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GREEN STAR SA CERTIFIED BUILDINGS: ACTUAL VS EXPECTED ENERGY PERFORMANCE

by

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Mini-dissertation submitted in partial fulfilment of the requirements for the degree of

Master of Science (Real Estate)

in the Faculty of Engineering, Built Environment and Information Technology
University of Pretoria

Study Leader: Danie Hoffman

November 2018

Declaration

I, the undersigned, hereby confirmed that the attached treatise is my own work and that any sources are adequately acknowledged in the text and listed in the bibliography.

I accept the rules of the University of Pretoria and the consequences of transgressing them.

This treatise is submitted in partial fulfilment of the requirements for the MSc Real Estate degree at the University of Pretoria. It has not been submitted before for any other degree or examination at any other University.

Yovka Raytcheva-Schaap
Nov 2018

Abstract

Title: Green Star SA Certified Buildings: Actual Vs Expected Energy Performance

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Certification of buildings under the various environmental performance schemes such as LEED, BREEAM, Green Star, etc., has increased globally in response to the environmental challenges facing current and future generations.

The rating schemes place particular emphasis on building energy efficiency, aiming at reducing the effects of Global Warming, including climate change, habitat destruction, rising sea levels and reduced global food security. Energy related categories make up roughly 25% to 30% of the typical Green Start rating schemes (Doan *et al.*, 2017). The reduced environmental impact of energy consumption in buildings is assessed as part of the certification process through mathematical modelling of energy performance. No actual performance data is used in this process.

The certification of buildings, and in particular their modelled energy performance results, creates expectations of actual performance. Building owners expect improved efficiencies over the norm to justify the increased capital outlay and increased lease rentals of this type of building. Tenants on the other side, expect improved efficiencies that translate into real operational savings, thereby justifying the increased rentals.

The aim of this research is to verify if Green Star certified buildings exhibit energy performance in line with expectations created during the certification process. This was done through:

a) A comparison of the actual energy performance of twelve office buildings in Johannesburg with their expected (modelled) energy performance derived during the certification; and
b) Structured interviews with the facilities managers / representatives of these twelve buildings.

The results of the structured interviews empirically confirm a positive correlation between key Green Star energy related requirements and operational practices on the one hand, and energy performance on the other hand. These include comprehensive commissioning, building tuning, effective metering strategies, etc.

At the same time, the energy performance analysis suggests that buildings included in this sample generally underperform when compared to their modelled normalised energy performance, i.e. certification alone does not guarantee energy efficient buildings.

The findings of this research are intended to assist various property sector stakeholders to improve the energy performance of buildings they develop, design, certify, operate, occupy or invest in.

Acknowledgements

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Abbreviations

ASAQS – Association of South African Quantity Surveyors

ASHRAE – American Association of Heating, Refrigeration and Air-conditioning Engineers

BREEAM – Building Research Establishment Environmental Assessment Method

CASBEE – Comprehensive Assessment System for Built Environment Efficiency

CIBSE – Chartered Institute of Building Services Engineers

CFC - Chlorofluorocarbons

CO_2 – Carbon Dioxide

EPA – Environmental Protection Agency

EUI – Energy Use Intensity

GBCSA - Green Building Council of South Africa

GBCA - Green Building Council Australia

GLA – Gross Lettable Area

HVAC – Heating, Ventilation and Air Conditioning

IEQ – Indoor Environmental Quality

IPCC – Intergovernmental Panel on Climate Change

kWh – Kilowatt-hour

LEED – Leadership in Energy and Environmental Design

NABERS - The National Australian Built Environment Rating System (NABERS)

SA – South Africa

USGBC – United States Green Building Council

UA – Usable Area

CHAPTER 1 - INTRODUCTION TO THE STUDY

1.1. Introduction

> *"Will our children ask, why didn't you act? Or [will they] ask,*
> *How did you find the moral courage to rise up and change?"*
>
> **Al Gore**
> Founder and Chairman,
> The Climate Reality Project

Environmental sustainability has become a major focus over the last few decades, driven by a long progression of environmental crises brought on by human activities since the Industrial Revolution, such as:

- Global warming / climate change due to increased greenhouse gas emissions;
- Ozone layer depletion due to chlorofluorocarbons (CFC's) and similar emissions;
- Inner city air pollution (smog);
- Pollution of natural waterways and ground water;
- Overuse of natural resources;
- Loss of natural habitat.

Buildings and the construction industry have a significant contribution towards the environmental challenges facing current and future generations. In response, the development of sustainable or green buildings is increasingly being embraced globally.

Following the global trend, South Africa now has over 400 Green Star certified buildings of which approximately 200 are certified as New Construction – an achievement that clearly demonstrates the commitment to the industry transformation led by major real estate owners, developers and the wider stakeholder groups. This transformation would not have been possible without the efforts of the Green Building Council of South Africa (GBCSA) in developing, setting out and managing the Green Star certification schemes.

Green buildings are designed and constructed to have reduced negative impact on the environment by being, for example, energy and water efficient, and at the same time promote occupants' health and wellbeing.

The reduced environmental impact is assessed as part of the certification process through mathematical calculations and modelling of building performance.

The Green Star rating schemes place particular emphasis on building energy efficiency, in response to the real current threats of Global Warming, such as climate change, habitat destruction, rising sea levels and reduced global food security. Energy related categories make up roughly 30% of the typical Green Start rating schemes.

The purpose of this research is to establish whether certified green buildings do generally perform in line with expectations, in terms of energy, and assist in identifying possible reasons, if not. As such, the research highlights the energy performance of 12 Green Star SA New Construction As-Built certified buildings by examining the energy consumption of the buildings since the certification, or when consumption data became available, until and including 2017. The consumption data of each building for 2017 is also compared to the energy simulations' results derived during the certification of the buildings. Lastly, the facilities management function and operational processes are briefly examined in relation to typical green star requirements for improving energy performance.

1.2. The problem

The energy performance modelling of buildings undergoing certification is carried out within the framework of a modelling protocol, which assumes standardised input variables for building operations, e.g. operating hours, occupancy, etc. No actual performance or consumption data is used in this process. Because of the theoretical nature of modelling, correlation of modelling results with actual performance cannot be taken for granted.

In practice, however, the results of performance modelling create expectations of actual performance. Building owners expect improved efficiencies over the norm to justify the increased capital outlay and increased lease rentals of this type of building. Tenants on the other side, expect improved efficiencies that translate into real operational savings, thereby justifying the increased rentals.

The environmental performance of certified buildings, e.g. reduction of CO_2 emissions, is also important when financial decisions are made by both owners and tenants as many of them constitute listed companies subject to social and environmental responsibility reporting.

The financial value of the improved efficiency becomes a key driver in the development feasibility for building owner and tenant alike, even if that expectation cannot be justified given the theoretical nature of performance modelling.

By assessing the actual energy performance of Green Star New Construction As-Built certified buildings, this research aims to establish whether these buildings fulfil stakeholders' expectations set out during the design and construction stages of the buildings through theoretical modelling of performance.

1.3. The Sub-problems

Sub-problem one:
How does actual energy performance of the buildings compare to the simulated energy performance as established during the certification process?

Sub-problem two:
What energy consumption and energy use intensity (EUI) trends are the buildings exhibiting once in operations?

Sub-problem three:
What facilities management / operating factors contribute to improving the energy performance of the buildings?

1.4. Definition of terms

Climate Change
The change expected to occur to the world's climate due to human activities that emit greenhouse gases, such as burning fossil fuel (cars and electricity generation) and deforestation.

Commissioning
The advancement of an installation from the state of static completion to full working order to the specified requirements. It includes the setting to work of an installation, the regulation of the system and the fine tuning of the system.

Energy Use Intensity (EUI)

Energy use intensity (EUI) is an industry recognised metric that many ratings tools and international studies use to compare building energy efficiency. The EUI is defined as:

$$EUI(kWh/m2) = \frac{Annual\ Energy\ Consumption\ (kWh)}{Building\ Area\ (m2)}$$

For the purpose of this study, annual energy consumption is the whole building annual electricity consumption in kWh while the building area is the Gross Lettable Area (GLA) of the whole building in m^2.

Green Building

A building, which is energy efficient, resource efficient and environmentally responsible - it incorporates design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and occupants.

Greenhouse Effect

(1) The warming of the earth’s surface and lower atmosphere as a result of carbon dioxide and water vapour, which absorb and reradiate infrared radiation, in the atmosphere;

(2) An intensification of this warming effect from human-induced increase in carbon dioxide and other greenhouse gases in the atmosphere from the burning of fossil fuels.

Greenhouse Gases (GHGs)

Trace gases such as carbon dioxide, water vapour, methane, and CFCs that are relatively transparent to the higher-energy sunlight but trap the lower-energy infrared radiation.

Gross Lettable Area (GLA)

The Gross Lettable Area (GLA) or Rentable Area in m^2 per the SAPOA definitions of 1 August 2005 is the total area of the building enclosed by the dominant face, adjusted by deducting major vertical penetrations. It comprises the usable area plus common areas of the building but excludes car parking. GLA is therefore the area assigned for exclusive use by occupants / tenants, including common areas such as:

- Building entrance foyers;
- Plant and server rooms on tenant floors;

- Toilet areas on the tenant floors;
- Access or circulation areas on tenant floors.

Occupancy Hours

The Occupancy Hours are defined as the hours for which the building is occupied, measured on a weekly basis when 20% or more of the normal, permanent occupants of the building are present. It is important to note that this measurement is taken in terms of business or normal office activities and not in terms of plant Heating, Ventilation and Air Conditioning (HVAC) system operations.

The occupancy hours of common areas and circulation areas are taken to be equal to the operating hours of the office portions which they serve.

Renewable Energy

An energy source that, from an earth perspective, is continually being replenished, e.g. solar energy

Usable Area (UA)

The floor area capable of exclusive occupation by the tenant (refer SAPOA definition 1st Aug 2005). Consists of the total area of the building enclosed by the Dominant face, adjusted by deducting all Common Areas and Major Vertical Penetrations. No deductions shall be made for columns.

1.5. Research Approach and Methodology

The purpose of the study is to establish whether green buildings do generally perform in line with expectations, in terms of energy, and assist in identifying possible reasons, if not. It consists of:

a. Comprehensive literature review covering climate change and sustainable development, the effect of buildings / construction industry on the environment, green buildings and certification schemes, green buildings in South Africa, energy performance as a major component in certification schemes, energy performance of certified buildings (new construction) and future trends in energy performance;
b. Comparison of actual energy performance of 12 Green Star SA As-built certified office buildings in Gauteng to normalised simulated energy performance;
c. Trending of the energy consumption and Energy Use Intensity (EUI) of these buildings over a number of years;

d. A survey into facilities and operations management practices and correlation of these to the energy performance of the buildings.

Quantitative research was carried out to arrive at an informed response to the main question and sub-questions as defined in Sections 1.2 and 1.3 above.

1.5.1. Data types and sources

The table below depicts the data types, format and sources where the data was obtained from.

Table 1: Data types, format and sources

Reference	Type of Data	Format	Source
Sub-Problem 1	Green Star Ene-1 GHG Emissions Credit Completed Calculators and Reports for As-built rating	Adobe Acrobat Files	Building Owners and Green Star Accredited Professionals (APs)
	Building Parameters: • GLA • Vacancies • Occupancy • Occupancy Hours	MS Excel Tables / E-mails	Respective Facilities / Properties Managers
Sub-Problem 1&2	Actual energy consumption	Adobe Acrobat Files or MS Excel tables	Respective Facilities /Properties Managers or Utilities Companies
Sub-Problem 3	Response to a survey / questionnaire	MS Excel Table	Included in Appendix A

1.5.2. Delimitations

- The research intends to compare the actual and expected performance of certified buildings and identify possible facilities management and operating practices which have positive impact on energy performance;
- The scope of the study is limited to 12 office buildings certified with the GSSA Office V1 As-Built certification scheme between 2010 and 2017;
- All buildings are located in the Gauteng province;
- All buildings are in operation for more than 24 consecutive months;
- The performance analysis is based on ~~a~~ whole building consumption data;
- The energy consumption of data centres within the office buildings, where separately metered, was excluded from the whole building energy consumption;

- Trending of energy performance is carried out for a period since consumption data became available until end of 2017;
- The performance data used for comparison is 12 months energy consumption data of 2017;
- Metered data is used for the analysis, except for one building where Eskom consumption data was provided, with the assurance from the particular Utility Service Provider that the Eskom data has been reconciled with the building's metered data;
- The study took place from 1 Aug 2018 to 31 Oct 2018.

1.5.3. Assumptions

Building Occupancy

Where the number of average occupants over a year could not be provided by the participants in the research, it was assumed that the building had an occupancy rate of 10m^2/person over the Usable Area (UA) and 15m^2/person over the Gross Lettable Area (GLA). The above assumption is based on recommendation by the representatives of the building owners who provided operational data and participated in the interviews.

Computer Density

Computer density (computers/m^2) was assumed to be equal to occupancy density of the building, i.e. one computer per occupant.

1.6. Importance of and / or need for the study

The research aims at improving the understanding of

a) The correlation between the expected and actual energy performance of Green Star certified buildings; and
b) Facilities management / operational practices that support Green Star certified buildings to achieve optimal energy performance during the operational phase.

To our knowledge, a research of this nature has not been carried out in South Africa yet. With close to 200 Green Star SA New Construction certified buildings in Oct 2018, it is essential to understand whether these buildings are delivering on the promise made at certification. The new construction / major refurbishment certifications require financial resources and effort by all involved – developers, designers, engineers, consultants, GBCSA staff and assessors. Significant part of those relate to the energy performance of the buildings which, for many reasons, could be compromised during the operational phase.

By understanding the gap between normalised simulated performance and the actual energy performance of buildings, concerted effort can be applied to correct shortfalls and align the performance to targets established during design. Without this, the construction industry will fail to deliver on the transformation efforts to curb the effects of greenhouse gas emissions and climate change, environmental protection and efficient resource use.

This research will ultimately serve the real estate sector - property owners, developers, tenants, facilities managers and investors, the GBCSA as well as other key stakeholders such as the construction industry, academia and property professionals, by providing evaluation of the energy performance of Green Star certified buildings and facilities management practices that contribute to optimising of the operational energy performance.

Although the scope of the study is limited to 12 buildings in one geographic location, the approach and methods used can be applied to a larger sample of buildings throughout the country. Future extension of this research will deepen the understanding of energy performance of certified buildings and inform ways in which to operate buildings so that appropriate targets are identified and achieved.

CHAPTER 2 - LITERATURE SURVEY

2.1. Introduction

Literature review forms a major component of this research firstly to contextualise the research and secondly where applicable, to inform the content of the surveys to be carried out with participating facilities managers.

The surveyed literature can be categorised as follows:

- Climate change and sustainable development;
- The effect of buildings on the environment;
- Green buildings – definitions and benefits;
- Major Green Building Councils and rating systems;
- Green Buildings development in South Africa– new construction and performance rating;
- Importance of the energy category;
- Energy performance of certified buildings.

Details related to the above categories are provided in the following sections of this chapter.

2.2. Climate change and sustainable development

Sustainability or sustainable development encompasses all facets of society - industry, transport, agriculture, construction, government and, as defined by the Brundtland Commission, entails “meeting the needs of the present without compromising the needs of the future” (Brundtland, 1987).

The above definition places responsibility on humanity, amongst others, for prudent use of natural resources so that long term benefits are created for current and future generations. This, unfortunately, has not been the case in the past couple of centuries. The industrial revolution saw an increase in the burning of fossil fuel for industrial process to unprecedented levels. The availability of energy was the very catalyst of the industrial age, making possible large-scale manufacturing and giving rise to large scale exploitation of resources, both fuel and raw materials. The environmental effect, caused by indiscriminate use of resources during the industrialisation and the years that followed, was not grasped until few decades back. Rachel Carson’s *Silent Spring* published in 1962, warning of the unpredictable negative consequences of industrial and technological advancement, is considered as one of the events that triggered the wider environmental movement (Suzuki and Dressel, 2004). For the first time the negative impact of human activities on nature were pointed out, initiating the broader environmental crusade. In the years that followed, the scientist established the direct link between human induced activities and industries and climatic changes, which led ultimately to the enforcement of the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 (UNFCCC, 2014).

The effect of human industrial activities on our planet's environment has been extensively explored by scientist. While still controversial for some, the fact that industrial human activities, underpinned by burning of fossil fuel, are the cause of climate change has become widely recognised and accepted. This was again reconfirmed in the assessment report issued by Intergovernmental Panel on Climate Change (IPCC) in April 2014, setting out recommendations for mitigation and adaptation to climate change in line with the objectives of the UNFCCC (IPCC, 2014b).

Climate change has become an integral part of our reality. In the past years, we have witnessed changes in weather patterns caused by the average increase in temperatures on the planet (WWF, 2018). Anthropogenic (human induced) greenhouse gas emissions are at the centre of global warming. Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), etc., retain heat in the atmosphere, resulting in rising of the average temperatures on the planet. Consequently, this affects negatively the fragile balance of conditions that sustain life on Earth. Unpredictable and extreme weather, namely heat waves, floods, tropical storms, hurricanes are causing devastation in various parts of the world as existing infrastructure and natural habitats are incapable of withstanding events of such intensity (WWF, 2018).

Greenhouse gas emissions for the period of 1970 to 2000 have grown on average by 0.4 (1.3%) Giga tonne carbon dioxide equivalent ($GtCO_2eq$) per year (IPCC, 2014a). In the following period of 2000 to 2010, however, the emissions have increased on average by 1.0 $GtCO_2eq$ (2.2%) per year, representing the highest level of anthropogenic greenhouse gas emissions in human history. Despite mitigation intervention being implemented in this period, the emissions recorded in 2010 were 49 $GtCO_2eq/yr$, representing an approximate increase of 4.5%.

The table and the graph below depict the distribution of greenhouse gas emissions per economic sector for 2010 (IPCC, 2014a).

Economic Sector	Direct Emissions (%)	Indirect Emissions (%)	Total (%)
Electricity and Heat Generation	25	0	25
Agriculture, Forestry and Other Land Use	24	0.87	24.87
Buildings	6.4	12	18.4
Transport	14	0.3	14.3
Idustry	21	11	32
Other Energy	9.6	1.4	11

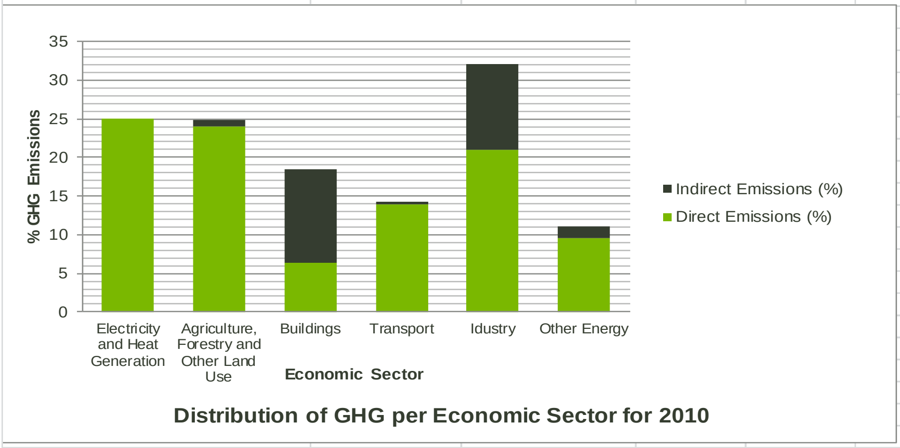
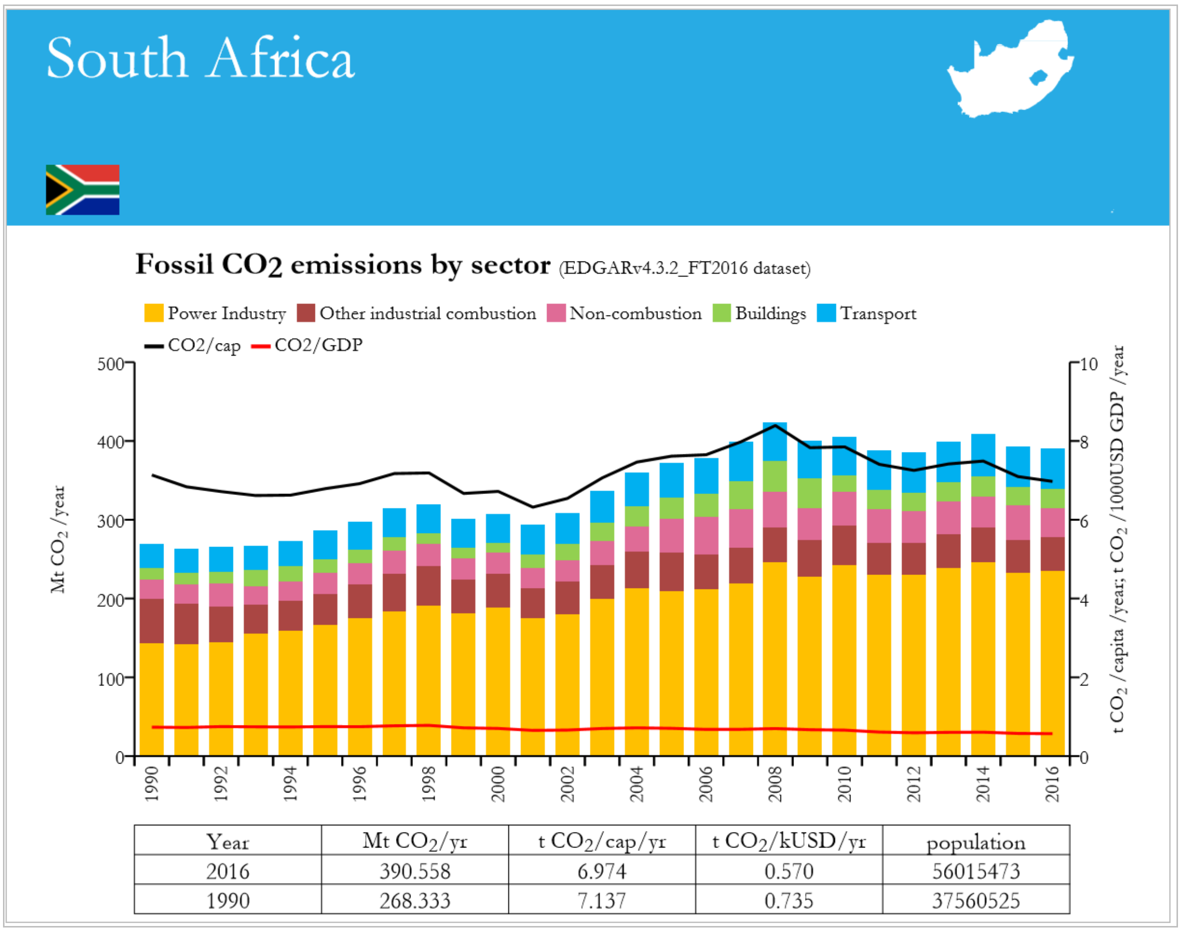


Figure 1: Distribution of greenhouse gas emissions per economic sector (IPCC, 2014a)

Globally, buildings account for the highest indirect greenhouse gas emissions levels comparable to the ones of the industrial sector. Indirect greenhouse gas emissions relate to the electricity that buildings consume. In 2010, the electricity consumption of buildings globally accounted for 51% of the total electricity consumption for the period (IPCC, 2014b). The building sector's greenhouse gas emission and electricity consumption figures of South Africa for 2006 are of similar order. The sector accounted for 31% of the total electricity consumption, whilst the CO_2 emissions, both direct and indirect were 23% of the total CO_2 emissions for the period (United Nations Environment Programme, 2009).

In South Africa, 90% of electricity is generated by burning of coal, with the remaining 10% attributed to nuclear and hydro sources (Department of Energy, 2013). Given the above figures, it is not surprising that South Africa rates 16th in the world for CO_2 emissions from fossil fuel use and cement production, 15th for CO_2 emissions per capita from fossil fuel use and cement production, and 3rd for CO_2 emissions per unit of GDP from fossil fuel use and cement production (Jos G.J. Olivier; Greet Janssens-Maenhout; Marilena Muntean; Jeroen A.H.W. Peters, 2016).

The South African CO_2 emissions for the period of 1990-2016, as recorded by The Emissions Database Global Atmospheric Research (EDGAR), are depicted in the following graph.



Year	Mt CO_2/yr	t CO_2/cap/yr	t CO_2/kUSD/yr	population
2016	390.558	6.974	0.570	56015473
1990	268.333	7.137	0.735	37560525

Figure 2: South Africa: Fossil CO_2 emissions by sector (The Emissions Database for Global Atmospheric Research (EDGAR), 2016)

It can be observed that since 1990 the South African CO_2 emissions have steadily increased and although it may be expected that the country comes close to meeting stated targets for 2030 its targets are "Highly insufficient" (Climate Action Tracker, 2017). This is mainly attributed to the fact that the coal fired power generation, which supplies 93% of electricity, is on track to grow in the next few years with the new coal plants coming on line. At the same time, power generation from renewable sources and investment in such is being hindered by the lack of supporting regulatory environment and political will to develop it.

Another interesting graph published in the 2016 report by the PBL Nederland's Environmental Assessment Agency depicts South Africa as one of the eight main coal producing and coal consuming countries in the world.

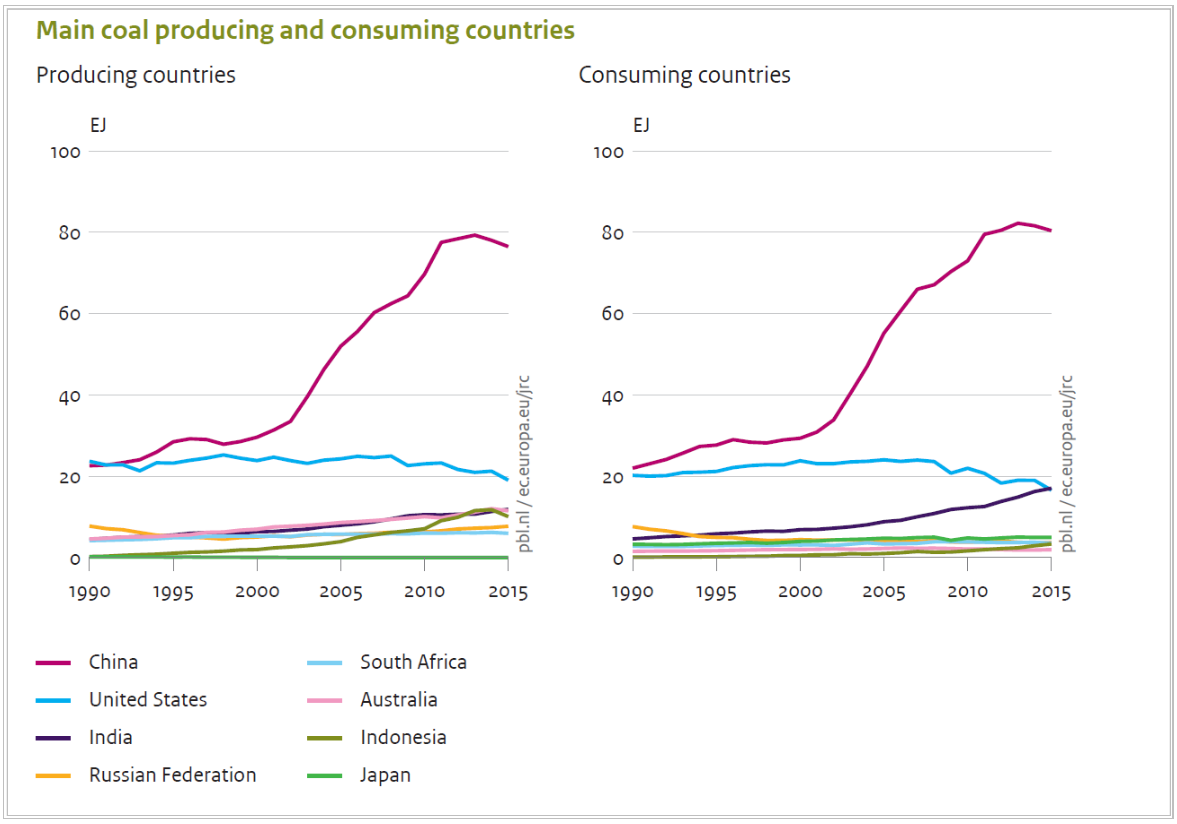


Figure 3: Main coal producing and consuming countries (Jos G.J. Olivier; Greet Janssens-Maenhout; Marilena Muntean; Jeroen A.H.W. Peters, 2016)

Whilst various intervention in response to climate change have been implemented globally and locally in the past few years, these interventions are insufficient to limit the rising global average temperature to below 2°C compared to pre-industrial levels. The limit of below 2°C rising average temperatures entails the reduction of the 2020 predicted greenhouse gas emissions, namely 59 $GtCO_2eq$ in a “business as usual” scenario by 17 $GtCO_2eq$, to levels way below the recorded ones in 2010 of 50.1 $GtCO_2eq$. The reduction target of the global buildings sector is set at a range of 1.4 to 2.9 $GtCO_2eq$ for up to 2020 (UNEP, 2013).

In 2015, the United Nations Framework Convention on Climate Change (UNFCCC) held its 21st Conference of the Parties (COP21) in Paris, where 195 participants “adopted the first-ever universal, legally binding global deal’ (European Commission, 2016). COP21 re-iterated that the greenhouse gas emissions levels for 2020 and 2030, as estimated based on intended nationally determined contributions, will not result in fulfilling the scenario for least-cost 2°C limit and that “much greater emission reduction efforts will be required”. A new ambitious limit of 1.5°C temperature rise above pre-industrial levels was called for and the Intergovernmental Panel on Climate Change (IPCC) was invited “to provide a special report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission s pathways” (UNFCCC. Conference of the Parties (COP), 2015).

Although COP21 / Paris Agreement was considered a historic event (The World Bank, 2015) and a turning point in global action on climate change (World Resource Institute, 2015), the more recent UN report on emissions gap reviles that even if implemented, the commitments made by the signatories of the Paris Agreement are not sufficient to hold global warming by 2030 below 2°C compared to pre-industrial levels. The report states that for the 2°C goal, this shortfall could be 11 to 13.5 $GtCO_2eq$, whereas for the 1.5°C goal, it could be as much as 16 to 19 $GtCO_2eq$ (United Nations Environment Programme (UNEP), 2017).

Whilst all sectors of the economy contribute to greenhouse gas emissions, scientists have established that buildings sector is one of the major energy consumer and CO_2 emitter at the same time. Current figures published by the European Commission indicate that buildings are accountable for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU. In addition, approximately 35% of the EU’s buildings are older than 50 years and almost 75% of the building stock is inefficient (European Commission, 2018).

The US Energy Information Administration (EIA, 2017) projects that the building sector, consisting of both residential and commercial structures, will be responsible for almost 21% of the of the world’s total energy consumption in 2040. The building sector energy consumption is predicted to increase by 32% between 2015 and 2040, primarily because of large, emerging economies where populations is and will be undergoing extensive urbanisation. As a result, buildings “represent a critical piece of a low-carbon future and a global challenge for integration with sustainable development” (IPCC, 2014b)

The next section provides further details on buildings and their effect on the environment.

2.3. The effect of buildings on the environment

The buildings constitute an asset class that creates value for various stakeholders, such as owners, developers, occupants, shareholders and communities. On the other hand, buildings are resource intensive – they use large amounts of natural resources that are in limited supply, such as electricity, water, timber, etc. Buildings consume large quantities of electricity, yet, according to Energystar.gov, an average building wastes 30% of the energy it consumes due to inefficient operation (Energystar.gov, 2018).

Buildings are the source of environmental pollution. The electricity that they consume is mostly generated through burning of coal, which has the highest contribution to CO_2 emissions. Large quantities of CO_2 are emitted during the manufacturing of construction materials notably steel, cement, bricks, etc.

Uncontrolled and unfiltered storm water runoff from buildings often causes flooding and pollution of the natural watercourses.

Buildings are also responsible for the emissions of substances such as Chlorofluorocarbons (CFCs) and Hydrochloroflourocarbons (HCFCs). These substances (covered under the Montreal Protocol) are used as refrigerants in air-conditioning systems and in some insulation materials. Both CFCs and HCFCs have been known to cause long-term damage to the Earth's stratospheric ozone layer and to have significant global-warming potentials.

In addition, the indoor environment of buildings, if neglected, can have negative effect on the wellbeing of occupants due to insufficient fresh air and natural day light, disconnect from the natural environment, chemicals used in the interior finishes that emit volatile organic compounds, high ambient and equipment noise level. The tables below provide a summary of buildings resource use and pollution levels, in global terms.

Table 2: Buildings - Estimated global resource use (Wilmot Dixon, 2010)

Resource	(%)
Energy	45–50
Water	50
Materials for buildings and roads (by bulk)	60
Agricultural land loss to buildings	80
Timber products for construction	60 (90% of hardwoods)
Coral reef destruction	50 (indirect)
Rainforest destruction	25 (indirect)

Table 3: Buildings - Estimated contribution to global pollution (Wilmot Dixon, 2010)

Pollution	(%)
Air quality (cities)	23
Climate change gases	50
Drinking water pollution	40
Landfill waste	50
Ozone depletion	50

Lastly, buildings have long lives – they are constructed to provide utility for current and future generations. Therefore, the buildings' immediate and future effect on the environment and occupants must be carefully evaluated. These effects must inform the design, operations and most importantly the real estate valuation models, which until now have not accounted for environmentally and occupant responsible properties.

2.4. Green buildings

The movement towards green or sustainable buildings was created due to the extensive negative effect of the construction sector on the environment. Various organisations and authorities, worldwide, initiated rating schemes for the assessment of the environmental performance and characteristics of buildings against predetermined criteria. More than sixty countries in the world have their own rating systems, with criteria varying from country to country depending on each country's environmental context, climate, natural resources, electricity, water availability. (Dwaikat and Ali, 2016).

The most prominent schemes and most widely used ones are BREEAM (British Research Establishment Environmental Assessment Method), which is credited as the first assessment tool for green buildings and LEED (Leadership in Energy and Environmental Design). Buildings certified under BREEAM are expected to have 6-30% lower energy cost than non-certified buildings, whilst LEED rated buildings are said to have 18-39% lower energy use in comparison to their non-certified counterparts (Doan *et al.*, 2017).
This section provides a brief overview of green buildings definitions, the major green building councils in the world and respective schemes.

2.4.1. Definitions and characteristics

Green building, as defined by the Green Building Council of South Africa, “incorporates design, construction and operational practices that significantly reduce or eliminate the negative impact of development on the environment and people. Green buildings are energy efficient, resource efficient and environmentally responsible.” (GBCSA, 2014a)

Van Wyk (2010:23) provides an alternative definition incorporating aspect such as energy, water and resource efficiency, improved occupant health and productivity and reduction of “waste, pollution and environmental degradation”.

McLennan (2005:337) implies that green buildings are the result of sustainable design which constitutes a philosophy aiming to “maximise the quality of the built environment while minimising or eliminating the negative impact to the environment” and advocates the following sustainable design principles:

- Respect for the Wisdom of Natural systems – The Biomimicry Principle;
- Respect for People – The Human Vitality Principle;
- Respect for Place – The Ecosystem / Bioregion Principle;
- Respect for the Cycle of Life – The “Seven Generations” Principle;
- Respect for Energy and Natural Resources – The Conservation and Renewable Resources Principle; and
- Respect for Process – The Holistic Thinking Principle.

A parallel between the above definitions suggests that there are distinct characteristics that define green buildings, namely environmental and waste responsibility, efficient energy, water and other natural resources use, care for the people and the ecological systems affected by the building. Life expectancy and use are other important characteristics that inform the design, construction and operation of the green buildings.

Green buildings require fully integrated approach to design in order to achieve the desired sustainability outcomes. The process unfolds with the identification of various interdependencies between the building elements (envelope) and the associated building services. A typical example of integrated approach is the design of a high performance multi-functional façade optimised for daylight harvesting, mixed mode ventilation, thermal comfort, external views and solar control. Integrated design requires concurrent inputs by the architect, the façade engineer, the mechanical and electrical engineers to establish the balance between conflicting parameters such as energy and day light, fresh air distribution and energy, external views and thermal comfort, etc. Integrated design leads to the optimal performance of the building whilst limiting the negative effect on the environment and at the same time improving the experience of occupants.

2.4.2. Benefits and Costs

Typical benefits that green buildings can deliver are summarised in the following table.

Table 4: Summary of benefits attributed to Green Buildings (GBCSA, 2014a)

Benefit	Qualitative or Quantitative Description
Lower Operating Costs	Energy savings between 25% and 50% compared to SANS 204 compliant building. Shorter pay back periods for energy and water saving initiatives.
Higher Returns on Asset	6% and 5% higher returns in US and Australia. Data for South Africa is still limited.
Increased Property Value	11% and 12% valuation premiums in US and Australia respectively. Data for South Africa is still limited.
Reduced Liability and Risk	Future proofed against increases in utility costs, potential utilities problems, legislative requirements for utilities, carbon taxes, costly retrofits, etc.
Ability to Attract and Retain Government and Other Major Tenants	Department of Public Works is likely to follow other governments in setting requirements for Green Buildings in government accommodation. This will apply to large multinational tenants.
Responsible Investing	South Africa will follow international trends for responsible, sustainable and ethical investment
Increased Productivity	Studies show that higher indoor environment quality, lead to up to 20% improvements in productivity.
Competitive Edge in Attracting and Retaining Talent	Younger graduates are increasingly aware of environmental and health issues.
Minimising the Cost and Impacts of Churn	Increased comfort, occupant satisfaction and flexibility in spaces.

As the multi-dimensional benefits of green buildings have become more evident and are detailed in various studies, so are the costs related to design, construction and certification of such buildings. Often, the perceived cost premium of green buildings in compression to the conventional type is cited by investors and developers as the reason for undertaking a conventional development instead of green (Dwaikat and Ali, 2016). The same study, through an extensive research of literature on upfront costs of green buildings, established that there are controversial results, but the majority of cases examined cited a cost range of -0.4% to 21%.

In a recent South African study by the GBCSA, ASAQS and UP on the cost of green buildings, it was found that locally the green buildings, on average, command 5% premium, but depending on the case, the premium could be as low as 1.1%. The study involving 54 Green Star rated buildings throughout the country, also revealed that the green cost premium increases as the rating aspirations of a project increase, i.e. on average, for a 4 Star Green Star SA rated building the premium is 4.5%, for a 5 Star rated building, 6.6% and for 6 Star rated building – 10.9% (GBCSA, ASAQS, UP, 2016).

The research by the GBCSA, ASAQS and UP is a considerable step in demystifying the cost premium of green buildings in comparison to their conventional counterparts, which until now has been the most significant obstacle for developing of green buildings in the country.

2.4.3. Major Green Building Councils and Rating Systems

a) *World Green Building Council*

The World Green Building Council was established in 2002 “with the mission of supporting the development of Green Building Councils around the world, as well as to unite them with a common voice and purpose” and “to create green buildings for everyone, everywhere - enabling people to thrive both today and tomorrow” (WGBC, 2018). With more than one billion square metres of green building certified space collectively by all members, the World Green Building Council facilitates global network and dialog for sustainable development leading to environmental, economic and social benefits.

a) *United States*

The United States Green Building Council (USGBC) was established in 1993 with the mission “to promote sustainability in the building and construction industry” (USGBC, 2014). USGBC is a non-profit organisation with current membership contingent of 13 000 organisations and more than 180 000 accredited Leadership in Energy and Environmental Design (LEED) professionals. USGBC is the custodian of the LEED certification system which was piloted in 1998 and official released in 2000.

The LEED certification system provides industry established benchmarks for a third-party validation of the green features of a building in terms of design, construction and operations. LEED certification can be undertaken for buildings in various countries and for new construction and major refurbishments type of projects, existing buildings, commercial interiors, core and shell, schools and homes. Neighbourhood development, retail and health types of certifications are currently in pilot phases.

Current published statistics indicate that globally there are more than 92 000 projects participating in LEED schemes for certification over 165 countries and that there are more than 2.2 million square feet of space certified daily (USGBC, 2018).

a) *United Kingdom*

The United Kingdom Green Building Council was established in 2007 with the mission "to radically improve the sustainability of the built environment by transforming the way it is planned, designed, constructed, maintained and operated" (UKGBC, 2014).
With over 400-member organisations, the UKGBC aims to influence government policies, lead industry action and build industry knowledge and green skills.

The most widely used in the UK and around the world certification system is the Building Research Establishment Environmental Assessment Methodology (BREEAM). Launched in 1990, BREEAM establishes the best practice benchmarks for sustainable design, construction and operation. With over half a million certified buildings throughout the world, BREEAM is one of the most recognised certification systems for building environmental performance (Nguyen and Altan, 2011). According to statistics published by BREEAM (2018), the certification system is currently used in more than 77 countries, with over 2 million registered buildings, and over 564 470 certificates achieved worldwide.

a) *Australia*

The Green Building Council of Australia was launched in 2002 with the mission "to develop a sustainable property industry for Australia and drive the adaptation of green building practices through market based solutions" (GBCA, 2018).
The Australian certification system is Green Star, which similarly to LEED and BREEAM, evaluates the sustainable characteristics of buildings and communities for both design and construction phases.

The Australian Green Star rating system is primarily used in Australia where more than 1750 projects have been certified (GBCA, 2018).

2.5. Green Buildings Development in South Africa

The South African built environment has undergone significant transformation since the establishment of the GBCSA in 2007 (GBCSA, 2018). With the assistance of the Australian Council, GBCSA adopted the Green Star certification system for the South African conditions and officially launched it in 2008.

Currently, the GBCSA certifies projects by means of the following tools, aligned with the different market sectors:

- Office
- Public and Education
- Retail Centre
- Multi Unit Residential
- Sustainable Precincts
- Interiors
- Existing Buildings Performance
- Net Zero / Net Positive
- Socio-economic Category Pilot

Buildings which do not fall under any of the above market sectors, such as hotels, hospitals, or mixed-use developments are rated with custom developed tool for the particular type of project.

The table below depicts the number of certified projects under the various GBCSA schemes up until May 2017. These include new construction for office, retail, multi-unit residential, public and education, custom such as industrial, hotel or mixed-use developments, as well as existing buildings performance and energy and water benchmarking for existing buildings (GBCSA, 2017).

Table 5: Certified buildings under the Green Star SA schemes (GBCSA, 2017)

Count of GS Certification	GS Certification								
Year Certified	**CUS**	**EBP**	**EWP**	**INT**	**MUR**	**OFF**	**PEB**	**RETAIL**	**Grand Total**
2009						1			1
2010						3		1	4
2011					1	7			8
2012						15			15
2013					1	18	2		21
2014		2				24			26
2015		29	19	4		28	3		83
2016	3	34		5		28	3	1	74
2017	1	7	2	11	1	4	1		27
Grand Total	**4**	**72**	**21**	**20**	**3**	**128**	**9**	**2**	**259**

The corresponding graph beneath indicates the steady increase of certified buildings for the period of 2009-2017, with existing buildings performance (EBP) certification becoming more prominent in the last couple of years.

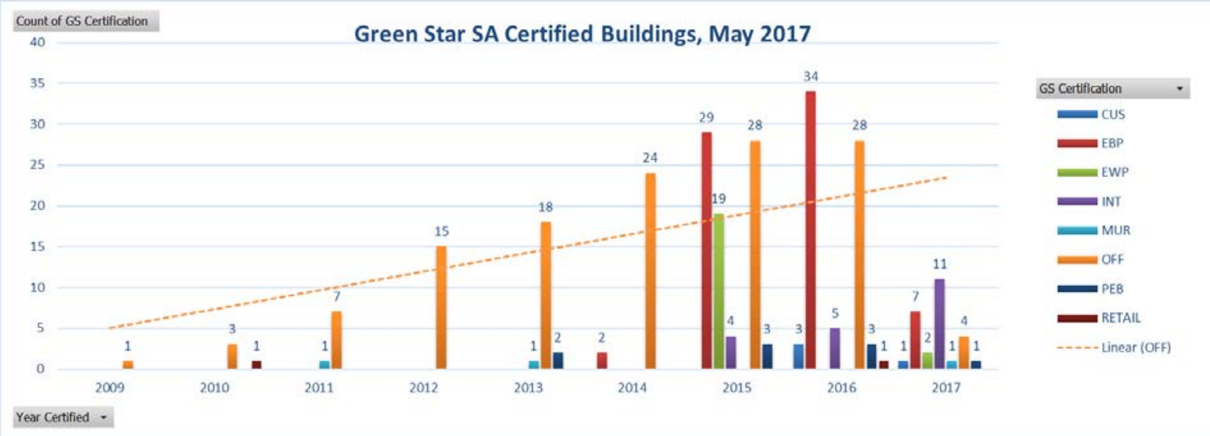


Figure 4: Green Star SA certified buildings (GBCSA, 2017)

The Green Star SA rating system has two major rating tools for the different stages of buildings' lifecycle, namely new construction and major refurbishment tool for design and construction stage and existing buildings performance tool for the operational stage.

Both tools will be used in the methodology of this research for evaluation of energy performance of green star certified buildings and therefore each of these is briefly detailed hereunder.

2.5.1. New construction and major refurbishment - Design and As-built rating

The Green Star SA New Construction (and major refurbishments) tools (Office, Retail, Public and Education, Custom Development, etc.) assess both the Design and As-Built phases of a new development or base building refurbishment. The same credits are applicable for both Design and As-Built certification, however compliance to criteria is demonstrated through different types of documents – tender or construction drawings for design rating and as-built drawings and commissioning records for as-built rating.

Similar to Green Star Australia, BREEAM and LEED, the system rates the environmental performance of the buildings' design and construction under a number of categories, including:

- Management;
- Indoor Environment Quality;
- Energy;
- Transport;
- Water;
- Materials;
- Land Use and Ecology;
- Emissions; and
- Innovation.

Each category consists of a number of credits with allocated points. Projects can elect the targeted credits and associated points depending on the desired certification outcome, namely 4, 5 or 6 Green Star SA. To undergo certification, projects are required to meet applicable eligibility criteria, relating to spatial differentiation, time of certification and conditional requirements for energy performance of the building and ecological characteristics of the site (GBCSA, 2014b).

The credit which assesses the greenhouse gas emissions and the energy performance of the building undergoing certification is Ene-1 GHG Emissions. The assessment involves energy performance modelling with inputs on the building envelope and all energy consuming and generating building services / systems. The simulations result is then compared to a notional building constructed to the 'deemed to comply' fabric and building services clauses of SANS 204:2008 Energy Efficiency in Buildings.

2.5.2. Existing Buildings Performance rating – buildings in operation

The Green Star SA Existing Buildings Performance tool assesses the environmental performance of buildings while in operational phase. As such the tool uses actual energy and water consumption data and operational policies, which is the main differentiator to the new construction tool.

The South African EBP tool was developed based on the Australian tool for existing buildings and the assessment is structured in the same categories as in the new construction tool. Energy performance is evaluated under Ene-1 credit, on the basis of a one years' consumption data of the whole building, excluding unoccupied area and area that has a significantly different energy load, e.g. data centre.

2.6. The importance of energy assessment under the various tools

The green building certification tools assess environmental performance and characteristics of buildings under various categories, e.g. energy, water, materials, etc., which are prioritised depending on the significance of a particular environmental problem in a country or a region. For example, the excessive use of fossil fuel for energy generation across the world leads to severe environmental damage from harmful emissions. As a result, in most environmental assessment tools priority is allocated to the energy category and related credits to boost energy optimisation in design and equipment, as well as electricity production from renewable sources (Suzer, 2015).

A different research by Doan *et al.* (2017) confirms the energy is the most important category for both BREEAM and Green Star in comparison to remaining categories of the tools. Again, this is due to the excessive direct and indirect energy use of the construction sector. As depicted in the graph below, in LEED V4, the Transport category has a similar priority to Energy, which also relates to CO_2 emissions and reduction thereof.

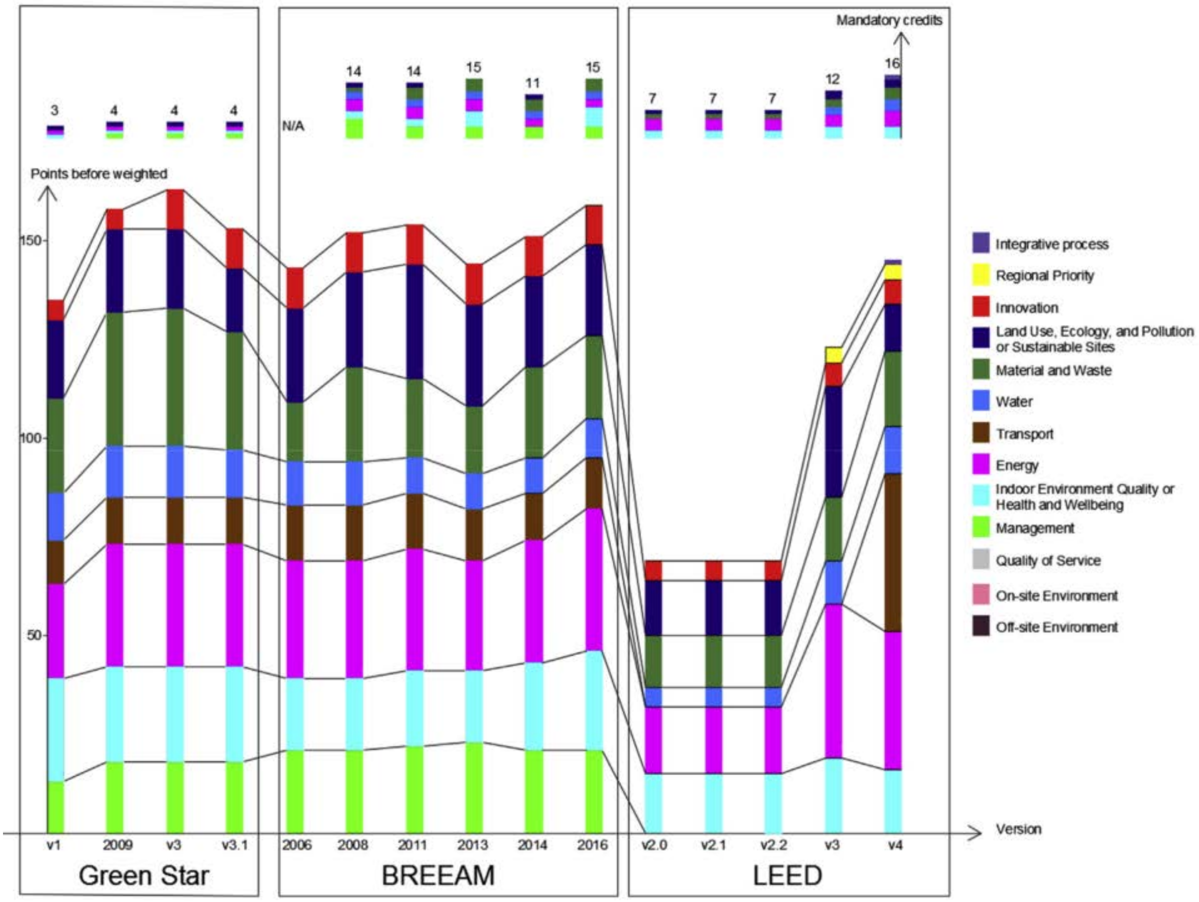


Figure 5: Comparison of categories' priorities in Green Star, LEED and BREEAM (Doan *et al.*, 2017)

The importance of the Energy category in LEED, BREEAM and Green Star is also depicted in the table and the graph below, detailed in a research by Illankoon *et al.* (2017), where the allocation of credit points is also given.

Table 6: Credit criteria of selected green rating tools (Illankoon *et al.*, 2017)

LEED (Building Design and Construction –115 credit points)	**BREEAM** (BREEAM New Construction – international – 130 credit points)	**Green Star** (Design and As Built – 100 credit points)
Location and transport (20)	Management (23)	Management (14)
Sustainable sites (10)	Health and wellbeing (17)	Indoor environment quality (17)
Water efficiency (12)	Energy (27)	Energy (22)
Energy and atmosphere (35)	Transport (12)	Transport (10)
Material and resources (14)	Water (9)	Water (12)
Indoor environmental quality (18)	Material (11)	Material (14)
Regional priority (4)	Waste (6)	Land use and ecology (6)
Integrative process (1)	Land use and ecology (12)	Emissions (5)
Accredited professional (1)	Pollution (13)	Innovation (10)
Innovation (5)	Innovation (10)	

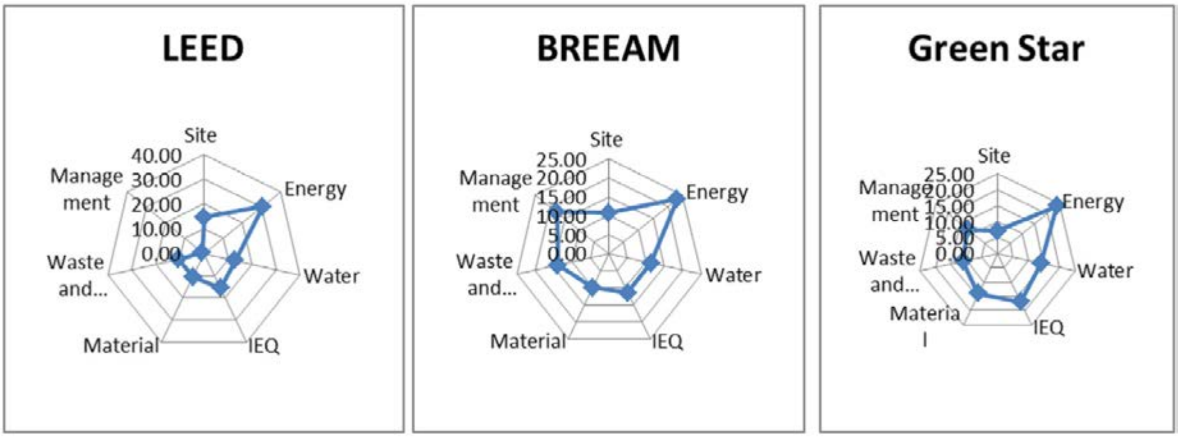


Figure 6: Radar diagram for Green Rating Tools based key credit criteria (Illankoon *et al.*, 2017)

In addition to having the highest allocation of points under the Energy category, all of the above tools set out prerequisites for rating of the buildings related to the Energy category. Compliance with the prerequisite requirements does not result in points added towards the final score of the project, they are mandatory and hence significant in awarding the certification.

Apart from Energy being the key category for certification of green buildings, the recent South African study on cost of green buildings (GBCSA, ASAQS, 2016) indicates that as much as 31% of the green cost premium relates to the Energy category, followed up by 26% of the green premium linked to Indoor Environment Quality. The remaining 42% of the green premium is almost equitably spread between the rest seven categories.

2.7. Energy performance of certified buildings (new construction)

Various studies, including research referred to in the previous section, confirm the importance of the energy category for rating of buildings with different green rating tools. For rating of newly constructed buildings, energy performance is established through modelling of the building's envelope and associated services to arrive at a predicted annual energy use or CO_2 emissions, which are then compared to the annual energy consumption of a notional building that meets the minimum code requirements.

To undergo certification, the building must firstly demonstrate equal or better energy performance in comparison to the notional building, i.e. fulfilling the energy related mandatory requirement for certification.

Achieving points under the Energy Performance credits (Green Star, LEED, BREEAM, etc.) creates an expectation that building firstly fulfils its environmental "duty" for limiting CO_2 emissions during operations and secondly that the optimised energy performance during the design results in actual energy savings during operation of the building.

This section will review a number of studies carried out to compare actual energy performance of certified buildings to their predicted energy performance during the certification of the buildings.

Several studies were conducted in the USA between 2006 and 2008 of LEED certified buildings to compare their actual energy consumption to the results from the simulations during certification, most significant being by Turner for 11 buildings, Diamond for 21 buildings and the New Building Institute (NBI) for 121 buildings (Li, Hong and Yan, 2014), (Menassa *et al.*, 2012), (Diamond *et al.*, 2011).

The results of these studies are somewhat inconsistent, with the first study concluding that the actual energy performance deviates from the simulated performance by more than 20% for all the buildings and that actual energy use in 40% of the buildings was greater than simulated. The second study observed, on average, only 1% lower than simulated energy performance but large variability, standard deviation of 46% in the sample set, indicating significant difference in performance among the buildings. The last study by the NBI concluded that LEED commercial buildings in the USA generally save 25-30% compared to energy use of non-certified buildings. The study, however, attracted extensive criticism related to the data collection method as well as the conclusions, which were inconsistent with the analysis results.

A research carried out by Li, Hong and Yan (2014) studied the energy performance and drivers of energy use in 51 high performance office building in the USA, Europe China and rest of Asia. All buildings were certified under the green rating systems used in the specific parts of the world - LEED, BREEAM, Green Star Australia, CASBEE, etc. with high level of performance, e.g. LEED Gold or Platinum, CASBEE "S", or China Three-Star, or Six-Star Green Star Australia. The buildings were occupied for at least one year after completion, giving the researchers the opportunity to assess the actual energy performance. The study established that nearly half of the buildings did not meet the American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 90.1-2004 energy target, as depicted in the graph below.

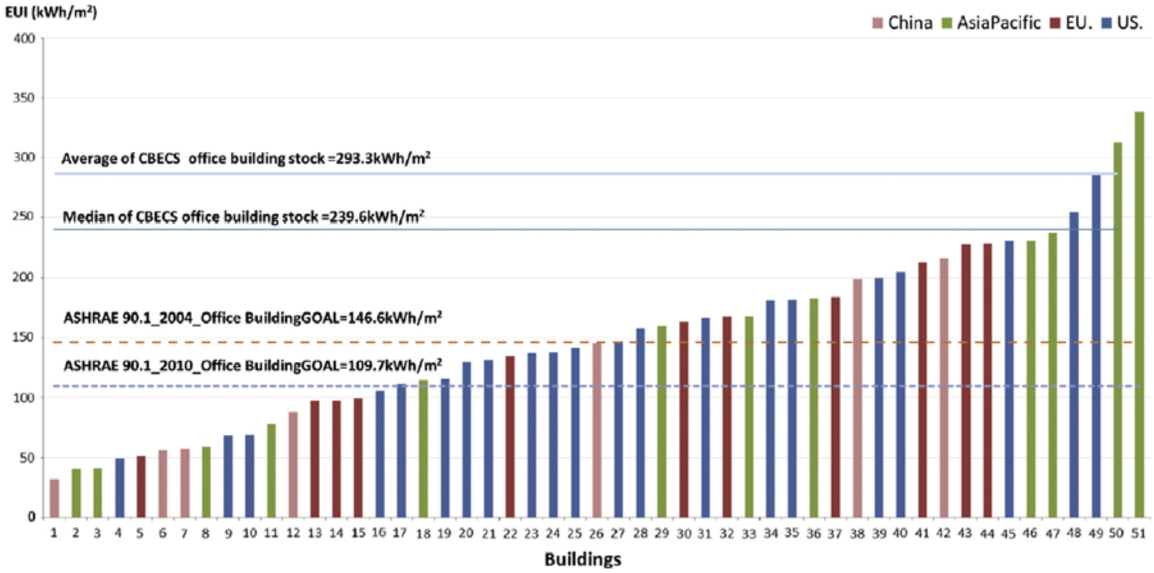


Figure 7: Distribution of EUIs of the 51 study buildings, compared to benchmarks (Li, Hong and Yan, 2014)

This finding ultimately raised the question how credible the certification schemes are (in terms of simulated energy performance) and how accurately they indicate that a building is energy efficient and suggested “that improvement in the design and operation of high performance buildings is needed to realise their energy-saving potential”. The research also evaluated six different factors that influence energy use in buildings, namely climate, building size, efficient technologies, occupant behaviour, and Operations & Maintenance, and found that “no single factor is decisive in determining a building’s actual energy performance”. It was further observed that whilst increasing the number of efficient technologies does not improve energy performance, occupant behaviour and O&M can significantly contribute to realising energy savings.

The study concluded that “an integrated design approach that takes account of all factors offers the greatest potential for producing a building whose actual performance is energy efficient”(Li, Hong and Yan, 2014).

The actual energy performance of eleven US Navy LEED-Certified buildings was researched in a study by Menassa *et al.* (2012). The study was undertaken to establish if the buildings have met the required base-line 30% reduction in energy consumption when compared to similar non-certified buildings. All buildings had achieved LEED certification prior to 2008 and actual consumption data was obtained for both sets, certified and not certified, for 2008-2009 period. The graph below depicts the results of the energy analysis of the eleven buildings, savings against non-LEED counterparts and against LEED Energy and Atmosphere points.

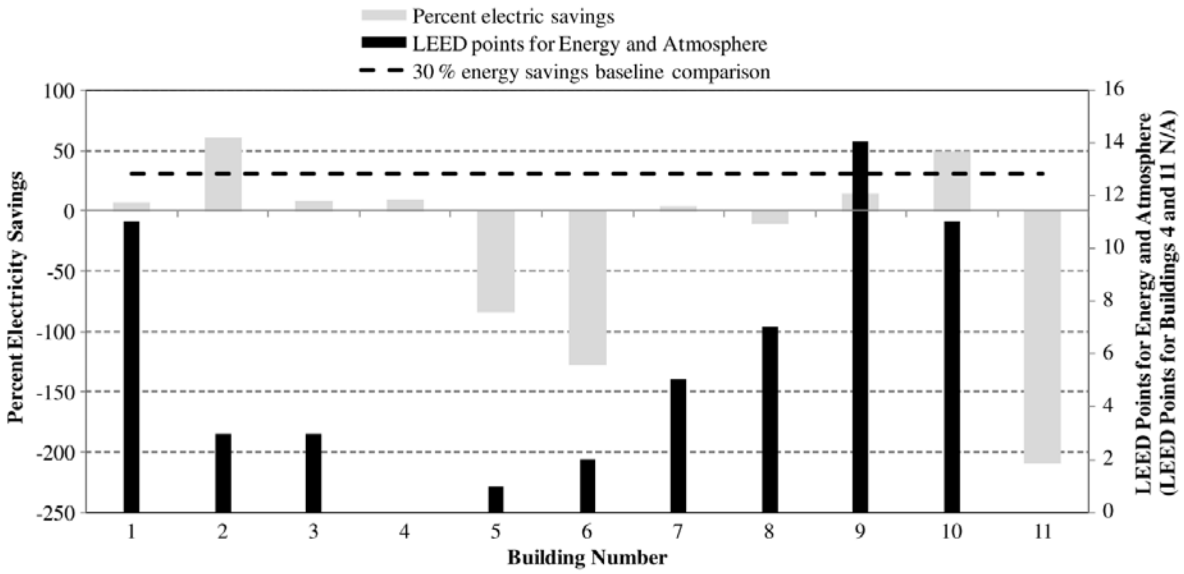


Figure 8: US Navy LEED Certified buildings – energy savings vs LEED Energy and Atmosphere points (Menassa *et al.*, 2012)

The research established that seven out of the eleven buildings achieved energy savings against their non-LEED counterparts, but only two of these buildings' savings exceeded the 30% target. Five of the buildings achieved savings of less than 15% of the target, whereas the remaining 4 buildings used more energy than the projected level.

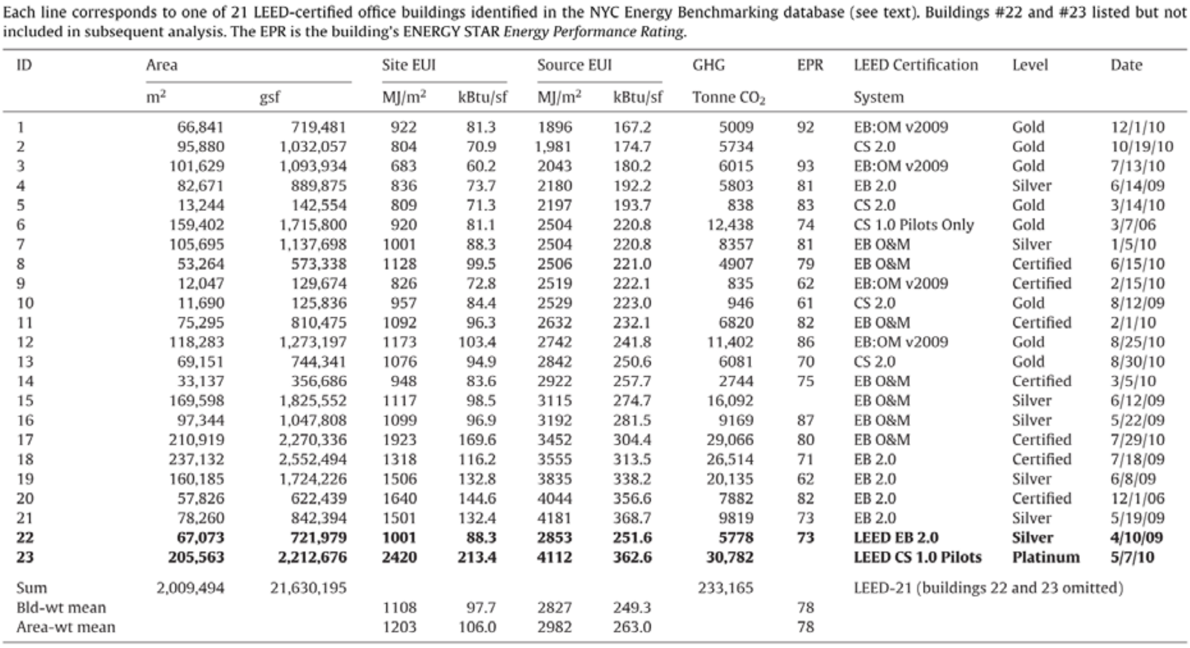
When energy savings and LEED points achieved were compared, it was concluded that there is no direct correlation between these parameters. Hence, the study highlighted that "LEED certification alone cannot guarantee the 30% savings for electricity" as initially envisaged and that the savings are not related to points awarded under the Energy category in the LEED certification process.

According to a research by Chen, Kleinman and Dial (2015), the actual energy performance of three LEED certified Ohio State University buildings was studied to determine how it compares to the energy model predictions used for the certification of the buildings. Of the three buildings evaluated, one had energy consumption about 30% lower than the predicted level, whereas the other two did not meet their energy targets, with the one, in particular, consuming 100% more energy than predicted. Further investigations were recommended by the researchers.

Finally and perhaps one of the more significant studies performed by Scofield (2013) on 953 office buildings in New York City involved the analysis of the buildings' 2011 energy consumption, greenhouse gas emissions and Energy Star Energy Performance Rating (EPR). 21 buildings of the total set were identified as LEED rated. The energy performance of these buildings was compared directly to the sub-set of non-LEED rated buildings' energy performance. This research also analysed previous studies on energy performance of LEED-certified buildings and found that, in general, there are two major shortcomings – firstly the relative scarcity of energy performance data for a representative and significant number of LEED-certified buildings. Data sets used in previous studies, except the US Navy study, referred to above, were not randomly constructed – only data from volunteering building owners was used, leading to bias results. The second shortcoming relates to the difficulty in finding appropriate group of non-LEED rated buildings for comparison of energy data, in other words "developing a credible matrix" for evaluation of LEED-certified buildings.

The table below identifies the 21 LEED-certified NYC office buildings included in the study and the associated figures represent the results of the study.

Table 7: List of LEED-certified buildings studied by Scofield (2013)



Each line corresponds to one of 21 LEED-certified office buildings identified in the NYC Energy Benchmarking database (see text). Buildings #22 and #23 listed but not included in subsequent analysis. The EPR is the building's ENERGY STAR *Energy Performance Rating*.

ID	Area		Site EUI		Source EUI		GHG	EPR	LEED Certification	Level	Date
	m²	gsf	MJ/m²	kBtu/sf	MJ/m²	kBtu/sf	Tonne CO_2		System		
1	66,841	719,481	922	81.3	1896	167.2	5009	92	EB:OM v2009	Gold	12/1/10
2	95,880	1,032,057	804	70.9	1,981	174.7	5734		CS 2.0	Gold	10/19/10
3	101,629	1,093,934	683	60.2	2043	180.2	6015	93	EB:OM v2009	Gold	7/13/10
4	82,671	889,875	836	73.7	2180	192.2	5803	81	EB 2.0	Silver	6/14/09
5	13,244	142,554	809	71.3	2197	193.7	838	83	CS 2.0	Gold	3/14/10
6	159,402	1,715,800	920	81.1	2504	220.8	12,438	74	CS 1.0 Pilots Only	Gold	3/7/06
7	105,695	1,137,698	1001	88.3	2504	220.8	8357	81	EB O&M	Silver	1/5/10
8	53,264	573,338	1128	99.5	2506	221.0	4907	79	EB O&M	Certified	6/15/10
9	12,047	129,674	826	72.8	2519	222.1	835	62	EB:OM v2009	Certified	2/15/10
10	11,690	125,836	957	84.4	2529	223.0	946	61	CS 2.0	Gold	8/12/09
11	75,295	810,475	1092	96.3	2632	232.1	6820	82	EB O&M	Certified	2/1/10
12	118,283	1,273,197	1173	103.4	2742	241.8	11,402	86	EB:OM v2009	Gold	8/25/10
13	69,151	744,341	1076	94.9	2842	250.6	6081	70	CS 2.0	Gold	8/30/10
14	33,137	356,686	948	83.6	2922	257.7	2744	75	EB O&M	Certified	3/5/10
15	169,598	1,825,552	1117	98.5	3115	274.7	16,092		EB O&M	Silver	6/12/09
16	97,344	1,047,808	1099	96.9	3192	281.5	9169	87	EB O&M	Silver	5/22/09
17	210,919	2,270,336	1923	169.6	3452	304.4	29,066	80	EB O&M	Certified	7/29/10
18	237,132	2,552,494	1318	116.2	3555	313.5	26,514	71	EB 2.0	Certified	7/18/09
19	160,185	1,724,226	1506	132.8	3835	338.2	20,135	62	EB 2.0	Silver	6/8/09
20	57,826	622,439	1640	144.6	4044	356.6	7882	82	EB 2.0	Certified	12/1/06
21	78,260	842,394	1501	132.4	4181	368.7	9819	73	EB 2.0	Silver	5/19/09
22	**67,073**	**721,979**	**1001**	**88.3**	**2853**	**251.6**	**5778**	**73**	**LEED EB 2.0**	**Silver**	**4/10/09**
23	**205,563**	**2,212,676**	**2420**	**213.4**	**4112**	**362.6**	**30,782**		**LEED CS 1.0 Pilots**	**Platinum**	**5/7/10**
Sum	2,009,494	21,630,195					233,165		LEED-21 (buildings 22 and 23 omitted)		
Bld-wt mean			1108	97.7	2827	249.3		78			
Area-wt mean			1203	106.0	2982	263.0		78			

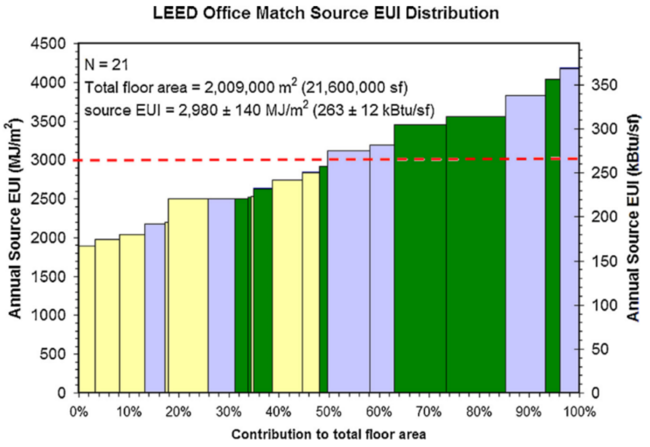


Figure 9: 21 NYC office LEED Buildings – EUI Distribution (Scofield, 2013)

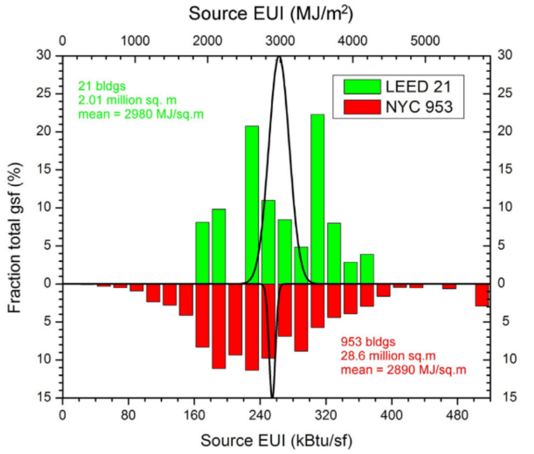


Figure 10: 21 NYC office LEED Buildings Source EUI histogram vs non-LEED NYC office buildings (Scofield, 2013)

Figure 9 above depicts distributed Energy Use Intensity (EUI) of the 21 LEED certified buildings, Gold – in yellow, Silver – in blue-grey, Certified – in green, with the average Source EUI of 263kBtu/sf/annum.

In summary, the NYC office buildings study concluded that the energy consumption and GHG emissions of the 21 LEED-certified buildings, collectively, showed no savings when compared to the non-LEED buildings sub-set. The subset of LEED Gold buildings had improved energy performance figures by 20% in comparison to the non-certified ones, but this was offset by the LEED-Silver and LEED-Certified buildings which underperformed, i.e. used more energy and emitted more GHG compared to the non-certified buildings. This meant that no evidence was provided by this research that “LEED certification, except Gold level, is moving NYC toward its goal of carbon neutrality”. It was also stated that one of the biggest challenges to understanding the efficiency of LEED rated buildings was the lack of measured energy performance for commercial buildings. And although the USGBC had been collecting such data as early as 2009, there was no indication of intensions to make this public (Scofield, 2013).

2.8. Conclusion

The effect of human industrial activities on our planet’s environment has been extensively explored by scientist. While still controversial for some, the fact that industrial human activities, underpinned by burning of fossil fuel, are the cause of climate change has become widely recognised and accepted.

Globally and in South Africa, governments and organisations are implementing strategies and interventions to curb the levels of greenhouse gas (GHG) emissions which are at the core of climate change. More concerted and radical efforts are however required to align global GHG emissions with targets for 2020 - 2040 set by the UNFCCC.

Buildings and the construction sector are found to generate extensive GHG emissions due to high direct and indirect energy use. On the other side, buildings and the construction sector offer the highest opportunity for most feasible interventions to limit the negative environmental effect. Sustainable development, including green buildings, was initiated in response to the harmful effect of industry, in general, and humans' activities on the environment.

Since the early 1990, various Green Building Councils were established to lead the transformation of the construction sector through introduction and implementation of sustainable design, construction and operation practices. The Green Building Councils facilitate the certifications of green buildings and are the custodians of the certification tools, which are now widely used in most of the countries around the world. It is advocated that green buildings are environmentally responsible, resource (energy, water, etc) efficient, occupant friendly, that they limit waste and at the same time enhance bio-diversity.
BREEAM, LEED and Green Star are the most widely used tools for certification of green buildings, with millions of square meters certified space in the UK, Europe, North America, Australia, South Africa and elsewhere in the world.

A key category in all of the tools is the Energy category, bearing the highest amount of points and linking to prerequisite requirements for rating. This is aimed at optimisation of the buildings energy performance and introduction of renewable energy sources. It is expected that green buildings will reduce energy consumption and GHG emissions by 25-50% in comparison with their non-certified counterparts which are code compliant. It is also expected that the reduction of energy consumption will result in operational / utility savings, which is accounted for when business case and capital layouts decisions are taken. It is researched in South Africa that the premium cost related to the energy category is the highest one of 31%, indicating that highest operational savings are also expected.
Hence, the energy category has a twofold promise - to fulfil its GHG obligations and to achieve financial savings as estimated in the design stage of the building.

The literature on energy performance of certified buildings reviewed in this chapter indicates that:

a) The research carried out to date has varied results – in most cases it was found that fewer buildings outperform expectations, while most not. There is no clear indication that, in general, certified buildings achieve expectations;
b) Certification levels (points) do not correspond with the actual performance in buildings;
c) Certification alone cannot guarantee the energy savings as initially envisaged and calculated through simulations;
d) Many of the buildings, including high performance ones, fall short of their energy saving potential, as established through simulations;
e) It can be more beneficial to certify buildings only based on actual performance;
f) There is no a single decisive factor in determining the energy performance of a building, including climate, building size, technologies, occupant behaviour, but energy performance can be driven by factors such as operating hours, number of occupants and the building functions (office, mixed use, etc.);
g) An integrated approach that accounts for all possible factors influencing energy is necessary to achieve intended performance;
h) There is no evidence that certified buildings are moving towards achieving the goal of carbon neutrality;
i) One of the biggest challenges to understanding the efficiency of rated buildings is the lack of measured energy performance for commercial buildings.

CHAPTER 3 - RESEARCH METHODOLOGY

3.1. Introduction

This chapter outlines the methodology applied to collect and analyse the relevant data in order to arrive at informed response to the main question / problem and the sub-problems of this research, defined as follows:

Main Problem:
Do Green Star certified buildings achieve stakeholders' energy expectations set out during the design and construction stages of the buildings through theoretical modelling of performance?

Sub-problem one:
How does actual energy performance of the buildings compare to the simulated energy performance as established during the certification process?

Sub-problem two:
What energy consumption and energy use intensity (EUI) trends are the buildings exhibiting once in operation?

Sub-problem three:
What facilities management / operating factors contribute to improving the energy performance of the buildings?

This follows on the previous Chapter 2 which covered an extensive literature review of buildings' effects on the environment, the fundamentals of green buildings and the energy performance of certified buildings mostly in the USA, but also of buildings located elsewhere.

3.2. Approach

The main problem of this research was to establish whether Green Star SA As-Built certified buildings, in general, perform in line with the energy expectations set out during the certification process. This was determined through comparison of energy performance results (annual Energy Use Intensity in kWh/m^2) from simulation / modelling with the actual annual consumption of the building and trending of available historical annual consumption data of these buildings over a representative period.

The dataset that was used for comparative purposes, was the 2017 calendar year consumption data. This was selected as the most recent and complete dataset for all buildings in the sample. It is important to note that the dataset incorporates one entire year in order to account for seasonal variations and is therefore representative of complete building performance.

In addition, interviews with the facilities managers of the participating buildings were carried out to determine how familiar they are with the Green Star certification scheme and what practices are implemented in support of energy targets established during the certification of the buildings. The correlation of their responses to questions from the survey and the energy use intensity (EUI) of the buildings for 2017 were then plotted on graphs to establish how the EUI may be affected by the knowledge and experience of the FMs as well as the implemented practices.

3.3. Buildings Selection

The following criteria were applied for the selection of the 12 participant buildings:

- Commercial buildings in Johannesburg, comprising office space;
- Non-office space, e.g. retail, within the buildings of less than 10% of GLA was considered acceptable;
- Green Star SA New Construction Office As-built V1 certified;
- Certification level: 4 and 5 Star;
- The buildings were in operations for at least 24 consecutive months;
- The buildings have a full set of energy consumption data for 2017;
- The buildings were occupied, preferably with limited vacancy during 2017, with only two of them having vacancies during 2017. Vacancies, if present, to be quantifiable in order to account for these.

3.4. Data Types and Sources

Table 8: Data types, format and sources

Reference	Data Type	Format	Source
Sub-Problem 1	Green Star Ene-1 GHG Emissions Credit Completed Calculators and Reports for As-built rating	Adobe Acrobat Files	Building Owners and respective Green Star Accredited Professionals (APs)
	Building Parameters: • GLA • Vacancies • Occupancy • Occupancy Hours	MS Excel Tables / E-mails	Respective Facilities / Properties Managers
Sub-Problem 1&2	Actual energy consumption	Adobe Acrobat Files or MS Excel tables	Respective Facilities /Properties Managers and/or Utilities Management Companies
Sub-Problem 3	Response to a structured survey / questionnaire	MS Excel Table	Included in Appendix A

3.5. Energy Use Intensity (EUI)

Energy use intensity (EUI) was used as the key parameter for comparison and trending of the buildings energy performance. Energy use intensity (EUI) is an industry recognised metric that many rating tools and international studies use to compare building energy efficiency. The EUI of a building is defined as:

$$\boldsymbol{EUI}(\boldsymbol{kWh/m^2}) = \frac{\boldsymbol{Annual\ Energy\ Consumption}\ (\boldsymbol{kWh})}{\boldsymbol{Building\ Area}\ (\boldsymbol{m^2})}$$

Equation 1

For the purposes of this research, annual energy consumption is the whole building annual electricity consumption in kWh while the building area is the gross lettable area (GLA) of the whole building in m^2.

3.6. Data Analysis

3.6.1. Sub-problem one: Modelled vs Actual EUI

Modelled Data Normalisation

The Ene-1 Greenhouse Gas Emissions Credit reports, including energy calculators, were obtained from the relevant Green Star Accredited Professionals. The data from each energy calculator was tabled in MS Excel spreadsheets where specific corrections were applied to normalise modelled energy consumption (kWh/year) and Energy Use Intensity (EUI, kWh/m^2/year) before comparing to actual consumption of the buildings.

The Energy Modelling Protocol of the Green Star SA Version 1 Certification Scheme stipulates the following operational parameters for the simulation of energy performance:

Lighting (in office areas):	12W/m^2
Occupancy:	15m^2/person
Occupancy hours (per office weekly profiles):	48.4/week

Lastly, the Energy Use Intensity of buildings, when modelled, is calculated based on the Usable Area of the building.

Other than these prescribed parameters, the Green Star modelling protocol includes parameters that are intended to match the actual building parameters and as such they do not require normalisation.

The table below lists the corrections that were applied to the simulated datasets to arrive at normalised values for comparison with the actual consumption and EUI.

Table 9: Corrections to energy simulations datasets

Corrections	Modelling Protocol & Calculator fixed values	Correction for normalisation of simulated data set
1. Lighting (in office areas)	12W/m^2	As defined in the energy modelling report, under actual office lighting load. If not defined, electrical load of 7W/m^2 was used as conservative value representative of current lighting technologies.
2. Area to determine EUI	UA	GLA, as provided by building owners and facilities managers. GLA is more widely used in real estate as opposed to UA.
3. Occupancy	15m^2/person over UA	Actual occupancy in numbers as provided by the building owners or facilities managers.
4. Occupancy hours	48.4/week	Actual occupancy hours as obtained from the building owners and facilities managers. Actual occupancy hours range between 50 and 120hours/week.
5. Vacancy	0%	As advised by the relevant participants

<u>Equations Used in Corrections</u>

a) Lighting loads adjustment

Where the actual lighting load for office areas was not stipulated in the Energy Report submitted for certification, a load of 7W/m^2 was applied in calculating the adjusted load.

$$\boldsymbol{Adjusted\ Lighting\ Load\ (kW/m2) = 0.007x\ Operating\ Hours\ x\ Office\ Area}$$

Equation 2

where the Operating Hours = 2767.4/year as directed in the modelling protocol.

b) Vacancy

Vacancy within the building, where present and confirmed by the facilities managers, was accounted for in calculating the occupancy rate, using the following formulae:

$$\boldsymbol{Number\ of\ Occupants = \frac{(GLA - Vacant\ Area)}{Advised\ Occupancy\ Rate}}$$

Equation 3

$$\boldsymbol{Adjusted\ Occupancy\ Rate\ \left(m^2/person\right) = \frac{GLA}{Number\ of\ Occupants}}$$

Equation 4

c) Correction factor for actual occupancy and hours

The following formulae were applied to calculate a correction factor for occupancy and occupancy hours. Equation 5 constitutes the energy benchmarking model for existing buildings, a tool developed for GBCSA in 2012 (Bannister and Chen, 2012). The research carried out by Bannister and Chen for development of the mathematical model involved data collection of some 300 South African office buildings and formulation of exhaustive statistic relationships, e.g. EUI dependency on climate, size of building, occupancy, etc. The mathematical model calculates the predicted consumption of a building, given the computer density (assumed to be the same as occupancy density for this study), occupancy hours, the annual wet bulb average temperature (for Johannesburg=11.54°) and the GLA of the building.

$$\begin{aligned}\boldsymbol{Predicted\ Consumption\ (kWh)} \\ &\boldsymbol{= \{(173 + 1440 x Computer\ Density) x [1 + 0.0114 x (Occupancy\ Hours} \\ &\boldsymbol{- 45.9)] + 2.42 x (Annual\ T_{avg\_wb} - 12.3)\} x GLA x 0.882}\end{aligned}$$

Equation 5

Equation 6 was then used to calculate the correction to the simulated EUI, to account for actual occupancy and occupancy hours.

$$\begin{aligned}\boldsymbol{Correction\ Factor} \\ &\boldsymbol{= Predicted\ Consumptiom_{Actual}\ /Predicted\ Consumptiom_{Simulated}}\end{aligned}$$

Equation 6

Actual Consumption Data Corrections

Some of the buildings in the sample contain significant data centres separately metered as advised by the facilities mangers. The energy consumption of these data centres within the office buildings, where separately metered, was excluded from the whole building energy consumption.

Analysis

Once normalised, the simulated energy data set was compared to the actual energy consumption data of the buildings, provided either as metered data or utility accounts, for 2017.

The metric used for comparison of building performance is the difference between the respective modelled and actual EUI.

$$\Delta \boldsymbol{EUI} = \boldsymbol{EUI}_{\boldsymbol{Actual}} - \boldsymbol{EUI}_{\boldsymbol{ModelledNormalised}}$$

Equation 7

ΔEUI constitutes a normalised method for comparison of building performance as it accounts for both building size and certification level, 4 or 5-Star rating. By applying ΔEUI analysis, each building is compared to its own benchmark in a normalised way, which removes potential bias.

MS Excel graphs were plotted to depict the difference between the two sets of data i.e. $\mathrm{EUI}_{\mathrm{Actual}}$ and $\mathrm{EUI}_{\mathrm{ModelledNormalised}}$, average values and histogram showing the distribution of EUI within the sample.

3.6.2. Sub-problem two: 2013 - 2017 Energy consumption and EUI trends

The actual consumption data used for the analysis of sub-problem one was also used for sub-problem two, with the addition of all available historic data for annual consumption. The consumption data was summarised annually in MS Excel spreadsheet for the period of Jan 2013 until Dec 2017.

Graphs were plotted to observe occurring trends over the abovementioned timeframe – these are included in the following Chapter.

3.6.3. Sub-problem three: Facilities and operations management factors that influence EUI

Questionnaire

Quantitative and research was carried out based on questionnaire with structured and in-depth questions, as included in Appendix A.

Set-out in two sections, the questionnaire aims firstly to determine the length of participants' involvement with the particular building, type of facilities management deployed and their exposure to Green Star certification and training. The second part of the questionnaire is building specific and focuses on aspects that affect the energy consumption of buildings, such as commissioning, building tuning, training on building services and sustainability aspects of these, energy targets, metering, engagement with tenants on energy targets, etc.

All questionnaires were completed as part of a personal interview conducted with the respective representative of building owners.

Participants' Roles within the Organisations

Representatives of building owners' organisations were interviewed for each of the participating buildings. With minor exception, all participants were in senior facilities management roles and as such had control over the operations of the building services and the related budgets.

Analysis

The data was analysed by means of MS Excel tables and histograms. Graphs representing participants' responses and the related building performance (ΔEUI) were produced to examine potential correlations. Based on this comparison, it was possible to identify practices / factors that influence energy performance of the buildings.

3.7. Summary

A brief review of the approach, data types, format and sources for this research was presented in this section. Methodology applied, including the relevant equations, for correction of the simulated energy consumption as well the actual energy consumption was detailed. The data results and analysis detailed in the following chapters will inform the response to the main problem of the study, i.e. are green star certified buildings achieving expected energy performance?

CHAPTER 4 - RESULTS

4.1. Introduction

Whilst Chapter 3 defines the methodologies applicable for the research, this chapter constitutes presentation of the data as depicted through analysis in MS Excel tables and graphs. The following aspects are detailed:

- Participating buildings – parameters;
- Sub-problem one - data and graphs;
- Sub-problem two - data and graphs;
- Sub-problem three – data and graphs.

4.2. Participating Buildings

Twelve buildings were included in the research in line with the delimitations stated in Section 1.5.2 Delimitations.

4.2.1. Location and Green Star Certifications

The table below lists the participating buildings, their location, type of Green Star certification, level achieved and year of certification.

Eight of the buildings in the sample were rated as 4-Star, whilst three achieved a 5-Star rating.

Table 10: Participating Buildings: Location and GSSA Certification

Buildings	Location	Rating Tool	Design/As-Built/Int/EBP/EWP	Year Certified	Rating Achieved
B1	Johannesburg	Office v1	As Built	Sep-10	4 Star
B2	Johannesburg	Office v1	As Built	Jun-13	5 Star
B3	Johannesburg	Office v1	As Built	Apr-14	4 Star
B4	Johannesburg	Office v1	As Built	Sep-14	5 Star
B5	Johannesburg	Office v1	As Built	Feb-15	5 Star
B6	Johannesburg	Office v1	As Built	Aug-15	4 Star
B7	Johannesburg	Office v1	As Built	Aug-15	4 Star
B8	Johannesburg	Office v1	As Built	Feb-16	4 Star
B9	Johannesburg	Office v1	As Built	Feb-16	4 Star
B10	Johannesburg	Office v1	As Built	Jun-16	4 Star
B11	Johannesburg	Office v1	As Built	Dec-16	4 Star
B12	Johannesburg	Office v1	As Built	Sep-17	4 Star

4.2.2. Areas

The buildings' Usable Area (AU) range from approximately 3 600m^2 to 44 300m^2 and the GLA, which is primarily used in the research, range between approximately 4 500m^2 and 65 200m^2. The largest UA as a percentage of GLA belongs to B2 and B10, being 90%, whilst B9 has the smallest UA expressed as a percentage of the GLA, namely 66%.

Table 11: Building Areas

Buildings	UA (m^2)	GLA (m^2)	% of UA
B1	36 339	45 027	81%
B2	11 932	13 235	90%
B3	26 799	37 473	72%
B4	44 283	65 218	68%
B5	19 384	24 354	80%
B6	3 635	4 516	80%
B7	15 565	19 908	78%
B8	25 296	33 006	77%
B9	25 805	39 041	66%
B10	22 206	24 716	90%
B11	29 480	39 863	74%
B12	16 776	19 251	87%

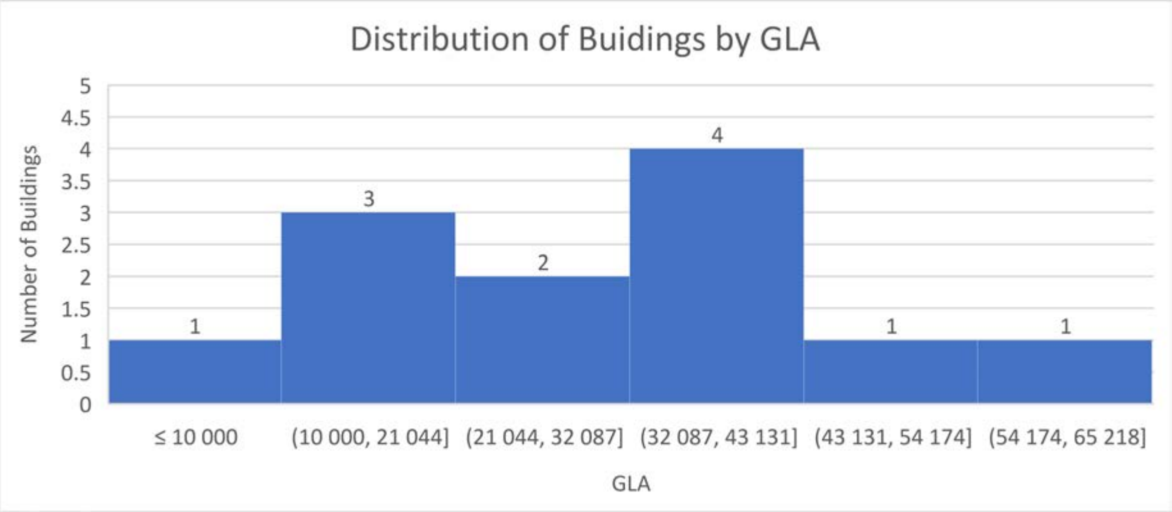


Figure 11: Distribution of Buildings by GLA

Based on the above, majority of the buildings fall within GLA between 10 000m^2 and 40 000m^2. Although the sample is limited to 12 buildings, there is a representative building in each area group defined by an increment of 11 000m^2.

Previous research carried out to determine factors influencing the energy efficiency in buildings established that there is no correlation between GLA or building size and EUI, and therefore size (GLA) is not a significant contributor to energy efficiency in buildings (Bannister and Chen, 2012).

4.2.3. Occupancy, Occupancy Hours and Vacancy

The occupancy numbers or rates and vacant areas of each building for 2017 were advised by the facilities managers. These numbers are shown in the table below. An average occupancy rate of 17m^2/person over the GLA was calculated for the sample and is depicted in the following graph.

Table 12: Building Occupancy, Occupancy Hours and Vacancy

Buildings	GLA (m²)	Occupancy Hours/Week	Number of Occupants / Computers	Occupancy Rate (m²/person)	Vacancy (m2)	Vacancy (%)
B1	45 027	50	2904	16	0	0%
B2	13 235	50	850	16	0	0%
B3	37 473	50	2000	19	0	0%
B4	65 218	60	4400	15	0	0%
B5	24 354	60	812	30	12177	50%
B6	4 516	50	302	15	0	0%
B7	19 908	80	1281	16	700	4%
B8	33 006	120	2950	11	0	0%
B9	39 041	60	2603	15	0	0%
B10	24 716	50	989	25	9886	40%
B11	39 863	70	2591	15	1000	3%
B12	19 251	60	1284	15	0	0%
			Avg Occupancy Rate:	**17**		

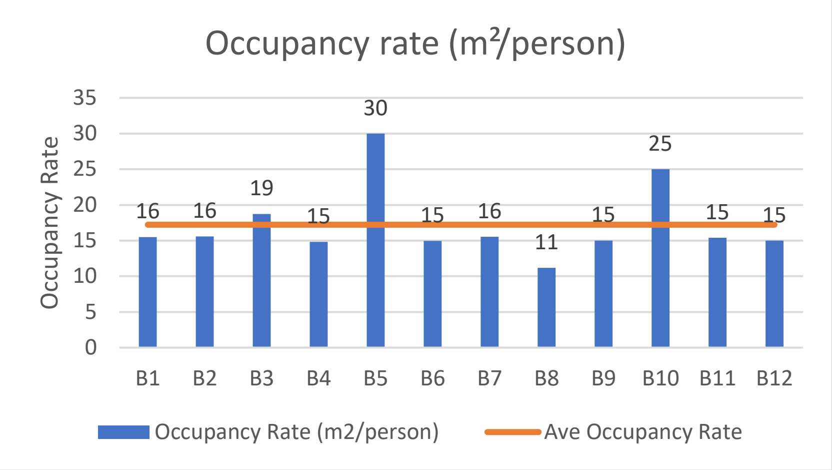


Figure 12: 2017 Building Occupancy Rate over GLA

As can be seen from the graph, majority of the buildings in the sample have an occupancy rate aligned with the average, except buildings B5 and B10. These buildings were reported to have had considerable vacant area during 2017 and as a result the respective occupancy rate was calculated at 30m^2/person and 25m^2/person. Building B8 is the most densely occupied in the sample with 11m^2/person over the GLA.

4.3. Sub-problem One: Modelled vs Actual EUI

4.3.1. Modelled Data Normalisation

Table 13 below depicts a summarised dataset of all buildings as obtained from the corresponding Green Star Ene-1 Greenhouse Gas Emissions Credit Calculators, whilst Table 14 on the same page depicts the first correction applied to the modelled dataset, the adjustment of the lighting load (Tenant Lighting column).

Table 13: Summarised Modelled Dataset - Green Star Energy Calculators

Buildings	Building Areas (m2)				Energy Use (kWh/year)														Total Energy Use (kWh/year)	
	UA	Car Park	Sub Basement	External Area	Heating	Cooling	Pumps	Fans	Extract	Non Ten Lighting	Car Park Lighting	External Lighting	Lifts	Hot Water	Misc Equip	Tenant Lighting	Small Power	Supp Cooling	Base Bldg Total	Whole Bldg Total
B1	36 339	43 468	43 468	9 616	79 178	510 328	312 551	435 088	872 654	309 007	121 634	11 592	162 459	76 919	0	1 537 099	2 031 965	134 638	2 891 410	6 595 112
B2	11 932	19 270	14 182	1 028	10 242	249 509	30 719	186 232	229 029	41 161	75 918	13 585	26 037	9 140	1 330	546 651	131 311	54 826	872 902	1 605 690
B3	26 799	58 750	49 190	3 348	85 667	644 521	76 709	620 355	226 441	407 319	279 407	74 444	182 053	64 348	0	428 164	1 638 720	122 413	2 661 264	4 850 561
B4	44 283	122 990	98 392	16 329	385	236 434	623 011	1 090 563	2 604 574	616 572	300 387	20 810	516 694	100 731	59 978	2 027 860	2 821 647	188 776	6 170 139	11 208 422
B5	19 384	12 203	0	0	23 081	229 290	43 582	93 206	25 796	43 265	78 283	18 268	33 996	572	4 192	887 655	1 174 795	38 004	593 531	2 693 985
B6	3 635	4 516	1 934	627	17 505	39 118	0	10 539	13 572	47 174	32 225	12 354	10 103	10 282	0	58 158	0	10 288	192 872	261 318
B7	15 565	33 226	14 369	0	19 697	201 578	0	152 523	98 551	123 115	258 031	427	88 490	168	1 307	712 760	970 449	51 396	943 887	2 678 492
B8	25 296	37 689	0	0	108 297	266 618	41 573	157 525	48 018	86 217	104 948	3 824	56 827	14 180	2 321	1 158 385	1 565 617	49 436	890 348	3 663 786
B9	25 805	64 537	50 609	4 324	41 767	180 443	60 861	31 283	2 027 450	141 127	352 753	15 045	470 865	19 809	3 419	1 181 712	1 608 943	63 556	3 344 822	6 199 033
B10	22 206	25 377	0	585	130 125	423 866	254 135	60 291	92 816	129 278	106 381	6 951	76 121	27 292	49 866	809 917	1 395 789	84 369	1 357 122	3 647 197
B11	29 480	62 709	54 559	3 655	26 182	580 473	47 216	248 886	1 434 288	665 742	357 141	996	160 789	19 668	5 330	1 348 014	1 835 370	73 722	3 546 711	6 803 817
B12	16 776	30 325	22 311	1 541	59 918	233 571	75 400	172 472	539 230	146 321	199 064	68 696	103 845	22 845	0	1 205 696	1 005 225	57 639	1 621 362	3 889 922

Correction 1: Lighting Load Adjustment

The lighting load of office areas (tenant lighting) was corrected to more accurately reflect the real lighting loads, as described in CHAPTER 3 - Research methodology. The annual tenant lighting load is reduced, leading to reduced total energy use of the whole building (last column in the table below).

Table 14: Summarised Modelled Dataset – Correction 1 - Lighting Load

Buildings	Building Areas (m2)				Energy Use (kWh/year)														Total Energy Use (kWh/year)	
	UA	Car Park	Sub Basement	External Area	Heating	Cooling	Pumps	Fans	Extract	Non Ten Lighting	Car Park Lighting	External Lighting	Lifts	Hot Water	Misc Equip	Tenant Lighting	Small Power	Supp Cooling	Base Bldg	Whole Bldg
B1	36 339	43 468	43 468	9 616	79 178	510 328	312 551	435 088	872 654	309 007	121 634	11 592	162 459	76 919	0	703 952	2 031 965	134 638	2 891 410	5 761 965
B2	11 932	19 270	14 182	1 028	10 242	249 509	30 719	186 232	229 029	41 161	75 918	13 585	26 037	9 140	1 330	311 590	131 311	54 826	872 902	1 370 629
B3	26 799	58 750	49 190	3 348	85 667	644 521	76 709	620 355	226 441	407 319	279 407	74 444	182 053	64 348	0	519 145	1 638 720	122 413	2 661 264	4 941 542
B4	44 283	122 990	98 392	16 329	385	236 434	623 011	1 090 563	2 604 574	616 572	300 387	20 810	516 694	100 731	59 978	1314935	2 821 647	188 776	6 170 139	10 495 497
B5	19 384	12 203	0	0	23 081	229 290	43 582	93 206	25 796	43 265	78 283	18 268	33 996	572	4 192	375 503	1 174 795	38 004	593 531	2 181 833
B6	3 635	4 516	1 934	627	17 505	39 118	0	10 539	13 572	47 174	32 225	12 354	10 103	10 282	0	70 416	0	10 288	192 872	273 576
B7	15 565	33 226	14 369	0	19 697	201 578	0	152 523	98 551	123 115	258 031	427	88 490	168	1 307	285 612	970 449	51 396	943 887	2 251 344
B8	25 296	37 689	0	0	108 297	266 618	41 573	157 525	48 018	86 217	104 948	3 824	56 827	14 180	2 321	457 460	1 565 617	49 436	890 348	2 962 861
B9	25 805	64 537	50 609	4 324	41 767	180 443	60 861	31 283	2 027 450	141 127	352 753	15 045	470 865	19 809	3 419	614 758	1 608 943	63 556	3 344 822	5 632 079
B10	22 206	25 377	0	585	130 125	423 866	254 135	60 291	92 816	129 278	106 381	6 951	76 121	27 292	49 866	430 170	1 395 789	84 369	1 357 122	3 267 450
B11	29 480	62 709	54 559	3 655	26 182	580 473	47 216	248 886	1 434 288	665 742	357 141	996	160 789	19 668	5 330	456 518	1 835 370	73 722	3 546 711	5 912 321
B12	16 776	30 325	22 311	1 541	59 918	233 571	75 400	172 472	539 230	146 321	199 064	68 696	103 845	22 845	0	324 981	1 005 225	57 639	1 621 362	3 009 207

Correction 2: EUI over GLA

Per the described methodology, the modelled dataset was corrected for calculations of EUI over GLA. This is depicted in Table 15 below where UA and Energy Use Whole Bldg values were transferred from Table 14. GLA is now used to calculate the EUI (last column of the table)

Table 15: Summarised Modelled Dataset - Correction 2 - EUI over GLA

Buildings	Building Areas (m^2)		Energy Use Whole Bldg kWh/year	EUI over UA (kWh/m^2/yr)	EUI over GLA (kWh/m^2/yr)
	UA	GLA			
B1	36 339	45 027	5 761 965	159	128
B2	11 932	13 235	1 370 629	115	104
B3	26 799	37 473	4 941 542	184	132
B4	44 283	65 218	10 495 497	237	161
B5	19 384	24 354	2 181 833	113	90
B6	3 635	4 516	273 576	75	61
B7	15 565	19 908	2 251 344	145	113
B8	25 296	33 006	2 962 861	117	90
B9	25 805	39 041	5 632 079	218	144
B10	22 206	24 716	3 267 450	147	132
B11	29 480	39 863	5 912 321	201	148
B12	16 776	19 251	3 009 207	179	156

A key observation following this step of analysis is that building B6 exhibits much lower EUI in comparison to the rest of the buildings at 75kWh/m^2 over UA and 61kWh/m^2 over GLA. Further investigation into the modelled data for this building revealed that it achieved 8 points under Ene-1 Greenhouse Gas Emissions Credit. The points are allocated based on the improvement of energy consumption of the modelled building over that of a notional building which is SANS204 compliant. Whilst the result of 8 points can be considered credible, it is possible that the simulation setup of both notional and actual buildings to determine energy consumption is overly optimistic, which would result in an unreasonably low consumption and EUI.

It is, therefore, important to verify simulated data and results prior to Green Star certification as the simulated results should be realistic and indicative of actual operational energy performance targets, which may not to be the case with building B6.

Building B6 was included in the analysis without correction for this possible discrepancy.

Corrections 3, 4, 5: Calculation of adjustment factor for actual occupancy and hours

The table below depicts the values used to calculate the energy correction factor for actual occupancy and hours, applied in the normalisation of the modelled dataset. The actual occupancy over GLA value has been adjusted for vacancy as shown in Table 12: Building Occupancy, Occupancy Hours and Vacancy, above.

Equation 5 and Equation 6 were applied in calculating the Theoretical EUI Sim and EUI Actual of a typical building, using the two sets – Sim Occupancy and Hours and Actual Occupancy and Hours. The ratio between the theoretical building's EUI Actual and EUI Sim is the Energy Correction Factor taken forward in the next step.

Table 16: Calculation of correction factor for actual occupancy and occupancy hours

Buildings	Input		Simulation Data			Actual Data		Corrections		
	UA [m^2]	GLA [m^2]	Sim occ over UA [m^2/p]	Sim occ hours [h/w]	Sim occ over GLA [m^2/p]	Actual occ over GLA [m^2/p]	Actual occ hours [h/w]	Theoretical Typical Building EUI		Energy correction for occupancy and hours
								Sim [kWh/m^2/yr]	Actual [kWh/m^2/yr]	
B1	36339	45 027	15	48.4	19	16	50	225.59	243.84	**1.08**
B2	11932	13 235	15	48.4	17	16	50	233.82	243.48	**1.04**
B3	26799	37 473	15	48.4	21	19	50	217.59	229.05	**1.05**
B4	44283	65 218	15	48.4	22	15	60	214.44	274.95	**1.28**
B5	19384	24 354	15	48.4	19	30	60	224.63	224.63	**1.00**
B6	3635	4 516	15	48.4	19	15	50	225.41	247.00	**1.10**
B7	15565	19 908	15	48.4	19	16	80	223.40	323.77	**1.45**
B8	25296	33 006	15	48.4	20	11	120	222.06	489.27	**2.20**
B9	25805	39 041	15	48.4	23	15	60	212.87	273.77	**1.29**
B10	22206	24 716	15	48.4	17	25	50	233.55	211.29	**0.90**
B11	29480	39 863	15	48.4	20	15	70	219.71	298.12	**1.36**
B12	16776	19 251	15	48.4	17	15	60	231.20	273.82	**1.18**

Modelled Normalised Dataset

The last two columns show the normalised modelled Energy Use (kWh/year) and EUI (kWh/m^2/year) following the application of all corrections. For comparison of actual and normalised modelled data, the normalised EUI will be now used.

Table 17: Modelled Normalised Dataset

Buildings	Building Areas (m^2)		Simulated Energy Use (kWh/yr)	Simulated EUI over GLA (kWh/m^2/yr)	Occupancy & Ops Hours Correction	Simulated Energy Use with Corrections	Simulated EUI with Corrections
	UA	GLA					
B1	36 339	45 027	5 761 965	128	**1.08**	6 227 918	138
B2	11 932	13 235	1 370 629	104	**1.04**	1 427 215	108
B3	26 799	37 473	4 941 542	132	**1.05**	5 201 767	139
B4	44 283	65 218	10 495 497	161	**1.28**	13 456 931	206
B5	19 384	24 354	2 181 833	90	**1.00**	2 181 888	90
B6	3 635	4 516	273 576	61	**1.10**	299 782	66
B7	15 565	19 908	2 251 344	113	**1.45**	3 262 883	164
B8	25 296	33 006	2 962 861	90	**2.20**	6 528 262	198
B9	25 805	39 041	5 632 079	144	**1.29**	7 243 318	186
B10	22 206	24 716	3 267 450	132	**0.90**	2 956 015	120
B11	29 480	39 863	5 912 321	148	**1.36**	8 022 072	201
B12	16 776	19 251	3 009 207	156	**1.18**	3 563 890	185

4.3.2. Actual Consumption Data – Summary

A summary of the participating buildings' actual consumption data for 2017 is shown on the table below. The actual consumption data was extracted from excel spreadsheets or Adobe Acrobat billing records as provided by the respective facilities managers or utilities management companies.

Table 18: Summary of Actual Energy Use for 2017

Buildings	2017 Actual Energy Use (kWh/yr)	2017 Actual EUI (kWh/m^2/yr)	Occupancy (m^2/person)	Occupancy Hours (week)
B1	9 636 592	214	16	50
B2	2 083 380	157	16	50
B3	6 207 334	166	19	50
B4	14 779 526	227	15	60
B5	3 739 114	154	30	60
B6	995 130	220	15	50
B7	4 615 679	232	16	80
B8	6 312 422	191	11	120
B9	11 119 583	285	15	60
B10	3 211 755	130	25	50
B11	6 299 205	158	15	70
B12	5 157 068	268	15	60
	Average:	**200**	**17**	**63**

Where significant data centres were present in some of the buddings and these were separately metered, as advised by the facilities managers, their consumption was subtracted from the whole building consumption. The EUI was calculated by applying Equation 1, with GLA as shown in the previous tables.

The actual EUI of the buildings was plotted against Occupancy and Occupancy Hours values in the respective Figure 13 and Figure 14 below.

As can be seen from the figures, 50% of the buildings have a higher than average EUI for 2017, whilst the other 50% showed lower than average values.

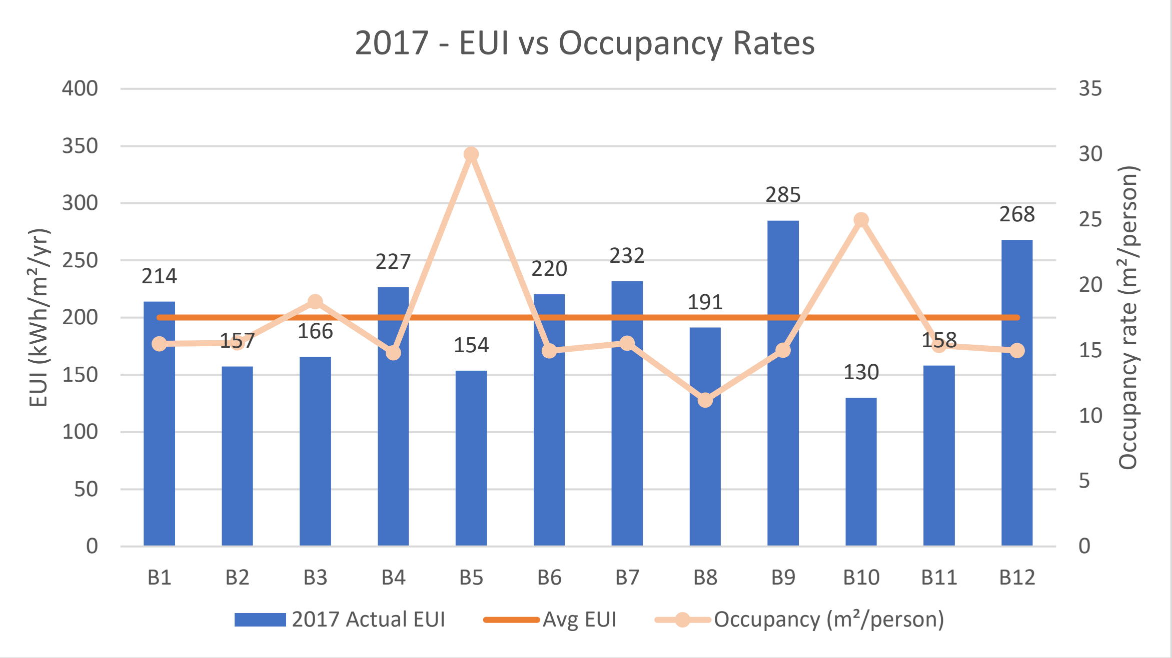


Figure 13: 2017 – EUI vs Occupancy Rates

The samples' EUI range between 130kWh/m^2/year and 285kWh/year, with an average EUI of 200kWh/m^2/yr. Building B9 has the highest EUI in the sample, 42% higher than the average EUI, whereas B10 shows the lowest EUI, 35% lower than the average value.

Figure 13 demonstrates an inverse correlation between EUI and Occupancy rate, i.e. generally, lower occupancy rate (high number of occupants) results in higher EUI, which is intuitively correct.

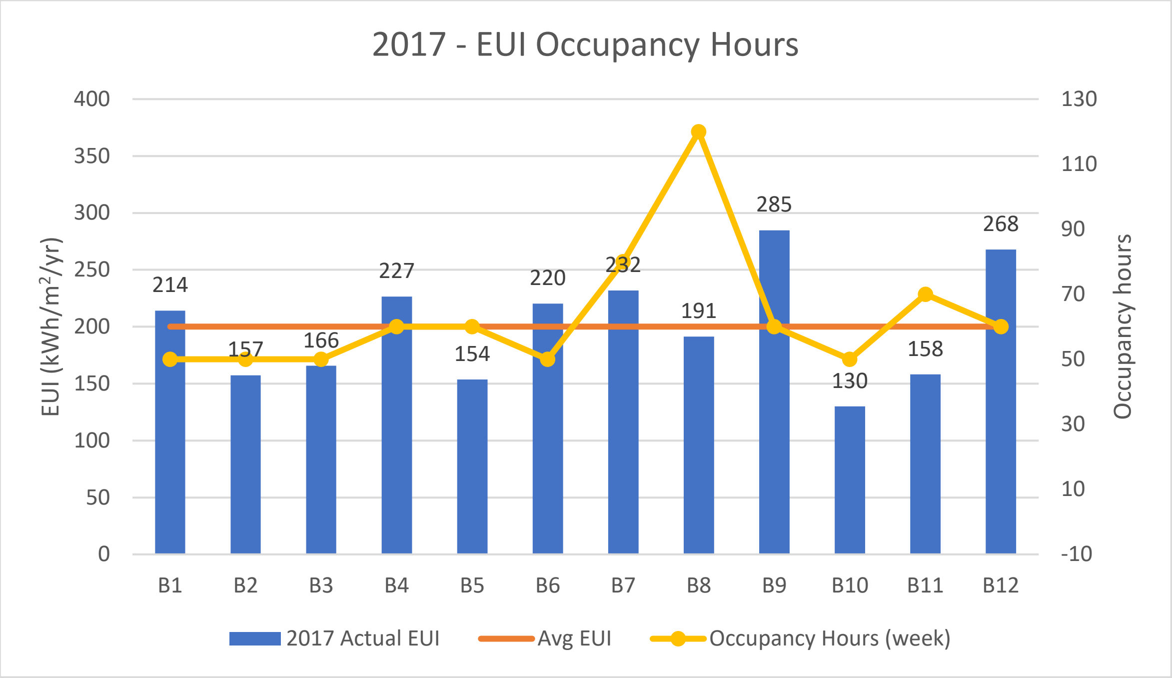


Figure 14: 2017 – EUI vs Occupancy Hours

Figure 14, on the other hand, demonstrates a direct correlation between EUI and occupancy hours, i.e. high occupancy hours generally result in higher EUI.

In both graphs building B8, which reportedly functions as a call centre, constitutes an exception. It has the highest occupancy and operates longest hours, yet it’s EUI is slightly below the average value of the sample.

While the above graphs may be used to compare the energy performance of the buildings in the sample against each other, for the purposes of this study it is more important that the graphs depict the validity of the actual consumption dataset.

4.3.3. Comparison of buildings performance

As detailed in the preceding sections, normalisation of the modelled consumption data was carried out to account for parameters in the Green Star modelling protocol which are prescribed and not fully aligned with actual values or use. These include:

- Tenant lighting;
- Use of GLA instead of UA;
- Occupancy;

- Occupancy Hours; and
- Vacancy.

The actual consumption of the buildings for 2017, as advised by the facilities managers, was also adjusted to exclude the energy consumption of significant data centres, where these were present and separately metered.

Table 19 below summarises EIU values for both cases, average values and the difference depicted as ΔEUI. These values are presented in the associated Figure 15 and Figure 16 for visual presentation of the data. Whilst Figure 15 depicts the data in order of Buildings B1 to B12, Figure 16 depicts order of performance from best to worst.

Table 19: Summary of Modelled Normalised EUI and Actual EUI

Buildings	ModNorm EUI	Actual EUI	$\Delta EUI=(EUI_{Actual}-EUI_{Mod})$	% Increase on ModNorm EUI	Cert Level	Year Cert	Cert Age
B1	138	214	76	55%	4 Star	2010	8
B2	108	157	50	46%	5 Star	2013	5
B3	139	166	27	19%	4 Star	2014	4
B4	206	227	20	10%	5 Star	2014	4
B5	90	154	64	71%	5 Star	2015	3
B6	66	220	154	232%	4 Star	2015	3
B7	164	232	68	41%	4 Star	2015	3
B8	198	191	-7	-3%	4 Star	2016	2
B9	186	285	99	54%	4 Star	2016	2
B10	120	130	10	9%	4 Star	2016	2
B11	201	158	-43	-21%	4 Star	2016	2
B12	185	268	83	45%	4 Star	2017	1
Average:	**150**	**200**					

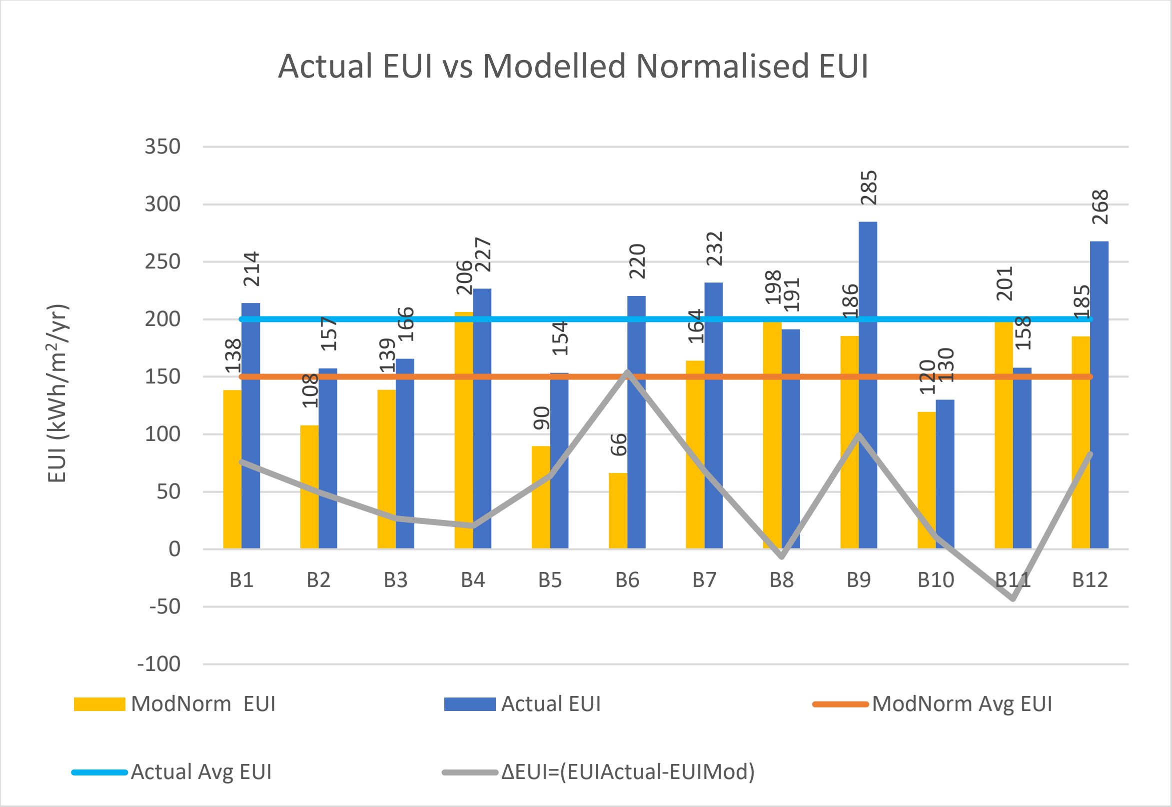


Figure 15: Actual EUI vs Modelled Normalised EUI

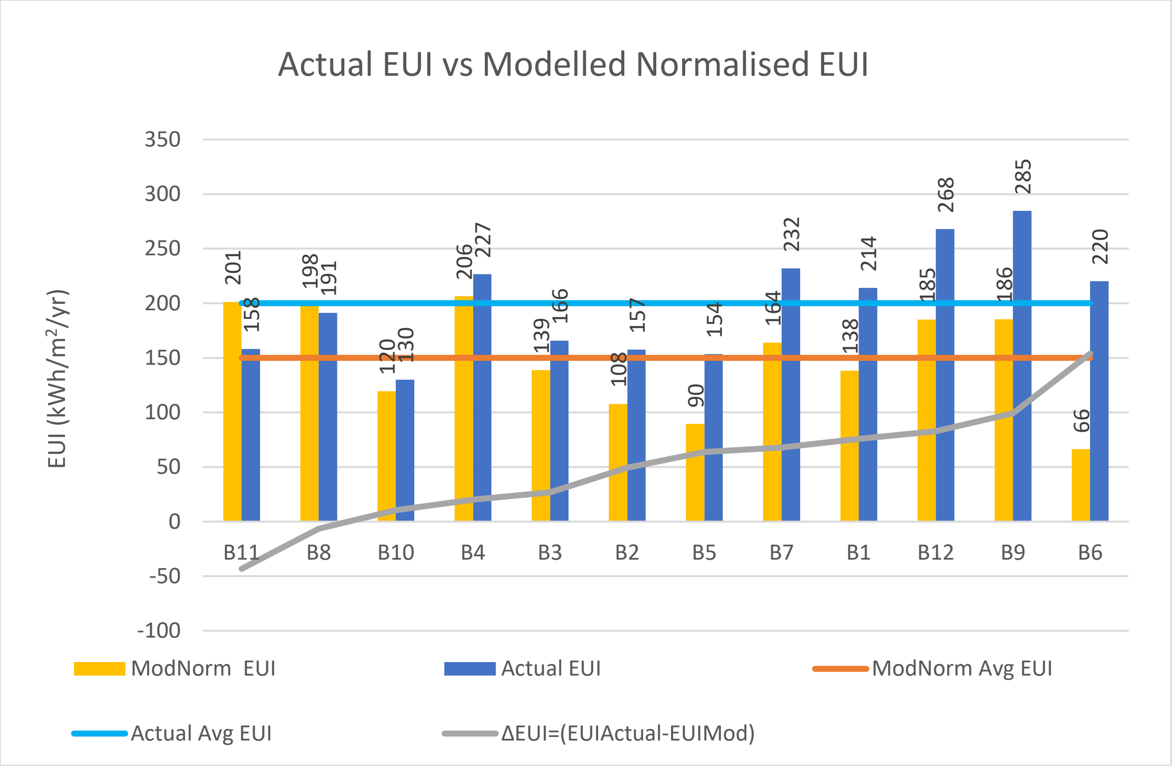


Figure 16: Actual EUI vs Modelled Normalised EUI (in order of performance)

The energy performance of the buildings is depicted by the grey line which represents the difference between the actual EUI and the modelled normalised EUI, ΔEUI.

Overall and per Figure 17 below, eleven of the twelve buildings show variance on modelled normalised EUI between -21% and 71%.
Five out of these eleven buildings (45%) have variance between -21% and 21%, with two of them outperforming their modelled normalised EUI, and three with variance between 9% and 19%.

The remaining six buildings underperform in comparison to their modelled normalised EUI with variance exceeding 40% and up to 71%.

Building B6, as previously discussed, appears to have an energy model which results in unreasonably low consumption and EUI. With modelled normalised EUI of 66kWh/m^2/yr and an actual EUI of 220kWh/m^2/yr, the ΔEUI of the building is 154kWh/m^2, which renders it the worst performer of the sample. Further investigations are necessary to understand the significantly higher ΔEUI.

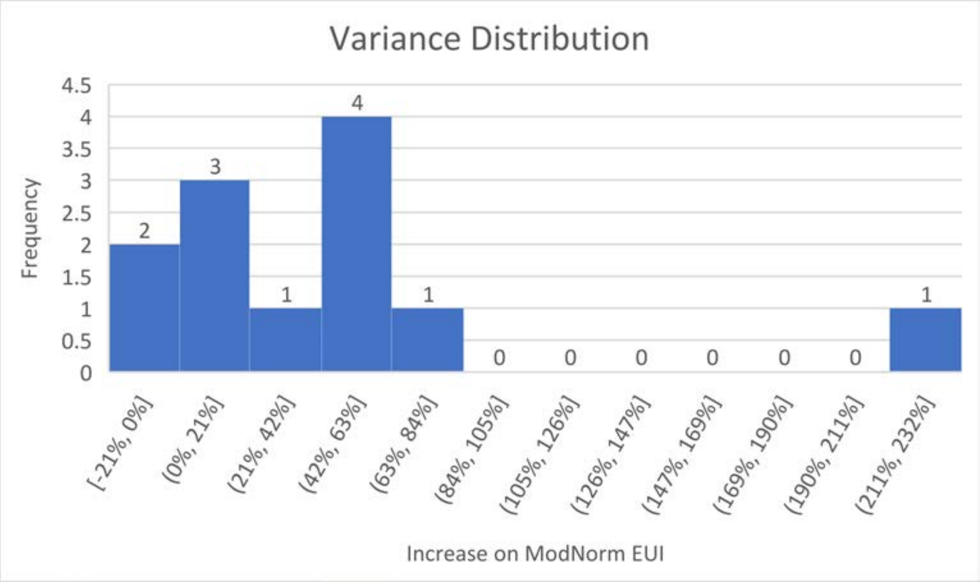


Figure 17: Variance Distribution

Looking at the average EUI for both cases, $EUI_{ModNorm}$=150kWh/m^2/yr, whilst EUI_{Actual}=200kWh/m^2/yr, therefore 33% increase on the modelled normalised value.

If, however, Building B6 is excluded from the sample due to its out of range modelled EUI, the respective numbers are 158kWh/m^2/yr and 198kWh/m^2/yr and the normalised increase is therefore 26%.

This research therefore indicates that Green Star certified buildings generally underperform by 26% relative to expectation.

4.3.4. Certification Level and Certification Age – effect on performance

Additional analysis was carried out to establish whether the certification level and certification age (current year less year of certification) influence the energy performance of the buildings, ΔEUI.

Certification Level vs ΔEUI

As shown in the histogram below (Figure 18), the level of rating within the sample of this study, has inverse correlation to ΔEUI, i.e. 5-Star rated buildings exhibit lower average ΔEUI by 23% as opposed to the 4-Star rated buildings. This may be attributed to the generally higher quality of building envelope and higher energy efficient services implemented in the 5-Star cases, but possibly also because of greater incentive to realise the more substantial investment in sustainability in a 5-Star building.

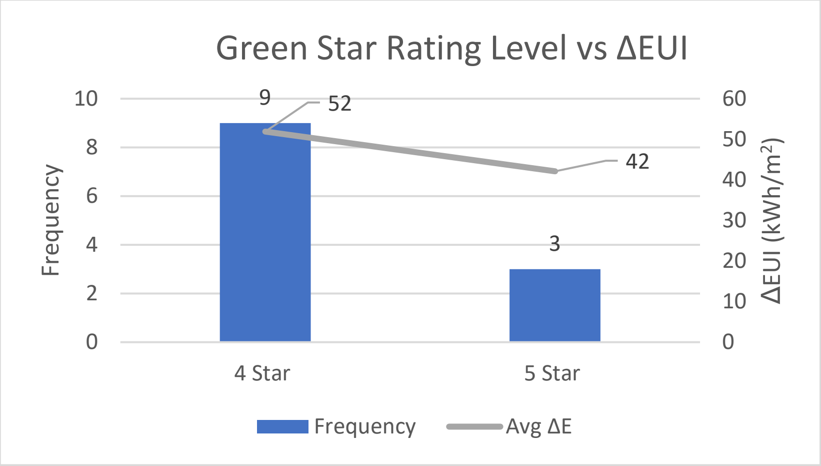


Figure 18: Green Star Certification Level vs Energy Performance (ΔEUI)

Figure 19 below shows the relationship between certification age of the buildings and energy performance expressed by the difference between actual EUI and modelled normalised EUI. The graph depicts a minor invers correlation between age of certification and performance, i.e. a slight increase of ΔEUI with the age of certification.

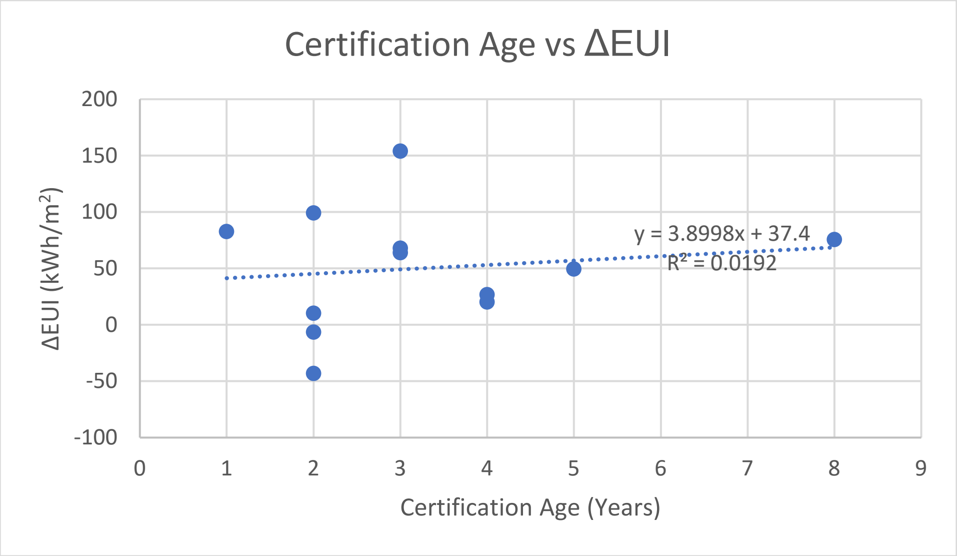


Figure 19: Certification Age vs Energy Performance (ΔEUI)

This could be attributed to increase of knowledge on building envelope and building services performance since the earlier days of Green Star as well as the technological advancement in energy efficient equipment, specifically the lighting technologies.

4.4. Sub-problem Two: 2013 - 2017 Energy consumption and EUI trends

By using the actual energy consumption data of the twelve buildings, as submitted by the participating companies and/or their utilities management companies, the aim is to establish what energy consumption and energy use intensity (EUI) trends the buildings exhibit once in operation.

The actual energy consumption data was extracted from MS Excel spreadsheets and Adobe Acrobat files with billing records and includes all available historic data for annual consumption as well as the 2017 data used for analysis under Sub-problem One. The tables below summarise the monthly consumption data into years and the respective EUI.

Where significant data centres were present and separately sub-metered, as advised by the facilities managers, their energy consumption was subtracted from the energy consumption of the whole building.

Table 20: Actual Energy Consumption (2013-2017)

Buildings	2013	2014	2015	2016	2017
B1	8 837 286	10 502 755	10 057 620	8 424 661	9 636 592
B2	2 441 838	2 875 859	2 831 191	2 226 573	2 083 380
B3	6 609 661	6 843 209	6 686 898	6 347 082	6 207 334
B4		15 968 267	15 404 871	15 103 694	14 779 526
B5			4 740 932	4 330 795	3 739 114
B6			2 965 140	1 666 026	995 130
B7					4 615 679
B8				5 487 061	6 312 422
B9		6 743 385	10 207 473	10 678 471	11 119 583
B10			3 549 455	3 570 465	3 211 755
B11				6 088 802	6 299 205
B12			16 932 730	4 849 769	5 157 068

Table 21: Actual EUI (2013-2017)

Buildings	2013	2014	2015	2016	2017
B1	196	233	223	187	214
B2	184	217	214	168	157
B3	176	183	178	169	166
B4		245	236	232	227
B5			195	178	154
B6			657	369	220
B7					232
B8				166	191
B9		173	261	274	285
B10			144	144	130
B11				153	158
B12			880	252	268

Based on the above tables, the following graphs were produced to verify whether any trends can be observed.

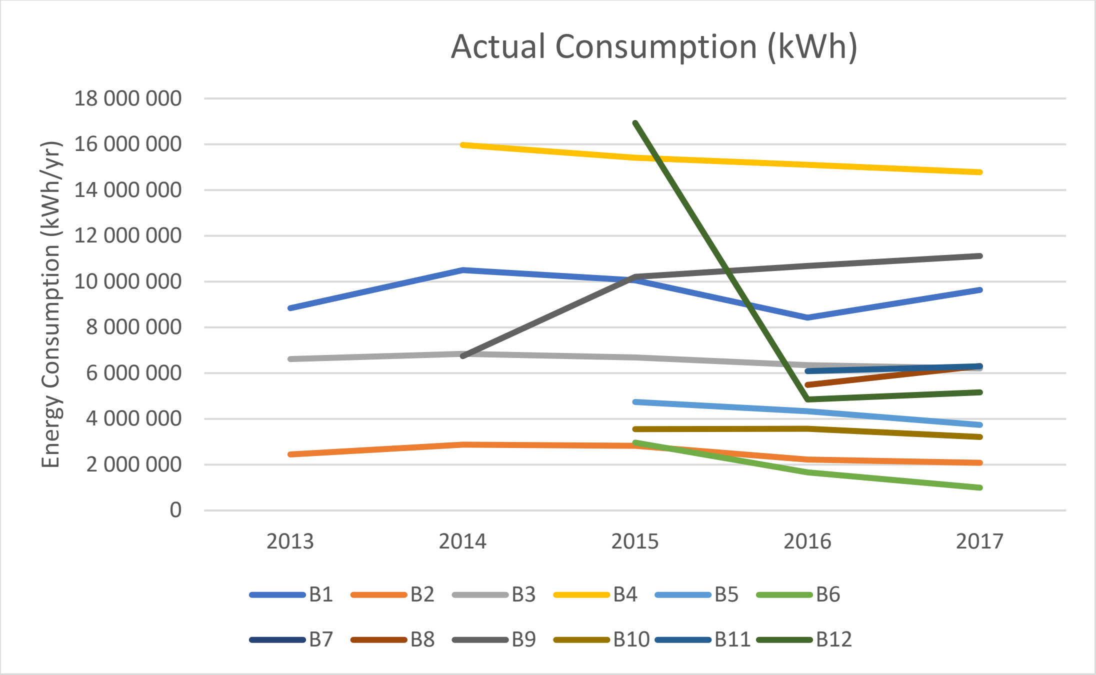


Figure 20: Actual Energy Consumption (2013-2017)

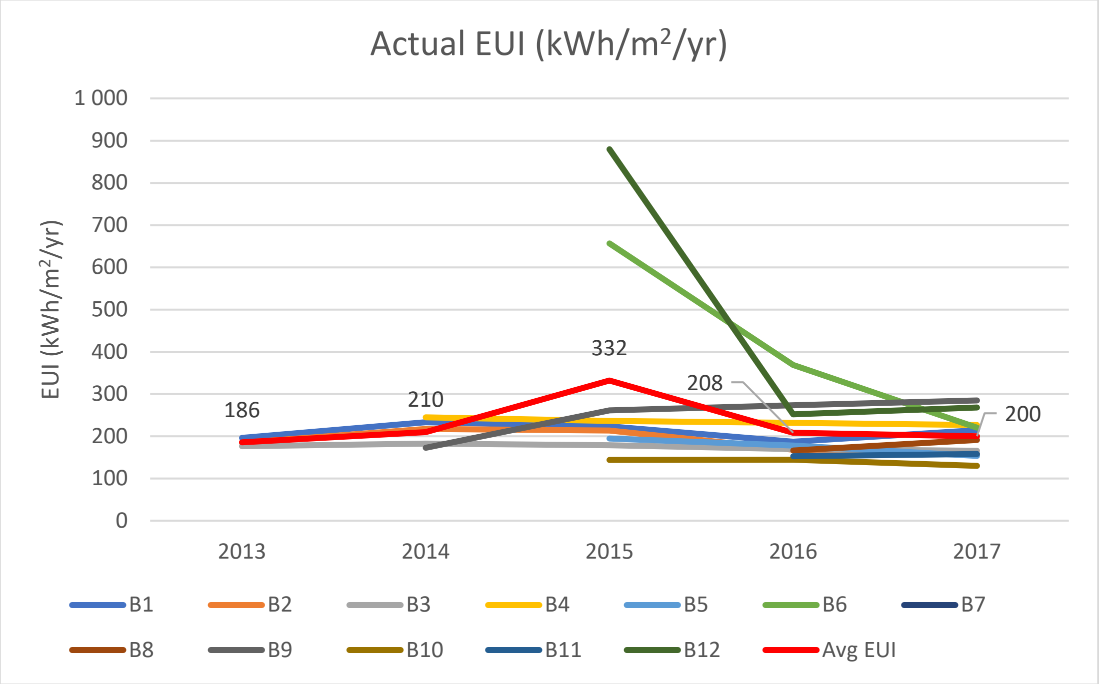


Figure 21: Actual EUI (2013-2017)

The general expectation for Green Star rated buildings is that they are energy efficient by design and that they operate in a way which realises the potential operational efficiency and reduction of greenhouse gas emissions, particularly in the face of rising challenges related to global warming and climate change.

The energy consumption graph above, however, gives a different perspective. With the exception of three buildings B4, B5 and B6 which show reduction in energy consumption over the years, the rest of the buildings show stable or increased energy consumption.
While the energy consumption of these buildings is affected by changing circumstances over the years such as occupancy, occupancy hours and vacancy, the graph clearly indicates that collectively, the buildings are not driving energy reduction.

A case in point is building B6 - with a GLA of 4500m^2, this building consumes almost the same amount of energy as building B2 which has a GLA of 13 200m^2. This discrepancy is clearly depicted also in Figure 21, where the EUI of the buildings over the years is plotted. The high EUI in 2015 is reduced over the following years to align with the average EUI of 200kWh/me/yr by 2017, which is also higher than expected.

There is also a discrepancy related to Building B12 showing high consumption in 2015, which is significantly reduced in 2016. As advised by the respective facility manager, this building's consumption was metered together with a neighbouring building until 2016, and separately metered thereafter, hence the change in the recorded consumption levels.

The observations above go hand in hand with the analysis carried out under Sub-problem One, namely that Green Star certified buildings, as included in this research, operate above their energy expectations and do not fulfil the sustainability objectives set out during the development phases of the projects.

4.5. Sub-problem Three: Facilities and operations management factors that influence EUI

Sub-problem Three, by means of a structured questionnaire, seeks to provide better understanding of the facilities management function in relation to Green Star requirements. As such, the questionnaire developed for this purpose addresses two key aspects, firstly the knowledge and the experience of the facilities managers of the Green Star certification scheme and secondly, how Green Star energy strategies implemented as part of design are supported during the operation of the building.
Graphs representing participants' responses and the related building performance (ΔEUI) were produced to examine potential correlations.

The most pertinent questions, responses and associated graphs are included hereunder.

General Questions

Questions 2 to 5 were included in the questionnaire to determine:

a) The length of involvement of the participant with the particular building;
b) What type of facilities management is deployed by the organisation owning the building;
c) The exposure of the participating facilities managers to the Green Star process and attendance of Green Star related training.

Most of the participants reported involvement in the building between 1 and 4 years and knowledge of Green Star practices, however only seven of the twelve had attended formal Green Star or sustainability training.

2. Length of involvement with this building												
Length of involvement	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Less than 1 year									x	x		
1 to 4 years		x	x		x	x	x	x			x	
4 to 8 years	x			x								x
More than 8 years												

3. Does your company perform the FM function internally or is it outsourced?												
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Internal	x	x		x	x	x	x	x			x	x
Outsourced										x		
Tenant responsible for FM			x									
Combined									x			
Uncertain												

4. Are you familiar with the Green Star SA certification process?												
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Yes	x	x			x	x	x	x		x	x	x
No				x								
Uncertain / limited understanding			x						x			

5. Have you attended any Green Star or other sustainability training courses?												
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Yes	x		x			x	x			x	x	x
No		x		x	x			x	x			

In some of the cases there appear to be no correlation between participants responses and the building performance. Correlations, however, were found in the following instances:

6.	How many buildings does your company own?												
		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
	Less than 5												
	5 to 9	x	x						x				
	10 to 29										x		
	30 to 50			x		x							
	More than 50				x		x	x				x	x

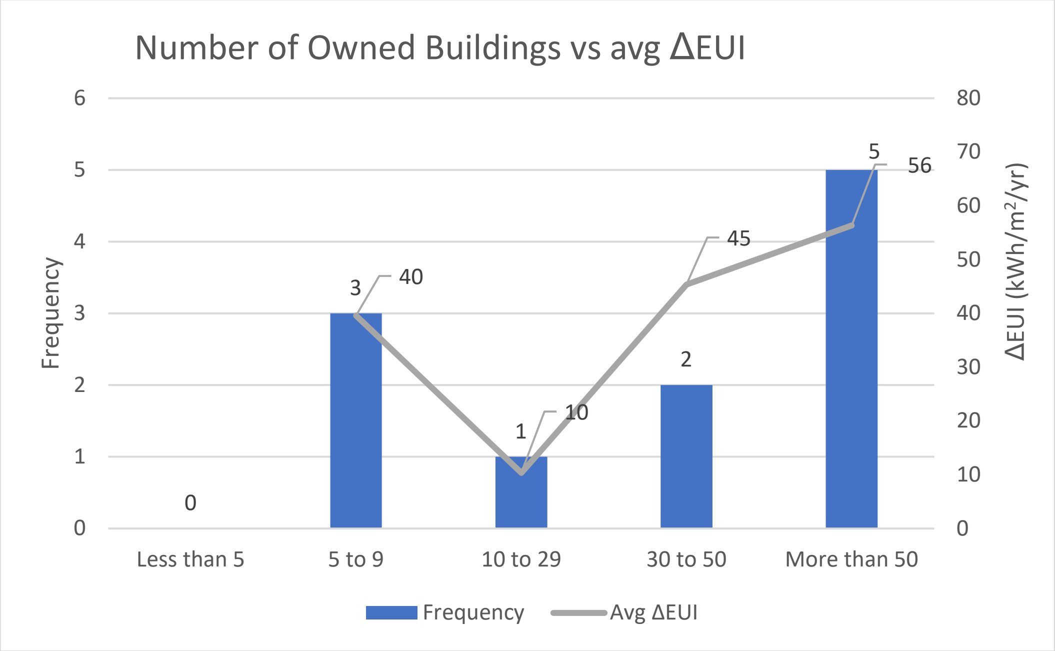


Figure 22: Number of Owned Buildings vs avg ΔEUI

As can be seen from the above figure, the buildings within smaller portfolios show better performance in comparison to the buildings within larger portfolios. The lowest average ΔEUI is calculated for buildings within portfolio of 10 to 29, possibly indicating most optimal number of buildings and well-established skills to run operations. Buildings within smaller portfolios, between 5 and 9 buildings exhibit higher ΔEUI potentially resultant from more costly operations and less established skills. Buildings within the large portfolios of more than 50 buildings show negative correlation towards optimal performance.

Building Specific Questions

1. Was the building comprehensively commissioned prior to handover for operations, in line with CIBSE or ASHRAE guidelines?

			B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
		Yes		x		x	x		x			x	x	
		No						x		x				x
		Uncertain	x		x						x			

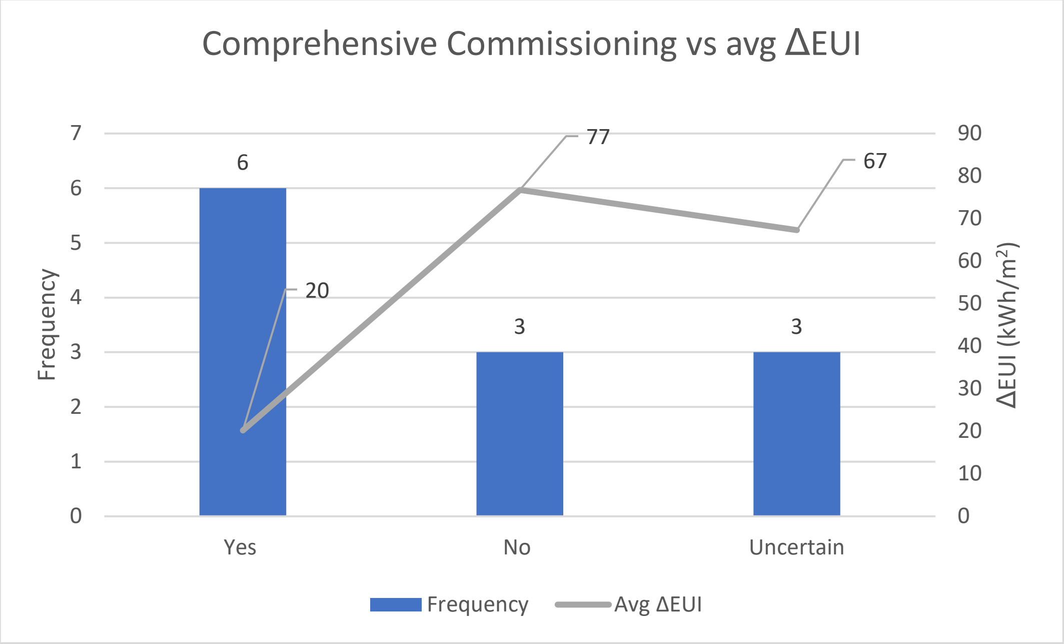


Figure 23: Comprehensive Commissioning vs ΔEUI

50% of the participants responded positively to comprehensive commissioning of the building, whilst equal number of the remaining participants stated no or were uncertain. The graph clearly indicates that buildings which were subjected to comprehensive commissioning have improved energy performance over those that were not. The strong relation between performance and commissioning is confirmed by the average ΔEUI of the commissioned buildings, which is 74% lower than the average ΔEUI of the non-commissioned buildings.

2. Was there a building tuning process undertaken following practical Completion or occupation?

			B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
		Yes		x		x	x		x	x		x	x	x
		No												
		Uncertain	x		x			x			x			

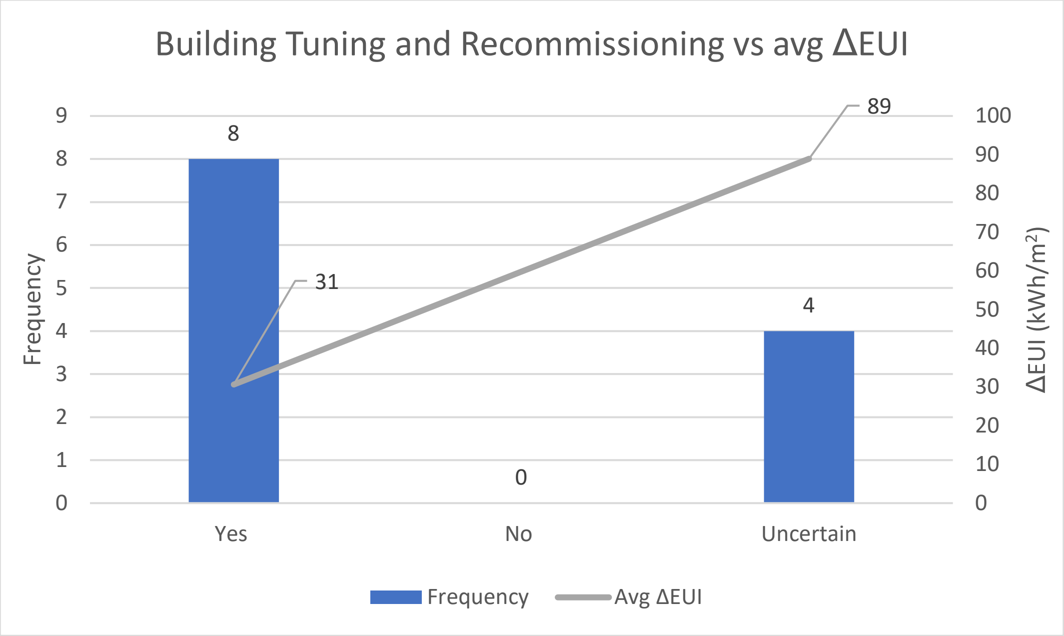


Figure 24: Building Tuning and Recommissioning effect on avg ΔEUI

66% of the participants could confirm that the buildings they represent had undergone building tuning. As with commissioning, a strong relation is observed between building tuning and energy performance, denoted by ΔEUI. The ΔEUI of tuned buildings is 66% lower than that of building that most likely were not tuned (respondents stated “uncertain”). As tuning is an intensive process which involves the building owner and the facilities manager, it can be reasonably assumed that where the participant stated “uncertain”, the building was not tuned.

7. Are you familiar with energy and water consumption targets for the building established during the Green Star certification process?

			B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
		Yes		x			x			x		x		x
		No			x	x		x	x		x		x	
		Uncertain	x											

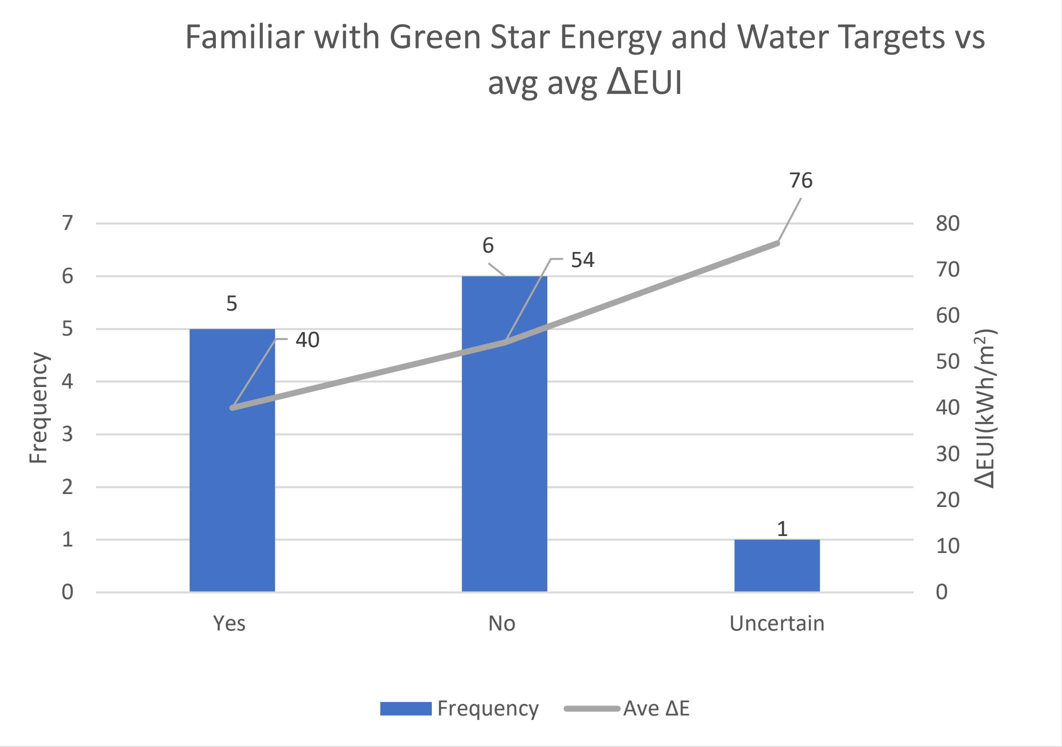


Figure 25: Familiarity with Green Star Energy and Water Targets

Out of the twelve participants in the survey, five were familiar with the Green Star Energy and Water Targets documented in the Building Users Guide, six didn’t know about the targets and one was uncertain.

A strong relationship between knowledge of Green Star targets and energy performance (ΔEUI) is also present here, with ΔEUI of buildings where the facilities managers were familiar with the targets being 26% lower than that of buildings where they were not.

13. Were you part of developing of the metering strategy for this building?

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Yes	x					x						
No		x	x	x	x		x	x	x	x	x	x

14. In your opinion, does the metering strategy of the building accurately inform the energy performance, i.e. is the metering strategy effective?

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Yes	x	x		x			x	x		x		
No			x			x			x		x	x
Uncertain					x							

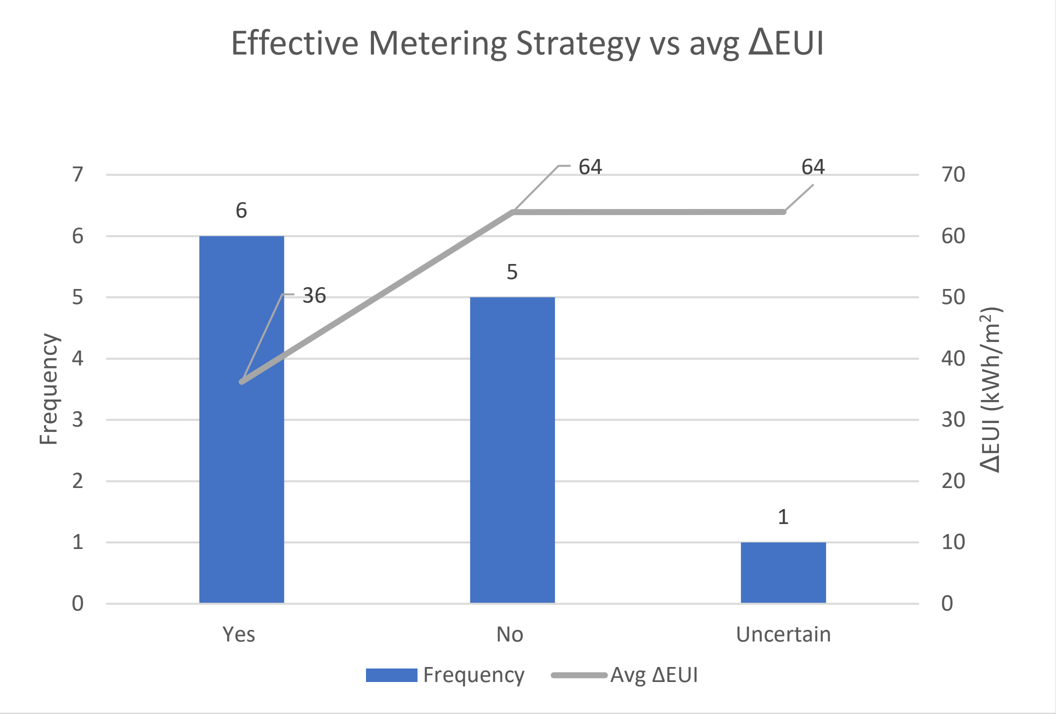


Figure 26: Effective Metering Strategy

Questions 13 and 14 above relate to energy metering in buildings. Of the twelve participants, only two took part in developing of the metering strategies and six could confirm the effectiveness of the implemented metering strategy. Energy metering was found to correlate with energy performance, with ΔEUI of buildings where effective strategy was confirmed being lower by 43% in comparison to buildings where metering was considered ineffective.

17. Are tenants continuously informed of the building’s energy performance, change of equipment and change of energy targets?

			B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
		Yes	x	x			x			x		x		
		No			x	x		x	x		x		x	x
		Uncertain												

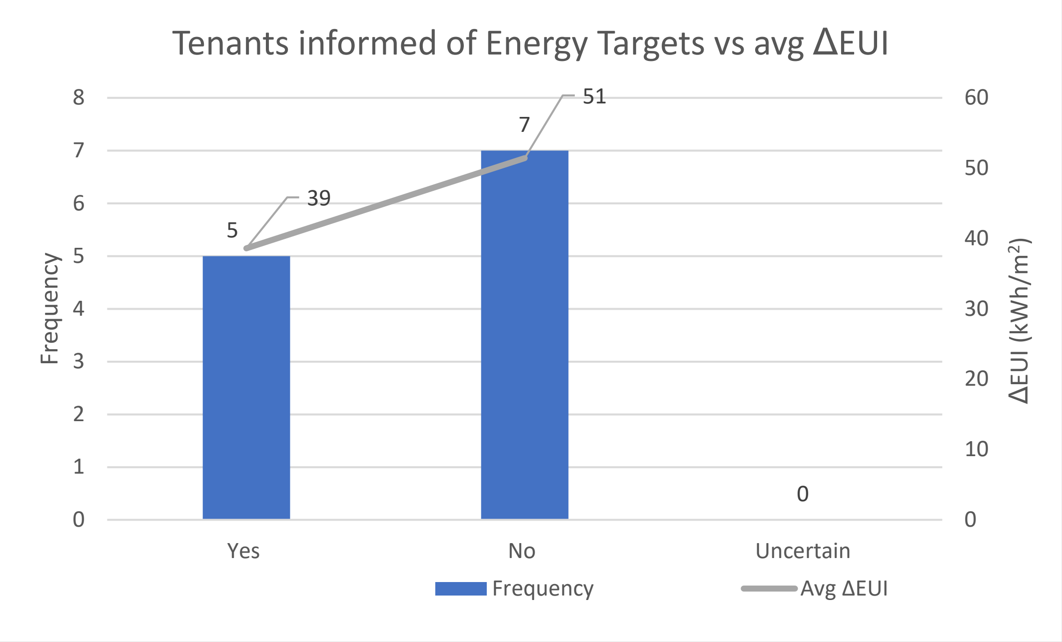


Figure 27: Tenants Informed of Energy Targets

Improvement of performance by 25% is present (lower ΔEUI) resultant from continuous engagement with tenants on energy performance, energy targets and change of equipment.

18. Is the energy performance of the building linked to your Key Performance Indicators (KPIs)?

			B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
		Yes	x	x						x		x		x
		No			x	x	x	x	x		x		x	
		Uncertain												

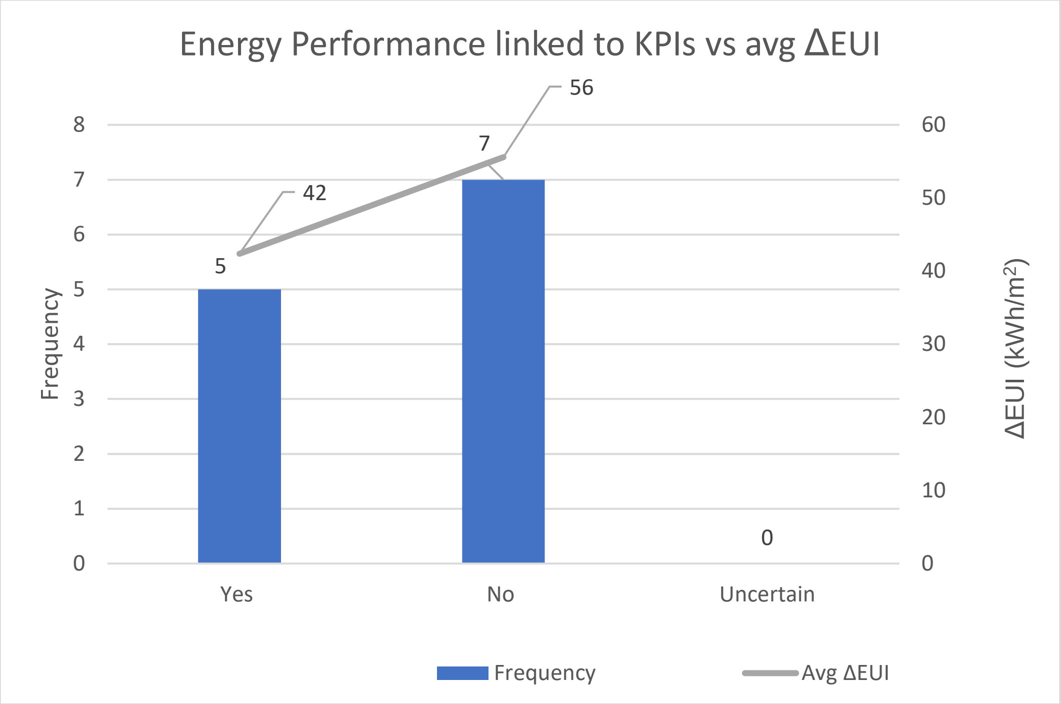


Figure 28: Energy Performance linked to KPI

Improvement of energy performance by 24% (lower ΔEUI) as a result of facilities manager's KPI being linked to the energy performance of the bidding.

4.6. Summary

This chapter presents a summary of the complete sets of data as collected from the participant in the survey and the related brief analysis. This includes:

a) Green Star Ene-1 GHG Emissions Credit reports and calculators' data and the relevant adjustments thereof;

b) Full annual sets of actual energy consumption data for the period 2013-2017, as available and submitted by the participants; and

c) Participants response to key questions from the survey carried out as part of the research.

The next chapter will include a brief discussion on the findings of this study.

CHAPTER 5 - DISCUSSION

5.1. Introduction

The preceding Chapter 4 presents the data used for the research as well as results derived from the data analysis, and as such includes the relevant tables and graphs depicting the results from the analysis.

This chapter provides a brief discussion on the data obtained from the participating parties for the three sub-problems and the analysis carried thereof.

5.1.1. Sub-problem One: Modelled vs Actual EUI

The key question of Sub-problem One was: How does actual energy performance of the buildings compare to the simulated energy performance as established during the certification process?

Firstly, a methodology for comparison of modelled energy consumption and EUI to actual energy consummation and EUI was developed. This entailed the normalisation of prescribed by the Green Star SA V1 Modelling Protocol parameters with the actual numbers as obtained by the participating facilities managers. The following parameters were normalised for comparison of energy consumption and EUI:

- Usable Area;
- Occupancy;
- Occupancy hours; and
- Vacancy.

Secondly, the actual consumption dataset was also adjusted to account for energy consumption of significant data centres within the researched buildings and in support of their operations. This adjustment was done based on the confirmation of the facilities manager for buildings where significant data centres were present and separately metred.

The key parameter used for comparison, as described under the Methodology Chapter, was Energy Use Intensity (EUI), with the difference between EUI_{Actual} and $EUI_{ModelledNormalised}$, namely ΔEUI giving the performance of the twelve buildings.
Lower ΔEUI indicates better performance, aligned with expectations, whereas higher ΔEUI indicates underperforming buildings.

Based on the above, two of the buildings exhibited negative ΔEUI, meaning that they outperform their Green Star modelling normalised energy results by 3% and 21% respectively.

The remaining buildings had positive ΔEUI, with 3 of them showing limited variance in performance of between 0 and 21%, and 4 of the buildings having a major variance between 42% and 63%.

One of the buildings exhibited results out of range in comparison to the rest, indicating that further investigations are necessary to explain the discrepancy.

The result of this comparison indicates that 42% of the buildings in the sample are relatively well aligned with energy expectations set out during certification, having variance in performance between -21% and 21% on modelled normalised EUI. 50% of buildings in the sample exhibit variance on modelled normalised EUI between 21% and 84%. Building B6 (8% of the sample) shows unreasonably high difference between actual and modelled normalised EUI and as a result cannot be considered representative.

Minimum EUI for a fully occupied building in the sample was 157kWh/m^2/yr, with average EUI at 200kWh/m^2/yr. This compares favourably with the study carried out in 2012 by Exergy (Australia) where some 300 South African buildings were researched to establish energy and water consumption benchmarks. The research found that the average EUI of that sample was 219kWh/m^2/yr (Bannister and Chen, 2012).

The analysis carried out to determine if Green Star certified buildings achieve their energy expectations confirms that:

- The applied methodology provides reasonable means for investigating the energy performance of certified buildings;
- Buildings included in this sample mostly underperform in terms of energy when compared to modelled normalised energy consumption;

- A smaller number of buildings exhibited close alignment with or outperformed modelled normalised EUI;
- On average, green buildings outperformed typical office buildings by 10% based on the Banister and Chen research in 2012.

5.1.2. Sub-problem Two: 2013 - 2017 Energy consumption and EUI trends

What energy consumption and energy use intensity (EUI) trends are the buildings exhibiting once in operations?

Similar to the results from the analysis under Sub-problem 1, the presentation of the annual energy consumption data in graphs, for the period 2013-2017, indicates that small number of buildings from the sample exhibit slight reduction in energy consumption over the representative period. Majority of the buildings show either stable or increased energy consumption. The reasons for this could vary – increased occupancy, extended occupancy hours, changes in vacancy, etc.

The general observation of this analysis is that collectively the buildings in the sample are not reducing energy consumption and the associated GHG emissions. While Green Buildings are typically tuned (where relevant credit is targeted) immediately after occupation, some buildings display reducing energy trends well beyond this period which may be an indication of the need for a long-term tuning.

Increased control by building owners, tenants and facilities managers over the energy consumption and EUI is required to understand the drivers and timeously deploy interventions to align the building with its expected energy performance.

5.1.3. Sub-problem Three: Facilities and operations management factors that influence EUI

What facilities management / operating factors contribute to improving the energy performance of the buildings?

To answer this above question, a structured survey was carried out with facilities managers representing building owners' organisations. The survey / questionnaire was set out in two sections, general questions and building specific questions.

Responses to Key General Questions

The aim of this sections was to establish the recipient's length of involvement with the specific building, exposure to Green Star processes and attendance of Green Star training. Most of the respondents reported involvement in the building between 1 and 4 years and knowledge of Green Star practices, however only seven of the twelve had attended formal Green Star or sustainability training.

Despite the fact that Green Star SA has been in existence since 2009 and the effort by GBCSA to develop training courses and set up an education faculty, it appears that many of the facilities managers have not received any formal training. The buildings included in the research sample are some of the most sophisticated and complex building in Johannesburg. Yet 3 of the 12 participants indicated that they are not familiar, or they are uncertain of the Green Star process whereas 5 of the 12 participants confirmed that they have not attended any formal Green Star / sustainability training. This begs the question – can the buildings' energy performance or lack of it be related to the Green Star / sustainability knowledge and experience of the facilities managers?
Further investigations are required to establish the validity of the above observation.

Responses to Key Building Specific Questions

The aim of this section of the survey was to establish what Green Star interventions and operational processes in support of energy performance were implemented in the buildings and how they influence the performance.

It was found empirically that a strong correlation exists between energy performance (lower ΔEUI) and the following green star interventions or operational practices implemented in the buildings:

- Comprehensive commissioning (in line with CIBSE or ASHRAE standards);
- Building tuning;
- Familiarity with the Green Star energy targets established during certification;
- Effective metering strategy;
- Continuous engagement with tenants on building energy performance, targets, and change of equipment;

- Energy performance linked to KPI of the facilities manager.

Buildings that had implemented the above processes, as confirmed by the participating facilities managers, exhibited lower average ΔEUI than the ones that hadn’t. Based on the empirical evidence derived from the interviews of facilities managers representing the twelve buildings in the survey, it can be ascertained that implementing of the above processes during final construction and operation of a building is likely to result in an improved energy performance.

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

This chapter contains a short summary of the study, the associated findings and recommendations related to green building practices in support of improved energy performance and further research.

6.1. Summary

Given the significant contribution of buildings and the construction industry towards the environmental challenges facing current and future generations, the development of sustainable or green buildings is increasingly being embraced globally.

Green buildings are designed and constructed to have reduced negative impact on the environment by being, for example, energy and water efficient, and at the same time promote occupants' health and wellbeing. The reduced environmental impact is assessed as part of the certification process through mathematical calculations and modelling of building performance.

The Green Star rating schemes place particular emphasis on building energy efficiency, in response to the real current threats of Global Warming, such as climate change, habitat destruction, rising sea levels and reduced global food security. Energy related categories make up roughly 30% of the typical Green Start rating schemes.

For certification of buildings, simulation of energy performance based on a modelling protocol is carried out. The Green Star modelling protocol prescribes standardised fixed values for a number of variables, including office areas lighting load, occupancy, occupancy hours, vacancy. Due to the theoretical nature of modelling, the simulated energy performance of a building may not represent the building's actual performance.

In practice, however, the results of performance modelling create expectations of actual performance. Building owners expect improved efficiencies over the norm to justify the increased capital outlay and increased lease rentals of this type of building. Tenants on the other side, expect improved efficiencies that translate into real operational savings, thereby justifying the increased rentals.

The purpose of this research was to establish whether certified green buildings do generally perform in line with expectations, in terms of energy, and assist in identifying possible reasons, if not.

12 Green Star SA New Construction As-Built certified buildings in Johannesburg were included in this research, in accordance with selection criteria detailed under Section 3.3. To establish the energy performance of these buildings, the energy consumption data of each building for 2017 was compared to the energy simulations' results derived during the certification of the buildings. The energy consumption trends of these buildings since the certification, or when consumption data became available, until and including 2017 was also assessed. Lastly, the facilities management function and operational processes were briefly examined in relation to typical green star requirements for improved energy performance.

The salient findings of this research can be summarised as follows:

- The applied methodology for normalising simulated energy consumption and comparison to the actual energy consumption of the buildings for 2017 provides reasonable means for investigating the energy performance of certified buildings;
- Buildings included in this sample mostly underperform in terms of energy when compared to modelled normalised energy consumption;
- On average, the buildings in the sample underperform by 26% relative to expectations;
- A smaller number of buildings exhibited close alignment with or outperformed modelled normalised EUI. Two of the twelve buildings (16%) outperformed expectations, whereas two exhibited a variance not exceeding 10% relative to expectation.
- On average, green buildings outperformed typical office buddings by 10% based on the Banister and Chen research in 2012;
- Significant portion of buildings demonstrate increasing energy consumption trends over the representative period of 2013 until 2017;
- 5-Star GSSA certified buildings in the sample demonstrate improved energy performance as opposed to 4-Star buildings.

The facilities managers' response to the structured questionnaire empirically confirmed the positive influence of key Green Star energy related requirements and operational practices on the energy performance of the buildings. These include:

- Comprehensive commissioning (in line with CIBSE or ASHRAE standards);
- Building tuning;
- Familiarity with the Green Star energy targets established during certification;
- Effective metering strategy;
- Continuous engagement with tenants on building energy performance, targets, and change of equipment;
- Energy performance linked to KPI of the facilities manager.

It is also evident that while majority of the participating facilities managers were familiar with the Green Star certification process, very few of them have attended formal Green Star training. Further research is necessary to verify the influence of training on the energy performance of green star rated buildings.

Lastly, the results of this research are consistent with the findings of international studies and academic research on energy performance of certified buildings, as included in Chapter 2 Literature Review, namely:

- In most cases it was found that fewer buildings outperform expectations, while most not. There is no clear indication that, in general, certified buildings achieve expectations;
- Certification alone cannot guarantee the energy savings as initially envisaged and calculated through simulations;
- Many of the buildings, including high performance ones, fall short of their energy saving potential, as established through simulations;
- It could be more beneficial to certify buildings only based on actual performance;
- There is no evidence that certified buildings are moving towards achieving the goal of carbon neutrality;
- One of the biggest challenges to understanding the efficiency of rated buildings is the lack of measured energy performance for commercial buildings.

6.2. Conclusion

This study highlights the energy performance of 12 Green Star Office v1 As-built certified buildings by comparing simulated energy performance to actual energy performance. It is the first of its kind in offering a structured approach to assess the problem of expected vs actual energy performance in buildings.

The key outcome of the research is that the majority of buildings in this sample do not achieve the expected energy performance per Green Star simulation.

While the scope of the study is of limited nature, it includes a representative sample of commercial office buildings and it could be reasonably assumed to apply to typical green buildings in general.

The methodology put forward to compare dissimilar buildings with varying operational parameters can be used going forward to conduct similar analysis on a much wider sample of buildings, including conventional (not green) buildings.

6.3. Recommendations

The results of this research clearly indicate that more than 60% of the buildings in the sample underperform in relation to certification expectation for energy. Based on the research results, the following items could be expected to reduce the gap between expected and actual energy performance:

- Comprehensive commissioning to be strongly considered as part of the Green Star certification of buildings;
  The results of this research demonstrate strong correlation between CIBSE / ASHRAE type of commissioning and energy performance and although the credit is elective under the Green Star rating scheme, on the basis of the above is strongly recommended;
- Building tuning is an elective credit in the Green Star rating scheme. Due to positive correlation between building tuning and improved energy performance, it is recommended that the credit is strongly considered as part of the certification process;
  In addition, building tuning and the involvement of the engineers who designed the energy intensive building services should be considered as an on-going intervention. This can contribute towards improving the energy performance of the building during its operation and the continuous alignment with energy expectations set out during the design and construction of the building;
- Evaluation of proposed (in new buildings) and implemented (in already rated buildings) metering strategies with the participation of the facilities managers. Based on the interviews with the facilities managers, it was reported that most of them did not participate in defining the metering strategy of the building and that the metering strategies in half of the buildings were deficient. Involving the facilities managers in setting up the metering strategies will result in deeper understanding of energy uses within the building, the expected consumption and monitoring of these, not only from billing perspective but to optimise the energy performance of the building;
- Involvement of the facilities managers as early as the initial phases of design development. Facilities managers are responsible for the operation of buildings and the associated services and can provide valuable input to design and equipment selection. This will promote more active involvement in the operational phase of the building and optimising of energy performance;

- Energy performance of the building to be linked to KPI of facilities managers, where this has not been done yet;
- Data centres' energy consumption to be separately metered where this is not done yet;
- Prior to certification, simulated energy performance of both notional and actual buildings to be verified to reflect realistic values. Building B6 in the research appear to have been certified with overoptimistic energy performance for both notional and actual buildings.

Recommendations to further this research are as follows:

- Expand research to include larger sample, i.e. more than 12 buildings and verify the findings of this research;
- Investigation of energy performance related to SANS204 specified energy consumption values for office buildings;
- Investigate the energy performance of owner occupied vs tenant occupied buildings;
- Investigate the structure of management fees charged by the property companies - in particular how utilities charges are handled and the effect of that on energy performance of tenanted buildings;
- Comparison of energy performance of Green Office Buildings with typical office buildings;
- Comparison of energy performance of current Green Buildings with historic expectations for energy efficient buildings.

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APPENDIX A: QUESTIONNAIRE

SECTION B: PROPOSED INTERVIEW QUESTIONS

General Questions

1. Current occupation and job title

____

2. Length of involvement with this building

Less than 1 year	
1 to 4 years	
4 to 8 years	
More than 8 years	

3. Does your company perform the FM function internally or is it outsourced?

Yes	
No	
Uncertain	

4. Are you familiar with the Green Star SA certification process?

Yes	
No	
Uncertain	

5. Have you attended any Green Star or other sustainability training courses?

Yes	
No	

6. How many buildings does your company own?

Less than 5	
5 to 9	
10 to 29	
30 to 50	
More than 50	

7. How many of the owned buildings are Green Star SA New Construction certified (Design and As-built)? Please state the number.

Design	
As-built	
Uncertain	

8. How many of the owned buildings are Green Star SA Existing Building Performance (EBP) certified? Please state the number.

EBP Certified	

Uncertain	

9. What is your perception – do Green Star SA certified buildings, in general, perform in line, or better than expected, in terms of energy and water consumption?

Totally Disagree	
Disagree	
Uncertain	
Agree	
Totally Agree	

Please explain your answer:

(Turn page to the next set of questions)

Building Specific Questions

The next set of questions relates to the building/s included in the research

1. Was the building comprehensively commissioned prior to handover for operations, in line with CIBSE or ASHRAE guidelines?

Yes	
No	
Uncertain	

2. Was there a building tuning process undertaken following practical Completion or occupation?

Yes	
No	
Uncertain	

3. Were you part of the Green Star Design and As-built certification process during the following stages?

Design development	
Equipment selection	
Commissioning	
Building tuning	
Other (Please state)	
None	

4. At handover of the building, were there training sessions on building services and the sustainability aspects of these?

Yes	
No	
Uncertain	

5. If yes to the above question, were you part of these training sessions?

Yes	
No	

6. Are you familiar with the Building Users Guide produced as part of the Green Star certification process?

Yes	
No	
Uncertain	

7. Are you familiar with energy and water consumption targets for the building established during the Green Star certification process?

Yes	
No	

Uncertain	

8. Is the energy performance of the building being tracked continuously?

Yes	
No	
Uncertain	

9. If yes to the above, does the building have a specific monthly energy consumption target and what is this target?

Yes	
No	
Uncertain	

Targets:		kWh
		kVA

10. Are there any programs in place for improving of the building's energy performance?

Yes	
No	
Uncertain	

11. If yes to the above, please state what are these programs?

12. Does the building have a metering strategy other than what Green Star requires?

Yes	
No	
Uncertain	

13. Were you part of developing of the metering strategy for this building?

Yes	
No	

14. In your opinion, does the metering strategy of the building accurately inform the energy performance, i.e. is the metering strategy effective?

Yes	
No	
Uncertain	

15. If no to the above, please explain why, in your opinion, the metering strategy is ineffective.

16. Please state what is the current maintenance budget (R/m^2) for this building?

____

17. Are tenants continuously informed of the building's energy performance, change of equipment and change of energy targets?

Yes	
No	
Uncertain	

18. Is the energy performance of the building linked to your Key Performance Indicators (KPIs)?

Yes	
No	
Uncertain	

19. In your opinion, what are the two most important actions that can be undertaken for this building to improve the energy performance and why?
