ASSESSING THE ENERGY PERFORMANCE GAP BETWEEN 6-STAR AND NET-ZERO ENERGY BUILDINGS FOR SOUTH AFRICA

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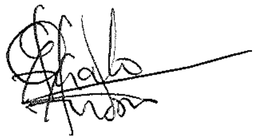
Declaration

I declare that this research report is my own work except where otherwise acknowledged. It is being submitted to the University of the Witwatersrand, Johannesburg, for the degree of Master of Architecture in Sustainable and Energy Efficient Cities (SEEC) It has not been submitted before for any degree or examination at any other University.



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Abstract

Energy efficiency in buildings has been systematically coupled with the green-rating of buildings based on systems such as the Star-rating of the Green Building Council of South Africa (GBCSA). Net-zero energy buildings (NZEBs) have also been receiving increased attention as a way of addressing concerns over depleting energy resources (especially for fossil fuels), increasing energy-costs and greenhouse gas (GHG) emissions which contribute to global warming and climate change.

With a focus on reduction in contribution to GHG-emissions and thus enhancing climate change mitigation of 6-Star green-rated buildings the study applied a case-study approach based on energy performance of the Department of Environmental Affairs (DEA) Building in Pretoria. Secondary data show that the building's status quo energy performance is 112kWh/m^2/yr. Within the temperate-interior climatic zone for Pretoria (as per energy efficiency regulations for buildings in South Africa), psychrometric chart analysis showed that the building could achieve a higher level of thermal comfort through further optimization of passive design interventions.

Edge-tool simulation results on full optimization of passive design and energy efficiency interventions indicate that a net-zero energy building (NZEB) performance of the same sized building could achieve an energy performance level of 45kWh/m^2/yr, thus revealing an energy performance gap of 67kWh/m^2/yr. This translates to 60% savings compared to the status quo 6-Star performance of 3 076 291kWh/year. Assessment of roof-area for solar PV system indicated that it is adequate for the energy balance towards a NZEB.

Assessment of simple payback period per intervention indicates less than one-year payback period for tenant lighting while tenant equipment indicates a payback period of just over a year and PV-installation at three-years. The findings indicate that the intervention-costs for migration to NZEB fall within the acceptable range for South African investors (maximum of 3 to 5 years). The above findings indicate that the pursuit of NZEBs would significantly contribute towards mitigation of GHG-emissions and climate change and thus calls for further exploration of pathways towards mandatory NZEBs for South Africa.

Key words: *Edge-tool* for energy simulation, energy efficiency for buildings, energy performance gap, net-zero energy building (NZEB), payback period, psychrometric-chart analysis.

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Table of Contents

List of Figures

List of Tables

List of Appendices

List of acronyms and abbreviations

AC	Air Conditioning
APEC	Asia-Pacific Economic Cooperation
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BESTEST	Building Energy Simulation Test
BIM	Building Information Management
BMS	Building Management System
BRE	Building Research Establishment (UK)
BREEAM	Building Research Establishment Environmental Assessment Method
CBD	Central Business District
CO_2	Carbon Dioxide
COA	Cost Optimum Analysis
COT	City of Tshwane
CSIR	Centre for industrial and Scientific Research
DALI	Digital Addressable Lighting Interface
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
ECBC	Energy Conservation Building Code
EIA	Environmental Impact assessment
EPBD	Energy Performance Buildings Directive (European Union)

EPW	Energy Plus Weather
EU	European Union
FSC	Forest Stewardship Council
GBCs	Green Building Councils
GBCA	Green Building Council of Australia
GBCSA	Green Building Council of South Africa
GHG	Green House Gas
HVAC	Heating Ventilation and Air Conditioning
IASS	The Institute for Advanced Sustainability Studies
ICT	Information Communication Technology
IECC	International Energy Conservation Code
IEQ	Indoor Environmental Quality
IEA	International Energy Agency
IFC	International Finance Cooperation
IPCC	Inter-governmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IT	Information Technology
KPA	Kilopascal
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
LED	Light-Emitting Diode

MOCAA	Museum of Contemporary Arts Africa
MSL	Mean Sea Level
MS	Member State
NAEEEC	National Appliance and Equipment Energy Efficiency Committee
NASA	National Aeronautics and Space Administration
NBI	New Building Institute
NERSA	National Energy Regulator of South Africa
NIST	National Institute of Standards and Technology
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory (US)
NZEBs	Net-Zero Energy Buildings
OECD	Organisation for Economic Co-operation and Development
ODP	Ozone Depleting Potential
PMV	Predicted Mean Vote
PPP	Public Private Partnership
PV	Photovoltaic
PVC	Polymerizing Vinyl Chloride
QDC	Queensland Development Code (Australia)
RE	Renewable Energy
RM	Ringgit Malaysian (Malaysian Ringgit)

SA	South Africa
SANS	South African National Standards
SEB	Sarawak Energy Building
SSIC	Site Solution Innovation Centre (Johannesburg)
UCTS	University College of Technology Sarawak
USBC	United States Building Council
US	United States
UK	United Kingdom
VOC	Volatile Organic Compounds
WWTPS	Waste Water Treatment and Purification System
ZEB	Zero Energy Building

Chapter 1: Background and contextualization of the study

1.1 Global overview

The built environment is currently the world's single largest contributor to greenhouse gas (GHG) emissions and accounts for over 40% of primary energy use and 24% of GHG emissions. (IEA, 2019). In the United States, buildings generally account for almost two-thirds of national electricity consumption and more than one-third of total primary energy use (Kriner, 2006). The built environment consumes around a third of our water and generates 40% of our waste. Such energy-use and related CO_2 emissions entails both direct (on-site use of fossil fuels) as well as indirect use in relation to electricity-generation and embodied energy in the processing of construction materials and on-site construction operations.

Energy efficiency is one of the key tools to tackle two of the biggest challenges of climate change and energy security. In order to mitigate catastrophic climate change, it is generally acknowledged that by 2050, the world needs to reduce CO_2 emissions by 50% from the current levels with a targeted reduction of at least 40% below the 1990 levels by the year 2030. Similar commitments have been made by countries such as South Africa and China towards the reduction of CO_2 emissions by 50% from the current levels (Dutil and Rousse, 2012)

Although the green building concept has not been translated into a commonly applied standard in practice, its use has been on the rise in the United States, Australia and Europe in the past two to three decades (DEAT, 2009b). In addition to energy performance in green buildings, a new dimension known as net-zero energy buildings (NZEBs) has also come into play and such buildings are deemed to perform better than green-rated buildings with respect to energy consumption and CO_2 emissions reduction due to their tremendous potential in transforming the way buildings use and generate their own energy (Shehadi, 2020).

Importance of NZEBs

A zero energy building, also known as a zero net energy (ZNE) building, net zero energy building (NZEB), or net zero building implies a building with a zero net energy consumption such that the total amount of energy utilised by the building on an annual basis is equal to the amount of renewable energy created on site. As a result, such buildings do not increase the amount of greenhouse gas emissions (GHSs) in the atmosphere. As shown in Figure 1, the word 'net' emphasises the energy exchange amongst buildings and energy infrastructure such that the building-grid interaction allows ZEBs to become active parts of the renewable energy infrastructure. This means that NZEBs generate energy to power themselves and some of this energy may be exported as well.

ZNE thus has an unprecedented potential to change the way buildings utilize energy which could be driven by ultra-efficiency goal to be defined by building owners define and pursued by design teams can reach and desirable by occupants. However, an increasing number of buildings are achieving this standard thereby gradually raising confidence that a ZNE is realistic and achievable taking into account modern building technologies as well as design approaches (Banerjee, 2015).

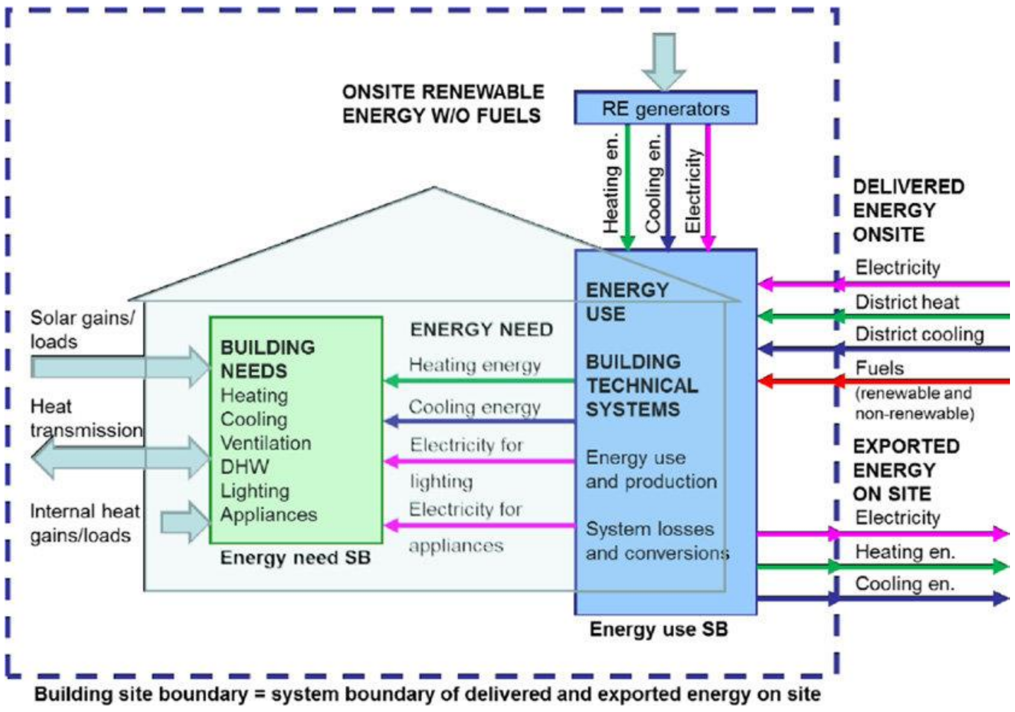

Figure 1: Net delivered energy in NZEBs, Source: Banerjee (2015: 144)

Developments in green-rated buildings in the South African context

Green star is a voluntary building performance rating tool administered by the Green Building Council of South Africa (GBCSA) to assess the performance of a building and its impact on the environment based on nine pre-set components and criteria relating to its design, construction, and envisaged operation. The components include management**,** indoor environment quality (IEQ), energy, emissions, transport, materials, water, land use and ecology, emissions and innovation (GCSA, 2013). This allows for certification of buildings based on three levels of achievement where the 4-star refers to Best Practice, 5-star refers to South African Excellence and 6-star refers to World Leadership level (GBCSA, 2011). Green star tools also vary according to building types where green-star office, residential and education are some of the examples.

Each component is then structured into a range of performance credits which guide performance assessment of design-interventions (as designed) and the actual building once completed (as built). As an extension, the rating of buildings as operated is undertaken through an alternative tool for existing buildings which covers both green-rated as well as unrated buildings.

Whereas there has been increasing awareness of green buildings practice in South Africa, the implementation has remained relatively weak. Increasing awareness is mainly associated with the ongoing crisis in electricity supply, growing awareness of water scarcity especially in view of ongoing climate change impacts and the increase in demand for green rated buildings, especially by both local international organisations operating in South Africa (Marco, 2017).

In contrast to green rated buildings, NZEB refers to a high energy performance building of which primary energy consumption is covered to a very significant extent by energy from renewable sources. NZEBs are also defined as technologically innovative buildings whereby, in an average year, the building produces as much electrical plus thermal energy from renewable energy sources as the building consumes (Rosen, 2012: 2286). In further elaboration, Torcellini et al. (2010) define net-zero energy buildings (NZEBs) as residential or commercial buildings with significantly reduced energy needs such that efficiency-gains enable the balance of energy needs to be offset with generation from renewable energy technologies. Aelenei et al. (2013) further identifies three main types of NZEBs which are as net-zero site energy, net-zero source energy and net-zero energy cost. Some of the advantages or disadvantages of NZEBs are illustrated in Figure 2.

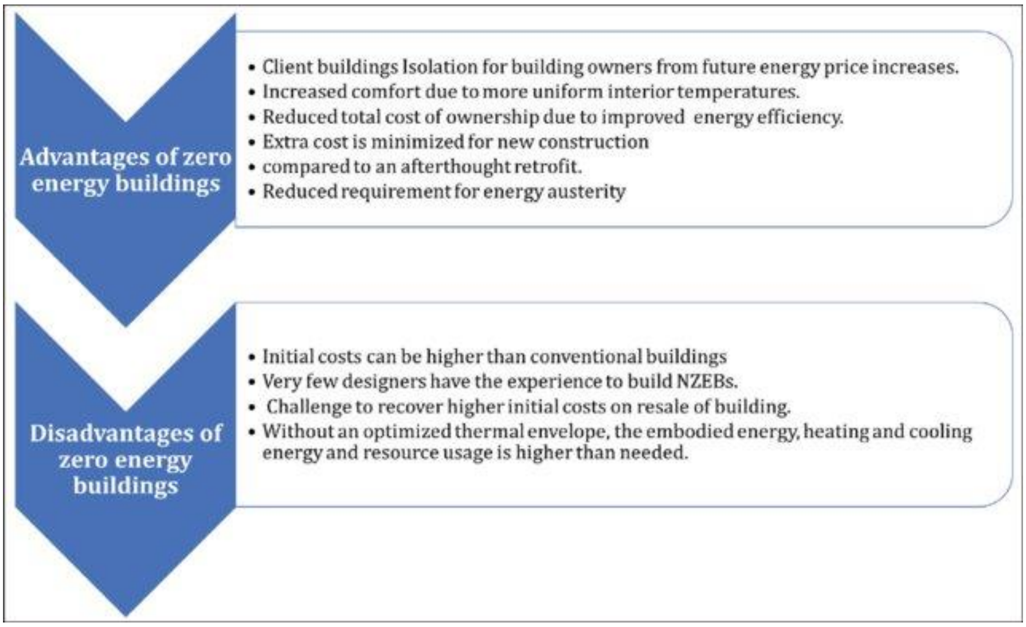

Figure 2: Advantages and disadvantages of NZEBs, Source: (Dhote & De, 2021: 40)

1.2 Rationale of the study

The energy topic has become increasingly critical in architecture especially as buildings are high consumers of energy and architects, as well as the public, are consequently becoming more interested in mitigating their energy use (Scognamiglio et al. 2012). With regard to renewable energy for buildings, initial focus was directed towards on-site thermal solar-collectors (especially for solar water-heating) especially in sunny countries such as Greece and Israel. Subsequently, innovation and diffusion of solar power generation based on PV technology has driven the rapid decline in related upfront cost, mainly due to China's initiatives to break open the protected industrialized world market for PV technology (GBCSA, 2017).

In June 2018, South Africa was rated as the 14th highest carbon emitter in the world and the highest in Africa, with emissions totaling 414.4 million tons (IEA, 2018). IEA further estimates South Africa's emissions at 1.2% of total global CO_2 emissions and over 34% of Africa's total CO_2 emissions (IEA, 2018). Organisations (business and other entities) as well as individuals and households in South African cities contribute to over a third (37%) of national energy consumption and nearly half (46%) of national electricity consumption and are therefore responsible for nearly half of the country's GHG-emissions from electricity (Sustainable Energy Africa, 2015). This demonstrates the need for emissions reduction for South Africa in general, but more so, through its reduction in emissions related to production and operation of its buildings.

As part of exploring and mapping approaches for such reductions, South Africa recorded its first net zero energy building in 2016 with the launch of the net zero certification scheme, which rewards projects for completely neutralizing (Net Zero) or positively redressing (Net Positive) their environmental impacts under four categories: carbon, water, waste and ecology. As noted by the Green Building Council South Africa (GBCSA, 2017) the certified net-zero buildings are:

- the Vodafone Site Solution Innovation Centre (SSIC) in Midrand, Gauteng (which is rated as net- zero carbon and ecology),
- the Estuaries Plaza in Century City in Cape Town (which is rated as net-zero water, but not energy),
- the Greenfields Industrial Park (for the base building) in Cape Town (which is rated as net-zero carbon),
- the two Dam (in operation) in Montagu in the Western Cape, also rated as net-zero carbon.

Green Building Council South Africa (GBCSA, 2017) further notes certification of other buildings listed below as net zero:

- 78 Corlett drive that achieved net-zero carbon (pilot) level 1 certification in late November 2017
- Ballito Hills Life Style Centre located in Dolphin Coast, Kwazulu Natal
- Greenfield Industrial Park located in Cape Town-Western Cape
- Lords View Industrial Park located in Johannesburg-South Africa and
- MDA Property Holdings Pty Ltd located in Johannesburg-South Africa

Other buildings such as the District (in Cape Town) has achieved net zero water, Virgin Active, Constantia (in Cape Town) as well as Vleihuis Development (in Johannesburg) and Wild Coast Sun (in Cape Town) have also been rated as net zero (GBCSA, 2017).

On the other hand, in 2017, GBCSA's green building rating system reached its milestone of 250th green building certification in Africa, with 20 buildings rated as 6-star and therefore deemed to be at World Leadership level. As discussed in detail under literature review in Chapter 2 (see for example Figure 7), all rated buildings address certain aspects of energy- use reduction (towards mitigation of GHG-emission) as one of the rating components.

1.3 Problem statement

With a focus on the built environment, a 6-star GBCSA green-rated building, though considered top tier in the rating scale might not necessary be as energy efficient in relation to GHG-emissions reduction when compared with a net zero energy building. This has necessitated the need to understand the gap between the two highly rated building types and to find a way to bridge the performance gap as this gap might be of negative impact towards achieving energy efficiency focused on climate change mitigation where optimizing for GHG-emissions reduction is the primary goal. The study therefore prioritizes the assessment of the energy-performance gap between 6-star and net-zero energy buildings in South Africa in order to assess possible measures towards closing the gap. This was guided by the overall research question and related sub-question as highlighted in the next sub-section

1.3.1 Overall research question and sub-questions

The overall research question of the study was therefore conceptualized as follows:

> What is the energy-performance gap between 6-star green rated commercial buildings vis-à-vis their simulated NZEB performance and what would be the desirable pathway towards the adoption and scaling-up of NZEB practice in South Africa?

In order to facilitate data collection and analysis, the research question was structured into the following sub-questions:

1. Given passive design and energy efficiency optimization interventions, what is the energy-performance gap between 6-star and NZEBs in South Africa?
2. What is the energy-performance and cost-savings associated with enhancement from 6-star to NZEB levels?
3. How could the technical energy-performance, market and cost barriers from 6-star to NZEBs enhancement be addressed?
4. What could be the desirable pathway from voluntary to mandatory NZEBs for South Africa?

1.4 Working hypothesis

The study hypothesized that a fully optimized building in terms of passive design strategies would achieve satisfactory thermal comfort at a lower energy consumption level when assessed through NZEB than when star rated. This is attributed to the fact that a building may achieve star rating but might not be energy efficient. This is because the rating targets specific areas such as carbon, ecology, water, and waste. Furthermore, net zero energy buildings offer a holistic solution by isolating building owners from future increases in energy prices, increase thermal comfort due to more uniform interior temperatures and reduced requirement for energy austerity.

In contrast, this study hypothesized that the 6-star rated buildings in South Africa so far are not ambitious on generating energy on site. They are therefore not as efficient compared to the NZEBs and they still rely on importing electricity from the national/local grid (and thus fall short of the NZEBs performance), while also discounting/forfeiting the potential of exporting surplus energy to the grid.

Net zero buildings on the other hand are known to utilize less energy than 6 star rated buildings due to their combined energy-performance improvements and reliance on renewable sources to supply their energy-balance.

1.5 Limitations of the study

The study assessed the energy performance gap between a 6-star rated building and a net-zero energy building for South Africa in order to evaluate the case for buildings to drive towards the attainment of net-zero energy performance standards. The key limitation of the study is the fact that the simulation to attain a NZEB standard is based on the context of an existing building which is already 6-star rated. This implies that the building has already attained a certain level of energy efficiency before further interventions to get to net zero energy. However, the study is not intended to serve as a basis for the retrofit of the existing building to attain a net-zero level but rather to provide context and guidance for design-approach for new buildings towards attaining a net-zero energy building performance.

The lack of literature on buildings that have achieved net-zero energy rating/performance in South Africa was the other limitation of the study and in order to fill this gap, studies on net-zero energy buildings from other countries such as USA, Germany and China were appraised as the countries have readily available data to substantiate the attainment of net zero energy buildings

Another limitation relates to uncertainties over the feed-in-tariffs of the generated energy as commitment by relevant municipal distributor (City of Tshwane) is still at a developmental stage and not yet fully operational. Therefore, the concept of net-zero energy building is based on an assumption of an ideal case of supportive policy and regulations which hopefully will be resolved in the near future and thus provide a catalyst towards the move from voluntary to mandatory implementation.

1.6 Definition of terms

The definitions of the key terms used in the study are as follows:

Climate Consultant - Free, easy-to-use, graphic-based computer program that displays climate data in dozens of ways useful to architects, builders, contractors, and homeowners. Key parameters of the program include temperature, humidity, wind velocity, sky cover and solar radiation in both 2-D and 3-D graphics for every hour of the year in either metric or imperial units (US Department of Energy, 2012).

Edge Software – is a green building certification system that facilitates the exploration of technical solutions at the early design stage in order to reduce operational expenses and environmental impacts of a building in its operational stage (International Finance Cooperation, 2020).

Energy performance gap - In the context of this study, this denotes the disparity between energy-use of a 6-star rated building and a net-zero energy building in their operational stage over a period of one year.

Green star (GBCSA) – A building performance rating tool (administered by GBCSA) that evaluates the performance of a building and its impact on the environment based on pre-set components and criteria relating to the design, construction, and operation of green buildings. It allows for certification of buildings based on the following levels of achievement: 4-star (referred to as Best Practice), 5-star (referred to as South African Excellence) and the 6-star (referred to as World Leadership) (GBCSA, 2011).

Net-zero energy buildings (NZEBs) are defined as technologically innovative buildings whereby, in an average year, the building produces as much electrical plus thermal energy from renewable energy sources as the building consumes, Rosen (2012: 2286).

Net-zero site energy: A site level ZEB produces at least as much energy as it uses in a year, when accounted for at the site level.

Net-zero source energy: A source referenced ZEB produces at least as much energy as it uses in a year, when accounted for at the energy-source. Source-energy refers to the primary energy used to generate and deliver the secondary energy consumed by the building. To calculate a building's total source-energy, imported and exported direct energy consumed/generated is multiplied by the appropriate site-to-source conversion multipliers (Torcellini *et al.*, 2010: 2).

Net-zero energy cost refers to the amount of money the utility pays the building owner for the energy the building exports to the grid. This cost is at least equal to the amount the owner pays the utility for the energy services and energy used over the year (Crawley, 2010: 9).

Net-zero energy emissions building implies a building that produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources (Torcellini, *et al.*, 2006).

SANS10400-XA is the South African National Standards which stipulates the minimum requirements for energy efficiency and environmental sustainability in building design. This is based on the application of Regulations XA to the overall building regulations under SANS10400 (SANS, 2021).

SANS 204 refers to the standard which sets energy performance for buildings in South Africa and also applied as the basic-minimum performance required for a building to qualify for green-star rating by GBCSA. It contains performance levels that are higher than SANS 10400-XA and sets out the general requirements for achieving energy efficiency in all types of new buildings, for both naturally and artificially ventilated buildings (SANS, 2021).

1.7 Structure and outline of study

This research report comprises six chapters and Chapter 1 provides an overview and rationale of the study, statement of the research problem and the main research question as well as the sub-questions. The chapter also provides the working hypothesis, limitations of the study and finally the definition of key terms used in the study. This is followed by Chapter 2 which reviews existing literature relating to NZEBs and 6-star rated buildings as prioritized under the research problem section of the study. Studies on the analysis of the NZEBs concepts from a global perspective are initially appraised followed by studies on the South African context. Insights on bridging the energy-efficiency gap and an overview of the possible process of migrating from 6-star rated buildings to NZEBs are then articulated. The chapter then concludes with a presentation of the conceptual framework of the study.

Chapter 3 presents the approach, method and tools used for data collection and analysis towards addressing the research question of the study. The chapter starts with an overview on the overall research approach followed by a discussion on data collection tools and analyses towards the derivation of the sub-findings as per the sub-questions as well as overall findings in relation to the research question.

Chapter 4 addresses Sub-question 1 of the study with regard to identifying the energy-performance gap between the 6-star rated DEA Building case study building and a modelled NZEB of the same nature and in the same location based on comparative analyses of the base case (as is) and the simulated building (based on Edge-Tool software) towards a net-zero energy building. The analysis is closely referenced to the climate of Pretoria based on psychrometric chart analysis of the respective climatic zone. Analyses of the various interventions towards a net-zero performance for the case-study building are presented.

Chapter 5 addresses Sub-questions 2, 3 and 4. Data and analyses of the technical and cost savings as well as technical, market and cost barriers on pathway to NZEBs are presented. The appraisal and sub-findings on how these barriers could be addressed are then presented. Insights towards a pathway from voluntary to mandatory NZEBs were derived to guide sub-findings on the move from voluntary to mandatory NZEBs for South Africa. Chapter 6 presents the consolidation of the sub-findings from Chapters 4 and 5 in order to derive the overall findings on the overall research question and also draw conclusions of the study. This is followed by recommendations for further research in this field especially in relation to the limitations highlighted in Section 1.5 of this report. The last section of the report presents the reference-list followed by Appendices A to H.

Chapter 2: Literature Review

2.1 Introduction

Guided by the overall research question and sub-questions, this chapter reviews a purposefully selected sample of existing studies regarding NZEBs and 6-star rated buildings, especially with a focus on the energy-performance gap between the two types of buildings. The key insights from the review were then applied towards the conceptualization of the theoretical framework that served to guide the rest of the study.

The chapter is structured into nine key sections. Section 2.2 presents appraisal of studies on key NZEBs concepts, while Section 2.3 presents an appraisal of studies on related global NZEBs perspectives. . Section 2.4 presents appraisal of studies on energy-performance gap between 6-star and NZEBs, followed by policy pathways regarding energy performance certification of buildings in Section 2.5 and NZEBs performance in Section 2.6. Section 2.7 appraises studies on the link between NZEBs and cost reduction, followed by appraisal of studies on the process of migrating from 6-star rated buildings to NZEBs in Section 2.8. Section 2.9 appraises the energy weighting for green-star rating and lastly, Section 2.10 presents the conceptual framework of the study.

2.2 Analysing the NZEBs and net-zero energy communities

Rosen (2012) shows that buildings are responsible for a significant portion of GHG emissions mainly due to electricity consumption where, at a global level, half of the electricity consumed can be attributed to buildings. Buildings are also largely responsible for the peaks in electricity demand, which are commonly due to space heating, cooling, lighting and appliances. These GHG emissions could be mitigated by redesigning and ensuring that buildings are energy efficient as well as by making buildings energy generators based on renewable energy resources. The development of technologically advanced high-performance NZEBs can thus contribute significantly towards sustainable development goals of a city or country in general. Rosen (2012) defines a NZEB as one that, in an average year, produces as much electricity plus thermal energy from renewable energy sources as it consumes. Furthermore, building on the work of NZEBs, increasing research has been reported in recent years on net-zero energy communities.

The assertion by Rosen (2012: 2284) implies that countries or governments should work together with private sector in transforming existing buildings to be energy efficient and ensuring that new buildings are not only energy efficient, but also generating their own energy. A smart net-zero energy approach would therefore be required to ensure an integrated whole-building systems design where heating, ventilation and air conditioning (HVAC), lighting, storage and renewable energy components are linked and building envelopes are responsively designed.

Highly performing active and passive technologies have been developed to address the need for improved energy efficiency and sustainability of the built environment. Moreover, shifting the scale of analysis from the single building to the settlement level allows further optimisation through sharing and community-level management of energy supply and demand (Nematchoua et al. 2021). The single building would therefore be considered as a part of a community-level renewable and sustainable resource system (Piselli et al. 2021:1).

The preceding argument by Piselli et al. (2021:1) implies that community residents and building users must reduce consumption of off-site energy sources such as grid electricity and fuel delivered through pipe or truck in favour of locally generated heat and power for their buildings. In order to achieve net-zero energy consumption, a building must generally be equipped with energy efficient appliances and also provide for its own on-site power generation. In particular, the building must ensure optimized design that reduces the need for energy inputs towards heating and lighting (Crawford, 2014).

A net-zero site-energy building produces at least as much renewable energy as it uses in a year, when accounted for at site (building system boundary level). A NZEB produces as much energy on-site as it uses over the course of a year. If the building uses 10,000kWh/yr, it would then produce 10,000kWh/yr or more.

Furthermore, a source NZEB produces and exports (or purchases) at least as much renewable energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to extract, process, generate, and deliver the energy consumed at the site (Bailes, 2013; Torcellini et al. 2010).

Bailes (2013) and Torcellini et al. (2010) highlight the need for raising awareness of NZEBs amongst key actors in the sector including architects, code officials, building developers, design-build professionals and materials/component manufacturers to enable them to make provisions for overcoming the barriers, gaps and challenges identified in the practices of the NZEB projects.

2.3 Global perspectives on NZEBs

Reducing energy-use and GHG-emissions in the building sector through energy conservation and efficiency improvements constitutes a key strategy for achieving global environmental goals. Building energy performance simulation is used as a tool to guide the designing, operation and retrofitting of buildings for energy efficiency and savings in utility costs. The growing practice of NZEBs demonstrate a growing trend of gradual adoption by property developers and building professionals. Some of the global goals include the mandate for United States (U.S) Federal Government buildings (existing and new ones) to be NZEB rated by 2030 (Crawford, 2014).

It is evident from the preceding argument that energy efficiency is achievable through green building interventions as well as high efficiency appliances, HVAC and lighting systems. On-site renewable energy resources such as solar radiation provide alternative energy for the balance of energy needs in the operation of buildings. Over time, energy consumption will balance-out energy production thereby resulting in a NZEB. Sometimes, a building can achieve energy surplus that can be exported back to the grid or to other neighbouring buildings, depending on applicable policies and regulations of a city or country.

Roderick et al. (2009) report on the increasing global effort towards sustainability in the construction industry where the reduction of its energy consumption in both the construction and operation of buildings constitute the key priority. This has led to the emergence and application of green building performance rating schemes such as Leadership in Energy and Environmental Design (LEED, US and Canada), Building Research Establishment Environmental Assessment Method (BREEAM, UK) and Green Star (Australia and South Africa). The most critical component for credits under the rating schemes is the mitigation of energy consumption. This is also the essential factor in the overall effort to achieve sustainable buildings and one of the strategies towards mitigation of GHG-emission and the resultant contribution to climate change.

2.4 Energy performance gap between 6-star and NZEBs

Figure 3 presents the key NZEB concepts as a framework towards the assessment of the gap between the 6-star rated buildings and NZEBs for South Africa.

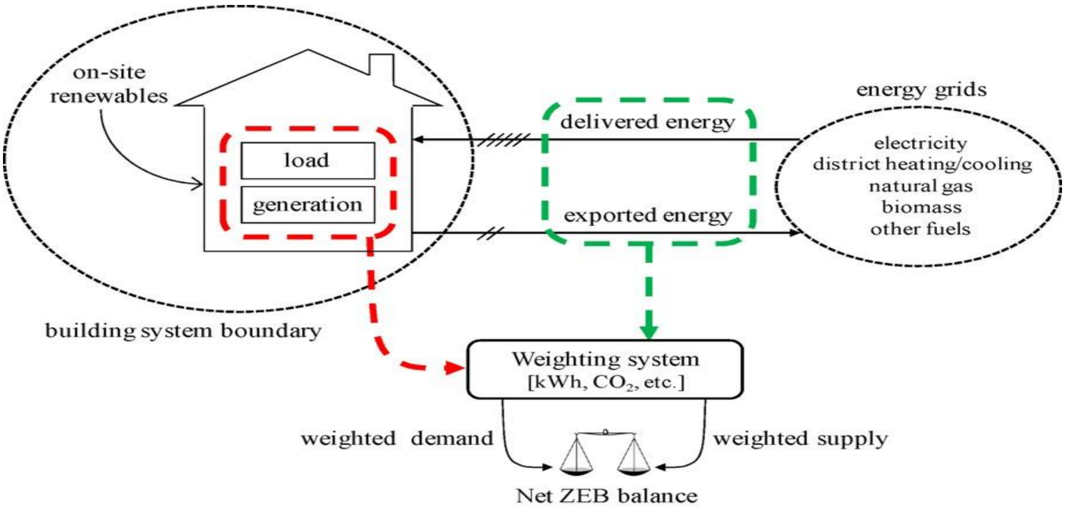

Figure 3: System structure and basic elements of NZEB, Source: (Sartori et al, 2012: 3)

As shown above, the building system boundary implies the domain within which to compare energy flows into and out of the system. This could be a physical boundary which encompasses a single building or a group of buildings. It is also applied to determine whether the renewable resources considered are ‘on site’ or ‘off site’. The balance boundary determines which energy uses, for instance, heating, cooling or ventilation is included in the balance. Srinivasan, Braham, Campbell and Curcija (2011: 3370) concur that the boundary of the system is defined by the boundaries of the property on which the building is located. The building structure is therefore an essential component of the building system.

Energy grids refer to the supply of energy carriers such as electricity, natural gas, thermal networks for district heating/cooling, biomass and other fuels. A grid may be a two-way grid, delivering energy back to itself as well. Exported energy implies the energy flowing from the building system to the grids, specified per each energy carrier in (kWh/y) or (kWh/m^2/yr).

Given that N ZEBs produce as much energy on-site as they consume in a year, several interventions/technologies are needed to reach this goal. For instance, high-efficiency HVAC systems are already available and are cost effective (Goldstein, 2012). Innovative technologies such as electro-chromic glass (which have been predicted to improve durability and performance while dropping in cost) will continue gaining acceptance, thus ultimately becoming viable competitors to conventional glazing systems. It is expected that stringent government regulations (possibly similar to the European Union's - EU, directive mandating near net-zero energy buildings in all new projects will drive down costs and encourage energy-efficiency innovations in the US and globally as well. Such measure would bring in a number of professionals and manufacturers into the space thereby creating a competitive market that would lead to cost reduction thus enhancing affordability (Goldstein, 2012).

In a bid to address energy crisis and mitigate greenhouse gas (GHG) emissions in the property sector, green building councils have been established in various countries to assess and rate performance of buildings at design and construction stages. Green building councils (GBCs) now exist in around 70 countries across the world and the intention is to increase this number. The long-term goal is to have a GBC in every country in order to make green buildings a reality for everyone, everywhere (World Green Building Council, 2020). Some of the councils also assess and rate operation stages for buildings in terms of energy efficiency and renewable energy performance levels which are expected to be more stringent relative to the mandatory levels for their respective country.

In South Africa, 4-star rating (under GBCSA's greenstar) is termed as "best practice" while 5-star is termed as "South African excellence" and 6-star as "world leadership". Besides improving environmental efficiencies in buildings, such rating systems also aim at boosting productivity of users, creating green jobs and improving the health and wellbeing of respective communities (The Green Building Council of Australia, 2015). Beyond the environmental performance rating, NZEB goes further to target net-zero in externally supplied energy for the building per year of operation (energy neutral building). Such a building therefore delivers as much energy to the supply grid as they consume from the grid (IEA, 2021).

Mellon (2011) states that green-building rating tools mainly assess building performance "as- designed" and "as-built", but not "as-operated". As a complementary tool, green star-energy performance for Australia addresses the gap between 'design' and 'as built' certifications versus performance during operation stage as well as providing a tool for assessing the continued sustainability performance of existing buildings.

Given the rapid innovations and related adoption rates, NZEBs are no longer being considered as ideas/goals to be achieved in a remote future, but instead, they are now viewed as realistic solutions for pursuing energy security and the mitigation of the CO_2 emissions in the building sector (IEA, 2008). This emerges from increasing acceptance that NZEBs lead to energy conservation with the key benefits of extension of life of our limited natural resources through reduction in consumption rates, thus mitigating the risk of climate change as well as facilitating cost-savings. Table 1 presents the key categories of ZEB and their key features.

Table 1: Summary of ZEB categories and key features, (Torcellini et al., 2006: 11)

Definition	Positive Features	Key constraints	Other Issues
Site ZEB	• Easy to implement. • Verifiable through on-site measurements • Conservative approach to achieving ZEB • No externalities affect performance, can track success over time. • Easy for the building community to understand and communicate • Encourage energy-efficient buildings designs	• Requires more PV export to offset natural gas • Does not consider all utility costs (can have a low load factor) • Not able to equate fuel types • Does not account for nonenergy differences between fuel types (supply availability, pollution)	
Source ZEB	• Able to equate energy value of fuel types used at the site • Better model for impact on national energy system • Easier ZEB to reach	• Does not account for non-energy differences between fuel types (supply availability, pollution) • Source calculations too broad (do not account for regional or daily variations in electricity generation heat rates) • Source energy use accounting and fuel switching can have a larger impact than efficiency technologies • Does not consider all energy costs (can have a low load factor)	• Need to develop site-to –source conversion factors, which require significant amount of information to define

Cost ZEB	• Easy to implement and measure • Market force result in a good balance between fuel types. • Allows for demand-responsive control • Verifiable from utility bills	• May not reflect impacts to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid • Requires net-metering agreement such that exported electricity can offset energy and nonenergy charges • Highly volatile energy rates make for difficult tracking over time	• Offsetting monthly service and infrastructure charges require going beyond ZEB • Net metering is established, often with capacity limits and at buyback rates lower than retail rates
Emissions ZEB	• Better model for green power • Accounts for non-energy differences between fuel types (pollution, greenhouse gases) • Easier ZEB to reach		• Need appropriate emission factors

The International Energy Agency (IEA) (2010) observed that an understanding of the existing policies on energy performance certification has evolved to serve as a reliable guide on policy concerns of NZEB-certification. This is based on the fact that there has been tremendous technical and policy activity in recent years aimed at improving building energy-performance both on a voluntary and mandatory basis. Moreover, with a focus on getting to very-low-energy buildings and targeting net-zero-energy or emissions buildings, governments have established ambitious, and sometimes highly aspirational, policies and targets for NZEBs to become standard practice. One such goal is that new buildings built after 2020 (or 2030 and beyond) would be zero energy (or nearly net zero). IEA (2010) further reports that the pathway to energy-performance certification of buildings involves four key stages which are planning, implementation, monitoring and evaluation.

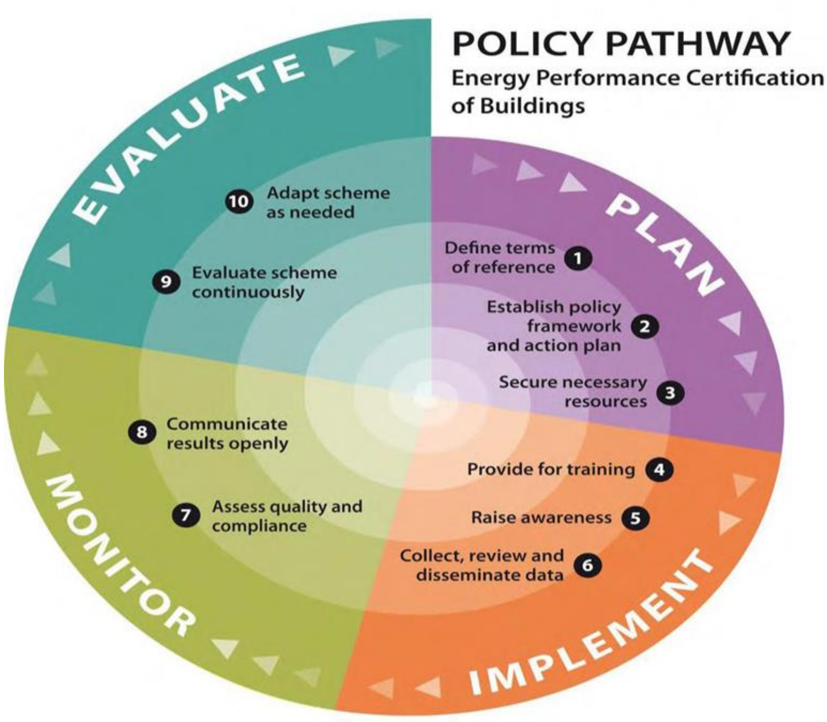

Figure 4: Policy framework and pathway for energy performance certification of buildings, Source: (IEA, 2010: 20).

It is evident from Figure 4 that organs of state and owners of buildings must adhere to the stipulated processes for submission of energy performance certificates. This is well demonstrated through the EU's energy performance in buildings directive (EPBD), which aims to improve energy-performance and reduce associated CO_2 emissions for member-states.

The planning stage involves three steps of defining the terms of reference for the framework, establishing the policy framework and action plans, and securing necessary resources (IEA, 2010). Some of the key discussions entail determining the scope, mandatory versus voluntary, types of buildings, advice and green elements to be covered. It also includes engaging key stakeholders, establishing continuous collaboration between all involved authorities and setting realistic timeframes as well as allocating sufficient resources, developing action/master plans to ensure adherence during implementation stage (Laustsen, 2011).

The implementation stage involves key elements such as training and approval of assessors, starting early and approving only the best, developing standards or guidelines for the assessment, communicating openly and giving stakeholders access, establishing database systems that collect information centrally, keeping control over quality, ensuring sufficient assessors before the start of scheme and ensuring one-stop information centres (IEA, 2010).

The monitoring stage is an on-going process whose elements include developing an overall quality assurance approach, setting sufficient resources for the process, keeping to high quality as well as implementing complaint and appeal procedures and processes, communicating both good and bad news, and lastly, taking action wherever needed (IEA, 2010).

Some of the key lessons learnt include the need for making continuous evaluations, improving quality, transforming results into savings, using and supporting results with other policies, considering the life cycle approach and other environmental mechanisms (IEA, 2010). The evaluation stage involves key elements to ensure high quality and systematic compliance with national building regulations, to maximize the benefits through revisions of the scheme and to adapt calculation methodologies to support stricter building standards (IEA, 2010).

2.5 South Africa's mandatory energy performance certification as gazetted

Under Notice 700 of government gazette 43792 of 8 December 2020, The Minister of Mineral Resources and Energy has, under section 19(1)(b) of the National Energy Act, published regulations for the mandatory display and submission of energy performance certificates (EPC) for buildings in. Briefly, it covers buildings with a total net floor area of over 1,000m^2 in the public sector and 2,000m^2 in the private sector. The energy performance rating on the EPC refers to the net energy consumed in kWh per m^2 per annum. The EPC must be displayed in the foyer of the building and a copy to be submitted to the South African National Energy Development Institute (SANEDI) every 5 years (Green Building Design Group, 2021).

It is essential to note that the new legislation is not applicable to factories and manufacturing plants but only for offices and other public buildings such as places for entertainment and public assembly, theatrical and indoor sports activities as well as places of instruction. Such buildings include schools, malls, theatres and places of work that are bigger than 2,000m^2. Government buildings larger than 1,000m^2 must also comply with the new legislation. Buildings that have been in operation for less than 2 years or have been subject to a major renovation within the past 2 years are exempted. Moreover, the new regulation stipulates that there are certain areas that can be excluded from the calculations, such as garages, car parks and storage areas (Petrie, 2021).

An energy performance certificate, similar to those displayed on household appliances, must be issued by an accredited body in accordance with SANS 1544:2014-energy performance certificates for buildings. This certificate must rank the energy rating (ER) of a building on a performance scale (A-G). This is to the maximum energy consumption (kWh/m^2/a) per building type as per the SANS 10400 XA.

2.6 Passive versus active NZEBs performance interventions

In a bid to cope with the post 2020 policy of al all buildings built after 2020 to be zero energy or net zero, various greenhouse gas emissions reduction target set by various countries were reviewed in terms of passive and active strategies. While passive strategies refer to reducing the building, energy demands at the early stage of a building's life cycle through architectural design strategies or interventions, the active strategies represent ways to reduce building energy consumption through energy production (Organisation for Economic Co-operation and Development, (OECD), 2020).

Scognamiglio et al. (2013) notes that there is no standard approach for designing and realizing NZEB, primarily because there are many possible combinations of building envelope, utility equipment and on-site energy production equipment able to achieve net-zero energy performance. Passive interventions (for thermal and visual comfort) therefore play a crucial role in addressing NZEB design as they directly influence the heating, cooling, ventilation and lighting loads of the building's mechanical and electrical systems. In turn, this would influence the generation capacity of renewable energy technology/system for the balance of energy required (Scognamiglio et al, 2013).

2.7 The link between NZEBs and cost-optimal levels

Ferrara et al. (2018) argue that the recast EPBD in EU states (where each member state must ensure that minimum energy-performance requirements) are set with a view of achieving at least cost-optimal levels of energy efficiency. In addition, each member state should also provide plans to promote the cost-effective transformation of existing buildings into NZEB. Since there is no quantitative definition for NZEB (different member state have to define their respective performance level of a nearly ZEB), cost optimum levels have been established to encourage each member state to relate their energy-performance requirements to the relevant cost-optimal levels.

The EBPD also requires that the European Commission should be provided with regular reports on the results of these calculations and the related policy plans, in order to assess each member state's progress towards achieving cost-optimal and NZEB levels as guided in the four stages shown in Figure 5.

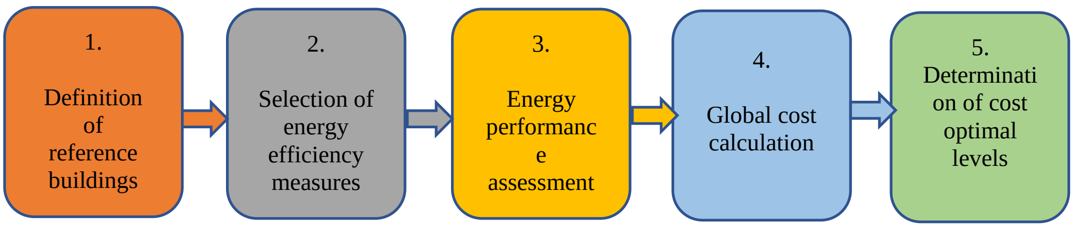

Figure 5: The multistep methodology for COL applications. Source: (Ferrara et al, 2018: 3)

Groezinger et al. (2014) contends that while cost-optimality is the prevailing framework for evaluating energy-performance for renovation of existing buildings, it will also serve as a benchmark for the design of new buildings as from 2021. This will bring a smooth and consistent transition of policies and markets from cost-optimality to NZEBs which is needed to drive the full implementation of the NZEB concept. With net-zero energy consumption becoming increasingly viable for existing buildings, a 1980s-era building in

California (US) was transformed into net-zero energy as illustrated in Figure 6. The professional team installed two types of PV panels as well as a solar tree and three wind turbines to generate energy and create a conducive training environment. Figure 6 and 7 demonstrate two buildings generating on-site energy using PV technology.

Figure 6: A 1980s-era building transformed into NZEB in California. Source: (Penny 2014: 10)

Figure 7: Germany's solar-coated building. Source: (Solar decathlon, 2014: 14)

Review of the two buildings (the eco-refurbishment of the 1980s-era building and Germany's solar coated building) demonstrate the use of solar panels for renewable energy with different approaches to their integration into the building system. However, the solar panels serve the same purpose of generating renewable energy from solar radiation as a renewable resource. Whereas the installation may be initially expensive compared to the conventional grid-supplied electricity, cost- savings would be realized to cover the building's payback period and beyond. It is therefore important that payback periods and initial investment costs for selected retrofit packages are assessed considering the future lifespan of the building. Together with these, possible subsidy opportunities should be investigated so that investors can timeously get their return on investments (Sağlam et al. 2019).

2.8 Process of migrating from 6-star rated building to NZEBs

This section presents the review of existing literature that could provide insights towards the assessment of the gap between 6-star and NZEBs in South Africa. The section analyzes the potential impacts of migrating from 6- star to NZEBs, especially with regard to policy interventions.

2.8.1 Set vision and targets

The setting of a vision and related targets requires a clear definition of the desired goal (such as net-zero energy, near net-zero energy, passive house, carbon neutral or percent better than baseline), associated metrics (such as site energy, source energy, carbon intensity) and target years. The vision could also include plans for the renovation of the existing building stock (Frappé-Sénéclauze and Kniewasser, 2015).

2.8.2 Develop an energy code roadmap

This entails the setting of a transparent and predictable roadmap outlining how energy codes would evolve to meet these targets in order to allow industry and institutional actors to adequately prepare and plan for code changes, minimize surprises and increase cost effectiveness. It also allows manufacturers of building components to foresee demand for energy efficient products and prepare to meet the market demand as it emerges (Frappé- et al, 2015).

Similarly, Rosenberg et al. (2015) highlight that future energy codes should ensure that low performing design options are eliminated or balanced with high performing options. Energy codes should be developed with some level of overall building energy-performance target based on a view of the building as a system and thus accounting for building system and climate interactions.

Van Geem (2014) argues that energy codes and standards set minimum efficiency requirements for new and renovated buildings thus assuring reductions in energy use and emissions over the life of the building. As a building's operation and environmental impact is largely influenced by design decisions, energy codes present a unique opportunity to assure savings through efficient building design, technologies and construction practices. Once a building is constructed, it can be significantly more expensive to retrofit for higher efficiency levels.

2.8.3 Benchmarking energy-performance

Turner and Frankel (2008) note that performance outcome-based codes provide the ultimate in confirmed energy-efficiency, thus allowing for comparison between the actual energy- use versus the desired target set at a design stage. Benchmarking actual building energy-use is thus a vital part of any energy management program and could become an extension of building energy code requirements. Studies have shown that buildings do not always achieve the results predicted by simulations at design stage. Performance at operational stage is therefore crucial towards facilitating corrective action and demonstrating desired movement towards the desired energy goal.

2.8.4 Addressing performance gap through outcome-based codes or other policies

Building energy-performance, including code compliance, is demonstrated by analysis of energy-use data after occupancy under outcome-based codes, rather than assumed-performance based on review of prescriptive requirements or modelling of buildings at design stage. The central purpose of outcome-based codes is to minimize the performance gap between expected versus actual energy performance, and to incentivize strategies for energy savings through system-level design, occupant engagement, continuous optimization of building operations and quality installations (Frappé-Sénéclauze and Kniewasser, 2015).

2.9 Energy weighting for green star rating in South Africa

According to GBCSA (2013), the Green Building Council developed the Green Star South Africa rating tools to provide an objective measurement for green buildings in South Africa as well as the rest of Africa. These tools recognise and reward environmental leadership in the property industry. The green star tools are created for each building type and are mainly aimed at supporting design professionals and developers in creating buildings that emit lesser amount of greenhouse gases, produce less waste, and enhance occupants' productivity and health as well as ensuring higher satisfaction. The tools are based on nine different components, with each allocated a range of credits that address environmental and sustainability aspects of design, construction and operation of a building.

The components are management, indoor environmental quality (IEQ), energy, transport, water, materials, land use and ecology, emissions and innovation, with socio-economic as an additional voluntary component. By applying environmental weighting to each category score (see Figure 8 for respective weightings), Green Star South Africa ensures that each category is correctly represented within the rating tool, and in line with evolving knowledge of the industry locally and globally (GBCSA, 2013).

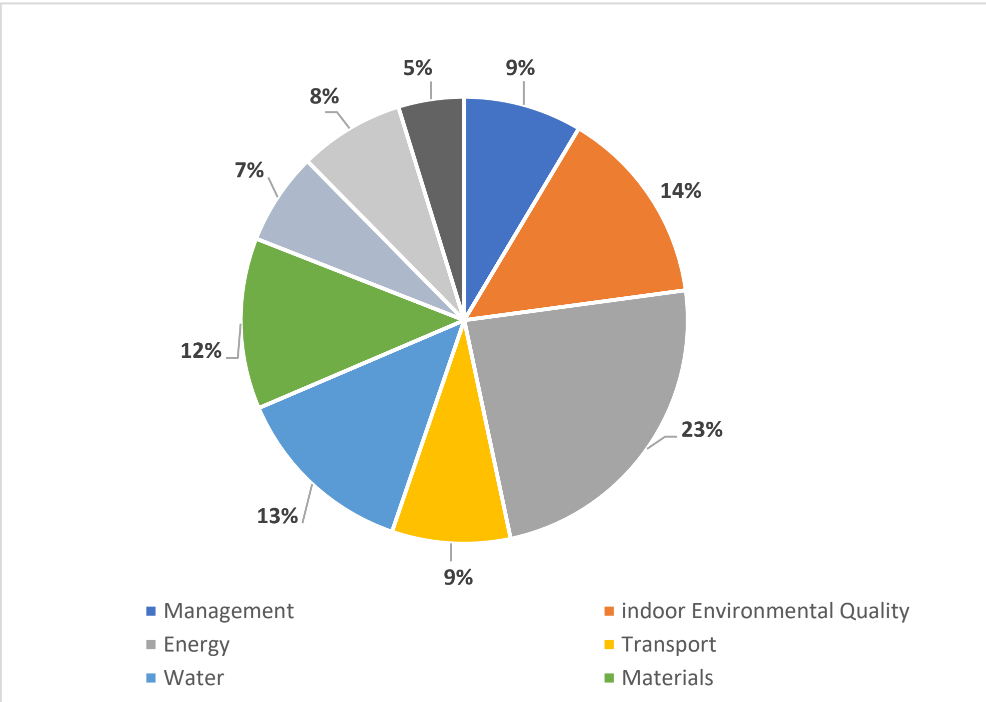

Figure 8: Green Star rating/weighting components and credits. Source: Ferrara et al, (2018: 3)

It is evident from Figure 8 that a highest percentage of 23% was on overall energy consumption and reduction of GHG-emissions linked with energy generation. This is followed by 14% for indoor environmental quality and 13% for usage of water. Management and transport are weighted equally (9% for each), whilst the lowest percentage 5% is allocated for innovations. Materials component is weighted at 12% with emissions at 8% and land use and ecology at 7%. This means that moving towards net zero energy would be targeting the highest weighted component of energy and would therefore resonate with the emphasis of green-rating schemes.

2.10 Conceptual framework

ZEB focuses on buildings connected to energy infrastructures and not on autonomous buildings. To this effect, the term NZEBs can be used to refer to buildings that are connected to large scale energy infrastructure. The wording 'net' underlines the fact that there is a balance between energy taken from or supplied back to the energy grids over a period, which is normally one year (Sartori et al. 2012). ZEBs have a simple common goal, which is neutral result in energy or emission balance, which should be achieved in most cases within a period of one year. With NZEB-goal, the full optimization of passive design strategies becomes a major factor towards influencing the energy demand/load of a building (Scognamiglio et al. 2013). Based on this understanding, Figure 8 presents the conceptual framework of the study where implementation strategies for the NZEB (through prioritizing the reduction of the building's energy demand) is prioritized as the critical focus. The strategies are divided into energy demand (passive and active strategies), energy generation (energy production and distribution) for the active strategies and the advanced strategies.

As illustrated in Figure 9, the study of NZEBs is guided by a conceptual framework based on the key interacting categories of responsive strategies. The passive strategies help to realize net-zero energy through the reduction of the building energy demand by introducing responsive architectural/engineering design techniques in the early design stage. This entails passive sustainable and energy saving strategies. The active strategies rely on the generation of energy through renewable sources and energy storage or interacting with the grid for import and export of energy required for the energy-balance. The advanced strategies take the implementation of NZEBs further into the building's life cycle and would thus include balancing out the embodied energy and related GHG-emissions. The advanced strategies were excluded from the scope of the study.

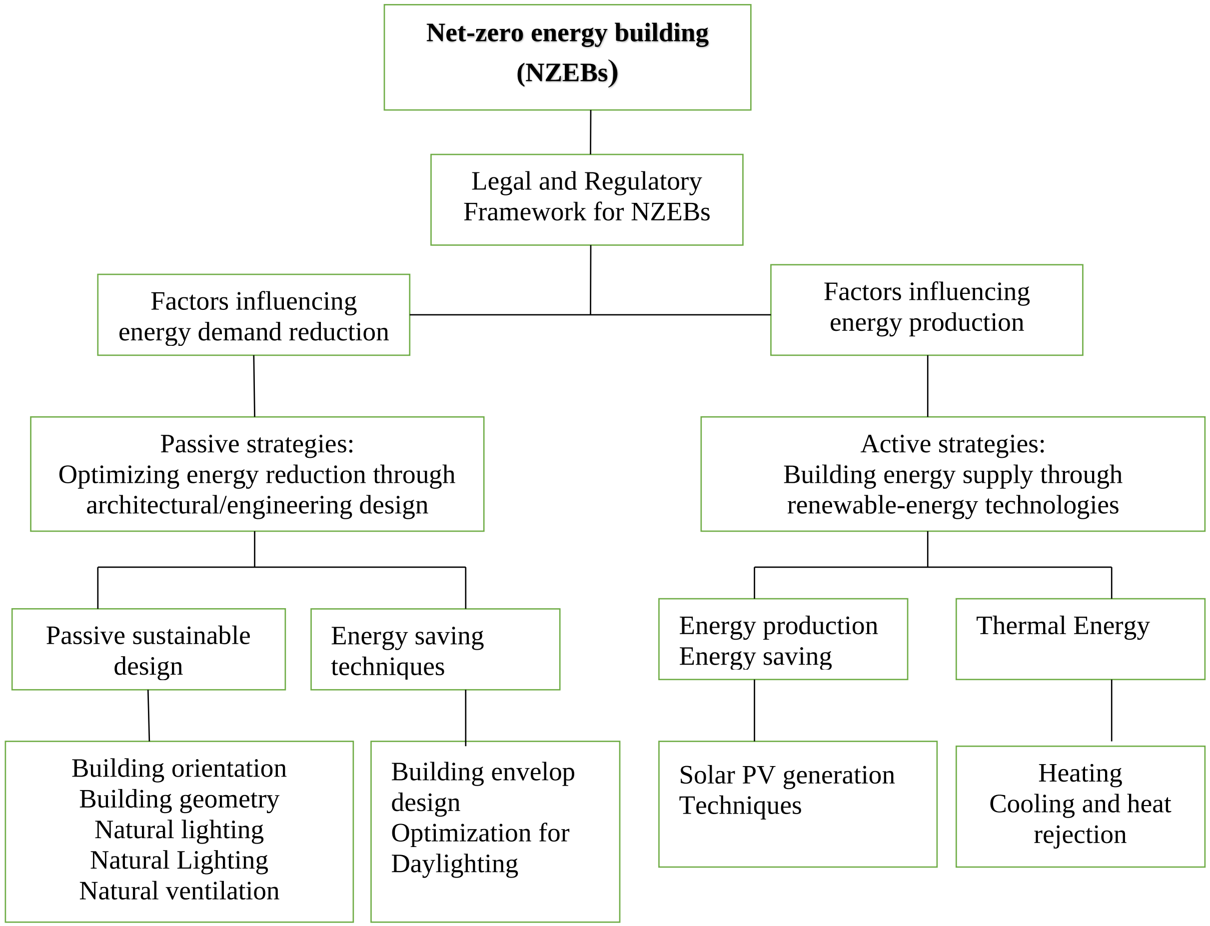

Figure 9: Conceptual framework of the study in relation to NZEB strategies. Source: Researcher's own construct (2021)

Chapter 3: Research Method

3.1 Overview on research approach

This chapter presents the research method and tools employed in addressing the research question and related sub-questions of the study. This includes data collection and analyses tools as well as related ethical considerations. The chapter concludes with an overview on the context of the building purposely selected for case study.

Bryman and Bell (2011) guide that research design is essentially a framework for the collection and analyses of data in order to facilitate derivation of findings on the research question. Based on the insights from literature review in Chapter 2 and the research question raised in Chapter 1, the study applied a qualitative study approach based on the case study of a purposely-selected building. Baxter and Jack (2008) suggest that a case study approach provides the exploration of an issue through a variety of lenses and in consideration of different features of the phenomenon of the study.

However, the study also entails a quantitative component based on statistical analyses of energy-use data of the case study building over a one-year period. The quantitative component applied a building energy modelling and simulation tool that allows design teams and project owners to assess the most cost-effective ways to incorporate energy saving interventions for diverse building types such as homes, hotels, hospitals, offices and retail spaces.

The *Edge software* (green building certification system) facilitates for the discovery of technical solutions at the early design stage with the aim of reducing operational expenses and environmental impact over the life cycle of the building (IFC, 2016:3). Based on the information inputs and selection of green measures, the *Edge* tool revealed projected operational-savings and reduced carbon emissions. This overall picture of performance was then applied towards articulating the business case for the design and construction of NZEBs. Table 2 demonstrates the research design and overall approach applied for the study.

Table 2: Research design and overall study approach

Stage	**Case study**	**Assess**	**Evaluate**	**Integrate**
1	Appraisal of a selected (existing) 6-Star Green Star rated building in South Africa.	Assess the current state of the building's energy performance.	Determine the energy performance components that make a 6-star Green-Star building.	Evaluate possibilities as well as opportunities of improvement.
2	(Appraisal of a selected) Net-zero building in South Africa.	Analysis current performance of net-zero energy buildings in South Africa.	Appraise case studies on extending to net-zero energy buildings in other countries to inform base case.	Appraise the opportunities and benefits of NZEBs in South Africa.
3	Consolidation and derivation of findings.	Analysis of the performance gap between the 6 star and net-zero buildings.	Evaluate ways in which to bridge the energy-performance gap.	Simulate for the various interventions to take the 6-star to a NZEB.

3.2 Data collection and analysis tools

Arising from the overall research question and related sub-questions, Table 3 presents a summary of data collection and analyses tools applied in the entire research process.

Table 3: Summary of data collection and analyses tools

Sub-question		Data needed and data collection tools	Data analyses tools and
1	What is the energy-performance gap between 6-star rated and NZEBs in South Africa and what would be the associated climate change mitigation potential?	Through the DEA-Building Facilities Manager, BMS (Building Management System) provided energy consumption data in the operation phase of the 6-star rated building. This entailed automated data collection based on meters and sub meters as well as building-integrated sensors and ICT-systems. Climate and psychometric-chart data for Pretoria were obtained from Climate Consultant through an EPW weather file of the study area. This allowed for the derivation of parameters for the passive	The *Edge-Tool* building simulation software was utilized to analyse the data. Psychometric charts were used for climate analysis and identification of passive-design interventions.
2	What are the energy performance and cost-savings associated with 6-star rated versus NZEBs?	Obtain energy performance and cost saving data of a 6-star rated building that has received intervention from 6-star to NZEBs as per the case study interventions.	Literature and *Edge-Tool* software were used to assess the most cost-effective ways to incorporate energy saving options into the case study-building.

3	How could the technical, market and cost barriers from 6-star to NZEBs enhancement be addressed?	Obtain secondary Data from reviewed literature of what has been implemented locally and internationally on challenges to migrating from 6-star to NZEBs to enable analysis and derivation of	A comparative data analysis for standard buildings versus energy efficient buildings was undertaken.
4	What could be the desirable pathway from voluntary to mandatory NZEBs for South Africa.	Obtain secondary data from reviewed literature on key approach and specific instruments utilized in other countries.	A comparative analysis of voluntary versus mandatory approach and their impact and success per country reviewed and how this could relate to the South African scenario.
	Main research question: What is the energy-performance gap between 6-star green rated commercial buildings versus their simulated NZEB performance and what would be the desirable pathway towards the adoption and scaling up of NZEB practice in South Africa?	The data analyses and sub-findings on the sub-questions were consolidated and synthesized in order to derive the overall findings of the study based on the main research question.	The overall consolidation of the sub-findings demonstrated that it is feasible, viable and economical to advance 6-star rated buildings into NZEBs thereby compelling the market to respond or to buy into the idea of NZEBs.

3.3 Case study overview of the DEA Building in Pretoria

This section provides an overview on the DEA Building, which serves as the head office of the Department of Environmental Affairs of the Government of South Africa. It was purposely selected for this study because it is one of the few buildings in South Africa that has achieved 6-star rating in-design, as-built and as-operated. The building is located within the suburb of Arcadia which is considered as one of the gateways to Pretoria's inner city.

Figure 10: Contextual location of Pretoria within South Africa, Source: (Adapted from google maps)

3.3.1 Climatic conditions of Pretoria

Pretoria's climatic region is classified as sub-tropical with warm and temperate conditions where the average annual temperature ranges from 12°C in June (in winter) to 24°C in December (in summer) Kottek et al. (2006). In addition, it has long hot and wet summers followed by short cool-to-cold and dry winters. Rain is mainly concentrated in the summer months, with dry conditions prevailing over winter. The city experiences the typical winters of South Africa with cold, clear nights and mild to moderately warm days. The city is located at 1,281m above sea level (Kottek et al. 2006). In reference to the energy efficiency regulations for new buildings in South Africa (SANS 10400-XA, SANS 2011:15) the climatic region of Pretoria is classified as Zone 2, temperate interior.

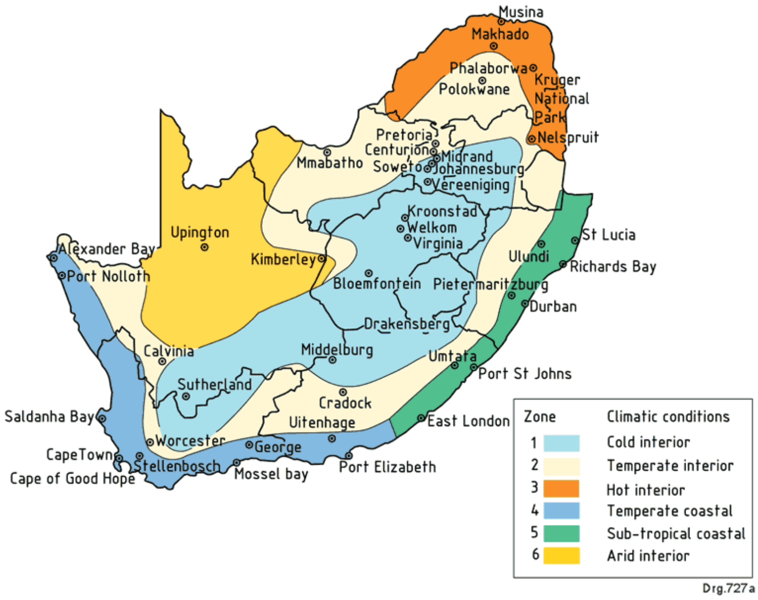

Figure 11: Climate zone for Pretoria, Source: (SANS 10400-XA, 2011: 15)

3.3.2 Site context and surroundings

The site is located to the east of Steve Biko Street, with Southpansberg road to the north and Oumanshoop Street to the west (see Figure 12).

Figure 12: Locality map of the DEA Building in Pretoria. Source: Adapted from Google Maps)

The building is 30,654m^2 in size and the shape of the land, orientation, and topography permits for the location of the large effective office wings along a north – south central spine. This enabled the building to centralize the support services along the spine and to keep the floor plates as open and multifunctional as possible. The wings are mainly oriented north/south, which optimizes solar gains on north-facades as well as for the roofs. The wings also allow for green spaces between the wings as well as enough daylight penetration into the wings.

The building design integrated a wide range of passive-design and energy efficiency interventions such as double-glazed windows, evaporative cooling methods for air conditioning, photovoltaic cells, and solar hot water heating on rooftop, north/south orientation as well as highly developed building envelope insulation design. On water component, the building design also integrated rainwater and greywater harvesting and recycling (DEA, 2017: 1).

The size of the site made it possible to distribute the floor space relatively evenly to create a general height of only three storeys, which can be accessed comfortably by stairs. Each office wing includes a central atrium with internal planting at ground level and clerestory windows above the roof to enhance daylight into the building. This also encourages natural ventilation using stack effect and night-flushing ventilation of thermal mass. “The building is conceived within three distinct elements, consisting of the masculine or utilitarian machinelike office wings, the feminine and organic central reception building, and finally the bridge structure' thread that link all of the elements together”, DEA, 2017: 6).

It was noted that the Department’s environmental and sustainability aspirations were communicated through the architectural language that demonstrated aspects of sustainable design, energy and resource efficiency through the extensive use of outdoor and indoor planting, expressive water collection features and a PV system installed on the roofs. Materials-selection was noted to have been largely driven by sustainability, longevity and ease of maintenance. The building has come to be regarded as good demonstration of how government should lead by example through forefront sustainable innovation (DEA, 2017). Figure 13 shows a modeled perspective view of the building.

Figure 13: The DEA Building in Pretoria, Source: (DEA, 2017: 1)

3.4 Ethical considerations

In ensuring adherence to ethics in research as guided by the University of the Witwatersrand, ethics clearance was obtained before commencing with the research (see Appendix H). In particular, the researcher obtained formal permission letter from the facilities manager (Mvelo Facilities Managers) of the case study building which allowed the researcher to use the building as the case study building. However, due to the unique nature of the case-study, it was not possible to ensure anonymity for the building. This is mainly because the specific location, as well as specific input data on occupation/use-type (with related energy consumption) were essential data parameters for use as baseline input data into the *Edge-Tool* simulation software. The permission letter was therefore issued with an understanding that anonymity for the building and its user as well as operator cannot be guaranteed. In addition, it is a public building which aspires to "lead by example" in environmental sustainability and cannot therefore, at the same time, remain anonymous.

Chapter 4: Passive design optimization and energy-performance gap

4.1 Introduction

This chapter presents data and analyses towards addressing the core aim of the study, which is to assess the energy-performance gap between a 6-star building and a NZEB, with focus on addressing Sub-question 1. In particular, the chapter works towards an understanding of site-climate, responsive passive design interventions, the use of energy efficient building materials as well as the use of renewable energy systems required for a building of the nature and size of Department of Environmental Affairs (DEA) Building to achieve a net-zero energy performance.

In order to give clarity to the above, the study utilized the DEA Building as the base case to demonstrate how such a building in the study area could attain NZE rating. The DEA Building is noted to be performing efficiently in its energy use as a 6-star rated building relative to the prevailing energy-efficiency regulations for new buildings (SANS10400-XA) in South Africa, which came into effect in 2011. This is indicated by the energy performance data obtained from the building management system (BMS) versus the mandatory performance levels required under SANS10400-XA (SANS, 2011).

This is consistent with the view of Frappé- Sénéclauze and Kniewasser (2015) who argue that, under outcome-based codes, building performance (and code compliance) is demonstrated by analyses of energy-use data after occupancy rather than assumed performance based on review of prescriptive requirements or modelling and performance-simulation in the process of design. The central purpose of outcome-based codes is to minimize the performance gap between expected and actual energy- performance, and to incentivize energy savings through system-level design, occupant engagement, continuous optimization of building operations and quality installations.

4.2 Data collection and analyses for DEA building

Table 5 presents the operational energy-use data of the building indicating the total energy-use intensity for the year as well as highlighting the energy consumption of each of the key energy-use components per year, the energy-use per m^2 per year (kWh/m^2/yr) and the percentage annual contribution of each of the use components.

The data for the study is based on three parameters namely:

- Predicted results using known design parameters as input.
- Operational data displaying annual energy-use and use intensity.
- Operational data demonstrating amount of solar PV-generation available on site.

The DEA 6 star rated building is considered to be energy efficient and the following were noted to be the major energy-use components:

- Cooling and heat rejection at 6.3 kWh/m^2/yr,
- Fans (mechanical air movement) at 5.3 kWh/m^2/yr,
- Tenant lighting at 37 kWh/m^2/yr,
- Small power (tenant equipment at 49 kWh/m^2/yr and
- Supplementary cooling (additional cooling requirement) at 4.6 kWh/m^2/yr.

Table 4: DEA Building operational data, 2018. Adapted from Imvelo Facilities Management (2018:4).

	6-Star Rated Building	6-Star Rated Building	6-Star Rated Building
	Operational energy use kWh/yr 2017/2018	Operational energy use kWh/m^2/yr 2017/2018	% of energy use
Fuel CO_2 factor	1.2	1.2	1.2
Heating	38 162	1.4	1.2
Cooling & heat Rejection	174 448	6.3	5.6
Pumps	1 560	0.05	0.05
Fans	147 684	5.3	4.8
Extract and miscellaneous fans	30 784	1.1	1
Non-tenant area lighting	67 700	2.5	2.2
Car park lighting	35 399.60	1.3	1,1
External lighting	27 708	1	1
Lifts	42 167.40	1.5	1.3
Domestic hot water	24 324.90	0,8	0.7
Lighting tenant	1 011 198	37	33
Small power (tenant)	1 349 005	49	44
Supplementary cooling (Tenant)	126 149	4.6	4
Sub Totals (kWh/yr.)	**3 076 291**	**112**	**100**

This section analyses the various interventions that led to the building attaining the 6-star rating and also investigates possible additional interventions or strategies to further reduce the reliance of the building on external energy supply. The study established that a 6-star building is one that meets criteria for a high level of environmental performance as described by the GBCSA's green star rating system (GBCSA, 2016). However, the rating system only assesses the base building (and therefore does not include energy use-types such as tenant lighting and power) in the final performance calculation. It is therefore possible for a building to achieve the 6-star rating without being as energy-efficient as a net zero building. While green star rating entails a wide range of components (including management provisions for operation-stage, indoor environmental quality, energy, transport, water, materials, land use and ecology, emissions and innovations – See Figure 7, Chapter 2, Section 2.9), net-zero energy only focuses on the entire energy component of the building, and especially during its operational-stage, rather than “as-designed” or “as built” which are the common focus stages for green-rating.

The above statement is substantiated through the analysis of a few 6-star rated building scores as reported by the GBCSA (GBCSA, 2016). The buildings include DEA Building, Pretoria, Upper Grayston Drive, Sandton, No.5 Silo, Cape Town and WWF Building, Braamfontein. The buildings achieved 6-star rating at different credit-points. The minimum credit-points required to attain a 6-star rating is 75 points out of 100 across the nine components highlighted earlier. Four of the five buildings achieved the 6-star rating with scores of 82 points for the DEA Building, 75 points, 79 points, and 76 points for No.5 Silo, Upper Grayston Drive and WWF Building respectively.

Taking the DEA Building as an example, the points were recorded as follows: Management (7.5), Indoor environmental quality (10), Energy (24.2), Transport (6.4), Water (13), Materials (9.2), Land-use and ecology (3.1), Emissions (3.2) and Innovation (5). The implication of the above credit-point system is that the building could have scored more in other areas and less in energy but still achieve the 6-rating. In addition, the building almost achieved the maximum credit-points set for energy component in green-star office manual which is 30--points (GBCSA, 2014, pp33-34).

On the scoring for energy component, the DEA Building achieved its points based on design-integration of various energy-efficiency interventions comprising of both passive and active design strategies. The passive design strategies include, building orientation, as individual blocks of the building enjoy north and south orientation with fenestration concentrated on these north and south facades thereby taking full advantage of natural ventilation, hence reducing the building’s dependence on mechanical ventilation (DEA, 2017).

According to DEA (2017), another passive design strategy was the use of lightly tinted, double-glazing with high luminous efficacy to ensure good daylight penetration with minimal heat energy gain from solar radiation outdoors. The application of carefully detailed and constructed high-performance insulation in the envelope with minimal thermal bridging (including exterior walls and roofs) was another intervention that added to the attainment of the energy-score.

The building also incorporated high efficiency lighting and control as well as night-flush ventilation of thermal mass. The internal areas are characterized by low levels of volatile organic compounds (VOC) finishes and off-shutter concrete with durability as a key focus point. In addition, the building has a dedicated weather station as well as rainwater harvesting and greywater recycling. Other sustainability features and building services include a solar PV generation plant on the roof, a full function biometric security system and full energy monitoring and control through a central BMS System. The HVAC system is comprised of a two-stage evaporative cooling plant serving each block of the building with special areas supplemented with traditional refrigerant-based AC systems (DEA, 2017).

It was noted that the building's operational energy target (based on the client's brief) was not to exceed 115 kWh/m^2/yr. Secondary data for 2017/2018 indicates that the building is currently operating at 112 kWh/m^2/yr (see Table 5). Based on the secondary data, it was noted that the average energy use of the building is 256,357.58 kWh/month, which thus amounts to 3 076 291 kWh/yr. Based on the usable floor area of 27 258 m^2, this translates to 112 kWh/m^2/yr and thus marginally surpasses the 115 kWh/m^2/yr energy-use intensity target set by the client.

In order to re-assess the performance of the building and its energy-efficiency measures, secondary data in Table 5 were inputted into the *Edge* Simulation Tool and the energy-efficiency performance of the building was recorded as 42.14%. as against 100% of a notional SANS 10400-XA building (building of the same size, shape and zoning arrangement as the actual building with the same conventions relating to measurement of dimensions). The simulation output is represented in Figure 14.

Review of the initial data shows that the 6-star building is performing better in terms of its energy-use intensity than the predicted energy-use, though the difference is minimal. The actual operational data therefore shows energy-consumption of

112kWh/m^2/yr with total of 13.8% (15.49kWh/m^2/yr) of the total energy-use being generated by means of PV-panel system installed on the roof. The renewable on-site energy generation is presented in Appendix A. The table in Appendix E indicates the predicted consumption (115kWh/m^2/yr) based on the following energy-use intensity by use-type:

- Tenant equipment accounts for 49.8kWh/m^2/yr,
- Lighting accounts for 37.3kWh/m^2/yr,
- Heating accounting for 2kWh/m^2/yr,
- Fans stand at 19kWh/m^2/yr,
- Cooling accounts for 46.7kWh/m^2/yr
- Pumps accounting for 8.5kWh/m^2/yr
- Others at 29.6kWh/m^2/yr

In contrast, the operational data of 2017/2018 energy-use intensity (112kWh/m^2/yr) of the various use-types are:

- Tenant equipment accounting for 49kWh/m^2/yr,
- Lighting accounts for 37kWh/m^2/yr,
- Heating accounting for 1.4kWh/m^2/yr
- Fans stand at 5.3kWh/m^2/yr.
- The cooling and heat rejection accounts for 6.3kWh/m^2/yr with the
- Pumps accounting for 0.05kWh/m^2/yr
- Others at 12.75kWh/m^2/yr

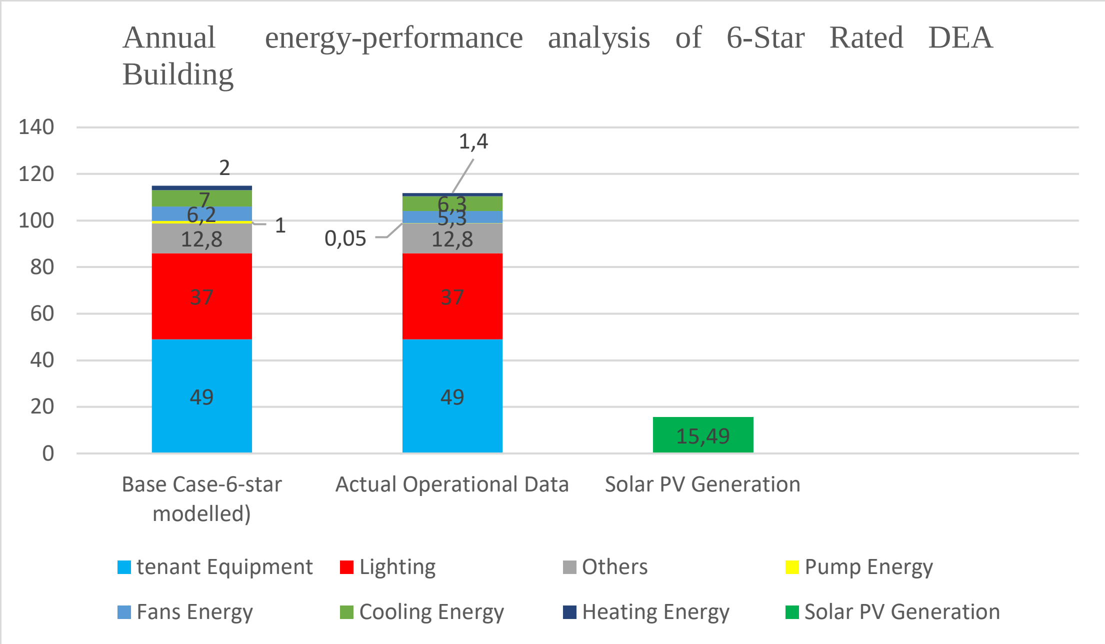

Figure 14: Annual energy-performance analysis of DEA Building, Source: Adapted from Imvelo Facilities Management (2018:6).

4.3 Bioclimatic assessment of the climate of the study region - Pretoria

In order to pursue the drive from a 6-star rating to a NZE rating for the DEA Building, an understanding of the bioclimatic conditions of the building's location was undertaken. A psychrometric chart analysis of the study region was also undertaken to gain insight on monthly and annual temperature and humidity distribution of the region and its implications on the overall energy consumption of the building especially in relation to thermal comfort in the building (thermal comfort is influenced by environmental variables such as temperature, radiation, humidity and air movement). The analysis was subsequently applied towards appraising for additional energy efficiency interventions for advancing the DEA Building towards a NZE performance.

The operational data of the building as well as the "as-built" drawings (initially obtained as secondary data), coupled with the interventions stated earlier (see Section 4.2), indicates that the effect of climate was taken into consideration towards the design of the building in order to achieve a 6-star rating. This explains to a significant extent why the building is performing better than a notional

SANS10400-XA building of the same nature under the given climatic conditions.

4.3.1 Climate analysis of the study area

Climate data of the study area were obtained as secondary data from online Climate Consultant software (DOE, 2012). These data are recorded on hourly basis and covers monthly mean averages of relative humidity, solar radiation and wind speed as well as dew point and dry bulb temperatures. The data were converted into graphs by means of psychrometric charts (see Section 4.3.2 and Appendices J-1 to J-2) in order to allow insight on potential for achieving thermal comfort in absence of additional energy input (Tesisat, 2016).

Based on monthly temperatures for Pretoria show that the mean temperature difference for winter versus summer months is approximately 9°C, while the difference between maximum and minimum temperature during the summer months is approximately 18°C with an increase in the difference of temperature to approximately 23°C in winter. The annual mean dry bulb temperature in Pretoria is noted to be about 19°C and this value is close to the comfort zone at between 20.5°C and 24°C. These are temperatures under shade and therefore do not include heat gain due to direct solar radiation.

In summer, cooling interventions would be required for indoor thermal comfort. The low mean dry-bulb temperature in winter (especially in June and July) is approximately 7°C, which is significantly lower than what is stipulated under comfort zone. In order to accurately determine the climate conditions, factors such as solar radiation must be taken into consideration. Graph B builds on the information presented on Graph A as it incorporates the effects that solar radiation has on the overall temperature (dry-bulb and wet-bulb). Graph B in Appendix F indicates that during the summer season, the dry bulb temperatures rise beyond the comfort zone whereas during winter months the external temperatures just barely approach the comfort zone.

Graph C in Appendix F highlights the relationship between relative humidity and daily temperature experience throughout the year. Since warm air has the capacity to store more moisture than cold air, the overall relative humidity on a daily basis decrease as the temperature increases during the day and increases as the temperature decreases at night. In summer, the relative humidity experienced is approximately 82%, whereas during the day it averages at approximately 40%. In winter, the maximum relative humidity at night is approximately 78%, and averages at approximately 22% during the day. These fluctuations respond inversely to the dry-bulb temperatures. The relative humidity is higher in summer than in winter and this is attributed to the summer rain experience in Pretoria.

Psychrometric Charts - Pretoria findings

In order to ascertain the possibilities of achieving thermal comfort through optimisation of passive design strategies, the study carried out psychrometric chart analysis of the study area for January to December. The annual psychrometric chart (January to December) shows that 27% of the data points fall within the comfort zone thus acounting for 2 353 hours out of a total of 8 760 hours. With the implemention of comprehensive passive design strategies as indicated in Appendix F, a significant improvement of 82% of the data points falling into the comfort zone can be achieved while the balance of 18% would still require active measures to drive the entire building to a 100% level within the comfort zone.

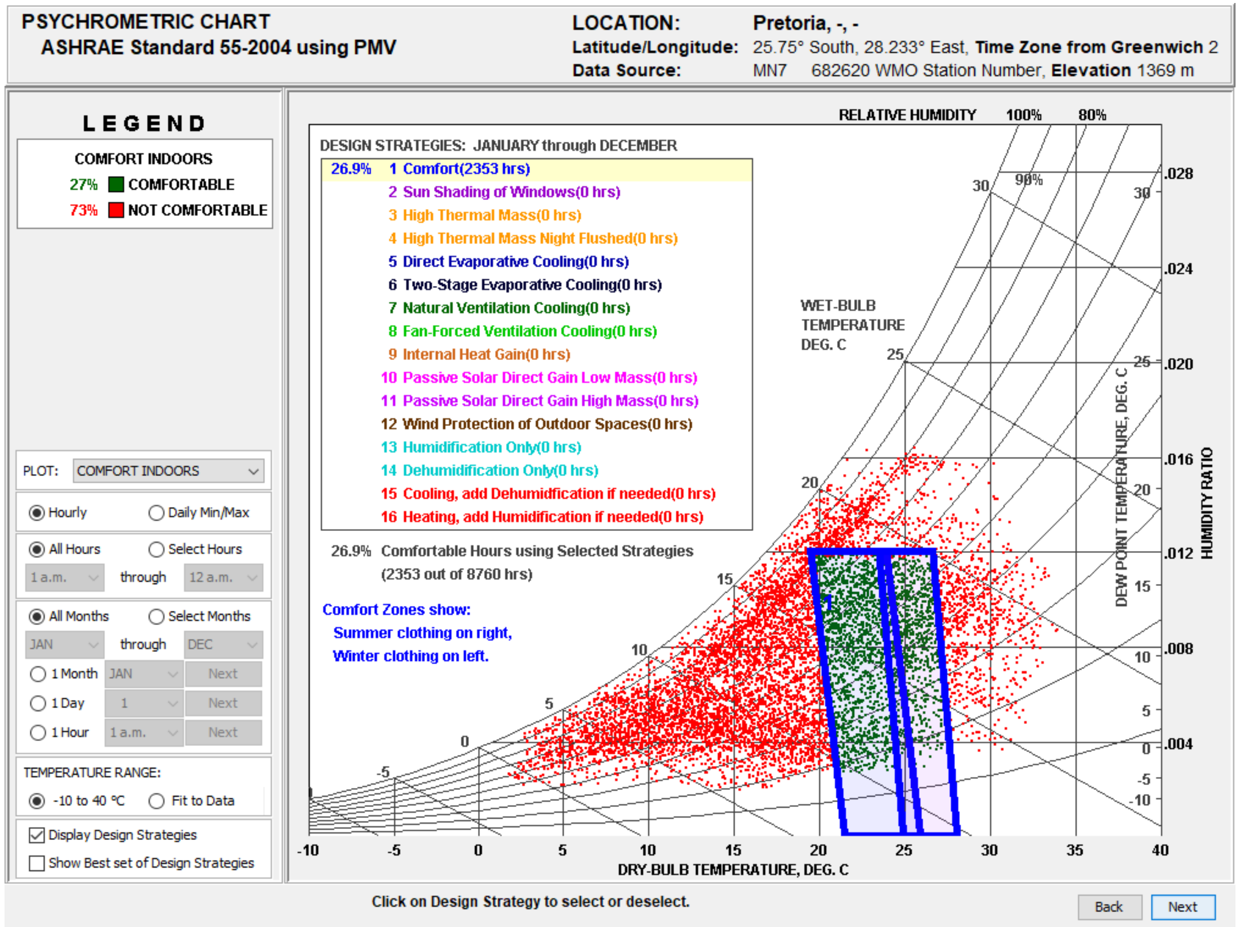

Figure 15: Psychrometric chart A (Jan to Dec.) showing climatic influence on thermal comfort without passive design strategies in building design (Source: Adapted from climate consultant 6.0).

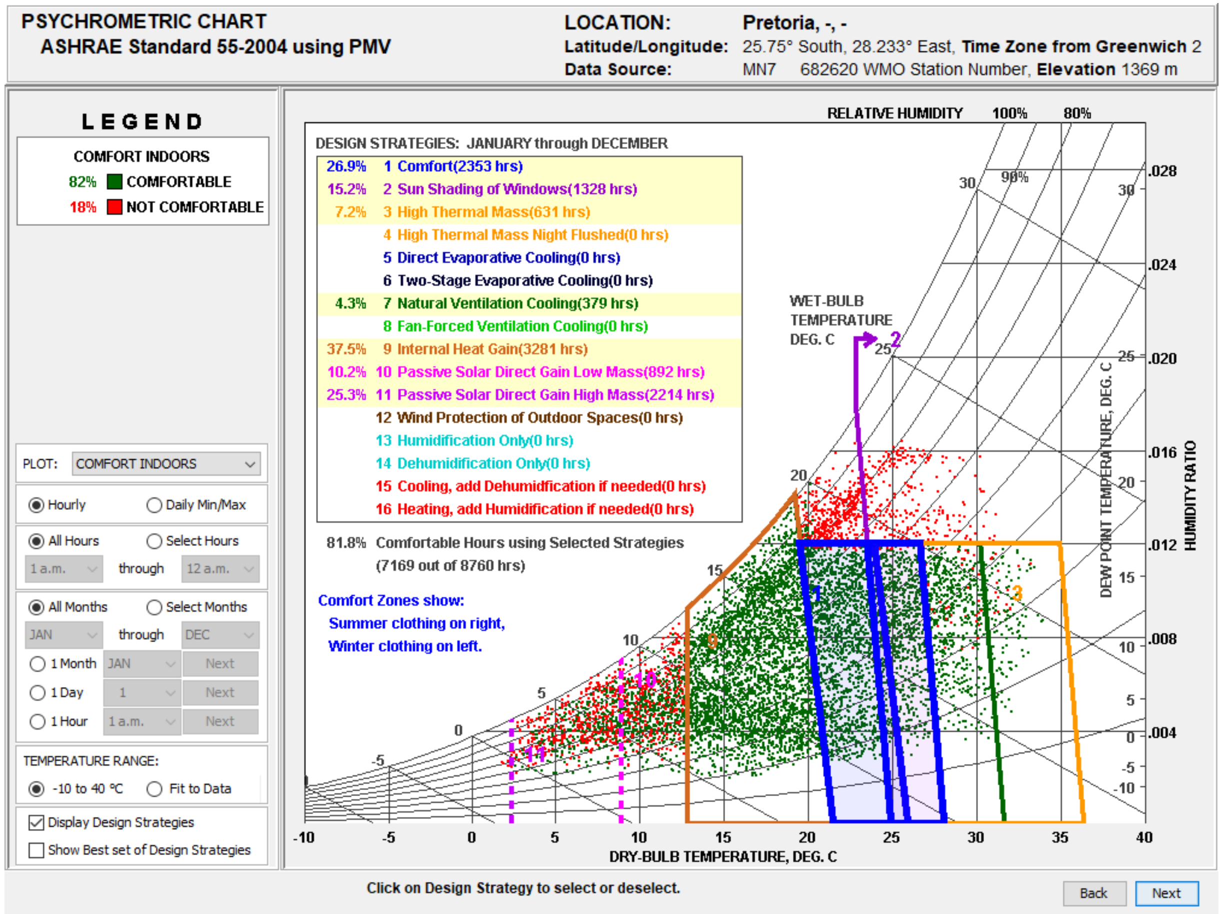

Figure 16: Psychrometric chart B (Jan to Dec.) showing climatic influence on thermal comfort with passive design strategies in building design (Source: adapted from climate consultant 6.0).

The percentage of data-points falling within the comfort zones however differ from month to month based on the seasons as explained below and with the charts in Appendix F-1 to F-12. The month of January shows that 35% of the data-points falls into the comfort zone, thus accounting for 259 out of 744 hours. With comprehensive passive design strategies such as building layout, envelope thermophysics, building geometry, air-tightness and infiltration performance a total of 78% of the data points can fall into the comfort zone, thus accounting for 577 out of 744 hours, with the balance of 22% requiring active measures to achieve comfort.

The month of February shows a similar pattern with 34% of the data-points falling into the comfort zone, thus accounting for 231 out 672 hours and with comprehensive passive design strategies, the comfort zone rises to 79% (533 out of 672 hours). The month of March indicates 33% of data-points within the comfort zone and this rises to 78% of the data points being in the comfort zone due to passive design strategy interventions. The month of April indicates the data-points of 33% in the comfort zone and achieving a comfort zone of 91% with passive design strategy interventions, thus accounting for 658 out of 720 hours. The months of May to July indicates a different pattern with the data points as shown in Appendix F-5 to F-7 with the average temperatures and humidity beginning to reduce, thus requiring heating and humidification to reach comfor zone. During these months, the data-points fall to the left of the comfort zone. The month of May indicates 16% of the data points falling into a comfort zone (covering a total of 116 out of 744 hours) and rising to 81% with passive design interventions.

The month of June demonstrates a worst case as only 4% of the data-points fall within the comfort zone, and thus requiring a whole lot of a combination of passive and active measures to achieve thermal comfort in the building. With passive design interventions as exhibited in the DEA Building, 74% of the data-points can fall into the comfort zone. The July month, still in the winter season being the coldest month has data-points falling into the comfort zone for just 5% and with passive design interventions, this rises to 72% of the data-points.

From the month of August through to December, the data-points once again start moving to the right (towards the comfort zone), and thus increasing the temperature and humidity and reducing the need for much of the active measures. August comfort zones rises to 19% based on climate and 83% with full optimisation of passive design while September, October, November and December achieves comfort zones of 93%, 92%, 90% and 72% respectively.

The above analysis indicates that with full optimisation of passive design strategies, office buildings within the study area would require less of active measures to achieve comfort. A further reduction in the energy-use of the building could be achieved through analysis of the energy-use types in the building such as equipment and lighting which are not accounted for in the green building rating calculations.

4.4 The process towards assessment for NZEB

This section explores options available to attain NZE rating for this type of building within the given climatic region. The building plans (initially obtained as secondary data in PDF format – see Appendix B, pages 130 - 4) were re-drawn in ArchiCad to generate the building model shown below for ease of reference when entering data into the *Edge* Tool software for simulations under different scenarios.

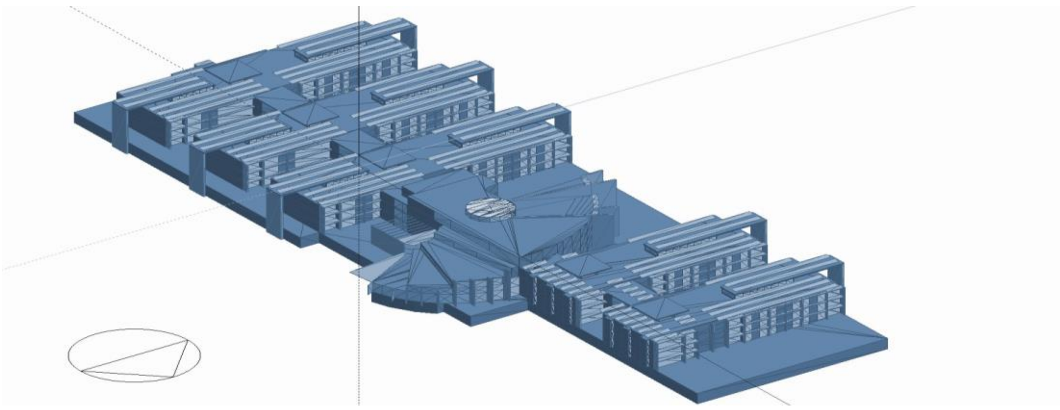

Figure 17: Building model of DEA Building as created in ArchiCad, Source: Adapted from "as-built" drawings accessed from Boogertman + Partners, (2014).

Based on the psychometric charts of Pretoria, the attainment of a NZEB would be significantly influenced by factors such as climate, passive design strategies, the use of energy-efficient building materials as well as the use of renewable energy systems.

In order to determine the energy-performance gap between the 6-star rated DEA

Building and a NZEB version of the same building, the data in Table 5 were utilized as the base-case scenario for advancing the 6-star rated DEA Building to a NZE standard. The analysis of the data in Section 4.2 indicates that the major energy-use components of the building in its current state are cooling and heat rejection at 6.3 kWh/m^2/yr, fans at 5.3 kWh/m^2/yr, tenant lighting at 37 kWh/m^2/yr, small power at 49 kWh/m^2/yr and supplementary cooling at 4.6 kWh/m^2/yr. The data also indicates that other energy components would have minimal contribution to the energy-use of the building as they have already been significantly optimized for energy-efficiency. It should also be noted that the roof-top PV-installation currently generates 13.8% of the total energy-use of the building.

4.5 Discussion of interventions

As stated earlier, the drive to net-zero requires passive and active energy-reduction interventions and this section discusses the interventions applied to the energy needs of the building from its current usage before proceeding to input the data into the *Edge* Tool software. The critical components requiring interventions are as follows: tenant lighting, small power (tenant equipment which mainly relate to plug-loads), the reduction of phantom load (which means energy consumed by appliances or device even when they are switched off - see Section 4.4.1.3 for definition) and installation of PV system.

Based on the data presented in Table 5 and the appraisal of the interventions carried out to get the building to a 6-star rating, almost all passive design interventions needed to advance the building to a net-zero energy standard were already comprehensively optimized towards the 6-star rating. These include effective use of natural ventilation and day-lighting, the use of evaporative cooling, implementation of double glazing, adequate window-to-wall ratio and effective orientation of the building among others. The key data parameters and criteria as well as the primary and secondary sources utilized in the intervention for the three key elements with high consumption are presented below.

Table 5: Data parameters and criteria for primary and secondary data sources

Sub-question 1	Key interventions	Secondary data sources	Primary data sources
What is the energy performance gap between 6-star and NZEBs in South Africa and what would be the associated climate change mitigation potential? There three key interventions and data sources for this sub-question are shown in subsequent columns. The related data sources under each criterion are shown in columns 3 (secondary data) and 4 (primary data).	Criteria 1: Lighting	Criteria 1: Lighting	Criteria 1: Lighting
	Introduction of additional LED lighting to cover areas that are not covered.	Source: Data obtained from the 6 star modelled data.	Source: Data obtained through Edge simulation software.
	Introduction of occupancy sensors to cover major areas not covered presently	Source: Data obtained from the BMS system for the building operational data	Source: Data obtained by direct observation during site visit (walk through assessment)
	Introduction of motion sensor to areas not covered.	Source: Data obtained from the BMS system for the building operational data.	Source: Data obtained by direct observation during site visit (walk through assessment)
	Criteria 2: Equipment	Criteria 2: Equipment	Criteria 2: Equipment

	Replacement of all high energy IT equipment and systems with EPA rated Energy Star equipment.		Source: Data obtained by direct observation during site visit (walk through assessment).
	The introduction of virtual server to reduce the number of servers required for the entire system in the building.		
	Criteria 3: Power	Criteria 3: Power	Criteria 3: Power
	Development of protocols for the unplugging of devices that are not in use by the introduction of Phantom Load Reduction by mitigating phantom loads when devices are not in use.		Source: Data obtained by direct observation during site visit (Walk through assessment).

Cooling/heat rejection and fans

The study noted that both cooling and heat rejection depends on energy-use for the fans and as shown in Table 5, the heating and cooling have been drastically reduced and further interventions will not yield much impact towards lowering the energy-use. The supplementary cooling is fully dependent on a compressor-based air conditioning system and has also not been altered as any further intervention will mean a replacement to a non-compressor- based cooling system which will increase the fan energy requirement of the building (GBCSA, 2018).

Small power (tenant equipment)

With reference to Table 5, small power (tenant equipment) did not form part of the modelling protocol of the initial design, and as stated earlier, this component consumes 49% of the total energy use of the building. This load is referred to as plug and process loads (PPLs). Lobato et al (2012) define plug and process loads in office buildings as energy loads that are not related to general lighting, heating, cooling and water heating and typically do not provide thermal comfort to the occupant. Related equipment ranges from computers, servers and other types of common devices that are most likely not energy rated, hence their high energy demand.

Fisher et al, (2006:119) demonstrates that the use of energy-star rated equipment combined with automatic controls can reduce plug loads by up to 50% compared to a typical office building of this nature. This implies a 50% reduction compared to the current PPLs energy-use of 1 349 005 kWh/yr. Dean (2014) also notes that in order to lower PPLs energy-use it is recommended that the EPA energy star-rating system (which has been validated to be a reliable indicator for low energy-performance) be utilized in a building. Based on direct observation during one of the walkthrough energy audit visits, the current PPLs in the DEA Building are not energy-star rated.

Phantom load reduction

Appliances and equipment account for about 33% of commercial building electricity consumption (Mckenney et al, 2010). In addition to the reduction of energy-use by selecting energy star-rated equipment, Emmerson, et al (2017) noted that most appliances consume electricity even when they are switched off. This is referred to as phantom loads and it represents a significant energy drain. Phantom load reduction is therefore crucial and it is recommended that when not in use, protocol for unplugging such devices be developed. Interestingly, with the use of smart technology, all phantom loads can be automatically eliminated when devices are not in use. This was applied to further reduce total PPLs load of 1 349 005 kWh/yr by 83% (a reduction from 1 349 005 kWh/yr to 229 331 kWh/yr).

Lighting (tenant lighting)

The simulation indicated a reduction of the energy-use from 1 011 190 kWh/yr to 374 140 kWh/yr, thereby lowering energy-use from $12W/m^2$ to $4.8W/m^2$. As shown in Figure 16, the intervention thus produced a 63% energy-saving in lighting for the building, thus allowing for further progress towards NZE performance. The same is then applied to area-lighting (non-tenant lighting) in the building and the combined outcome for lighting is represented in Figure 18.

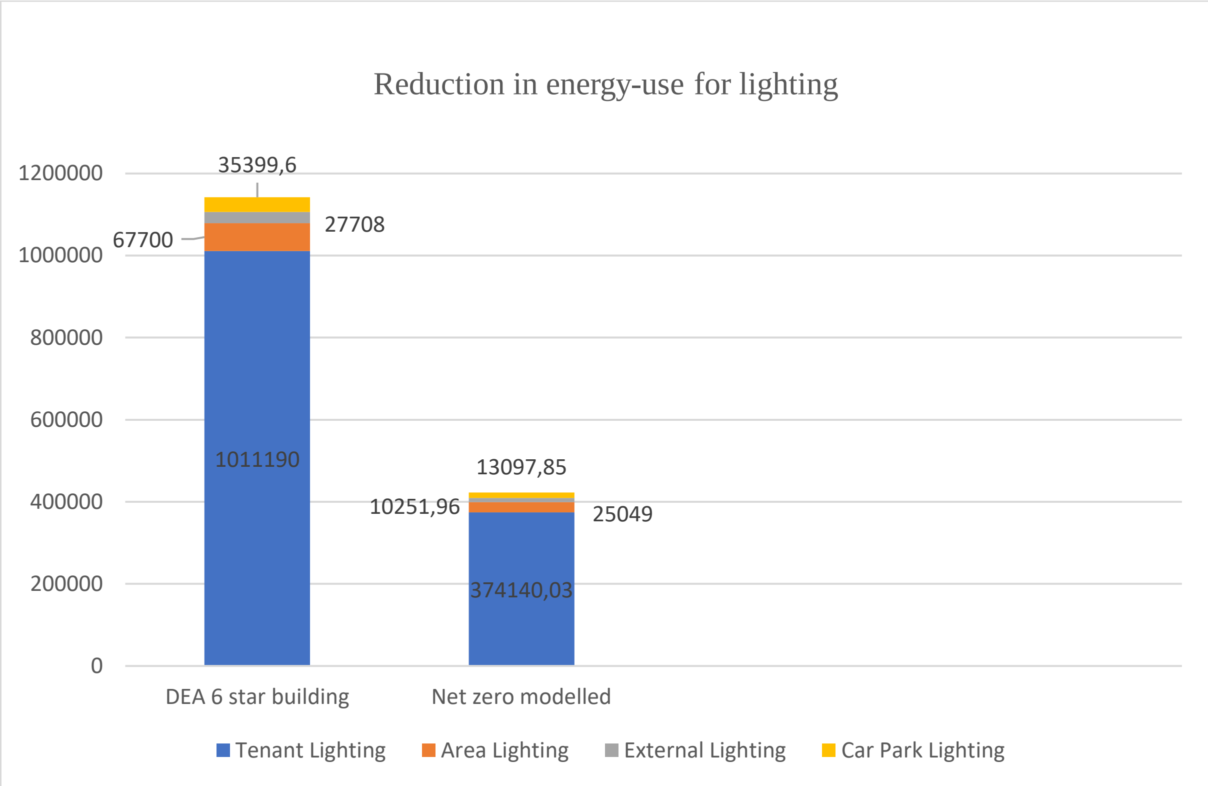

Figure 18: Reduction in energy-use for lighting (from 12W/m^2 to 4.8W/m^2) based on *Edge* Tool simulation.

Installation of photovoltaic solar panel

The study notes that the current PV-installation covers 38% of the available roof space while an additional 5% is occupied by other equipment such as cooling and solar hot-water systems. The available roof space for installation of additional panels is approximately 40% of the total roof space. This is adequate for the required renewable energy generation based on PV-system since the additional roof space needed to accommodate additional PV-installation to meet the energy-balance is 36%.

4.6 Simulation and analysis of energy-efficiency interventions

The energy-use intensity of 112 kWh/m^2/yr (see Table 4) is used as the base-case for the drive towards achieving NZEB. The data were entered into the *Edge* Tool software and the interventions as discussed above were applied to lighting and PPLs load. In addition, solar panels were added to provide additional generation. The sub-findings from the psychometric chart analyses (as per Figure 15 and 16 as well as in Appendix F) gives an indication of thermal comfort levels achievable through passive-design interventions within Pretoria's climatic-zone.

The output of the simulation for the prioritized interventions is presented in Table 6, which shows the base case as well as the with-interventions scenarios as the basis for determining the gap between the 6-star and NZEB. The table is also illustrated in a bar chart in Figure 18 which indicates the base case, the with-interventions and the solar generation capacity of the roof-top PV-installation.

Table 6: Energy efficiency gap between 6-star rated DEA Building versus simulated NZEB

Energy efficiency gap - 6 star rated DEA-Building versus NZEB						
	6 Star Rated Building	6 Star Rated Building	6 Star Rated Building	NZEB	NZEB	NZEB
	Operational Energy Use kWh/Year 2017/2018	Operational Energy Use kWh/m²/year 2017/2018	% of energy use	Modelled Energy Use kWh/Year for net zero	Modelled Energy Use kWh/m²/year	% of Energy use
Fuel CO2 Factor	1.2	1.2	1.2	1.2	1.2	1.2
Heating	38 162	1.4	1.2	38 162	1.4	3
Cooling & Heat Rejection	174 448	6.3	5.6	174 448	6.3	14
Pumps	1 560	0.05	0.05	1 560	0.05	0.1
Fans	147 684	5.3	4.8	147 684	5.3	12
Extract and Miscellaneous	30 784	1.1	1	30 784	1.1	2.5
Non-Tenant Area Lighting	67 700	2.5	2.2	25 049	0.9	2
Car Park Lighting	35 399.60	1.3	1.1	13 097.85	0.48	1.1
External Lighting	27 708	1	1	10 251.96	0.37	0.8
Lifts	42 167.40	1.5	1.3	42 167.40	1.5	3.4
Domestic Hot Water	24 324.90	0.8	0.7	24 324.90	0.8	2
Lighting Tenant	1 011 190	37	33	374 140.03	13.7	30.1
Small Power (Tenant)	1 349 005	49	44	229 330.85	8.4	19
Supplementary Cooling (Tenant)	126 149	4.6	4	126 149	4.6	10
SUB TOTALS (kWh/Year)	3 076 291	112	100	1 237 148.99	45	100

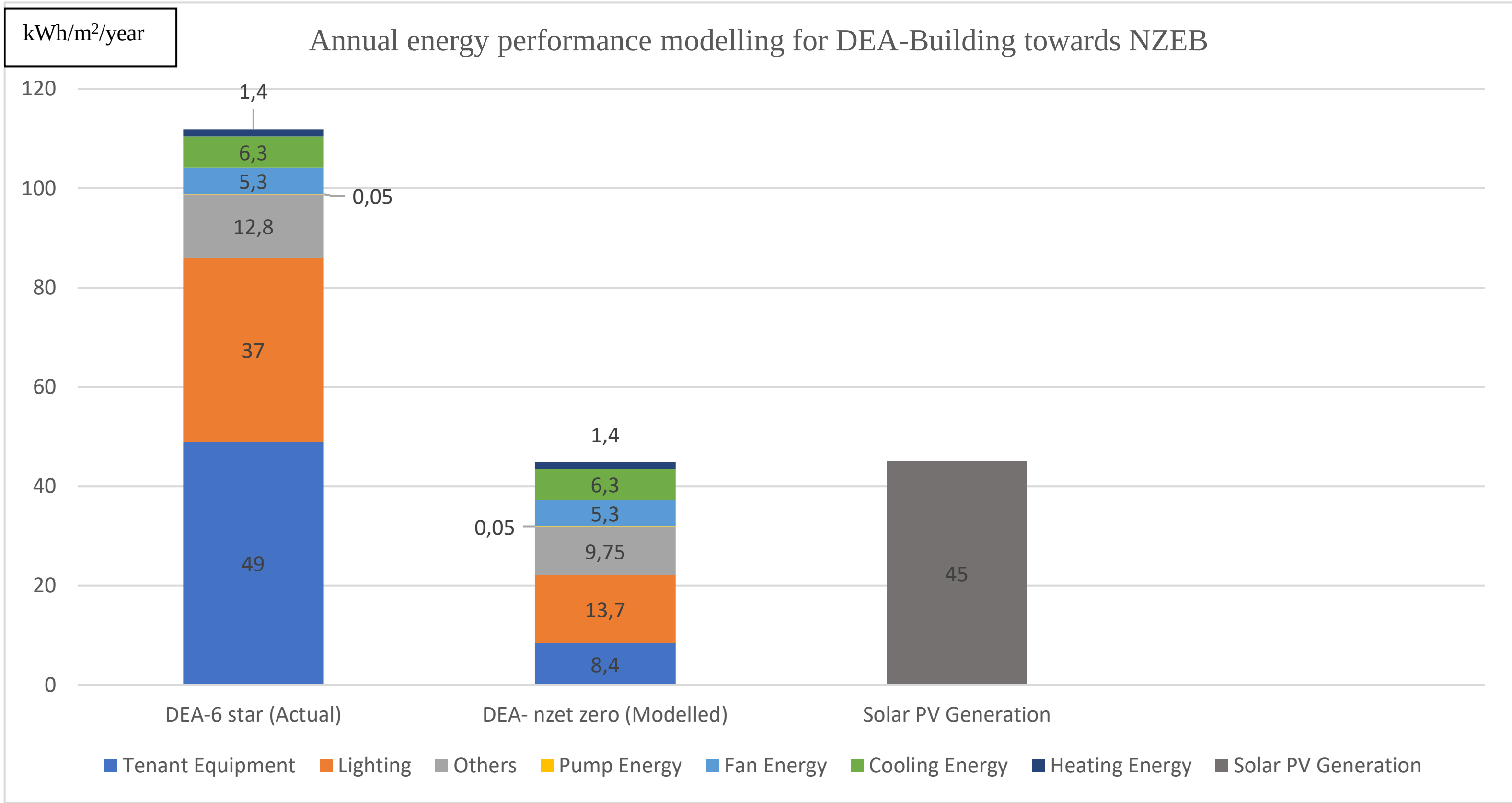

Figure 19: Annual energy performance analysis towards a NZEB for Pretoria based on *Edge* Tool simulation in kWh/m^2/year.

Figure 19 indicates the energy consumption data of each of the components of the NZEB versus the 6-star rated building in relation to their energy demand with the DEA 6-star building as a base case. From the *Edge* Tool simulation results, energy savings of 1 839 142 kWh/yr was achieved as against the base case of 3 076 291 kWh/yr. This implies that the energy-use intensity of a NZEB DEA Building with total area of 30,654sqm would be at 45kWh/m^2/yr as compared to current intensity of 112kWh/m^2/yr. This will amount to an energy-performance gap of 67kWh/m^2/year between 6-star rated and a NZEB of the DEA Building type and within the climatic region of the study area. The energy requirement of 45kWh/m^2/yr is generated by means of roof-top PV-installation with the generation-capacity shown in Figure 18.

Based on the *Edge* Tool simulation results, the DEA Building as baseline building indicates an energy-efficiency of 42% amounting to average monthly energy-use of 256 357kWh/Month and annual use of 3 076 291kWh/yr. Based on the psychometric charts, the energy-use of the DEA Building indicates that passive design strategies have been comprehensively optimized and implemented. As a result, interventions for simulation were prioritized towards the components highlighted in Table 6 above.

These sub-findings for sub-question 1 are consistent with Rosen (2015) who argue that the way in which buildings are designed and constructed could be transformed to mitigate energy use and related emissions as well as improving the potential for buildings to become net-energy generators. The development of technologically advanced high-performance NZEBs can therefore contribute significantly towards sustainable development goals of a city or country in general.

Chapter 5: Cost savings, barriers and pathways from voluntary to mandatory NZEBs

5.1 Introduction

This chapter presents data and analyses in response to Sub-questions 2 to 4 which address cost savings associated with enhancement from 6-Star to NZEB performance levels, the technical, market and cost barriers from 6-Star to NZEBs practice and the desirable pathway within voluntary versus mandatory NZEBs for South Africa. The chapter starts with a comparison of construction costs of two NZEBs versus a conventional building in Malaysia in order to appraise the cost difference between the two cases. This is followed by a presentation and analyses of secondary data on barriers towards migrating from 6-Star to NZEBs, and finally, the chapter presents secondary data analyses on policy pathway towards a mandatory rather than voluntary NZEBs for South Africa based on existing policies as well as insights from the specific instruments utilized in the secondary-data cases analyzed.

5.2 Cost savings associated with 6-Star and NZEBs

The viability of 6-Star versus NZEBs is dependent on energy-use intensity (EUI) and energy-cost intensity (ECI), which in turn depend largely on the interventions (passive and active measures) implemented to obtain the energy performance outcomes. Insights from literature reviewed in Chapter 2 indicated that 6-Star and NZEBs perform better than a conventional building in terms of their energy performance, even though both frequently entail higher initial construction costs.

In a bid to evaluate cost-effectiveness of NZEBs, Shabrin et al (2017) analyzed construction costs between the Sarawak Energy Building (SEB) headquarters and the University College of Technology Sarawak (UCTS) Campus versus a conventional building in Malaysia to highlight the cost-difference between a conventional building and a NZEB. The case of Malaysia has been used due to the fact that the case buildings gave detailed comparison of the building's energy index values, investment analysis and the construction cost which was not readily available for other buildings. The study noted that for the SEB headquarters, cost of construction was Ringgit Malaysian (RM) 200 million for a floor area of 59 388m^2, amounting to RM3 368/m^2, while the construction cost for an average standard office in Malaysia then was RM1 596/m^2. For the same floor area as SEB Headquarters, this would translate to an approximate cost of RM95 million. Based on the above, the construction cost of an NZEB would be around RM104 million higher due to the implementation of green technologies. For the UCTS Campus, the construction cost was approximately RM357.7 million with a floor area of approximately 300 184m^2. The construction cost for an average standard school or university in Malaysia is RM762.50/m^{2,} (Shabrin et al. 2017). This would translate to an approximate cost of RM228.89 million. This indicates a cost-difference of RM128.81 million between the construction-cost of a NZEB versus a conventional building equivalent.

Pless et al. (2014) noted that, although data on construction costs of NZEBs are limited, the NREL Research Support Facility (a large office building in Golden, Colorado), was procured at a typical construction budget for the area. As argued by Matt et al. (2014), even though high efficiency components often cost more than standard-efficiency equivalent, innovative design and construction teams have developed a variety of strategies to offset the cost of implementing the best-in-class efficiency required to achieve NZEB. Torcellini et al., (2004) noted that a study of six high-performance buildings in the US showed that a NZEB-rating also facilitated energy-cost savings (in their operation and maintenance phase) ranging from 12 - 67%. The savings were mainly based on a whole-building design process, which included the systematic application of energy-performance simulation software for quantifying goals and evaluating impacts of design alternatives.

Pless et al. (2014:4) stated that, based on the NREL experience, achieving cost-savings in a NZEB is primarily influenced by the following design approaches:

- Prioritizing energy efficiency as a project goal which might entail trade off on cost investment in architectural elements that do not impact or assist in energy performance

- Integration of simple and passive efficiency solutions, with an emphasis on envelope-performance optimization

- Downsizing or eliminating heating, ventilation, and air conditioning (HVAC) equipment mainly through optimization of passive envelope design

- Maximizing the use of modular and repeatable design solutions.

- Specifying readily available and tested technology and focusing on the implementation details

- Implementing experimental solutions only when necessary for NZEBs and incorporating the appropriate system expertise onto the project team

- Incorporating a continuous value engineering process as part of the integrated design effort that facilitates choice and decision-making in cost tradeoffs across design disciplines

- Engaging experienced key subcontractors early in the design process

Cost payback period for DEA NZEB interventions.

Brown & Matysiak (2002) define payback period as a simple analysis to estimate the time taken for cash inflows to balance-out the original capital outlay of an investment venture. Payback period thus gives an indication to investors on the time it will take to recover the initial capital outlay, which therefore gives an initial estimate of the viability of the project. Kneifel (2014) similarly refers to a simple payback as the number of years it will take for the future cost savings to offset the initial investment costs.

In their comparison of the acceptable payback period in North America, Coetzee et al. (2015) pointed out that 15% of investors will prefer a payback period of 1-3 years, while 40% would accept 4-5 years, and 27% between 6-9 years. Only a limited proportion of 18% of participants would accept 10 years and above. This indicates that for majority of investors, the preferred period would be at a maximum of 3 to 5 years. However, in the South African context, SEA, (2017), noted that the current payback period is in the region of 6 to 9 years. This is pointed out to be dependent on tariffs as most commercial and industrial customers are on tariffs that have a significant fixed demand charge component. In a similar line of thought, IASS/CSIR, (2019) note that at present, payback times in South Africa average 6 – 10 years for commercial PV systems and are highly dependent on the valuation of PV by the local utility.

Coetzee et al. (2015) note that the above findings closely correlate with experiences in the South African market, where developers require shorter payback periods. This was however noted as a critical barrier to green building in South Africa because the entity that pays for the design and building of the facility is often not the one that operates and maintains it, and as such, the benefit of the additional cost gets to accrue to a different party – the tenant.

In order to assess the cost savings (utility cost reduction) associated with DEA-Building, secondary data of the conventional/notional building and the 6-Star rated building (see Appendix C) were entered into the *Edge-tool* software in order to ascertain the utility cost savings based on the interventions from a conventional to a 6-Star building. As shown in Appendix C, the results of the *Edge-tool* simulation indicate that the notional building would operate at an average utility cost of R 978 806.93 /month whereas a 6-Star rated building would operate at an average utility cost of R 412 990.63/month (see Appendix G for the secondary data of the 6-Star and the notional building respectively). This translates to a cost saving of R 565 816.30/month. Using the 6-Star rated DEA Building as a base case and a utility cost of R412 990.63/month, the utility cost was further reduced to R 367 720.94/month for NZEB, which translates to an additional cost saving of R 45 269.69 /month (see Appendix D for the simulation result as well as the input data).

Based on the *Edge*-tool results as stated above, the study utilized the utility cost of R 412 990.63/month as the base-case to migrate from 6-star to NEZB. This then forms the basis of determining the utility cost reduction from 6-star to NZEB. This aligns with Torcellini et al., (2004) analysis where energy cost savings for NZEBs range from 12-67%.

Following on Gorshkov and Vatin (2018:68), the derivation of payback period is based on the simple payback formula as a ratio of the value of the incremental cost of implementing the selected green building intervention to the utility cost reduction achieved due to cost savings per year which was obtained from the *Edge* simulation software as shown in Appendices D and E. The simple payback period was therefore derived as follows:

Simple payback period = IC0/ CF1

- ❖ Where IC0 is the value of the incremental (additional) cost of implementing the selected green building interventions.
- ❖ CF1 is the cash flow achieved due to utility cost-savings per year facilitated by the green building design interventions.

Based on the above formula, the payback period of the 6-star rated DEA Building is calculated drawing from the output of the *Edge*-tool simulation result as indicated in Appendix C with an incremental cost of R 40,889,228.84 and a utility cost-reduction of R412 990.63/month (amounting to R 4,955,887.56 per year). By applying the above formula, the payback period is 5 years -see Appendix C). On the other hand, based on the incremental cost of R 41,098,476.40 ZAR and a utility cost reduction of R 367,720.94/month (which amounts to 4,412,651.28 (ZAR) per year, the payback period of the NZEB interventions will be 4 years (see Appendix D).

This study further assessed the payback periods of the various interventions independently in order to ascertain the interventions with shorter payback period. This also allowed the study to compare the outcome with acceptable payback period for investors in South Africa. The three main interventions assessed were lighting, energy efficient PPLs and roof top PV-installations. To carry out the payback period calculation, the electricity cost per kWh was determined while also factoring envisaged tariff increases in view of trend of increases in recent years. This information formed the basis of estimating the electricity cost per kWh and hence determining the cost payback of the interventions as detailed below.

Based on the National Energy Regulator of South Africa (NERSA) approved tariffs, it is noted that from the year 2011 to 2020, electricity tariffs have increased from R0.86 to R1.81, implying that the cost of electricity per kWh rose by R0.9, which amounts to approximately R0.1 increase per year and an annual increase of 9%. The study utilized the electricity tariff of 2020/2021 of R1.81 because the cost was implemented in 2020. However, projections were made over a period of ten years on a similar rate and tariff increase. This translates to the electricity (cost per kWh) of R1.8 + R0.9 to tally at R2.7 by year 2030. This tariff will be applied towards determining the cost payback of interventions for the projected 10-year period.

Cost payback period for tenant lighting

As pointed out in Section 4.4.1, tenant lighting load was not included in the initial design/modelling protocol. It was therefore necessary to estimate how much the replacement of the conventional (T5) light bulbs with LED bulbs could contribute towards a building of this nature attaining the NZEB standard. The analysis of the intervention shows a reduction in energy use from 1 011 190 kWh/yr to 374 140 kWh/yr. This closely aligns with Ahmad et al. (2017) findings where energy-savings of LED bulbs and the annual cost savings was about 47% of lighting energy consumption. The investment cost for LED-bulbs and installation was obtained from the current construction market rate in terms of construction cost per m^2 for electrical installation. The installation cost for a conventional sophisticated building of the nature of DEA stands at R800/m^2 but the bulb component would constitute about 30% of the entire installation cost. The derived intervention-cost was coupled with the energy savings associated with the two types of buildings and a payback period of less than one year was derived as shown in Table 8. This implies that the total period within which the additional cost of the intervention of LED lighting towards achieving NZEB will be achieved in less than a year.

Table 7: Payback period calculation for tenant lighting intervention

Energy Savings Payback Calculation

Intervention	**LED Lighting**		
Estimated Installed Cost (R)	1 063 062	Additional cost to upgrade from conventional to LED lighting	**PAYBACK reached in year where cells turn GREEN in Accumulative Total**
Estimated Saving (kWh/annum)	637 050,00	Annual saving from LED lighting over conventional lighting	
			Annual Increase in Energy Cost
			9%

	Year	Energy Saved on Site (kWh)	Energy Cost (R)	**Total Annual Saving (R)**	**Accumulative Total (R)**	**Year**
2020	1	637 050	**1,81**	1 153 061	1 153 061	**1**
2021	2	637 050	2,0	1 256 836	2 409 896	**2**
2022	3	637 050	2,2	1 369 951	3 779 848	**3**
2023	4	637 050	2,3	1 493 247	5 273 094	**4**
2024	5	637 050	2,6	1 627 639	6 900 733	**5**

Cost payback period for small power (tenant equipment)

With computers being the most energy-intensive tenant-equipment in commercial/office buildings, the cost payback period calculation focused on the desk-top computers versus laptops. The *green office guide* published by National Appliance and Equipment Energy Efficiency Committee (2019) notes that an average computer power-rating is 49 Watts when fully on, 29 Watts when asleep and 2 Watts when switched off but LCD laptops utilize only 15-25 Watts when fully on and are therefore much more energy efficient.

On tenant equipment replacement with EPA-rated equipment, it was noted under Section 4.4.1.3 that annual electrical energy use would be reduced from 1 349 005 kWh/yr to 229 330.85 kWh/yr. This facilitated the derivation of the payback period of the intervention. Based on the 850 computers (Imvelo Facilities Management, 2018:9) currently being used in the building, the non-rated desktop computers cost R8 950 (Hewlett-Packard pricelist 2019) per system while EPA-rated laptops would cost R13 450 (Hewlett-Packard pricelist, 2019) per system. Based on the above, the payback period for the intervention was assessed to be slightly over a year as shown on Table 9.

Table 8: Payback period calculation for tenant small power (tenant equipment) intervention

Energy Savings Payback Calculation

Intervention	**Small Power**	
Estimated Installed Cost (R)	3 825 000	Additional cost for providing laptops instead of desktops for all 850 building occupants
Estimated Saving (kWh/annum)	1 119 675	Annual energy saving from changing to laptops from desktops

PAYBACK reached in year where cells turn GREEN in Accumulative Total

Annual Increase in Energy Cost **9%**

	Year	Energy Saved on Site (kWh)	Energy Cost (R)	**Total Annual Saving (R)**	**Accumulative Total (R)**	**Year**
2020	1	1 119 675	**1,81**	2 026 612	2 026 612	**1**
2021	2	1 119 675	2,0	2 209 007	4 235 619	**2**
2022	3	1 119 675	2,2	2 407 817	6 643 436	**3**
2023	4	1 119 675	2,3	2 624 521	9 267 957	**4**
2024	5	1 119 675	2,6	2 860 728	12 128 685	**5**

Cost payback period for solar PV

Janse van Vuuren (2016) argues that with the expected lifetime of 20 years for solar panels, a longer payback period of up to 15 years could be accepted as this would indicate a payback before the end of the solar panels' lifetime. This is an indication that implementing solar PV is worth considering because once the solar PV system has been paid off, it will continue to generate value thereafter at no cost.

Given the status quo for total installed capacity of 397kWp and PV generation standing at 15.49kWh/m^2/yr at a cost of 9.8Wp (Pandarum, 2018:3), a NZEB would require a total installed capacity of 1 153kWp at a cost of 9.8Wp to generate 45kWh/m^2/yr. To achieve the above, an estimated additional installed cost of R7 404 800 after factoring the projected price decline of solar PV by 57% between 2015 and 2025 (IRENA, 2016). The estimated savings per annum in kWh amounts to 1103 760 (756 x 4 x 365). Using the solar PV calculator below, the solar pv intervention gives a payback period of 3 years.

Table 9: Payback period calculation for solar PV intervention

Energy Savings Payback Calculation

Intervention	**Solar PV**	
Estimated Additional Installed Cost (R)	**7 408 800**	Baseline has 397kWp system. Cost reflects additional to make it 1153 kWp
Estimated Saving (kWh/annum)	**1 103 760**	Saving from providing additional 756 kWp PV system for the building

PAYBACK reached in year where cells turn GREEN in Accumulative Total

Annual Increase in Energy Cost: **9%**

	Year	Energy Saved on Site (kWh)	Energy Cost (R)	**Total Annual Saving (R)**	**Accumulative Total (R)**	**Year**
2020	1	1 103 760	**1,81**	1 997 806	1 997 806	**1**
2021	2	1 103 760	2,0	2 177 608	4 175 414	**2**
2022	3	1 103 760	2,2	2 373 593	6 549 007	**3**
2023	4	1 103 760	2,3	2 587 216	9 136 223	**4**
2024	5	1 103 760	2,6	2 820 066	11 956 288	**5**

5.3 Sub-question 3: Technical, market and cost barriers from 6-star to NZEBs enhancement.

Having investigated the technical performance (energy-use reduction) and cost-savings associated with both 6-Star and NZEBs, this section appraises the barriers that hinder the implementation of NZEBs. It also looks at measures to address them to ensure that the attainment of NZEBs becomes a reality in South Africa’s building and property sectors.

Generally, barriers are assessed in terms of technical and non-technical criteria. Technical barriers include economic, financial, legal as well as social challenges. They also include lack of skills and expertise across the construction sector as well as uncertainty about how technologies perform. On the other hand, non-technical barriers address environmental, functional and design challenges (Ostende et al. 2017).

With respect to economic and financial barriers, although energy savings of a NZEB project can be expected in the long term, adoption has been unpopular due to high initial investment costs of related interventions such that the construction cost ends up being higher than for a standard/conventional building. The fact that energy costs are volatile also further reinforces this barrier as it creates a challenge to achieving affordable NZEB projects due to introducing uncertainty on actual monetary savings.

The legal barrier mainly stems from lack of coherence in policy and regulations while social barriers relate to a conditioning factor that influence the choice of technologies to be implemented, especially in view of lack of environmental awareness among developers and their professional teams. Social barrier entails lack of knowledge about the technology, ease of use which refers to concern on the functionality of the technology, relative advantages and disadvantages that comprises of quality of construction and designs as well as the extra cost when compared to a conventional building and social norms which entail inadequate exposure and familiarity with net zero energy buildings.

For South Africa, the specific barriers are attributed to the following factors:

- Perception of costs as higher than they actually and lack of incentives

- The water shortage in the country could be considered as a barrier in terms of developing green buildings and the absence of systematic research on the average cost-premium of developing a net zero energy building

As noted in GBCA (2011:2), Davis Langdon (2010) reported that many industry professionals still maintain the belief that NZEBs cost around 17% more than a conventional building. In contrast, Shabrin et al. (2017) note that although the construction cost of a NZEB has been proven to be higher than that of a conventional building, the higher cost can be motivated on the basis of the cumulative savings arising from the lower energy consumption during the operation phase.

A growing body of literature indicates that government has a significant role to play in ensuring that the goals of NZEBs are coherently pursued and achieved. For example, Parene et al, (2012) argue that if overall government policies on sustainable development are lacking, it becomes increasingly difficult to adopt NZEB practice in isolation. Additionally, lack of coordination between authorities lead to unstructured administrative procedure which will eventually constitute an obstacle for project owners.

Ostende et al., (2017), further highlights the lack of policy coherence as a major legal barrier especially where different national and urban planning regulations are incoherently applied within a context where the most effective energy measures are deemed not to be cost-effective. The study noted that verifying and understanding the existing regulations (and especially the urban-planning regulations and local energy regulations) should be the first step towards addressing the legal barrier.

On the non-technical barriers, Ostende et al., (2017) noted that environmental aspects form a major component of the implementation of NZEBs. These include attributes such as climate conditions, building orientation, site characteristics as well as future urban planning. On the environmental and functional aspects, lack of skills and expertise across the sector and uncertainty about how technologies perform has emerged as a major barrier. Berggren et al (2013) noted that technical systems such as solar thermal collectors, PV-technologies and heat pumps, if properly designed, could reduce the operating energy-use. In particular, their study highlights the crucial need for the professional team to have context-specific understanding which would allow them to differentiate and assess the various technology options in relation to their specific project needs and constraints.

The barriers appraised in this section are directly applicable in the South African context, especially because the concept of NZEBs constitutes a new paradigm in the building and property-development sectors of the economy. There is therefore an urgent need to address the barriers through coherent policy and regulations as discussed in Section 5.4.

Figure 18 gives a summary of the barriers, actors and possible solutions to the promotion of NZEBs. The figure indicates and reinforces the idea that many barriers depend on others and unlocking some of them leads to automatically resolving others or being resolved with little effort. The figure points out three main barriers as follows: regulatory and legislative, social conditioning factors and economic barriers and each of the barriers has its own actors that assist in generating possible solutions. Overcoming these barriers would ensure the effective adoption as well as implementation of NZEBs.

The regulatory and legislative barriers require the local and national authorities as well as legislators as actors to enact laws and regulations to allow for the promotion of NZEB as well as regulate the various obstacles associated with NZEB. It notes that the action of the actors leads to breaking such barriers thereby ensuring that there are no bottlenecks in the promotion of NZEBs. On the social conditioning factors, industry players such as the professional team, suppliers, maintenance and facilities-management professionals as well as installers of NZEB technologies need to assume the responsibility of breaking the associated barriers. The economic barriers on the other hand, sees the end users who are not promoters as well as promoters who are also end users as the key players and these actors assist in breaking the economic barriers.

The figure indicates the dependency of the barriers on one another thus highlighting the principle that breaking the legal barriers could lead to increased diffusion of NZEB ideas. It also shows that the action on the social conditioning factors also leads to increased diffusion of NZEB and therefore aids in the breaking of the economic barriers.

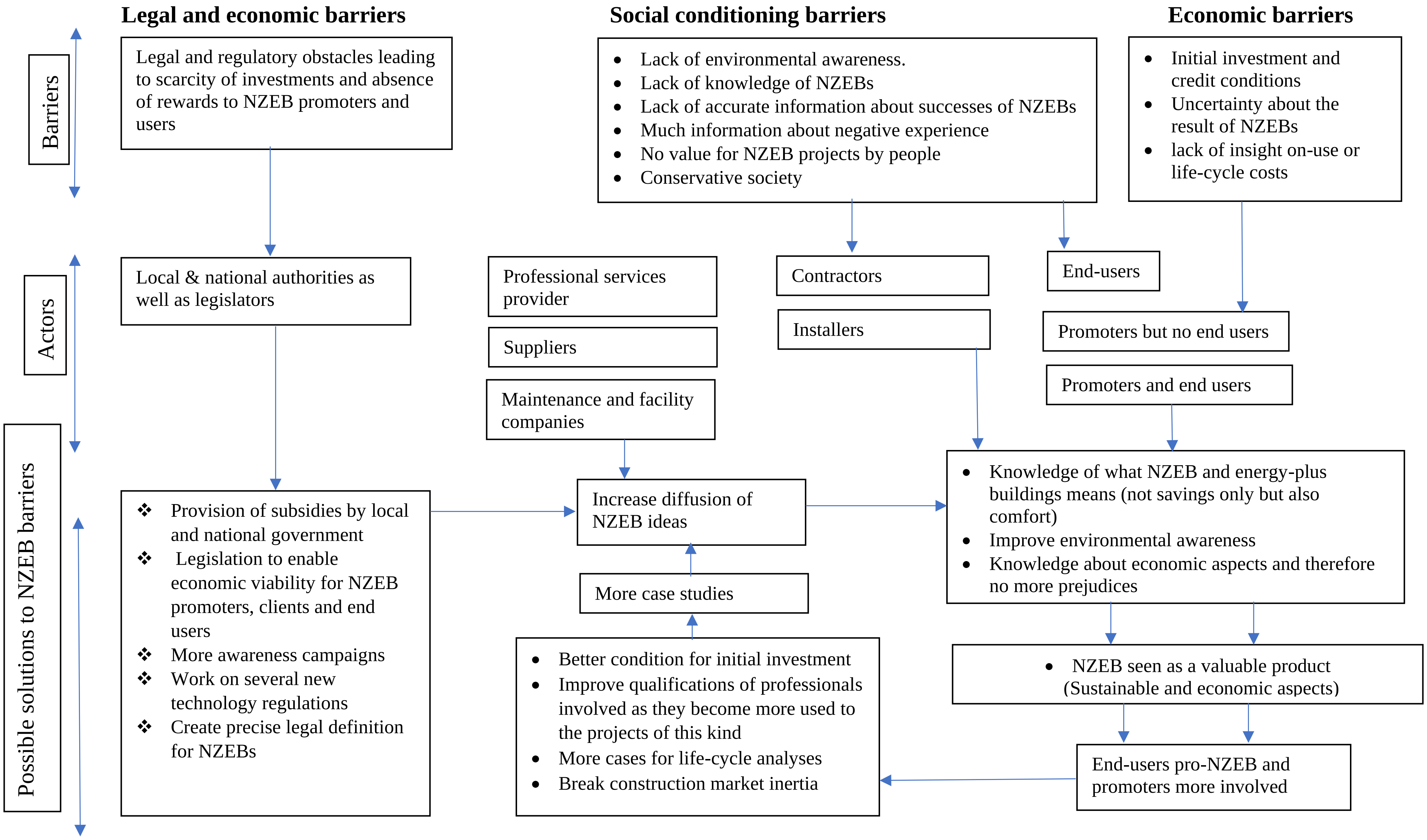

Figure 20: Summary of barriers, actors and possible solutions. Source: Adapted from Ostende et al., (2017: 39)

5.4 Sub-question 4: The desirable pathway from voluntary to mandatory NZEBs for South Africa

IEA (2019) noted that the decarbonization of the global building stock through improvements on related energy performance is being undertaken by policy makers and other stakeholders in the built environment and construction sectors and South Africa is not an exception. The relevant policies and regulations are often implemented through building standards and codes but within the context of overall national and international policies aimed at GHG-emission reduction in mitigation of climate change.

Drawing from literature review in Chapter 2, and with particular reference to Section 2.5 on approaches towards NZEBs as it relates to the gazetted South Africa's mandatory performance certification, the uptake and adoption of responsive practices has been slow and inconsistent. The Sustainable Building and Construction Initiative (SBCI, 2017) argues that mandatory regulatory and control measures are probably the most cost-effective measure for sustainable buildings.

However, this has largely failed in South Africa where many White Papers, Regulations and Gazette Notices have been published but with minimal impact on adoption. This is mainly because enforcement mechanisms have remained relatively weak. In particular, it has been demonstrated that incentives such as grants and rebates are necessary for any country to overcome the initial-cost barrier towards the adoption of innovations for sustainability.

To address this challenge, this section presents an analysis of secondary data on a purposely selected sample of countries where such policies have been implemented, and primarily focusing on relevance/impact towards achieving NZEBs. The case study countries are the EU-region, the US, Mexico and India. Applicable insights towards a responsive policy scenario for South Africa are then articulated.

Table 10: Overview of secondary data on Sub-question 4

Country	European Union	United State of America	Mexico	India
❖ Key Policies	❖ Energy Performance of Building Directive (EPBD) 2002/91/EC ❖ Energy Performance of Building Directive (EPBD) 2010/31/EU recast ❖ Energy efficiency directive (EED) 2012/27/EU ❖ Directive on renewable energy sources (209/28/EC) ❖ Directive on eco-design and energy labelling (2009/125/EC and 2010/30/EC)	❖ Federal Leadership in Environmental, Energy and Economic Performance (Executive order 13514) ❖ The Energy Independence and Security Act of 2007 ❖ Planning for Federal Sustainability in the Next Decade (Executive order 1363)	❖ International Energy Conservation Code (IECC-Mexico)-voluntary at national level but for mandatory enforcement at state and municipal level	❖ Energy Conservation Act, 2001 ❖ Energy Conservation Building Codes (ECBC) ❖ Green Rating for Integrated Habitat Assessment (GRIHA)
❖ Approach and instruments	❖ Regulatory and control mechanism (building codes, targets, certification and labelling, compliance, mandatory audit) ❖ Economic and market-based instrument (energy saving performance contracting, energy saving certificate) ❖ Fiscal instruments and incentives (tax reduction/exemption, grants, subsides, soft loan, taxation, net metering rules and feed-in-tariffs). ❖ Information and voluntary actions (education and training, demonstrations, information tools and research and development)	❖ Building codes and standards-ANSI/ASHRAE/IESNA STANDARD 90.1, ASHRAE Advanced Energy Design Guides (AEDG), ASHRAE Standard 189.1-2017, International Energy Conservation Code (IECC) ❖ Economic and market-based instrument (energy saving performance contracting, energy saving certificate) ❖ Fiscal instruments and incentives (tax reduction/exemption, grants, subsides, soft loan, taxation, net metering rules and feed-in-tariffs). ❖ Information and voluntary actions (education and training, demonstrations, information tools and research and development)	❖ Regulatory and control mechanism (building codes) ❖ Fiscal instruments and incentives (incentives)	❖ Regulatory and control mechanism (Building codes, certification) ❖ Fiscal instruments and incentives (incentives)

❖ Key outcomes and impact	❖ Increase renewable energy share in the national grid mix ❖ To achieve a fossil fuel free country by 2050. ❖ Reduce building sector greenhouse gas emission.	❖ Reduction of greenhouse gas emissions, a priority for Federal agencies. ❖ Enhance improvements in the environmental, energy and economic performance of federal agencies.	❖ Opens up electricity market for new on-and off-site renewable electricity generation and purchase opportunities ❖ Provides companies with 100% tax depreciation on the cost of installing on-site pv systems and other renewable energy equipment. ❖ Sets requirements for commercial buildings and residential buildings less than three floors.	❖ Ensure a minimum and maximum energy efficiency of 35% and 50% respectively against a conventional building ❖ Provides multiple green building rating and certification scheme coupled with training to support interested parties ❖ Opens up the electricity market and allows users to take part in non-utility PPAs ❖ Creates incentives through financial and non-financial rewards.
❖ Effectiveness in tackling barriers and mapping pathways.	❖ Achieving higher energy savings and reduced CO_2 emissions from the building sector ❖ The development of strategies for mobilizing upscaled investment in deep energy efficiency renovation ❖ Contributes to the reduction of energy use in European buildings, through the exchange of knowledge and best practices in the field of energy efficiency and energy savings between all 28 European union member states plus Norway.	❖ Protection of the environment while producing and consuming energy. ❖ Assuring a secure supply of energy, ❖ Keeping energy costs low enough to meet the needs of a growing economy.	❖ Reduction of energy generation cost due to the rapid declining costs of renewable energy at the international level ❖ Emission reductions and decarbonization efforts, to address climate change by emission reductions and decarbonization efforts. ❖ Addressing social inequalities produced by the electricity sector in its generation and use	❖ Promotion of significant advancement in availability of energy efficient building materials and equipment, ❖ Development of credible research institutions, laboratory and research and development facilities, ❖ Uptake of green building rating programs and enlargement of a pool of energy efficient building experts.

❖ Key secondary data sources.	❖ Zhang et al. (2015). Zero-energy buildings-an overview of terminology and policies in leading world regions ❖ Giama et al. (2020). Energy policy and regulatory tools for sustainable buildings ❖ Ostende et al. (2017). Potential Barriers in the construction process of a NZEB and Energy+ Buildings.	❖ Perry, C., (2018). Pathways to zero energy buildings through building codes. ❖ XU Wei, X., Zhang, S. (2018). APEC Nearly (net) zero energy building roadmap.	❖ Becqué, et al. (2019). Accelerating building decarbonization: eight attainable policy pathways to net zero carbon buildings for all ❖ SEMARNAT (2016). Intended Nationally Determined Contribution, Secretaría de Medio Ambientey Recursos Naturales (Esteves, 2012). Social impact assessment: the state of the art' Impact Assessment and Project Appraisal	❖ Jain, et al (2017). Roadmap to fast track adoption and implementation of energy conservation building code (ECBC) at the urban and local level ❖ Becqué, et al. (2019). Accelerating building decarbonization: eight attainable policy pathways to net zero carbon buildings for all

Comparative analysis on approaches and specific instruments

Based on secondary data presented in Table 8 and the specific instruments implemented, the analysis compared the various policies and instruments in order to derive insights towards a transitioning pathway for South Africa. In this regard, Berardi (2013) notes that there are four major instruments that various countries utilize to implement the policies they adopt and depending on the country, the implementation of the policies and the instrument chosen could be either voluntary or mandatory. The instruments are regulatory and control mechanisms, economic or market-based instruments, fiscal instruments and incentives as well as support for voluntary actions through information/communication and co-ordination.

With reference to India, the data shows that even though energy efficiency policies were adopted over 15 years ago, they have not been implemented as a mandatory requirement for buildings. This is because the country's national Energy Conservation Building Code (ECBC) opted for voluntary implementation and primarily relies on the willingness of states and municipalities to adopt and incorporate the policies into their local codes (Becqué et al., 2019). Based on the voluntary nature of the ECBC, the country mainly utilizes the regulatory and control mechanism instrument (especially the building codes and certification) as well as fiscal instruments and incentives to implement the energy policy.

As in India, the adoption and enforcement of energy codes in the US falls under the purview of states and local authorities. This is also the situation with Mexico where the adopted policy (referred to as the International Energy Conservation Code - IECC-Mexico) is voluntary at national level but mandatory at the level of states and municipalities (Yu et al., 2014). The US also relies on implementation by states and municipalities but with mandatory requirement through the Federal Energy Independence and Security Acts of 2007. In addition, the Department of Energy (DoE) has established aggressive goals of creating technology and knowledge base for cost effective zero-energy commercial buildings by 2025 (Zhang et al. 2015). The US is also noted to be utilizing all four policy instruments and most states are implementing the policies with these instruments as in the case of the State of California which is one of the front runners in the US. They have also adopted mixed approach of voluntary and mandatory building energy code instruments and a series of codes have been implemented as indicated in Table 8.

Comparative analysis of key outcomes and impact

As highlighted in Table 8, the implementation of policies towards achieving zero energy buildings indicates differences in outcomes of the instruments and their respective impacts across the countries. The data overview and analyses indicate that mandatory and voluntary approaches contribute differently towards achieving the goal of NZEB and therefore present varying potential for enabling or disabling local players to pursue the NZEB target (Becqué et al. 2019).

Based on the approaches and instruments, outcomes for each country are discussed in relation to impact on the reduction of energy consumption from fossil fuel and lowering the building sector's greenhouse gas emissions. Zhang et al. (2015) notes that one of the major outcomes of the EU policy framework is the increase in renewable energy share in the national grid mix.

In a similar manner, the outcome and impact of the US approach accounts for the enhanced improvements in environmental, energy and economic performance of the agencies, while also reducing greenhouse gas emissions. Ohlan (2017) notes that the drive to NZE has significant positive impact on India's economic growth based on the policy outcomes compared to energy impact on economic growth in the 1970-2012 period. This positive impact is noted across all the case-study countries.

Bulavskaya, and Reynès (2018) note that in the drive for a fossil fuel free country such as in the EU's net-zero energy policy, more jobs are created in the renewable energy space because wind and solar power generation are more intensive in capital and labour than fossil fuel plants even though they are less intensive in energy generated. In general, the outcomes of the policies led to opening up of the electricity market as seen in India and Mexico.

Comparative analysis of overall effectiveness

Based on Inter-governmental Panel on Climate Change (IPCC) Special Report on Renewable Energy Sources and Climate Change Mitigation, policy effectiveness is defined as "the extent to which intended objectives are met. For instance, the actual increase in the amount of renewable electricity generated or share of renewable energy in total energy supply within a specified time period" (IRENA, 2012:12). In principle, the effectiveness of a policy instrument serves as a measure of the degree to which a predefined policy-goal can be achieved as a result of systematic implementation of the policy (Held et al., 2014).

Evaluation of policy effectiveness is concerned with measuring and benchmarking the outcomes that energy policies have delivered (IRENA, 2012:7). The evaluation of policy effectiveness is country specific. A good example is found in the EU where there has been appetite for comparing policy approaches across nations within the context of successive directives and targets (IRENA, 2012:12)

Building codes have been noted to be one of the most effective pathways with respect to embedding NZEB-practice as they seek to address common barriers to energy efficient building design. The implementation of building codes has been achieved in the four case studies analyzed in Table 8 based on the principle of plan, implement, monitor and evaluate (as mapped in Chapter 2, Section 2.5). Within the EU, the effectiveness of the building codes has led to reduction in greenhouse gas emissions from buildings thus contributing to higher energy savings (Zhang et al. 2015). This is also noted in the case of Mexico where, the implementation of building codes and incentives has led to the reduction of energy cost as well as mitigating social inequalities produced by the electricity sector in its generation and use (Becqué, et al. 2019).

The effectiveness of responsive energy efficiency regulations in building codes is noted to be largely due to the fact that they set minimum requirements for building design, construction and operation to protect public health, safety and the natural resources (Vaughan, et al., 2013). In the US, these codes have also targeted environmental protection goal while reducing energy consumption and also contributing towards energy security (Perry 2018). This trend has also led to the promotion and advancement of availability of energy efficient building materials, equipment and technologies in a similar manner to the case of India (Jain, et al 2017).

Vaughan, et al. (2013) note that although these codes have been shown to be effective in some countries, their continued and sustained effectiveness lies in the regular upgrade of the codes to ensure that new products and practices make their way into building design and construction at the right time. Updating the codes every three years is therefore recommended as an optimal process to ensure that new technologies, materials and methods as well as better approach to health and safety can be incorporated into the next generation of buildings with sufficient time for proof of performance.

Insights towards pathways for South Africa

The building sector accounts for more than 25% of the GHG emissions of South African cities and as such, actions need to be taken to develop buildings that are energy efficient in order to reduce related emissions. It is expected that by the year 2030, about 70% of South Africans will be living in the cities and this is translating into increasing demand for housing, commercial buildings, office space, schools and hospitals among other building-types (C40 Cities Climate Leadership Group, 2018) To sustain the demand and to deliver on South Africa's commitments to the Paris Agreement on climate change, these buildings would need to meet high energy-efficiency performance standards, which thus necessitates the urgency for pursuing NZEBs.

Given that the concept of NZEBs is relatively new in South Africa, it has to overcome several barriers which confront any diffusion of innovations in any market. Currently, the country does not have any act, legislation or regulation that specifically govern the implementation of NZEBs even though the broader energy-efficiency policy and legislative frameworks are in place. These include the White Paper on Energy Policy for Republic of South Africa, 1998, Integrated Energy Plan 2003, National Energy Regulator Act of 40 of 2004, National Energy Bill 2004 and the National Climate Change Response Strategy 2004 among others, Milford, 2009). However, none of them specifically addresses the issues around the adoption of NZEBs.

The GBCSA was established in 2007 to oversee the voluntary development of green building solutions with energy-efficiency as one of the key components (GBCSA, 2007). This became a way forward for the building sector as it entails the implementation of the Green Star rating and certification system ranging from 1-Star to 6-Star. GBCSA also recently introduced the net-zero rating system (covering water, waste, ecology, carbon) with a total of 8 (eight) net-zero building certifications awarded so far. Six (6) of them are rated as net-zero carbon and the other two are rated as net-zero water and ecology. Only one out of the 6 has achieved both ecology and net zero carbon (GBCSA, 2007).

Whereas South Africa already has relatively well-developed climate change and energy-efficiency policies and legislative frameworks, the extent to which the frameworks can be linked to the building sector for the pursuit of achieving NZEBs has not been clearly defined (Milford, 2009). Insights from Sections 5.4.1 to 5.4.3 clearly indicate that countries that are making significant progress towards achieving NZEB are implementing their policies through mandatory regulations and other specific policy instruments such as fiscal incentives.

As noted in other countries, implementation of a combination of responsive policy instruments has been more effective and especially through the mandatory pathway (mainly demonstrated by the case of the EU). South Africa could therefore aim for a better way to enforce a mandatory approach and thus initiate the drive with instruments that have shown effectiveness within building sectors in other countries. Some of these policy instruments have been identified in the National Energy Strategy of South Africa and other draft policies and strategies but have not been developed further towards implementation. These include appliance standards; mandatory audit requirement and labelling as well as building energy performance certification programmes. Other proven international policies such as tax exemptions/reductions should also be adopted into South Africa’s framework to ensure success in the drive towards NZEBs.

The adoption of such policy instruments and the move from the current voluntary to mandatory policies would, in addition, ease the cost barrier for the development of NZEBs. The use of incentives would also significantly encourage developers and building owners towards the goal of NZE. Drawing from the reviewed literature and the findings of this study, the adoption of this initiative could act as a model to ensure that the government is leading the path towards NZEBs. This would in turn drive down cost and encourage energy efficient innovations in South Africa as well as boost investor-confidence in the drive to achieving NZE-practice in the country. The introduction of such incentives would thus constitute a major pathway to ensure adoption of the mandatory policies into the building bylaws and practices in the country.

Chapter 6: Consolidation of sub-findings and deriving overall findings of the study

6.1 Findings and overall conclusions

The study analyzed the energy-performance gap between a 6-Star green-rated commercial building in comparison with its simulated NZEB equivalent as a case study for South Africa. The study also looked at the pathway towards closing the gap and making NZEB-practice a reality for the country. This chapter consolidates the findings on each sub-question as substantiated in Chapters 4 and 5 in order to derive overall findings on the overall research question regarding the energy-performance gap between 6-Star green rated commercial buildings vis-a-vis their simulated NZEB performance and the desirable pathway towards the adoption and scaling up of NZEB practice in South Africa.

6.1.1 Sub-findings to Sub-question 1

Energy-performance gap between 6-Star and NZEBs in South Africa and the associated climate-change mitigation potential

In order to address the sub-question, one important consideration was a clear understanding of the climatic conditions of the study area, especially with regard to varying temperature cycle (daily, seasonal and annual cycles). Psychrometric chart analyses for Pretoria gave insight on opportunities for achieving thermal comfort by passive thermal control strategies and interventions.

The analyses indicated that the design of buildings in the study area would attain a thermal comfort of an average of 39% on an annual basis and on full optimization of passive design strategies, the overall energy loads would be reduced leading to a thermal comfort of about 83% annually. However, a further reduction of the energy load is also achievable by means of plug load and motion sensors. Based on this, a performance gap of about 17% between the 6-star rated DEA Building and a NZEB of the same size in Pretoria was derived.

Based on full optimization of passive design and energy efficiency strategies, *Edge-*

tool simulation results indicate that a NZEB of the same size (and for the same climatic zone) would achieve an energy-performance level of 45kWh/m^2/yr. This translates to 59.8% (1 839 142.01kWh/yr) savings on status quo performance and an energy-efficiency performance gap of 67kWh/m^2/yr. The simulation results also showed that the payback period of both types of investment would be 5-years for the 6-star rated versus conventional building and 4-years for the NZEB versus 6-star rated building.

The building can therefore feasibly attain a NZE rating since reliance on non-renewable source of energy can be reduced to zero. The energy needs would therefore be met through passive design strategies and reliance on renewable source (roof-top solar-PV) for the generation of the energy-balance which was estimated to be 45kWh/m^2/yr. The key sub-finding for the sub-question is that an energy efficiency performance gap of 67kWh/m^2/yr does exist between a 6-star rated model versus a NZEBs version of the building.

6.1.2 Sub-findings to Sub-question 2

Cost savings associated with 6-star and NZEBs

The 6-star rated building as well as the NZEB were deemed to perform well in terms of their energy efficiency while also facilitating cost-savings. The energy-performance and cost-saving potential depends on the level of passive and active interventions implemented on the 6-star and NZEB respectively.

The cost savings are mostly dependent on the utility-cost. Based on the *Edge*-tool simulation, a cost-saving estimate of R 201 141.68 /Month (based on cost annual energy-consumption reduction savings of R 2 413 700.16/yr.) was derived. The derivation of the payback period of both buildings was based on the *Edge* Tool using the simple payback formula where simple payback period = IC_0/ CF_1 as pointed out in Section 5.2. The estimated payback period is between 4 years for the 6-star to NZEB interventions and 5 years for the conventional to 6-star rated building interventions.

With respect to the cost-saving potential, the study finds that due to the level of technology utilized in both building types, the cost associated with these buildings are relatively higher than the cost of a notional SANS 204 building (hence the cost-premium principle). In response to the overall research question, the NZEB would however provide improved thermal comfort at lower energy-use intensity than the 6-star rated building due to full optimization of passive design strategies thereby creating the performance gap between the 6-star and NZEBs.

6.1.3 Sub-findings to Sub-question 3

Addressing technical, market and cost barriers from 6-star to NZEBs enhancement practices

Even though NZEBs can be theoretically demonstrated to be efficient in terms of energy-demand and thermal comfort performance, their adoption and scale-up in the property market is inhibited by a complex set of barriers which hinder implementation in practice. The barriers include higher construction costs, inadequate government policies and regulations for energy-efficient/NZE buildings.

The study finds that inadequate relevant skills and expertise across the construction sector as well as inadequate knowledge of the rapidly evolving technologies as well as uncertainty about the performance of the new technologies has been a major barrier. Training of professionals and other stakeholders (such as workers responsible for the execution of on-site activities) in NZEB design and construction would thus empower the actors in terms of design and decision-making on innovations and technologies towards achieving NZEB. The absence of this kind of intervention is likely to translate into cost increases, inadequate optimization of strategies as well as economic under-performance of the building and may also result in non-integrated design process that would in turn serve as disincentive for further adoption and diffusion. The study also found that lack of knowledge or experience in the control systems and in new technologies by the operation and maintenance staff may generate unexpected costs in operation and maintenance.

Inadequate government policies and regulations for energy-efficient/NZEBs was also noted from the study as a barrier and it was found that government has a significant role towards ensuring responsive and up to date policies in support of pursuing NZEBs goals. Addressing this barrier requires government to provide stable and continuing policy reforms on energy efficiency at national and regional levels as well as creating roadmaps at regional levels in collaboration with all stakeholders. It was noted that by taking the lead and also providing incentives to support the pursuit of NZEBs government could assist in creating public and builder awareness of the benefits associated with NZEBs.

6.1.4 Sub-findings to Sub-question 4

Desirable pathway from voluntary to mandatory NZEBs for South Africa

Policy initiatives are crucial towards ensuring the transition from the status quo voluntary implementation of NZEBs to a mandatory regime. As pointed out earlier, this pathway has been adopted by several countries to ensure compliance towards the goal of reducing GHG emissions through lowering energy-use in buildings.

Such policy initiatives must be embedded into law coupled with systematic regulations to ensure compliance by all in design, construction and management of buildings towards achieving NZE performance. Whilst South Africa currently has a policy framework and regulations on energy efficiency for new buildings, this has not yet translated into a bold policy on NZEBs across new and existing building sub-sectors. To actualize this, it is essential that a roadmap is developed with clear targets towards NZEB-performance within a set time-horizon.

6.2 Consolidation of sub-findings into overall findings and conclusion

The study primarily focused on assessing the energy efficiency gap between 6-Star rated buildings versus NZEBs for South Africa. As part of the study objectives, the study assessed the effects of full optimization of passive design and energy efficiency strategies on the final energy-use of a commercial building, the cost savings as well as barriers and responsive policy pathways towards energy-use reduction through NZEBs.

Secondary data on case study building show that the building's status quo energy-use intensity is 112kWh/m^2/yr. Within the temperate-interior climatic zone for

Pretoria (as per energy efficiency regulations for buildings in South Africa), psychometric chart analyses showed that at a 6-star rating, the building had achieved full optimization of passive design interventions relative to thermal comfort.

Edge-tool simulation results on full optimization of passive design and energy efficiency interventions indicate that an NZEB of the same size could achieve an energy performance level of 45kWh/m^2/yr, thus revealing an energy performance gap of 67kWh/m^2/yr. This translates to 60% savings compared to the status quo 6-star performance of 3 076 291kWh/yr. Assessment of roof-area for solar PV system indicated it is adequate for generating the energy balance towards a NZEB. The analyses carried out in the study clearly demonstrates that, with full optimization of passive design and energy efficiency strategies, an NZEB in the climatic zone for Pretoria can achieve a significantly improved energy performance when compared to a 6-star rated green building.

In addition to energy-use reduction, the study established that within a NZEB-model, the DEA Building would achieve a cost saving of R 1 604 604.80/yr based on utility cost reduction as derived from *Edge*-tool simulation (see Table 10). The cost-savings were then applied towards the assessment of simple payback period per intervention which showed 4 years for tenant lighting, 3 years for tenant equipment (PPLs) and 5 years for PV-installation. The findings indicate that payback period for most of the intervention-costs for migration to NZEB fall within the acceptable range for South African investors (a majority of whom would accept a maximum of 3 to 5 years). Bearing in mind that PV-technology costs are expected to continue declining, payback period for PV-installation can be expected to fall within the acceptable range of 3-5-years in another 5 to 10-years.

The study further identified that the adoption and implementation of policy at national and regional government levels would be a major pre-requisite for ensuring that NZEBs become mandatory rather than voluntary. The study also identified that the principles of setting energy targets, designing and building to the set target, as well as monitoring and diagnosis during operational phase constitutes a major factor towards achieving consistency in NZEB-performance.

The study found that the energy use of the building largely depends on the equipment used, and that most of the equipment in DEA Building are not EPA-rated, thus contributing largely to the building's energy demand. A requirement for all tenant equipment to be EPA-rated (primarily through mandatory equipment energy-consumption standards or similar national level regulation) would thus constitute a key element towards ensuring the attainment of NZEB-performance. The study also established that the process of power buy-back to the grid is crucial towards attaining and maintaining the NZEB-performance and as such, respective power utilities as well as the relevant municipal distributors should be engaged to support the initiatives in order to offset energy usage with credit for energy exported to the grid in order to further incentivize NZEBs.

In conclusion, a clear energy-performance gap does exist as per the analysis and based on the case study, a gap of 67kWh/ m^2/yr has been indicated for this case and this accounts for a need to purse the agenda for the adoption and scaling-up of NZEB practice in South Africa.

6.3 Recommendation for further research

Based on the analysis of energy performance and all other insights drawn from the study, further research is needed towards aligning the built environment professionals, government and the general public toward a concerted effort in advancing the target of achieving NZE in all existing and new buildings. This section highlights the key issues identified for further research. The recommendations are based on the following key issues:

- Policy framework
- Coverage of other climatic zones of South Africa
- Improved data on cost of NZEBs
- Impact of local materials on the overall cost of NZEBs.

With regard to policy framework, the study looked into various policies that are paving the way for the adoption and implementation of the concept of NZEBs in other countries. Further research is therefore required towards evolving more specific policies and regulations for the adoption and implementation of NZEBs in South Africa. Such studies would highlight the best pathway for the adoption of energy efficiency frameworks towards mandatory NZEBs standards and regulations.

On climatic zones, whereas the temperate-interior climatic zone has been the focus of this study, energy efficiency regulations for buildings in South Africa recognizes a total of six (6) climatic zones. To ensure a country wide adoption of the NZEB concept, it is imperative that similar studies are carried out in the other climatic regions in order to consolidate a more comprehensive perspective of viability across the different zones.

Further studies would also be needed towards a clear understanding of the actual cost of NZEBs as most of the available data are based on extremely few cases of constructed NZEBs which do not allow for generalizations across diverse countries and regions. The absence of such systematic data has been one of the main limitations of this study as this has impact on decisions regarding the initial investment cost as well as assessing the payback period. On payback period, it is recommended that detailed studies be carried out based on payback period per intervention rather than a payback period of the entire development. Such studies would ensure that cumulative data per intervention are systematically tracked thereby easing viability assessment by developers and investors as well as the design professionals. Such studies could also extend into the more comprehensive full life-cycle cost analyses within specific climatic zones.

The implementation of NZEBs in South Africa to date heavily relies on imported equipment and technologies. This has direct impact on the total construction cost as well as overall viability of NZEBs. Further research towards related cost-mitigation through localized materials, equipment and technologies would therefore play a major role towards expediting the adoption of NZEBs practice in the country.

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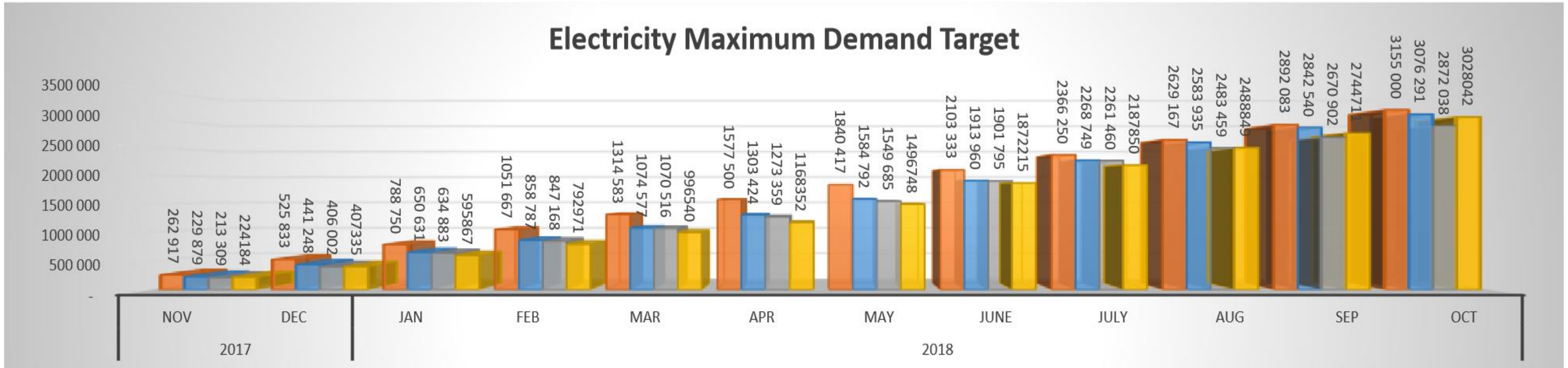
Appendix A:

Electricity maximum demand/electricity consumption target and on-site renewable target

Electricity Maximum Demand

As defined in the energy consumption baseline model and as defined in the PPP-Agreement to be 3155000kWh/yr

The chart below indicates the contractual obligation target compared to the actual performance accumulated on a monthly basis.



	2017		2018									
	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct
Target Kwh/Month Accumulated	262 917	525 833	788 750	1051 667	1314 583	1577 500	1840 417	2103 333	2366 250	2629 167	2892 083	3155 000
Actual Usage Kwh/Month Accumulated	229 879	441 248	650 631	858 787	1074 577	1303 424	1584 792	1913 960	2268 749	2583 935	2842 540	3076 291
Previous year Actual Usage Kwh/Month Accumulated (2015/2016)	213 309	406 002	634 883	847 168	1070 516	1273 359	1549 685	1901 795	2261 460	2483 459	2670 902	2872 038
Previous year Actual Usage Kwh/Month Accumulated (2016/2017)	224184	407335	595867	792971	996540	1168352	1496748	1872215	2187850	2488849	2744711	3028042

Items to note: The maximum energy demand consumption is within the demand target.

Electricity Maximum Demand Target									
Year	Month	Solar Usage (kWh)	Council Usage (kWh)	Total Usage (kWh)	Actual usage kWh/month accumulated	Target kWh/month	Target kWh/month accumulated	Previous Year Actual Usage kWh/month accumulated (2015/2016)	Previous Year Actual usage kWh/month accumulated (2016/2017)
2017	Nov	43059	186 820	229 879	229 879	262 917	262 917	213 309	224184
	Dec	36771	174 598	211 369	441 248	262 917	525 833	406 002	407335
2018	Jan	43731	165 652	209 383	650 631	262 917	788 750	634 883	595867
	Feb	31194	176 962	208 156	858 787	262 917	1051 667	847 168	792971
	Mar	37366	178 424	215 790	1074 577	262 917	1314 583	1070 516	996540
	Apr	31040	197 807	228 847	1303 424	262 917	1577 500	1273 359	1168352
	May	34244	247 124	281 368	1584 792	262 917	1840 417	1549 685	1496748
	June	30631	298 538	298 538	1913 960	262 917	2103 333	1901 795	1872215
	July	27912	326 876	354 788	2268 749	262 917	2366 250	2261 460	2187850
	Aug	35455	279 731	315 186	2583 935	262 917	2629 167	2483 459	2488849
	Sep	39003	219 602	258 605	2842 540	262 917	2892 083	2670 902	2744711
	Oct	34406	199 345	233 751	3076 291	262 917	3155 000	2872 038	3028042
2017/2018	Total for the 12-month period	424812	2651479	3076291		3155 000			

Formulas:

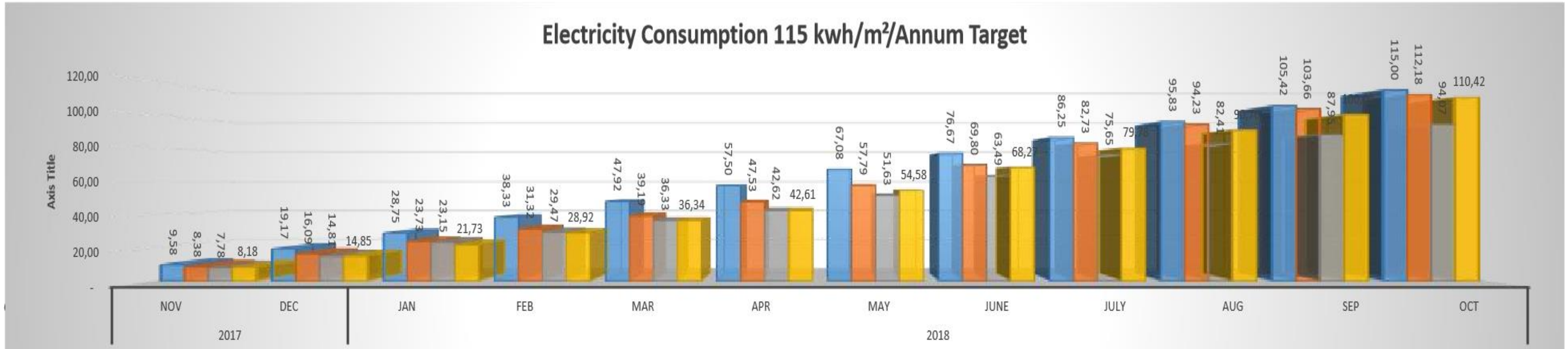
Target kWh/m²/month = 3,155,000/12

kWh/m²/month = solar usage (kWh)/27 422 m²

Electricity consumption

115kWh/m^2/yr of which 10% shall be renewable energy

The chart below indicates the comparison between the targeted 115 kwh/m²/yr consumption and the actual energy consumption accumulated on a monthly basis.



	2017		2018									
	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct
Target Kwh/m²/Month Accumulated	9,58	19,17	28,75	38,33	47,92	57,50	67,08	76,67	86,25	95,83	105,42	115,00
Actual Kwh/m²/Month Accumulated	8,38	16,09	23,73	31,32	39,19	47,53	57,79	69,80	82,73	94,23	103,66	112,18
Previous year Actual Kwh/m²/Month Accumulated (2015/2016)	7,78	14,81	23,15	29,47	36,33	42,62	51,63	63,49	75,65	82,41	87,95	94,07
Previous year Actual Kwh/m²/Month Accumulated (2016/2017)	8,18	14,85	21,73	28,92	36,34	42,61	54,58	68,27	79,78	90,76	100,09	110,42

Items to note:

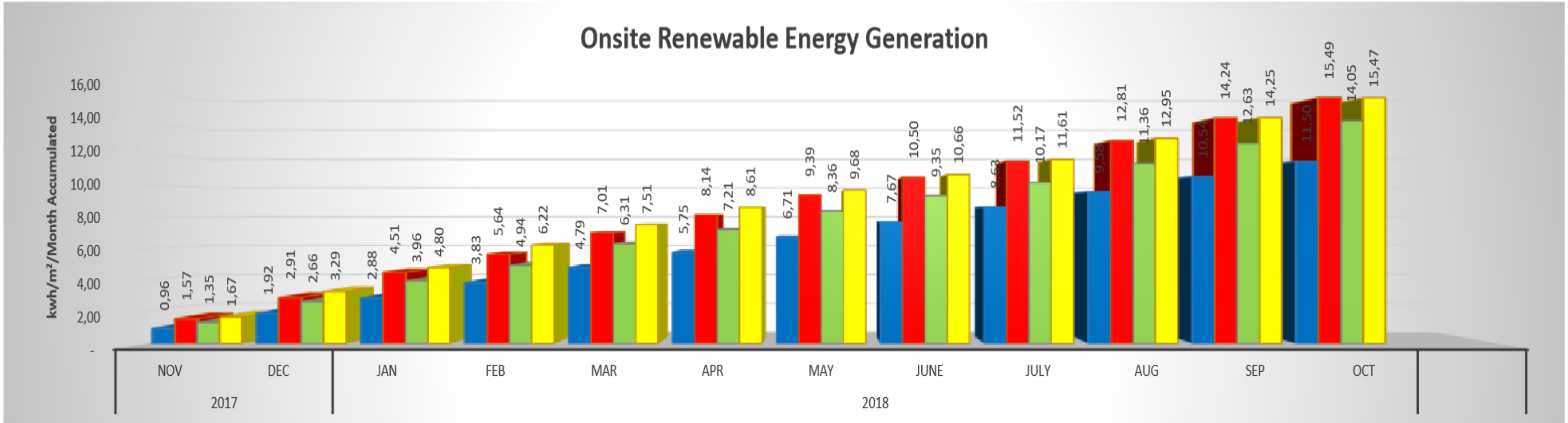
- The electricity consumption of not more than 115kWh/m²/yr was under with an actual of 112,18 kwh/m²/yr.

Electricity Consumption 115 kwh/m2/Annum Target										
Year	Month	Solar Power Usage (kwh)	Council Usage (kWh)	Total Usage (kWh)	Target kWh/Month	Target kWh/ m2/Month	Target kWh/m2/month accumulated	Target kWh/m2/month actual	Previous Year Actual Usage kWh/m2/Month Accumulated (2015/2016)	Previous Year Actual Usage kWh/m2/Month Accumulated (2016/2017
2017	Nov	43 059	186820	229879	9,58	9,58	8,38	8,38	7,78	8,18
	Dec	36 771	174598	211369	9,58	19,17	7,71	16.09	14,81	14,84
2018	Jan	43 731	165652	209383	9,58	28,75	7,64	23,73	23,15	21,73
	Feb	31 194	176962	208156	9,58	38,33	7,59	31,32	29,47	28,92
	Mar	37 366	178424	215790	9,58	47,92	7,87	39,19	36,33	36,34
	Apr	31 040	197807	228847	9,58	57,50	8,35	47,53	42,62	42,61
	May	34 244	247124	281368	9,58	67,08	10,26	57,79	51,63	54,58
	June	30 631	298538	329169	9,58	76,67	12,00	69,80	63,49	68,27
	July	27 912	326876	354788	9,58	86,25	12,94	82,73	75,65	79,78
	Aug	35 455	279731	315186	9,58	95,83	11,49	94,23	82,41	90,76
	Sep	39 003	219602	258605	9,58	105,42	9,43	103,66	87,95	100,09
	Oct	34 406	199345	233751	9,58	115,00	8,52	112,18	94,07	110,42
2017/2018	Total for 12-month period	424812	2651 479	3076 291	115,00		112,18			

Formulas:
Target kwh/m²/month = 115kWh/m²/yr
Actual kWh/m²/month = Actual power usage (kWh) / 27 422m²

Onsite renewable energy generation 11.5 kWh/m²/yr

The chart below indicates the contractual obligation target compared with the actual performance of the building accumulated on a monthly basis.



	2017		2018									
	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct
Target Solar Kwh/m²/Month Accumulated	0,96	1,92	2,88	3,83	4,79	5,75	6,71	7,67	8,63	9,58	10,54	11,50
Solar Kwh/m²/Month Accumulated (2017/2018)	1,57	2,91	4,51	5,64	7,01	8,14	9,39	10,50	11,52	12,81	14,24	15,49
Previous year actual Solar Kwh/m²/Month Accumulated (2016/2017)	1,35	2,66	3,96	4,94	6,31	7,21	8,36	9,35	10,17	11,36	12,63	14,05
Previous year actual Solar Kwh/m²/Month Accumulated (2015/2016)	1,67	3,29	4,80	6,22	7,51	8,61	9,68	10,66	11,61	12,95	14,25	15,47

Items to Note:

The renewable energy generation performance has exceeded the target of 115 kWh/m²/yr for the year by 15.49 kWh/m²/yr

Onsite Renewable Energy Generation								
Year	Month	Solar Power Usage (kwh)	Target Solar kWh/m2/ Month	Target Solar kWh/m2/Month/ Accumulated	Solar kWh/m2/ Month	Solar kWh/m2/ Month/ Accumulated (2017/2018)	Previous year actual solar kWh/m2/Month accumulated (2015/2016)	Previous year actual solar kWh/m2/Mo nth accumulated (2015/2016)
2017	Nov	43 059	0,96	0,96	1,57	1,57	1,67	1,35
	Dec	36 771	0,96	1,92	1,34	2,91	3,29	2,66
2018	Jan	43 731	0,96	2,88	1,59	4,51	4,80	3,96
	Feb	31 194	0,96	3,83	1,14	5,64	6,22	4,94
	Mar	37 366	0,96	4,79	1,36	7,01	7,51	6,31
	Apr	31 040	0,96	5,75	1,13	8,14	8,61	7,21
	May	34 244	0,96	6,71	1,25	9,39	9,68	8,36
	June	30 631	0,96	7,67	1,12	10,50	10,66	9,35
	July	27 912	0,96	8,63	1,02	11,52	11,61	10,17
	Aug	35 455	0,96	9,58	1,29	12,81	12,95	11,36
	Sep	39 003	0,96	10,54	1,42	14,24	14,25	12,63
	Oct	34 406	0,96	11,50	1,25	15,49	15,47	14,05
2017/2018	Total for 12-month period		11,50		15,49			

Formulas:

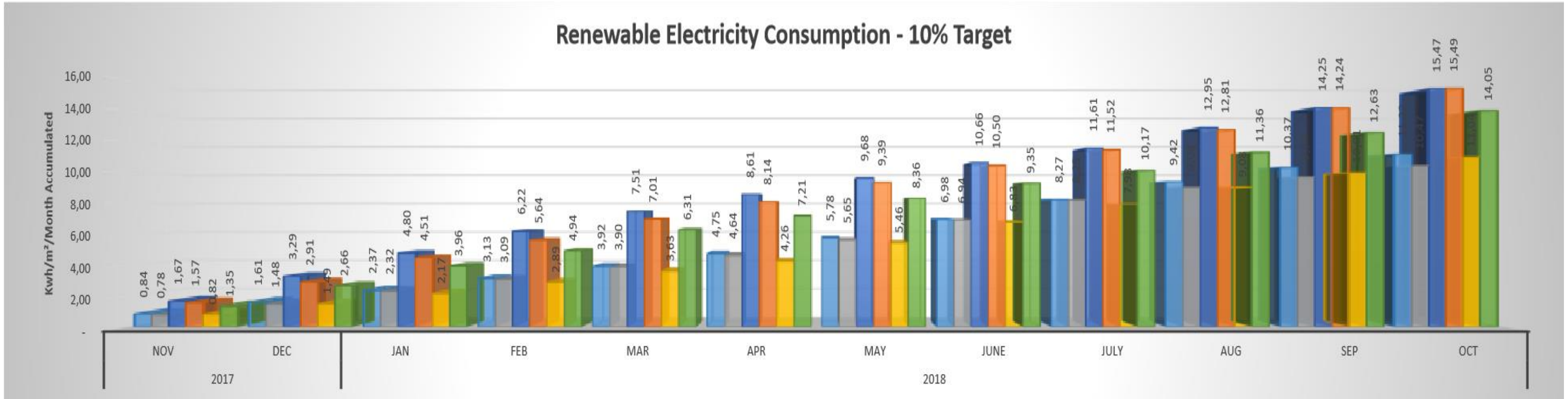
Target Solar kWh/m²/month = 115kWh/m²/yr

Solar kWh/m²/month = Solar power usage (kWh) / 27 422m2

Electricity consumption

115kWh/m2/yr of which 10% shall be renewable energy

The chart below indicates the comparison between the targeted (10% renewable energy of the actual consumption) and the actual renewable consumption accumulated on a monthly basis.



	2017		2018									
	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct
Target 10% of Total Usage Kwh/m²/Month Accumulated	0,84	1,61	2,37	3,13	3,92	4,75	5,78	6,98	8,27	9,42	10,37	11,22
Previous year Actual Target 10% of Total Usage Kwh/m²/Month Accumulated (2015/2016)	0,78	1,48	2,32	3,09	3,90	4,64	5,65	6,94	8,25	9,06	9,74	10,47
Previous year Actual Solar Usage Kwh/m²/Month Accumulated (2015/2016)	1,67	3,29	4,80	6,22	7,51	8,61	9,68	10,66	11,61	12,95	14,25	15,47
Actual Solar Usage Kwh/m²/Month Accumulated	1,57	2,91	4,51	5,64	7,01	8,14	9,39	10,50	11,52	12,81	14,24	15,49
Previous year Actual Target 10% of Total Usage Kwh/m²/Month Accumulated (2016/2017)	0,82	1,49	2,17	2,89	3,63	4,26	5,46	6,83	7,98	9,08	10,01	11,04
Previous year Actual Solar Usage Kwh/m²/Month Accumulated (2016/2017)	1,35	2,66	3,96	4,94	6,31	7,21	8,36	9,35	10,17	11,36	12,63	14,05

Items to Note:

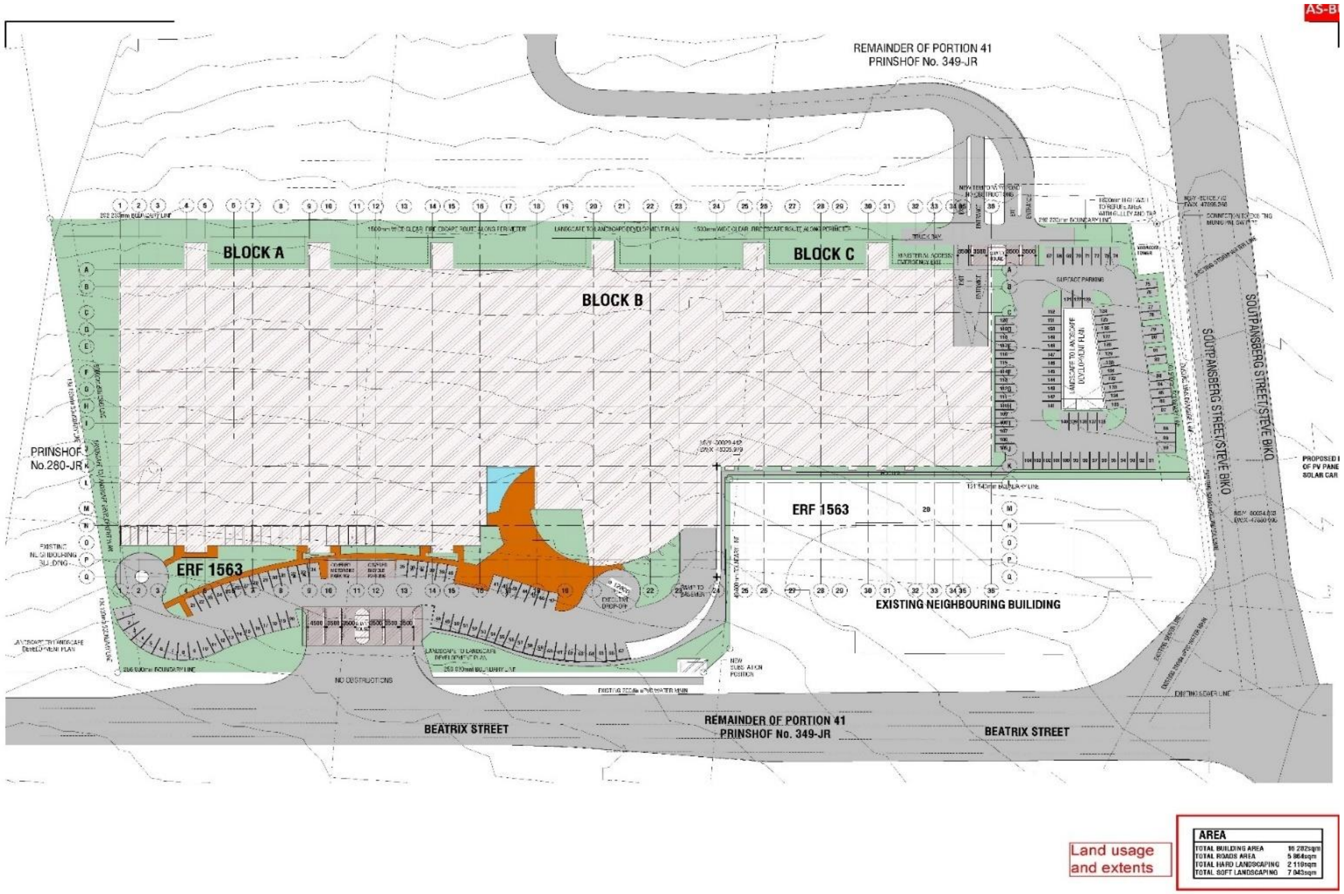
The renewable electricity consumption for October was 14.71% of the building’s total consumption.

Renewable Electricity Consumption-10% Target												
Year	Month	Solar Usage (kwh)	Council Usage (kwh)	Total Usage (kwh)	Target kWh/ m2/M onth	Target 100% of Total Usage kWh/m2/Mont h Accumulated	Actual kWh/m 2/Mont h	Actual Solar Usage kWh/m2/ Month Accumul ated	Previous year Actual Target - 10% of Total Usage kWh/m2/Mont h Accumulated (2015/2016)	Previous year Actual Solar Usage kWh/m2/Mont h Accumulated (2015/2016)	Previous year Actual Target 10% of Total Usage kWh/m2/ Month Accumulated (2016/2017)	Previous year Actual Solar Usage kWh/m2/Mont h Accumulated ((2016/2017)
2017	Nov	43 059	186 820	229 879	0,84	0,84	1,57	1,57	0,78	1,67	0,82	1,35
	Dec	36 771	174 598	211 369	0,77	1,61	1,34	2,91	1,48	3,29	1,49	2,66
2018	Jan	43 731	165 652	209 383	0,76	2,37	1,59	4,51	2,32	4,80	2,17	3,96
	Feb	31 194	176 962	208 156	0,76	3,13	1,14	5,64	3,09	6,22	2,89	4,94
	Mar	37 366	178 424	215 790	0,79	3,92	1,36	7,01	3,90	7,51	3,63	6,31
	Apr	31 040	197 807	228 247	0,83	4,75	1,13	8,14	4,64	8,61	4,26	7,21
	May	34 244	247 124	281 368	1,03	5,78	1,25	9,39	5,65	9,68	5,46	8,36
	June	30 631	298 538	329 169	1,20	6,98	1,12	10,50	6,94	10,66	6,83	9,35
	July	27 912	326 876	354 788	1,29	8,27	1,02	11,52	8,25	11,61	7,98	10,17
	Aug	35 455	279 731	315 186	1,15	9,42	1,29	12,81	9,06	12,95	9,08	11,36
	Sep	39 003	219 602	258 605	0,94	10,37	1,42	14,24	9,74	14,25	10,01	12,63
	Oct	34 406	199 345	233 751	0,85	11,22	1,25	15,49	10,47	15,47	11,04	14,05
2017/ 2018	Total for 12-month period	424 812	2 651 479	3 076 291	11,22		15,49					

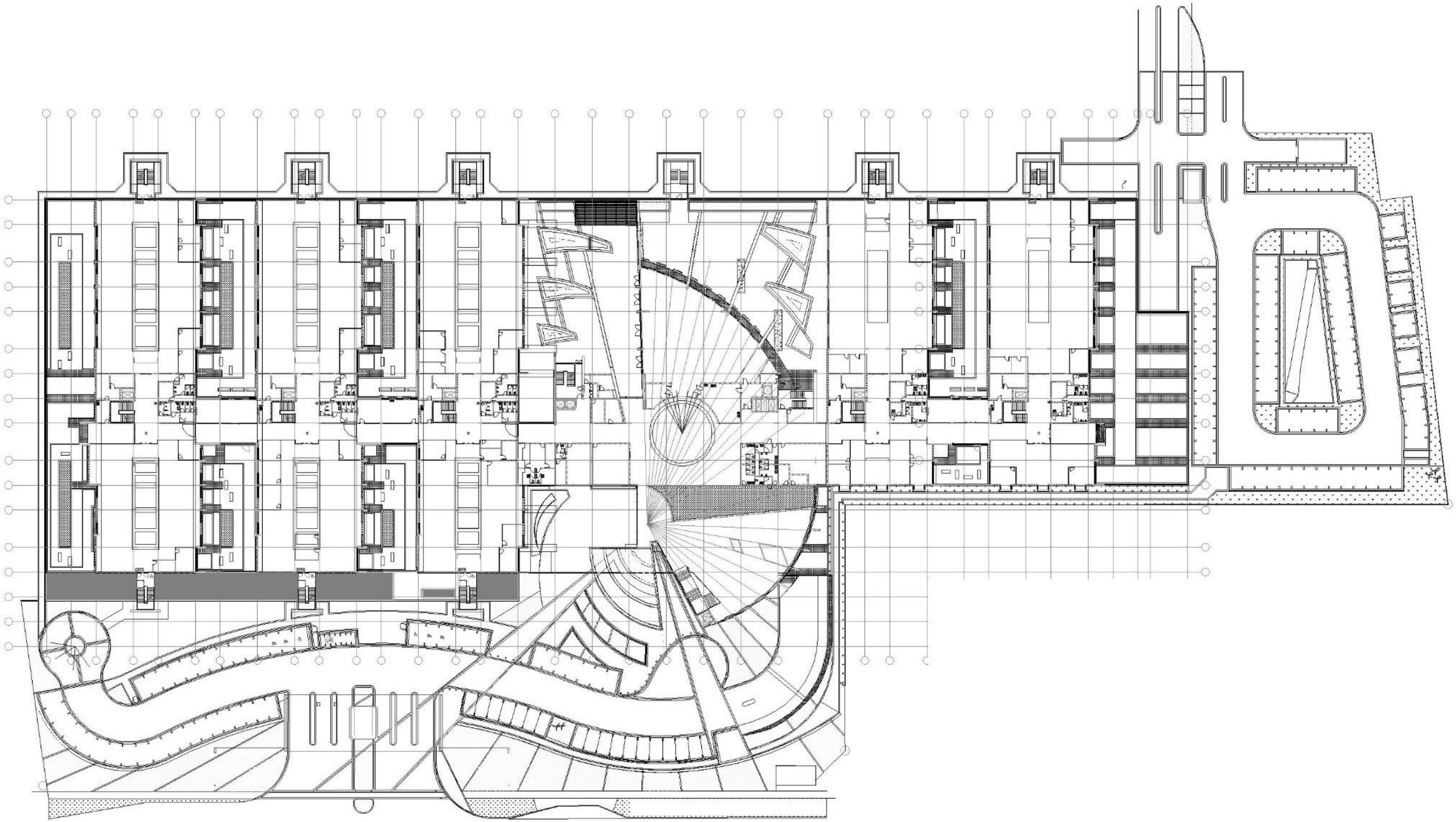
The renewable electricity consumption for year to date is 13.80% of the building's total consumption.

Appendix B

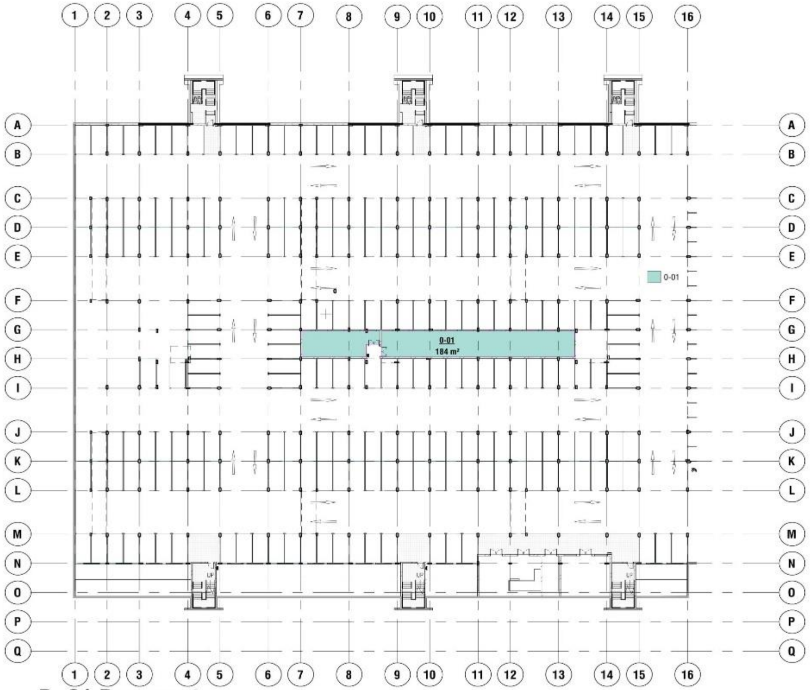
Case study building plans (adapted from architect's "as-built" drawings)



Site Plan Layout



Typical Floor Plan for all Floors

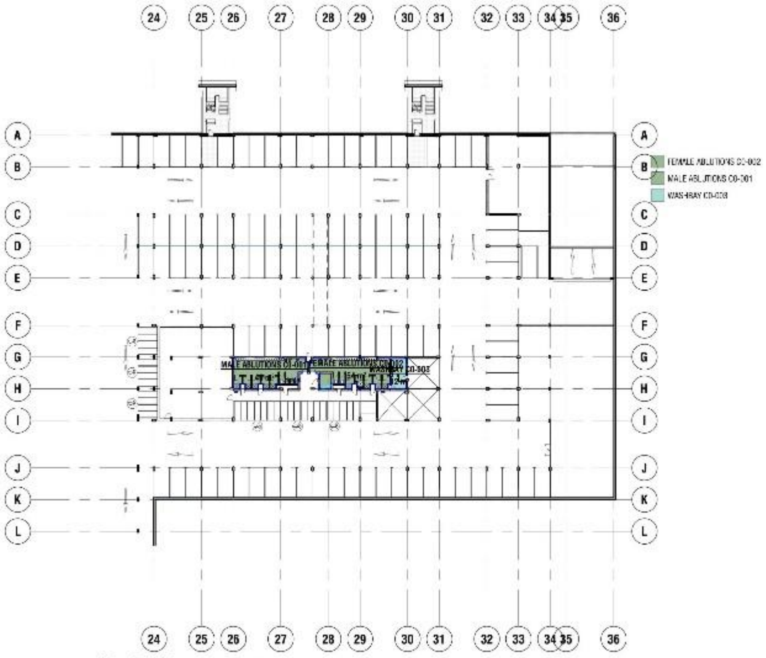


B -01 Basement

SCALE: **1 : 500**

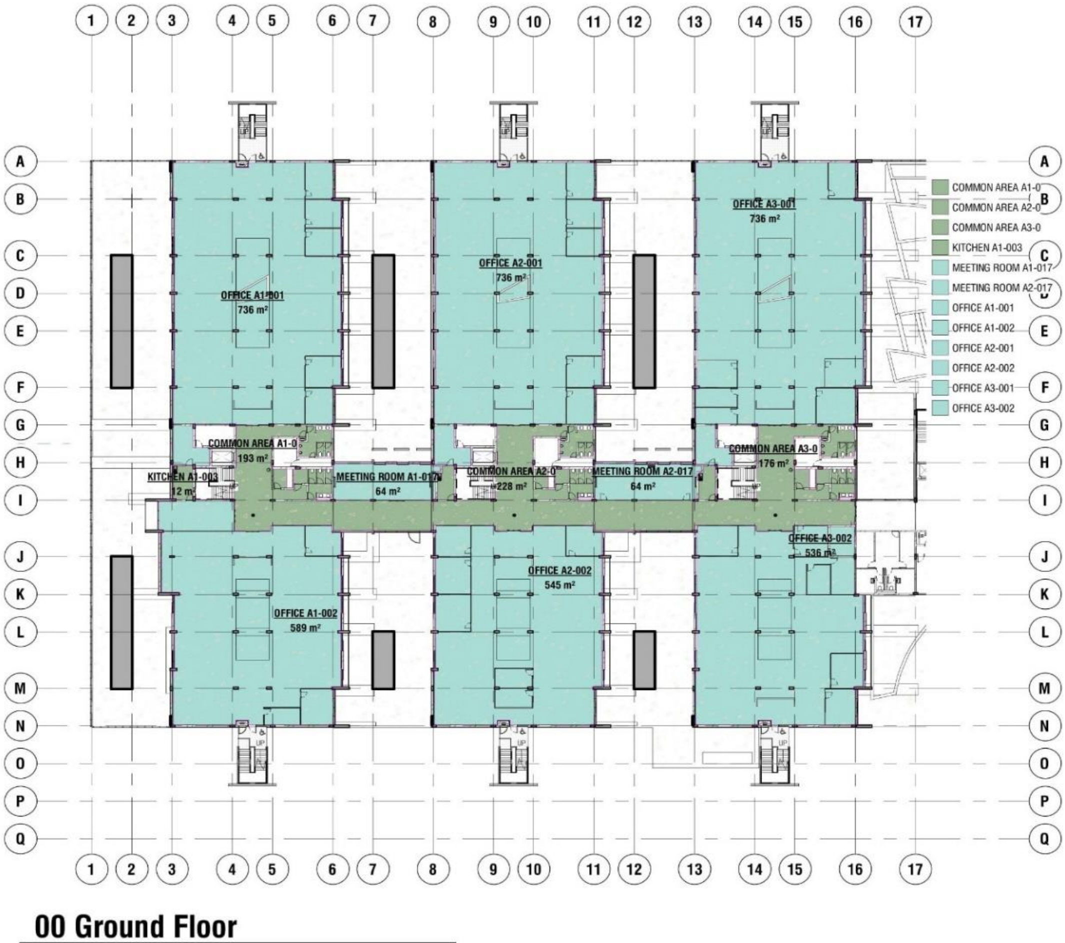
B -01 Basement

SCALE: **1 : 500**



B -01 Basement

SCALE: 1 : 500



00 Ground Floor

SCALE: 1 : 500

Ground Floor Layout: Typical for First and Second Floor

Ground Floor Layout: Typical for First and Second Floor

00 Ground Floor

SCALE: 1 : 500

00 Ground Floor

SCALE: 1 : 500

Appendix C

Edge Tool Assessment for 6-star rated DEA Building and input data

Subproject Name: DEA-Academic Research Work 42.14% | 39.40% | 20.52%

Final Energy Use (kWh/Month)
256,730.46

Final Water Use (m³/Month)
2,975.00

Base Case Utility Cost (ZAR/Month)
978,806.93

Utility Cost Reduction (ZAR/Month)
412,990.63

Energy Savings (MWh/Year)
2,234.76

Embodied Energy in Materials Savings (GJ)
14,663.42

Carbon Emissions (tCO_2/Year)
1,766.30

Operational CO_2 Savings (tCO_2/Year)
1,286.22

Embodied Energy Savings (MJ/m²)
681.45

Incremental Cost (ZAR)
40,889,228.84

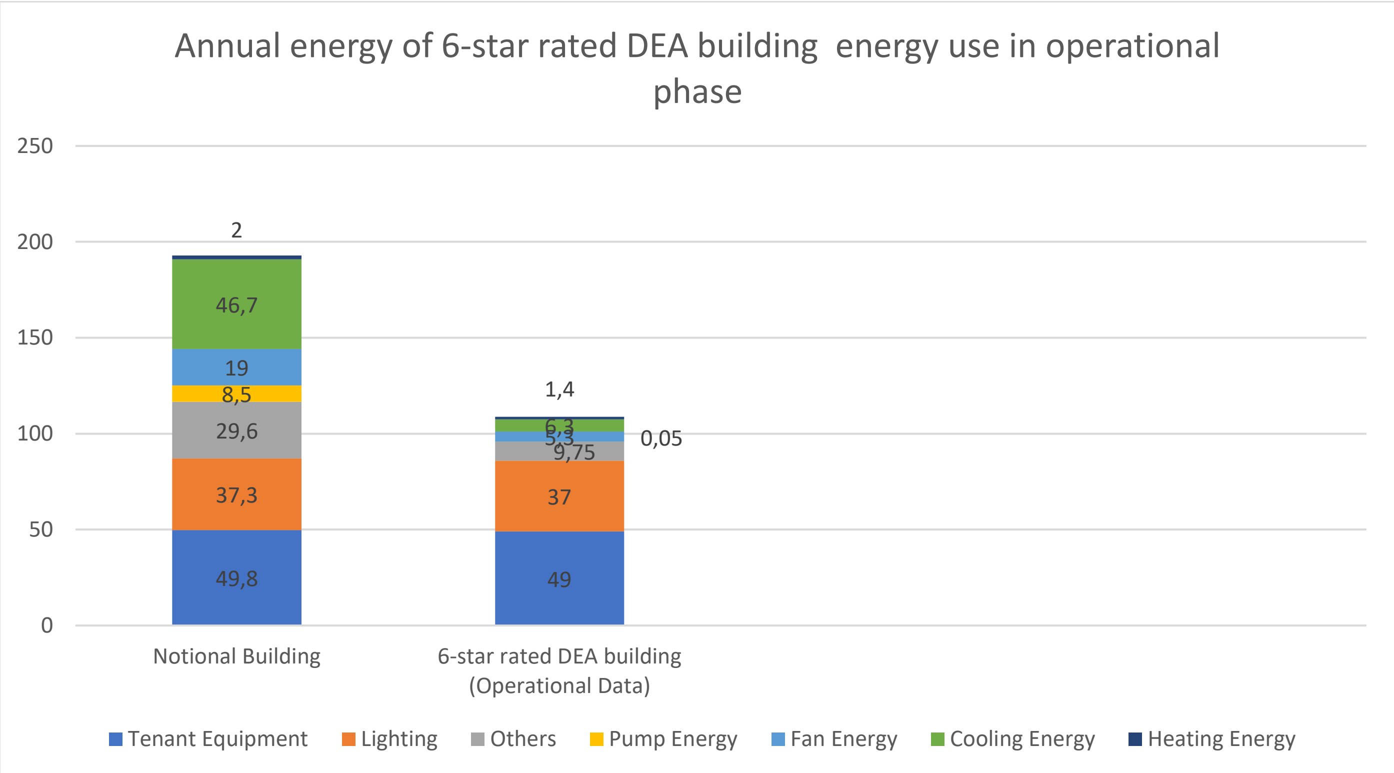
Payback in Years (Yrs.)
5.3

Water Savings (m³/Year)
16,765.65

Total Subproject Floor Area (m²)
27,258

ENERGY SAVINGS **EDGE ADVANCED**

Energy Efficiency Measures 42.14% **Meets EDGE Energy Standard**



Energy Efficiency Measures 42.14%

OFE01 Reduced Window to Wall Ratio - WWR of 30%

OFE02 Reflective Paint/Tiles for Roof - Solar Reflectivity (albedo) of 0.7

OFE03 Reflective Paint for External Walls - Solar Reflectivity (albedo) of 0.7

✓ OFE04 External Shading Devices - Annual Average Shading Factor (AASF) of 0.61

AASF 0.61

✓ OFE05 Insulation of Roof : U-value of 0.2

W/m².K 0.2

✓ OFE06 Insulation of External Walls : U-value of 0.3

W/m².K 0.3

OFE07 Low-E Coated Glass : U-value of 3 W/m².K and SHGC of 0.45

✓ OFE08 Higher Thermal Performance Glass : U- value of 1.5 W/m².K and SHGC of 0.32

W/m².K 1.5 SHGC 0.32

OFE09 Natural Ventilation with Operable Windows and No A/C

OFE10 Ceiling Fans for Office Spaces

OFE11 Variable Refrigerant Flow (VRF) Cooling System - COP of 3.5

OFE12 Air Conditioning with Air Cooled Screw Chiller - COP of 3.3

OFE13 Air Conditioning with Water Cooled Chiller - COP of 6.71

OFE14 Ground Source Heat Pump - COP of 5.2

OFE15 Absorption Chiller Powered by Waste Heat - COP of 0.7 OFE16 Radiant Cooling and Heating System - COP of RC 7.19

OFE17 Recovery of Waste Heat from the Generator for Space Heating

OFE18 Variable Speed Drives on the Fans of Cooling Towers

✓ OFE19 Variable Frequency Drives in AHUs

OFE20 Variable Speed Drives Pumps

OFE21 Sensible Heat Recovery from Exhaust Air - Efficiency of 60%

OFE22 High-Efficiency Boiler for Space Heating - Efficiency of 90%

✓ OFE23 Air Economizers During Favorable Outdoor Conditions

✓ OFE24 Energy-Saving Light Bulbs - Internal Spaces

✓ OFE25 Energy-Saving Light Bulbs - External Spaces

OFE26 Lighting Controls for Corridors and Staircases

✓ OFE27 Occupancy Sensors in Bathrooms, Conference Rooms, and Closed Cabins

✓ OFE28 Occupancy Sensors in Open Offices

✓ OFE29 Daylight Photoelectric Sensors for Internal Spaces

OFE30 Solar Photovoltaics - 25% of Total Energy Use

OFE31 Other Renewable Energy for Electricity Generation

OFE32 Offsite Renewable Energy Procurement - Equal to 100% of total Operational CO2

OFE33 Carbon Offset - 100% of Total CO_2

Appendix D

Edge Tool Assessment DEA NZEB and input data

Subproject Name: DEA Research Final 2020

67% | 46.53% | 21.06%

Results

Final Energy Use (kWh/Month) 103,095.74

Operational CO_2 Savings (tCO_2/Year) 1,177.27

Final Water Use (m^3/Month) 2,441.84

Embodied Energy Savings (MJ/m^2) 699.47

Base Case Utility Cost (ZAR/Month) 412,990.63

Incremental Cost (ZAR) 41,098,476.40

Utility Cost Reduction (ZAR/Month) 367,720.94

Payback in Years (Yrs.) 4.

Energy Savings (MWh/Year) 1,839.44

Water Savings (m^3/Year) 18,413.42

Embodied Energy in Materials Savings (GJ) 15,051.11

Total Subproject Floor Area (m^2) 27,258

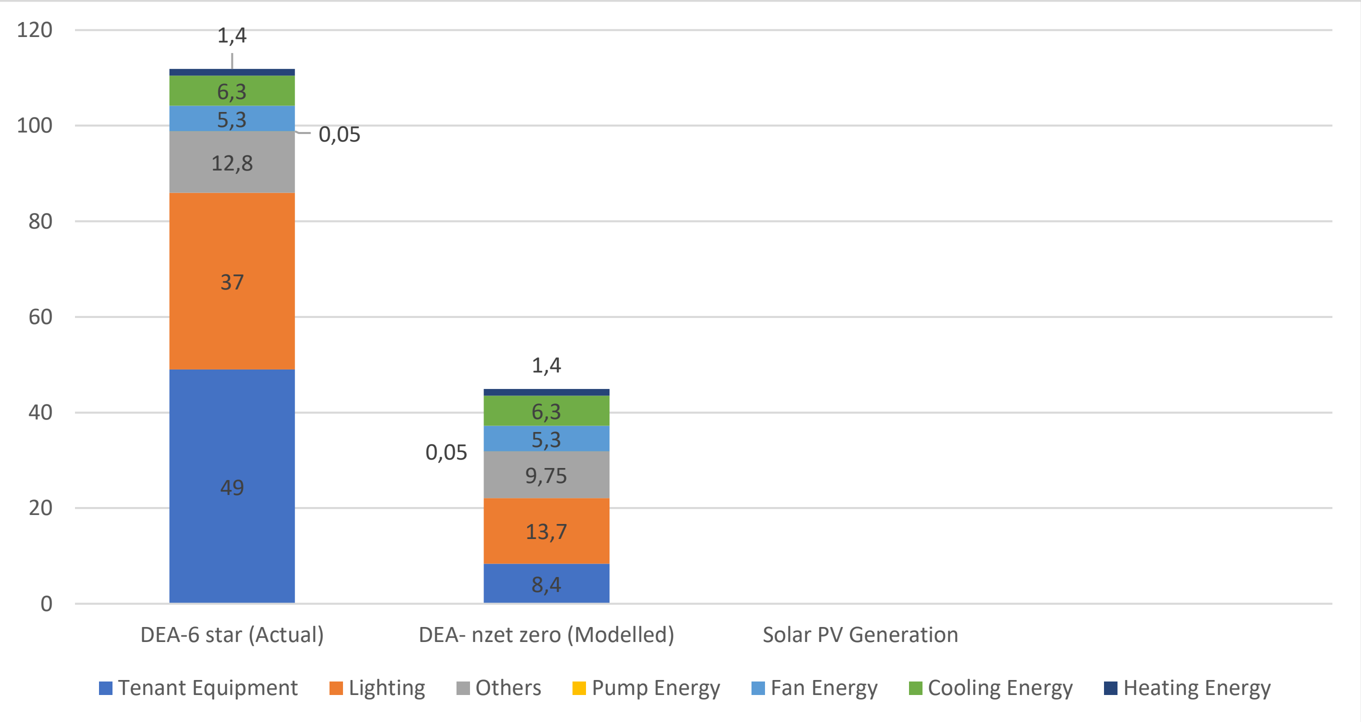
Carbon Emissions (tCO_2/Year) 730.70

ENERGY SAVINGS

EDGE ADVANCED

Energy Efficiency Measures 67%

Meets EDGE Energy Standard



Energy Efficiency Measures 67%

OFE01 Reduced Window to Wall Ratio - WWR of 30%

OFE02 Reflective Paint/Tiles for Roof - Solar Reflectivity (albedo) of 0.7

OFE03 Reflective Paint for External Walls - Solar Reflectivity (albedo) of 0.7

✓ OFE04 External Shading Devices - Annual Average Shading Factor (AASF) of 0.61

AASF 0.61

✓ OFE05 Insulation of Roof: U-value of 0.2

W/m². K 0.2

✓ OFE06 Insulation of External Walls: U-value of 0.3

W/m². K 0.3

OFE07 Low-E Coated Glass: U-value of 3 W/m².K and SHGC of 0.45

✓ OFE08 Higher Thermal Performance Glass: U- value of 1.5 W/m². K and SHGC of 0.32

W/m². K 1.5 SHGC 0.32

OFE09 Natural Ventilation with Operable Windows and No A/C

OFE10 Ceiling Fans for Office Spaces

✓ OFE11 Variable Refrigerant Flow (VRF) Cooling System - COP of 4

COP 4

OFE12 Air Conditioning with Air Cooled Screw Chiller - COP of 3.3

OFE13 Air Conditioning with Water Cooled Chiller - COP of 5.39

OFE14 Ground Source Heat Pump - COP of 5.2

OFE15 Absorption Chiller Powered by Waste Heat - COP of 0.7

OFE16 Radiant Cooling and Heating System - COP of RC 4

OFE17 Recovery of Waste Heat from the Generator for Space Heating

✓ OFE18 Variable Speed Drives on the Fans of Cooling Towers

✓ OFE19 Variable Frequency Drives in AHUs

OFE20 Variable Speed Drives Pumps

OFE21 Sensible Heat Recovery from Exhaust Air - Efficiency of 60%

OFE22 High-Efficiency Boiler for Space Heating - Efficiency of 90%

✓ OFE23 Air Economizers During Favourable Outdoor Conditions

✓ OFE24 Energy-Saving Light Bulbs - Internal Spaces

✓ OFE25 Energy-Saving Light Bulbs - External Spaces

✓ OFE26 Lighting Controls for Corridors and Staircases

✓ OFE27 Occupancy Sensors in Bathrooms, Conference Rooms, and Closed Cabins

✓ OFE28 Occupancy Sensors in Open Offices

✓ OFE29 Daylight Photoelectric Sensors for Internal Spaces

✓ OFE30 Solar Photovoltaics - 10% of Total Energy Use

OFE31 Other Renewable Energy for Electricity Generation

OFE32 Offsite Renewable Energy Procurement - Equal to 100% of total Operational CO2.

OFE33 Carbon Offset - 100% of Total CO_2

Appendix E

Table for predicted energy use of DEA Building

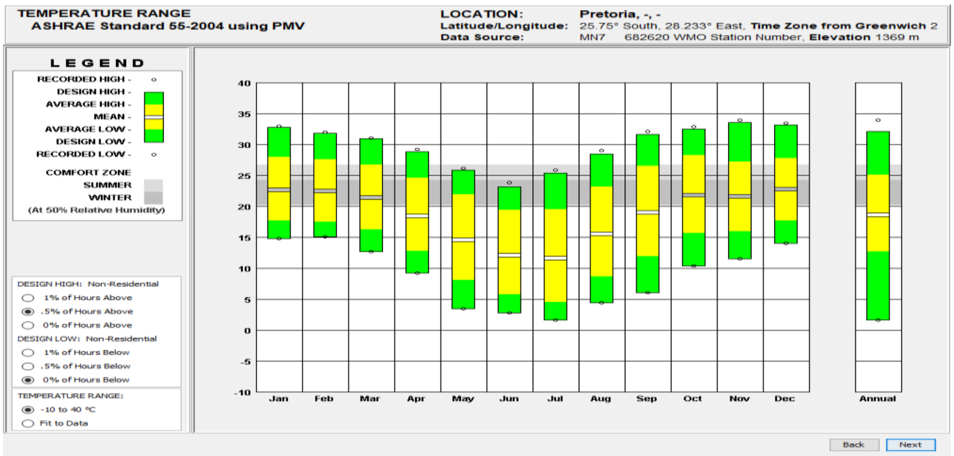
	Notional SANS 204 Building	Notional SANS 204 Building	Notional SANS 204	6-Star Rated Building (Predicted)	6-Star Rated Building (Predicted)	6-Star Rated Building
	Operational Energy Use kWh/Year	Operational Energy Use kWh/m²/year 2017/2018	% of energy use	Modelled Energy Use kWh/Year for net zero	Modelled Energy Use kWh/m²/year	% of Energy use
Fuel CO2 Factor	1.2	1.2	1.2	1.2	1.2	1.2
Heating	55 008	2.0	1.1	41 937	1.5	1.3
Cooling & Heat Rejection	1 271 869	46.7	24	178 804	6.6	5.7
Pumps	231 279	8.5	4.4	4 965	0.18	0.15
Fans	523 252	19	10	152 481	5.6	4.9
Extract and Miscellaneous	92 314	3.4	1.8	32 996	1.2	1.1
Non-Tenant Area Lighting	278 468	10.2	5.2	71 571	2.6	2.3
Car Park Lighting	126 918	4.7	2.4	38 936	1.4	1.2
External Lighting	90 156	3.3	1.7	31 580	1.2	1.0
Lifts	29 781	1.1	0.6	45 970	1.7	1.5
Domestic Hot Water	58 832	2.2	1.1	27 915	1.0	1.0
Lighting Tenant	1 017 190	37.3	19.3	1 017 190	37.3	32.5
Small Power (Tenant)	1 356 705	49.8	26	1 356 705	49.8	43.3
Supplementary Cooling (Tenant)	127 187	4.7	2.4	130 620	4.8	4.2
SUB TOTALS (kWh/Year)	5 259 959	193	100	3 134 670	115	100

Appendix F

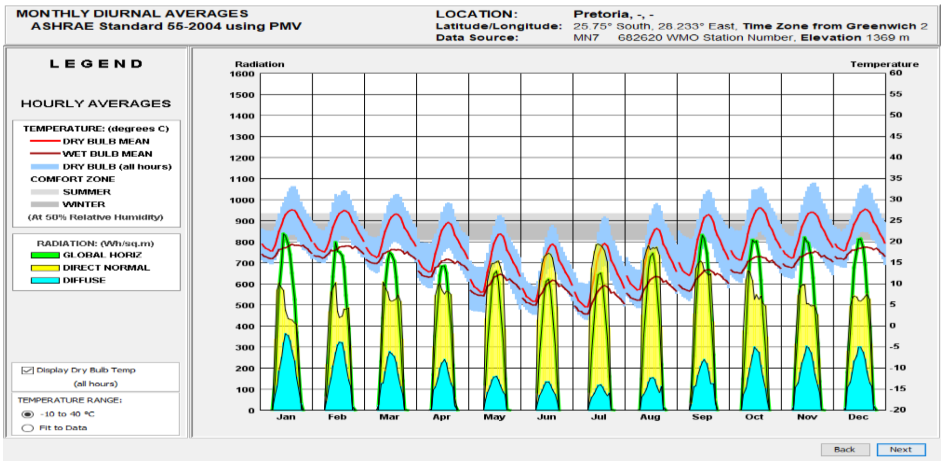
Climate analysis -Pretoria and Psychometric chart, January to December

(adapted from Climate Consultants)

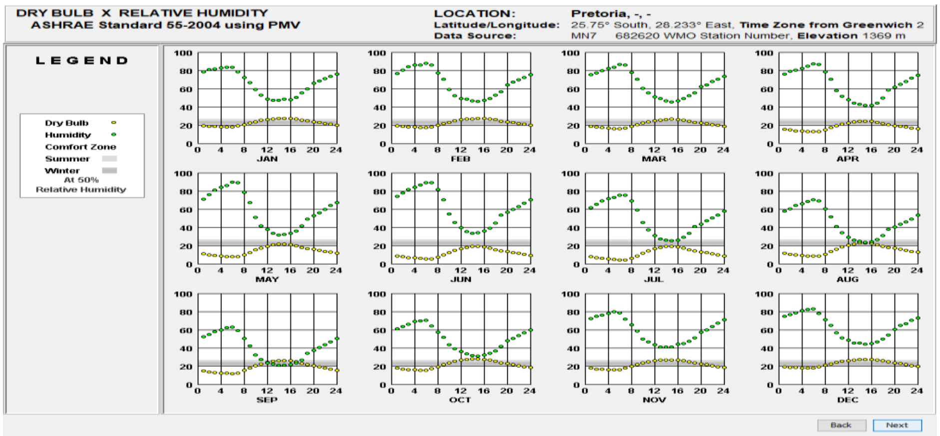
F-Graph A



F-Graph B



F-Graph C



Pretoria psychometric chart F-1-January

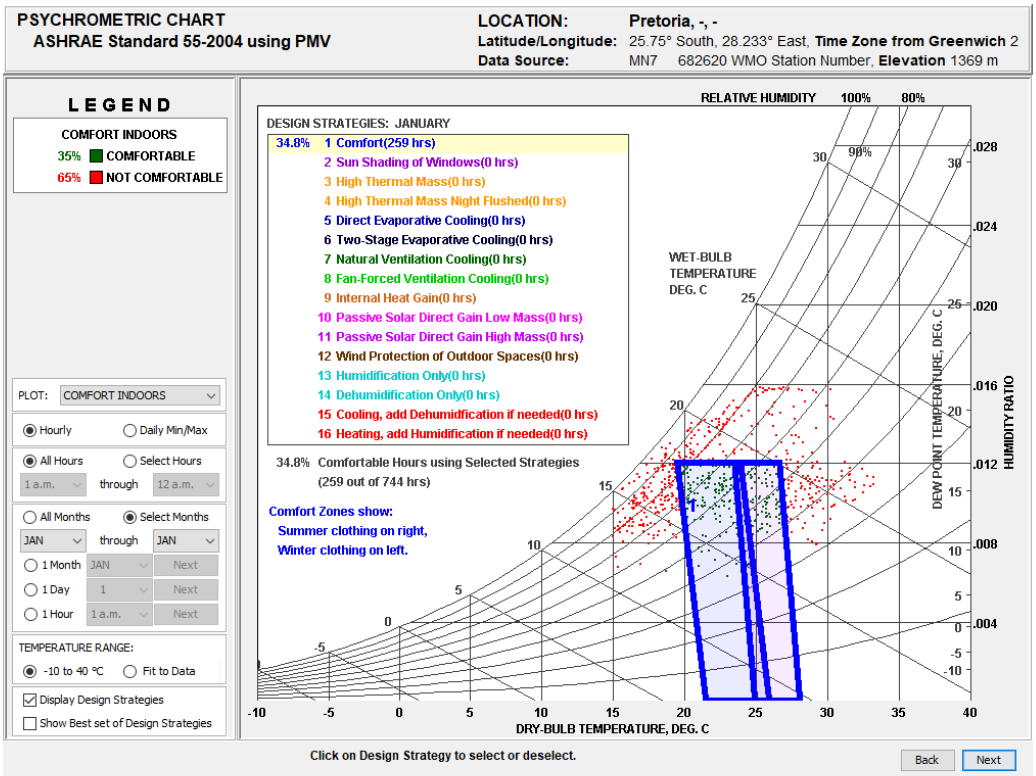


Chart based on climatic influence only

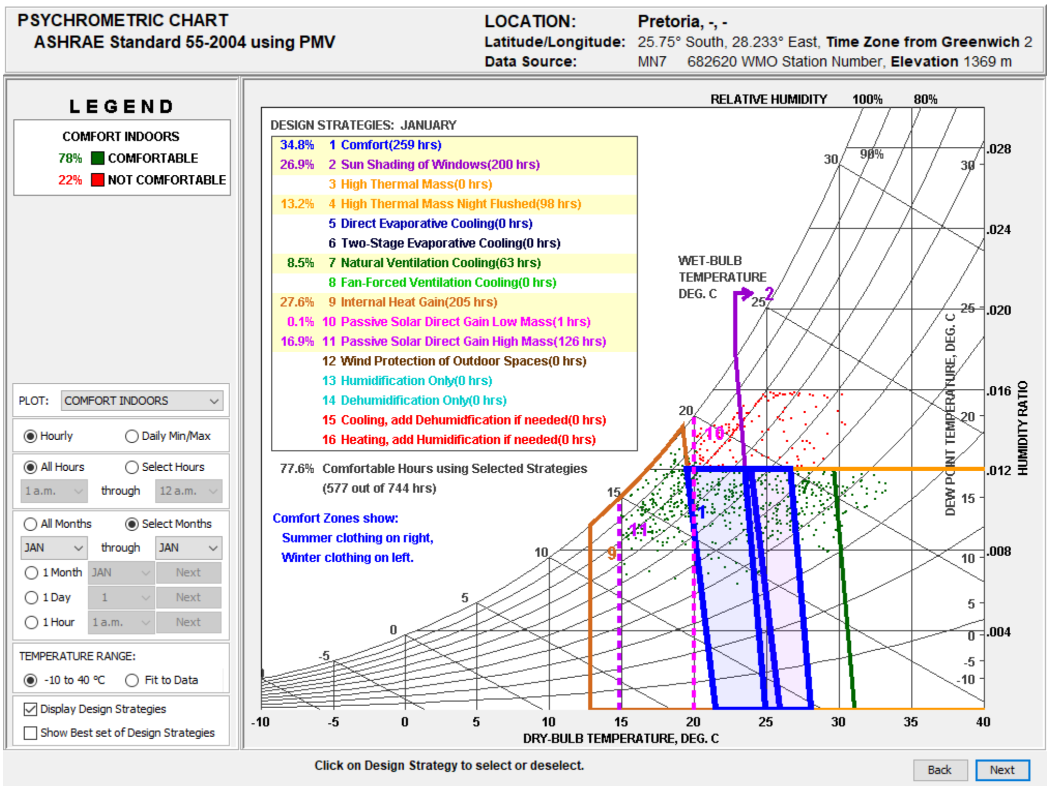


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-2-February

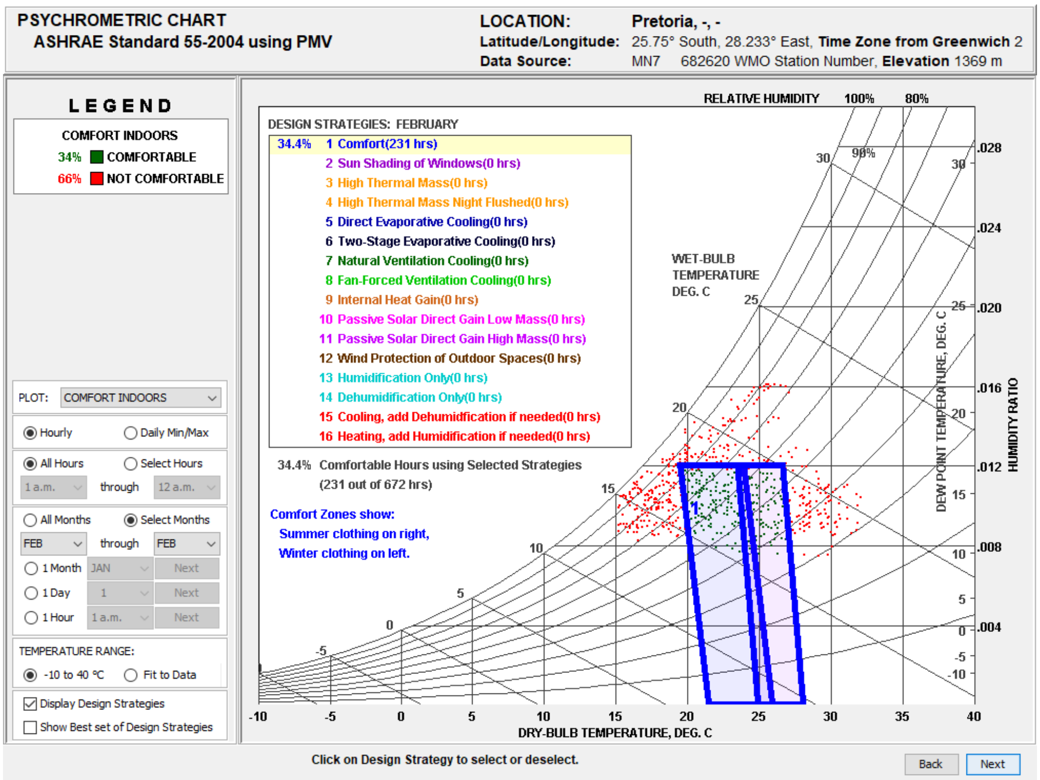


Chart based on climatic influence only

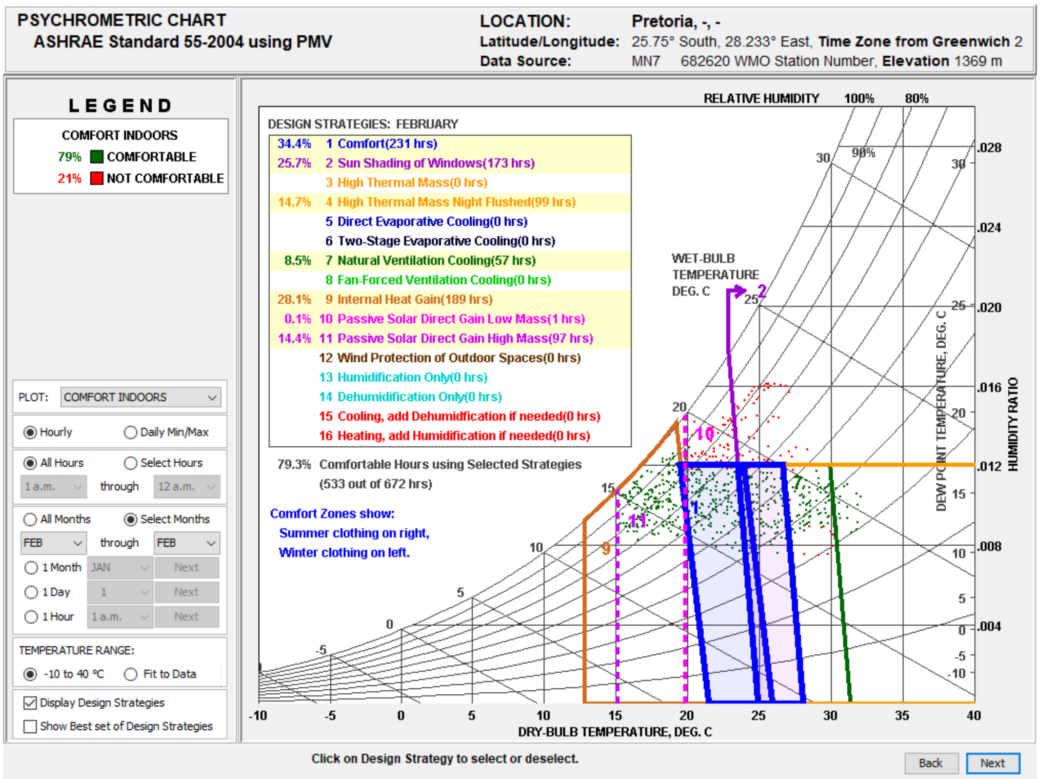


Chart based on Climate and full optimization of passive design strategies

Psychrometric chart F-3-March

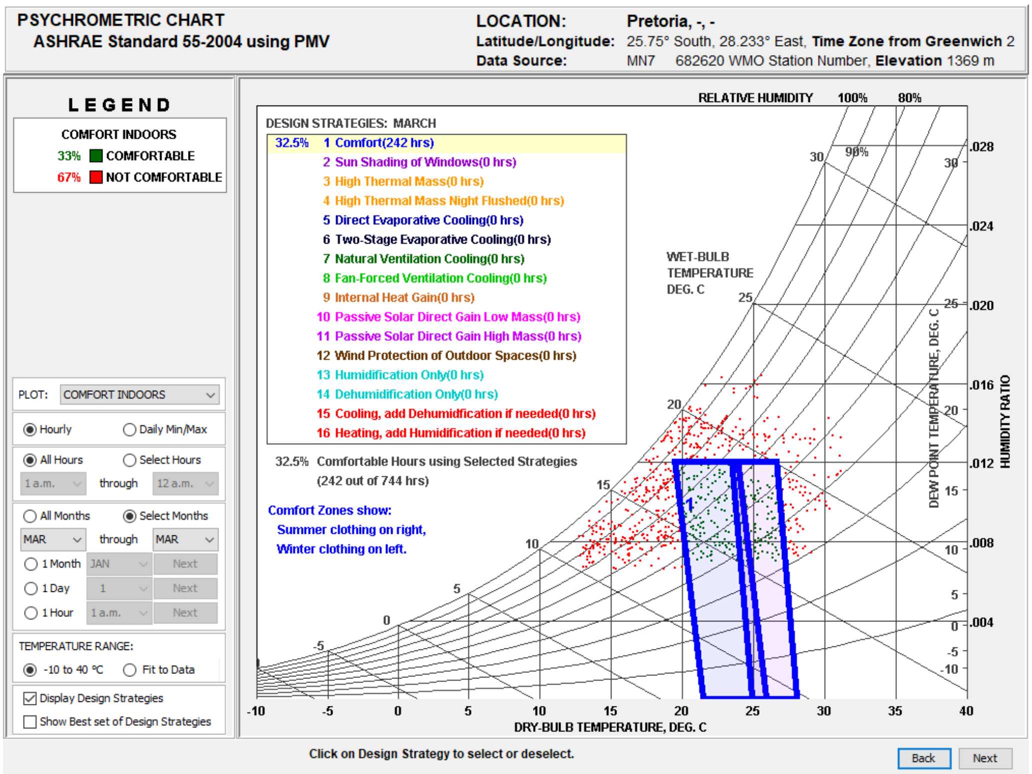


Chart based on climatic influence only

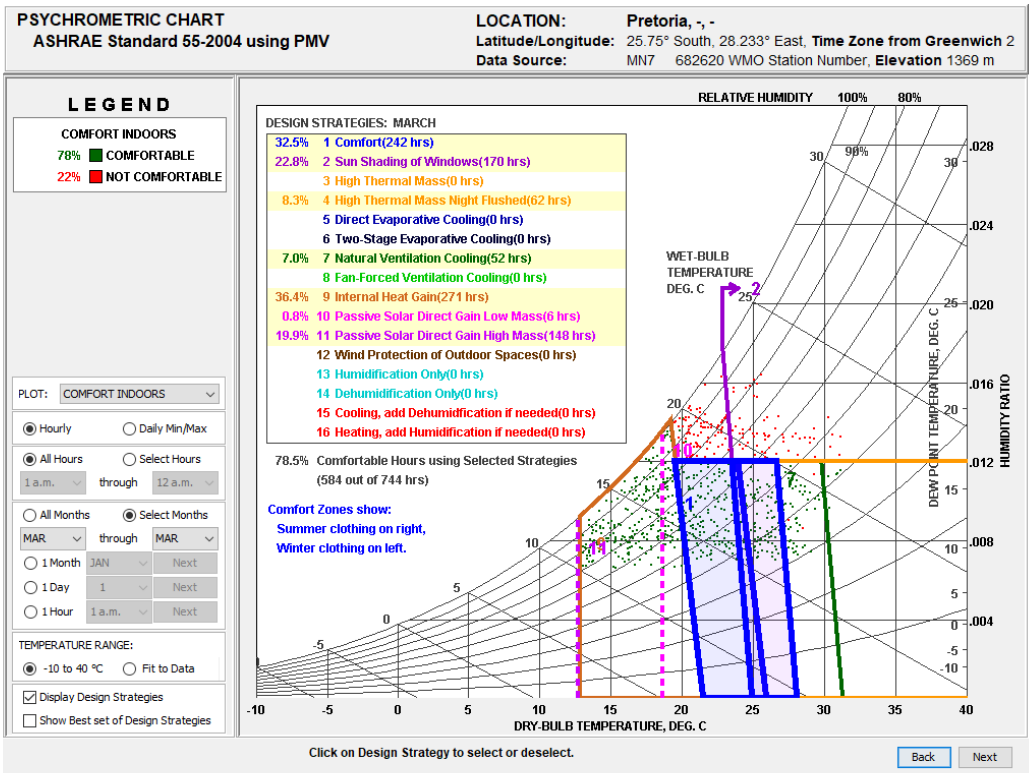


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-4-April

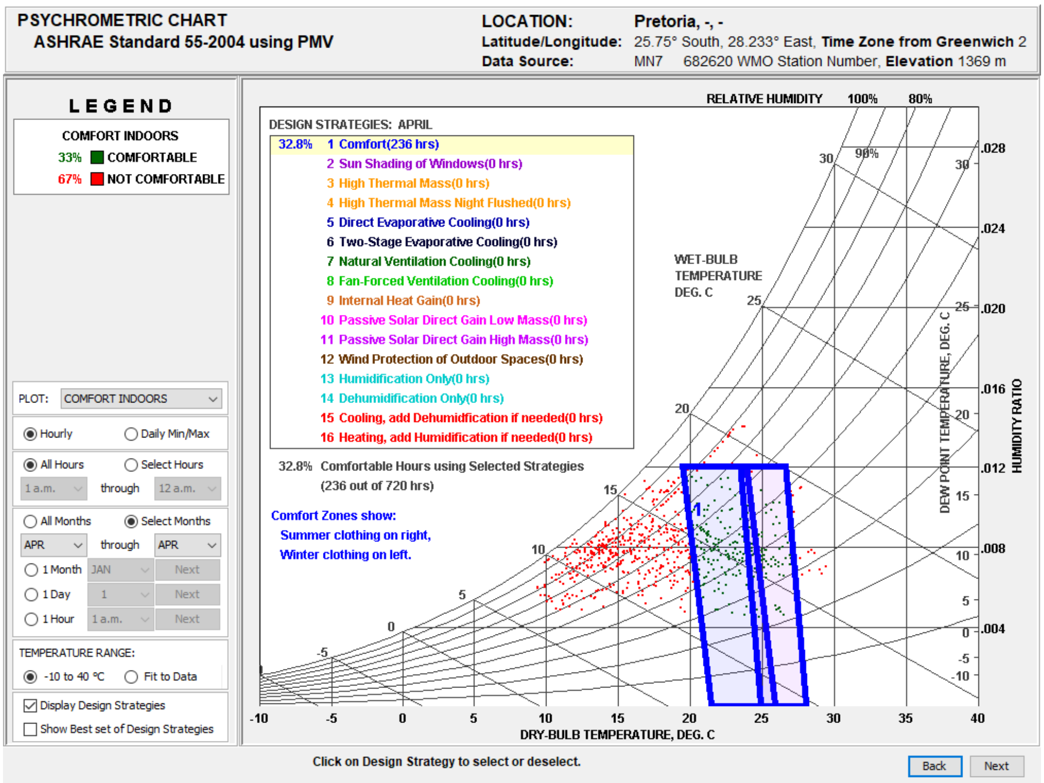


Chart based on climatic influence only

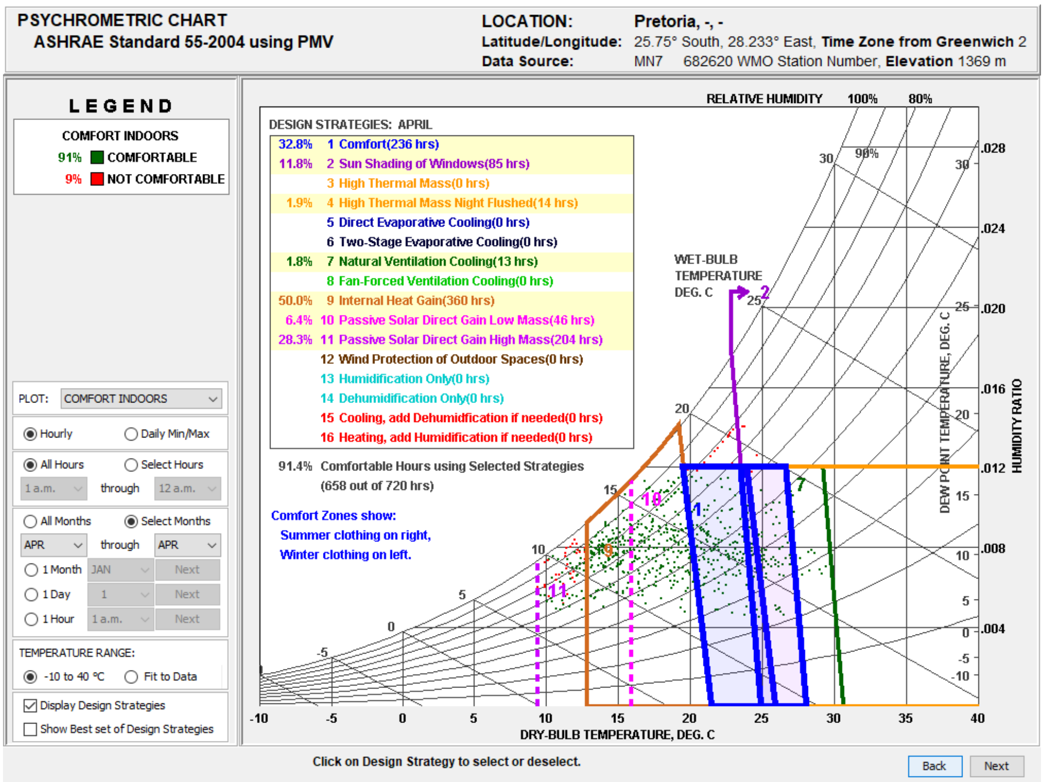
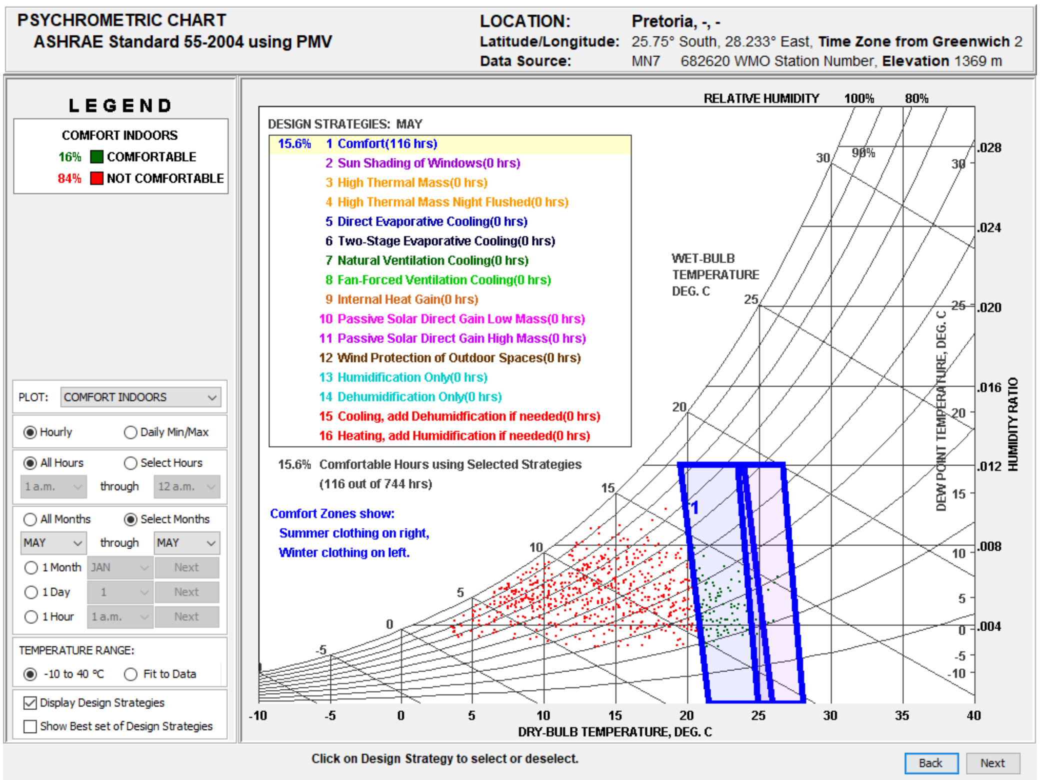


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-5-May



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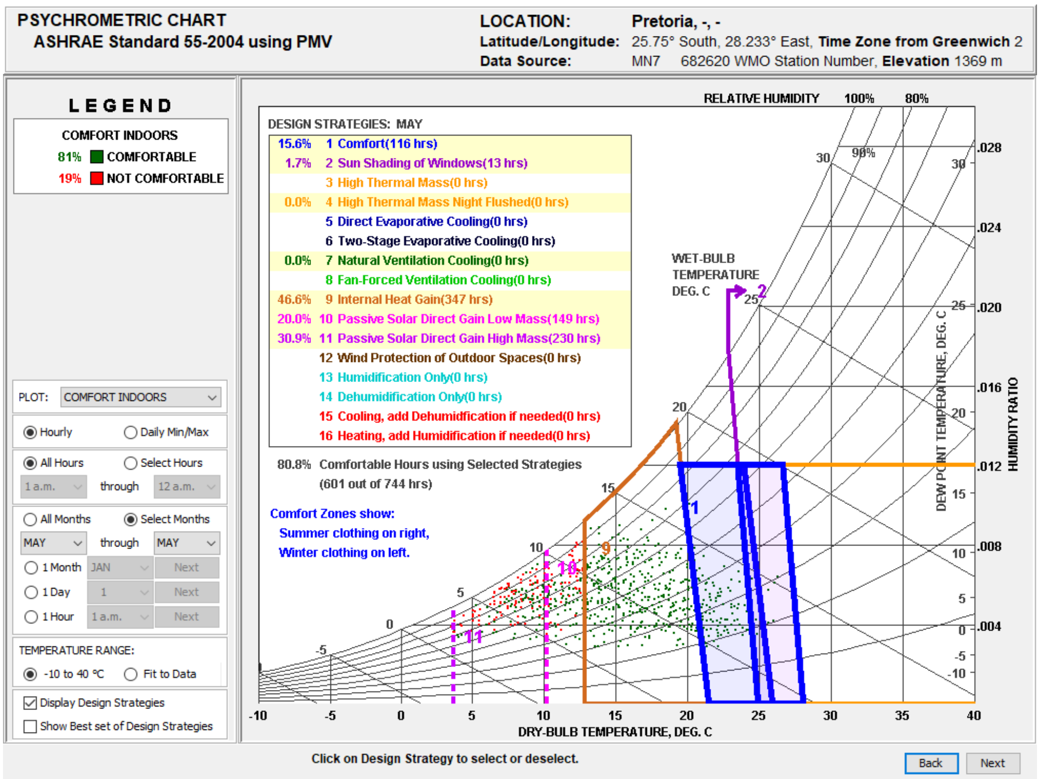


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-6-June

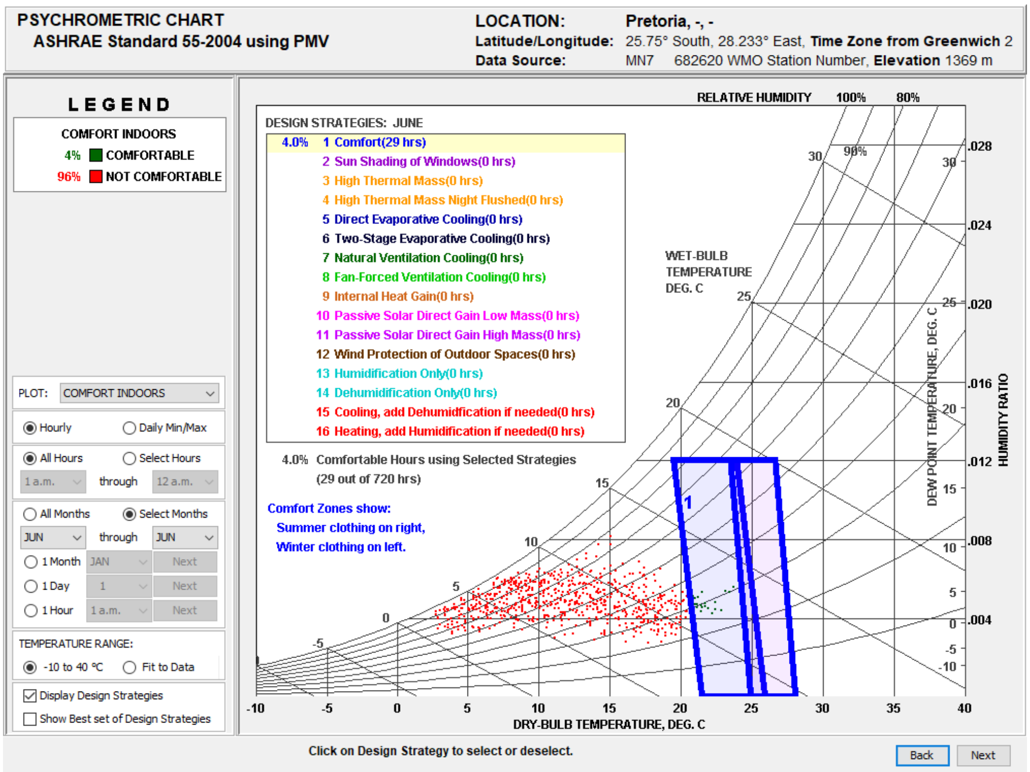


Chart based on climatic influence only

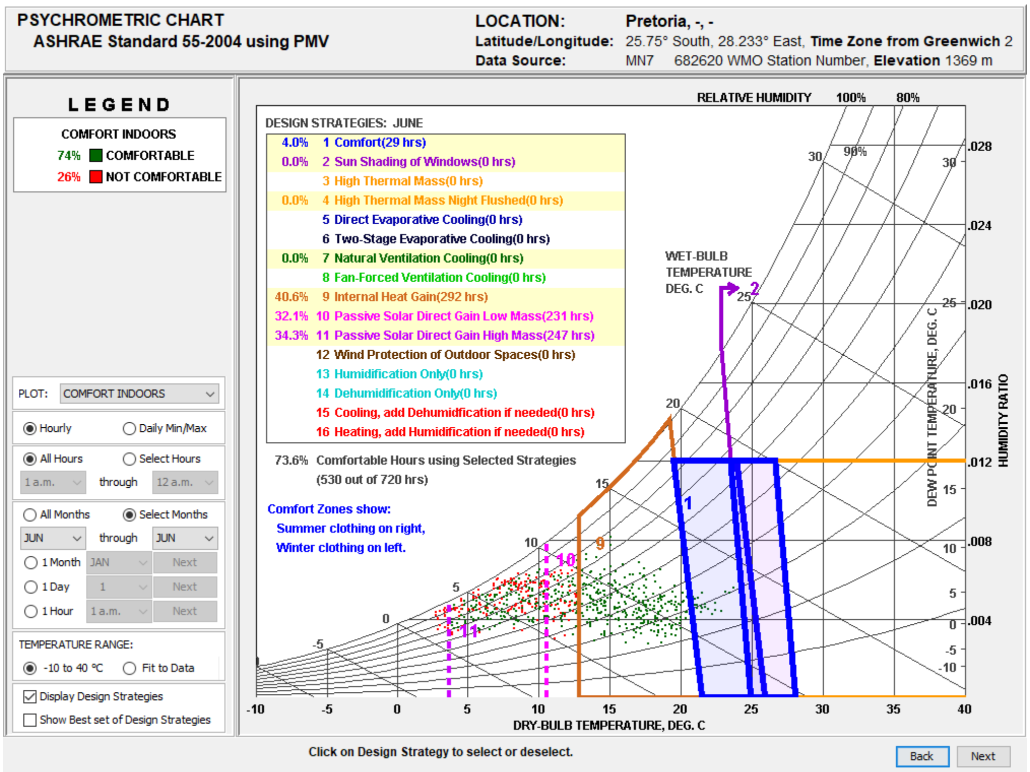


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-7-July

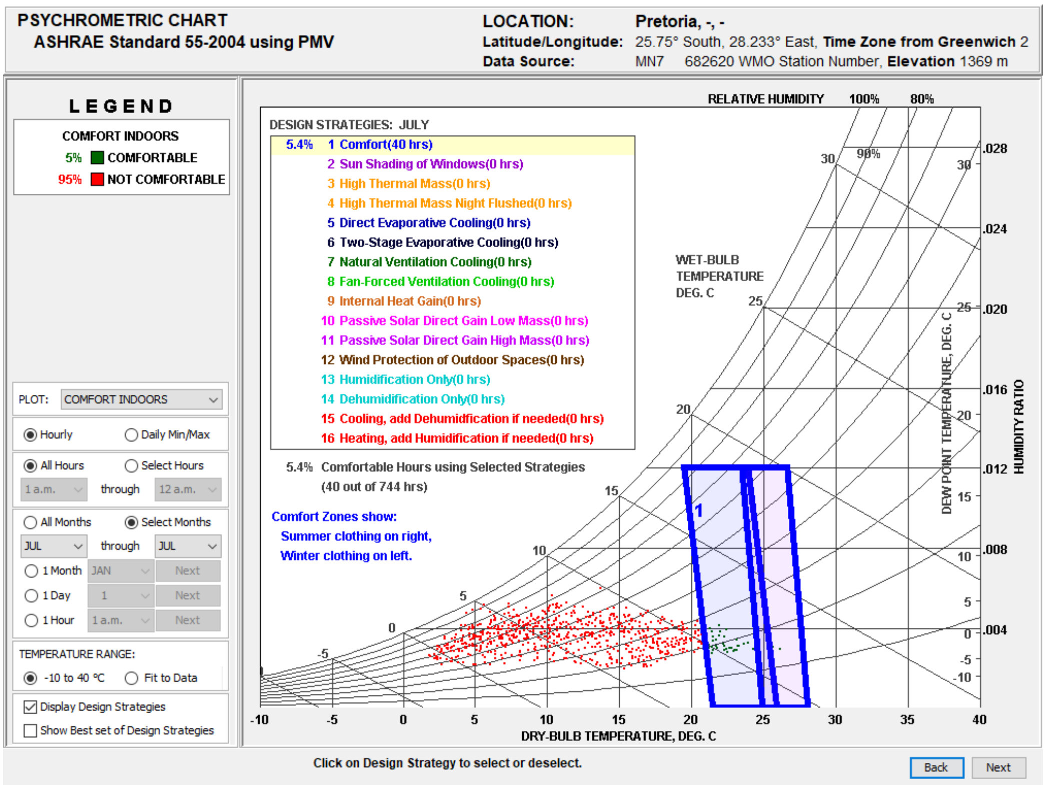


Chart based on climatic influence only

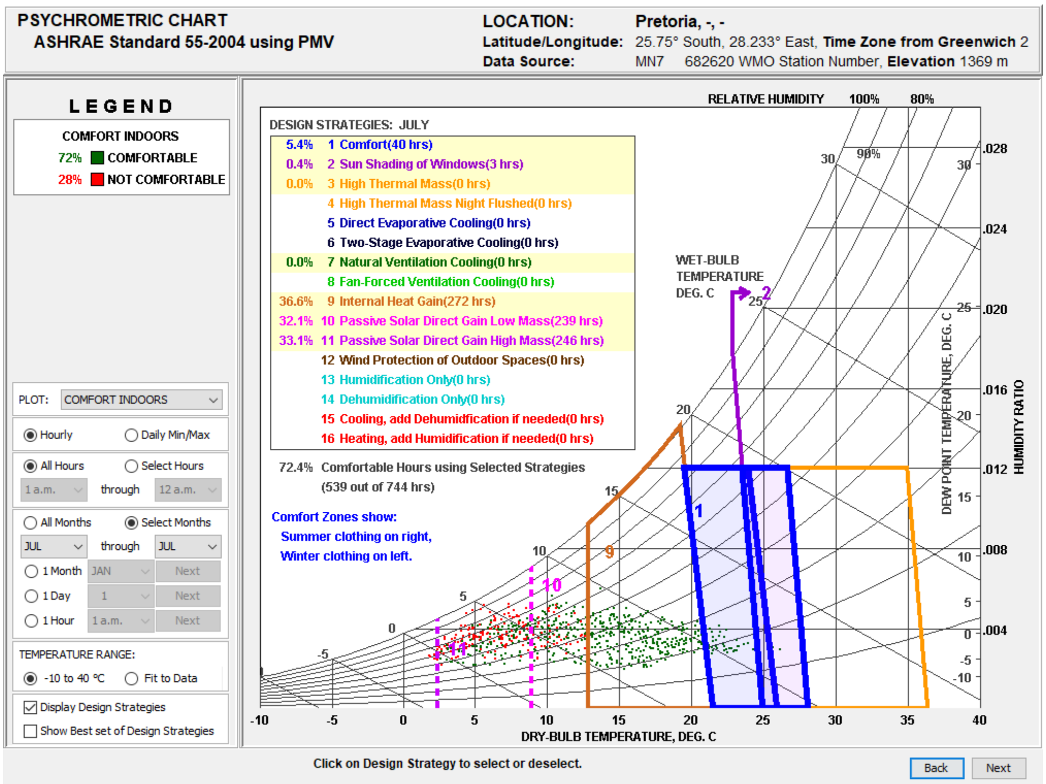


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-8-August

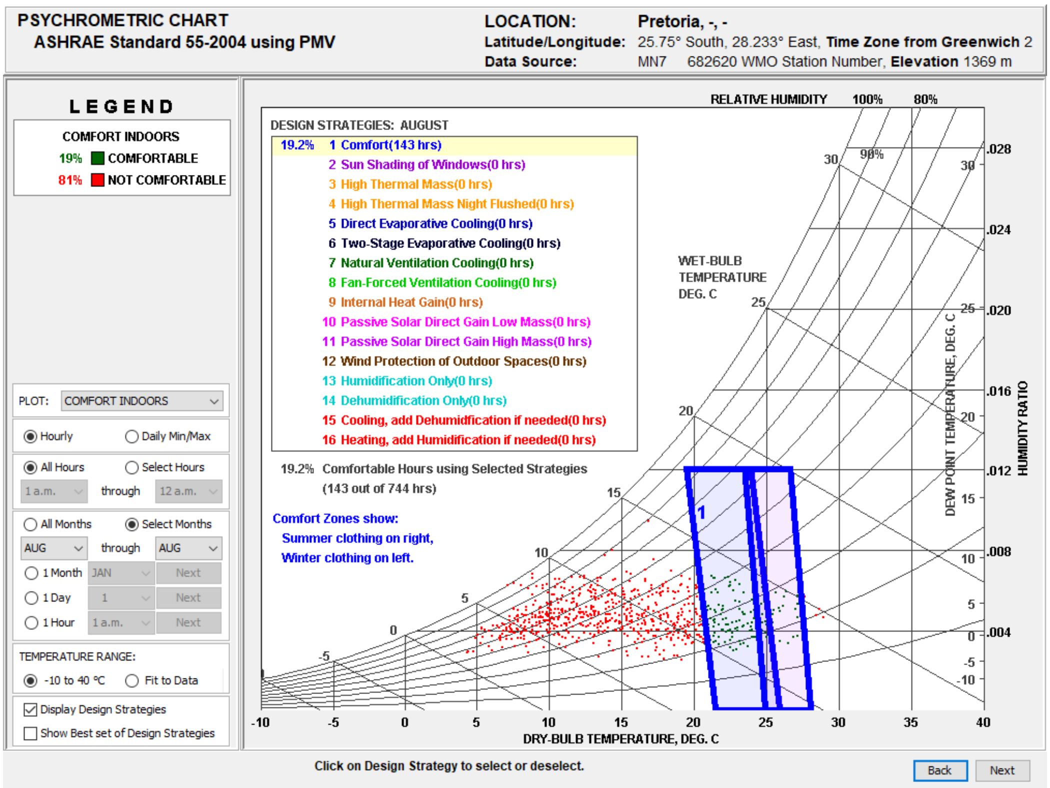


Chart based on climatic influence only

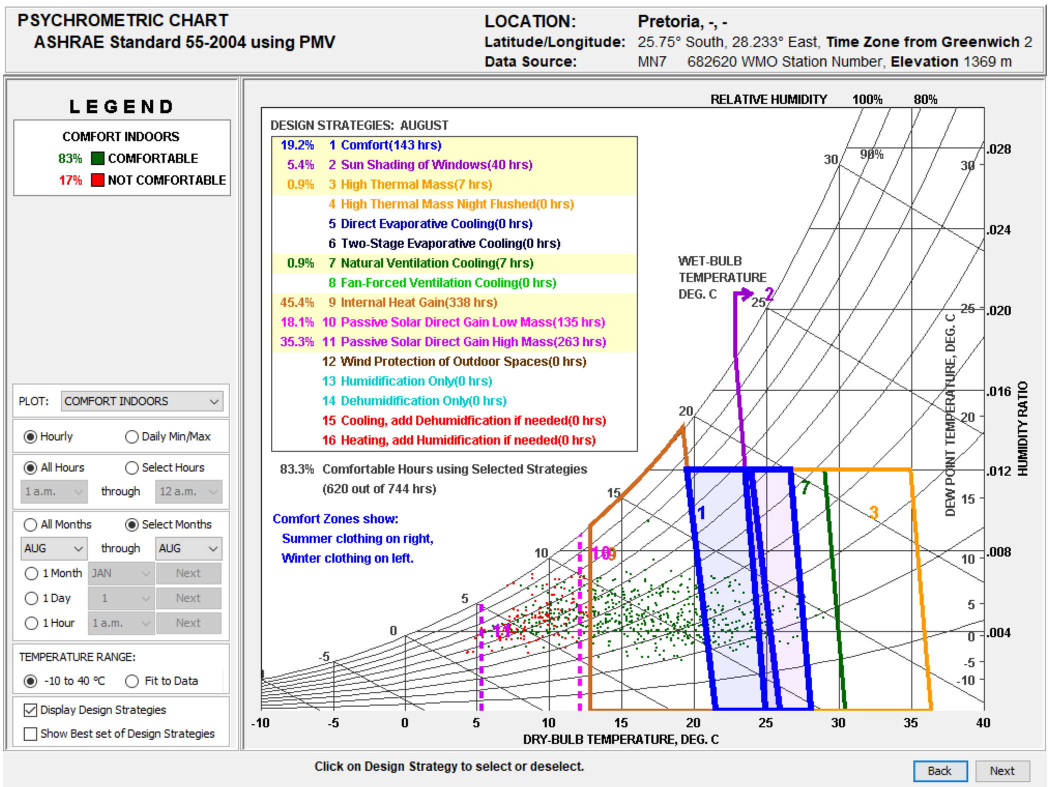


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-9-September

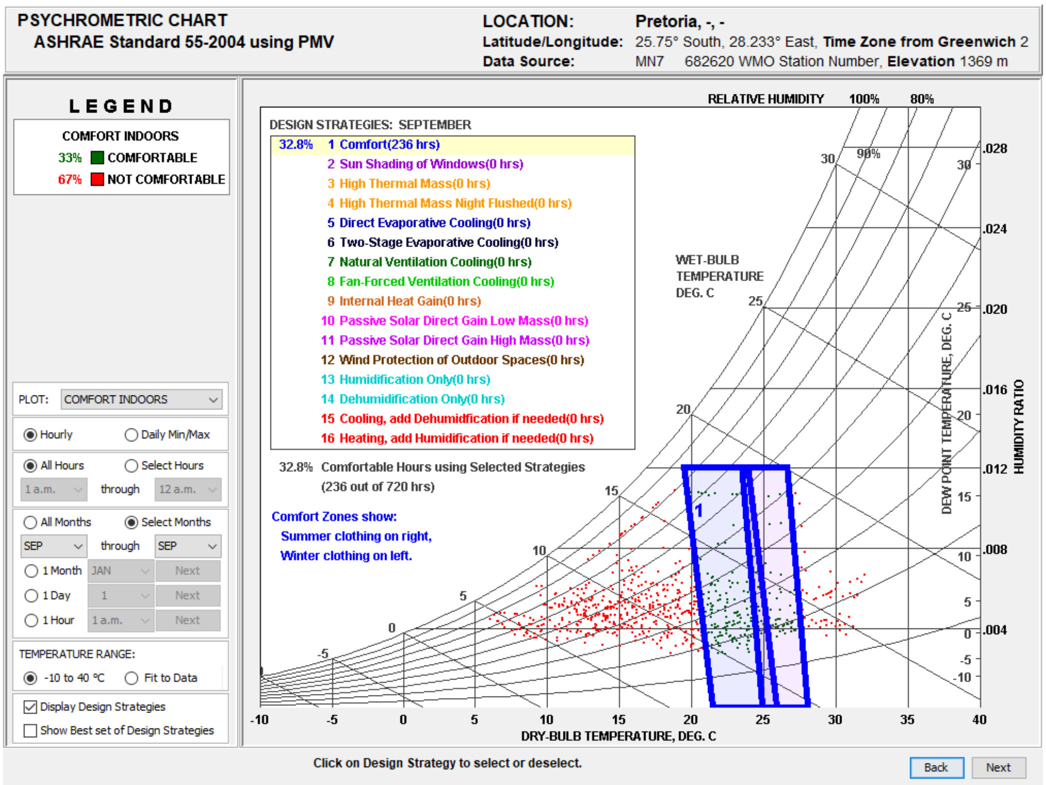


Chart based on climatic influence only

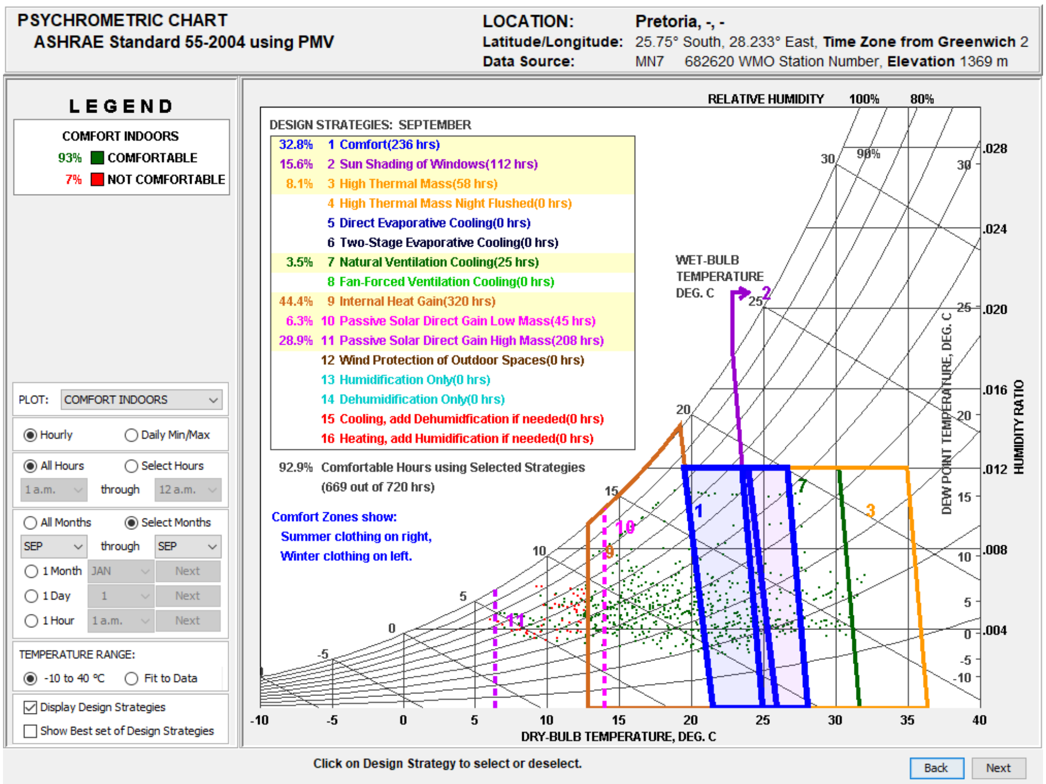
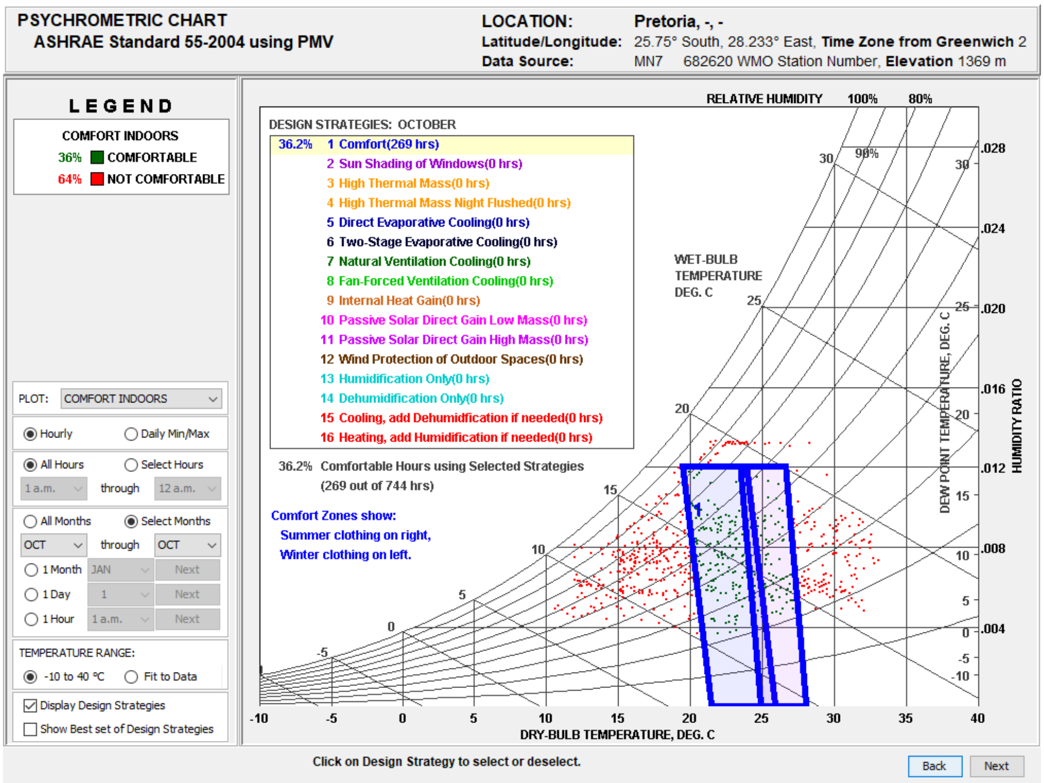


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-10-October



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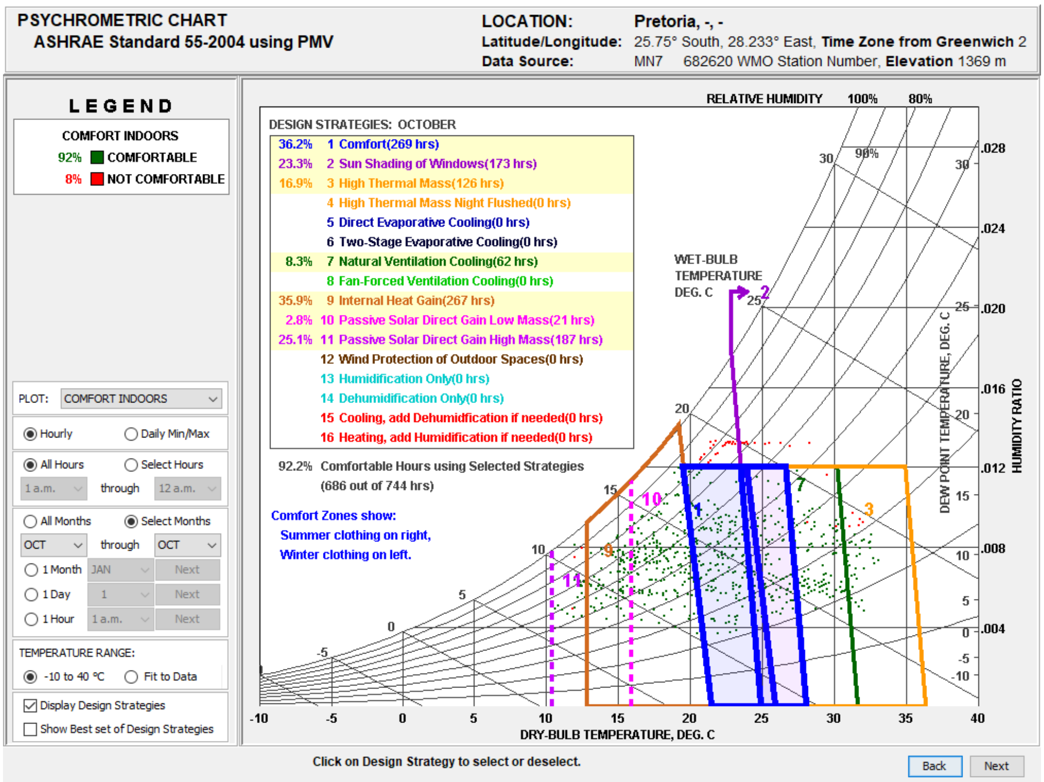


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-11-November

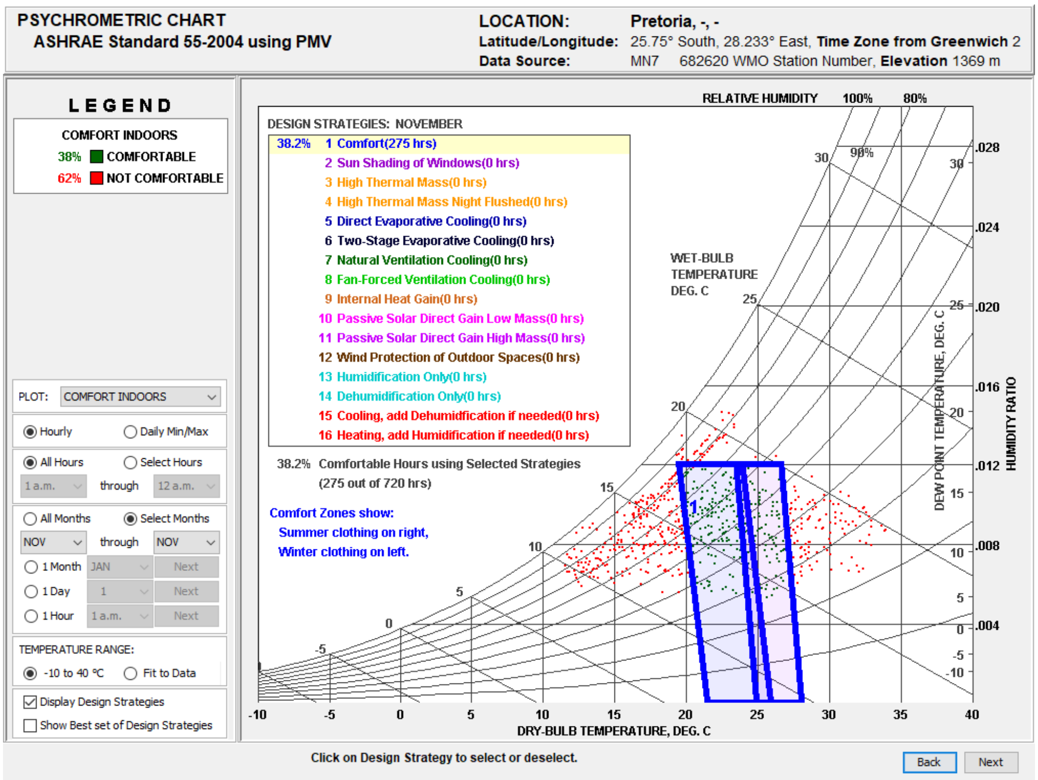


Chart based on climatic influence only

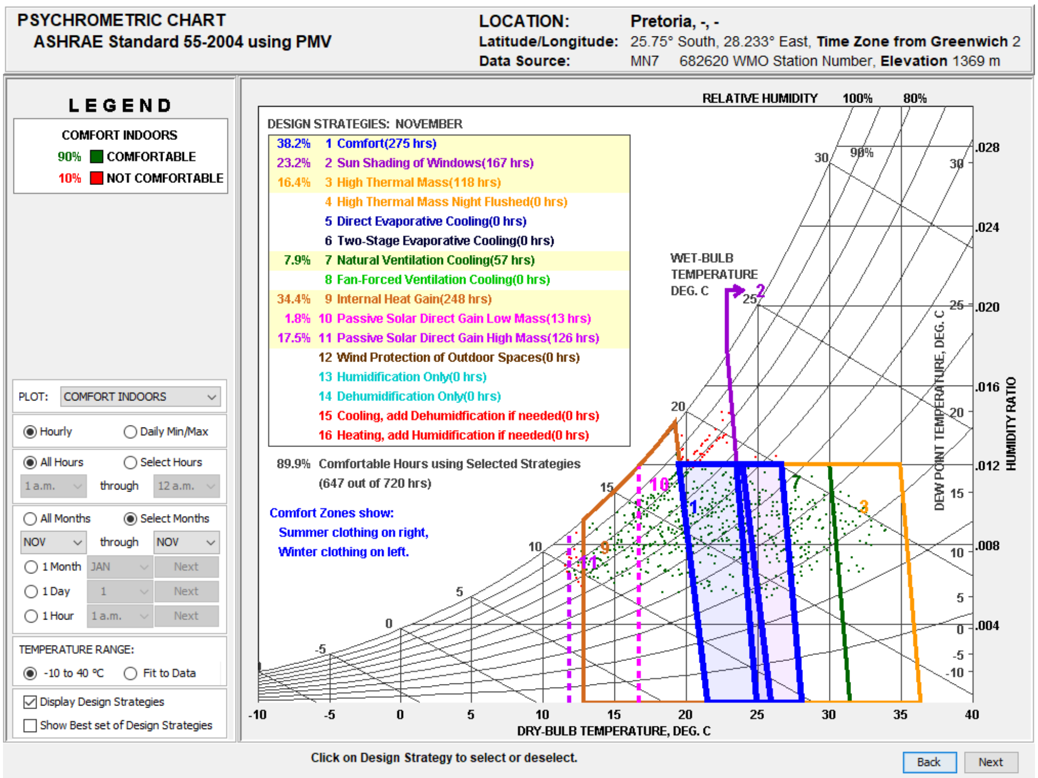


Chart based on climate and full optimization of passive design strategies

Psychrometric chart F-12-December

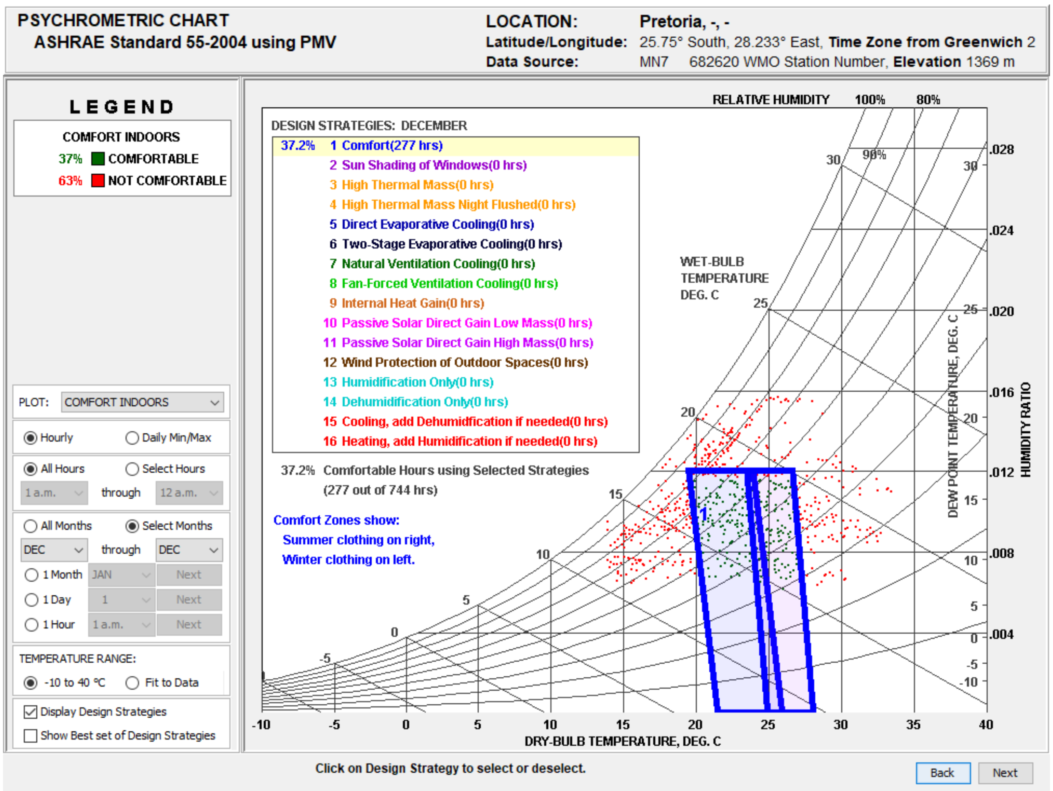


Chart based on climatic influence only

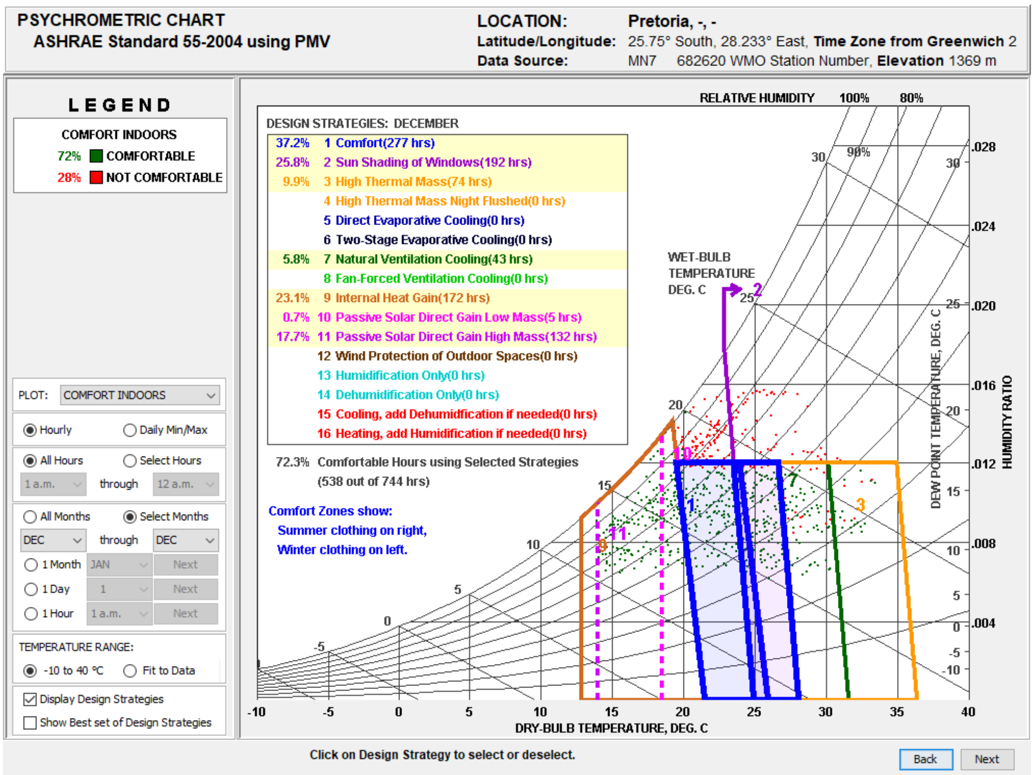
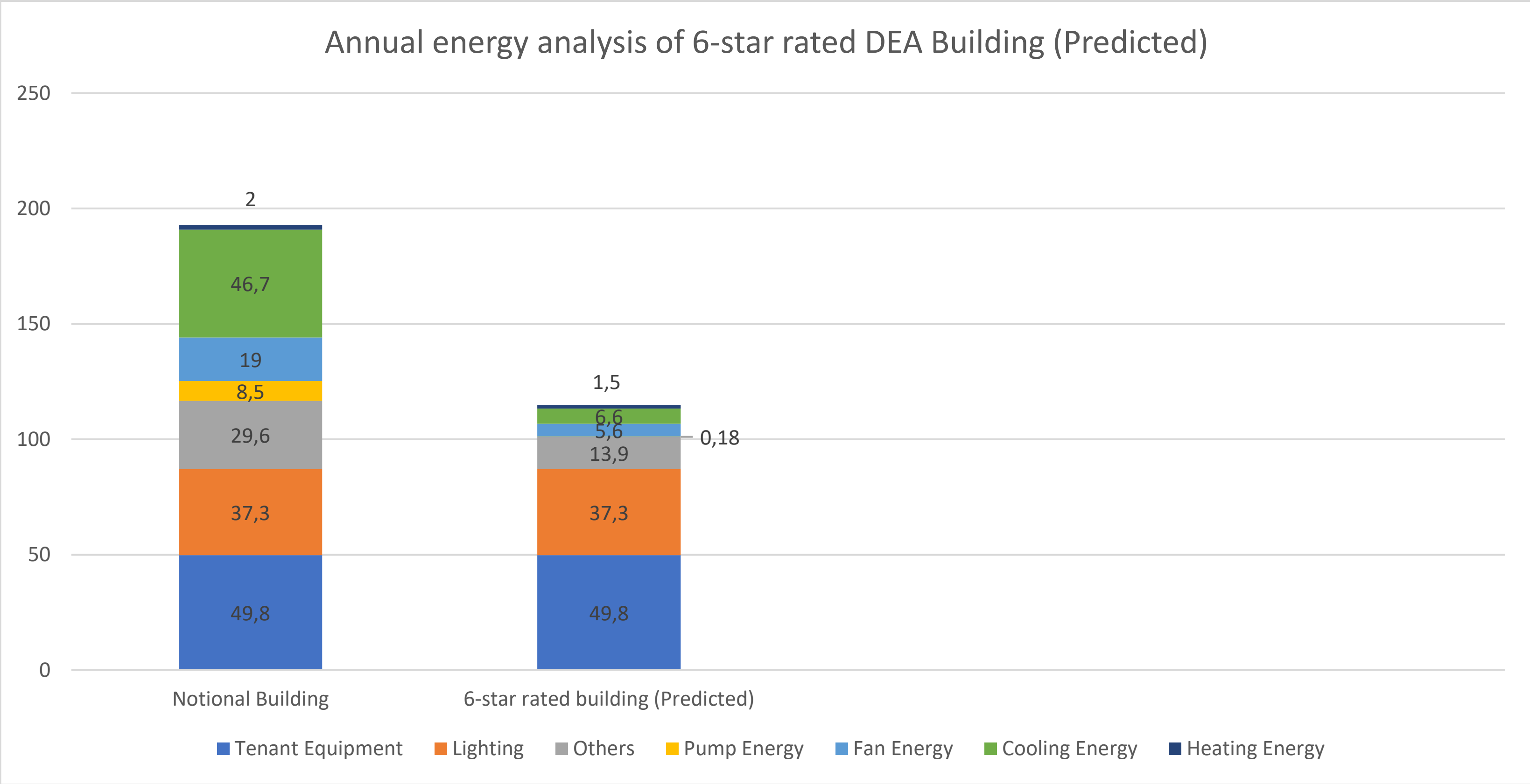


Chart based on climate and full optimization of passive design strategies

Appendix G

Bar chart for conventional building



Appendix H: Ethics clearance certificate for the study

SCHOOL OF ARCHITECTURE AND PLANNING
HUMAN RESERCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE
PROTOCOL NUMBER: SOAP124/01/09/2016

PROJECT TITLE:	Assessing the energy performance gap between 6-star and net zero energy buildings for South Africa
INVESTIGATOR/S:	Andrew Analo (Student No. 580259)
SCHOOL:	Architecture and Planning
DEGREE PROGRAMME:	MArch in Sustainable and Energy Efficient Cities (March SEEC)
DATE CONSIDERED:	30 November 2016
DECISION OF THE COMMITTEE:	APPROVED
EXPIRY DATE:	30 November 2017

CHAIRPERSON ____________________
(Professor Daniel Irurah)

DATE:

cc: Supervisor/s: Prof. Daniel Irurah

DECLARATION OF INVESTIGATORS

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to endure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Signature   **Date** 6/12/2016

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