energy costs, energy consumption and CO_2 emissions are computed using the same approach as in Table 8.2 according to the current annual energy and water consumptions, and CO_2 emissions recorded from the three buildings as shown in Table 8.1.

As discussed in the previous section and from Table 8.2, Buildings 1 and 2 only achieved five upgrading activities each, whilst Building 3 satisfied seven. Only Building 3 has done some upgrading to water efficiency, whilst none of the buildings have done any upgrade to waste management. Even though the three buildings had achieved some savings on annual energy and water consumption, they can achieve further potential savings by improving other activities as identified in the SMOB that were not undertaken.

Similarly, according to the SMOB the three buildings have done some work in routine and ad hoc maintenance. However, there are some further potential savings for the three buildings when addressing the missing issues as identified in the SMOB. By applying the SMOB in maintaining existing buildings, further performances can be achieved in potentially savings annual energy consumption and also CO_2 emissions.

Table 8.4 presents further potential annual savings which these three case study buildings can achieve using the SMOB. Systems or equipment marked as '–' have already been done in the current maintenance practices and included in Table 8.2. Therefore they are not included in the calculation here in Table 8.4.

Table 8.4 presents annualised capital costs and additional maintenance costs for upgrading which have been derived from Table 7.1 in Chapter 7. The three case studies – with current ages from 22 to 31 years old – are all due for a major refurbishment, within the next few years. This means that all essential items with life spans of 15 and 30 years will have to be replaced in this process. Since they have to be replaced anyhow, there is no additional cost for their inbuilt energy efficiency so that the effective opportunity cost of the new items are zero, independent of their nominal capital costs. This goes for lifts and escalators (A.1.4), hot water systems (A.1.1), new HVAC systems (A.2.2) etc.

The costs listed in Table 8.4 are gross costs of installing each item. Where the annualised capital cost plus the annual maintenance costs are less than the annual savings in energy costs, the replacement will be profitable, independent of the state of repair of the replaced items. Where the replaced items are at the end of their life span, the investments need to be done even if the capital cost is higher than the savings in costs. However, when such items to be replaced are still functioning and have years left or their life span, the opportunity costs must be calculated individually.

Other items on the lists are delivering new functions rather than replacing existing, such as for instance automatic sun shading (A.2.3). In these cases, the total capital cost, added to the annual maintenance costs must be less than the annual savings to justify the investment.

To illustrate this, for Building 1, installing solar-boosted hot water system (A.1.1) with an annual cost of \$0.47 (annualised capital cost) plus \$0.20 annual maintenance cost for a total annual cost of \$0.67 with savings of \$2.68 would always be profitable; upgrading lifts and escalators (A.1.4) with total annual costs of \$2.77 and savings of \$1.07 will be profitable only at the end of the life of the existing installation while automatic sun shading (A.2.3) with total cost of \$33.69 (\$31.73+\$1.96) and savings of \$3.82 will not be profitable as a new or replacement investment.

From Table 8.4 the additional maintenance costs for the three buildings are approximately 83% for both Buildings 1 and 2, and 51% for Building 3 of the SMOB. With regards to potential savings on energy costs Building 2 has the highest of 45% of the SMOB and followed by Building 1 of 40% and Building 3 of 27%. With regards to potential savings on energy consumptions and CO_2 emissions Building 2 has the highest of 44% and next are Building 1 of 40% and Building 3 of 27%.

Table 8.4 Potential further annual savings using SMOB in upgrading or improving for the three case study buildings

SMOB Issues		SMOB (Table 7.1)		Building 1					Building 2					Building 3				
		Annualised Capital Cost	Additional Annual Maint. Cost	Annualised Capital Cost	Additional Annual Maint. Cost	Potential Annual Savings in Upgrading/Improving Using the SMOB on: Energy Cost [1]	Energy Uses [2]	CO_2 [3]	Annualised Capital Cost	Additional Annual Maint. Cost	Potential Annual Savings in Upgrading/Improving Using the SMOB on: Energy Cost [1]	Energy Uses [4]	CO_2 [5]	Annualised Capital Cost	Additional Annual Maint. Cost	Potential Annual Savings in Upgrading/Improving Using the SMOB on: Energy Cost [1]	Energy Uses [6]	CO_2 [7]
		$/m^2		$/m^2			kWh/m^2	kgCO$_2$/m^2	$/m^2			kWh/m^2	kgCO$_2$/m^2	$/m^2			kWh/m^2	kgCO$_2$/m^2
A. Upgrading																		
A.1 Energy Efficiency	A.1.1 Installing solar-boosted hot water systems	0.47	0.20	0.47	0.20	2.68	7.66	8.58	0.47	0.20	2.16	6.17	6.74	0.47	0.20	2.84	8.12	8.80
	A.1.2 Installing or upgrading BMCS	0.08	0.02		-	-	-	-		-	-	-	-	0.08	0.02	1.14	3.25	3.52
	A.1.3 Installing solar power systems per kW/m^2	0.05	0.05	0.05	0.05	1.39	3.98	4.46	0.05	0.05	1.12	3.21	3.50	0.05	0.05	1.48	4.22	4.57
	A.1.4 Upgrading lifts and escalators	2.77	0	2.77	0	1.07	3.06	3.43	2.77	0	0.86	2.47	2.70	2.77	0	1.14	3.25	3.52
	A.1.5 Upgrading electrical/power switchgears	11.87	0	11.87	0	1.39	3.98	4.46	-	-	-	-	-	-	-	-	-	-
A.2 Indoor Climate	A.2.1 Recommissioning or tuning HVAC systems	0.30	0	-	-	-	-	-	0.30	0	3.04	8.68	9.47	-	-	-	-	-
	A.2.2 Upgrading to new technology HVAC systems	15.25	1.00	-	-	-	-	-		-	-	-	-	-	-	-	-	-
	A.2.3 Installing automatic sun shading to reduce heat gain or loss	31.73	1.96	31.73	1.96	3.82	10.91	12.23	31.73	1.96	3.08	8.80	9.60	-	-	-	-	-
A.3 Lighting Efficiency	A.3.1 Installing lighting motion sensors	0.43	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A.3.2 Replacing with LED lighting	6.19	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	A.3.3 Installing automatic dimming lighting systems	6.12	1.28	6.12	1.28	1.70	4.85	5.43	6.12	1.28	1.37	3.91	4.27	6.12	1.28	1.80	5.14	5.57
A.4 Environmental Materials	A.4.1 Upgrading internal finishes with eco materials	6.48	0	6.48	0	0.36	1.02	1.14	6.48	0	0.29	0.82	0.90	6.48	0	0.38	1.08	1.17
A.5 Water Efficiency	A.5.1 Installing or upgrading water control sensors	1.65	0.20	1.65	0.20	0.03	0.09 [8]	0.09 [9]	1.65	0.20	0.02	0.06 [10]	0.06 [11]	1.65	0.20	0.02	0.06 [12]	0.06 [13]
	A.5.2 Installing or upgrading water-efficient devices and fixtures	3.99	0	3.99	0	0.11	0.32 [8]	0.34 [9]	3.99	0	0.07	0.21 [10]	0.22 [11]	-	-	-	-	-
	A.5.3 Reusing and recycling rainwater and grey or black water	6.75	1.41	6.75	1.41	0.07	0.20 [8]	0.22 [9]	6.75	1.41	0.05	0.14 [10]	0.14 [11]	6.75	1.41	0.05	0.14 [12]	0.15 [13]
A.6 Waste Management	A.6.1 Providing breakdown waste disposal space	0.15	0.03	0.15	0.03	2.16	6.16 [14]	6.53 [15]	0.15	0.03	2.16	6.16 [14]	6.53 [15]	0.15	0.03	2.16	6.16 [14]	6.53 [15]
B. Routine Maintenance																		
B.1 Periodic cleaning and servicing	B.1.1 Electrical systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.1.2 HVAC systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.1.3 Lighting systems	-	-	-	-	0.95	2.70	3.03	-	-	0.76	2.18	2.38	-	-	-	-	-
	B.1.4 Interior	-	-	-	-	0.24	0.68	0.76	-	-	0.19	0.54	0.59	-	-	0.25	0.72	0.78
	B.1.5 Water systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.1.6 Waste disposal space	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B.2 Periodic inspecting to prevent breakdown	B.2.1 Electrical systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.2.2 HVAC systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.2.3 Lighting systems	-	-	-	-	0.63	1.80	2.02	-	-	0.51	1.45	1.59	-	-	0.67	1.91	2.07
	B.2.4 Interior	-	-	-	-	0.16	0.45	0.50	-	-	0.13	0.36	0.40	-	-	0.17	0.48	0.52
	B.2.5 Water systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	B.2.6 Waste disposal system	-	-	-	-	0.16	0.45	0.50	-	-	0.13	0.36	0.40	-	-	0.17	0.48	0.52

SMOB Issues		SMOB (Table 7.1)		Building 1					Building 2					Building 3				
		Annualised Capital Cost	Additional Annual Maint. Cost	Annualised Capital Cost	Additional Annual Maint. Cost	Potential Annual Savings in Upgrading/Improving Using the SMOB on: Energy Cost [1]	Energy Uses [2]	CO_2 [3]	Annualised Capital Cost	Additional Annual Maint. Cost	Potential Annual Savings in Upgrading/Improving Using the SMOB on: Energy Cost [1]	Energy Uses [4]	CO_2 [5]	Annualised Capital Cost	Additional Annual Maint. Cost	Potential Annual Savings in Upgrading/Improving Using the SMOB on: Energy Cost [1]	Energy Uses [6]	CO_2 [7]
		$/m²		$/m²			kWh /m²	$kgCO_2$ /m²	$/m²			kWh /m²	$kgCO_2$ /m²	$/m²			kWh /m²	$kgCO_2$/m²
C. Ad Hoc Maintenance																		
C.1 Inspecting and repairing breakdowns	C.1.1 Electrical systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C.1.2 HVAC systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C.1.3 Lighting systems	-	-	-		0.62	1.76	1.97	-	-	-	-	-	-	-	-	-	-
	C.1.4 General repairing/ restoring to interior	-	-	-	-	0.15	0.44	0.49	-	-	0.12	0.35	0.39	-	-	0.16	0.47	0.51
	C.1.5 Water systems	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C.1.6 Waste disposal system	-	-	-	-	-	-	-	-	-	0.17	0.47	0.52	-	-	0.22	0.62	0.67
	Upgrading:	**94.28**	**6.21**	**72.03**	**5.14**	**14.78**	**42.24**	**46.91**	**60.46**	**5.14**	**14.22**	**40.63**	**44.14**	**24.52**	**3.20**	**10.99**	**31.41**	**33.89**
	Routine maintenance:	**0**	**0**	**0**	**0**	**2.13**	**6.08**	**6.81**	**0**	**0**	**1.72**	**4.90**	**5.35**	**0**	**0**	**1.25**	**3.58**	**3.88**
	Ad hoc maintenance:	**0**	**0**	**0**	**0**	**0.77**	**2.20**	**2.47**	**0**	**0**	**0.29**	**0.83**	**0.90**	**0**	**0**	**0.38**	**1.09**	**1.18**
	Total:	**94.28**	**6.21**	**72.03**	**5.14**	**17.68**	**50.52**	**56.19**	**60.46**	**5.14**	**16.23**	**46.36**	**50.39**	**24.52**	**3.20**	**12.63**	**36.08**	**38.95**
	% of SMOB	**100**	**100**	**76.40**	**82.78**	**39.70**	**39.88**	**39.88**	**64.13**	**82.78**	**44.71**	**44.28**	**44.28**	**26.01**	**51.43**	**26.87**	**27.41**	**27.41**

Note:
[1] $0.35 (Energy price adapted from Synergy 2016) x Annual savings on energy consumption of buildings (kWh/m²)
[2] 2,256,933 kWh/year (total of annual energy consumption of Building 1) x Percentage (%) of savings (Table 7.2) / 17,682m2 (GFA of Building 1)
[3] 2,528,224 kg CO_2/year (total of emissions of Building 1) x Percentage (%) savings (Table 7.2) / 17,682m² (GFA of Building 1)
[4] 4,125,003 kWh/year (total of annual energy consumption of Building 2) x Percentage (%) of savings (Table 7.2) / 40,089m² (GFA of Building 2)
[5] 4,501,961 kg CO_2/year (total of emissions of Building 2) x Percentage (%) savings (Table 7.2) / 40,089m2 (GFA of Building 2)
[6] 6,134,401 kWh/year (total of annual energy consumption of Building 3) x Percentage (%) of savings (Table 7.2) / 45,356m² (GFA of Building 3)
[7] 6,649,808 kg CO_2/year (total of emissions of Building 3) x Percentage (%) savings (Table 7.2) / 45,356m² (GFA of Building 3)
[8] 18,539 kWh (Table 8.3) x Percentage (%) of savings (Table 7.2) / 17,682m² (GFA of Building 1)
[9] 19,652 kg CO_2 (Table 8.3) x Percentage (%) of savings (Table 7.2) / 17,682m² (GFA of Building 1)
[10] 27,785 kWh (Table 8.3) x Percentage (%) of savings (Table 7.2) / 40,089m² (GFA of Building 2)
[11] 29,452 kg CO_2 (Table 8.3) x Percentage (%) of savings (Table 7.2) / 40,089m² (GFA of Building 2)
[12] 32,008 kWh (Table 8.3) x Percentage (%) of savings (Table 7.2) / 45,356m² (GFA of Building 3)
[13] 33,928 kg CO_2 (Table 8.3) x Percentage (%) of savings (Table 7.2) / 45,356m² (GFA of Building 3)
[14] 16.44 kWh/m² Waste related-energy consumption (Section 8.3.2, p. 13) x Percentage (%) of savings (Table 7.2)
[15] 17.72 kg CO_2/m² Waste related-CO_2 emissions (Section 8.3.2, p. 13) x Percentage (%) of savings (Table 7.2)

8.4.1 Building 1

In improving energy efficiency for Building 1, there are seven items in Table 8.4 where potential savings can be achieved if addressed. The potential savings on adopting the SMOB will lead to savings in the range approximately \$0.03–3.8/m^2, 0.1–11 kWh/m^2 and 0.1–12 kg CO_2/m^2 respectively for energy cost, energy consumption and CO_2 emissions.

The total annualised capital cost for the seven upgrading items in SMOB in improving energy efficiency is estimated to approximately \$59.5/m^2 or 63% of total annualised capital cost. From this, the annualised capital costs for installing solar-boosted hot water systems are approximately \$0.5/m^2 (A.1.1); installing solar power systems, \$0.05/m^2 (A.1.3); upgrading lifts and escalators, \$2.8/m^2 (A.1.4); upgrading electrical/power switchgears, \$11.9/m^2 (A.1.5); installing automatic sun shading to reduce heat gain or loss, \$31.7/m^2 (A.2.3); installing automatic dimming lighting systems, \$6.1/m^2 (A.3.3); and upgrading internal finishes with eco materials, \$6.5/m^2 (A.4.1).

The highest savings on energy use is installing automatic sun shading to reduce heat gains or losses (A.2.3), or replacing single with double-layer glass or installing blinds that will provide annual savings on energy consumption and CO_2 emissions of approximately 9% (Table 7.1) with an annualised capital cost of \$31.7/m^2. The additional annual maintenance cost of this work is estimated to approximately \$2/m^2 and the savings on energy cost is estimated to approximately \$3.8/m^2, 11 kWh/m^2 of energy consumption and 12 kg CO_2/m^2 on emissions.

Installing a solar-boosted hot water system (A1.1) would provide a savings on energy consumption and CO_2 emissions of approximately 6% (Table 7.1) with an annualised capital cost of \$0.5/m^2. The additional annual maintenance cost of this work is estimated to approximately \$0.2/m^2 and the savings on energy cost is estimated to approximately \$2.7/m^2, 8 kWh/m^2 on energy consumption and 9 kg CO_2/m^2 on CO_2 emissions. Upgrades of lifts and escalators (A.1.4) will provide annual savings of approximately 2% (Table 7.2) with an annualised capital cost of \$2.8/m^2, and the savings on energy cost are estimated to approximately \$1.1/m^2 with no additional annual maintenance cost, also approximately 3 kWh/m^2 on energy consumption and 3 kg CO_2/m^2 on CO_2 emissions.

The least savings is upgrading internal finishes with eco-materials (A.4.1) will provide annual savings of approximately 1% (Table 7.1) with an annualised capital cost of $\$6.5/m^2$, and the savings on energy cost are estimated to approximately $\$0.4/m^2$ with also no additional annual maintenance cost, from this savings approximately 1 kWh/m^2 on energy consumption and 1 kg CO_2/m^2 on emissions would be achieved.

In improving water efficiency, installing or upgrading water efficient devices and fixtures (A.5.2) can provide the highest savings of approximately 30% on water consumption (from Table 7.2) with an annualised capital cost of $\$4/m^2$. There is no additional annual maintenance cost and savings on energy cost are estimated approximately $\$0.1/m^2$. This can provide savings approximately 0.3 kWh/m^2 on energy consumption and 0.3 kg CO_2/m^2 on emissions. Reusing and recycling rainwater and grey or black water (A.5.3) can provide savings of approximately 20% on water consumption with annualised capital costs of $\$6.8/m^2$ and additional annual maintenance cost and savings on energy cost estimated to approximately $\$1.4/m^2$ and $\$0.1/m^2$ respectively. From this upgrading/improving savings of approximately 0.2 kWh/m^2 on energy consumption and 0.2 kg CO_2/m^2 on emissions can be achieved. The potential savings on annual energy cost in installing or upgrading water control sensors (A.5.1) is approximately 8% with an annualised capital cost of $\$1.7/m^2$ and additional annual maintenance cost approximately $\$0.2/m^2$. This upgrading/improving can provide savings approximately $\$0.03/m^2$ on energy cost, 0.1 kWh/m^2 on energy consumption and 0.1 kg CO_2/m^2 on emissions.

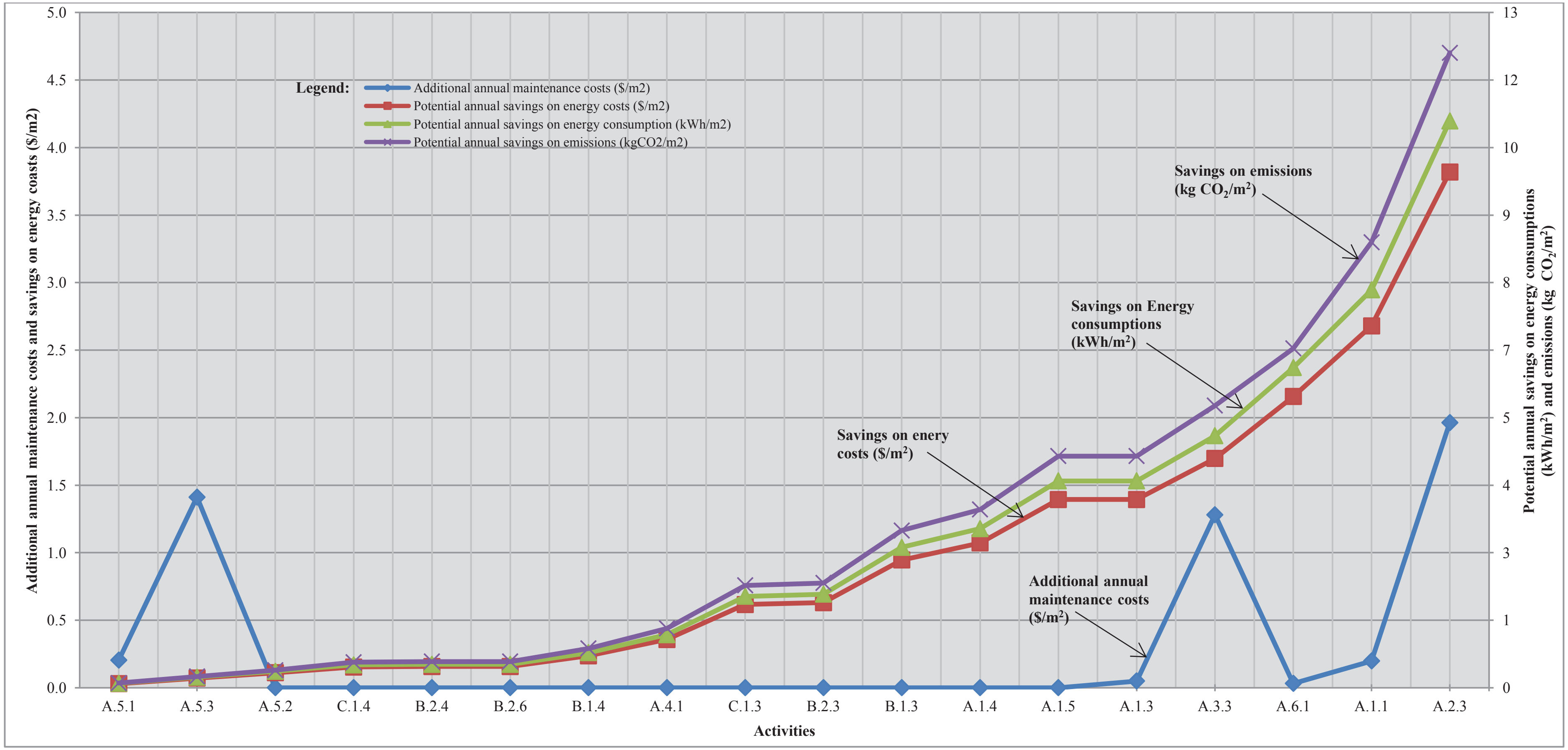
In waste management, providing breakdown waste disposal space (A.6.1) can reach a savings approximately 38% on waste disposal (from Table 7.1) with an annualised capital cost of $\$0.2/m^2$. This can provide savings approximately $\$2.2/m^2$ on energy cost, 6 kWh/m^2 on energy consumption and 7 kg $CO2/m^2$ on emissions; whist the additional annual maintenance cost is estimated to approximately $\$0.03/m^2$.

In routine maintenance of cleaning (B.1.3 and B.1.4) and periodic inspection (B.2.3, 2.4 and 2.6) can provide further savings of approximately $\$2.1/m^2$, 6 kWh/m^2 and 7 kg CO_2/m^2 on energy cost, use and CO_2 emissions. In ad hoc maintenance, inspecting and repairing the lighting systems (C.1.3) and the interior (C.1.4) will provide savings of approximately \$0.8/m^2, 2 kWh/m^2 and 2 kg CO_2/m^2 on energy cost, use and CO_2 emissions.

The annual potential savings that can be achieved in Building 1 are also illustrated in Figure 8.1. The figure presents the potential annual savings that can be achieved by upgrading activities as identified in the SMOB which have not been performed in the current maintenance practice of the three buildings. The figure presents four trends which denote for annual maintenance costs per \$/m^2 (blue line), annual savings on energy costs per \$/m^2 (red line), annual savings on energy consumption per kWh/m^2 (green line) and annual savings on CO_2 emissions per kg CO_2/m^2 (purple line). The horizontal axis (activities) presents systems/equipment which can be improved or upgraded. The left vertical axis presents additional annual maintenance costs and potential annual savings on energy costs (\$/m^2) which range from 0–\$5/m^2. The right vertical axis denotes potential annual savings on energy consumption (kWh/m^2) and annual savings on CO_2 emissions (kg CO_2/m^2). The trends are presented with upward lines.

From the Figure 8.1 installations for reusing and/or recycling rainwater and grey or blackwater (A.5.3) would provide a saving on annual energy cost approximately \$0.1/m^2 (red line presented on the left vertical axis) and the savings on energy consumption and CO_2 emissions is low approximately 0.2 kWh/m^2 and 0.2 kg CO_2/m^2 (green and purple lines presented on the right vertical axis). Upgrading lifts and escalators (A.1.4) provides higher savings on both energy consumptions and CO_2 emissions approximately 3 kWh/m^2 and 3 kg CO_2/m^2 (green and purple lines presented on the right vertical axis), the savings on energy costs is approximately \$1.1/m^2 and no additional annual maintenance cost. The highest savings on energy consumptions and CO_2 emissions for Building 1 are installing an automatic sun shading to reduce heat gain or loss in the building (A.2.3) that saves approximately 11 kWh/m^2 and 12 kg CO_2/m^2 (green and purple lines presented on the right vertical axis). The savings on annual energy cost is also better than improving/upgrading other systems in this assessment, approximately \$3.8/m^2 and the additional annual maintenance cost is approximately \$2/m^2 (red and blue lines presented on the left vertical axis).

Figure 8.1 Potential annual savings in upgrading for Building 1using the SMOB



Note:

A.1.1 Installing solar-boosted hot water systems
A.1.3 Installing solar power systems per kW/m2
A.1.4 Upgrading lifts and escalators
A.1.5 Upgrading electrical/power switchgears
A.2.3 Installing automatic sun shading to reduce heat gain or loss
A.3.3 Installing automatic dimming lighting systems
A.4.1 Upgrading internal finishes with eco materials
A.5.1 Installing or upgrading water control sensors
A.5.2 Installing or upgrading water efficient devices and fixtures
A.5.3 Reusing and recycling rainwater and grey or black water
A.6.1 Providing breakdown waste disposal space
B.1.3 Periodic cleaning and servicing to lighting systems
B.1.4 Periodic cleaning and servicing to interior
B.2.3 Periodic inspecting to prevent breakdown lighting systems
B.2.4 Periodic inspecting to prevent breakdown to interior
B.2.6 Periodic inspecting to prevent breakdown waste disposal system
C.1.3 Inspecting and repairing breakdowns lighting systems
C.1.4 Inspecting and repairing/restoring breakdowns to interior

8.4.2 Building 2

Table 8.4 shows the potential annual savings which Building 2 can achieve using the SMOB. All calculations are done as for Building 1. Installing automatic sun shading to reduce heat gain or loss (A.2.3) will provide the same high rate of annual savings on energy consumption and CO_2 emissions approximately 9% (from Table 7.1). The additional annual maintenance cost of this work is estimated approximately \$2/m^2 and savings are estimated approximately \$3.1/m^2 on annual energy costs, and approximately 9 kWh/m^2 on energy consumption and 10 kg CO_2/m^2 on emissions.

Upgrading internal finishes with eco-materials (A.4.1) will also provide annual savings of approximately 1%, and 1 kWh/m^2 on energy consumption and 1 kg CO_2/m^2 on emissions, and the savings on annual energy costs are estimated \$0.3/m^2 and no additional annual maintenance cost. Upgrades of lifts and escalators (A.1.4) will also provide annual savings approximately 2%, and the savings are estimated as approximately \$0.9/m^2 and no additional annual maintenance cost, and also approximately 2 kWh/m^2 on energy consumption and 3 kg CO_2/m^2 on emissions can be achieved.

Like Building 1, the highest savings in energy use is gained by installing automatic sun shading to reduce heat gains or losses (A.2.3) or replacing single with double-layer glass or internal blinds that will provide a savings of approximately 9% on energy consumption. Next are recommissioning or tuning the HVAC system (A.2.1) to provide a savings of approximately 8%, and installing automatic dimming lighting systems (A.3.3) to provide a savings of approximately 4% on energy consumption (refer to Table 7.1, Chapter 7).

The total annualised capital cost for the upgrading of the seven items in the SMOB to improve energy efficiency is estimated to approximately \$48/m^2 or 51% of the total. From this, the annualised capital costs for installing solar-boosted hot water systems are approximately \$0.5/m^2 (A.1.1); installing solar power systems, \$0.05/m^2 (A.1.3); upgrading lifts and escalators, \$2.8/m^2 (A.1.4); recommissioning or tuning HVAC systems, \$0.3/m^2 (A.2.1); installing automatic sun shading to reduce heat gain or loss, \$31.8/m^2 (A.2.3); installing automatic dimming lighting systems, \$6.1/m^2 (A.3.3); and upgrading internal finishes with eco materials, \$6.5/m^2 (A.4.1).

Improving water efficiency, installing or upgrading water efficient devices and fixtures (A.5.2) can provide a highest savings of approximately 30% on water consumption. As for Building 1, savings on energy cost are estimated to be approximately \$0.1/m^2 and no additional annual maintenance cost. This can provide savings of approximately 0.2 kWh/m^2 on energy consumption and 0.2 kg CO_2/m^2 on emissions. Reusing and recycling rainwater and grey or black water (A.5.3) can provide savings of approximately 20% on water consumption for which the additional annual maintenance cost and savings on energy cost are estimated to be approximately \$1.4/m^2 and \$0.1/m^2 respectively. From this upgrading/improving savings of approximately 0.1 kWh/m^2 on energy consumption and 0.1 kg CO_2/m^2 on emissions can be achieved. The potential savings on annual energy cost in installing or upgrading water control sensors (A.5.1) is approximately 8% with additional annual maintenance cost approximately \$0.2/m^2. This upgrading/improving can provide savings approximately \$0.02/m^2 on energy cost, 0.1 kWh/m^2 on energy consumption and 0.1 kg CO_2/m^2 on emissions.

Same as for Building 1, the total annualised capital cost for improving water efficiency is estimated to approximately \$12.4/m^2 or 13% of total annualised capital cost of the SMOB. Of this, the annualised capital costs for installing or upgrading water control sensors are approximately \$1.7/m^2 (A.5.1); installing or upgrading water-efficient devices and fixtures, \$4/m^2 (A.5.2); and reusing and recycling rainwater and grey or black water, \$6.8/m^2 (A.5.3).

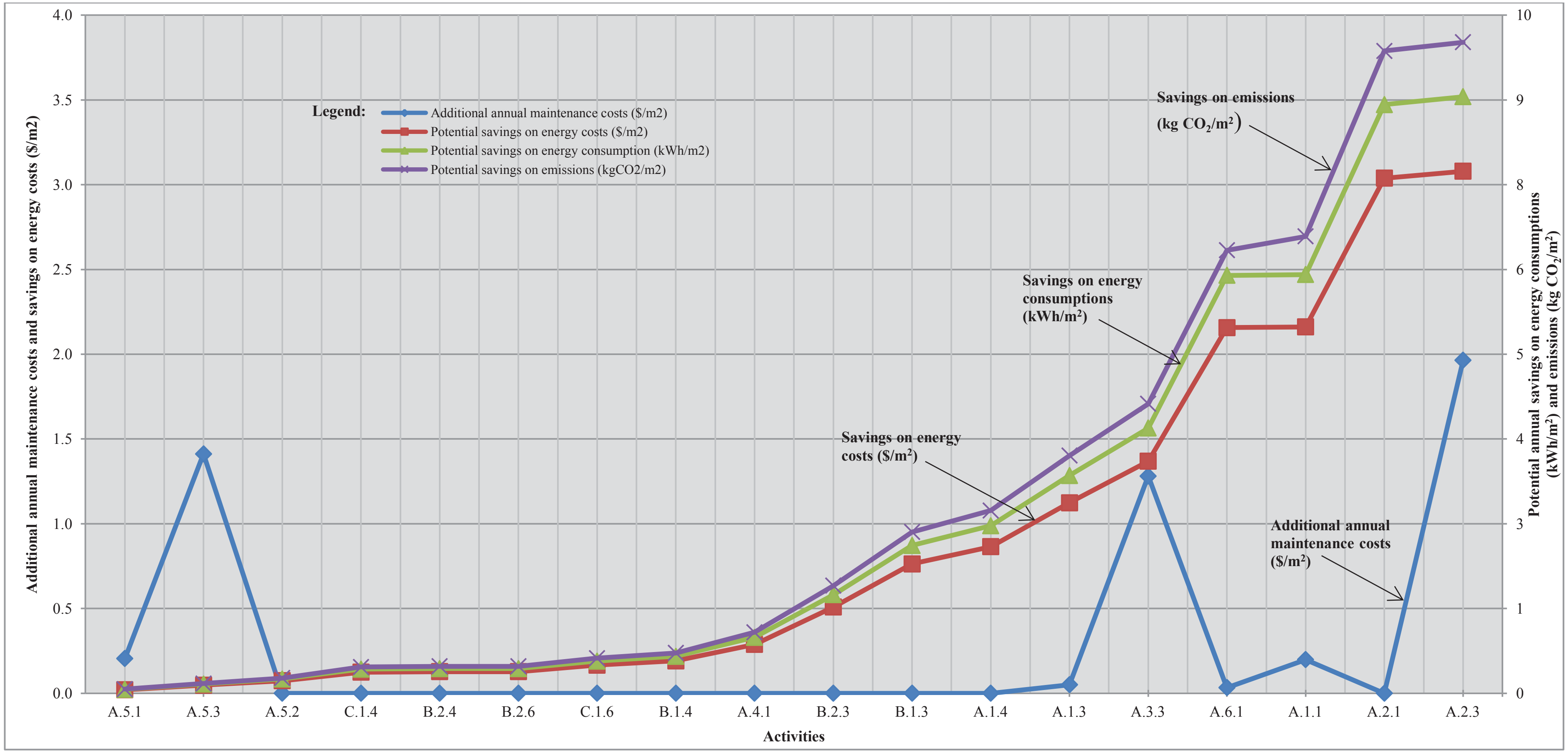
In waste management, same as for Building 1, providing breakdown waste disposal space (A.6.1) can reach savings of approximately 38% on waste disposal. This means savings of approximately \$2.2/m^2 on energy cost, 6 kWh/m^2 on energy consumption and 7 kg CO_2/m^2 on emissions; whist the annual maintenance cost is estimated approximately \$0.03/m^2. The annualised capital cost for this upgrading/improving is also approximately \$0.2/m^2 or 0.2% of total annualised capital cost of the SMOB.

In routine maintenance, as for Building 1, periodic inspection of lighting systems (B.2.3) and cleaning and servicing (B.1.3) will provide annual savings of approximately 1% and 2% of energy use. Totally, improving in routine maintenance can provide savings of approximately \$1.7/m^2 of annual energy costs, 5 kWh/m^2 on energy consumption and 5 kg CO_2/m^2 on emissions.

Ad hoc maintenance, inspecting and repairing breakdowns of the waste disposal space (C.1.6) and general repairing/restoring to interior (C.1.4) will provide potential savings of approximately 0.5% and 0.3% on energy use annually respectively. Totally, in improving ad hoc maintenance can provide savings of approximately \$0.3/m^2 of annual energy costs, 1 kWh/m^2 of energy consumption and 1 kg CO_2/m^2 of emissions (see Table 8.4).

The annual potential savings that can be achieved in Building 2 are illustrated in Figure 8.2. The figure presents the potential annual savings that can be achieved by upgrading systems which have not been performed in the current maintenance practice. The figure presents four variables which denote annual maintenance costs per \$/m^2 (blue line), annual savings on energy costs per \$/m^2 (red line), annual savings on energy consumption per kWh/m^2 (green line) and annual savings on CO_2 emissions per kg CO_2/m^2 (purple line). The horizontal axis (activities) presents systems/equipment which can be improved or upgraded and the note explains the assessed systems/equipment. The left vertical axis presents annual maintenance costs and potential annual savings on energy costs (\$/m^2) which range from 0–\$4/m^2. The right vertical axis denotes potential annual savings on energy consumption (kWh/m^2) and annual savings on CO_2 emissions (kg CO_2/m^2). The trends are presented with upward lines. From the Figure 8.2 we can see that installing a system which can reuse and/or recycle rainwater and grey or black water (A.5.3) would provide a savings on annual energy cost of approximately \$0.1/m^2 (red line presented on the left vertical axis) and the savings on energy consumption and CO_2 emissions is too low of 0.1 kWh/m^2 and 0.1 kg CO_2/m^2 (green and purple lines presented on the right vertical axis) as for Building 1. Upgrading lifts and escalators (A.1.4) provides higher savings on both energy consumptions and CO_2 emissions approximately 2 kWh/m^2 and 3 kg CO_2/m^2 (green and purple lines presented on the right vertical axis), the savings on energy costs is approximately \$0.9/m^2 and no additional annual maintenance cost. The highest savings on energy consumptions and CO_2 emissions for Building 2 are installing automatic sun shading to reduce heat gains or losses in the building (A.2.3) that saves approximately 9 kWh/m^2 and 10 kg CO_2/m^2 (green and purple lines presented on the right vertical axis). The savings on annual energy cost is also better than improving/upgrading other systems in this assessment, approximately \$3.1/m^2 and the additional annual maintenance cost is approximately \$2/m^2 (red and blue lines presented on the left vertical axis).

Figure 8.2 Potential annual savings in upgrading for Building 2 using the SMOB



Note: A.1.1 Installing solar-boosted hot water systems
A.1.3 Installing solar power systems per kW/m^2
A.1.4 Upgrading lifts and escalators
A.2.1 Recommissioning or tuning HVAC systems
A.2.3 Installing automatic sun shading to reduce heat gain or loss
A.3.3 Installing automatic dimming lighting systems
A.4.1 Upgrading internal finishes with eco materials
A.5.1 Installing or upgrading water control sensors
A.5.2 Installing or upgrading water-efficient devices and fixtures
A.5.3 Reusing and recycling rainwater and grey or black water
A.6.1 Providing breakdown waste disposal space
B.1.3 Periodic cleaning and servicing to lighting systems
B.1.4 Periodic cleaning and servicing to interior
B.2.3 Periodic inspecting to prevent breakdown lighting systems
B.2.4 Periodic inspecting to prevent breakdown to interior
B.2.6 Periodic inspecting to prevent breakdown waste disposal system
C.1.4 Inspecting and repairing/restoring breakdowns to interior
C.1.6 Inspecting and repairing breakdowns waste disposal system

8.4.3 Building 3

Table 8.4 also shows the potential annual savings Building 3 can achieve. All calculations are completed in the same way as for Buildings 1 and 2. In upgrading, work which provides the lowest rate of savings approximately 2% is through installing or upgrading BMCS (A.1.2); upgrading internal finishes with eco-materials (A.4.1); and upgrading lifts and escalators (A.1.4). The annual savings are approximately $\$1.1/m^2$, $\$0.4/m^2$ and $\$1.1/m^2$ respectively. The additional annual maintenance cost of installing or upgrading BMCS (A.1.2) is $\$0.02/m^2$ and there are no additional annual maintenance costs for the last two upgraded works.

Installing a solar-boosted hot water system (A.1.1) will provide savings approximately 6% on energy consumption, $\$2.8/m^2$ on annual energy costs, 8 kWh/m^2 on energy consumption and 9 kg CO_2/m^2 on emissions. Installing an automatic dimming lighting system (A.3.3) will provide an annual savings of approximately 4% on energy consumption, $\$1.8/m^2$ on annual energy costs, 5 kWh/m^2 on energy consumption and 6 kg CO_2/m^2 on emissions. Installing a solar power system (A.1.3) will provide a savings approximately 3% on energy consumption, $\$1.5/m^2$ on annual energy costs, 4 kWh/m^2 on energy consumption and 5 kg CO_2/m^2 on emissions. Upgrading lifts and escalators (A.1.4) will provide savings approximately 2% on energy consumption, $\$1.1/m^2$ on annual energy costs, 3 kWh/m^2 on energy consumption and 4 kg CO_2/m^2 on emissions.

The total annualised capital cost for improving energy efficiency is estimated to approximately $\$16/m^2$ or 17% of total annualised capital cost of the SMOB. From this, the annualised capital costs for installing solar-boosted hot water systems are approximately $\$0.5/m^2$ (A.1.1); installing or upgrading BMCS (A.1.2) and installing solar power systems (A.1.3), $\$0.1/m^2$ each; upgrading lifts and escalators, $\$2.8/m^2$ (A.1.4); installing automatic dimming lighting systems, $\$6.1/m^2$ (A.3.3); and upgrading internal finishes with eco materials, also $\$6.5/m^2$ (A.4.1).

As Building 3 has improved water efficiency with installation flux-vales to water closets, the upgrade/improving water consumption can be performed in reusing and recycling rainwater and grey or black water (A.5.3) which can provide savings of approximately 20% on water consumption. The additional annual maintenance costs and savings on energy costs are estimated to approximately \$1.4/m^2 and \$0.1/m^2 respectively. From this upgrading/improving savings of approximately 0.1 kWh/m^2 on energy consumption and 0.2 kg CO_2/m^2 on emissions can be achieved. The potential savings on annual energy cost in installing or upgrading water control sensors (A.5.1) is approximately 8% with additional annual maintenance cost approximately \$0.2/m^2. This upgrading/improving can provide savings of approximately \$0.02/m^2 on energy cost, 0.1 kWh/m^2 on energy consumption and 0.1 kg CO_2/m^2 on emissions.

The total annualised capital cost for improving water efficiency is estimated to approximately \$8.4/m^2 or 9% of total annualised capital cost of the SMOB. Of this, the annualised capital costs for installing or upgrading water control sensors accounts for approximately \$1.7/m^2 (A.5.1); and reusing and recycling rainwater and grey or black water, \$6.8/m^2 (A.5.3).

In waste management, as with Buildings 1 and 2, providing breakdown waste disposal space (A.6.1) can reach savings of approximately 35% on waste disposal. This can provide savings of approximately \$2.2/m^2 on energy cost, 6 kWh/m^2 on energy consumption and 7 kg CO_2/m^2 on emissions; whist the additional annual maintenance cost is estimated to approximately \$0.03/m^2. The annualised capital cost for this upgrading/improving is approximately \$0.2/m^2 or 0.2% of total annualised capital cost of the SMOB.

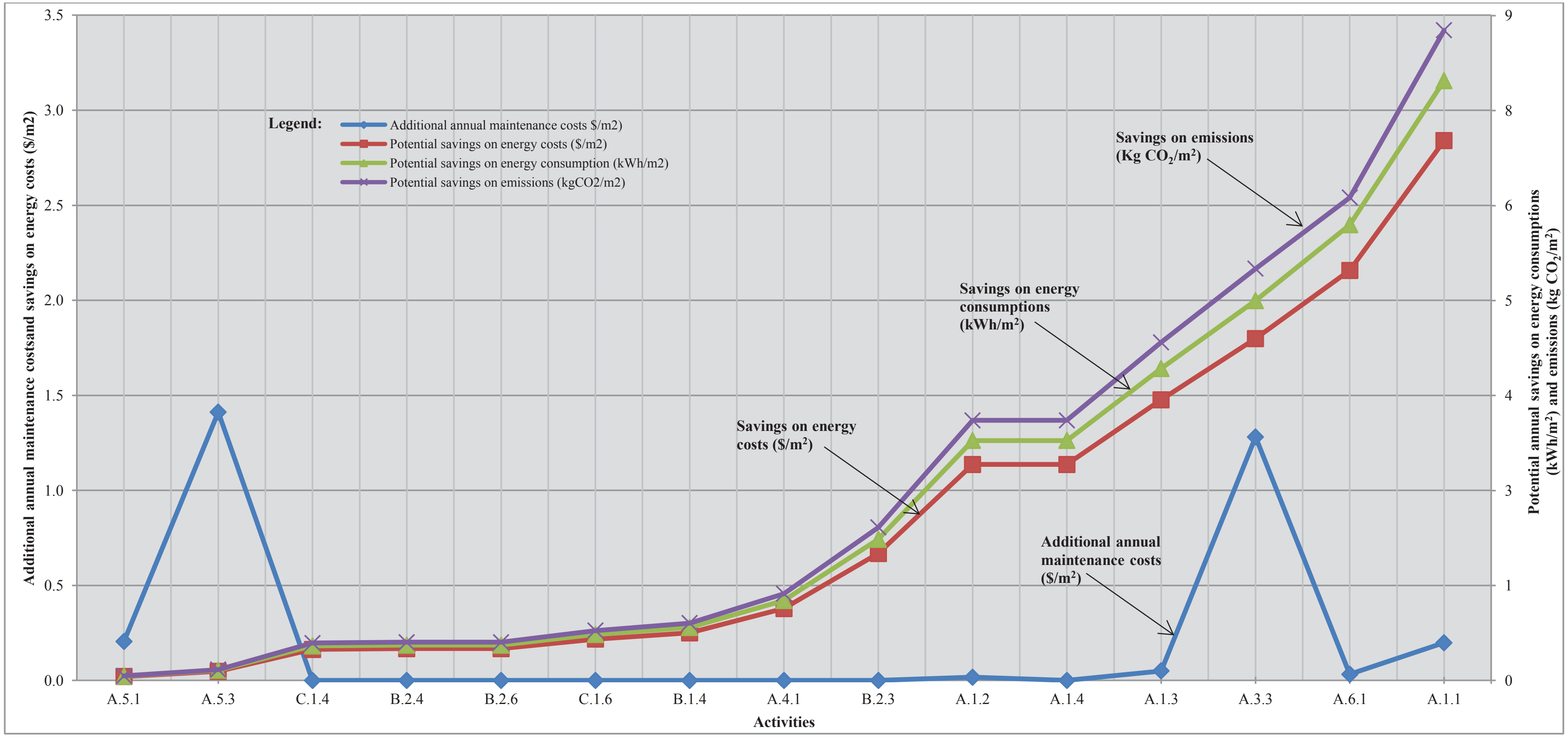
In routine maintenance, periodic inspecting of lighting systems (B.2.3) will provide annual savings of approximately 1% on energy use. Periodic inspections both of the interior (B.2.4) and waste disposal system (B.2.6) will each provide savings of approximately 0.4% on energy per year. In total, improving routine maintenance can provide savings of approximately \$1.3/m^2 on annual energy costs, 4 kWh/m^2 on energy consumption and 4 kg CO_2/m^2 on emissions.

In ad hoc maintenance, as with Building 2, inspecting and repairing/restoring the waste disposal system (C.1.6) will provide a savings of approximately 0.5% and inspecting and repairing the interior (C.1.4) will provide a savings of approximately 0.3% on energy use annually. Totally, improving ad hoc maintenance will provide savings of approximately \$0.4/m^2 on annual energy costs, 1 kWh/m^2 on energy consumption and 1 kg CO_2/m^2 on emissions as shown in Table 8.4 while percentages of savings in improving/upgrading of systems/equipment are shown in Table 7.1 (Chapter 7).

The annual potential savings that can be achieved in Building 3 are illustrated in Figure 8.3. The figure presents the potential annual savings that can be achieved by upgrading systems which have not yet been upgraded under the current maintenance practice. The figure presents four curves which denote annual maintenance costs per \$/m^2 (blue line), annual savings on energy costs per \$/m^2 (red line), annual savings on energy consumption per kWh/m^2 (green line) and annual savings on CO_2 emissions per Kg CO_2/m^2 (purple line). The horizontal axis (activities) presents systems/equipment which can be improved or upgraded and the note explains the assessed systems/equipment. The left vertical axis presents annual maintenance costs and potential annual savings on energy costs (\$/m^2) which range from 0–\$3.5/m^2. The right vertical axis denotes potential annual savings on energy consumption (kWh/m^2) and annual savings on CO_2 emissions (kg CO_2/m^2).

From Figure 8.3, same as Buildings 1 and 2, it reveals that installing a system that can reusing and recycling rainwater and grey or black water (A.5.3) would provide a savings on annual energy cost, approximately \$0.1/m^2 with the additional annual maintenance cost is approximately \$1.4/m^2 (red and blue lines presented on the left vertical axis). However, savings on energy consumptions and CO_2 emissions are approximately 0.1 kWh/m^2 and 0.2 kg CO_2/m^2 (green and purple lines presented on the right vertical axis). Installing a solar power system (A.1.3) would provide better savings on energy consumptions, approximately 4 kWh/m^2, and CO_2 emissions, approximately 5 kg CO_2/m^2 (green and purple lines presented on the right vertical axis). The additional annual maintenance cost approximately \$0.1/m^2; however, the annual savings on energy cost is approximately \$1.5/m^2 (red and blue lines presented on the left vertical axis). The highest savings on energy consumptions and CO_2 emissions for Building 3 is installing a solar-boosted hot water system (A.1.1). The savings on energy consumption and CO_2 emissions are approximately 8 kWh/m^2 and 9 kg CO_2/m^2 (green and purple lines presented on the right vertical axis). The savings on annual energy cost is approximately \$2.8/m^2 and the additional annual maintenance cost is approximately \$0.2/m^2 (red and blue lines presented on the left vertical axis).

Figure 8.3 Potential annual savings in upgrading for Building 3 using the SMOB



Note:

A.1.1 Installing solar-boosted hot water systems
A.1.2 Installing or upgrading BMCS
A.1.3 Installing solar power systems per kW/m^2
A.1.4 Upgrading lifts and escalators
A.3.3 Installing automatic dimming lighting systems
A.4.1 Upgrading internal finishes with eco materials
A.5.1 Installing or upgrading water control sensors
A.5.3 Reusing and recycling rainwater and grey or black water
A.6.1 Providing breakdown waste disposal space
B.1.4 Periodic cleaning and servicing to interior
B.2.3 Periodic inspecting to prevent breakdown lighting systems
B.2.4 Periodic inspecting to prevent breakdown to interior
B.2.6 Periodic inspecting to prevent breakdown waste disposal system
C.1.4 Inspecting and repairing/restoring breakdowns to interior
C.1.6 Inspecting and repairing breakdowns waste disposal system

Table 8.5 summaries the estimates of annual costs and savings for the three case study buildings. They are categorised into: upgrading maintenance in energy consumption; upgrading maintenance in water consumption; upgrading maintenance in waste management; routine maintenance; and ad hoc maintenance. The estimated annual savings of the dollar value ($), which depends on the buildings GFA, are presented with $/m^2, energy consumptions are kWh/m^2, and emissions are Kg CO_2/m^2.

Table 8.5 Potential annual savings in upgrading or improving for the three case study buildings using the SMOB

Project ID	Category	Annualised Capital Cost	Additional Annual Maint. Cost	Potential Annual Savings from SMOB		
				Energy Cost	Energy Use	CO_2
		$/m^2			kWh/m^2	Kg CO_2/m^2
Building 1	Upgrading - Energy	59.49	3.49	12.41	35.47	39.73
	Upgrading - Water	12.39	1.62	0.21	0.61	0.64
	Upgrading - Waste	0.15	0.03	2.16	6.16	6.53
	Routine maintenance	0	0	2.13	6.08	6.81
	Ad hoc maintenance	0	0	0.77	2.20	2.47
	Total:	**72.03**	**5.14**	**17.68**	**50.52**	**56.19**
Building 2	Upgrading - Energy	47.92	3.49	11.92	34.06	37.18
	Upgrading - Water	12.39	1.62	0.14	0.40	0.43
	Upgrading - Waste	0.15	0.03	2.16	6.16	6.53
	Routine maintenance	0	0	1.72	4.90	5.35
	Ad hoc maintenance	0	0	0.29	0.83	0.90
	Total:	**60.46**	**5.14**	**16.23**	**46.36**	**50.39**
Building 3	Upgrading - Energy	15.97	1.55	8.77	25.05	27.15
	Upgrading - Water	8.40	1.62	0.07	0.20	0.21
	Upgrading - Waste	0.15	0.03	2.16	6.16	6.53
	Routine maintenance	0	0	1.25	3.58	3.88
	Ad hoc maintenance	0	0	0.38	1.09	1.18
	Total:	**24.52**	**3.20**	**12.63**	**36.08**	**38.95**

Table 8.5 shows that by using the SMOB, Buildings 1 can be improved to achieve a total annual savings approximately 51 kWh/m^2 on energy consumption and 56 kg CO_2/m^2 on CO_2 emissions, which leads to a savings of approximately $18/m^2 on annual savings on energy costs. The annualised capital cost in upgrading/improving is approximately $72/m^2 and the additional annual maintenance cost is $5/m^2.

Building 2 can be improved to achieve a total annual savings of approximately 46 kWh/m^2 and 50 kg CO_2/m^2 which leads to a savings of approximately \$16/m^2 annually savings on energy costs in maintenance. The annualised capital cost in upgrading/improving is approximately \$60/m^2 and the additional annual maintenance cost is also \$5/m^2.

Building 3 can be improved to achieve a total annual savings of approximately 36 kWh/m^2 and 39 kg CO_2/m^2 which leads to a savings of approximately \$13/m^2 on energy costs in building maintenance per year. The annualised capital cost in upgrading/improving is approximately \$25/m^2 and the additional annual maintenance cost is \$3/m^2.

8.5 Potential Savings for the Case Study Buildings in Expected Increase of Energy Price

The assessment of potential savings for the case study buildings after an expected increase of the price of energy can be found using the SMOB. The calculation is based on the costs of energy consumption for the three buildings in the current maintenance practices. The annual energy consumptions of each building are shown in Table 8.1.

The energy costs and savings on energy costs are denoted by the dollar value (\$), while annual energy consumptions by the three buildings are presented as kWh. The estimated potential savings on energy costs for the three buildings if hypothetically to be increased by 10% are summarised in Table 8.6. The current energy price is approximately \$0.35/kWh adapted from the current Standard Electricity Prices and Charges of the Synergy (2016).

Table 8.6 Potential savings with an expected increase of energy price by 10% using the SMOB

Building ID	Energy consumptions in current maintenance practices [1] (Table 8.1)	Savings on energy consumptions after upgrading [2]	Energy Consumptions After Upgrading [3]	Costs on Energy Consumptions in Current Maintenance Practices [4]	Costs on Energy Consumptions After Upgrading/ Improving [5]	Costs on Energy Consumptions After Savings on Energy Price Increased by 10% [6]
	(kWh)			($)		
Building 1	2,256,933	893,383	1,363,550	789,927	477,243	458,208
Building 2	4,125,003	1,858,551	2,266,452	1,443,751	793,258	758,152
Building 3	6,134,401	1,636,223	4,498,178	2,147,040	1,574,362	1,531,267

Note:
1 Current energy consumptions derived from Table 8.1
2 Total savings on buildings energy consumptions (Table 8.4) x buildings GFA (Table 8.1)
3 Energy consumptions in current maintenance practices - [Sum of savings on energy consumptions of buildings (Table 8.4) x GFA of buildings (Table 8.1)]
4 Energy consumptions in current maintenance practices x $0.35/kWh (Synergy 2016)
5 Energy consumptions after upgrading based on SMOB x $0.35/kWh (Synergy 2016)
6 Energy costs after upgrading - energy costs after upgrading x 10% (assumed energy price increased) x potential annual savings on energy consumptions (Table 8.4)

Table 8.6 assumes current maintenance practices that all systems/equipment embedded in the buildings are operated as usual and that no system/equipment is improved or upgraded. The annual energy consumption, shown in Column 2, of Building 1 is 2,256,933 kWh, Building 2 is 4,125,003 kWh and Building 3 is 6,134,401 kWh (from Table 8.1).

From the calculation in Table 8.4, the total potential annual savings on energy consumption for Building 1 in upgrading/improving items in Table 8.4 is approximately 893,383 kWh, equivalent to 51kWh/m^2 per GFA. The calculations are the same for Buildings 2 which is approximately 1,858,551 kWh and 46kWh/m^2 per GFA; and Building 3 is approximately 1,636,223 kWh and 36kWh/m^2 per GFA.

Accordingly the savings of energy consumptions after upgrading/improving are approximately 1,363,550 kWh, 2,266,452 kWh and 4,498,178 kWh respectively for Buildings 1, 2 and 3 (Column 4, Table 8.6). The costs of energy consumption based on the current energy price in current practices are approximately $789,927, $1,443,751 and $2,147,040 respectively for Buildings 1, 2 and 3 with current Standard Electricity Prices and Charges of the Synergy (2016) (Column 5, Table 8.6). However after the buildings are upgraded or improved, the costs on energy consumptions are now reduced to approximately \$477,243, \$ 793,258 and \$1,574,362 respectively for Buildings 1, 2 and 3 (Column 6, Table 8.6). Further savings on energy costs if in an expected increase of energy price by 10% from the current price, the costs on energy consumptions of the buildings will then be reduced to approximately \$458,208 for Building 1, \$758,512 for Building 2 and \$1,531,267 for Building 3 (Column 7, Table 8.6).

From these calculations, it is clear that at the current maintenance practices, all systems/equipment embedded in the buildings operated as usual and no systems/equipment upgraded or improved; the key stakeholders should bear full costs on energy consumptions approximately \$789,927 for Building 1, \$1,443,751 Building 2 and \$2,147,040 for Building 3 as indicated in Column 5, Table 8.6. When the buildings are upgraded/improved, the costs on energy consumptions would be reduced to approximately \$477,243 for Building 1, \$ 793,258 for Building 2 and \$1,574,362 for Building 3 (Column 6, Table 8.6). The savings on energy consumption after upgrading/improving of Building 1 is \$312,684 (\$789,927 - \$477,243) due to the total of potential annual savings on energy consumption is approximately 51kWh/m^2 or 40% (Column 8, Table 8.4). The savings of Building 2 is approximately \$650,493 (\$1,443,751 - \$793,258) due to the total of potential annual savings on energy consumption is approximately 46kWh/m^2 or 44% (Column 13, Table 8.4). The savings of Building 3 is approximately \$572,678 (\$2,147,040 - \$1,574,362) due to the total of potential annual savings on energy consumption is approximately 36kWh/m^2 or 27% (Column 18, Table 8.4).

Further savings on energy consumption that could be obtained in case the energy price increased by 10% for Building 1 are approximately \$19,034 (\$477,243 x 10% x 39.9%) as calculated in Column 8, Table 8.4. For Building 2, further savings are approximately \$35,106 (\$793,258 x 10% x 44.3% (Column 13, Table 8.4)); and for Building 3 approximately \$43,095 (\$1,574,362 x 10% x 27.4% (Column 18, Table 8.4)).

Figures 8.4 also present the costs on energy consumption for the three case study buildings due to the potential savings on energy costs for the three case buildings in respected electricity price would be increased by 10% by using the SMOB.

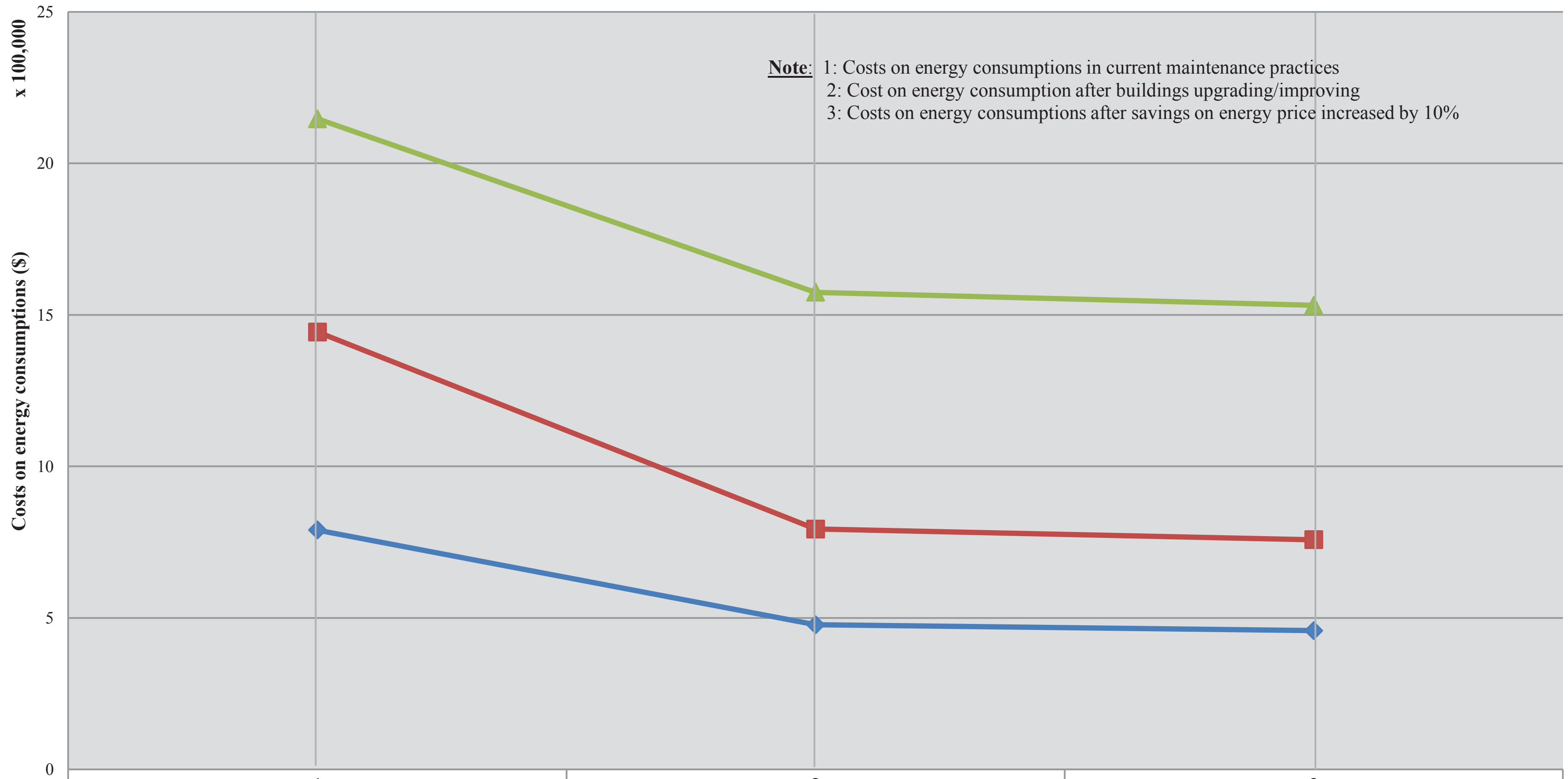
The horizontal axis denotes for three estimated costs on energy consumptions which include:

- Costs on energy consumptions in current maintenance practices
- Cost on energy consumption after buildings upgrading/improving
- Costs on energy consumptions after savings if energy price is increased by 10%

The vertical axis is presented with dollar values ($) which range from 0–$2,500,000 (on the figure the range is from 0–$25 x 100,000). The blue line denotes the costs of energy consumption for Building 1, red for Building 2 and green for Building 3. When the buildings are maintained at the current maintenance practices, the costs on energy consumptions would be approximately $789,927 for Building 1, $1,443,751 for Building 2 and $2,147,040 for Building 3 (1). However, when the buildings are upgraded or improved, the costs on energy consumptions would be reduced to approximately $477,243 for Building 1, $793,258 for Building 2 and $1,574,362 for Building 3 (2). The reductions are the result of the potential annual savings on energy consumptions by upgrading/improving the buildings as calculated in Table 8.4. The savings on energy costs in upgrading/improving are approximately $312,684, $650,493 and $572,678 for Buildings 1, 2 and 3 respectively.

If energy prices increase by 10%, the costs of energy consumption for Building 1 is approximately $458,208, Building 2 is $758,152 and Building 3 is $1,531,267 (3). The savings on energy costs of Building 1 is approximately $19,034, Building 2 is $35,106 and Building 3 is $43,095 (as discussed above). The calculations here do not include savings on reduction of other costs, such as costs on broken-down of systems/equipment, cost on labour to repair or restore the broken-down systems/equipment, etc. when new maintenance procedures that becomes profitable once the buildings are improved.

Figure 8.4 Potential savings in upgrading or improving for the three case building in expected energy price increased by 10%



	1	2	3
Building 1	$789,927	$477,243	$458,208
Building 2	$1,443,751	$793,258	$758,152
Building 3	$2,147,040	$1,574,362	$1,531,267

8.6 Summary

This chapter has investigated three case studies to analyse the current maintenance practices for existing office buildings located in the Sydney CBD in aim to verify the SMOB. The study compared the current maintenance practices with the SMOB (the best practice) in satisfying environmental protection. It is significant that even though the three buildings have realised some annual savings on energy and water consumption in their current maintenance practices, there is room for more improvement, particularly in upgrading work.

By applying the best practice as developed in the SMOB, Building 1 can obtain further savings of up to 51 kWh/m^2 on energy consumption, 0.8 kL/m^2 on water consumption and 56 kg on CO_2 emissions per year. When improving, the annual energy intensity of the building will reduce to approximately 77 kWh/m^2, water use to approximately 0.5 kL/m^2 and emissions to approximately 87 kg CO_2/m^2 per year; and the savings on annual energy costs for the improvement is estimated approximately \$18/m^2 per year. To these savings, the annualised capital cost for improving is approximately \$72/m^2 and the additional annual maintenance cost is approximately \$5/m^2 per year.

Building 2 can save up to 46 kWh/m^2 on energy consumption, 0.5 kL/m^2 on water consumption and 50 kg on CO_2 emissions annually. When improving, the annual energy intensity of the building will reduce to approximately 57 kWh/m^2, water use to approximately 0.4 kL/m^2 and emissions to approximately 62 kg CO_2/m^2 per year; and the savings on annual energy cost for the improvement is estimated approximately \$16/m^2 annually. To these savings, the annualised capital cost for improving is approximately \$60/m^2 and the additional annual maintenance cost is approximately \$5/m^2 annually.

Lastly, Building 3 can save up to 36 kWh/m^2 on energy consumption, 0.3 kL/m^2 on water consumption and 39 kg on CO_2 emissions per annum. When improving, the annual energy intensity of the building will reduce to approximately 99 kWh/m^2, water use to approximately 0.6 kL/m^2 and pollution to approximately 108 kg CO_2/m^2 per annum; and the savings on annual energy cost for the improvement is estimated approximately $\$13/m^2$ per annum. To these savings, the annualised capital cost for improving is approximately $\$25/m^2$ and the annual maintenance cost is approximately $\$3/m^2$ per annum.

There are no records for waste management in all three of the case study buildings. Therefore, it is assumed that providing a waste disposal space is necessary to sort solid, office and household waste to reuse and/or recycle where possible. This can provide an annual savings approximately 38% on waste disposal to each building.

According to Hestnes and Kofoed (2002); and Steinfeld, Bruce and Watt (2011), an office building running with an annual energy intensity under 100kWh/m^2 may be recognised as a green building and satisfies the environment protection requirements. The results show that the SMOB can be applied as a sustainable maintenance practice for an office building to become environmentally friendly. When applying the SMOB to maintain buildings, the annual energy consumption per GFA (kWh/m^2), the annual water consumption per GFA (kL/m^2), and particularly the annual emissions per GFA (kg CO_2/m^2) of an existing office building will be significantly decreased. As a result, the building will be more environmentally friendly.

Through these case studies, the SMOB has been verified. It can be easily applied as the mainstream practice for maintenance of a non-green office building. It can also be applied as an associated or alternative program for an existing office building which has some green performance in maintenance practices to make the building more sustainable. It will provide cost-benefits in maintaining the building on a long term strategy, enhance the internal comfort and well-being of occupiers, and satisfy the requirements of environmental protection regulations.

9. Summary and Conclusions

9.1 Introduction

This chapter presents a summary of this research, which aims to analyse the interaction between the environment and existing buildings, develop potential strategies for the lessening of CO_2 emissions by reducing energy and water consumption through sustainable maintenance practices. This research involved examination of the environmental problems linked to maintenance practices for office buildings. It also investigated the current and future actions of the industry's professionals on the impacts between office buildings and the environment. The outcomes derived from these studies, is the development of a model for the sustainable maintenance of office buildings (SMOB), which is based on a long-term perspective to improve existing building performance. The thesis presents findings to support the concept that an existing office building's performance can be improved through utilising sustainable maintenance practices.

Knowledge of the negative impacts of office buildings on the environment and ways to minimise these impacts have been examined. The research carried out: a comprehensive review of theories and theoretical literature to establish a framework for the project; a questionnaire survey, a focus group discussion and a Delphi study to develop the SMOB. The SMOB was verified against three existing office buildings in the Sydney CBD. The results show that the SMOB can be utilised as an effective framework to maintain office buildings more sustainably. The details of this research are summarised in this chapter.

9.2 Research Overview

The main aim of this research was to analyse the impact of existing building on the environment and to establish strategies to reduce energy and water consumption, and CO_2 emissions. The study investigated ways for office buildings to be maintained more sustainably. Continuing to maintain an office building under traditional maintenance practices will cause significant environmental impact in its long-term operation, and thus accelerating the effects of climate change. For existing office buildings to be more sustainable, best practices and new technologies should be implemented along with energy- and water-efficient strategies. From these implementations the impacts between office buildings and the environment will significantly be reduced. Throughout the research, sustainable maintenance determinants were identified in the SMOB that can be used as a benchmark solution for improving the performance of office buildings and thus reduce the impact on the environment by reducing energy and water consumption, and CO_2 emitted from the buildings as discussed in Chapter 7.

Many existing office buildings in Australia are old and do not comply with environmental performance requirements. Building owners may be reluctant to invest in utilising sustainable maintenance because of the uncertainty about long-term value of their investment. However the utilisation of sustainable maintenance is an important option to address this uncertainty in the long-term when environmental considerations are required. Upgrading the building’s sustainability standards, improving building systems and building services with new technologies and environmental strategies for maintenance were the focus for this research (details are discussed in Chapter 5).

Strategies for sustainable maintenance practices to reduce energy and water consumption, and CO_2 emissions can be carried out to improve efficiency in office buildings. Systems that consume the highest levels of energy are the HVAC and lighting systems. Systems which consume high levels of water are toilets and urinals, washbasins and cooling towers. These are the main systems that must be improved for energy and water efficiency. However, the study found that most existing office buildings in Sydney are currently maintained via traditional standard practices. Many service systems and equipment are outdated and have not undergone improvements or upgrades for years. The study has also identified a number of key factors and limitations in applying sustainable maintenance of existing office buildings. The study has revealed that sustainability is a relatively new concept of maintenance practice for existing office buildings as discussed in Chapter 6.

The aspects of energy and water efficiency are the main drivers in improving sustainability of existing office buildings. The “greenness” of a building or system is largely evaluated using LCA, whilst the investment cost over the lifetime of a building or system is usually assessed by LCC. However an application of LCA or LCC alone cannot provide a full assessment of the environmental impact levels as well as the cost of sustainable maintenance under both environmental and economic criteria. The combination of LCA and LCC for decision-making, as suggested from this research and discussed in Chapter 4, can concurrently identifying the environmental burden, cost, and savings of an office building over the buildings life cycle. Nevertheless, this approach has not been extensively used by most key stakeholders of buildings who play an important role in improving current maintenance practices to be more environmentally friendly.

To conduct this research, research questions were established and literature review was undertaken and results identified that there were gaps between traditional and sustainable maintenance practices for office buildings and these gaps were confirmed from the industry questionnaire survey and focus group discussion. Case studies as discussed in Chapter 8 quantified these gaps using the SMOB and demonstrated the potential benefits should the SMOB be used in maintaining existing office buildings.

For the full range of possibilities for data collection in answering the research questions, a mixed research method was used, which combined quantitative and qualitative research methods, including a survey questionnaire, a focus group discussion, and a Delphi study. The aim of the questionnaire survey was to ascertain the perceptions of office buildings professionals about current and future practices towards sustainable maintenance of office buildings. The questionnaire was designed based on a comprehensive literature review, and then tested and amended via comments received from a pilot survey. The mean difference tests using the SPSS software showed that there were no significant differences between groups of respondents' answers to the survey questionnaire. Therefore, the responses of respondents to the survey were reliable.

The primary purpose of the focus group discussion was to evaluate and consolidate the most critical issues identified from respondents of the survey. The purpose of the Delphi study was to obtain a broad agreement from a group of experts in ranking these critical issues for making current and future maintenance practices of existing office buildings more environmentally friendly.

The three-round Delphi study was used to collect expert opinions and outcomes from data analyses of these processes show that:

- Buildings maintained with traditional maintenance practices consume energy and water excessively and hence generates high level of CO_2 to the environment.

- Sustainable maintenance practices will be a potential solution for existing buildings to improve performance by improving efficient uses of energy and water and waste disposal management and therefore, CO_2 emissions will be great reduction.

- Many existing office buildings are currently maintained with traditional practices. However, key stakeholders are willing to apply sustainable maintenance as mainstream practices for the buildings whenever possible.

These outcomes therefore form the determinants in the development of the SMOB and the details of the SMOB are discussed in Chapter 6. The development of the SMOB was based on questions about the improvement of maintenance practices for office buildings sustainably. Those questions were:

- What things can be improved?

- How are they improved?

- How much does it cost for the improvements?

- What benefits are received from the improvements?

As the SMOB established (Chapter 7), the most critical criteria as identified in improving maintenance practices for office buildings are:

- Improving energy consumption by upgrading the HVAC systems, lighting systems, electrical controlling and monitoring systems via BMCS.
- Improving water consumption by installing water-efficient fixtures/devices, harvesting rainwater and recycling grey/black water.
- Using low environmental impact materials and finishes in maintenance work.
- Providing disposal/storage space to recycle and reuse waste aiming to reduce waste to landfill.

The verification of the SMOB was demonstrated using multiple case studies to identify potential savings on energy consumptions and emissions in Chapter 8. Three existing office buildings in the Sydney CBD were selected for the case studies and they were used to examine:

- What impacts of the buildings' current maintenance practices against the SMOB?
- How much has been impacted?
- How to improve?

The SMOB also analysed the costs and likely savings which can be potentially achieved for office buildings. It was clear in the analysis that when the SMOB was used in improving maintenance practices, buildings can achieve high rates of savings on energy and/or water uses in buildings annually. Consequently, the buildings can contribute less CO_2 emissions to the environment. The result of the case studies verified that the SMOB is robust and answers questions as stated above.

9.3 Contributions to Knowledge

The main contribution of this research is the SMOB for improving maintenance of office buildings sustainably. The SMOB provides a framework for stakeholders in the industry to assess and improve the maintenance programs for their office buildings to be sustainable. Fundamentally, the SMOB provides both the theoretical perspective and practical means to assess and improve office building performance during the operating stage. As results from the case studies, stakeholders will be potentially rewarded with reduced costs and increased savings when applying the SMOB.

The analysis from the case studies has shown that the SMOB is an effective model suited for improving environmental performance of existing office buildings and can be used to set benchmarks for more environmentally friendly office buildings. This research has made a number of other useful contributions to the office building industry. They include:

- In assist key stakeholders to assess their office buildings and to satisfy environmental and economic measurements over the long-term, a combined LCA and LCC assessment process was developed. This process can be flexibly applied to assess life cycle evaluation for office buildings (details are discussed in Chapter 4).

- In the survey process, the research found that most stakeholders in the building industry acknowledge that there are significant impacts between office buildings and the environment. The reason is that many existing office buildings are currently maintained with traditional practices. That makes buildings consume high rates of energy and water and consequently emit high rates of CO_2 to the environment, contributing to the acceleration of climate change.

- Improving environmental performance of existing buildings is one of the most important solutions to environmental problems. However, sustainable maintenance practices for office buildings are currently not effectively applied. Only 17% of existing office buildings are utilising sustainable maintenance as mainstream practices, while 65% of the others will consider to do so in six to ten years or more, and 18% of the remainders are not considered as discovered in Chapter 6. Therefore, office buildings are a significantly large area for sustainable maintenance development.

- Currently, most stakeholders in the building industry have limited knowledge about new technological advances in sustainable maintenance practices. This is due to financial constraints and external factors, such as lack of cooperation between owners and tenants. Towards, approving government's incentives, strengthening building regulations, etc. That is why most buildings are still maintained with traditional maintenance practices. Reasons for accelerating the development of sustainable maintenance practices for office buildings were provided through this research (details are discussed in Chapter 6).

- In investigating the current maintenance practices for the buildings in the case studies, the research found that upgrading maintenance for improving the buildings is still limited. Many systems/equipment have not been upgraded or improved since installed in the buildings. To improve the environment, therefore, sustainable maintenance practices for office buildings should be developed more rapidly. The acceleration of sustainable maintenance development for office buildings needs to be supported by the government (as discussed in Section 7.3.4, Chapter 7 and Section 9.6.2).

- The development of the SMOB has opened opportunities for further research on sustainable maintenance practices for office buildings and other types of buildings locally and internationally.

9.4 Limitations of the Research

As stated, this research aims to show the applicability of SMOB to improve environmental performance of existing office building so that CO_2 emissions can be reduced. It may assist stakeholders in appraising and improving their buildings incorporating environmental and economic approaches with better costs and savings in return.

Limitations to this study are due to the financial constraint, as outlined below:

- Knowledge acquired for developing the SMOB is based on data collection and analysis from the survey, focus group discussion and Delphi study. A sample of participants for these studies was derived from a selected sampling of professionals in the property management sector and members of professional institutes who are current practitioners in office buildings. Therefore, their perspectives and experiences may only reflect problems within the context of office buildings.

- The critical factors of environmental issues, and cost and savings in improvements to existing office buildings as identified in this research may be restricted to the time of the research. Environmental and economic criteria may vary over time, and people's perspectives, experiences, awareness and the condition of environmental problems may change.

Despite these constraints, the conceptual purpose of the study remains the same. The limitations do not weaken the essence of the research but merely present opportunities for further research.

9.5 Research Findings

As discussed in Chapter 1, the aim of this research is to examine and analyse the issues relating to the maintenance of office buildings which improve the environment, and to develop a strategic model for the maintenance practices – making the performance of existing office buildings more sustainable over the long term. Based on this aim, three research questions were developed, and seven research aims and objectives established. The outcomes of the research satisfied all of the aims and objectives, discussed as follows.

9.5.1 Satisfying the Research Questions

Question 1

How does the application of sustainable maintenance interact with existing office buildings?

This research has revealed that sustainable maintenance practices are important for the environmental impacts of existing office buildings. The SMOB was developed as a result of this research. As shown in Table 7.1 (Chapter 7) upgrading, an existing office building can achieve savings up to 59% on energy consumption, 58% on water consumption and 38% on waste disposal. The annual savings in routine and ad hoc maintenances can reach up to 25% and 10% on energy consumption respectively. From these savings the rate of CO_2 emissions will be substantially reduced.

Case studies analysed in Chapter 8 have verified that when applying the SMOB further savings on energy and water consumptions and more reduction of CO_2 emissions from the buildings can be achieved. As shown in Table 8.5, the total further annual savings on energy consumption and CO_2 emissions of Building 1 is approximately 51 kWh/m^2 and 56 kg CO_2/m^2; Building 2 is 46 kWh/m^2 and 50 kg CO_2/m^2; and Building 3 is 36 kWh/m^2 and 39 kg CO_2/m^2 per year.

In water efficiency, when improving the potential annual savings of Building 1 is approximately 0.8 kL/m^2 on water usage hence to savings approximately 0.6 kWh/m^2 on energy consumption and 0.6 kg CO_2/m^2 on emissions annually. Building 2 is 0.5

kL/m^2 hence to savings approximately 0.4 kWh/m^2 and 0.4 kg CO_2/m^2. Building 3 is 0.2 kL/m^2 hence to savings approximately 0.2 kWh/m^2 and 0.2 kg CO_2/m^2. In waste management, by providing a breakdown waste disposal space each building can achieve the potential annual savings approximately 6 kWh/m^2 and 7 kg CO_2/m^2 per annum.

Question 2

What are the costs and savings in improving/upgrading existing office buildings using a sustainable maintenance strategy?

As discussed in Chapter 7, sustainable maintenance practices generate savings on energy and water costs during the building's life span. The SMOB provides four sustainable indicators and its extension includes 23 criteria that have been verified to provide improved savings when applied as an alternative program to current maintenance practices. Especially, the SMOB provides three-level of upgrading including Level 1 work having annualised capital cost varies from approximately 0.1 to \$3/m^2, Level 2 varies from \$3 to \$7/m^2 and Level 3 varies from \$7 to \$32/m^2. Key stakeholders can flexibly apply either minor or major improvements/upgrades to the buildings systems or equipment depending on their available budgets and the cost of traditional maintenance.

Question 3

What are the behaviours of stakeholders in applying sustainable maintenance practices to existing office buildings for today and tomorrow?

As discussed in Chapter 6, the analysis of data from the survey has revealed professionals in the industry are aware that the ineffective use of energy and water in buildings causes significant negative impact to the environment. Traditional maintenance practices could not be an effective and efficient way to improve the buildings with efficient use of energy and water and also waste disposal to the landfill. So, the damage of our environment will be increased if traditional maintenance practices are continued.

However, the research has revealed that stakeholders' response in applying sustainable maintenance practices to existing office buildings is still low. As discussed in Chapter 6 sustainable maintenance practices are currently used for only 17%, of buildings, while 65% are considering changing over in six to ten years. Eighteen per cent didn't suggest any plans for change.

Therefore, the use of sustainable maintenance practices must be accelerated in order to protect the environment. The SMOB has verified that the use of sustainable maintenance practices can significantly improve an existing office building's sustainability over its life span.

9.5.2 Reviewing the Research Aims and Objectives

The aim of this research is to establish a method to analyse the interaction between the environment and existing buildings, to examine how the impact of existing buildings on the environment can be reduced and to suggest strategies by which any negative effects can be minimised, relaying primarily on the market within a framework of Government regulations.

Reducing the impact on the environment means developing maintenance strategies for the long term reduction of energy and water consumption and reduction of waste which will reduce the emissions of CO_2 and conserve scarce water resources.

In the process, the following objectives have been satisfied:

Objective 1 – Review traditional practices in the maintenance of office buildings

The traditional maintenance practices of office buildings have been reviewed extensively in literature review and discussed in Chapter 2. As illustrated in the study, CO_2 is the main substance emitted causing the acceleration of climate change and raising the Earth's surface temperature. The increased surface temperature results in buildings consuming energy and water excessively to provide occupants consistent comfort and as a result, more CO_2 emissions into the environment. This cycle has continued on for many decades. This vicious cycle will continue unless green buildings or sustainable buildings are rapidly developed.

The study found that existing non-green office buildings are main contributors of CO_2 to the environment due to the inefficient uses of energy and water within the buildings, responsible for approximately 25% energy, 15% water and 40% waste to landfill. The study also found that many existing non-green office buildings are currently operated and maintained using traditional maintenance practices. The literature review identified that traditional maintenance practices are not effective enough to reduce the energy and water consumption as well as waste disposal in buildings.

Objective 2 – Investigate sustainable maintenance practices

The sustainable maintenance practices of office buildings have also been reviewed extensively in the literature and discussed in Chapter 3. The study has identified sustainable maintenance practices that will reduce their environmental impacts. An office building maintained with a better sustainable maintenance practice will significantly reduce the end use of energy by up to 57% per year compared to buildings with average energy performance (Steinfeld, Bruce & Watt 2011). A target reduction of 35% of potable water consumption is required from 2011–2020; and a further reduction by 10% by 2020 (NSW Office of Water 2010; Radcliffe 2006 cited in Chen, Ngo & Guo 2012). The best practice of waste management can reduce waste to landfill up to 50% (Miller, Khan et al. 2005 cited in Terry & Moore 2008). From these, the CO_2 emissions can be reduce by approximately 1.4 billion tonnes or 29% or even at zero-net with further commitment (IPCC 2007 cited in Ürge-Vorsatz, Koeppel & Mirasgedis 2007b). Sustainable maintenance practices will change a non-green building to become an environmentally friendly building.

An effective and efficient way to approach sustainable maintenance and minimise negative environmental impacts is by upgrading the building to more environmentally friendly systems or components. Sustainable maintenance can be performed by improving/upgrading systems or equipment in existing office buildings. It provides a large savings of energy consumptions with energy being the largest expense in operating office buildings. The primary benefit from energy savings is the result in lower annual cost to operate and maintain overall and thus, higher return. Sustainable maintenance combined with new technology will provide an even greater reduction in running costs of the buildings. The reduction of CO_2 through sustainable maintenance practices is mainly accomplished with the reduction of energy and water consumptions. Therefore to reduce CO_2 emissions and improve the environment, the use of energy and water in office buildings are needed to be reduced.

Objective 3 – Identify stakeholders' views in the design and performance of maintenance strategies for office buildings to satisfy environmental protection

This thesis has examined stakeholders' views in performance of maintenance strategies for office buildings to satisfy environmental protection requirements. The investigation utilised questionnaire surveys, focus group discussions and a Delphi study. In Chapter 6, the survey suggested that approximately 72% of respondents agreed or strongly agreed that existing buildings impact the environment because they are energy and water inefficient. The analysis also identified that 91% of the respondents agreed or strongly agreed that sustainable strategies must be developed and incorporated into building maintenance. Ninety percent of respondents agreed or strongly agreed that further growth in sustainable maintenance practices is desirable.

The outcomes of the focus group discussion and Delphi study recognises that building stakeholders believe that the most important factors in sustainable maintenance development is the improvement of energy and water efficiency, lighting systems, indoor environment, environmentally friendly materials, and waste management through a sustainable maintenance strategy with government legislation and support. The main systems which are needed to reduce energy consumption and CO_2 emissions are the HVAC systems, lighting systems, electrical switchgears, lifts and escalators, sun shading system and reuse or recycle rainwater, grey and/or black water uses in the buildings. The viewpoints derived from stakeholders have been incorporated in the development of the SMOB to improve sustainable maintenance practices of existing buildings.

Objective 4 – Examine costs and savings to stakeholders from the design and performance of sustainable maintenance in long-term performance

In Chapter 4, the study has acknowledged that the rapid growth of the property industry has accelerated continuous change in the environment, including technology, standards, policies and regulations towards environmental and economic impacts. Existing office buildings, particularly non-green ones, are likely to not keep up with the changes.

The study has revealed that stakeholders may be reluctant to invest money in improving their existing buildings because they lack knowledge in applying the new technology of sustainable maintenance. Another concern is uncertainty in ways to assess energy and water efficiency as a long term approach for improving their buildings to satisfy the environmental protection requirements. The LCA for appraisal the environmental approach and LCC for the evaluation of economic approach are possible solutions for the problems. A suggested combination assessment on the environmental and economic aspects using LCA and LCC methods for the decision-making process can satisfy both environmental requirements and economic measurements.

Objective 5 – Identify stakeholders' responses to the maintenance of non-green office buildings through case studies

In studying three high-rise office buildings as case studies in Chapter 8, the analysis has found that even though all three buildings have improved some systems and equipment, their current maintenance practices were not adequate. At the current maintenance practices, the annual energy consumption of Building 1 is 128 kWh/m^2 and emission is 143 kg CO_2/m^2 annually; Building 2 is 103 kWh/m2 and 112 kg CO_2/m^2; and Building 3 is 135 kWh/m^2 and 147 kg CO_2/m^2 (Table 8.1).

As shown in Table 8.4 Building 1 can be improved to achieve total potential annual savings of approximately 51 kWh/m^2 of energy consumption and 56 kg CO_2/m^2 of CO_2 emissions, which results in an annual savings of approximately \$18/m^2 of energy costs in building maintenance. The calculation can reduce the energy consumption of Building 1 from 128 to approximately 77 kWh/m^2 and emissions from 143 to approximately 87 kg CO_2/m^2 annually.

Building 2 can be improved to achieve total potential annual savings of approximately 46 kWh/m^2 of energy consumption and 50 kg CO_2/m^2 emissions that results in an annual savings of approximately \$16/m^2 on energy costs in maintenance. The calculation can reduce the energy consumption of Building 2 from 103 to approximately 57 kWh/m^2 and emissions from 112 to approximately 62 kg CO_2/m^2 per annum.

Building 3 can be improved to achieve total potential annual savings of approximately 36 kWh/m^2 of energy consumption and 39 kg CO_2/m^2 emissions which results in an annual savings of approximately \$13/m^2 on energy costs in maintenance. The calculation can reduce the energy consumption of Building 3 from 135 to approximately 99 kWh/m^2 and emissions from 147 to approximately 108 kg CO_2/m^2 per year. In water efficiency, by using the SMOB, Building 1 can reduces the annual water consumption from 1.3 to approximately 0.5 kL/m^2, Building 2 from 0.9 to 0.4 kL/m^2 and Building 3 from 0.9 to 0.6 kL/m^2 per year.

Objective 6 – Develop a strategic model for sustainable maintenance over the long-term strategies of office buildings, balancing environmental and economic concerns

A strategic Model of Sustainable Maintenance of Office Buildings (SMOB) has been developed from the results of industry survey, focus group discussions and Delphi study. The model delivers a framework of improving sustainability performance of existing office buildings.

The SMOB provides four sustainable indicators and especially, 23 criteria for improving current maintenance practices for an office building that will achieve better sustainability. The criteria covers all the necessary activities to improve maintenance practices for office buildings that include routine maintenance, ad hoc maintenance and upgrading maintenance together with external factors to support the improvements. Each criterion denotes a system or equipment which is necessary to be improved or upgraded aimed to reduce the use of energy or water in running the systems or equipment over its long term performance as shown in Figures 7.1 and 7.2, Chapter 7. The SMOB will assist stakeholders in applying sustainable maintenance practices over the long term in balancing environmental and economic concerns. In environmental

performance, the SMOB provides a method for existing office buildings to achieve energy and water efficiency, increase the usefulness of environmental materials, decrease waste disposed to landfill, and in particular, minimise CO_2 emitted to the environment. It provides a framework for lessening the impacts between office buildings and the environment and therefore reducing the effects of climate change.
In economic performance, the SMOB provides a tool for evaluation benefits for the costs incurred in improving current maintenance practices for existing office buildings with three levels of improvements/upgrades: lower, intermediate and higher capital costs as shown in Figure 7.4, Chapter 7. This provides the building owners flexibility in applying the SMOB to the buildings depending on their budgets. The SMOB will also provide cost savings and increased benefits from the maintenance of building systems and equipment as a result of improvements over the long-term.

Objective 7 – Verify the effectiveness and usefulness of the SMOB

As analysed in Chapter 8, the developed SMOB has been verified to be useful and practical as a framework to analyse the interaction between the environment and existing buildings and to suggest strategies to reduce negative effects of existing buildings have on the environment during the operating stage of a building's life cycle. The features of SMOB can be applied to improve an existing office so that it is more sustainable and satisfy environmental protection requirements through sustainable maintenance practices. Therefore impacts can be minimised for the long term reduction of energy and water consumption and reduction of waste and CO_2 emissions. The case studies have verified that the SMOB framework provides a platform to change a non-performing office building and become a green building by using the SMOB as the mainstream maintenance practice.

The assessment on the environmental approach has shown that by using the SMOB the case study buildings can potentially achieve a great savings on CO_2 emissions to the environment. The total annual CO_2 emissions from Building 1 was reduced from 143 to approximately 87 kg CO_2/m^2, Building 2 from 112 to 62 kg CO_2/m^2 and Building 3 from 147 to 108 kg CO_2/m^2 per year.

The evaluation on the economic approach indicated that the cost benefits through improvement/upgrade systems or equipment embedded in the buildings provide great savings in return from the costs involved. Building 1 achieved a potential annual savings approximately $18/m^2$, Building 2 $16/m^2$ and Building 3 $13/m^2$ per year.

Additionally, the calculation of the three case study buildings based on the SMOB in Chapter 8 has found that all three would achieve energy intensity under 100kWh/m^2 annually. As a result, they may be recognised as environmentally friendly buildings and satisfies the environment protection requirements according to Hestnes and Kofoed (2002); and Steinfeld, Bruce and Watt (2011).

9.6 Recommendations for Further Research

As specified, the research has identified four principal sustainable development indicators that can support improvements to an office building via improving routine, ad hoc, upgrading maintenance and external factors. Twenty-three criteria to improve maintenance practices for office buildings have been identified. During the research it was noted that there is scope for further study. It is suggested that the following further research is desirable to increase and expand the findings associated with this research project.

9.6.1 Cooperation of Building Owners, Professionals and Tenants

The focus of this research was to explore building professionals' perceptions in relation to the significance of the environment in building maintenance. From the surveys, the perspectives of these professionals in improving maintenance practices considered additional costs on environmental performance for sustainable maintenance of office buildings. Even though most professionals are aware of the environmental crisis, due to budget constraints and uncertain costs of environmental development, most of these office buildings are maintained with conventional maintenance practices (as discussed in Chapter 6). Consequently, they may retain these practices for a long time. This research has found that a large number of key stakeholders and professionals in office buildings have limited knowledge about new technologies for the development of sustainable maintenance practices for office buildings. Therefore, education would provide those people with knowledge about new technologies on green or sustainable buildings. Further research can investigate the level of knowledge key stakeholders and building professionals require for sustainable buildings, the benefits in upgrading to new technologies, a convenient way for the programs of education and skill training to be delivered, and the length of time necessary for these programs to run.

Another concern is the lack of cooperation between owners and tenants in the performance of sustainable maintenance of office buildings. Lack of cooperation can mean sustainable maintenance practices are ineffective, as pointed out by Pati, Park and Augenbroe (2010). Cooperation could accelerate the development and establishment of sustainable maintenance practices as the mainstream practice for office buildings. Further research can investigate how cooperation could be generated, how to convince the parties to maintain the cooperation, and what benefits each party can gain from the cooperation. For cooperation to be successful, a win-win solution could be considered. Further research can also establish a metaphor for the incorporation and exchange of information between these parties.

9.6.2 Support from Government

Hassler (2009) points out that there are limitations on green building instruments in the achievement of long-term targets for existing office buildings. These limitations include: insufficient information provided in the building industry, the effects of long-term performance being barely known, the economic framework preferring to demolish and rebuild rather than retain existing buildings, and the current legal framework being mostly suited to new buildings and new developments. However, this research has found that existing office buildings can be maintained and improved to become more sustainable as demonstrated in the three case studies in Chapter 8. Further research can investigate how the government can effectively support the application of sustainable maintenance to become the standard practice for existing office buildings; how regulations will suit the long-lasting effects of existing office buildings; and how incentive programs will influence and expedite the application of sustainable maintenance practices for existing office buildings.

9.6.3 Improvements to the Environmental and Economic Approaches

This research investigated the improvement to our environment through improving strategic maintenance programs for existing office buildings. The study mainly focused on maintenance practices for service systems and equipment for energy and water efficient consumption within the buildings, from environmental and financial viewpoints. The best practices in energy and water efficiency can be further achieved through improving the building's envelope and spaces, green roof, passive natural air comfort, garden and ornaments, operation of the buildings, and occupants behaviour in reducing consumption of energy and water within the buildings. Further research can investigate these categories, particularly occupants behaviour in the use of energy and water within office buildings, for further improvement of our environment with better costs and benefits.

The research has found that water leaks in office buildings take place at a rate of 26% of water consumption annually (Australian Department of the Environment and Heritage 2006; Chen, Ngo & Guo 2012; City West Water 2014). The leaks might have occurred due to piping systems, water devices/fixtures, running HVAC systems, particularly the water cooling towers, and due to occupants behaviour. Water leaks increase costs in operation and maintenance of office buildings and waste water. Water leakage could be further researched to reduce or stop this problem for office buildings and extended to other types of building.

This is particularly important if energy and water efficiency is further analysed to have a more comprehensive improvement on costs and savings over the long-term. Therefore, the research on energy and water analysis is extremely important for further research in order to provide further environmental improvement and more transparent analysis in costs and benefits of sustainable maintenance practices.

Moreover, Berardi (2013) argues that many difficulties still exist in the definition of a sustainable building, as the term is technologically not clear. That can lead to confusion, delay and/or avoidance in developing sustainable maintenance practices for office buildings due to the uncertainty of the definition of sustainable buildings within the industry. Therefore, further research can investigate this area in establishing a clear and comprehensive definition of sustainable maintenance of office buildings, so that professionals within the property management sector can agree on how to make office buildings sustainable.

9.6.4 Extending on from the SMOB

This thesis has concentrated on investigating ways to improve current maintenance practices for existing office buildings for sustainability in the long term performance. The outcome is the SMOB, which opens up many opportunities for further research.

The literature review found that even though there are a large number of research studies in the building industry to explore or test, there is little research that studies the sustainable maintenance of office buildings, as discussed in Chapter 5. Moreover, there are not many strategic models for the sustainable maintenance of office buildings established in the industry. Therefore, this area has immense room for further research to improve maintenance practices for office buildings.

Case studies of three high-rise office buildings located in the Sydney CBD were used to verify the SMOB, but this is a limitation of the research. Furthermore, the investigation on the case studies was conducted only on the base buildings, due to limitations in accessing tenants spaces. Therefore, further research would be necessary to investigate the whole building if possible.

In addition, the case studies for this research were conducted with private office buildings only. It is considered that public office buildings might have the same problems as private office buildings do. Thus, further research can investigate ways to improve public office buildings to become sustainable. Both private and public office buildings could contribute to conforming to environmental protection requirements.

The scope of this research only studied existing high-rise office buildings. Further research can be carried out on other types of buildings; for example, low-rise office buildings, retail, industrial, warehouses, schools, hotels and motels, and residential buildings. Significantly, all types of buildings impact the environment. The level of impact is hypothesised to depend on the type of building. Therefore, further research can investigate each type of building to identify the necessary environmental maintenance criteria that will accelerate the rate of improving the environment.

This research only investigated existing office buildings in the city of Sydney, so it only represents the characteristics and culture of Sydney's office buildings. Thus, further research can study different characteristics and cultures in other cities and states across Australia. Studies from different geographic areas and regions will provide different strategic ways for developing sustainable maintenance practices for office buildings in the relevant areas and regions.

Furthermore, additional research can investigate other areas and regions internationally. Climate change is a global crisis. Improving the global environment means looking at global activities. Sustainable maintenance of office buildings is necessary across different global areas and regions due to its effects being different from area to area and region to region. Applying the SMOB internationally will provide interesting opportunities for comparisons and exchange of information. These opportunities will enhance the robustness of the methodology for practicing sustainable maintenance of office buildings and therefore improving the environment.

Finally, as identified by the Green Building Council of Australia (2008) and confirmed by this research, improving sustainable maintenance practices for existing office buildings in a long term approach has been largely untapped. Therefore, this study on sustainable maintenance will open up many opportunities for further research on the development of sustainable maintenance practices for office buildings and other types of building.

9.7 Conclusion

The objective of this research project was to provide a framework for maintenance that reduces energy and water consumption, and CO_2 emitted from existing office buildings through applying sustainability as part of the mainstream practices. This resulted in the development of the SMOB. The model will assist stakeholders to improve their existing office building performance to become more environmentally friendly through sustainable maintenance practices.

Based on this objective, the research has extensively reviewed traditional maintenance practices against sustainable maintenance practices, and the assessment of sustainable maintenance practices across environmental and economic factors. The knowledge acquired from the reviews established a framework for further investigation into the development of SMOB through the process of questionnaire survey, focus group discussion and Delphi study; and finally case studies used to verify that the SMOB is applicable.

The investigation found that a building using the SMOB as a framework for sustainable maintenance practices may significantly reduce the use of energy and water, and reduce CO_2 emissions in the buildings. The investigation also found that a non-green building can be improved to satisfy the environmental protection requirements and become a green or sustainable building.

SMOB provides a method for improved environmental performance in energy efficiency, indoor climate or indoor environment quality, lighting efficiency, water efficiency, increased use of environmentally friendly materials, decreased waste disposed to landfill, and in particular minimising CO_2 emissions into the environment. This will lessen the impact of office buildings on the environment and therefore reduce the effects of climate change. The SMOB also provides three levels on costs required to improve or upgrade the building's systems and equipment over the long term and balancing environmental and economic aspects. The savings provided by the SMOB are the dollar value on energy cost per GFA per square metre ($\$/m^2$), kilowatts of energy consumed per hour per GFA per square metre (kWh/m^2) and kilograms of CO_2 emitted per GFA per square metre (kg CO_2/m^2). Using the SMOB as either a mainstream or an alternative practice for building maintenance could result in an existing office building moving from a non-green building to environmentally friendly building.

The SMOB has positively answered all of the questions, and satisfied all the aims and objectives established by the research project. It provides the best solution for improving existing office buildings via sustainable maintenance practices over the long term. The research is complete at this stage; however, it has opened up opportunities for further research in many other areas. The findings can be further investigated to accomplish the ultimate target of reducing CO_2 emissions from the buildings, encourage and increase sustainable maintenance practices for office buildings in other regions.

Appendix 1-1 Sustainable Maintenance of Office Buildings Pilot Survey

The aim of this survey is to gather your personal opinions regarding improving office buildings aiming for sustainability and environmental protection. The collected data will contribute to the research project of improving office buildings to be environmentally-friendly, particularly, through maintenance practices in the industry. The survey is confidential and no identity will be revealed from the survey. The survey reply will be used for research purposes only.

Thank you very much for your participation in the survey.

Dinh Manh Nguyen
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University of Technology Sydney
Email: Dinh.M.Nguyen@student.uts.edu.au

Part I: General Information

(To check: double click on box, checked and OK)

1.1 Your gender: ☐ Male ☐ Female

1.2 Your age:

☐ 25 or under	☐ 36 – 45	☐ 56 – 65
☐ 26 – 35	☐ 46 – 55	☐ Over 65

1.3 Your Academic qualifications:

☐ PhD ☐ Master ☐ First Degree

☐ Other (please specify):

1.4 Your professional qualifications:

☐ AIQS	☐ BIFM	☐ CIOB	☐ FMA
☐ ICE	☐ IFMA	☐ RAIA	☐ RICS

☐ Other (please specify):

1.5 Please indicate your current position held in the industry (please tick only one):

☐ Building Owner ☐ Developer ☐ Architect/Engineer

☐ Builder/Contractor ☐ Facility Manager ☐ Tenant

☐ Other (please specify):

1.6 How long have you been working in your current position?

☐ 5 years or under ☐ 11 – 15 years ☐ Over 20 years

☐ 6 – 10 years ☐ 16 – 20 years

1.7 For each of the following statements, please indicate whether you agree or disagree with that statement:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Existing buildings impact on the environment because they are energy and water inefficient.	☐	☐	☐	☐	☐
Sustainability initiatives are important in the maintenance of buildings.	☐	☐	☐	☐	☐
The current practices of building maintenance do not support sustainable maintenance of buildings thus radical changes may be required.	☐	☐	☐	☐	☐
Sustainability strategies need to be developed and incorporated into the current maintenance practices of buildings.	☐	☐	☐	☐	☐
Sustainability maintenance of buildings will grow substantially over the next five years.	☐	☐	☐	☐	☐
Further growth in the sustainability maintenance of buildings is desirable.	☐	☐	☐	☐	☐

1.8 In your opinion, please indicate the importance of each of the following factors in influencing the current uptake of sustainability initiatives in building maintenance:

	Very unimportant	Un-important	Neutral	Important	Very important
Time	☐	☐	☐	☐	☐
Cost	☐	☐	☐	☐	☐
Community perception	☐	☐	☐	☐	☐
Professional knowledge and expertise	☐	☐	☐	☐	☐
Availability of environmental friendly materials	☐	☐	☐	☐	☐
Maintenance practices	☐	☐	☐	☐	☐
Current Government policies/legislation	☐	☐	☐	☐	☐
Performance data of sustainable technologies	☐	☐	☐	☐	☐
Commercial incentive	☐	☐	☐	☐	☐
Commitment of property owners	☐	☐	☐	☐	☐

1.9 Please rank the importance of the following factors to sustainability maintenance of office buildings:

	Very unimportant	Un-important	Neutral	Important	Very important
Indoor air quality	☐	☐	☐	☐	☐
Use of low environmental impact materials	☐	☐	☐	☐	☐
Use of recycled building materials	☐	☐	☐	☐	☐
Replace existing system with green energy	☐	☐	☐	☐	☐
Harvest rainwater	☐	☐	☐	☐	☐
Recycle grey or black water	☐	☐	☐	☐	☐
Develop sustainable strategies	☐	☐	☐	☐	☐
Develop legislation to sustainability maintenance of buildings	☐	☐	☐	☐	☐

1.10 Do you have experience in maintaining office buildings?

☐ Yes (Please go to Q 2.1)

☐ No (Please go to Q 3.1)

Part II: Sustainable Maintenance of Office Buildings

2.1 How long have you been in a role maintaining buildings?

☐ Less than 5 years ☐ 11 – 15 years ☐ 21 – 25 years

☐ 6 – 10 years ☐ 16 – 20 years ☐ 26 – 30 years

☐ More than 30 years

2.2 What major difficulties have you experienced in the maintenance of buildings? E.g. Insufficient fund.

2.3 When maintaining a building, do you apply sustainable practices?

☐ Always ☐ Mostly ☐ Not at all

If you answer "always", what sustainability initiatives have you taken into maintaining buildings?

If you answer "mostly", what sustainability initiatives have you taken into maintaining buildings?

If you answer "not at all", would you consider doing so in the next two years?

☐ Yes ☐ No ☐ Cannot decide

2.4 Does your company have an organizational sustainability policy?

☐ Yes ☐ No

2.5 What do you think you can do to improve maintenance practices to be more environmentally-friendly?

2.6 What time frames do you envisage within which sustainable maintenance could potentially be the mainstream practice in the industry?

☐ Already mainstream practice ☐ 6-10 years ☐ More than 15 years

☐ Next 5 years ☐ 11-15 years ☐ Never

Part III: Further Participation (Optional)

3.1 Would you like to be contacted for participation in a focus group discussion or a Delphi study to further assist this research?

☐ Yes ☐ No

If YES, please insert:

Your name: ______________________

Your telephone number: ______________________

Or your Email addresses: ______________________

Thank you very much for your participation in this survey.

Appendix 1.2 Sustainable Maintenance of Office Buildings Main Survey

The aim of this survey is to gather your opinions in regard to sustainability in office buildings and environmental protection.

The survey results will contribute to research which aims to identify strategies for improving the environmental performance of office buildings through building maintenance practices.

The survey will be used for academic research purposes only and survey responses will be treated as confidential information by UTS. Survey results will be reported / presented in an aggregated form only.

No individual contributor, employer or related organisation will be identifiable from the results of survey data analysis or analysis reporting or any related publication materials.

The survey will take only minutes to complete.

We thank you very much for your participation in this research project.

Dinh Manh Nguyen
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University of Technology Sydney
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Part I: General Information

(To check: double click on box, checked and OK)

1.1 Your gender: ☐ Male ☐ Female

1.2 Your age:

☐ 25 or under ☐ 36 – 45 ☐ 56 – 65

☐ 26 – 35 ☐ 46 – 55 ☐ Over 65

1.3 Your Academic qualifications:

☐ PhD ☐ Master ☐ First Degree

☐ Other (please specify):

1.4 Your professional memberships (You can tick more than one):

☐ AIQS ☐ BIFM ☐ CIOB ☐ FMA ☐ ICE

☐ IFMA ☐ RAIA ☐ RICS ☐ API ☐ AIM

☐ Other (please specify):

1.5 Please indicate your current position held in the industry (Please tick only the best one):

☐ Owner ☐ Asset Manager ☐ Facility Manager

☐ Property Manager ☐ Sustainability Manager ☐ Tenant / Tenant Representative

☐ Leasing Agent ☐ Builder / Contractor ☐ Building Services Professional

☐ Other (please specify):

1.6 How long have you been in your current role?

☐ 5 years or under ☐ 11 – 15 years ☐ Over 20 years

☐ 6 – 10 years ☐ 16 – 20 years

1.7 For each of the following statements, please indicate whether you agree or disagree with that statement in regards to office building maintenance:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Existing buildings impact on the environment because they are energy and water inefficient.	☐	☐	☐	☐	☐
Sustainability initiatives are important in the maintenance of buildings.	☐	☐	☐	☐	☐
The current practices of building maintenance do not support sustainable maintenance of buildings thus changes may be required.	☐	☐	☐	☐	☐
Sustainability strategies need to be developed and incorporated into building maintenance practices.	☐	☐	☐	☐	☐
Sustainable maintenance practices will gain momentum over the next five years.	☐	☐	☐	☐	☐
Further growth in the sustainable maintenance practices is desirable.	☐	☐	☐	☐	☐

1.8 Please indicate the importance of each of the following factors in influencing the current uptake of sustainability initiatives in office building maintenance:

	Very Unimportant	Un-Important	Neutral	Important	Very Important
Time	☐	☐	☐	☐	☐
Cost	☐	☐	☐	☐	☐
Community perception	☐	☐	☐	☐	☐
Corporate social responsibility policies	☐	☐	☐	☐	☐
Professional knowledge and expertise	☐	☐	☐	☐	☐
Availability of environmental-friendly materials	☐	☐	☐	☐	☐
Pre-existing maintenance practices	☐	☐	☐	☐	☐
Current Government policies / legislation	☐	☐	☐	☐	☐
Performance data of sustainable technologies	☐	☐	☐	☐	☐
Potential Government incentives	☐	☐	☐	☐	☐
Demands from property tenants	☐	☐	☐	☐	☐
Commitment of property owners	☐	☐	☐	☐	☐

1.9 Identify how significant the following factors are in regard to achieving sustainable maintenance practices for office buildings:

	Very unimportant	Un-important	Neutral	Important	Very important
Indoor air quality	☐	☐	☐	☐	☐
Use of low environmental impact building materials	☐	☐	☐	☐	☐
Use of recycled building materials	☐	☐	☐	☐	☐
Purchasing green energy	☐	☐	☐	☐	☐
Replace existing system with energy efficient devices	☐	☐	☐	☐	☐
Harvesting rainwater	☐	☐	☐	☐	☐
Recycle grey or black water	☐	☐	☐	☐	☐
Impact of building sustainability "management committee's"	☐	☐	☐	☐	☐
Development of sustainable management strategies for the building	☐	☐	☐	☐	☐
Develop legislation for sustainable maintenance of office buildings	☐	☐	☐	☐	☐
Specified cleaning products / paints	☐	☐	☐	☐	☐

1.10 Do you have experience in maintaining office buildings?

☐ Yes (Please go to Q 2.1)

☐ No (Please go to Q 3.1)

Part II: Sustainable Maintenance of Office Buildings

2.1 How long have you been involved in decisions relating to office building maintenance?

☐ Less than 5 years ☐ 11 – 15 years ☐ 21 – 25 years

☐ 6 – 10 years ☐ 16 – 20 years ☐ 26 – 30 years

☐ More than 30 years

2.2 In a general sense, what are the major difficulties you experience in regard to the maintenance of office buildings?

2.3 When maintaining an office building, do you apply sustainable practices?

☐ Always ☐ Mostly ☐ Not at all

If you answered "always", what sustainability initiatives have you undertaken in maintaining office buildings?

If you answered "mostly", what sustainability initiatives have you undertaken in maintaining office buildings?

If you answered "not at all", would you consider doing so in the next two years?

☐ Yes ☐ No ☐ Cannot decide

2.4 Does your company have an organizational sustainability policy?

☐ Yes ☐ No

2.5 Would you suggest ways of improving maintenance practices to be more environmentally friendly?

2.6 What time frames do you envisage within which sustainable maintenance could potentially be mainstream practice in the industry?

☐ Already mainstream practice ☐ 6-10 years ☐ More than 15 years

☐ Next 5 years ☐ 11-15 years ☐ Never

2.7 Current legislation is effective enough to ensure that due consideration is given to sustainable building maintenance practices.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2.8 When performing / arranging maintenance activities on office buildings, I use sustainable materials and/or products, such as non-toxic, reusable, renewable and / or recyclable items if they are readily available even at a higher price.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

☐ This question is not applicable to my role

2.9 I advise key-stakeholders to use sustainable materials and / or products, such as non-toxic, reusable, renewable and/or recyclable items.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

☐ This question is not applicable to my role

Part III: Further Participation (Optional)

3.1 Would you like to be contacted for participation in a focus group discussion or a Delphi study to further assist this research?

☐ Yes ☐ No

If YES, please insert:

Your name: ____________________

Your telephone number: ____________________

Or your Email addresses: ____________________

3.2 Would you like to receive a copy of the survey results analysis when available?

☐ Yes ☐ No

If YES, please insert:

Your name: ____________________

Your telephone number: ____________________

Or your Email addresses: ____________________

Thank you very much for your participation in this survey.

Appendix 2.1 Mean Difference Tests for Six Questions of Survey Question 1.7

The followings are the tests using SPSS for mean difference of groups of samples for six sub-questions, 1.7.1 to 1.7.6, of the Survey Question 1.7. Refer Appendix 1 for further details on the questionnaire.

T-Test between Owners and Tenants

Group Statistics

	Respondents Positions	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	Owner/Developer	6	**82.1667**	**13.52652**	5.52218
	Tenant	6	**66.6667**	**22.40238**	9.14573

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainability Development	Equal variances assumed	2.925	.118	**1.451**	**10**	**.177**	15.50000	10.68358	-8.30450	39.30450
	Equal variances not assumed			1.451	8.218	.184	15.50000	10.68358	-9.02308	40.02308

There was no significant difference in the score for Owners (M=82%, SD=13.50) and Tenants (M=67%, SD=22.40) in opinions on development of sustainable maintenance strategies for existing office buildings conditions; t(10)=1.45, p=0.177. These results identify that the opinions of Owners and Tenants are completely independence to each other. Specifically, our results identify that Owners and Tenants have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices.

T-Test between Asset/Property Managers and FM/Sustainability Managers

Group Statistics					
	Respondents Positions	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	Asset/Property Managers	6	**76.5000**	**24.08942**	9.83446
	FM/Sustainability Managers	6	**76.0000**	**13.85641**	5.65685

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainability Development	Equal variances assumed	2.390	.153	**.044**	**10**	**.966**	.50000	11.34534	-24.77899	25.77899
	Equal variances not assumed			.044	7.982	.966	.50000	11.34534	-25.67257	26.67257

The same as the test between Owners and Tenants, there was no significant difference in the score for Asset/Property Managers (M=77%, SD=24.00) and Facility/Sustainability Managers (M=76%, SD=13.86) in opinions on development of sustainable maintenance strategies for existing office buildings conditions; t(10)=0.44, p=0.97. These results identify that the opinions of Asset/Property Managers and Facility/Sustainability Managers are completely independence to each other. Specifically, our results identify that Asset/Property Managers and Facility/Sustainability Managers also have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices.

One-way ANOVA Test between Owners, Tenants, Asset/Property Managers and Facility/Sustainability Managers.

One-way

Descriptives

Sustainability Development

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Owners/Developers	6	**82.1667**	**13.52652**	5.52218	67.9715	96.3619	64.00	100.00
Tenants/Leasing Agents	6	**66.6667**	**22.40238**	9.14573	43.1568	90.1765	44.00	100.00
Asset/Property Managers	6	**76.5000**	**24.08942**	9.83446	51.2197	101.7803	33.00	94.00
FM/Sustainability Managers	6	**76.0000**	**13.85641**	5.65685	61.4586	90.5414	50.00	90.00
Total	24	75.3333	18.68193	3.81343	67.4446	83.2220	33.00	100.00

Test of Homogeneity of Variances

Sustainability Development

Levene Statistic	df1	df2	Sig.
1.726	3	20	.194

ANOVA

Sustainability Development

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	741.667	**3**	247.222	**.679**	**.575**
Within Groups	7285.667	**20**	364.283		
Total	8027.333	23			

A One-way between Subjects ANOVA was conducted to compare the effect of opinions on development of sustainable maintenance practices for existing office buildings. There was no significant effect their opinions at the $p > 0.05$ level for the four conditions [$F(3, 20) = 0.68$, $p = 0.58$].

Post Hoc Tests

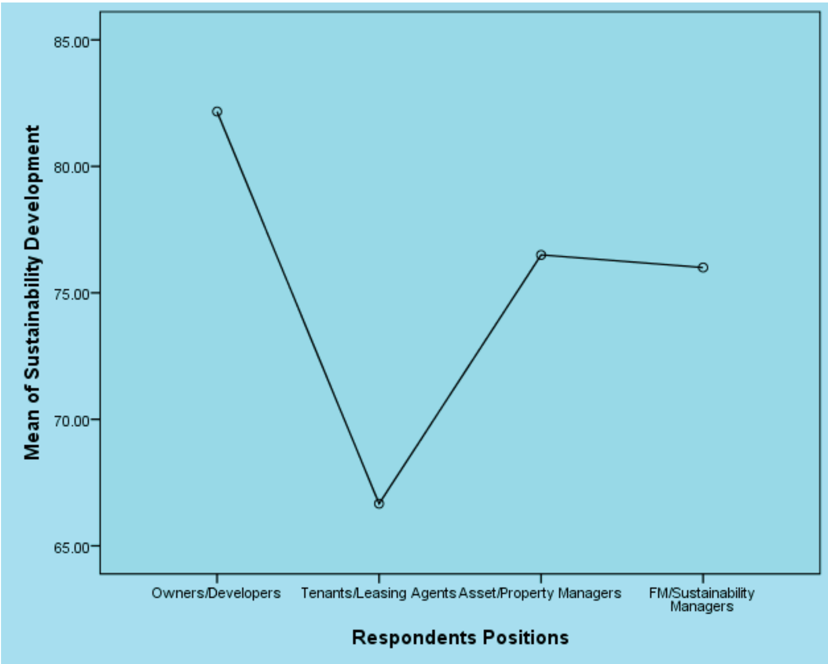
Multiple Comparisons							
Dependent Variable: Sustainability Development							
	(I) Respondents Positions	(J) Respondents Positions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Owners/Developers	Tenants/Leasing Agents	15.50000	11.01943	.510	-15.3427	46.3427
		Asset/Property Managers	5.66667	11.01943	.955	-25.1760	36.5093
		FM/Sustainability Managers	6.16667	11.01943	.943	-24.6760	37.0093
	Tenants/Leasing Agents	Owners/Developers	-15.50000	11.01943	.510	-46.3427	15.3427
		Asset/Property Managers	-9.83333	11.01943	.809	-40.6760	21.0093
		FM/Sustainability Managers	-9.33333	11.01943	.831	-40.1760	21.5093
	Asset/Property Managers	Owners/Developers	-5.66667	11.01943	.955	-36.5093	25.1760
		Tenants/Leasing Agents	9.83333	11.01943	.809	-21.0093	40.6760
		FM/Sustainability Managers	.50000	11.01943	1.000	-30.3427	31.3427
	FM/Sustainability Managers	Owners/Developers	-6.16667	11.01943	.943	-37.0093	24.6760
		Tenants/Leasing Agents	9.33333	11.01943	.831	-21.5093	40.1760
		Asset/Property Managers	-.50000	11.01943	1.000	-31.3427	30.3427
Dunnett T3	Owners/Developers	Tenants/Leasing Agents	15.50000	10.68358	.634	-20.2068	51.2068
		Asset/Property Managers	5.66667	11.27879	.995	-32.4458	43.7791
		FM/Sustainability Managers	6.16667	7.90534	.959	-19.1277	31.4610
	Tenants/Leasing Agents	Owners/Developers	-15.50000	10.68358	.634	-51.2068	20.2068
		Asset/Property Managers	-9.83333	13.42986	.969	-52.8445	33.1779
		FM/Sustainability Managers	-9.33333	10.75381	.933	-45.1484	26.4818
	Asset/Property Managers	Owners/Developers	-5.66667	11.27879	.995	-43.7791	32.4458
		Tenants/Leasing Agents	9.83333	13.42986	.969	-33.1779	52.8445
		FM/Sustainability Managers	.50000	11.34534	1.000	-37.6959	38.6959
	FM/Sustainability Managers	Owners/Developers	-6.16667	7.90534	.959	-31.4610	19.1277
		Tenants/Leasing Agents	9.33333	10.75381	.933	-26.4818	45.1484
		Asset/Property Managers	-.50000	11.34534	1.000	-38.6959	37.6959

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the four conditions as Owners (M=82%, SD=13.53), Tenants (M=67%, SD=22.40), Asset/Property managers (M=77, SD=24.00) and Facility/Sustainable Managers (M=76%, SD=5.66).

Homogeneous Subsets

Sustainability Development			
	Respondents Positions	N	Subset for alpha = 0.05
			1
Tukey HSD[a]	Tenants/Leasing Agents	6	66.6667
	FM/Sustainability Managers	6	76.0000
	Asset/Property Managers	6	76.5000
	Owners/Developers	6	82.1667
	Sig.		.510
Means for groups in homogeneous subsets are displayed.			
a. Uses Harmonic Mean Sample Size = 6.000.			

Means Plots



Outcome

There was no significant effect on the opinions of four positions of Owners, Tenants, Asset/Property managers and Facility/Sustainable Managers on development of sustainable maintenance strategies for existing office buildings at $p > 0.05$ level for the four conditions [$F(3, 20) = 0.68$, $p = 0.58$].

Post Hoc comparisons using the Tukey HSD test indicated that there was no significantly different for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the four conditions as Owners (M=82%, SD=13.53), Tenants (M=67%, SD=22.40), Asset/Property managers (M=77, SD=24.00) and Facility/Sustainable Managers (M=76%, SD=5.66).

Taken together, these results identify that the opinions of the four conditions of Owners, Tenants, Asset/Property managers and Facility/Sustainable Managers are completely independent to each other. Specifically, our results identify that Owners, Tenants, Asset/Property managers and Facility/Sustainable Managers have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water, and sustainable maintenance strategies should be developed for maintenance practices.

T-Test between Respondents aged 25 y/o and under vs. Respondents aged 26–35 y/o.

Group Statistics					
	Respondents Age	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	25 y/o and under	6	**80.6667**	**18.77942**	7.66667
	26 - 35 y/o	6	**78.3333**	**19.20069**	7.83865

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainability Development	Equal variances assumed	.001	.970	**.213**	**10**	**.836**	2.33333	10.96459	-22.09729	26.76396
	Equal variances not assumed			.213	9.995	.836	2.33333	10.96459	-22.09892	26.76559

There was no significant difference in the score for Respondents aged 25 years old and under (M=81%, SD=18.78) and Respondents aged 26 – 35 years old (M=78%, SD=19.2) in opinions about development of sustainable maintenance strategies for existing office buildings conditions; t(10)=0.213, p=0.84. These results identify that the opinions of Respondents aged 25 years old and under and Respondents aged 26 – 35 years old are completely independence to each other. Specifically, our results identify that Respondents aged 25 years old and under and Respondents aged 26 – 35 years old have the same opinion the existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices.

T-Test between Respondents aged 25 y/o and under vs. Respondents aged 46–55 y/o.

Group Statistics					
	Respondents Age	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	25 y/o and under	6	**80.6667**	**18.77942**	7.66667
	46 - 55 y/o	6	**77.1667**	**17.38294**	7.09656

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainability Development	Equal variances assumed	.283	.606	**.335**	**10**	**.745**	3.50000	10.44696	-19.77727	26.77727
	Equal variances not assumed			.335	9.941	.745	3.50000	10.44696	-19.79605	26.79605

There was no significant difference in the score for respondents aged at 25 years old and under (M=81%, SD=18.78) and respondents aged at 46–55 years old (M=77%, SD=17.40) in opinions on development of sustainable maintenance strategies for existing office buildings conditions; t(10)=0.335, p=0.75. These results identify that the opinions of respondents aged at 25 years old and under and Respondents aged at 46–55 years old are completely independence to each other. Specifically, our results identify that respondents aged at 25 years old and under and respondents aged at 46–55 years old have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices.

One-way ANOVA Test between Six Categories of Age of Respondents

One-way

Descriptives

Sustainability Development

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
25 y/o and under	6	**80.6667**	**18.77942**	7.66667	60.9589	100.3745	50.00	100.00
26 35 y/o	6	**78.3333**	**19.20069**	7.83865	58.1834	98.4832	43.00	94.00
36 - 45 y/o	6	**79.6667**	**15.27962**	6.23788	63.6317	95.7016	50.00	91.00
46 - 55 y/o	6	**77.1667**	**17.38294**	7.09656	58.9244	95.4089	44.00	93.00
56 - 65 y/o	6	**78.8333**	**13.97736**	5.70623	64.1650	93.5017	57.00	93.00
65 y/o and over	6	**83.3333**	**21.03014**	8.58552	61.2636	105.4031	50.00	100.00
Total	36	79.6667	16.57192	2.76199	74.0595	85.2738	43.00	100.00

Test of Homogeneity of Variances

Sustainability Development

Levene Statistic	df1	df2	Sig.
.366	5	30	.868

ANOVA

Sustainability Development

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	139.000	**5**	27.800	**.088**	**.994**
Within Groups	9473.000	**30**	315.767		
Total	9612.000	35			

A One-way between Subjects ANOVA was conducted to compare the effect of opinions on development of sustainable maintenance practices for existing office buildings. There was no significant effect their opinions at the $p > 0.05$ level for the six conditions [$F(5,30) = 0.88$, $p = 0.99$].

Post Hoc Tests

Multiple Comparisons

Dependent Variable:Sustainability Development

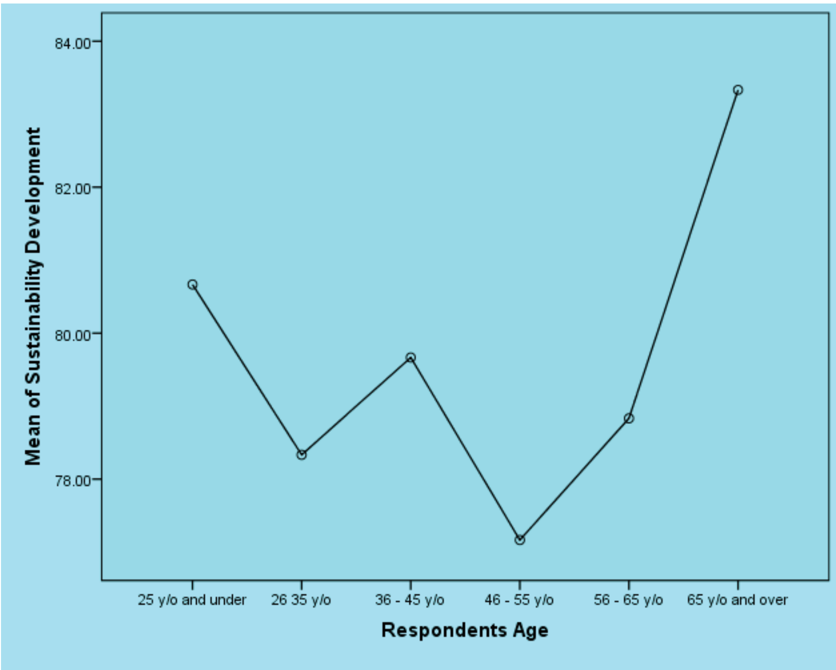
	(I) Respondents Age	(J) Respondents Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	25 y/o and under	26 35 y/o	2.33333	10.25941	1.000	-28.8716	33.5383
		36 - 45 y/o	1.00000	10.25941	1.000	-30.2050	32.2050
		46 - 55 y/o	3.50000	10.25941	.999	-27.7050	34.7050
		56 - 65 y/o	1.83333	10.25941	1.000	-29.3716	33.0383
		65 y/o and over	-2.66667	10.25941	1.000	-33.8716	28.5383
	26 35 y/o	25 y/o and under	-2.33333	10.25941	1.000	-33.5383	28.8716
		36 - 45 y/o	-1.33333	10.25941	1.000	-32.5383	29.8716
		46 - 55 y/o	1.16667	10.25941	1.000	-30.0383	32.3716
		56 - 65 y/o	-.50000	10.25941	1.000	-31.7050	30.7050
		65 y/o and over	-5.00000	10.25941	.996	-36.2050	26.2050
	36 - 45 y/o	25 y/o and under	-1.00000	10.25941	1.000	-32.2050	30.2050
		26 35 y/o	1.33333	10.25941	1.000	-29.8716	32.5383
		46 - 55 y/o	2.50000	10.25941	1.000	-28.7050	33.7050
		56 - 65 y/o	.83333	10.25941	1.000	-30.3716	32.0383
		65 y/o and over	-3.66667	10.25941	.999	-34.8716	27.5383
	46 - 55 y/o	25 y/o and under	-3.50000	10.25941	.999	-34.7050	27.7050
		26 35 y/o	-1.16667	10.25941	1.000	-32.3716	30.0383
		36 - 45 y/o	-2.50000	10.25941	1.000	-33.7050	28.7050
		56 - 65 y/o	-1.66667	10.25941	1.000	-32.8716	29.5383
		65 y/o and over	-6.16667	10.25941	.990	-37.3716	25.0383
	56 - 65 y/o	25 y/o and under	-1.83333	10.25941	1.000	-33.0383	29.3716
		26 35 y/o	.50000	10.25941	1.000	-30.7050	31.7050
		36 - 45 y/o	-.83333	10.25941	1.000	-32.0383	30.3716
		46 - 55 y/o	1.66667	10.25941	1.000	-29.5383	32.8716
		65 y/o and over	-4.50000	10.25941	.998	-35.7050	26.7050
	65 y/o and over	25 y/o and under	2.66667	10.25941	1.000	-28.5383	33.8716
		26 35 y/o	5.00000	10.25941	.996	-26.2050	36.2050
		36 - 45 y/o	3.66667	10.25941	.999	-27.5383	34.8716
		46 - 55 y/o	6.16667	10.25941	.990	-25.0383	37.3716
		56 - 65 y/o	4.50000	10.25941	.998	-26.7050	35.7050
Dunnett T3	25 y/o and under	26 35 y/o	2.33333	10.96459	1.000	-37.9849	42.6516
		36 - 45 y/o	1.00000	9.88377	1.000	-35.6818	37.6818
		46 - 55 y/o	3.50000	10.44696	1.000	-34.9623	41.9623
		56 - 65 y/o	1.83333	9.55714	1.000	-33.9671	37.6338
		65 y/o and over	-2.66667	11.51038	1.000	-45.1091	39.7757
	26 35 y/o	25 y/o and under	-2.33333	10.96459	1.000	-42.6516	37.9849
		36 - 45 y/o	-1.33333	10.01776	1.000	-38.5887	35.9220
		46 - 55 y/o	1.16667	10.57381	1.000	-37.7969	40.1303
		56 - 65 y/o	-.50000	9.69565	1.000	-36.9182	35.9182
		65 y/o and over	-5.00000	11.62564	1.000	-47.8241	37.8241
	36 - 45 y/o	25 y/o and under	-1.00000	9.88377	1.000	-37.6818	35.6818
		26 35 y/o	1.33333	10.01776	1.000	-35.9220	38.5887
		46 - 55 y/o	2.50000	9.44840	1.000	-32.3688	37.3688
		56 - 65 y/o	.83333	8.45412	1.000	-30.3057	31.9724
		65 y/o and over	-3.66667	10.61236	1.000	-43.5379	36.2046
	46 - 55 y/o	25 y/o and under	-3.50000	10.44696	1.000	-41.9623	34.9623
		26 35 y/o	-1.16667	10.57381	1.000	-40.1303	37.7969
		36 - 45 y/o	-2.50000	9.44840	1.000	-37.3688	32.3688
		56 - 65 y/o	-1.66667	9.10616	1.000	-35.4986	32.1653
		65 y/o and over	-6.16667	11.13877	1.000	-47.4506	35.1173
	56 - 65 y/o	25 y/o and under	-1.83333	9.55714	1.000	-37.6338	33.9671
		26 35 y/o	.50000	9.69565	1.000	-35.9182	36.9182
		36 - 45 y/o	-.83333	8.45412	1.000	-31.9724	30.3057
		46 - 55 y/o	1.66667	9.10616	1.000	-32.1653	35.4986
		65 y/o and over	-4.50000	10.30884	1.000	-43.7111	34.7111
	65 y/o and over	25 y/o and under	2.66667	11.51038	1.000	-39.7757	45.1091
		26 35 y/o	5.00000	11.62564	1.000	-37.8241	47.8241
		36 - 45 y/o	3.66667	10.61236	1.000	-36.2046	43.5379
		46 - 55 y/o	6.16667	11.13877	1.000	-35.1173	47.4506
		56 - 65 y/o	4.50000	10.30884	1.000	-34.7111	43.7111

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the six conditions as respondents having 25 years old and under (M=81%, SD=18.78), 26–35 years old (M=78%, SD=19.20), 36–45 years old (M=80%, SD=15.28), 46–55 years old (M=80%, SD=15.28), 56–65 years old (M=79%, SD=13.98), and 65 years old and over (M=83%, SD=21.00).

Homogeneous Subsets

Sustainability Development			
	Respondents Age	N	Subset for alpha = 0.05
			1
Tukey HSD[a]	46 - 55 y/o	6	77.1667
	26 35 y/o	6	78.3333
	56 - 65 y/o	6	78.8333
	36 - 45 y/o	6	79.6667
	25 y/o and under	6	80.6667
	65 y/o and over	6	83.3333
	Sig.		.990
Means for groups in homogeneous subsets are displayed.			
a. Uses Harmonic Mean Sample Size = 6.000.			

Means Plots



Outcome

There was no significant effect on the opinions of six categories of age of respondents on development of sustainable maintenance strategies for existing office buildings at $p > 0.05$ level for the four conditions [$F(5,30) = 0.88$, $p = 0.99$].

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the six categories of age as respondents having 25 years old and under (M=81%, SD=18.78), 26–35 years old (M=78%, SD=19.20), 36–45 years old (M=80%, SD=15.28), 46– 5 years old (M=80%, SD=15.28), 56–65 years old (M=79%, SD=13.98), and 65 years old and over (M=83%, SD=21.00).

Taken together, these results identify that the opinions of the respondents over six categories of age are completely independent to each other. Specifically, our results identify those Owners, Asset/Property Managers, Facility/Sustainability managers, Tenants, Building Service Professionals and Other Professionals have the same opinion that existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices. These opinions are not affected by the age of respondents.

Appendix 2.2 Mean Difference Tests for Three Questions of Survey Question 1.7

The followings are the tests using SPSS for mean difference of groups of samples for three questions, 1.7.1, 1.7.3 and 1.7.4, of the Survey Question 1.7. Refer Appendix 1 for further details on the questionnaire.

T-Test between Owners and Tenants

Group Statistics

	Respondents Positions	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	Owner/Developer	3	**78.33**	**19.088**	11.020
	Tenant	3	**62.67**	**32.332**	18.667

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainability Development	Equal variances assumed	1.954	.235	**.723**	**4**	**.510**	15.667	21.677	-44.518	75.851
	Equal variances not assumed			.723	3.243	.518	15.667	21.677	-50.484	81.817

There was no significant difference in the score for Owners (M=78%, SD=19.10) and Tenants (M=63%, SD=32.33) in opinions on development of sustainable maintenance strategies for existing office buildings conditions; t(4)=0.72, p=0.510. These results identify that the opinions of Owners and Tenants are completely independence to each other. Specifically, our results identify that Owners and Tenants have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices.

T-Test between Asset/Property managers and FM/Sustainability Managers

Group Statistics					
	Respondents Positions	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	Asset/Property Managers	3	**64.00**	**28.618**	16.523
	FM/Sustainability Managers	3	**71.33**	**20.133**	11.624

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainability Development	Equal variances assumed	.312	.606	**-.363**	**4**	**.735**	-7.333	20.202	-63.422	48.756
	Equal variances not assumed			-.363	3.590	.737	-7.333	20.202	-66.040	51.373

The same as the test between Owners and Tenants, there was no significant difference in the score for Asset/Property Managers (M=64%, SD=28.62) and Facility/Sustainability Managers (M=71%, SD=20.13) in opinions on development of sustainable maintenance strategies for existing office buildings conditions; t(4)=-0.36, p=0.74. These results identify that the opinions of Asset/Property Managers and Facility/Sustainability Managers are completely independence to each other. Specifically, our results identify that Asset/Property Managers and Facility/Sustainability Managers also have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices.

One-way ANOVA Test between Owners, Tenants, Asset/Property Managers and Facility/Sustainability Managers.

One-way

Descriptives								
Sustainability Development								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Owners/Developers	3	**78.33**	**19.088**	11.020	30.92	125.75	64	100
Tenants/Leasing Agents	3	**62.67**	**32.332**	18.667	-17.65	142.98	44	100
Asset/Property Managers	3	**64.00**	**28.618**	16.523	-7.09	135.09	34	91
FM/Sustainability Managers	3	**71.33**	**20.133**	11.624	21.32	121.35	50	90
Total	12	69.08	22.845	6.595	54.57	83.60	34	100

Test of Homogeneity of Variances			
Sustainability Development			
Levene Statistic	df1	df2	Sig.
.637	3	8	.612

ANOVA					
Sustainability Development					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	472.917	**3**	157.639	**.239**	**.867**
Within Groups	5268.000	**8**	658.500		
Total	5740.917	11			

A One-way between Subjects ANOVA was conducted to compare the effect of opinions on development of sustainable maintenance practices for existing office buildings. There was no significant effect their opinions at the $p > 0.05$ level for the four conditions [$F(3, 8) = 157.64$, $p = 0.87$].

Post Hoc Tests

Multiple Comparisons							
Dependent Variable: Sustainability Development							
(I) Respondents Positions		(J) Respondents Positions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Owners/Developers	Tenants/Leasing Agents	15.667	20.952	.875	-51.43	82.76
		Asset/Property Managers	14.333	20.952	.900	-52.76	81.43
		FM/Sustainability Managers	7.000	20.952	.986	-60.10	74.10
	Tenants/Leasing Agents	Owners/Developers	-15.667	20.952	.875	-82.76	51.43
		Asset/Property Managers	-1.333	20.952	1.000	-68.43	65.76
		FM/Sustainability Managers	-8.667	20.952	.975	-75.76	58.43
	Asset/Property Managers	Owners/Developers	-14.333	20.952	.900	-81.43	52.76
		Tenants/Leasing Agents	1.333	20.952	1.000	-65.76	68.43
		FM/Sustainability Managers	-7.333	20.952	.984	-74.43	59.76
	FM/Sustainability Managers	Owners/Developers	-7.000	20.952	.986	-74.10	60.10
		Tenants/Leasing Agents	8.667	20.952	.975	-58.43	75.76
		Asset/Property Managers	7.333	20.952	.984	-59.76	74.43
Dunnett T3	Owners/Developers	Tenants/Leasing Agents	15.667	21.677	.960	-91.71	123.05
		Asset/Property Managers	14.333	19.861	.961	-79.56	108.22
		FM/Sustainability Managers	7.000	16.017	.997	-63.04	77.04
	Tenants/Leasing Agents	Owners/Developers	-15.667	21.677	.960	-123.05	91.71
		Asset/Property Managers	-1.333	24.929	1.000	-111.04	108.37
		FM/Sustainability Managers	-8.667	21.990	.998	-115.32	97.98
	Asset/Property Managers	Owners/Developers	-14.333	19.861	.961	-108.22	79.56
		Tenants/Leasing Agents	1.333	24.929	1.000	-108.37	111.04
		FM/Sustainability Managers	-7.333	20.202	.999	-101.12	86.45
	FM/Sustainability Managers	Owners/Developers	-7.000	16.017	.997	-77.04	63.04
		Tenants/Leasing Agents	8.667	21.990	.998	-97.98	115.32
		Asset/Property Managers	7.333	20.202	.999	-86.45	101.12

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the four conditions as Owners (M=78%, SD=19.09), Tenants (M=63%, SD=32.33), Asset/Property managers (M=64, SD=28.61) and Facility/Sustainable Managers (M=71%, SD=20.13.

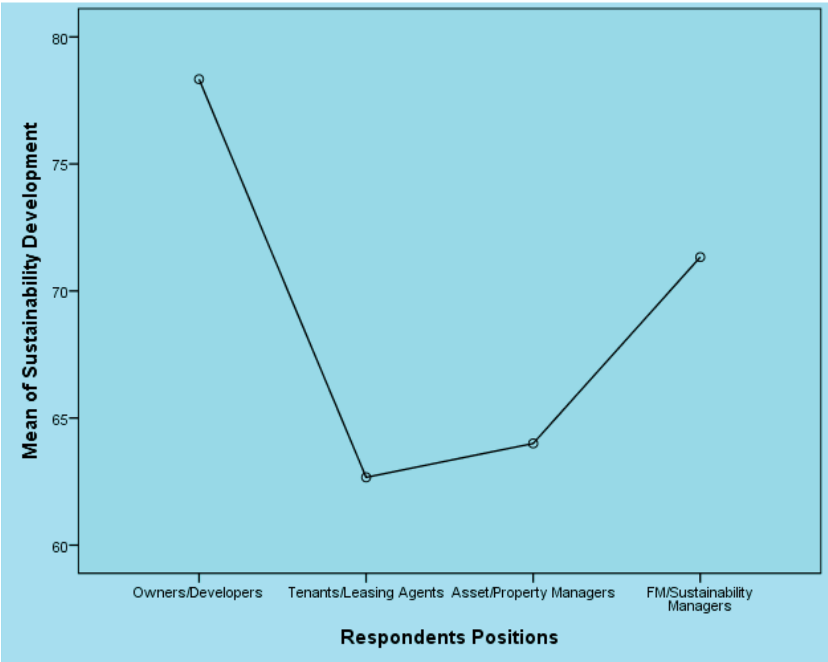
Homogeneous Subsets

Sustainability Development			
	Respondents Positions	N	Subset for alpha = 0.05
			1
Tukey HSD[a]	Tenants/Leasing Agents	3	62.67
	Asset/Property Managers	3	64.00
	FM/Sustainability Managers	3	71.33
	Owners/Developers	3	78.33
	Sig.		.875

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Means Plots



Outcome

There was no significant effect on the opinions of four positions of Owners, Tenants, Asset/Property managers and Facility/Sustainable Managers on development of sustainable maintenance strategies for existing office buildings at $p > 0.05$ level for the four conditions [$F(3, 8) = 157.64$, $p = 0.87$].

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the four conditions as Owners (M=78%, SD=19.09), Tenants (M=63%, SD=32.33), Asset/Property managers (M=64, SD=28.61) and Facility/Sustainable Managers (M=71%, SD=20.13).

Taken together, these results identify that the opinions of the four conditions of Owners, Tenants, Asset/Property Managers and Facility/Sustainable Managers are completely independent to each other. Specifically, our results identify that Owners, Tenants, Asset/Property Managers and Facility/Sustainable Managers have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water, and sustainable maintenance strategies should be developed for maintenance practices.

T-Test between Respondents aged 25 y/o and under vs. Respondents aged 26–35 y/o.

Group Statistics					
	Respondents Age	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	25 y/o and under	3	**66.67**	**23.352**	13.482
	26 - 35 y/o	3	**69.67**	**25.502**	14.723

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainability Development	Equal variances assumed	.000	.984	**-.150**	**4**	**.888**	-3.000	19.964	-58.429	52.429
	Equal variances not assumed			-.150	3.969	.888	-3.000	19.964	-58.598	52.598

There was no significant difference in the score for respondents aged 25 years old and under (M=67%, SD=23.67) and respondents aged 26–35 years old (M=70%, SD=69.67) in opinions on development of sustainable maintenance strategies for existing office buildings conditions; t(4)=-0.15, p=0.89. These results identify that the opinions of respondents aged 25 years old and under, and respondents aged 26–35 years old are completely independence to each other. Specifically, our results identify that respondents aged 25 years old and under, and respondents aged 26–35 years old have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water, and sustainable maintenance strategies should be developed for maintenance practices.

T-Test between Respondents aged 25 y/o and under vs. Respondents aged 46–55 y/o.

Group Statistics						
	Respondents Age	N	Mean	Std. Deviation	Std. Error Mean
Sustainability Development	25 y/o and under	3	**66.6667**	**23.35237**	13.48250
	46 - 55 y/o	3	**71.0000**	**24.87971**	14.36431

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Sustainability Development	Equal variances assumed	.015	.909	**-.220**	**4**	**.837**	-4.33333	19.70054	-59.03079	50.36412
	Equal variances not assumed			-.220	3.984	.837	-4.33333	19.70054	-59.11725	50.45058

There was no significant difference in the score for respondents aged at 25 years old and under (M=67%, SD=23.35) and respondents aged at 46–55 years old (M=71%, SD=24.88) in opinions on development of sustainable maintenance strategies for existing office buildings conditions; $t(4)=-0.22$, $p=0.84$. These results identify that the opinions of respondents aged at 25 years old and under and respondents aged at 46–55 years old are completely independence to each other. Specifically, our results identify that respondents aged at 25 years old and under, and respondents aged at 46–55 years old have the same opinion that the existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices.

One-way ANOVA Test between Six Categories of Age of Respondents

One-way

Descriptives

Sustainability Development

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
25 y/o and under	3	**66.67**	**23.352**	13.482	8.66	124.68	46	92
26 35 y/o	3	**69.67**	**25.502**	14.723	6.32	133.02	44	95
36 - 45 y/o	3	**71.67**	**20.526**	11.851	20.68	122.66	49	89
46 - 55 y/o	3	**71.00**	**24.880**	14.364	9.20	132.80	44	93
56 - 65 y/o	3	**74.00**	**14.731**	8.505	37.41	110.59	58	87
65 y/o and over	3	**72.33**	**25.423**	14.678	9.18	135.49	50	100
Total	18	70.89	19.241	4.535	61.32	80.46	44	100

Test of Homogeneity of Variances

Sustainability Development

Levene Statistic	df1	df2	Sig.
.205	5	12	.954

ANOVA

Sustainability Development

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	95.111	**5**	19.022	**.037**	**.999**
Within Groups	6198.667	**12**	516.556		
Total	6293.778	17			

A One-way between Subjects ANOVA was conducted to compare the effect of opinions on development of sustainable maintenance practices for existing office buildings. There was no significant effect their opinions at the $p > 0.05$ level for the six conditions [$F(5,12) = 0.37$, $p = 0.99$].

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Sustainability Development

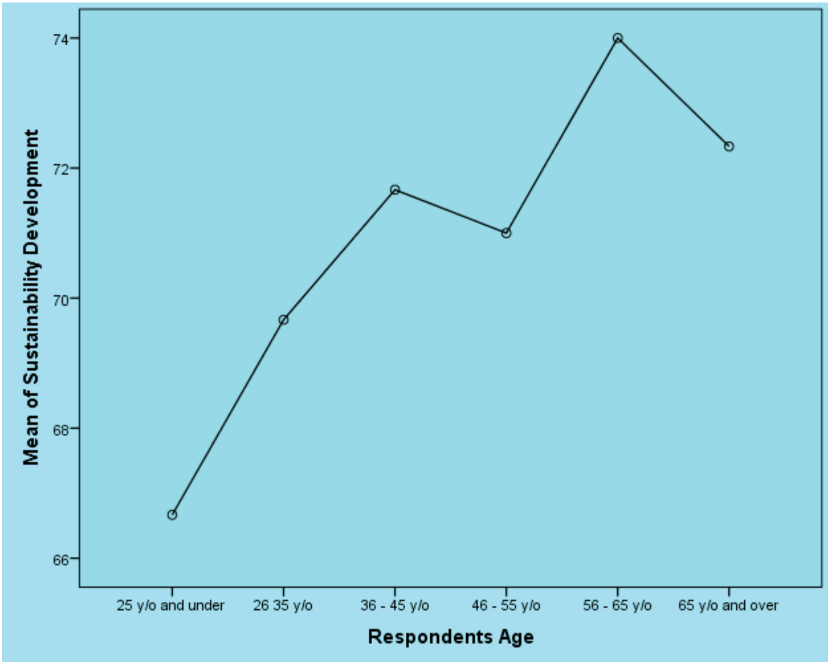
	(I) Respondents Age	(J) Respondents Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	25 y/o and under	26 35 y/o	-3.000	18.557	1.000	-65.33	59.33
		36 - 45 y/o	-5.000	18.557	1.000	-67.33	57.33
		46 - 55 y/o	-4.333	18.557	1.000	-66.67	58.00
		56 - 65 y/o	-7.333	18.557	.998	-69.67	55.00
		65 y/o and over	-5.667	18.557	1.000	-68.00	56.67
	26 35 y/o	25 y/o and under	3.000	18.557	1.000	-59.33	65.33
		36 - 45 y/o	-2.000	18.557	1.000	-64.33	60.33
		46 - 55 y/o	-1.333	18.557	1.000	-63.67	61.00
		56 - 65 y/o	-4.333	18.557	1.000	-66.67	58.00
		65 y/o and over	-2.667	18.557	1.000	-65.00	59.67
	36 - 45 y/o	25 y/o and under	5.000	18.557	1.000	-57.33	67.33
		26 35 y/o	2.000	18.557	1.000	-60.33	64.33
		46 - 55 y/o	.667	18.557	1.000	-61.67	63.00
		56 - 65 y/o	-2.333	18.557	1.000	-64.67	60.00
		65 y/o and over	-.667	18.557	1.000	-63.00	61.67
	46 - 55 y/o	25 y/o and under	4.333	18.557	1.000	-58.00	66.67
		26 35 y/o	1.333	18.557	1.000	-61.00	63.67
		36 - 45 y/o	-.667	18.557	1.000	-63.00	61.67
		56 - 65 y/o	-3.000	18.557	1.000	-65.33	59.33
		65 y/o and over	-1.333	18.557	1.000	-63.67	61.00
	56 - 65 y/o	25 y/o and under	7.333	18.557	.998	-55.00	69.67
		26 35 y/o	4.333	18.557	1.000	-58.00	66.67
		36 - 45 y/o	2.333	18.557	1.000	-60.00	64.67
		46 - 55 y/o	3.000	18.557	1.000	-59.33	65.33
		65 y/o and over	1.667	18.557	1.000	-60.67	64.00
	65 y/o and over	25 y/o and under	5.667	18.557	1.000	-56.67	68.00
		26 35 y/o	2.667	18.557	1.000	-59.67	65.00
		36 - 45 y/o	.667	18.557	1.000	-61.67	63.00
		46 - 55 y/o	1.333	18.557	1.000	-61.00	63.67
		56 - 65 y/o	-1.667	18.557	1.000	-64.00	60.67
Dunnett T3	25 y/o and under	26 35 y/o	-3.000	19.964	1.000	-106.59	100.59
		36 - 45 y/o	-5.000	17.951	1.000	-98.61	88.61
		46 - 55 y/o	-4.333	19.701	1.000	-106.34	97.68
		56 - 65 y/o	-7.333	15.941	1.000	-98.93	84.26
		65 y/o and over	-5.667	19.930	1.000	-109.05	97.72
	26 35 y/o	25 y/o and under	3.000	19.964	1.000	-100.59	106.59
		36 - 45 y/o	-2.000	18.900	1.000	-102.23	98.23
		46 - 55 y/o	-1.333	20.570	1.000	-107.64	104.97
		56 - 65 y/o	-4.333	17.003	1.000	-105.72	97.05
		65 y/o and over	-2.667	20.790	1.000	-110.07	104.74
	36 - 45 y/o	25 y/o and under	5.000	17.951	1.000	-88.61	98.61
		26 35 y/o	2.000	18.900	1.000	-98.23	102.23
		46 - 55 y/o	.667	18.622	1.000	-97.54	98.88
		56 - 65 y/o	-2.333	14.587	1.000	-82.24	77.58
		65 y/o and over	-.667	18.865	1.000	-100.63	99.30
	46 - 55 y/o	25 y/o and under	4.333	19.701	1.000	-97.68	106.34
		26 35 y/o	1.333	20.570	1.000	-104.97	107.64
		36 - 45 y/o	-.667	18.622	1.000	-98.88	97.54
		56 - 65 y/o	-3.000	16.693	1.000	-101.48	95.48
		65 y/o and over	-1.333	20.537	1.000	-107.46	104.79
	56 - 65 y/o	25 y/o and under	7.333	15.941	1.000	-84.26	98.93
		26 35 y/o	4.333	17.003	1.000	-97.05	105.72
		36 - 45 y/o	2.333	14.587	1.000	-77.58	82.24
		46 - 55 y/o	3.000	16.693	1.000	-95.48	101.48
		65 y/o and over	1.667	16.964	1.000	-99.35	102.68
	65 y/o and over	25 y/o and under	5.667	19.930	1.000	-97.72	109.05
		26 35 y/o	2.667	20.790	1.000	-104.74	110.07
		36 - 45 y/o	.667	18.865	1.000	-99.30	100.63
		46 - 55 y/o	1.333	20.537	1.000	-104.79	107.46
		56 - 65 y/o	-1.667	16.964	1.000	-102.68	99.35

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the six conditions as respondents having 25 years old and under (M=67%, SD=23.35), 26–35 years old (M=70%, SD=25.50), 36–45 years old (M=72%, SD=20.53), 46–55 years old (M=71%, SD=24.88), 56–65 years old (M=74%, SD=14.73), and 65 years old and over (M=72%, SD=19.24).

Homogeneous Subsets

Sustainability Development			
Respondents Age		N	Subset for alpha = 0.05
			1
Tukey HSD[a]	25 y/o and under	3	66.67
	26 35 y/o	3	69.67
	46 - 55 y/o	3	71.00
	36 - 45 y/o	3	71.67
	65 y/o and over	3	72.33
	56 - 65 y/o	3	74.00
	Sig.		.998
Means for groups in homogeneous subsets are displayed.			
a. Uses Harmonic Mean Sample Size = 3.000.			

Means Plots



Outcome

There was no significant effect on the opinions of six categories of age of respondents on development of sustainable maintenance strategies for existing office buildings at $p > 0.05$ level for the four conditions [$F(5,12) = 0.37$, $p = 0.99$].

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on development of sustainable maintenance practices for existing office buildings for the six categories of age as respondents having 25 years old and under (M=67%, SD=23.35), 26–35 years old (M=70%, SD=25.50), 36–45 years old (M=72%, SD=20.53), 46–55 years old (M=71%, SD=24.88), 56–65 years old (M=74%, SD=14.73), and 65 years old and over (M=72%, SD=19.24).

Taken together, these results identify that the opinions of the respondents over six categories of age are completely independent to each other. Specifically, our results identify those Owners, Asset/Property Managers, Facility/Sustainability managers, Tenants, Building Service Professionals and Other Professionals have the same opinion that existing office buildings impacts to the environment caused by inefficient uses of energy and water and sustainable maintenance strategies should be developed for maintenance practices. These opinions does not affect by the age of respondents.

Appendix 2.3 Mean Difference Tests for Six Questions of Survey Question 1.8

The followings are the tests using SPSS for mean difference of groups of samples for six questions, 1.8.2, 1.8.5, 1.8.8, 1.8.9, 1.8.10 and 1.8.12, of the Survey Question 1.8. Refer Appendix 1 for further details on the questionnaire.

One-way ANOVA Test between Six Categories of Age of Respondents

One-way

Descriptives

Main factors influence sustainability initiatives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
25 years old and under	6	**78.83**	**7.223**	2.949	71.25	86.41	69	85
26--35 years old	6	**84.33**	**8.548**	3.490	75.36	93.30	74	96
36-45 years old	6	**83.33**	**5.989**	2.445	77.05	89.62	75	91
46-55 years old	6	**86.17**	**1.329**	.543	84.77	87.56	84	87
56-65 years old	6	**94.17**	**4.875**	1.990	89.05	99.28	87	100
65 years old and over	6	**88.83**	**13.556**	5.534	74.61	103.06	67	100
Total	36	85.94	8.731	1.455	82.99	88.90	67	100

Test of Homogeneity of Variances

Main factors influence sustainability initiatives

Levene Statistic	df1	df2	Sig.
5.200	5	30	.001

ANOVA

Main factors influence sustainability initiatives

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	815.889	**5**	163.178	**2.643**	**.043**
Within Groups	1852.000	**30**	61.733		
Total	2667.889	35			

A one-way between subjects ANOVA was conducted to compare the effect of opinions on main factors that influence sustainability initiatives of maintenance practices for existing office buildings. There was a significant effect their opinions at the $p < 0.05$ level for the six conditions [$F(5,30) = 2.64$, $p = 0.04$].

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Main factors influence sustainability initiatives

	(I) Respondents Age	(J) Respondents Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	25 years old and under	26--35 years old	-5.500	4.536	.827	-19.30	8.30
		36-45 years old	-4.500	4.536	.917	-18.30	9.30
		46-55 years old	-7.333	4.536	.594	-21.13	6.46
		56-65 years old	-15.333*	4.536	.023	-29.13	-1.54
		65 years old and over	-10.000	4.536	.265	-23.80	3.80
	26--35 years old	25 years old and under	5.500	4.536	.827	-8.30	19.30
		36-45 years old	1.000	4.536	1.000	-12.80	14.80
		46-55 years old	-1.833	4.536	.998	-15.63	11.96
		56-65 years old	-9.833	4.536	.282	-23.63	3.96
		65 years old and over	-4.500	4.536	.917	-18.30	9.30
	36-45 years old	25 years old and under	4.500	4.536	.917	-9.30	18.30
		26--35 years old	-1.000	4.536	1.000	-14.80	12.80
		46-55 years old	-2.833	4.536	.988	-16.63	10.96
		56-65 years old	-10.833	4.536	.193	-24.63	2.96
		65 years old and over	-5.500	4.536	.827	-19.30	8.30
	46-55 years old	25 years old and under	7.333	4.536	.594	-6.46	21.13
		26--35 years old	1.833	4.536	.998	-11.96	15.63
		36-45 years old	2.833	4.536	.988	-10.96	16.63
		56-65 years old	-8.000	4.536	.503	-21.80	5.80
		65 years old and over	-2.667	4.536	.991	-16.46	11.13
	56-65 years old	25 years old and under	15.333*	4.536	.023	1.54	29.13
		26--35 years old	9.833	4.536	.282	-3.96	23.63
		36-45 years old	10.833	4.536	.193	-2.96	24.63
		46-55 years old	8.000	4.536	.503	-5.80	21.80
		65 years old and over	5.333	4.536	.845	-8.46	19.13
	65 years old and over	25 years old and under	10.000	4.536	.265	-3.80	23.80
		26--35 years old	4.500	4.536	.917	-9.30	18.30
		36-45 years old	5.500	4.536	.827	-8.30	19.30
		46-55 years old	2.667	4.536	.991	-11.13	16.46
		56-65 years old	-5.333	4.536	.845	-19.13	8.46
Dunnett T3	25 years old and under	26--35 years old	-5.500	4.569	.955	-22.40	11.40
		36-45 years old	-4.500	3.830	.961	-18.69	9.69
		46-55 years old	-7.333	2.998	.379	-20.76	6.10
		56-65 years old	-15.333*	3.557	.024	-28.83	-1.83
		65 years old and over	-10.000	6.271	.790	-34.74	14.74
	26--35 years old	25 years old and under	5.500	4.569	.955	-11.40	22.40
		36-45 years old	1.000	4.261	1.000	-15.09	17.09
		46-55 years old	-1.833	3.532	1.000	-17.78	14.11
		56-65 years old	-9.833	4.017	.337	-25.50	5.83
		65 years old and over	-4.500	6.543	1.000	-29.59	20.59
	36-45 years old	25 years old and under	4.500	3.830	.961	-9.69	18.69
		26--35 years old	-1.000	4.261	1.000	-17.09	15.09
		46-55 years old	-2.833	2.504	.958	-13.92	8.25
		56-65 years old	-10.833	3.153	.076	-22.53	.87
		65 years old and over	-5.500	6.050	.993	-30.15	19.15
	46-55 years old	25 years old and under	7.333	2.998	.379	-6.10	20.76
		26--35 years old	1.833	3.532	1.000	-14.11	17.78
		36-45 years old	2.833	2.504	.958	-8.25	13.92
		56-65 years old	-8.000	2.063	.081	-16.97	.97
		65 years old and over	-2.667	5.561	1.000	-28.09	22.75
	56-65 years old	25 years old and under	15.333*	3.557	.024	1.83	28.83
		26--35 years old	9.833	4.017	.337	-5.83	25.50
		36-45 years old	10.833	3.153	.076	-.87	22.53
		46-55 years old	8.000	2.063	.081	-.97	16.97
		65 years old and over	5.333	5.881	.992	-19.40	30.07
	65 years old and over	25 years old and under	10.000	6.271	.790	-14.74	34.74
		26--35 years old	4.500	6.543	1.000	-20.59	29.59
		36-45 years old	5.500	6.050	.993	-19.15	30.15
		46-55 years old	2.667	5.561	1.000	-22.75	28.09
		56-65 years old	-5.333	5.881	.992	-30.07	19.40

*. The mean difference is significant at the 0.05 level.

Post Hoc comparisons using the Tukey HSD test indicated that there was a significantly different for the mean scores of opinions on main factors that influence sustainability initiatives of maintenance practices for existing office buildings for the six conditions as respondents having 25 years old and under (M=79%, SD=7.23), 26–35 years old (M=84%, SD=8.55), 36–45 years old (M=83%, SD=5.99), 46–55 years old (M=86%, SD=1.33), 56–65 years old (M=94%, SD=4.88), and 65 years old and over (M=89%, SD=13.56).

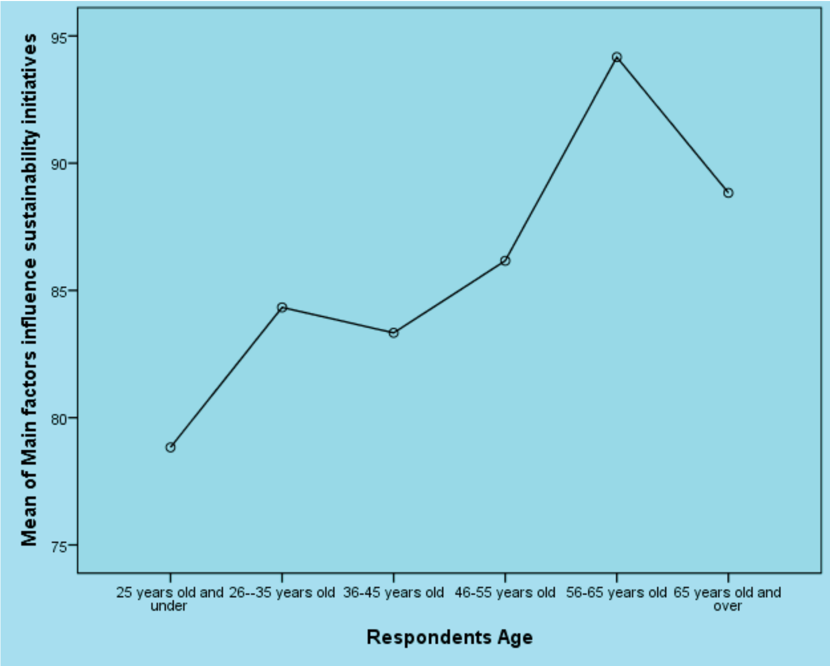
Homogeneous Subsets

Main factors influence sustainability initiatives				
	Respondents Age	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a]	25 years old and under	6	78.83	
	36-45 years old	6	83.33	83.33
	26--35 years old	6	84.33	84.33
	46-55 years old	6	86.17	86.17
	65 years old and over	6	88.83	88.83
	56-65 years old	6		94.17
	Sig.		.265	.193

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 6.000.

Means Plots



Outcome

There was a significant effect on the opinions of six categories of age of respondents on opinion to main factors that influence sustainability initiatives of maintenance practices for existing office buildings at $p < 0.05$ level for the six conditions [$F(5,30) = 2.64$, $p = 0.04$].

Post Hoc comparisons using the Tukey HSD test indicated that there was a significant difference for the mean scores of opinions on main factors that influence sustainability initiatives of maintenance practices for existing office buildings for the six categories of age as respondents having 25 years old and under (M=79%, SD=7.23), 26–35 years old (M=84%, SD=8.55), 36–45 years old (M=83%, SD=5.99), 46–55 years old (M=86%, SD=1.33), 56–65 years old (M=94%, SD=4.88), and 65 years old and over (M=89%, SD=13.56).

Taken together, these results identify that the opinions of the respondents over six categories of age are completely dependent to the age of respondents. Specifically, our results identify those Owners, Asset/Property Managers, Facility/Sustainability Managers, Tenants, Building Service Professionals and Other Professionals have their opinions over main factors that influence to sustainability initiatives for existing office buildings depending to the respondents' age, profession and position.

Appendix 2.4 Mean Difference Tests for Six Questions of Survey Question 1.9

The followings are the tests using SPSS for mean difference of groups of samples for six questions, 1.9.1, 1.9.2, 1.9.5, 1.9.6, 1.9.9 and 1.9.10, of the Survey Question 1.9. Refer Appendix 1 for further details on the questionnaire.

One-way ANOVA Test between Six Categories of Age of Respondents

One-way

Descriptives

Main factors achieving sustainability practices

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
25 years old and under	6	**77.67**	**14.583**	5.954	62.36	92.97	58	100
26--35 years old	6	**78.33**	**12.275**	5.011	65.45	91.21	57	94
36-45 years old	6	**81.00**	**9.859**	4.025	70.65	91.35	69	96
46-55 years old	6	**79.83**	**16.726**	6.828	62.28	97.39	50	93
56-65 years old	6	**82.67**	**9.750**	3.981	72.43	92.90	70	93
65 years old and over	6	**68.33**	**25.296**	10.327	41.79	94.88	33	100
Total	36	77.97	15.253	2.542	72.81	83.13	33	100

Test of Homogeneity of Variances

Main factors achieving sustainability practices

Levene Statistic	df1	df2	Sig.
1.343	5	30	.273

ANOVA

Main factors achieving sustainability practices

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	766.806	**5**	153.361	**.624**	**.683**
Within Groups	7376.167	**30**	245.872		
Total	8142.972	35			

A One-way between Subjects ANOVA was conducted to compare the effect of opinions on main factors that can be used to achieve sustainable maintenance practices for existing office buildings. There was no significant effect their opinions at the $p > 0.05$ level for the six conditions [$F(5,30) = 0.62$, $p = 0.68$].

Post Hoc Tests

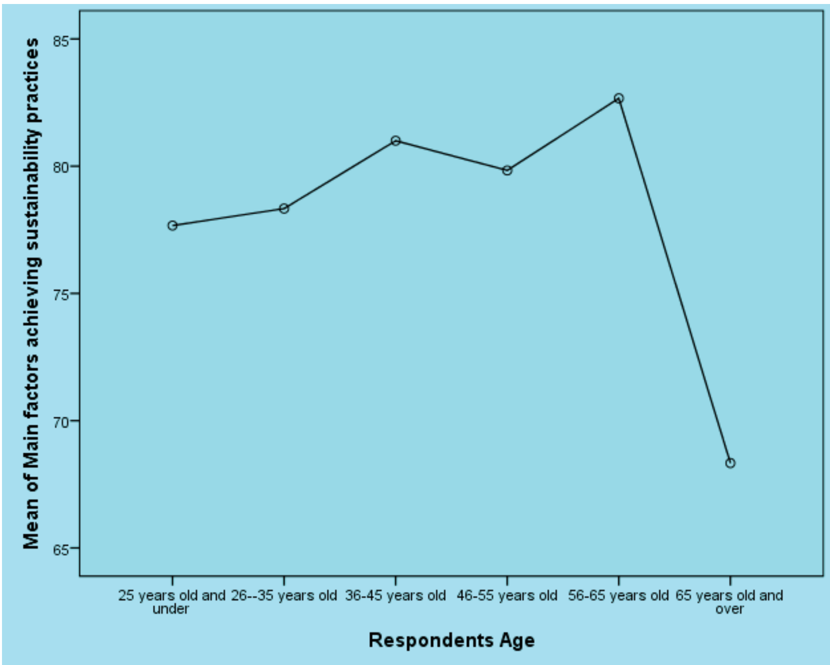
Multiple Comparisons							
Dependent Variable: Main factors achieving sustainability practices							
	(I) Respondents Age	(J) Respondents Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	25 years old and under	26--35 years old	-.667	9.053	1.000	-28.20	26.87
		36-45 years old	-3.333	9.053	.999	-30.87	24.20
		46-55 years old	-2.167	9.053	1.000	-29.70	25.37
		56-65 years old	-5.000	9.053	.993	-32.54	22.54
		65 years old and over	9.333	9.053	.904	-18.20	36.87
	26--35 years old	25 years old and under	.667	9.053	1.000	-26.87	28.20
		36-45 years old	-2.667	9.053	1.000	-30.20	24.87
		46-55 years old	-1.500	9.053	1.000	-29.04	26.04
		56-65 years old	-4.333	9.053	.997	-31.87	23.20
		65 years old and over	10.000	9.053	.876	-17.54	37.54
	36-45 years old	25 years old and under	3.333	9.053	.999	-24.20	30.87
		26--35 years old	2.667	9.053	1.000	-24.87	30.20
		46-55 years old	1.167	9.053	1.000	-26.37	28.70
		56-65 years old	-1.667	9.053	1.000	-29.20	25.87
		65 years old and over	12.667	9.053	.727	-14.87	40.20
	46-55 years old	25 years old and under	2.167	9.053	1.000	-25.37	29.70
		26--35 years old	1.500	9.053	1.000	-26.04	29.04
		36-45 years old	-1.167	9.053	1.000	-28.70	26.37
		56-65 years old	-2.833	9.053	1.000	-30.37	24.70
		65 years old and over	11.500	9.053	.798	-16.04	39.04
	56-65 years old	25 years old and under	5.000	9.053	.993	-22.54	32.54
		26--35 years old	4.333	9.053	.997	-23.20	31.87
		36-45 years old	1.667	9.053	1.000	-25.87	29.20
		46-55 years old	2.833	9.053	1.000	-24.70	30.37
		65 years old and over	14.333	9.053	.615	-13.20	41.87
	65 years old and over	25 years old and under	-9.333	9.053	.904	-36.87	18.20
		26--35 years old	-10.000	9.053	.876	-37.54	17.54
		36-45 years old	-12.667	9.053	.727	-40.20	14.87
		46-55 years old	-11.500	9.053	.798	-39.04	16.04
		56-65 years old	-14.333	9.053	.615	-41.87	13.20
Dunnett T3	25 years old and under	26--35 years old	-.667	7.782	1.000	-29.47	28.13
		36-45 years old	-3.333	7.186	1.000	-30.60	23.93
		46-55 years old	-2.167	9.059	1.000	-35.62	31.28
		56-65 years old	-5.000	7.162	1.000	-32.22	22.22
		65 years old and over	9.333	11.920	.998	-37.06	55.72
	26--35 years old	25 years old and under	.667	7.782	1.000	-28.13	29.47
		36-45 years old	-2.667	6.427	1.000	-26.55	21.22
		46-55 years old	-1.500	8.470	1.000	-33.28	30.28
		56-65 years old	-4.333	6.400	1.000	-28.14	19.47
		65 years old and over	10.000	11.478	.995	-36.02	56.02
	36-45 years old	25 years old and under	3.333	7.186	1.000	-23.93	30.60
		26--35 years old	2.667	6.427	1.000	-21.22	26.55
		46-55 years old	1.167	7.926	1.000	-29.57	31.90
		56-65 years old	-1.667	5.661	1.000	-22.48	19.15
		65 years old and over	12.667	11.084	.960	-33.40	58.73
	46-55 years old	25 years old and under	2.167	9.059	1.000	-31.28	35.62
		26--35 years old	1.500	8.470	1.000	-30.28	33.28
		36-45 years old	-1.167	7.926	1.000	-31.90	29.57
		56-65 years old	-2.833	7.904	1.000	-33.54	27.87
		65 years old and over	11.500	12.380	.993	-35.63	58.63
	56-65 years old	25 years old and under	5.000	7.162	1.000	-22.22	32.22
		26--35 years old	4.333	6.400	1.000	-19.47	28.14
		36-45 years old	1.667	5.661	1.000	-19.15	22.48
		46-55 years old	2.833	7.904	1.000	-27.87	33.54
		65 years old and over	14.333	11.067	.917	-31.74	60.41
	65 years old and over	25 years old and under	-9.333	11.920	.998	-55.72	37.06
		26--35 years old	-10.000	11.478	.995	-56.02	36.02
		36-45 years old	-12.667	11.084	.960	-58.73	33.40
		46-55 years old	-11.500	12.380	.993	-58.63	35.63
		56-65 years old	-14.333	11.067	.917	-60.41	31.74

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on main factors that can be used to achieve sustainable maintenance practices for existing office buildings for the six conditions as respondents having 25 years old and under M=78%, SD=14.58), 26–35 years old (M=78%, SD=12.28), 36–45 years old (M=81%, SD=9.86), 46–55 years old (M=80%, SD=16.73), 56–65 years old (M=83%, SD=9.75), and 65 years old and over (M=68%, SD=25.30).

Homogeneous Subsets

Main factors achieving sustainability practices			
	Respondents Age	N	Subset for alpha = 0.05
			1
Tukey HSD[a]	65 years old and over	6	68.33
	25 years old and under	6	77.67
	26--35 years old	6	78.33
	46-55 years old	6	79.83
	36-45 years old	6	81.00
	56-65 years old	6	82.67
	Sig.		.615
Means for groups in homogeneous subsets are displayed.			
a. Uses Harmonic Mean Sample Size = 6.000.			

Means Plots



Outcome

There was no significant effect on the opinions of six categories of age of respondents on opinion to main factors that can be used to achieve sustainable maintenance practices for existing office buildings at $p > 0.05$ level for the six conditions [$F(5,30) = 0.62$, $p = 0.68$].

Post Hoc comparisons using the Tukey HSD test indicated that there was no significant difference for the mean scores of opinions on main factors that can be used to achieve on development of sustainable maintenance practices for existing office buildings for the six categories of age as respondents having 25 years old and under (M=78%, SD=14.58), 26–35 years old (M=78%, SD=12.28), 36–45 years old (M=81%, SD=9.86), 46–55 years old (M=80%, SD=16.73), 56–65 years old (M=83%, SD=9.75), and 65 years old and over (M=68%, SD=25.30).

Taken together, these results identify that the opinions of the respondents over six categories of age of respondents are completely independent to the age of respondents. Specifically, our results identify those Owners, Asset/Property Managers, Facility/Sustainability Managers, Tenants, Building Service Professionals and Other Professionals have their no different opinions on main factors that can be used to achieve on development of sustainable maintenance practices for existing office buildings. These opinions does not affect by the age of respondents.

Appendix 3.1 SMOB Calculations – Costs and Savings on Upgrading

Table A3.1 Calculations of upgrading costs and savings on energy, water and CO_2 used in Table 7.1, Chapter 7 according to the SMOB

SMOB Issues		Estimated Capital Costs in Improving/upgrading			Estimated Additional Annual Maintenance Costs		Estimated Potential Savings on Energy Consumption			Reference	
		BPI 2016 [1]	Capital Costs Adapted in Base Year [2]	Estimated Capital Costs in Developing SMOB [3]	Ratios of Maintenance Costs to Capital Costs [4]	Estimated Maintenance Costs in Developing SMOB [5]	Building Service Savings [6]	System Savings [7]	Estimated Savings in Developing SMOB [8]	Capital Costs	Savings
		%	$/m^2		%	$/m^2	%				
A. Upgrading											
A.1 Energy efficiency	A.1.1 Installing solar-boosted hot water systems	32.64	7.47	9.91	2.0	0.20	12.00	50.00	6.00	[2, 4, 27]	[17]
	A.1.2 Installing or upgrading BMCS	16.75	0.80	0.93	1.8	0.02	12.00	20.00	2.40	[2, 21, 30]	[5]
	A.1.3 Installing solar power systems per kW/m^2	32.64	0.82	1.09	-	0.05	12.00	26.00	3.12	[2, 4, 28]	[5, 19]
	A.1.4 Upgrading lifts and escalators	12.23	51.62	57.93	0	0	8.00	30.00	2.40	[4]	[1, 6]
	A.1.5 Upgrading electrical/power switchgears	-	146.95	146.95	0	0	12.00	26.00	3.12	[2, 3, 4]	[5, 8, 11]
A.2 Indoor climate	A.2.1 Re-commissioning or tuning HVAC systems	32.64	2.00	2.65	0	0	57.00	14.80	8.44	[2, 4]	[5]
	A.2.2 Upgrading to new technology HVAC systems	-	319.29	319.29	-	1.00	57.00	30.00	17.10	[3, 29]	[5, 8, 11, 20]
	A.2.3 Installing automatic sun shading to reduce heat gain or loss	12.23	350.00	392.81	0.5	1.96	57.00	15.00	8.55	[2, 4, 30]	[5, 7, 9, 10, 18]
A.3 Lighting efficiency	A.3.1 Installing lighting motion sensors	32.64	4.00	5.31	1.0	0.05	19.00	14.00	2.66	[2, 4, 30]	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	A.3.2 Replacing with LED lighting	19.09	67.57	80.47	0	0	19.00	5.33	1.01	[2, 4]	
	A.3.3 Installing automatic dimming lighting systems	-	128.09	128.09	1.0	1.28	19.00	20.00	3.80	[2, 4, 30]	
A.4 Environmental materials	A.4.1 Upgrading internal finishes with eco materials	-	135.68	135.68	0	0	4.00	20.00	0.80	[4]	[5, 19]
A.5 Water efficiency	A.5.1 Installing or upgrading water control sensors	-	-	20.46	1.0	0.20	37.00	22.09	8.17	[4, 30]	[23, 24, 25]
	A.5.2 Installing or upgrading water efficient devices and fixtures	-	-	83.42	0	0	37.00	82.00	30.34	[4]	
	A.5.3 Reusing and recycling rainwater and grey or black water	32.64	106.47	141.22	1.0	1.41	39.00	50.00	19.50	[4, 30]	

SMOB Issues		Estimated Capital Costs in Improving/upgrading			Estimated Additional Annual Maintenance Costs		Estimated Potential Savings on Energy Consumption			Reference	
		BPI 2016 [1]	Capital Costs Adapted in Base Year [2]	Estimated Capital Costs in Developing SMOB [3]	Ratios of Maintenance Costs to Capital Costs [4]	Estimated Maintenance Costs in Developing SMOB [5]	Building Service Savings [6]	System Savings [7]	Estimated Savings in Developing SMOB [8]	Capital Costs	Savings
		%	$/m^2		%	$/m^2	%				
A.6 Waste management	A.6.1 Providing breakdown waste disposal space	42.52	2.27	3.24	1.0	0.03	50.00	75.00	37.50	[4, 26, 30]	[25, 26]

Calculation: (1), (2), (4), (6) and (7) data adapted from literature review (see the fowling references)
(3) = (2) + [(2) x (1) / 100] (Data cited in 2016 were not computed with BPI)
(5) = (3) x (4) / 100
(8) = (6) x (7) / 100

Notes: * An maintenance is additional for using green solutions. All annual maintenance costs are adjusted and they may vary depending to maintenance schedule, the size and operation of systems
The annual maintenance cost of LED lighting (A.3.2) is less or negative cost. Annual maintenance costs of Routine (B) and Ad Hoc (C) are included in Upgrading (A)

Reference
[1] Australian Building Code Board (2004)
[2] City of Melbourne (2007)
[3] CostWeb (2014) (www.costweb.com.au)
[4] Rawlinsons (2016)
[5] Steinfeld, Bruce and Watt (2011)
[6] De Almeida et al. (2012)
[7] Omer (2008)
[8] Jenkins, Liu and Peacock (2008)
[9] Medrano et al. (2008)
[10] Zain-Ahmed et al. (2002)
[11] Lecamwasam, Wilson and Chokolich (2012)
[12] Zografakis, Karyotakis and Tsagarakis (2012)
[13] Bourgeois, Reinhart and Macdonald (2006)
[14] Galasiu and Veitch (2006)
[15] Ihm, Nemri and Krarti (2009)
[16] Li, Lam and Wong (2006)
[17] Cabeza et al. (2014)
[18] Burton (2001)
[19] Bondanza (2011)
[20] Lecamwasam (2014)
[21] Commercial Buildings Committee (2014)
[22] Atif and Galasiu (2003)
[23] Australian Department of the Environment and Heritage (2006)
[24] Sydney Water (2007)
[25] Terry and Moore (2008)
[26] Resource NSW (2002)
[27] WePowr (2017)
[28] Blanch (2013)
[29] Price (2017)
[30] Wu (2010)

Appendix 3.2 SMOB Calculations – Savings on Routine and Ad Hoc Maintenances

Table A3.2 Calculations of potential savings of Routine and Ah Hoc maintenances used in Table 7.1, Chapter 7 according to the SMOB

SMOB Issues		Potential Savings on Energy Efficiency [1] (%)	Ratios of Routine and Ah Hoc to Savings on Upgrading [2] (%)	Estimated Savings in Developing SMOB [3] (%)	References
B. Routine maintenance					
B.1 Periodic cleaning and servicing	B.1.1 Electrical systems	18.00	15	3.18	[5, 8, 11]
	B.1.2 HVAC systems	45.00		7.94	[5, 8, 11, 20]
	B.1.3 Lighting systems	12.00		2.12	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	B.1.4 Interior	3.00		0.53	[5, 19]
	B.1.5 Water systems	4.00		0.71	[23, 24, 25]
	B.1.6 Waste disposal space	3.00		0.53	[25, 26]
	Total:	**85.00**	-	**15.00**	-
B.2 Periodic inspecting to prevent breakdown	B.2.1 Electrical systems	18.00	10	2.12	[5, 8, 11]
	B.2.2 HVAC systems	45.00		5.29	[5, 8, 11, 20]
	B.2.3 Lighting systems	12.00		1.41	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	B.2.4 Interior	3.00		0.35	[5, 19]
	B.2.5 Water systems	4.00		0.47	[23, 24, 25]
	B.2.6 Waste disposal system	3.00		0.35	[25, 26]
	Total:	**85.00**	-	**10.00**	-
C. Ad Hoc maintenance					
C.1 Inspecting and repairing breakdowns	C.1.1 Electrical systems	18.00	10	2.07	[5, 8, 11]
	C.1.2 HVAC systems	45.00		5.17	[5, 8, 11, 20]
	C.1.3 Lighting systems	12.00		1.38	[1, 5, 8, 11, 12, 13, 14, 15, 16, 22]
	C.1.4 General repairing/ restoring to interior	3.00		0.34	[5, 19]
	C.1.5 Water systems	5.00		0.57	[23, 24, 25]
	C.1.6 Waste disposal system	4.00		0.46	[25, 26]
	Total:	**87.00**	-	**10.00**	-

Calculation: (3) = (1) x (2) / 85

Reference
[1] Australian Building Code Board (2004)
[5] Steinfeld, Bruce and Watt (2011)
[8] Jenkins, Liu and Peacock (2008)
[11] Lecamwasam, Wilson and Chokolich (2012)
[12] Zografakis, Karyotakis and Tsagarakis (2012)
[13] Bourgeois, Reinhart and Macdonald (2006)
[14] Galasiu and Veitch (2006)
[15] Ihm, Nemri and Krarti (2009)
[16] Li, Lam and Wong (2006)
[19] Bondanza (2011)
[22] Atif and Galasiu (2003)
[23] Australian Department of the Environment and Heritage (2006)
[24] Sydney Water (2007)
[25] Terry and Moore (2008)
[26] Resource NSW (2002)

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