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THE PROFITABILITY OF GREEN RETROFITTING THE BUILDING ENVELOPE OF  
COMMERCIAL BUILDINGS IN CAPE TOWN

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Masters of Science degree in Property Studies

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## ABSTRACT

A notion exists that the operational savings stemming from Deep Energy Retrofits are not sufficient to justify its capital outlay. This notion has focused property developers' attention on the construction of new green buildings, rather than optimizing existing building stock. Producing new buildings, while many existing properties are utilized on a sub-optimal level, with low rental income and high vacancies is not only resource inefficient, but also contributes to a much greater carbon footprint. The aim of this research is to establish whether retrofitting is a viable means of optimizing energy consumption in buildings based on investment return.

The literature reveals that the façade is the most significant variable in energy optimisation in buildings and concluded that over-cladding strategies are generally the most efficient means to reduce heat transfer and control lighting levels. The research have been conducted by means of a two tiered methodology involving a case study approach, along with an experimental design, which was conducted through a simulation. A hypothetical building, representative of Cape Town's building stock was modeled and a number of façade over-clad strategies simulated to derive the most optimal solution. The simulation is conducted in *DOE Energy Plus* and *COMFEN GUI*. Capital cost data was collected and compared to energy cost savings in order to determine payback values.

It was found that over-clad strategies may be economically feasible, which delivered payback periods of between 5 and 19 years, depending on the strategy. A partial retrofit, involving only the East and West facades was found to be the most feasible from an investment point of view, where woven mesh screens delivered the best results.

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## LIST OF ABBREVIATIONS

Billion	Bn
Building Information Modeling	BIM
Central Business District	CBD
Deep Energy Retrofits	DER
Green Building Council of South Africa	GBCSA
Green House Gasses	GHG
Heating, Ventilation and Air-conditioning	HVAC
Life Cycle Cost Analysis	LCCA
Parts Per Million	ppm
Return on Investment	ROI
South African Rand	R
Square Metre	m <sup>2</sup>
United States Green Building Council	USGBC
United States	US
United States of America	USA

# **INTRODUCTION**

## **1.1 INTRODUCTION**

Chapter one provides a background to the phenomenon of Global Warming and how it has given rise to green building construction. Green Retrofitting is discussed in an introductory chapter as an alternative to the construction of new Green Buildings, where lower capital cost and overall carbon footprint are highlighted as key advantages. The chapter elaborates on the lack of quantifiable evidence supporting the financial incentives of Green Retrofitting. Finally, a number of retrofit strategies are outlined to provide some context on the current state of research as it pertains to Green Retrofitting.

## **1.2 BACKGROUND TO THE STUDY**

Global warming is the result of an excessive amount of carbon dioxide that is released into the Earth's atmosphere. In 1988, it was recorded that a total of 350 CO<sub>2</sub> parts per million (ppm) was floating around in the atmosphere; today this has been recorded to be close to 400ppm. Scientists have varying views on the saturation factor, but there seems to be some degree of consensus that at a level of 450ppm, the earth's temperature will rise to a level where the planet's ecological systems will become severely unstable. (Building Green Inc., 2008)

Buildings remain to be the single greatest users of energy and contributor of CO<sub>2</sub> emissions. Construction and the operational functions of buildings contribute to 40% of total energy consumption worldwide (Milne, 2013).

Significant and valuable research has been done in recent years, which is paving the way for new green buildings. Green buildings are buildings that are designed with the aim of reducing energy consumption through sustainable practices, which in turn alleviates the burden on scarce natural resources, while reducing carbon emissions (Milne, 2013). In 2011, the U.S Green Building market was estimated to be in the order of R920Bn, which grew to around R1003Bn in 2012 (Statista, 2013). This year, the

USGCB estimates that 40-48% of new commercial construction will be green, representing a market value in excess of R1416Bn (USGBC, 2015).

Most new Green Buildings focus on lowering carbon emissions through a reduction in operational energy consumption. Building operations account for a total of 83% of CO<sub>2</sub> emissions relating to the real estate sector. The remaining 17% comes from manufacturing, distribution and on-site operations. This aspect is significant and often ignored in the rating of successful green projects. (Department of Business Innovation and Skills DBIS, 2010)

The phenomenon of *Green Retrofitting* is gaining popularity among the green fraternity, with lower total carbon footprints and less land dedicated to buildings (Hughes, 2012). According to Hughes (2012) the energy savings produced by a new green building can take anywhere between 10 and 80 years to offset the environmental damages caused through the construction and manufacturing process.

### **1.3 INTRODUCTION TO THE STUDY**

The interest in green retrofitting is notable when one considers the involvement of the majority of firms, both locally and abroad. In South Africa, McGraw Hill's Smart Watch report (2013) suggests that 60% of firms that are involved in the development of new commercial buildings indicated that they have green plans for the future, with 58% of firms reporting that their green plans will entail some degree of retrofitting their existing buildings. Even though these figures suggest a significant interest in green retrofits, some industry players remain skeptical (Ibid).

In a survey conducted by Johnson Controls, whereby 1400 executive facility managers were interviewed to establish the biggest barrier to energy retrofits, it was found that in 21% of cases, payback and return on investment (ROI) was perceived as being the most significant barriers (White, 2010). In another survey conducted by McGraw Hill, 86% of firms noted their concerns relating to the high cost of retrofitting (Mahlaka, 2014).

The variability in survey results seems to spring from the fact that the green retrofitting covers such a wide implementation area that it is difficult to quantify the results and make reasonable comparisons (Benson, 2011). High level retrofits for example, include changing light bulbs and the installation of automation sensors (Nock, 2010). This bracket represents the majority of retrofit projects as it requires minimal capital outlay and disruption, while reducing operational costs – it is also easy to quantify the benefits (Ibid). DER's are intense large scale retrofits, which can comprise of strategies that are so extensive that only the concrete structure is reused (Ibid). These initiatives can be highly complex and the strategies employed are as varied as the buildings themselves. It can also be a highly disruptive process as ongoing tenancies may be in place (Miller, E & Buys, L, 2008). Research does however show that Deep Energy Retrofits have the greatest sustainability benefits and is significantly superior to high-level retrofits (Connely and Adams, 2009).

The problem has significance in that, as there remain to be little evidence to suggest the financial incentive in DER's, developers will continue to invest in new buildings which leaves a carbon trail that could otherwise have been avoided (Miller, E & Buys, L, 2008).

#### Green Retrofitting Defined

Doug Gatlin, VP of the marketplace development division at the U.S. Green Building Council defines Green Retrofitting as: “... *any kind of upgrade at an existing building that is wholly or partially occupied to improve energy and environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise—all done in a way that it is financially beneficial to the owner*” (Lockwood, 2009, p. 48). His definition may be reduced to three main focus areas, namely, optimal use of natural resources, an increase in spatial quality and increase in profitability. Like any commercial enterprise, the implementation of retrofit projects is driven by their degree of profitability. In the same report compiled by Lockwood it is argued that even though green upgrades are qualitatively the right thing to do by contributing to sustainability, it may not always be the case in a quantitative

sense. To do so, a definitive payback period needs to be established that is fact based and that can be benchmarked.

### Strategies

The leading engineering consultancy on Green Buildings, Arup has developed a matrix for green retrofitting, which is classified under 5 levels relating to the intensity of retrofitting. It specifically focuses on thermal comfort, energy and water consumption as well as mechanical and electrical systems. Level one constitutes minor intervention which is aimed at boosting current functionality, such as blind control, improving daylight or updating certain building services. Level two may include actions such as the removal of suspended ceilings to expose thermal mass. In a level three retrofit major changes are commissioned and may include the replacement of floor surfaces, major building services and external solar control. The next level involves only retaining the substructure, while level 5 involves a complete demolition and rebuild. (Connely and Adams, 2009)

The Arup report identified 195 retrofit strategies that are grouped under 17 categories, ranging from management and economic aspects to material use, emissions, energy consumption and water usage. Arup's strategies relating to energy and lighting, energy and HVAC, energy and built fabric as well as materials have particular significance in DER's, where the façade plays a dominant role. For each category of implementation a number of initiatives has been listed and rated based on cost, environmental benefit, occupant benefit and value creation. According to the authors, Connely and Adams (2009) the initiatives cannot be randomly selected, instead implementation should be specific to the building type, but also to the structural and climatic needs as projected in a baseline analysis. (Ibid)

## **1.4 PROBLEM STATEMENT**

The practice of Green Retrofitting has the potential to significantly reduce the consumption of scarce natural resources and in turn reduce the production of Green House Gasses (GHG). This can be accomplished by, (a) reducing the demand for the

construction of new Green Buildings and, (b) optimizing the energy consumption of buildings that are currently operational. Green retrofitting has been shown to have a significantly greater contribution to GHG reduction when DER's are performed, as opposed to level one retrofits. DER's involve the modification or upgrading of the building facade (envelope), where the literature demonstrates that the facade has the greatest effect on a building's energy consumption as it is directly responsible for the regulation of heat and lighting levels.

The problem lies in the fact that developers and property investors currently perceive DER's to be too expensive and deem the payback and ROI as insufficient to meet their investment requirements. As this notion remain to be the status quo, DER's are avoided by the largest players in the property development sphere and a continued focus is placed on the construction of new Green Buildings.

The optimal use of scarce resources has further relevance in a country such as South Africa, where service delivery and electricity provision has reached crisis levels.

## **1.5 RESEARCH QUESTIONS**

1. The first research question may be stated as; to what extent can operational savings from retrofitting the building envelope, justify the capital outlay as measured through payback required in the Cape Town market?
2. The second research question may be stated as; to what extent can operational savings from retrofitting the building envelope, justify the capital outlay as measured through return-on-investment required in the Cape Town market?

## **1.6 RESEARCH AIM**

The research study aims to assess whether the optimization of an existing building envelope can sufficiently reduce operational expenditure to be in line with expected payback and investment return embedded in the market, with specific focus on the Cape Town CBD.

## **1.7 RESEARCH HYPOTHESIS**

1. The first research hypothesis may be stated as: The optimization of an existing building envelope can sufficiently reduce operational expenditure to be in line with the payback expected by investors in the Cape Town market.

2. The second research hypothesis may be stated as: The optimization of an existing building envelope can sufficiently reduce operational expenditure to be in line with investment return expected by investors in the Cape Town market.

## **1.8 RESEARCH OBJECTIVES**

The objectives of the research are:

- To evaluate existing design strategies relating to building envelope design
- To understand material parameters, such as performance, cost and availability
- To investigate the physical implementation challenges embedded in envelope retrofitting
- To identify a hypothetical representative building to use as a case study on which an experiment can be performed in the form of a simulation, through which to implement and test the research assumption

## **1.9 RESEARCH METHOD**

### **1.9.1 Outline of Method**

Deep Energy Retrofits are inherently complex, as project parameters vary greatly. There are many aspects and levels of optimization, and it will be difficult to comprehensively test the profitability of a full-fledged Deep Energy Retrofit accounting for all factors. There are simply too many variables.

To conduct an empirical study, the investigation focuses on the building envelope, which is the most significant variable in determining lighting and cooling demand. Together, lighting and cooling account for around 57% of the total operational expenditure in commercial office buildings ( US Office of Energy Efficiency and Renewable Energy, 2008). A correlation therefore exists between the economic efficiency of the building envelope, and the perceived profitability of the total Deep Energy Retrofit. As such, the research question can be sufficiently addressed through an analysis of the cost and energy savings of an envelope retrofit.

### **1.9.2 Methods and Sources**

The research will be two tiered and mainly revolve around an experiment in the form of a simulation, in order to test variables established during primary data collection. The study has case study features in that a very specific object is being studied in a singular unique environment. The case study will focus on defining a hypothetical building that has been identified through the research as being representative of the problem.

Primary data will be collected from Books, journals and online sources. Secondary data in the form of specification sheets and costs will be collected from local material suppliers and the focus will be on cost, availability and the energy efficiency of materials which aids in the selection criteria of variables.

Further secondary data will be collected from industry professionals in the form of typical services design. This information will be used as part of a baseline analysis.

The third tier of data generated through the simulation scenarios will provide insight into the strategies and designs relating to DER's.

Building Information Modeling (BIM) and *Energy-Plus Simulator* will be used for the simulation.

In order to derive the Payback and ROI, cost estimates will be required. Through the assistance of a professional Quantity Surveyor, generic market rates will be obtained for general building work, while the accurate cost data as supplied by the manufacturers of the proposed materials will be used.

### **1.9.3 Justification of the Reference Building**

A building in the Cape Town CBD will be identified as the reference building. The motivation comes from the fact that the author is familiar with the area and for other logistical reasons; most importantly though, Cape Town has a number of high rise buildings that were constructed in the 1960's. Many of these buildings have highly inefficient float glass facades, which today is being referred to as so-called urban heat sinks.

### **1.10 DELIMITATIONS**

The research focuses specifically on energy consumption as it relates to the building envelope.

The study is not concerned with:

- Green Star status and the additional impact it may have on a rental premium. The study only focuses on the capital outlay vs. operational savings;
- Market conditions such as rental rates, vacancies and supply and demand factors, which typically plays a role in Retrofit feasibility; and
- HVAC or lighting design, as the assumption is made that these systems use proportionally more or less energy depending on the façade design.
- Other factors such as proximity and highest-best-use are not considered and general market rates are applied.
- The climatic characteristics which is used in the study such as climatic region, solar path, angle of incidence, including energy use density and the like, are derived and does not form part of the literature review to illustrate its theoretical position.
- Experimentation in a real world context. The assumption is be made that an 'archetypical' building can be created and its performance modeled, on the basis that these buildings are exposed to similar climatic and environmental variables.

There are other physical aspects which also affects project feasibility and its ability to attract a rental premium. There may for example be an expectation in the market that

green-rated projects are typically AAA or Premium rated and as such a certain amount of parking needs to be provided. These factors will also fall outside the scope of the investigation.

The study focuses on Cape Town. Material, climate and market data specifically pertain to this area. Office buildings has been chosen as the most relevant building type as they consume the most energy per square meter and has the greatest dependence on efficient facades.

## **1.11 CHAPTER OUTLINE**

The report has been structured in a linear sequential order. Chapter 2 provides for a literature review, where the following themes are investigated: Investors' motivation to invest in façade retrofits; Investors' requirements; the Retrofit execution process and Façade retrofit strategies. The research is guided towards Over-cladding strategies which is then researched and discussed in more detail. Section 7 addresses Over-cladding typologies on a conceptual level and section 8, on a technical level.

Chapter 3 provides a literature review of the research methodologies that have been investigated, which leads to an outline of the study's research design.

Chapter 4 presents the collection of data and is structured around the sampling procedure, the parameters of the case study and presents a breakdown of results of the various iterative analyses conducted. The chapter concludes with an overview of the findings and discusses the results in relation to the research aim and objectives.

Chapter 5 concludes the research study by restating the research questions and comments on whether these have been adequately addressed. It further restates the research aims and how this has been achieved through the research. Finally, the chapter is concluded with a final section of recommendations to industry stakeholders and the academic community.

# LITERATURE REVIEW

## 2.1 INTRODUCTION

The literature review has been structured around a few broad themes of research, which subsequently informs and focuses the research to more in-depth topics. The significance of the building envelope is researched as it relates to façade retrofits in order to provide a context for the research to follow. Investors' motivation to invest in façade retrofits are then discussed by looking at precedent studies, payback methods and revenue drivers. Investors' financial return requirements and the tools used to measure such returns are subsequently researched and discussed, along with the potential risks embedded in façade retrofit projects. This is followed by a section investigating the most significant façade retrofit strategies, ultimately leading to a more focused set of strategies based on optimal performance. Over-cladding typologies are researched in more detail and are discussed based on their technical performance through a case study analysis.

## 2.2 THE SIGNIFICANCE OF THE BUILDING ENVELOPE

The building envelope is considered to have the biggest impact on a building's overall green status (Urban Green, 2014). More specifically, it is seen to have the most significant impact on the thermal isolation of the interior as well as the indoor air and lighting quality (Connely and Adams, 2009). As such it impacts on heating and cooling demand, lighting requirement, but also occupant productivity (Ibid).

Studies conducted by the US Office of Energy Efficiency and Renewable Energy (2008), found that lighting and cooling account for around 57% of the total operational expenditure in commercial office buildings. A significant correlation therefore exists between the performance and cost parameters of the building envelope, and the total perceived profitability of DER's (Ibid).

The focus has always been on achieving building enclosures that would be durable and provide sufficient environmental separation. Today the need for energy efficiency is an important requirement and a consideration even in non-green rated projects (Kesik, 2014).

The enclosure is the primary environmental separator and moderator, and through its passive role can greatly affect heat, air, moisture and natural light penetration. An efficient envelope can therefore greatly reduce the load on mechanical and electrical supplementation, which reduces overall energy consumption. In this sense, the most comprehensive retrofit strategy would focus on a DER (Kesik, 2014).

## **2.3 INVESTOR MOTIVATION TO INVEST IN FAÇADE A RETROFIT**

### **2.3.1 Introduction**

Property investors and building owners may have different reasons for investing in façade retrofits, this may include perceived value in Green Star status (Institute for Building Efficiency, 2011), savings on operating expenses (Anderson, 2015) or an updated building image (Martinez, 2014).

### **2.3.2 Revenue and Green Star status**

Green retrofit projects, particularly DER's need to be financially feasible in order to attract the interest of commercial property developers and investors (Lockwood, 2009). Facade retrofits are known to be very expensive and most property investors remain skeptical about the potential returns that can be generated through facade retrofits (Ibid).

Applebaum (2008) describes how development consultancies in New York are starting to specialise in retrofit projects, and how this model allows for tenancies to remain in place while construction work takes place. The addition of another glass layer or screens has shown to significantly reduce energy consumption (Ibid).

He describes a number of successful retrofit projects to demonstrate its profitability – one of which is 1801K Street in New York City. The project involved the construction of a full height, floor-to-ceiling glass facade system. The renovation improved energy efficiency and also assisted the landlord to rent out larger blocks of space at a higher rental rate. After the renovation, the owners managed to increase their rental income by 40%. (Ibid)

Insofar facade retrofits are concerned, fairly little has been done in the South African context. Alison Groves from engineering firm WSP Africa remarks that about 95% of existing building stock does not currently comply with international sustainability standards (Mahlaka, 2014).

This is in contrast to the U.S, where currently there are around 139 million square meters of LEED-certified buildings and 232 million square meters of Energy Star-certified buildings (Institute for Building Efficiency, 2011). The US had 960 million square meters of office stock in 2013 as reported by Costar (2013). This results in 14,4% LEED certified buildings and 24,1% Energy Star certified buildings.

Such a large pool of certified buildings means that green building performance can be measured and analyzed very accurately. The research company, Johnson Controls compiled a report, evaluating trends and data of Green Buildings (Ibid), which found that, certified green buildings had increased rental rates between 2-17%. The lower figure was recorded in a study which concluded that Energy Star and LEED certified office buildings generated a rental premium of 2%. The higher figure was recorded in another study, in 2010 – 3 years later, where it was found that LEED certified buildings managed to generate an additional 15-17% rental income over and above its non-certified counterparts (Ibid).

The same study found that Green Buildings have an improved resale value of 5.8 – 35% and higher occupancy rates of 2 – 18%. Due to higher rental income, higher occupancy and lower operating expenses, the study found net operating income to be an average of 5.9% higher for Energy Star certified buildings compared to non-certified

buildings (Institute for Building Efficiency, 2011). In another study, it was found that rental rates for green certified buildings are on average 3-30% higher than non-certified buildings, with a premium on the selling price of around 16% (Martinez, 2014).

Capitalisation rates were also found to be lower in certified buildings, which were recorded to be between 40-55 basis points, therefore translating to increased property value – amounting to almost 10% (Ibid). A similar study conducted by the IPD in Australia, noted that certified buildings had a cap rate of 40 points lower than non-certified buildings (IPD Australia and New Zealand, 2011).

There are also other, less quantifiable advantages to Green Buildings that translate into financial value - such as productivity gains. A number of case studies has been conducted which found that occupants were more productive due to an increase in natural light (0.7 -23%), less noise (1.8 - 19.8%), better ventilation (0.6 - 7.4%) and the fact that occupants could customise their own micro climate (0.2-3%) (Loftness, 2003).

These figures are based on studies conducted in the USA and local data is still limited. Considering however the association between the Australian and South African Green Star agencies and the similarities in climate, studies conducted in an Australian context may hold certain relevance. Although the Australian Green Star rating system focuses mainly on new buildings, the NABERS rating system does make allowance for existing structures and retrofitting. In another study by Johnson Controls (White, 2010), 206 NABERS-rated office buildings were studied to determine whether its certification had any impact on value. It was concluded that a 5-star rating translated to a 9% increase in value, while a 3 - 4.5 star rating translated to 2-3% value premium. Conversely, buildings with a NABERS rating of less than 3 Stars had a discounted value of between 10% and 13%. This is in stark contrast to Australian Green Star rated projects where it was found that on average a 12% value premium was achieved (Loftness, 2003).

The Investment Property Databank (IPD) conducted their own study where it reviewed 1500 buildings, but with slightly different results. It was concluded that investment returns on NABERS certified buildings were 0,6% more than non-certified buildings,

whereas the return was 4% higher for Green Star certified buildings (IPD Australia and New Zealand, 2011).

Even though no concrete figures exist in the South African market – specifically relating to Green Star performance, it has been noted that the value of Green Buildings in South Africa remains strong (SA Commercial Property News, 2014). The current trend of operating cost increases, coupled with a general economic slowdown is an opportunity for greater investment in Green Projects, where new Green Projects or retrofitted projects can reduce operating costs by up to 30% (Ibid). This outlook corresponds to those of the Johnson Control studies (White, 2010), as Green Properties have lower vacancy, with higher rental income. Rental premium of up to 10% can be expected with cap rate discounts of up to 50 basis points. (SA Commercial Property News, 2014)

The GBCSA (2014) website details the most comprehensive empirical study as it pertains to the South African market and was done by the IPD. Due to a lack of available data this study doesn't make any direct reference to Green Star status, but instead focuses on basic energy efficiency by comparing properties with top-quartile energy efficiency with other properties in the IPD sample, totaling 461 properties. It was found that properties with top-quartile energy efficiency had a return of 15.9%, compared to 14.2% which represents returns from the remainder of the sample. The increase in value can be ascribed to a lower cap rate and lower vacancy compared to the sample group. Interestingly the energy efficient properties are on average 2 years older than the balance of the sample, which is testament to the positive impact of retrofitting initiatives.

### **2.3.3 Operating expenses**

An increase in property value can be ascribed to higher rental income, lower cap rate, lower vacancy and lower operating expenses. To a large extent, an increased rental return and lower cap rate is a consequence of lower operating costs, which makes a reduction in operating costs the most significant variable in terms of creating value for investors (Gallinelli, 2011).

According to the U.S Institute for Building Efficiency, which compared Energy Star certified projects with non certified projects, it was found that certified projects had a saving of up to 30% on operating expenses (Institute for Building Efficiency, 2011).

In the local context, rising energy, water and waste disposal costs should make the saving on operating costs even more significant (Anderson, 2015). Currently, the GBCSA reports savings of 25-50% on operating expenses of Green Buildings and states that payback periods will also become shorter as utility costs continue to rise (Ibid).

Mahlaka (2014) states that the Green Building Council of South Africa (GBCSA) consider average payback periods relating to retrofits to be 3 to 5 years. Koket *al.* (2012) conducted a survey in the U.S where owners of LEED certified buildings were interviewed to establish the challenges and perceptions relating to retrofits. The study found that in 45.5% of the cases, payback was less than 5 years; 31.8% had a payback of between 5 and 10 years; 9.1% was more than 10 years. It was noted that most of the retrofits involved high level retrofits, which involved basic, low cost changes such as lighting upgrades, which typically produces a quicker payback period.

The Canadian Green Building Council (CGBC, 2014) conducted a survey which shows that architects expect retrofits to have a payback period of between 6 to 10 years. In the same survey, building owners reported an expected payback of 3 to 5 years. The varying views may be attributed to the fact that where architects are involved, retrofits normally lean more towards deep energy retrofits, whereas basic retrofits are often conducted by buildings owners themselves.

Muldavin (2010) investigated the valuation of green properties in the USA and reports that cost savings of 30% in operating expenses will translate roughly to a 2% or more increase in value.

#### **2.3.4 Brand value and image**

The value created through brand perception and building image is less obvious and not easy to quantify. Yet, according to Mahlaka (2014) tenants are increasingly demanding

green space to show their commitment to sustainability. On a more tangible level corporations are looking at ways to reduce their firm's carbon footprints and to increase staff productivity (SA Commercial Property News, 2014). According to Anderson (2015) this also projects a positive image which is closely linked to the company brand. He goes on to say that, "a green building is a differentiated product, which is viewed as technologically advanced and environmentally and socially responsible" (Anderson, 2015:1).

A survey conducted by the Building Owners and Managers Association (BOMA) in the USA, found that 61% of real estate owners agreed that that a green building would enhance their corporate image and that this would be a factor in the selection criteria for new office space (Martinez, 2014).

## **2.4 INVESTOR REQUIREMENTS FOR RETROFIT INVESTMENTS**

### **2.4.1 Expected Returns**

Return on investment is the overriding factor in façade retrofit implementation (Lockwood, 2009). The projected investment returns rely on a number of factors, such as the method used to quantify returns (Martinez, 2014), Life Cycle Costs (LCC's) (Real, 2010), disruption of tenancies (Nock, 2010) and foreseeable risk (Ibid). This chapter will elaborate on these factors in more detail.

### **2.4.2 Overview**

Payback and Return on Investment (ROI) was seen to be considerable barriers to energy retrofits by facility managers (White, 2010). Capital availability is considered to be a primary issue in owner-occupier buildings or where creating property value is not the main focus of the business owner. However, for property developers looking to invest and hold a long term asset, capital availability becomes relative to value creation and as such is rather a factor of ROI and payback. In that sense it can be argued – as long as there's sufficient value, capital will follow. The Lockwood report (2009) states that the costs of retrofitting mostly depend on the characteristics of the structures to be retrofitted and include aspects such as the building's age, design and function.

Lockwood (2009) suggests that older buildings often present more lucrative retrofit opportunities than newer structures. In a 40 year old building for example, most equipment is drawing close to the end of its functional life and needs replacement, whereas a typical 15 year old structure falls in a difficult in-between period, as building owners are often reluctant to invest large capital amounts in an acceptably performing asset. In the USA whole-building retrofit projects can cost between \$18 to \$65/m<sup>2</sup>, with paybacks varying between two to fifteen years. White (2010) indicated that half of all property owners require a payback period of no more than 3 years, with a minimum IRR of 30%.

### **2.4.3 Measuring tools for expected returns on DERs**

#### **2.4.3.1 Introduction**

Accurately measuring expected returns for DER investments are critical to establish the financial feasibility of the project. A number of methods are used in determining the feasibility of capital projects, where simple payback and Life Cycle Cost Analyses are the most widely accepted means of measuring DER's.

#### **2.4.3.2 Simple payback method**

The most commonly accepted method of evaluating façade retrofits is the simple payback method (Martinez, 2014). It is also the simplest method of capital budgeting as it only refers to the number of time cycles - years or months, that the proposed cash inflows will equate the capital investment (Gallagher et al.,2007:265). Each method has it's own decision rule. When the payback method is chosen, firms first need to establish an acceptable payback period. The firm will then accept or reject the project based on the payback period. (Ibid)

The payback method is limited in the sense that it does not consider cashflows after the actual payback period. A project may be feasible over the long-run and this method should therefore not be used in isolation (Gallagher et al.,2007:266).

The payback method is heavily focused on implementation costs and the savings on energy costs that result from those changes (Martinez, 2014). The method does not

consider external factors such as interest rate, inflation, energy price fluctuation and the like.

#### **2.4.3.3 Life Cycle Cost Analysis (LCCA)**

There is a tendency amongst property developers and investors to evaluate real estate project feasibility in a very simplified manner – with such methods as the payback approach or cash-on-cash return (Martinez, 2014). This view is likely to be influenced by the investor's investment horizon and his risk profile. Institutional investors with a long-hold investment strategy will be more likely to investigate life cycle costs, compared to speculative developers that are focused on a develop-and-sell product (Real, 2010). Researchers have adopted different timeframes, but generally LCC studies were conducted over a period of between 20 and 50 years (Martinez, 2014).

Life Cycle Cost (LCC) studies can be an important consideration in any new development project, and it is especially relevant in sustainable project feasibility analysis. Real (2010) assess the importance of LCC analysis to sustainable design – and outlines the basic methodology and purpose of a LCCA. Essentially, it involves an economic evaluation of the various costs involved over a certain period of time. The purpose of such a study is to identify the most cost-effective design option, by considering all costs relating to the construction phase (capital cost), operation (operating costs), maintenance, replacement and residual value (Ibid).

Gupta (1983) estimated that about 75% of the LCC of a building comes from the operation and maintenance stages, which highlights the significance of the LCC analysis.

The basic steps in conducting a LCC study is generally accepted to consist of five main stages (Real, 2010) - starting with (a) the identification of project parameters; (b) making assumptions with regards to the study period, discount rate and inflation, (c) compiling the data, (d) compiling the cash flows and finally (e) computing LCC.

The standard method of calculating the LCC is by means of the Net Present Value (NPV). The sum of all future cash flows is discounted to the present value by using an appropriate discount rate that is deduced through market research. The NPV is useful in the sense that it provides an opportunity to compare the project profitability with competing alternative investments. (Ibid)

Typical data input involves material data from manufacturers and contractors, historical analysis data and data from modeling techniques (Schade, 2007). Since a LCC analysis involves a cash flow analysis, the old principle of garbage-in-garbage-out (GIGO) applies. LCCA has many advantages, but due its forward-looking nature requires many assumptions to be made. Material behavior, future operating costs and future discount and inflation rates are often very difficult to predict which can ultimately deliver unreliable results (Real, 2010). LCC studies need to be supported with an appropriate risk analysis so that results can be presented within ranges of certainty, rather than a definitive result. A number of risk strategies can be followed to account for inaccuracies; the most popular are Sensitivity Analyses (deterministic), Monte Carlo (probabilistic) and Fuzzy Set Theory. (Ibid)

#### **2.4.4 Variability of expected returns**

Milne (2013) reported that retrofits can be executed on varying levels of complexity. A number of level 1 and level 2 type retrofits, as per Arup's grading system, has however been conducted - which proved to be successful.

Table 2.1: Retrofit related savings in South Africa (Source: Adapted from Milne, 2013)

Level	Location	Value	Scope	Saving	Period of saving	Possible payback period
1	V&A Waterfront, Cape Town	R22m	Lighting; HVAC; and waste management	R15,5m	3 years	4.25 years
1	First Rand Offices, Johannesburg	R30m	Lighting; equipment; and water heating	R19m	3 years	4.73 years

Nock (2010) reported that level 1 retrofits, or “retro commissioning” delivers average electricity savings of between 10%-20% with a payback of just over one year. Cash-on-cash return on these investments comes in at around 90%, but commissioning should be repeated every 5 years to maintain cost savings.

The feasibility of DER's seems less obvious. Lockwood (2009) points out that the business case of DER's are inconsistent and unproven. The report argues that there is little evidence that these initiatives increase building value, produce higher rental income or decrease vacancy. This is especially true for short-hold investments – where ROI's and future energy costs are unknown. Nock (2010) argues that DER's aimed at energy savings of more than 20%, are less lucrative than a level 1 intervention. However, when DER's are conducted as part of renovation projects, where equipment needs to be replaced in anyway, the incremental cost of energy efficiency is as low as 5%. The scope of these renovations may involve new tenant fit-outs, scheduled upgrades for air-conditioning or the market repositioning of new owners. If DER's, capable of 20%-60% energy savings, are not conducted alongside planned renovation projects, payback can be as long as 12 years at \$22/m2. However, taking into consideration the soft benefits of brand value, occupant productivity and reduced vacancy, payback can be as low as 5 years (Nock, 2010).

Extensive DER's such as Net-Zero projects – where buildings consume energy which is less or equal to the amount of energy created on site – can have simple payback

periods as long as 20 years. These comprehensive retrofit projects can often only be justified through the increased productivity of happier and healthier office workers, which is reported to be as much as a 3%-25% productivity increase. The significance of these findings is well illustrated in a Life Cycle Cost Analysis (LCCA) study conducted over a 30 year period where a firm spent 2% on building construction, 6% on operations and maintenance and 92% on staff salaries (Romm, 1994). A marginal increase on staff productivity can therefore have a substantial effect and justify a comprehensive retrofit (Ibid). In South Africa the perceived benefits of green building such as workforce productivity are not yet fully reflected in the potential market premium of Green leases (Berning, 2012).

Martinez (2014) shares this view and argues that any study aimed at measuring retrofit value should also include other 'less tangible' improvements, such as staff productivity. It is proposed that benefits be classified as direct, indirect and intangible. Direct benefits would include any savings or benefits that result as a direct consequence of operational savings – such as reduced lighting and cooling expenses. Indirect benefits relates to employee costs – such as reduced absenteeism and therefore productivity, which relates to higher turnover and ultimately profit. Intangible benefits relates to the increase in rental income, a lower cap rate or increased building value which results from an improved design or sustainable image. (Ibid)

Martinez (2014) conducted a cost benefit analysis through different case studies and found that there was a significant variation between different evaluation methods. In one case the intangible benefits were included, in which case the simple payback method estimates a payback of 14.3 years, compared to 10.7 years produced through an alternative method. The variability in results is evidence of the unreliability of façade retrofit data inputs, specifically when it comes to financial performance. (Ibid)

#### **2.4.5 Maintaining existing tenancies**

On a more physical level, Nock (2010) suggests that the disruption caused by the construction process of DER's, especially with current tenancies in place can be

problematic. A solution needs to be devised, whereby existing tenancies can remain intact and income streams consistent (Ibid).

Most DER projects have a significant impact on current tenancies, where office workers are either (a) temporarily inconvenienced by construction activities, or (b) on a longer-term basis where relocation is required. In the former scenario where no relocation is required, noise, dust and privacy are of concern. In case of the latter, tenants may not want to relocate and may choose to terminate their lease agreements which can greatly affect overall project feasibility. (Saleff et al., 2009)

A number of activities can cause disruption to existing tenancies. During the construction process, several portions of the site will be occupied. Scaffolding, stockpiles, cranes and other support or storage structures may be required. Further allowance needs to be made for the delivery of construction material, equipment and workers. In urban environments, very strict health and safety measures may apply where temporary protection mechanisms should be allowed for – as well as temporary provision for public circulation space around and into the building. Depending on the impact on pedestrian and vehicular traffic, approval from local authorities will need to be obtained ahead of time. Planning and budgeting for these activities are integral to the feasibility of retrofit projects, which should be done in a way that allows work to be executed safely and with minimum interference. (Saleff et al., 2009)

Burton (2014) highlights three distinctive methods of façade retrofitting, namely refurbishment, re-cladding and over-cladding. Insofar existing tenancies are concerned, Burton considers over-cladding as the ideal solution in that renovation work can be conducted without having to vacate the building.

## **2.4.6 Minimising investment risk**

### **2.4.6.1 Introduction**

The management of risk is essential to any investment decision. It allows an investor to predict future returns with greater certainty and provides a basis to compare capital projects (Chong, 2003). An investor may be exposed to risk in a number of ways; in the

case of real estate, financing risk and government policy has specific significance (Nock, 2010).

#### **2.4.6.2 Financing risk**

Retrofitting is perceived to be capital intensive, with long payback periods and lower than acceptable ROI's. Obtaining suitable finance can therefore be difficult, with a number of complexities adding to the problem (Nock, 2010).

The Pike Research Report, cited by Nock (2010) suggests that when financing for DER's are sought, the lien on new equipment would require the building's original lender to provide consent, which may be difficult to obtain. Many commercial properties are owned by shell companies that own no real assets to secure further improvements.

It is also difficult to quantify the cost-savings that will be generated through the DER, and becomes problematic when structuring a loan. In the absence of a quantifiable investment proposal, stakeholders are unlikely to invest. Firms have definite debt ratios and caps and a DER project will have to compete with other investment opportunities the firm may have. (Nock, 2010)

#### **2.4.6.3 Legislative policy**

In South Africa, the barriers springing from the cost of retrofits are not alleviated by any significant government policies. Due to a number of socio-economic factors relating to poverty and unemployment, which has a direct relationship with industries that contribute heavily towards GHG production, transformation to a green economy with adequate green policy and incentives remains problematic. (Kaggwa, 2013)

International research indicates that policy with regards to tax rebates and incentives can play a large role in the feasibility of DER projects. While developers may be reluctant to invest in sustainability due to long payback periods, especially for short-hold investments, the long term sustainable benefits that are demonstrated in the research, will have a possible impact on the economy and can benefit society at large (Lockwood, 2009).

In South Africa, little has been done regarding any significant policy or incentives. There are some incentives for small scale energy retrofits, that typically fall in the level 1 scope, defined by Connely and Adams (2009). Other more significant incentives are outlined in Section 12L of the Income Tax Act (Government Gazette, 1997), which allows taxpayers to deduct 45c per kWh of energy saved. These savings need to be proven through a baseline analysis and should be conducted on an annual basis (Kasavel, 2014).

While the operational cost savings from a DER is passed down to the tenant, the premium levied on leases is often not sufficient to carry the costs of the total retrofit, leading to an imbalance between tenant and owner (Nock, 2010). To make a real difference and encourage developers to invest in projects that could yield energy savings of 50% or more, Nock (2010) suggests that legislative policy needs to be reconsidered. The Pike Report mentions a number of critical stages or intervention points, where the incremental costs of efficiency will be marginal. Policy should focus on these points of intervention, which are: Initial design stages, at building purchase stage, tenants' improvement intervals and between renovation cycles (Nock, 2010).

On a more physical level, the form, position and use of the building is governed by the zoning regulations as it applies to any particular municipal district. Investors need to acquaint themselves with these by-laws as they may seriously affect project feasibility. In South Africa, any new buildings - renovations or retrofits are further subject to the National Building Regulations of South Africa, chapter 204 (SANS 204, 2011), which was first introduced in 2011 as a means to promote responsible energy use and to support the conservation of scarce natural resources (Ibid). The document deals with building design as it relates to insulation, sealing, lighting and mechanical ventilation requirements.

## **2.5 RETROFIT EXECUTION PROCESS**

Optimizing an existing façade requires the input of many professionals, contractors and sub-contractors. Coordination between these teams is critical, especially since the

project parameters are already constrained due to the pre-existing nature of the building. The execution process can be divided in three main stages, (a) feasibility, (b) design and (c) implementation (Arsenault P. , 2015).

### **2.5.1 Feasibility stage**

The feasibility stage involves an assessment of the advantages and disadvantages, while looking into the overall profitability of the scheme (Seeley, 1995). Saleff & Kesik (2009) refers to this initial stage as the Conditional Assessment and Pro Forma stage, which includes the physical surveying of the existing structure as well as obtaining and collating all operating cost information. An energy model of the existing structure is also compiled at this stage, along with a high-level cost-benefit framework. These are then used as inputs in the schematic design stage. It is estimated that this process can take between 4 - 6 weeks (Saleff & Kesik, 2009).

### **2.5.2 Design stage**

The feasibility stage is followed by the design stage where info obtained from the feasibility study is captured in a design proposal. It is important that a value engineering process start as early as possible to ensure that the most efficient option is adopted. Value Engineering as a concept, involves a deliberate procedure aimed at optimizing investment value (Cullen, 2010). Value and economy is improved through considering and applying alternative designs, materials and methods (Ibid). This can be done through computer simulations, which allow the user to compare various alternatives in order to derive the most efficient design within building regulatory compliance (Arsenault, 2015).

Saleff & Kesik (2009) elaborate on the design stage in more detail and note two sub-stages, the schematic design stage and design development stage. It is assumed that an integrated design process is followed to allow for the most optimal design concept. Design development commences upon approval of the schematic design, where the

technical resolution and logistical aspects are documented. This stage can vary greatly and depending on project complexity, can extend for several months.

### **2.5.3 Implementation stage**

Lastly, the implementation phase, according to Arsenault (2015), starts off by obtaining the necessary local authority approval and by lining up all the contractors and sub-contractors. Any long-lead items should be ordered early in the process to avoid delays later on. Planning the project execution is critical where the phasing of work on a sectionalized basis may allow for faster delivery times and less disruption (Ibid).

Similar to the feasibility and design stages, the implementation stage can also be broken down into further sub-sections, starting with Contract Documentation (Saleff & Kesik, 2009). During this stage the professionals prepare all drawings and specifications necessary to tender the works. Depending on the scope and time constraints, the tender drawings can be sufficiently detailed for use during construction. For fast-tracked projects, the tender documents are issued with less detail and get to be resolved in more detail while the actual tender is being conducted. This allows for a quicker turn-around time, but more variability in tender pricing, which is then most often subject to re-measurement. Certain aspects of the design works can be sub-contracted to specialists depending on the level of detail that is required. This is followed by the Envelope Retrofit stage, which involves the actual construction work relating to the façade. Insufficient structural bearing and surface issues as well as damages to the existing façade need to be attended to before the new façade can be installed. (Saleff & Kesik, 2009)

If the project brief includes the replacement of the current HVAC system, the installation and setup of new equipment happens once the façade installation is mostly complete. The installation is reliant on the use of lifts and cranes to move heavy equipment up and down the building. Installation is followed by a Commissioning Stage which involves the fine-tuning and calibration of the HVAC systems over a discontinuous period. (Saleff & Kesik, 2009).

## **2.6 FAÇADE RETROFIT STRATEGIES**

### **2.6.1 Classification of façade retrofit strategies**

Façade upgrades are extensively varied and adaptations are as varied as the buildings themselves. Yet most façade upgrades can be classified in terms of its application. The research shows that in most instances a distinction is being made between (a) refurbishments, (b) re-cladding and (c) over-cladding (Burton, 2014).

#### **2.6.1.1 Refurbishments**

Refurbishment involves the process of making something new again. It differs from restoration in that refurbishment does not require the upgrade to mimic its original appearance, but rather suggests an upgrade which enables it to serve a similar functional purpose as was originally intended (Merriam Webster, 2016). In the case of retrofitting, these are basically window replacements, where existing frames, structure and substructure remains in-tact. At the most, seals, gaskets and beading may be replaced along with the glazing, but no frames are removed (Burton, 2014). This option is ideal where the building has heritage value or where windows are fitted as apertures, i.e. not full curtain walls. Planning approval is probably not needed and work can be executed with minimal disruption to current tenants. Burton (2014) notes that even though glass may be replaced with double or even triple glazing, the current thermal bridges and poor insulation that might exist in the current assembly will remain.

#### **2.6.1.2 Re-cladding**

Re-cladding resembles the most common form of façade renovation. It is essentially a renovation project which involves the complete removal of the existing façade and replacement with a new, more efficient façade (Branz, 2014). According to Burton (2014) re-cladding offers an opportunity for the complete rebranding of the existing property, while its thermal and lighting performance can be completely overhauled (Ibid). Compared to over-clad projects, re-cladding provides the opportunity for a revised ventilation strategy, where new technology may enable the use of openable

sections and ventilation panels. Revised ventilation strategies may reduce HVAC loads as natural ventilation is used to complement existing systems (Branz, 2014).

Re-cladding may hold further relevance, where the possibility exists of pushing the new façade further outwards to create additional rental space. The cost of the retrofit can in part be offset by the additional rental income, thereby adding to project feasibility (Burton, 2014). Even though re-cladding is much simpler to execute compared to over-cladding, many of the same constraints need to be considered. Edge conditions, loading capacity of the existing structure and floor heights need to be surveyed and analyzed before any work is planned.

Burton (2014) explains that although a new façade might be the most expensive option amongst façade retrofits, it is likely to be the lowest risk option (Ibid). The biggest drawback involves the disruption of current tenants and the potential loss in income where tenants may wish to relocate.

### **2.6.1.3 Over-cladding**

Burton (2014) described the process of over-cladding as involving the installation of a new building skin over the existing skin, by leaving the current façade in place. Over-clad systems therefore offer the opportunity to completely reinvent the appearance of the building. It is suggested that over-cladding is usually the lowest cost option as it involves no demolition; while the new system can take advantage of the current system's energy performance. Kesik (2009) agrees that over-cladding is the most economical strategy for tall building renewals.

Over-cladding does not affect the internal environment and can usually be installed without affecting existing tenants, which does not affect rental income during the construction process (Stewart, 2008). Furthermore, since the building is not materially changed, local authority approval should be simpler to obtain compared to other initiatives (Burton, 2014).

Over-clad projects require meticulous planning and surveying of the original façade. The condition, performance and structural ability of the existing façade should be established before any further planning can occur. This assessment will inform the parameters of the over-clad design and will confirm whether over-cladding is indeed the right solution (Burton, 2014).

The introduction of a new façade is likely to change the vapour pressures in the new façade that can lead to condensation elsewhere, which should be designed for. It is also important that particular attention is paid to the fixing of the new façade, which can either be fixed onto or through the existing façade. In each instance, the structural integrity of the existing façade should be considered, while thermal breaks will need to be considered around new fixing positions. (Saleff et al., 2009)

While over-cladding may be the most cost effective solution, it should be noted that the success or failure of this system will mostly depend on the construction details (Saleff et al., 2009). Other popular forms of over-cladding involve the addition of double skin facades (DSF), which has mostly found application in European countries, especially northern Europe (Gaspari, 2015).

#### 2.6.1.4 Summary of façade retrofit strategies

Table 2.2: Summary of Overclad typologies based on optimality (Source: Author)

Description	Refurbishments	Re-cladding	Over-cladding
Extent of replacement	Glazing only, with seals	Entire facade, incl. Structure, frames, glazing, infill panels	Glazing remains intact. No changes to existing structure. Therefore only additive.
Council Approvals	Unlikely	Likely	Likely
Tenant disruption	Medium	High	Almost none
Relative Cost	Medium	High	Low
Other advantages (excluding energy benefit)	None	Potential additional space	New aesthetic appearance
Potential limitations	Few	Cost, Approval and loss of income	Structural (mounting space and weight)

Over-cladding is can therefore be considered a simpler solution compared to Refurbishments and Re-cladding in that the existing structure remains unchanged. This translates to a lower relative implementation cost with almost no disruption to the current tenancies, which affects the building's income stream and therefore project feasibility. Based on this, Over-cladding may be considered the most appropriate retrofit strategy as far as financial feasibility is concerned.

## **2.7 OVER-CLADDING TYPOLOGIES**

### **2.7.1 Introduction**

According to Saleff et al. (2009), over-clad strategies that are most commonly used for solid building sections are (a) Exterior Insulation and Finishing Systems (EIFS), which includes a rear drainage system; and (b) panelized cladding with pressure moderated drain screens. Both these systems focus on dealing with surface moisture and façade drainage in the most effective manner. Other solutions include double skin facades, brise-soleil screens and horizontal shading devices.

### **2.7.2 Exterior Insulation and Finishing Systems (EIFS)**

In a study conducted by Dentz and Podorson (2014), it is noted that EIFS systems typically consist of the following layers: adhesive, foam insulation, reinforcing plaster or base coat, reinforcing mesh embedded in the base coat and the finishing coat. The system can be successfully applied to a number of existing base layers, such as timber or masonry. Modularised systems can be manufactured off-site, which is why the system is especially useful in commercial applications where little disruption is caused though reduced construction timeframes. Through their research, it was found that foam insulation layers of up to 38mm is the most efficient depth as thicker assemblies require cladding support brackets (Dentz & Podorson, 2014).

Dentz and Podorson (2014) focused on the relative cost efficiency of various EIFS thicknesses in certain climatic zones, while also focusing on how the prefabrication of

EIFS panels can successfully reduce the costs of DER's. A case study conducted by means of a simulation model found that EIFS modular systems can successfully reduce energy consumption in all tested climatic zones in the U.S market.

Lstiburek (2007) discusses the importance of drainage measures for EIFS systems and that by following the correct methods the system can be successfully applied in all climatic zones. EIFS gained popularity as early as the 1980's but started to show signs of failure due to moisture penetration which affected the base layers and sub-frame fixings. These systems were completely sealed as it was aimed at creating an absolute weather barrier. Moisture sensitive cladding materials, such as gypsum board and oriented strand boards or plywood sheathing didn't perform well in these arrangements, coupled with the fact that door and window openings could never be adequately sealed. These issues led to the development of drained EIFS which allows moisture to pass through the surface layer which then gets to be drained in an internal cavity. Modern-day drained EIFS assemblies are among the most robust and advanced moisture-controlled systems currently available (Lstiburek, 2007).

### **2.7.3 Structural Insulated Panels (SIP's)**

SIP's make up a modularized system that allows for fast-tracked construction timelines and with greater insulating capabilities than traditional site-built wood and steel framing systems (Reynolds & Stein, 1999). Individual units are manufactured with insulated cores and thermal storage surfaces, which ultimately is much lighter than traditional wall-type assemblies.

SIP's are normally constructed with a combination of polystyrene or foam-based cores with orientated strand board (OSB) outer sheeting. These OSB sheets are made from fast growing renewable wood species. The insulation layers that are used comprise mostly of air with 2% plastic content, which in terms of production still consumes 24% less energy compared to fiberglass insulation. (SIPS, 2009)

More recent technological advancements have focused on SIP's that comprise of aerogel or gas-filled cores. Gas-filled panels can be filled with elements such as Argon, Krypton or Xenon which then acts as a low conductivity sealed plastic bag draped over the façade (Reynolds & Stein, 1999).

#### **2.7.4 Vertical and horizontal shading screens**

Another means of façade over-cladding involves the post fixing of vertical shading screens or “brise-soleil”. Vertical shading devices have the ability to dramatically decrease solar heat gain in peak periods and thereby reducing active cooling required (Prowler, 2014). It was found for example that, depending on window arrangements and total exposure, shading screens can reduce annual HVAC energy consumption by 5-15%. These devices have further benefit in that occupant comfort is enhanced through glare and contrast ratio control.

Brise-soleil screens have the benefit of also shading the interior against low-lying afternoon sun exposure which is not the case with horizontal screens. Overhang-type screens are most effective at blocking solar radiation on the southern façade (in the USA), especially during the summer months where the solar inclination is higher.

#### **2.7.5 Double Skin Facades (DSF)**

##### **2.7.5.1 Overview**

Double Skin Facades (DSF's) resemble yet another category of over-clad systems, which are increasingly being incorporated in high-end commercial architecture in Europe and other areas of the Pacific Rim (Boake, 2003). Historically, DSF's referred to a wide range of secondary insulation layers. It is the concept of a secondary facade membrane that can respond to dynamic climatic conditions by enhancing the building's natural ventilation and thermal insulation (Ibid). The Trombe wall for example, which constitutes a mass wall element that absorbs heat and in turn creates a stack ventilation effect, can be considered a precursor to the modern concepts of DSF's (Ibid).

Today, DSF's are synonymous with double glass facades, which involve an independent glazing layer which covers the primary weatherproof façade. The two skins form an air corridor in between which acts as insulation against extreme temperatures, but also wind and noise. Sometimes, solar shading devices are positioned between the two skins to assist in the functioning of the DSF system (Pollard, 2008). DSF typologies can be categorized in a number of ways, but on the most abstract level one can distinguish between a Buffer System, Extract Air System and Twin Face System (Pollard, 2008).

The Buffer System assembly represents the earliest form of DSF and comprises two single glazed layers with a 250mm to 900mm sealed cavity in between. Fresh air is allowed to enter the building by means of a secondary HVAC system (Boake, 2003). The Extract Air System involves a glazing layer placed inside the primary façade layer to create an internal, sealed cavity. The heated air inside these cavities is mechanically extracted, while the interior gets to be cooled through HVAC with natural ventilation. Similar cavity spacing applies to this system. The Twin Face system is primarily different in that it allows for openable sections in the façade to allow for fresh air intake. The system is especially useful in cold climates where the heated cavity can radiate into the interior through the openable window sections. In summer, the windows may be opened at night to allow the building to release heat into the cavity which reduces the load on the HVAC systems (Ibid).

Dalangin (2013) draws a further distinction with regards to DSF classification, categorizing four distinct systems, namely Box, Shaft Box, Corridor and Multi Storey facades. These classifications relate to the sectionalizing of modern DSF typologies (Oesterle et al., 2001; Saelens, 2002 & E. Lee et al., 2002).

Due to the complexity of DSF's and the underlying efficiency in standardizing building components, manufacturers are increasingly looking to modular systems in an attempt to introduce more efficient and cost-effective façade solutions (Vaglio, 2010). The benefits

of modular or unitized systems are vast, including simplified installation, greater accuracy, less disruptive maintenance measures and fast-tracked construction timelines (Ibid). The partitioning of DSF assemblies has allowed manufacturers to produce façade components that can be completely pre-manufactured.

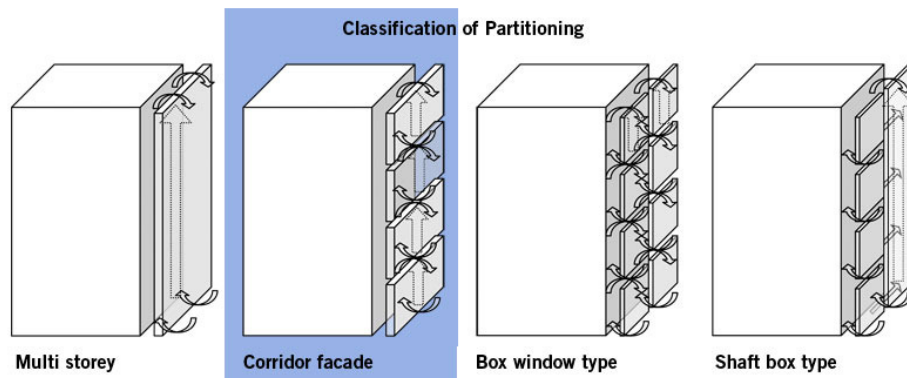


Figure 2.1: DSF classification systems (Source: Dalangin, 2013)

## 2.7.5.2 DSF systems

### 2.7.5.2.1 Shaft box

Shaft Box DCF's involves the partitioning of the façade in vertical and horizontal sections in an attempt to maximize natural draft through stack effect. This system only functions in naturally ventilated DSF's. Glazed façade modules are distributed across the façade on a floor-per-floor basis, but linking to vertical ducts in between that most often extends the full height of the façade. All façade modules are linked to these ducts, where heated air is allowed to escape through the duct or chimney. As the air heats up, it gets pulled into the duct thereby creating an upward movement of air which in turn pulls in fresh air through the box modules' openings. (Vaglio, 2010)

### 2.7.5.2.2 Corridor

The corridor DSF assembly involves a horizontally segmented façade, which is insulated per floor. Long corridors are wrapped across the façade, which is normally wide enough to allow for cleaning and maintenance. Each section operates independently from each other where horizontal openings allow for ingress and egress

air on a floor-per-floor basis. Ambient air is drawn through the lower opening as heated air within the cavity is allowed to rise and escape through the upper regions of the corridor. (Vaglio, 2010)

#### 2.7.5.2.3 Box window

The Box Type façade is similar to the Corridor façade in that all floors function independently from another with no vertical chimneys or inter-connecting ducts. It differs in the way that the Box Window system is also partitioned vertically across each floor. A series of box units therefore function independently from each other, which also makes this system the most modularized and preferred pre-fabricated solution (Dalangin, 2013).

#### 2.7.5.2.4 Multi-storey

This system is completely un-partitioned and also the most labour intensive in terms of on-site installation. The cavity void extends the full width and height of the façade that forms one large volume of space. Similar to the corridor façade, the DSF assembly generally has a cavity of sufficient width to allow for cleaning and maintenance. The cavity can either be naturally ventilated or operate via assisted mechanical ventilation measures. Hot air is drawn in near the base of the building and gets expelled at the top or roof level. For naturally ventilated systems, consideration of the opening sizes and cavity width is of particular significance to achieve the most optimal draft air movement. In existing building, this is most often governed by the extent and capabilities of the existing structure (Dalangin, 2013).

#### 2.7.5.3 Justification of DSF's

The cost and justification of double skin facades has been discussed in a number of studies, with varying views. *“DSF's are merely one approach to overcoming the large energy consumption and comfort problems that are created by excessive glazing areas of inferior performance.....The most environmentally sound..... solution avoids the problems that DSF's are intended to solve by reducing glazing area and increasing the quality of the glazing product.”* (Straube and Van Straaten, 2001:51)

Double skin facades are synonymous with the European urban landscape, especially in Northern Europe. According to Pollard (2008) this is due to the exceptional heating requirements, the desire for natural light in areas with low solar visual spectrum, coupled with high energy costs. It is noteworthy though that DSF's are increasingly being constructed in more moderate climates where heating requirements are less severe (Pollard, 2008). It is argued that this trend can partly be ascribed to a change in user expectations. Previously, buildings in moderate to hot climates could be sufficiently insulated by means of mass construction and shaded by more traditional means such as shading screens. However, with emerging modern building typologies and the requirements that go with it – especially in the case of office buildings, these traditional means are no longer adequate. Natural daylight, views, optimal and controlled thermal environments and a modern aesthetic is highly valued and no longer optional, regardless of its climatic region (Ibid).

Saelens et al. (2003) concluded that sophisticated control mechanisms are needed to adjust airflow within the DSF cavity, in addition to active shading devices for the assembly to function at an optimal level. DSF's can only deliver feasible results in the presence of complex control systems and the same benefits can more easily be achieved by employing simpler façade design strategies (Roth et al., 2007).

## **2.7.6 Case studies**

### **2.7.6.1 Introduction**

A number of façade remodeling strategies can be used to optimise the building's energy consumption. It ranges between reusing existing elements to replacing the entire façade. These strategies range between, re-cladding, over-cladding and double skin façade interventions.

### **2.7.6.2 Re-cladding**

A recent example of a re-clad project involves the upgrading of the Standard Bank Towers, situated in the Cape Town CBD. The development is owed by Redefine properties that spent a total of R533m to overhaul its 57 000m<sup>2</sup> investment at a yield of

6.4% - according to Mike Ruttel, director of development at Redefine. The building is 94% occupied and mostly comprise of premium grade offices with some retail space on street level. The new flush-glazed external façade will reduce cooling demand by 30% (Ruttel, 2015).

### **2.7.6.3 Over-cladding**

A number of over-clad strategies exist, ranging from the addition of a glazing layer or vertical solar screens, to horizontal shading devices. In a study conducted by Pejić (2014) shading devices were added to a student residence in Serbia, which showed a significant improvement in energy performance. 1m wide shading devices were positioned onto the façade, which was modeled using an energy simulation platform, *Energy Plus* - an open source analysis tool developed by the US Department of Energy. The software showed that additional savings can be made by replacing certain windows on the east and western facades and by reducing window height by 40cm (Pejić, 2014).

In a recent study conducted by Gaspari and others (2015), the impact on energy balance and microclimate was tested specifically through the use of over-cladding methods. The research was conducted through a case study where four different over-clad systems were tested in order to obtain the most energy efficient and cost effective combination. The variables included the addition of brise-soleil screens, glazing layers over existing windows and additional layers over existing non-glazed façade portions. The latter being in the form of insulation layers, membranes and cavities. The study concluded that the most cost-effective façade over-clad solution had a simple payback period of 8 years, compared to 12 years – which was the worst case scenario (Ibid).

### **2.7.6.4 Over-cladding: Insulated panels**

An EIFS overclad system was installed at the Blue Route Mall in Cape Town, when it was upgraded in 2010, 40 years after being constructed (Terraco Ltd., 2016). The structure was redressed with an Insulated Concrete Formwork (ICF) system, which enhances the energy consumption of the building, specifically HVAC loads. The system comprise of Styrobond DP basecoats and reinforced mesh with an applied finishing

layer. The company claims that their ICF Zenith system provides a competitive solution with high ROI and typical payback of 5 years (Ibid).

#### **2.7.6.5 Over-cladding: Shading Screens**

In a study conducted by Sabry et al (2013) the balancing of daylight and energy performance of solar screens was investigated in warm climates. The study specifically focuses on the axial rotation of shading screens and the aspect ratio of openings. The variables that were studied include screen solidity, depth, reflectivity, aspect ratio, louvre angle, rotation and colour (Sabry et al, 2013). The author notes the importance of achieving the right balance. At the extreme end of the spectrum, natural lighting might be compromised that will lead to additional lighting costs. On the other end, too little shading will have a minimal effect on cooling demand.

A number of screen combinations were modeled and tested through simulation processes, focusing on the city of Jeddah, Saudi Arabia. It was concluded that non-rotated screens where horizontal louvres were dominant – a ratio of 18:1, horizontal to vertical, performed the best on the north and south facades. This screen solution also performed well on the east and west facades, but was outperformed by a vertically rotated screen with an aspect ratio of 1:1. This combination of screens managed to enhance day lighting while minimizing total energy consumption by 25% (Ibid).

#### **2.7.6.6 DSF: Box window**

An example of this system can be seen at Levine Hall at the Pennsylvania School of Engineering, where a six-storey modular system was incorporated on the east and west facades (Vaglio, 2010). The same system was used at One River Terrace in New York - constructed in 2008, which was also the first residential building in New York to be awarded a LEED Platinum Rating. The façade comprised of 2.5ft and 5ft wide by 10.5ft tall modularized panels, which extends 31 floors. A 5 inch cavity separates the interior and exterior layers. The system's application is two-fold. In summer months the lower air vents are opened to allow hot air to circulate through the box thereby assisting natural ventilation of the cavity. In winter months the vents are closed, which keeps the hot air trapped in the cavity and thereby setting up a thermal layer that prevents

excessive heat loss. This feature reduced energy consumption in winter by 25% (Dalangin, 2013).

#### **2.7.6.7 DSF: Multi-storey**

A multi-storey system was employed at the Seattle Justice Centre which comprises a 30 inch cavity that extends over 13 floors and covering a total façade area of 18 000 square feet. The exterior skin comprises a single glazing layer, while the interior windows are insulated. The system is further complemented by a roller blind system that operates on historical season data (Vaglio, 2010).

#### **2.7.6.8 DSF: Warm climates**

In another study conducted by Saelens et al. (2003), a number of computer simulations were performed on different DSF assemblies as it relates to a hypothetical building in Belgium. It was found that sophisticated control mechanisms were needed to adjust airflow within the DSF cavity, in addition to active shading devices for the assembly to function at an optimal level.

A study conducted in the USA supports the view of Saelens et al. by concluding that DSF's can only deliver feasible results in the presence of complex control systems and that the same benefits can more easily be achieved by employing simpler façade design strategies. They highlighted the need for further study due to a lack of location specific data (Roth, Lawrence, & Brodrick, 2007).

## **2.8 TECHNICAL PERFORMANCE OF OVER-CLAD FACADES**

### **2.8.1 Performance Values**

This section investigates the material attributes of energy efficient materials, specifically as it relates to heat and light transfer.

#### **2.8.1.1 Heat flow and U-value**

Convection, conduction and radiation are three means by which heat can be transferred from one surface or space to another. When an object has a core temperature which is

different to its surroundings, heat will transfer to the cooler object. In case of convection, cool air molecules will absorb heat from an immediate surface. These molecules will then expand in size, rise and move the heat elsewhere. The inverse is also possible, where heated air molecules can transfer its energy to a cooler surface (Reynolds & Stein, 1999).

Conduction involves the direct transfer of heat through physical contact between solids, for example between earth and concrete or steel and glass (Anderson, 2006).

In case of radiation, heat is transferred in the form of electromagnetic waves over a distance. Radiation can take place through most atmospheric spaces where the moisture content is not excessively high (Ibid).

The U-value represents the collective energy flow, occurring through conduction, convection or radiation as it passes through any given material. This transfer of energy is due to the temperature differential between the inside and outside of a building for example (Ander, 2014). A higher value implies a greater flow of energy – where for example, a window with a high U-value would result in greater heat loss during winter. U values are expressed through BTU's per hour per square foot per degrees Fahrenheit. BTU's are a traditional British method of measurement which is an expression relating to energy input. Specifically, 1 BTU equals 1055 Joules, which is the amount of energy needed to raise the temperature of a pound of water by one degree Fahrenheit translates into  $W/m^2.K$  (Reynolds & Stein, 1999), which is Watts per square meter Kelvin, for a given thickness of that material. This means that if the U value of a certain material which is 100mm thick is equal to  $1W/m^2.K$ , then 1 Watt of heat will be transferred across  $1m^2$  of the material if the temperature difference between the two sides were 1 Kelvin (Ibid).

For a typical aluminum framed glass window, U-factors can range anywhere from 0,2 - 1,3. Based on this system of measurement, a window with U-value of 1 will lose twice as much heat as a window with U-factor 0.5 (Ander, 2014).

### **2.8.1.2 Resistance and R-value**

U-value and R-value is interrelated, but where the R value is specifically concerned with a material's ability to resist heat flow. For example, the R-value refers to the temperature difference that will cause 1 unit of heat to pass through 1 unit of area over a given period (Archmedia, 2015). It is therefore a measure of insulation efficacy, where a higher number implies greater efficacy, which can be expressed as  $(m^2 \times K) / W$  (Ibid).

Materials used in conjunction or sandwich assemblies will have a total R-value, which is the sum of their individual R-values and is therefore additive (Ibid). Resistant materials that are used for insulation can be categorized as (a) inorganic fibrous or cellular materials, (b) organic fibrous or cellular material and (c) metalized organic reflective membranes (Reynolds & Stein, 1999).

Inorganic fibrous or cellular materials typically include wool, glass and vermiculite, whilst organic fibrous or cellular material typically includes cotton, cork, rubber or polystyrene. Metalized organic reflective membranes typically include multilayered foil-type sheeting (Ibid). EIFS boards for example are typically constructed of expanded, rigid polystyrene which get to be applied to external plywood or other cementitious substrates (Ibid).

Surface resistance is increased when air movement is minimal. In the absence of severe airflow, a thin insulating layer of air is created along the entire surface. The resistance capability of this static air layer is equal to 12.7mm plywood. In the presence of air movement, the insulation drops significantly, such that a 6.7m/s wind will drop the resistance to about 25% of its still air capacity (Reynolds & Stein, 1999).

### **2.8.1.3 Solar Heat-gain Coefficient (SHGC)**

The SHGC represents a ratio which is an indication of how much of the sun's energy is transmitted through a window as heat. A higher SHGC means that more solar energy is allowed to pass through the window. A zero value implies that no solar heat is transmitted through the material (Ander, 2014). This value can increase to a maximum of 1, in which case all of the sun's heat is allowed to pass through the opening, which

will be the case when a window is left completely open. Similar to the U-value, the ratios are linear – so a panel with a 0,4 SHGC will allow twice as much solar heat to pass through compared to a SHGC panel of 0,2 (Ibid). The SHGC is a new terminology, which replaced the more outdated Shading Coefficient (SC) measure. The SC refers to the amount of heat gain passing through a glass panel as it compares to a clear 1/8<sup>th</sup> inch of single glazing.

A lower SHGC can significantly reduce HVAC energy demand, but due to a lower Lighting Transmission value, can increase the artificial lighting requirement. High SHGC glass panels are typically used in double skin façades which requires sufficient heat to pass into the cavity to enhance natural ventilation through stack effect (Ibid).

#### **2.8.1.4 Visible Transmittance**

This ratio is an expression of the portion of visual solar spectrum that is allowed to pass through a section of glazing. Sunlight is composed of a number of electromagnetic wavelengths which is called the solar spectrum (Berkeley Lab, 2015).

This spectrum includes infrared, ultraviolet and visible wavelengths – the latter being of significance in the VT ratio (Ander, 2014). Visible light is the only component of the solar spectrum that can be detected by the human eye. Ultraviolet light has a short wavelength and accounts for about 7% of the total spectrum, while Infrared accounts for 46%. Visible light therefore makes up 47% of the total energy contained in solar rays.

## **2.9 SUMMARY**

The literature suggests that the building envelope can be considered to have the biggest impact on a building's overall green status (Urban Green, 2014), where it is seen to have the most significant impact on the thermal isolation of the interior as well as the indoor air and lighting quality (Connely and Adams, 2009). It therefore affects heating and cooling demand, lighting requirement and also occupant productivity (Ibid).

Studies conducted by the US Office of Energy Efficiency and Renewable Energy (2008), found that lighting and cooling accounts for around 57% of the total operational expenditure in commercial office buildings. Refurbishing the building façade therefore has significance in terms of optimising overall energy consumption.

The research suggests that rental rates for green certified buildings are up to 30% greater than non-certified buildings with a sales premium of 16% on average (Martinez, 2014). Little substantive research has however been conducted regarding optimising building facades in order to achieve Green status. Lockwood (2009) notes that the business case of DER's are inconsistent and unproven, while White (2010) argues that Payback and Return on Investment (ROI) was seen to be considerable barriers to energy retrofits and that more research needs to be conducted to determine ultimate feasibility. Nock (2010) supports the notion and notes that Retrofitting is perceived to be capital intensive, with long payback periods and lower than acceptable ROI's.

In order to determine the feasibility of DER's, Martinez (2014) suggests that the simple payback method should be used, which is the most commonly accepted method. Gallagher (2007:266) notes that the payback method is limited in the sense that it does not consider future cashflows after the actual payback period and that a project may yet be feasible over the long-run. The payback method and cash-on-cash ROI is widely accepted by property investors, who may often not be interested in taking a longer view by using methods such as the LCCA (Martinez, 2014). This view is likely to be influenced by the investor's investment horizon and his risk profile. Payback and cash-on-cash return are therefore the more conservative methods, and it can be concluded that a project that is deemed feasible by these standards, will also be feasible in terms of a LCCA.

A number of façade upgrade strategies have been researched, which varies extensively. Yet most façade upgrades can be classified in terms of its application. The research shows that in most instances a distinction is being made between (a) refurbishments, (b) re-cladding and (c) over-cladding (Burton, 2014). Over-cladding was

noted to be the most optimal solution and becomes the basis of the research design strategy.

# RESEARCH DESIGN AND METHODOLOGY

## 3.1 CHAPTER OVERVIEW

The following chapter initiates by investigating various methodologies of research projects that are similar to the study. The theory behind these methodologies is then further researched to gain a broader understanding of its significance to the study. The chapter further elaborates into the research design and data collection strategies that are to be used.

## 3.2 METHODOLOGY PRECEDENT

### 3.2.1 Introduction

To gain a broader understanding of research methodology, Martinez (2014) and Sanguinetti (2012) provides a valuable framework as it applies to facades retrofits. The focus of their studies was specifically aimed at establishing a suitable method to assess energy façade retrofits.

Martinez (2014) outlines three methods of façade retrofit evaluation – deterministic methods, stochastic methods and financial methods. In deterministic methods of evaluation the results are specifically related to the inputs. In terms of façade retrofits this mostly takes place through mathematical formulae in order to predict future behavior. These studies can either be static or dynamic, where in a static process most parameters are fixed so that a steady-state analysis can be performed. Dynamic studies involve very complex calculations which are best executed through a simulation process.

Regardless, deterministic methods are often used as part of an iterative analysis, where the researcher constantly changes variables in order to get closer to a desirable result.

Examples of deterministic studies that involve dynamic simulations include a study done by Gucyeter (2012) where envelope retrofit strategies are tested in a calibrated model. Energy data collected over a 365 day period is fed into the model to determine annual energy use of a campus building. In another study, Singh investigates façade retrofits among other Energy Conservation Measures (ECM's) in an attempt to reduce energy consumption to zero net-energy status. Other studies have focused on LCA's by using energy model simulations (Martinez, 2014).

The stochastic model, Martinez (2014) explains, deals with random components that use a distribution as input, instead of fixed numbers. As such, the output will also be in the form of a distribution. These methods are useful in that the output distribution may reflect what the input should have been (Martinez, 2014). In some studies, multiple simulations using uncertain inputs are conducted, which are defined by appropriate probability distributions. These simulations then produce a range of likely outcomes and therefore doesn't require the manual iterative process often used in conjunction with deterministic studies. Sanguinetti (2012) for example simulated a number of different retrofit scenarios, involving different combinations of façade insulation that was tested against a base scenario. The most efficient façade make-up could be identified through the use of this statistical method.

Focusing on an integrated performance framework to guide façade retrofits, Sanguinetti (2012) argues that a more holistic approach to façade retrofit feasibility should be adopted. Three subsets are identified, which together informs total façade feasibility. These include delivery process, investment performance and environmental performance (Sanguinetti, 2012). The delivery process focuses on the construction period, where the method of construction is the most significant factor – adding to the existing façade or replacing the existing facade, in which case demolition activities have further significance. Environmental performance focuses purely on the quality and functioning of the newly installed system, while investment performance looks directly at the net financial gain derived through energy savings – as measured in terms of operating expenses. The three subsets are interrelated (Ibid).

Sanguinetti (2012) elaborates on each dimension of façade performance, relating it to a certain set of measurable criteria. In the case of environmental performance, it is noted that this aspect is directly related to the building users' activity and in turn their relative comfort. A baseline level of comfort needs to be maintained (Sanguinetti, 2012). Together, the façade and mechanical systems operates on a symbiotic basis, where any energy that is lost or gained through the façade is equalized by the mechanical systems. This applies to both temperature and lighting.

Visual comfort depends on lighting levels which can be measured through the Visual Comfort Probability Index (VCPi) for example. Thermal comfort is mostly measured through one of two indices, the Predicted Mean Vote (PMV) or the Predicted Percentage Dissatisfied (PPD) scales (Ibid). The Draft Rate (DR) is another feasible measure of thermal performance (Ibid).

The research has demonstrated that façade analyses and retrofit studies are well documented. In an attempt to define a suitable research methodology and to gain a better understanding, other research studies are retrieved.

### **3.2.2 Review of pertinent methodologies used by others**

#### **3.2.2.1 Source 1: Brunoro & Rinaldi (2011)**

##### **3.2.2.1.1 Aim of Study**

The authors set out to determine whether double skin glass facades are an effective strategy in a Mediterranean climate, specifically in Italy.

##### **3.2.2.1.2 Methodology**

A multiple case study was conducted, involving three existing buildings located in Italy, which have undergone a double skin façade retrofit. The researchers wanted to (a)

assess to what extent total energy consumption was reduced and (b) which retrofit solution is the most optimal strategy to achieve this end.

#### Data collection tool/s

Techniques used involve the studying of documents and records as well as structured surveys.

#### 3.2.2.1.3 Method

An energy analysis was conducted prior to the refurbishments, which included a study of operational expenses as a proxy for energy use. Thereafter the building was monitored for a period of one year, during which time the researchers collected operational cost data and also studying occupant comfort by means of surveys.

The study therefore is both quantitative and qualitative. Cost data is used as a proxy for energy use before and after the upgrades, which provides quantitative data. Occupant comfort was an additional measure which is qualitative in nature.

### **3.2.2.2 Source 2: Garmston, Fox, Pan, & Wilde (2013)**

#### 3.2.2.2.1 Aim of Study

The research paper is aimed at analyzing the selection process of facade retrofit strategies and to evaluate its relative success.

#### 3.2.2.2.2 Methodology

The research is based on a single case study approach which focuses on a 5 storey 1970's office building situated in England, and which has been retrofitted in 2011.

#### 3.2.2.2.3 Data collection tool/s

The researchers gathered data by means of (a) structured interviews with the design team and other key persons involved in the project; (b) gathering information through an in-depth documentation review; and (c) by thermo-graphic imaging of the building after the façade has been refurbished.

#### 3.2.2.2.4 Method

The study is of a qualitative nature as it mostly relies on the accounts of project stakeholders through interviews. This feedback was used to determine how the project team adopted a particular façade design, which was measured and benchmarked based on the work stages set out by the Royal Institute of British Architects (RIBA). After the completion of the façade upgrades, the authors performed a thermo-graphic mapping of the façade to determine the extent of energy transfer and relative success of the project team's decision making.

### **3.2.2.3 Source 3: Lea, Volker, Borges, Fisch, & Kuchen (2009)**

#### 3.2.2.3.1 Aim of Study

The study focuses on the geographical area of Brazil. The authors argue that highly glazed facades are not ideally suited to climates like that of Brazil which results in excessive energy consumption due to increased cooling demand. The study aims to illustrate how ventilated double skin facades can adequately address this problem.

#### 3.2.2.3.2 Methodology

This is a multiple case study which overlaps with experimental research and simulation. The research has case study features in that it investigates a setting within its real world context (Yin, 2004) - in this instance by means of a virtual simulation. Given the simulation, the authors are allowed to control the variables of the study and to compare them to a control group or base case, which also broadly categorizes this study as experimental research.

#### 3.2.2.3.3 Data collection tool/s

- Computer simulation data output
- Documentation review

- Weather data files as input

#### 3.2.2.3.4 Method

The study involved the mapping and simulation of nine hypothetical office buildings in Brazil, positioned in different states and along different latitudes. Each building was modeled on a single-room basis which was considered a representation of the larger building. The independent test variables in each case comprised of the window-wall-ratio (WWR), the glass type and room ratio and size to determine the annual energy consumption for different combinations of the variables.

In its review of methodologies pertaining to other similar studies, Lea,et al.(2009) cites Fisch et al. (2005). Their study drew from the methodology employed by Bremer et al. (2005) which also involved the adoption of a simulation programme focusing on single rooms only – in this case pertaining to the geographical area of Berlin. The authors modeled combinations of three different WWR's, three types of glazing, four shading devices and four orientations. The aim was to find the most optimal combination resulting in the lowest energy demand for lighting, cooling and heating functions.

#### **3.2.2.4 Source 4: Sabry, Sherif, Mahmoud, & Aly (2014)**

##### 3.2.2.4.1 Aim of Study

The objective of the research was to determine the most optimal window shading strategy for buildings in hot arid climates, in an attempt to reduce total energy demand, while finding a balance between cooling and lighting demand, without compromising visual comfort. The study focuses on solar screens and its material properties, along with permutations of layouts and assemblies.

##### 3.2.2.4.2 Methodology

The authors simulated a number of hypothetical cases and adjusted the independent variables to draw conclusions as it compares with a control group or base scenario. In that sense, the study is highly experimental in nature. The study methodology is very similar to that of Huckemann et al. (source 3) in that, while an experiment is conducted,

the experiment is strongly linked to a real geographical area. Weather data is imported into a simulation to replicate the climate of the city of Jeddah in Saudi Arabia. It therefore anchors this study in the greater framework of case study research.

#### 3.2.2.4.3 Data collection tool/s

- Computer simulation data output
- Documentation review
- Weather data file input

#### 3.2.2.4.4 Method

The research has been organised into three consecutive stages, which started with (a) testing various shading parameters, (b) evaluating each scenario and discarding cases where there was an occurrence of glare, and (c) determining the most balanced solution for each façade orientation in terms of energy savings.

During the first stage, the independent variables comprised of axial rotation and aspect ratio of screen elements. Screen depth, reflectivity and colour were kept constant. Materiality was therefore not the focus of this study and does provide some limitation. The authors did however adopt these properties from another study by Sherif et al. (2011a) where those variables were considered in depth and an optimal set was produced.

The test variables were adjusted for each façade orientation, north, east, south and west. Once cases which included occurrences of glare were omitted, the authors compared the five most optimal strategies with a reference building to determine energy cost savings.

Similar to the studies conducted by Huckemann et al. (2009) and Bremer et al. (2005), this study focused on a single room, with no external obstructions and an external ground reflectivity of 20%.

### **3.2.2.5 Source 5: Dernie & Gaspari (2015)**

#### **3.2.2.5.1 Aim of Study**

The purpose of the study was to evaluate various façade cladding combinations attempting to illustrate how these strategies can positively contribute to energy savings and a reduction in greenhouse gasses. Specifically, the study aimed to find a correlation between façade cladding interventions and profitability.

The authors note that global warming is a world-wide concern and that existing buildings will have to adapt to consume less energy. In that sense their research focuses on prefabricated and modularized over-cladding solutions.

#### **3.2.2.5.2 Methodology**

A combination of Case study, simulation and experimental research have been used in this particular study. The case study is of a singular nature and resembles a building situated in the urban fabric of London. Unlike Huckerman (2009), Bremer (2005) and Sabry (2014) this case study takes into account it's direct environment and considers the building holistically and does not generalize on a room-only basis.

#### **3.2.2.5.3 Data collection tool/s**

- Site surveying
- Documentation review
- Simulation output data
- Weather input data

#### **3.2.2.5.4 Method**

The study focuses on energy investment and embodied energy specifically as it relates to the façade cross section, with no consideration for any specific power units, HVAC system design or other mechanical ventilation systems - for which generic rates and units are adopted.

The authors note that the study is based on a case study simulation, where the initial stage involves defining the model inputs, including site features, weather data, building orientation and building layout. This information is then used to assemble a base case which sets up the boundary conditions of the study. Different renovation options are then tested, combining different materials and assemblies to achieve optimal energy targets. An energy investment analysis is then conducted through a life-cycle study to determine the overall profitability of the intervention.

#### **3.2.2.6 Source 6: Real (2010)**

Real's (2010) dissertation focused specifically on the building façade. She considers the façade a worthy subject of study due it being a significant part of the total construction, operational and maintenance costs. The study involved a simple case-study approach. A very select number of façade building materials were identified, where maintenance and replacement data as well as energy performance and cost data was obtained for each material. The façade materials were then combined in different layers and assemblies where in each case, construction cost, maintenance cost and U-coefficient was recorded. The results were then analyzed to reconfigure and assess 4 additional façade solutions, a base case, an improved version and 2 high-performance versions. Their results were then adjusted by means of a sensitivity analysis, specifically calibrating maintenance inputs, altering the study period and altering the discount rate. The study concluded that the façade strategies with the lowest construction costs were not the most profitable solution - where maintenance expenses had a significant impact on total returns.

### **3.2.3 Summary of methodological findings**

A review of the aforementioned literature illustrates a particular preference towards a case study approach. According to Yin (2004) the strength of case studies can be ascribed to the fact that the subject can be researched in its actual real life circumstances. In its basic form, he contrasts this to other methods such as surveys, experiments and statistical modeling, but also notes that some studies might use these

methods in combination. From the literature pertaining to building energy analysis, a combination of methods seems evident, where case studies, experiments and simulations are combined.

The notion of a combined approach is supported by Johansson (2003) who argues that case studies are different from other research methods in that it has the ability to combine different strategies so that a research problem can be studied from more than one angle. To that end Johansson (2003) considers the case study as a meta-method.

Technological means have enabled researchers to go beyond traditional case studies. (Kanaani et al., 2016)

Kanaani and Kopec (2016) cites the Webster Dictionary where in which a simulation is termed to be an imitation or counterfeit. This suggests some degree of replication to the extent that the simulation can be considered to present some sort of reality (Ibid). This setting up of a virtual reality creates an overlap with the 'real world' setting that Yin (2004) describes. It differs in that the variables may be manipulated which in turn is reminiscent of experiments (Trochim, 1996).

### **3.2.4 Conclusion of Methodologies used in Façade Performance Studies**

Regardless of the methodological position of simulation methods, the research clearly shows an overlap in methodologies and indicates that combined approaches sometimes has the ability to deliver more accurate results compared to more traditional modes of research. Trochim (1996) for example notes that simulations may in some cases be a better research technique compared to studying real world processes. In a real-world situation, the researcher may not necessarily be able to deduce the cause of certain outcomes – due to the dynamics and complexity of real world scenarios. In simulations however, the researcher has the ability to control all inputs thereby allowing him to correlate cause and effect, ultimately providing a much better understanding of the data.

### **3.3 LITERATURE REVIEW OF METHODOLOGIES**

#### **3.3.1 An overview of experiments and simulations**

##### **3.3.1.1 Introduction**

Experimental studies are rigorous processes and ideally applied in explanatory research (Bhattacharjee, 2012). The aim is to study the relationships between actions and reactions, where a limited number of independent variables can be manipulated to determine how that affects the outcome. This process can take place in a laboratory setting or in the field, depending on the nature of the research questions. (Ibid)

Key (1997) outlines the essentials of experimental research, which he notes as the manipulation of an independent variable, while keeping all other independent variables constant in a setting where all research subjects are exposed to exactly the same variables; ultimately, so that observations can be made that may lead to certain predictions that can be generalized (Key, 1997).

Gromm (2008) does however warn about the generalisability of experimental research methods and how this may produce skewed results, where small changes in the design process can have a significant impact on the results.

##### **3.3.1.2 Types of experimental design**

Pre-Experimental Design is loose in structure and can be a biased form of research. Leedy (1997) offers an explanation of three types of experimental designs; one for example involves the evaluation of the influence of a variable. This is called a one group pretest - posttest. The method aims to provide a measure of change but it does not provide conclusive results.

True Experimental Design, on the other hand gives the researcher more control and provides for a more refined study with greater validity. Again, three types are noted, one of which involves studying what the effect of a certain influence on a carefully controlled sample would be. This is the typical, traditional method of conducting experimental design.

A third approach to experimental design is called Quasi-Experimental. The notable difference lies in that the sample is not randomly selected. Four varieties of the Quasi-experimental approach has been identified. The aim of one of these approaches involves investigating a scenario where random selection or assignment is not practically possible. In this case the test and control group is not equivalent as is the case in true experiments.

### **3.3.1.3 Sampling**

Random selection or sampling and random assignment are two concepts that are synonymous with experimental design. Random sampling involves randomly drawing subjects from a population, which ensures a high generalisability in the findings. Random assignment refers to the process of randomly assigning subjects to the experimental groups and control group, which in turn ensures that the treatment of all groups are the same – thereby resulting in high internal validity. (Bhattacharjee, 2012)

### **3.3.1.4 The link between experiment and simulation**

Gromm (2008) notes that complexity theory is the most important development in modern science and he argues that the process of computer simulation is integral to this development. Although not exclusively, computer simulation does find application in complex processes that cannot be subjected to experimental control (which would remove the complexity) or where 100's or 1000's different outcomes may arise from very similar conditions. In that sense computer simulations offer the best method of studying processes which will be very difficult to study in vivo. Kaufmann and Smarr (1993) supports this notion and draws a comparison to weather balloons. In a simulation, variables like temperature, humidity, barometric pressure and air velocity can be accurately modeled by gathering data from millions of geometric points in virtual space. This modeling process produces far more significant results with greater accuracy, compared to gathering data from weather balloons.

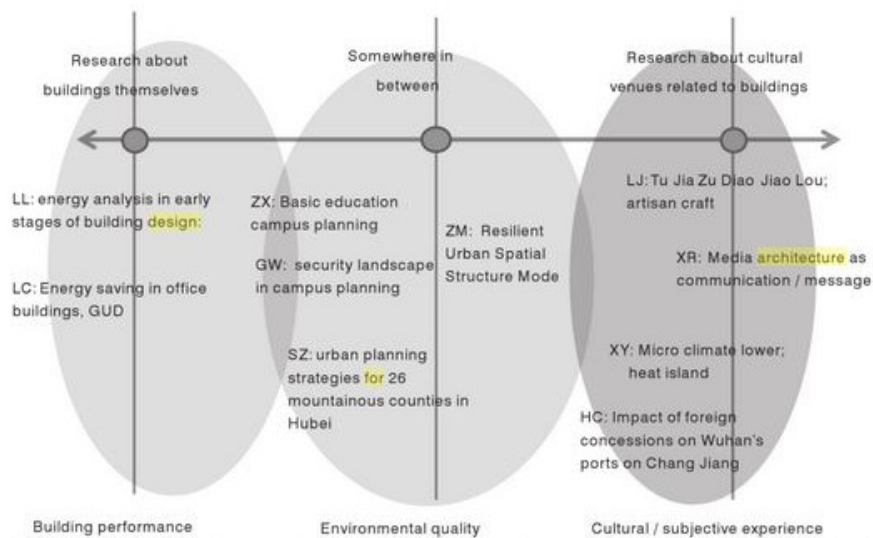


Figure 4.1 Range of research topics of doctoral students at the Huazhong University of Science and Technology, Wuhan, China, Spring 2014. Chart by author

Figure 3.1: DSF Architectural research study methodologies (Source: Wang, 2014)

Wang (2014) uses a diagram to represent a series of architectural research studies ranging from building performance, environmental quality and cultural experience. He argues that, even though all the studies pertain to architecture and buildings, how each of the focus areas will likely require completely different research methodologies. Wang (2014) notes that the studies portrayed on the left of the diagram focuses on energy consumption in buildings and that experimental research and simulation modeling forms the basis of this type of study. In experimental research, certain objects are isolated and studied while changing a number of independent variables and parameters in an attempt to study the object's behavior in each case. This is often measured against a control group or base case, which is left in an unaltered state. Ultimately, experiments aims to find causative factors in an isolated study, which then assists in predicting events in similar real life situations. Simulations on the other hand attempt to mimic real life scenarios by attempting to include all possible variables – this differentiates simulations from typical experimental studies.

Winsberg (2002) provides another perspective on where simulations lie in the greater academic methodological framework by comparing computer simulations to more traditional modes of research methodology. Many complex systems, especially in the field of physical science involve the construction and testing of mathematical models. Although this notion of 'testing' seems to resemble a typical experimental study, Winsberg (2002) suggests that these mathematical models are constructed by applying known theories thereby classifying it under the 'theories' domain. In his study he quotes three different views on how simulations are perceived to be classified methodologically. Firstly, there is a notion among some that simulations are metaphorical and simply brute-force means to solve complex problems. Others argue that simulations are mimicking real world scenarios and in that sense provides a suitable basis for experimentation. A third notion exists, whereby it is argued that simulations represent a new mode of scientific research and that it is neither experimental nor theoretical in nature.

Kauffman (1993) argues that simulations are very similar to experiments in two ways. Firstly, in that both are essentially focused on data analysis and secondly, both methods' constant concern with uncertainty and error. Kauffman (1993) goes on to suggest that although simulations are initially motivated by theory, the simulation model that is eventually constructed will involve a number of assumptions with no theoretical basis in itself. The simulation results therefore will not necessarily be representative of the original theory. The researcher therefore needs to ensure that uncertainties are adequately managed - similar to a laboratory experiment.

Hughes (1999) states that a simulation is 'conceptually inseparable' from an experiment in that the processes are almost identical. In a simulation the researcher would (a) write an algorithm that can replicate the scenario under study, (b) code this algorithm on a computer and (c) conduct experiments thereon. Ultimately, the reliability of the simulation will depend on 'to what extent and under what conditions, a simulation reliably mimics the physical system of interest'.

### **3.3.2 An overview of case study methodology**

#### **3.3.2.1 Introduction**

This form of research typically arise from two scenarios, firstly, when the research addresses a descriptive or explanatory question – in other words the question relates to what happens, why it happened or how it happened (Yin, 2004). Secondly, a case study allows researchers to make direct observations within a real-time natural context, as opposed to using derived data (Ibid).

#### **3.3.2.2 Process and characteristics**

Yin (2004) outlines three important steps to consider when conducting case study research. The first step involves the definition of the case that will be studied. Swanson et al. (2005) elaborates that the study needs to focus on a particular individual, an organization, or other definable means – in a singular or plural sense. Johansson (2003) further elaborates and defines ‘case’ in a more abstract sense, in that a case may be an object or even a process – whereas at a minimum it should be time and space specific.

The case is therefore bounded, which will be determined by the research problem and applicable theory. This will in turn inform the parameters of the study, the context and sample (Ibid).

Secondly, the researcher needs to decide on whether to conduct a single or multiple case studies (Yin, 2004). Another possible scenario might involve a holistic case with sub-cases, in which case data will be derived from the holistic case and sub-cases. Single case studies tend to be more detailed and focused, whereas multiple or embedded case studies and provides the researcher an opportunity to strengthen their findings (Ibid).

Swanson and Elwood (2005) adds that any case has an embedded nature, in that it's always embedded in a larger system or entity. Thirdly, Yin (2004) notes that the researcher needs to decide whether the study will adopt certain theories or whether a

theory will be challenged or even constructed. Using existing theories is a more limited approach, but it also acts to simplify the research process in that it may guide case selection, data collection and data analysis strategies. It also allows the researcher to focus his attention to a more defined research area (Ibid).

### **3.3.2.3 Mixed methods**

A review of methodologies as discussed in the previous chapter provides insight in the multi-faceted methodological nature of case studies. Swanson et al. (2005) cites Merriam (1988) who argues that because case studies are normally followed in 'why' and 'how' research inquiries they can mostly be considered as qualitative strategies. This seems to be true in educational research and has generally been true in the early stages of case study adoption, however – and extensive range of mixed method case studies have been conducted in recent decades where quantitative analysis has played an important role (Swanson et al, 2005).

Miles and Huberman(1994) states that quantitative measures employed in the case study allows for a more objective procedure as it avoids any potential bias which can often be present in qualitative research. They go on to state that these measures contextualise the findings and allows for comparison.

### **3.3.2.4 Sampling**

Swanson et al. (2005) highlights the importance of sampling by stating that, depending on the case, it may sometimes be impossible to include every person, group, organization or time period in the study. The sample will be guided by the research questions and relevant theories forming part of the research concept (Ibid). Invariably, the sample will adapt during the course of the investigation as new facts come to light, however, the researcher should nevertheless have a sampling plan that anticipates a range of possible situations, persons, organizations or whatever the research case may entail (Ibid).

### **3.3.2.5 Validity and reliability**

#### **3.3.2.5.1 Introduction**

Yin (2003) identifies four tests that should be conducted during any given case study in an attempt to validate the findings and provide evidence of reliability, which he terms: Construct Validity, Internal Validity, External Validity and Reliability.

#### **3.3.2.5.2 Construct validity**

This test according to Yin (2003) serves to establish whether the correct operational measures have been deployed for the concepts that are being tested. In other words, does the measure perform like the theory would suggest that a measure of that construct ought to perform (Ibid).

To satisfy this test, Yin (2003) suggests that the researcher ought to use multiple sources for evidence during the data collection phase, in addition to having informants review the draft research report prior to concluding the study.

#### **3.3.2.5.3 Internal validity**

This test is only applicable to explanatory or causal studies and not in descriptive or exploratory studies. The test specifically seeks to verify a causal relationship, where certain conditions are shown to genuinely lead to other conditions. In other words, the test ensures a logical and true progression of events, in an attempt to avoid false conclusions (Yin, 2003). This requirement may be satisfied by providing evidence of pattern matching, deploying logic models or by providing explanations during the data analysis stage (Ibid).

#### **3.3.2.5.4 External validity**

This aspect of research validity sets up the domain within which the study's findings may be generalized (Yin, 2003). This is achieved by making use of theory in single case studies and making use of replication in multiple case studies during the research design phase (Ibid).

#### 3.3.2.5.5 Reliability

The concept of reliability refers to the notion that the study process can be replicated by others and which processes will deliver the same findings. This is achieved by following the appropriate data collection protocols and research design as it pertains to case studies (Yin, 2003).

### **3.4 RESEARCH DESIGN**

#### **3.4.1 Introduction**

This section of the report provides an outline of the research strategy which would best address the research question. Links are drawn to the literature review on research methodologies and a review of other research studies described earlier in this report.

The main research question is to determine whether retrofitting the building envelope, can justify the capital outlay through the reduction in operational expenditure, specifically as it pertains to a particular geographical area. As stated earlier in the report, in order to address this question, it's important to first evaluate existing design strategies relating to building envelope design; to understand material parameters, such as performance, cost and availability and to recreate a setting within which the variables can be tested.

#### **3.4.2 Research design motivation**

It can be concluded from the literature review that the façade is the most significant variable in energy consumption in buildings - specifically office buildings, where the façade plays an integral role in lighting and cooling demand. In order to address the research question, it is essential to determine an economical and efficient façade solution. The research therefore needs to include the 'testing' of a number of façade scenarios in an attempt to find the most optimal solution. In that sense, an understanding of 'what happens' in each instance needs to be established. Yin (2004) describes these types of studies as being descriptive nature.

Secondly, the study focuses on a particular geographical area, with a particular built-fabric and unique climatic features. It therefore requires observations to be made within a real-time context. Considering the descriptive and real-time features of the study, a case study can be considered the best form of research to address the research question. A similar approach was followed by Brunoro (2011), Sabry (2014) and Gaspari (2015) as noted in the previous chapter.

A review of research methodology revealed the multi-faceted nature of case studies and how other forms of research may compliment the case study. In order to derive the most optimal retrofit strategy a set of independent variables needs to be tested and manipulated, while being compared to a base scenario. Experimental design as described by Bhattacharjee (2012) involves the study of relationships between actions and reactions, where a limited number of independent variables can be manipulated to determine how that affects the outcome. This process can take place in a laboratory setting or in the field, depending on the nature of the research questions. (Ibid)

Considering the potential cost and complexities of such an investigation, including the effect of external influence, a method needs to be formulated whereby the independent variables can be adjusted in a controlled setting. Gromm (2008) notes that simulations may be ideally suited in situations where complex processes that cannot be subjected to basic experimental control or where 100's or 1000's different outcomes may arise from very similar conditions. This view is supported by Kaufmann (1993) who noted that complex investigations can produce far more significant results and with greater accuracy, compared to gathering data taking a holistic view.

Lastly, according to Yin (1989) there are three scenarios in which the single case study method may be useful;

- (a) when the study is unique or of critical nature,
- (b) where a previously inaccessible phenomenon can be studied,
- (c) where a concrete theory is being tested, or

(d) when the research involves an exploratory or pilot study.

Based on these qualifications, a single case study is an appropriate method to address the unique contextual aspects of the research question, while the underlying algorithms deployed in the simulation procedure is based on concrete theories of climatology, heat transfer, heat gain, convection and conductance.

### **3.4.3 Procedural research method**

#### **3.4.3.1 Literature review**

The literature review guided the study to a more articulate investigation by providing insight into the motivation and requirements of retrofitting, the most significant variables in energy consumption in buildings, the different strategies of retrofitting and their relative costs as well as ways to measure these parameters. Specifically, it guided the investigation towards over-cladding as the most significant strategy in terms of the research question, which became the subject of further research and analysis. The literature review was based on the studying of books, journal articles, conference papers, theses and online sources.

#### **3.4.3.2 Survey of building stock in the research locale**

A survey was conducted by means of digitally collecting aerial and satellite footage of high-rise and medium-rise office buildings in the Cape Town CBD. This includes an axonometric view of the building facades which provides an understanding of the window-to-wall relationship of the facades. A physical on-foot survey was conducted to determine the façade materials, which was logged and analysed based on frequency.

#### **3.4.3.3 Review of façade assemblies available in the local market**

The literature review revealed a number of feasible over-clad strategies which involves vertical screens, louvers, blinds, fins and overhangs. Since the aim of the research is to establish whether these interventions may sufficiently reduce operating costs to justify the capital outlay, it's essential to identify products and manufacturers that can provide actual cost and material data as it applies to the local context. To avoid endless

permutations of scenario testing, the local availability of product sets up the first research parameter. Product information was gathered by conducting an online survey as well as contacting Quantity Surveyors and Architects to compile a list of potential product suppliers and installers.

#### **3.4.3.4 Simulation process**

*Energy Plus* is a software analysis tool which was developed by the US Department of Energy (U.S Department of Energy, 2015) and is considered to be the most accurate and comprehensive building energy simulator available. The tool does not provide a graphical user interface (GUI) and relies on an additional programme to control the variables and study parameters. A number of GUI's exist, but for the purpose of this study *Energy Plus* was used in conjunction with *COMFEN*, due to its focus on façade analysis.

Firstly, a hypothetical reference building was constructed, which is representative of the local building stock and a product of the building survey. The reference building was then simulated without applying any modifications in order to derive a base scenario and benchmark.

Each over-cladding strategy was then applied to the hypothetical building on a room-only basis to simplify the model's complexity and to optimise simulation time. The data was then extrapolated and used as proxy for the larger structure. Over-cladding strategies was applied to each façade - north, south, east and west. Results were collated and ordered in terms of its energy reduction capabilities. Where some strategies resulted in excessive glare being produced, those recordings have been omitted from further analysis.

#### **3.4.3.5 Collection of material cost**

The most optimal performing strategies were identified in each intervention category. Based on this, the suppliers of these products were approached to provide cost data relating to product and installation as it applies to the hypothetical reference building.

Each respondent was then supplied with the design parameters - as guided by the literature review.

### 3.4.3.6 Financial analysis

Finally, LCCA and DCF analyses were conducted. In each instance, the capital cost and operational savings are calculated to determine its payback or years' purchase. A sensitivity analysis provided further insight, where incremental adjustments were made to energy cost fluctuations, installation cost and material cost.

## 3.5 DATA COLLECTION

### 3.5.1 Primary and secondary data

*Table 3.1: Secondary data collection (Source: Author)*

<b>Data</b>	<b>Obtained from</b>
Material cost	Manufacturers
Energy cost	Eskom annual publication

*Table 3.2: Primary data collection (Source: Author)*

<b>Data</b>	<b>Obtained from</b>
Material cost	Suppliers
Labour and implementation cost	Suppliers
Photographic building survey	

### 3.5.2 Units of analysis: Input and output data

The following tables sets out the simulation input and output data.

Table 3.3: Constant fixed values for all scenarios (Source: Author)

Description of input	Value obtained from
Window Wall Ratio	Cape Town office survey
Room proportion	Cape Town office survey
Window Material	Cape Town office survey
Lighting Load	ASHRAE standard for offices
Equipment Load	ASHRAE standard for offices
Number of people	ASHRAE standard for offices

Table 3.4: External roller shades fixed values (Source: Author)

Space		
Orientation:	North	
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	continuous control set points
Equipment Load	8.07 W/m <sup>2</sup>	
Device		
Solar transmission	0.3	Te
Visible transmission	0.3	T.vis
Solar reflection	0.5	R
Visible reflection	0.5	LRV
Thermal transmission	0	W/m-K
Thermal emission	0.9	ratio
Conductivity	0.3	W/m-K

Table 3.5: External roller shades variable values (Source: Author)

Description		Value	Symbol
Thickness		0.75mm	(a)
		1.5mm	
Colour		white	(x)
		d-grey	(y)
Distance		100mm	(1)
		300mm	(2)
Automated	Static (always on)	various	S
	Dynamic (high solar)	various	D

Table 3.6: Venetian louvre screens fixed values (Source: Author)

<u>Space</u>		
Orientation:	North	
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	continuous control set points
Equipment Load	8.07 W/m <sup>2</sup>	
<u>Device</u>		
Transmittance	0	Te
Reflectance Front	0.7	R
Reflectance Back	0.7	R
IR Transmission	0.9	ratio
IR Emission Front	0.9	ratio
IR Emission Back	0.9	ratio
Conductivity	159.23	W/m-K

Table 3.7: Venetian louvre screens variable values (Source: Author)

Description	Value	Symbol
Tilt	90 degrees	(x)
Slat width	10	(a)
	20	(b)
	30	(c)
	40	(d)
	50	(e)
	60	(f)
	70	(g)
	80	(h)
Slat spacing	10	_(1)
	20	_(2)
	30	_(3)
	40	_(4)
	50	_(5)
	60	_(6)
	70	_(7)
	80	_(8)
Orientation	North	N
	East	E
	West	W

Table 3.8: Mesh screens fixed values (Source: Author)

<u>Space</u>		
Orientation:	North	continuous control set points
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	
Equipment Load	8.07 W/m <sup>2</sup>	
<u>Device</u>		
Colour	Grey	
Solar reflection	0.1	R
Visible reflection	0.1	R
Emissivity	0.9	ratio
Conductivity	0.09	W/m-K
Movement	Static	

Description	Value (mm)	Symbol
Thread diamtr	0.1	_(1)
	0.2	_(2)
	0.3	_(3)
	0.4	_(4)
	0.5	_(5)
Thread spacing	0.2	(a)
	0.3	(b)
	0.4	(c)
	0.5	(d)
	0.6	(e)

Table 3.9: Mesh screens variable values (Source: Author)

Table 3.10: Overhangs fixed values (Source: Author)

<u>Space</u>		
Orientation:	North	
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	continuous control set points
Equipment Load	8.07 W/m <sup>2</sup>	
<u>Device</u>		
Colour		Grey
Solar reflection	0.1	
Visible reflection	0.1	
Emissivity	0.9	
Conductivity	0.09	W/m-K
Thickness	100	mm

Table 3.11: Overhangs variable values (Source: Author)

Description	Value	Symbol
Depth	1000	1
	750	0.75
	500	0.5
	250	0.25
Number spaced equally starting from top	1	x1
	2	x2
	3	x3
Orientation	North	N
	East	E
	West	W

Output: For each scenario:

- Annual energy use (MJ/m<sup>2</sup>/yr and kWh/m<sup>2</sup>/yr)
  - o Total
  - o Lighting
  - o Cooling

### 3.5.3 Sampling

To assemble a model which will be representative of the research problem, it is necessary to conduct a basic sampling process.

Cottrell (2002) notes that a sample represents a subset of a larger population, where a population represents a total set of objects. In the case of the research, the population can be considered the office building stock in the Cape Town CBD.

Due to the variety of buildings in the area, it makes sense to compile a model which would set up a median, thereby producing more conclusive results. Cottrell (2012) states that this process of identifying a smaller population can greatly simplify the study. He notes that numerical values of a population are called their parameters. While the

actual parameters are typically known to the researcher at the time of sampling, their values are not. (Ibid)

The buildings have been selected based on their height and function as derived from an aerial photographic survey. In that sense the values of the actual parameters was not known at the time of sampling. This includes for example, window and wall materials and proportions. Certain buildings have however been excluded on the basis of function and size, which is termed Non-probability sampling (Statistics Solutions, 2015). A sample can be derived through Probability and Non-probability sampling. In case of the latter, the technique involves a sampling process whereby the probability exists that some elements can be specifically excluded. In Probability sampling every unit in the sample has a chance to be included (Ibid).

Imdadullah (2015) provides an outline of a typical statistical sampling process, which he defines as being (a) the defining the population, (b) specifying the measurable units, (c) selecting the appropriate measurable units, (d) determining the sample size, (e) actual sampling process, and (f) selection of data.

In the context of the research, the population is defined by the research question, which is medium to high-rise facades of office buildings. The measurable units are all the aspects that make up the façade assembly. For the purpose of the study, the appropriate measurable units constitute the façade components that have a direct impact on energy transfer through the façade, specifically in the form of heat and light. The sample size is also predetermined by the research question, which is focused on the central business district of Cape Town, South Africa.

## **3.6 STUDY VALIDITY AND RELIABILITY**

### **3.6.1 Construct validity**

As noted by Yin (2003) earlier in this chapter, the researcher ought to use multiple sources for evidence during the data collection phase, and notes that the test for

construct validity depends on whether the measure perform like the theory would suggest that a measure of that construct ought to perform (Ibid).

The collection of data relating to façade over-clad strategies was sourced from numerous sources, including Architects, Quantity Surveyors and online sources. Also, the underlying design of the software coding was developed and tested by qualified professionals from various backgrounds over a number of years and provides a solid platform which should attribute strong construct validity to the study.

### **3.6.2 Internal validity**

Due to the experimental qualities of the investigation, the research should have strong internal validity. According to Bhattacharjee (2012), the ability to link cause and effect by altering the independent variables in experimental research attributes strong causative qualities to the study.

### **3.6.3 External validity**

Bhattacharjee (2012) notes that experimental studies that are conducted in a laboratory or an artificial setting, which in this case takes the form of a reconstructed reality by means of a simulation set, have low external validity. In other words the results should only be generalized with caution. This is due to the fact that the artificial setting may not be an accurate representation of reality.

The sampling method is an attempt to deconstruct the typical façade features and to combine them in a model which will be more representative than only experimenting with a single building. In addition, experimentation on a single building in a real life setting have many external influences, including outliers that may negatively affect findings. In the case of a simulation model inputs, such as weather data is accurate and controlled. Significant research and development, conducted over many years have informed the underlying programming code and algorithms that drove the simulation process in this study. (U.S Department of Energy, 2015)

### **3.6.4 Reliability**

In order to ensure that the study is replicable as noted by Yin (2003), the data collection method is firstly driven by market availability of product. Even though it will be impractical to include all possible design strategies and permutations available, the simulation engine does allow for incremental calibration of the variables of the collected data. This process expands the range of possibilities and thereby increases the research reliability. The subsequent financial analysis stage does not draw on any assumptions with regards to the cost and availability of the adjusted (incremented) variables, but another stage of data collection ensues whereby actual cost data is collected for the chosen strategies.

A study following a similar methodology within the same timeframe and context should therefore produce significantly similar results.

### **3.7 LIMITATIONS OF STUDY**

The design implementations that are tested in this study may lead to other financial benefits and increase the overall profitability of the investment, over and above the return on operational expenses. In order to limit the scope of the study, these factors will not be considered. For example:

- An optimised façade may lead to Green Star status or improved perception, which may yield a rental premium over and above the direct operational savings due to lower energy costs.
- Life cycle costs may also have an impact, where material longevity and maintenance schedules are affected. Over the long run, this may have an effect on overall profitability.
- HVAC or lighting design also falls outside the scope this study. There is a degree of efficiency in the design of these systems as they respond to the various façade strategies. The simulation engine will however follow an

- algorithm that will proportionally size HVAC and lighting supply, without changing their design in principle.
- The study is inextricably linked to time. The collected cost data is a consequence of many market parameters, such as the macro economy, availability of materials, the labour market and other supply and demand factors embedded in the building industry.

### **3.8 ETHICS**

The study is generally not of a sensitive nature as information is mostly collected from public platforms, such as the World Wide Web and surveys which does not include human participation. Where cost data was gathered by means of quotations, participants were informed by email that the cost data supplied will form part of an academic study which might be made publicly available, but that their personal and company details will not be disclosed.

### **3.9 SUMMARY OF CHAPTER**

The research surrounding various methodologies of similar quantitative research projects have informed a clear outline of a suitable research design strategy. An experimental design with case study features will form the basis of the investigation. A simulation driven process of data gathering is proposed, which provides for highly calibrated setting to test variables in which real life influence can be controlled. The results produced from this study should be highly reliable and have strong validity.

## **RESEARCH ANALYSIS AND INTERPRETATION**

### **4.1 INTRODUCTION**

This chapter presents a hypothetical building which has features that represent the tall office building stock in Cape Town's CBD. This building forms the basis of the research study. From this model, one floor is extracted and modeled on a "per façade" basis. Different over-clad scenarios are tested on an iterative basis, and compared to a base scenario. In each instance, the most efficient over-clad strategy is identified. Each scenario is also tested in terms of their capital costs and compared to operational savings from reduced energy consumption to derive a payback figure in each instance.

### **4.2 SETTING UP THE CASE STUDY**

The hypothetical building, referred to as Building X used in this analysis was compiled to represent the most typical design features of tall office buildings in the Cape Town CBD.

The compilation took into consideration typical design features related to WWR and energy use density and established a representative local context so as to test the climatic impact on the façade decision.

#### **4.2.1 Design features**

##### **4.2.1.1 Window:Wall Ratio (WWR)**

A photographic survey was conducted to determine the window to wall relationships of tall office buildings in the Cape Town CBD - refer to Annexure 2.

It was found that for office buildings in the Cape Town CBD that are older than 15 years and higher or equal to 10 floors, that an average WWR of 41% results. A 20 meter

façade with 19m x 1.5m window area was modeled, which results in a 41% WWR. The representative window proportion and position was also derived from the survey data.

#### 4.2.1.2 Energy Use Density

Autodesk (2015) cites results obtained from the United States Department of Energy and presents the following average energy consumption values for office buildings:

Table 4.1: Average energy use consumption for office buildings (Source: Autodesk, 2015)

Lighting.power density (W/m <sup>2</sup> )	Equipment.power density (W/m <sup>2</sup> )	Plug.loads (W/m <sup>2</sup> )	@occupancy(pax/100m <sup>2</sup> )
11	14	8-27	5

For the purpose of the study, plug loads were assumed to be 8.07 W/m<sup>2</sup> to account for heat generation. This figure is likely to be substantially higher for office spaces where several desktop computers and printers are used. The figure is based on 18 people per 100m<sup>2</sup> using laptop computers at 45 Watts per machine, with no other office equipment. A desktop machine consumes on average 120 Watts, an office copier consumes 750 Watts and a refrigerator 750 Watts. In more traditional office settings, plug loads could be as great as 30W/m<sup>2</sup> during peak times.

Table 4.2: Proposed energy use consumption (Source: Author)

Lighting.power density (W/m <sup>2</sup> )	Equipment.power density (W/m <sup>2</sup> )	Plug.loads (W/m <sup>2</sup> )	@occupancy (pax/100m <sup>2</sup> )
10.76	8.07	30	18

### 4.2.1.3 Set points

The software has been calibrated according to an occupancy schedule which produces algorithms which allows for dynamic demand. A value of “1” would refer to maximum usage, where “0” refers to no demand. The following values displayed in Table 4.3 have been adopted in the simulation process:

Table 4.3: Occupancy, lighting and equipment schedule (Source: Mitchell et al., 2012)

Time	Occ. (week day)	Occ. (Sat.)	Occ. (all other days)	Light. (week day)	Light. (Sat.)	Light. (all other days)	Equip. (week day)	Equip. (Sat.)	Equip. (all other days)
24:00 – 5:00	0	0	0	0.05	0.05	0.05	0.4	0.3	0.3
5:00 – 6:00	0	0	0	0.1	0.05	0.05	0.4	0.3	0.3
6:00 – 7:00	0.1	0.1	0	0.1	0.01	0.05	0.4	0.4	0.3
7:00 – 8:00	0.2	0.1	0	0.3	0.01	0.05	0.4	0.4	0.3
8:00 – 12:00	0.95	0.5	0	0.9	0.5	0.05	0.9	0.5	0.3
12:00 – 13:00	0.5	0.5	0	0.9	0.5	0.05	0.8	0.5	0.3
13:00 – 14:00	0.95	0.5	0	0.9	0.5	0.05	0.9	0.5	0.3
14:00 – 17:00	0.95	0.1	0	0.9	0.15	0.05	0.9	0.35	0.3
17:00 – 18:00	0.7	0	0	0.7	0.05	0.05	0.8	0.3	0.3
18:00 – 20:00	0.4	0	0	0.5	0.05	0.05	0.6	0.3	0.3
20:00 – 22:00	0.1	0	0	0.3	0.05	0.05	0.5	0.3	0.3
22:00 – 24:00	0.05	0	0	0.1	0.05	0.05	0.4	0.3	0.3

## 4.2.2 The local context

### 4.2.2.1 Climatic region

Cape Town falls in the CSB climatic region, specifically - the warm-summer Mediterranean climatic group as classified by Koppen and Geiger (Robinson & Henderson-Sellers, 1999). Winters occur roughly from June to August and are moderately wet with average temperatures in the CBD ranging between 8.5 and 18 degrees Celsius. Summer months range from December to March and are warm with low precipitation; average temperatures range between 16 and 26 degrees Celsius.

As documented in Table 4.4, the total annual precipitation in the CBD is around 515mm and total annual sunshine is recorded at 3100 hours per year.

Table 4.4: Climate data for Cape Town 1961 – 1990 (Source WMO, 2016)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C	39.3	38.3	42.4	38.6	33.5	29.8	29.02	32.0	33.1	37.2	39.9	41.4	42.4
Average high °C	26.1	26.5	25.4	23.0	20.3	18.1	17.5	17.8	19.2	21.3	23.5	24.9	22.0
Daily mean °C	20.4	20.4	19.2	16.9	14.4	12.5	11.9	12.4	13.7	15.6	17.9	19.5	16.2
Average low °C	15.7	15.6	14.2	11.9	9.4	7.8	7.0	7.5	8.7	10.6	13.2	14.9	11.4
Record low °C	7.4	6.4	4.6	2.4	0.9	-1.2	-4.3	-0.4	0.2	1.0	3.9	6.2	-4.3
Average precipitation mm	15	17	20	41	69	93	82	77	40	30	14	17	515
Average precipitation days (≥ 0.1 mm)	5.5	4.6	4.8	8.3	11.4	13.3	11.8	13.7	10.4	8.7	4.9	6.3	103.7
Average relative humidity (%)	71	72	74	78	81	81	81	80	77	74	71	71	76
Mean monthly sunshine hours	337.9	297.4	292.9	233.5	205.3	175.4	193.1	212.1	224.7	277.7	309.8	334.2	3,094

Unique climatic features of the Cape Town CBD involves amongst others the “Cape Doctor” which is a strong south-easterly wind normally blowing in late spring or early summer. This is also the pre-dominant wind direction, with North Westerly winds normally accompanying rain spells (WMO, 2016).

#### 4.2.2.2 Solar path

In an article published by the CSIR, Conradie (2010) explores solar radiation in a South African context along with appropriate methods aimed at minimizing the negative effects of solar heat gain. An understanding of the solar path is critical in understanding the

functioning of solar screens and other means of façade insulation. On a micro-level and in terms of analyzing the solar effects on a singular building structure, the sky can be considered a hemispherical dome, arching over a flat horizontal ground plane. In this scenario – and in a South African context, the sun moves on a half-circular path over the observer’s position from east to west, with the east and west quadrants of the arc being symmetrical. At midday, the sun would have reached the highest point on the arc. On the Vernal and Autumnal equinoxes, the sun would rise exactly east and set exactly west of the observer’s position. These positions change in winter when the sun will rise and set north of the observer, while it will rise and set south of the observer’s position during summer time as explained in figure 4.1 (Conradie, 2010).

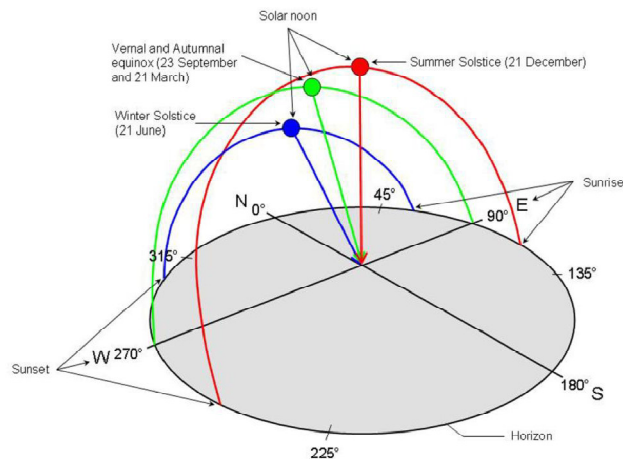


Figure 4.1: Solarpath (Source: Conradie, 2010)

#### 4.2.2.3 Angle of incidence

Conradie (2010) further describes the effects of the sun’s angle of incidence and how this affects the extent of radiation. When the sun intersects with any surface at an oblique angle, the total energy transfer will be less per sectional area. This is due to a lower energy density per surface area compared to a perpendicular intersection. The extent of radiation through the sun’s angle of incidence can be quantified by means of the Cosine Law, where the Cosine Factor is multiplied by the angle of incidence (Ibid).

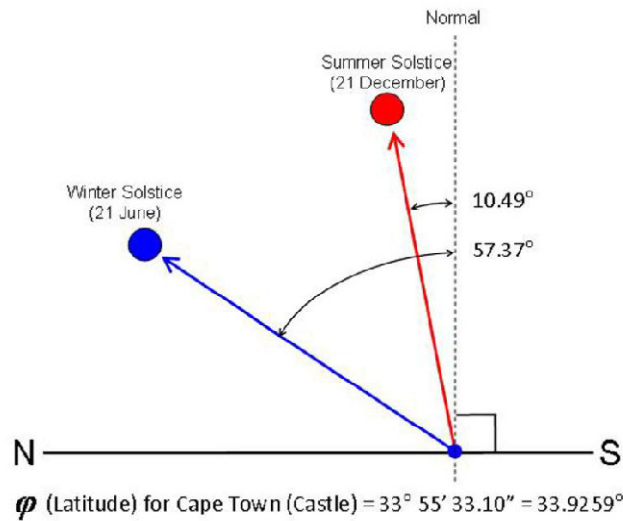


Figure 4.2: Winter and summer solstice (Source: Conradie, 2010)

The report collected solar incidence data for Cape Town as it would be on 12:00, 21 December and 12:00, 21 June. In winter on 21 June, the  $\cos(57.37\text{deg})$  radiation would be transferred to a surface, whereas in summer, on 21 December, 12:00 –  $\cos(10.49\text{deg})$  radiation will be transferred.

#### 4.2.2.4 Climate policy

Cape Town is situated in the Temperate Coastal region, where a maximum energy demand for office buildings has been set at 75 VA/m<sup>2</sup>, while maximum annual consumption is 185 kWh/m<sup>2</sup> (SANS 204, 2011).

Exterior wall insulation for office buildings in the temperate climatic zone is required to meet a CR value of 100 hours. In the same region, fenestration is also regulated whereby the SHGC should be limited to 0,13 and Conductance limited to 1,4, while various strategies concerning overhangs and screening is stipulated in more detail. The thermal resistance of roof assemblies has been limited to 3,7m<sup>2</sup>.K/W (SANS 204, 2011).

## 4.3 ITERATIVE ANALYSIS FOR ENERGY CONSUMPTION OF REFERENCE BUILDING

### 4.3.1 Scenarios

#### 4.3.1.1 External roller shades

Roller shades are fabric, mesh-like textiles that wind up on a roller moving up and down on the face of a building façade, either manually or mechanically. The textiles are rigid with translucent visibility and allows for minimal air movement. (The Lawrence Berkeley National Laboratory, 2015)

*Table 4.5: Fixed values used in testing external roller shades scenarios (Source: Author)*

#### Space

Orientation:	North	
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	with continuous control (by set points)
Equipment Load	8.07 W/m <sup>2</sup>	

#### Device

Solar transmission	0.3	Te
Visible transmission	0.3	T.vis
Solar reflection	0.5	R
Visible reflection	0.5	LRV
Thermal transmission	0	W/m-K
Thermal emission	0.9	ratio
Conductivity	0.3	W/m-K

Table 4.6: Variable values used in testing external roller shades scenarios (Source: Author)

Description	Value	Symbol	
Thickness	0.75mm	(a)	
	1.5mm	(b)	
Colour	white	(x)	
	d-grey	(y)	
Distance	100mm	_(1)	
	300mm	_(2)	
Automated	Static (always on)	S	
	Dynamic (high solar)	D	(draw when U > 0.8W/m <sup>2</sup> )

Table 4.7: Results (A) from testing external roller shades scenarios (Source: Author)

## Results

ID	Combination	Total Energy (MJ/m <sup>2</sup> /yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	RS_a1x_S	<b>236.21</b>	170.91	65.3	23.00%	
3	RS_a1y_S	<b>237.41</b>	172.11	65.3	22.60%	W
4	RS_a2x_S	<b>235.91</b>	170.61	65.3	23.09%	B
5	RS_a2y_S	<b>235.91</b>	170.61	65.3	23.09%	B
6	RS_b1x_S	<b>237.78</b>	172.48	65.3	22.48%	W
7	RS_a1y_S	<b>237.78</b>	172.48	65.3	22.48%	W
8	RS_b2x_S	<b>236.21</b>	170.91	65.3	23.00%	
9	RS_b2y_S	<b>236.21</b>	170.91	65.3	23.00%	
1	Base	<b>306.75</b>	266.04	40.71		
2	RS_a1x_D	<b>225.38</b>	160.08	65.3	26.53%	
3	RS_a1y_D	<b>226.09</b>	160.79	65.3	26.30%	
4	RS_a2x_D	<b>225.18</b>	159.88	65.3	26.59%	B
5	RS_a2y_D	<b>225.18</b>	159.88	65.3	26.59%	B
6	RS_b1x_D	<b>226.31</b>	161.01	65.3	26.22%	W
7	RS_a1y_D	<b>226.31</b>	161.01	65.3	26.22%	W
8	RS_b2x_D	<b>225.38</b>	160.08	65.3	26.53%	
9	RS_b2y_D	<b>225.38</b>	160.08	65.3	26.53%	

## Observations

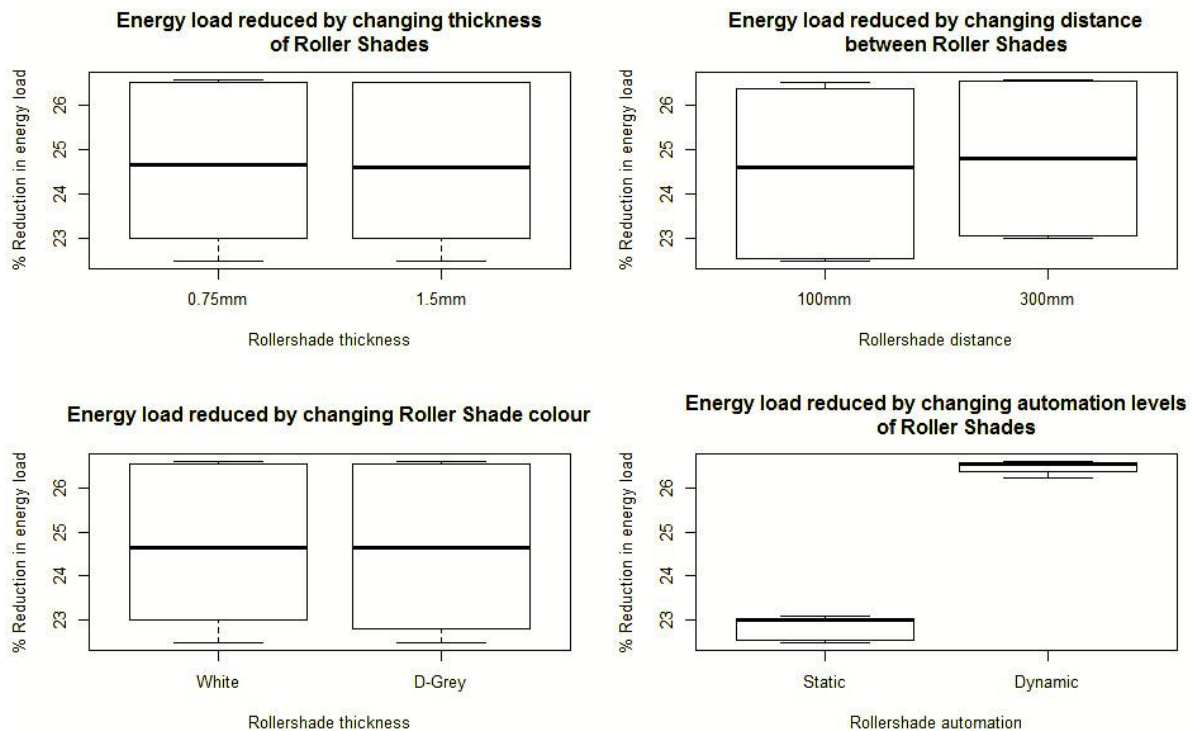


Figure 4.3: Mean and distribution of efficiency due to energy reduction of variables pertaining to roller shades (Source: Author)

- 1 Roller Shades have a significant reduction on total energy consumption with a mean reduction of 24.5% - see figure 4.3
- 2 Strategy changes have a marginal change on energy consumption, where the greatest change occurs due to automation
- 3 Best results in 'Static' and 'Dynamic' instances are similar
- 4 A change in Roller Shade strategy has no effect on lighting load
- 5 Best results (3,4) have in common: 'Thickness' = 0, 75mm and "Distance" = 300mm
- 6 Best results (3,4) are the same, therefore 'colour' has no effect on energy consumption
- 7 Worst results (6,7) have in common: "Distance" = 100mm

- 8 "Automation" is the most significant variable – see figure 4.3
- 9 'Dynamic' shades has better performance than fixed screens but there may be a disproportionate cost implication. Both results will be tested to determine the costing implication

## Adjustments

- 1 Reconstructed scenarios based on distance and 'Static' and 'Dynamic' will be tested
- 2 'Distance' iterations adjusted to 375mm (3), 450mm (4), 525mm (5)
- 3 Colour' = white, 'thickness' = 75mm

## Results

*Table 4.8: Results (B) from testing external roller shades scenarios (Source: Author)*

ID	Combination	Total Energy	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	RS_a3x_S	<b>235.49</b>	170.19	65.3	23.23%	W
3	RS_a4x_S	<b>235.13</b>	169.83	65.3	23.35%	
4	RS_a5x_S	<b>234.8</b>	169.5	65.3	23.46%	B
5	RS_a3x_D	<b>224.94</b>	159.64	65.3	26.67%	W
6	RS_a4x_D	<b>224.72</b>	159.42	65.3	26.74%	B
7	RS_a5x_D	<b>225.54</b>	160.24	65.3	26.47%	

## Observations

- 1 Again 'Dynamic' shades have performed better than 'Fixed' shades
- 2 There is a correlation between 'Distance' and energy reduction, but to a marginal extent
- 3 For fixed shades '4' performed best at 'Distance' = 525mm
- 4 For fixed shades '2' performed the worst at 'Distance' = 375mm

- 5 For dynamic shades '7' performed best at 'Distance' = 525mm
- 6 For dynamic shades '5' performed the worst at 'Distance' = 375mm

### To be included for further study

- 1 A negligible reduction in energy consumption can be observed as distance increases further. '300mm' distance will be used for further study
- 2 0.75mm Screen thickness was the most effective and will be used for further study
- 3 Colour had no impact and therefore any colour will be used
- 4 Both 'Static' and 'Dynamic' will be included due to potential disproportionate costs of motorising

### Best scenarios applied to East and West facades

#### Results

Table 4.9: Results (C) from testing external roller shades scenarios (Source: Author)

Orientation: West

ID	Combination	Total Energy	Cooling	Lighting	% opt	Observations
1	Base	<b>364.27</b>	317.91	46.36		
2	RS_a2x_S	<b>261.43</b>	183.44	77.99	28.23%	B
4	RS_a2x_D	<b>247.57</b>	169.58	77.99	32.04%	B

Orientation: East

ID	Combination	Total Energy	Cooling	Lighting	% opt	Observations
1	Base	<b>352.46</b>	305.46	47		
2	RS_a2x_S	<b>261.99</b>	184.14	77.85	25.67%	B
4	RS_a2x_D	<b>247.73</b>	169.88	77.85	29.71%	B

## Observations

- 1 A significantly increased load may be observed on both the east and west facades
- 2 The west façade experiences the greatest load
- 3 Interestingly the roller shades reduces energy consumption to very similar levels on both east and west facades, but has the greatest effect on the west façade

### 4.3.1.2 Venetian louvre screens

Venetian louvre screens are horizontal blinds fitted to the external façade of a building allowing a buffer to direct solar radiation. Solar rays are reflected away from the building by either static or movable (dynamic) louvers that are tilted towards the solar inclination angle. (Mark, 2012)

## Fixed Values

Table 4.10: Fixed values used for testing venetian blinds scenarios (Source: Author)

### Space

Orientation:	Not fixed. Want to test if different scenarios are correlated to orientation	
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	with continuous control (by setpoints)
Equipment Load	8.07 W/m <sup>2</sup>	

### Device

Transmittance	0	Te
Reflectance Front	0.7	R
Reflectance Back	0.7	R
IR Transmission	0.9	ratio
IR Emission Front	0.9	ratio
IR Emission Back	0.9	ratio
Conductivity	159.23	W/m-K

Movement	Static
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## Test 1: Determine impact of equilateral spacing and slat width at different sizes

### Variables

Table 4.11: Variable values (A) used for testing venetian blinds scenarios (Source: Author)

Description	Value	Symbol
Tilt	90 degrees	(x)
Slat width	10	(a)
	20	(b)
	30	(c)
	40	(d)
	50	(e)
	60	(f)
	70	(g)
	80	(h)
Slat spacing	10	_(1)
	20	_(2)
	30	_(3)
	40	_(4)
	50	_(5)
	60	_(6)
	70	_(7)
	80	_(8)
Orientation	North	N
	East	E
	West	W

## Results

Table 4.12: Results (A) from testing venetian blinds scenarios (Source: Author)

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	L_X_a_1_N	<b>240.9</b>	174.31	66.59	21.47%	B
3	L_X_b_2_N	<b>247.75</b>	182.13	65.62	19.23%	B
4	L_X_c_3_N	<b>248.44</b>	183.14	65.3	19.01%	
5	L_X_d_4_N	<b>248.72</b>	183.58	65.14	18.92%	
6	L_X_e_5_N	<b>248.95</b>	183.91	65.04	18.84%	
7	L_X_f_6_N	<b>249.97</b>	184.99	64.98	18.51%	W
8	L_X_g_7_N	<b>249.15</b>	184.22	64.93	18.78%	
9	L_X_h_8_N	<b>249.22</b>	184.33	64.89	18.75%	W

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>352.46</b>	305.46	47		
2	L_X_a_1_E	<b>311.88</b>	233.04	78.84	11.51%	B
3	L_X_b_2_E	<b>315.94</b>	237.85	78.09	10.36%	B
4	L_X_c_3_E	<b>317.39</b>	239.56	77.83	9.95%	
5	L_X_d_4_E	<b>318.09</b>	240.39	77.7	9.75%	
6	L_X_e_5_E	<b>318.57</b>	240.94	77.63	9.62%	
7	L_X_f_6_E	<b>318.85</b>	241.27	77.58	9.54%	W
8	L_X_g_7_E	<b>318.06</b>	240.52	77.54	9.76%	
9	L_X_h_8_E	<b>319.21</b>	241.7	77.51	9.43%	W

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>364.27</b>	323.56	40.71		
2	L_X_a_1_W	<b>313.78</b>	247.19	66.59	13.86%	B
3	L_X_b_2_W	<b>318.49</b>	252.87	65.62	12.57%	B
4	L_X_c_3_W	<b>320.17</b>	254.87	65.3	12.11%	
5	L_X_d_4_W	<b>320.96</b>	255.82	65.14	11.89%	
6	L_X_e_5_W	<b>321.44</b>	256.4	65.04	11.76%	
7	L_X_f_6_W	<b>321.77</b>	256.79	64.98	11.67%	
8	L_X_g_7_W	<b>322</b>	257.07	64.93	11.60%	W
9	L_X_h_8_W	<b>322.17</b>	257.28	64.89	11.56%	W

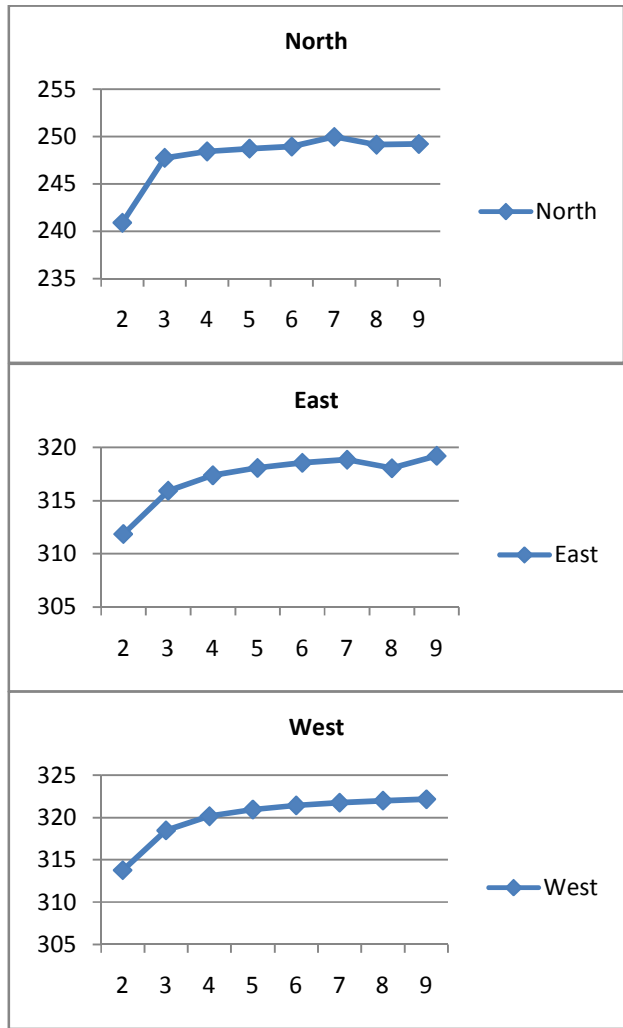


Figure 4.4: Degree of efficiency of all scenarios as based on each façade (Source: Author)

## Observations

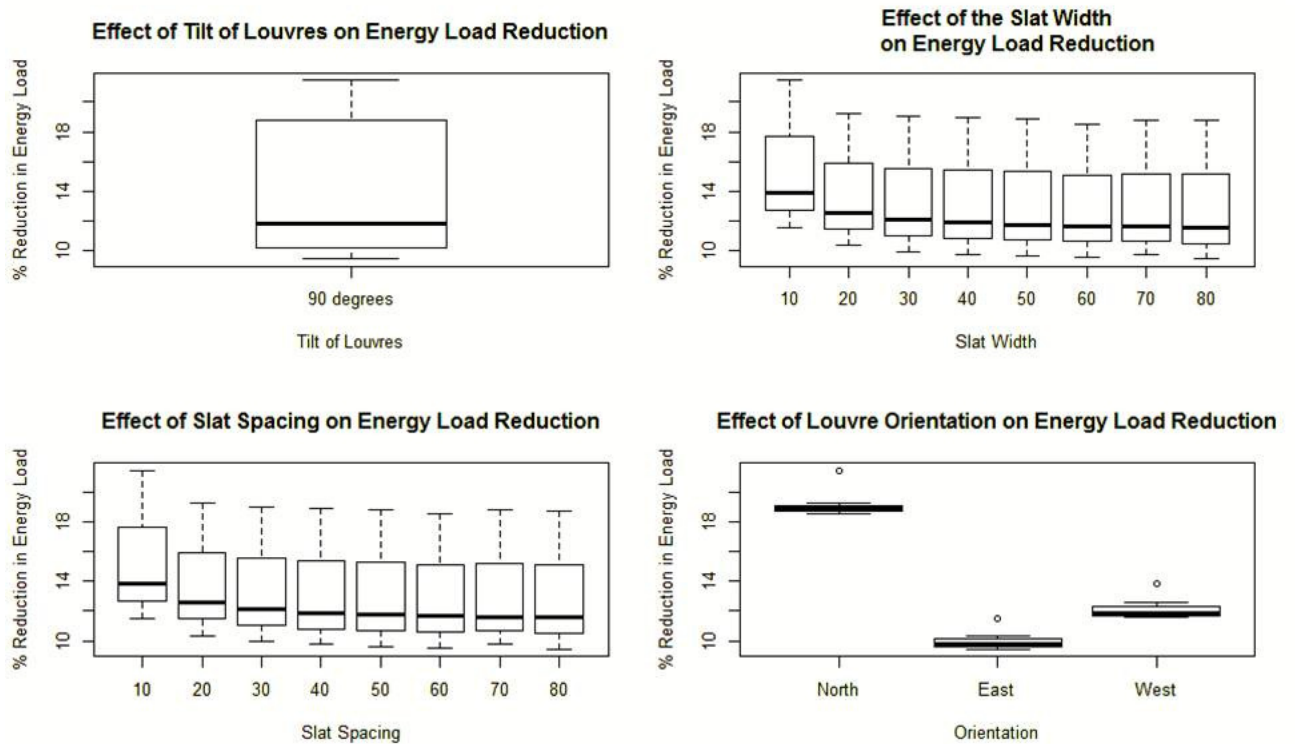


Figure 4.5: Mean and distribution of efficiency due to energy reduction; of variables pertaining to louvers  
(Source: Author)

- 1 Smaller louvres (where 'width' = 'spacing') perform slightly better than larger louvres (where 'width' = 'spacing') – refer to figure 4.5
- 2 The 10mm louvre performs relatively better than louvres '20mm' – '80mm'. Refer figure 4.5

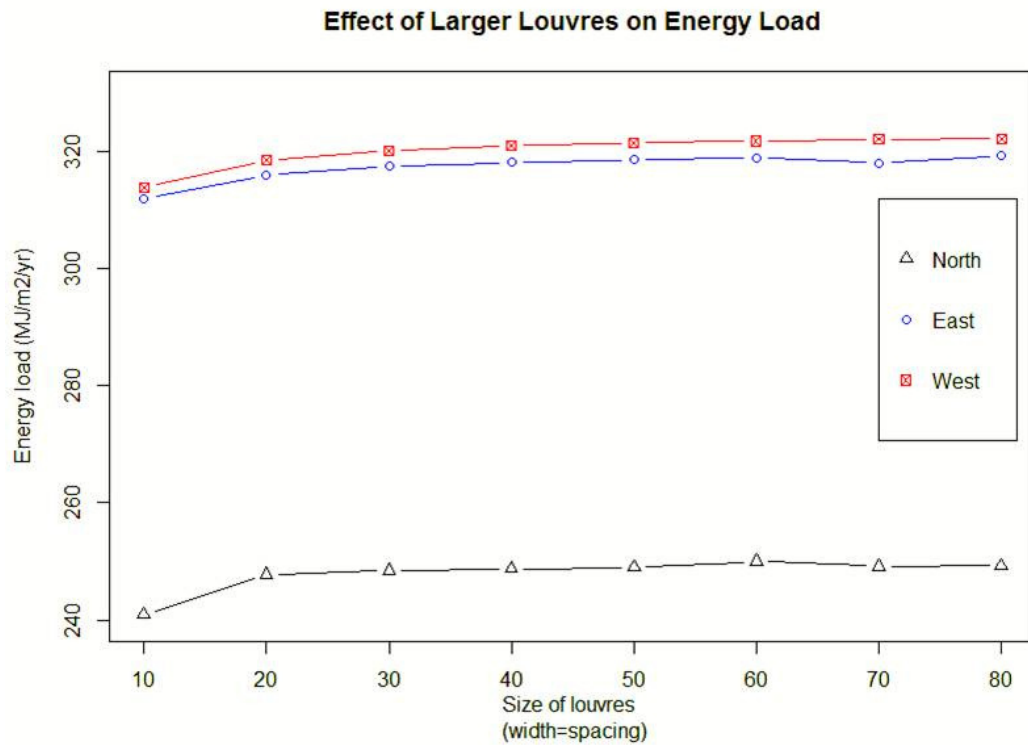


Figure 4.6: Plot showing the efficiency of larger louvres for each facade (Source: Author)

- 3 A similar effect occurs when similar configurations are applied to the 'North', 'East' and 'West' facades. Figure 4.6 shows that overall, changing the size of the louvres does not have a significant effect and that the North facade experiences the biggest improvement in facade strategies.

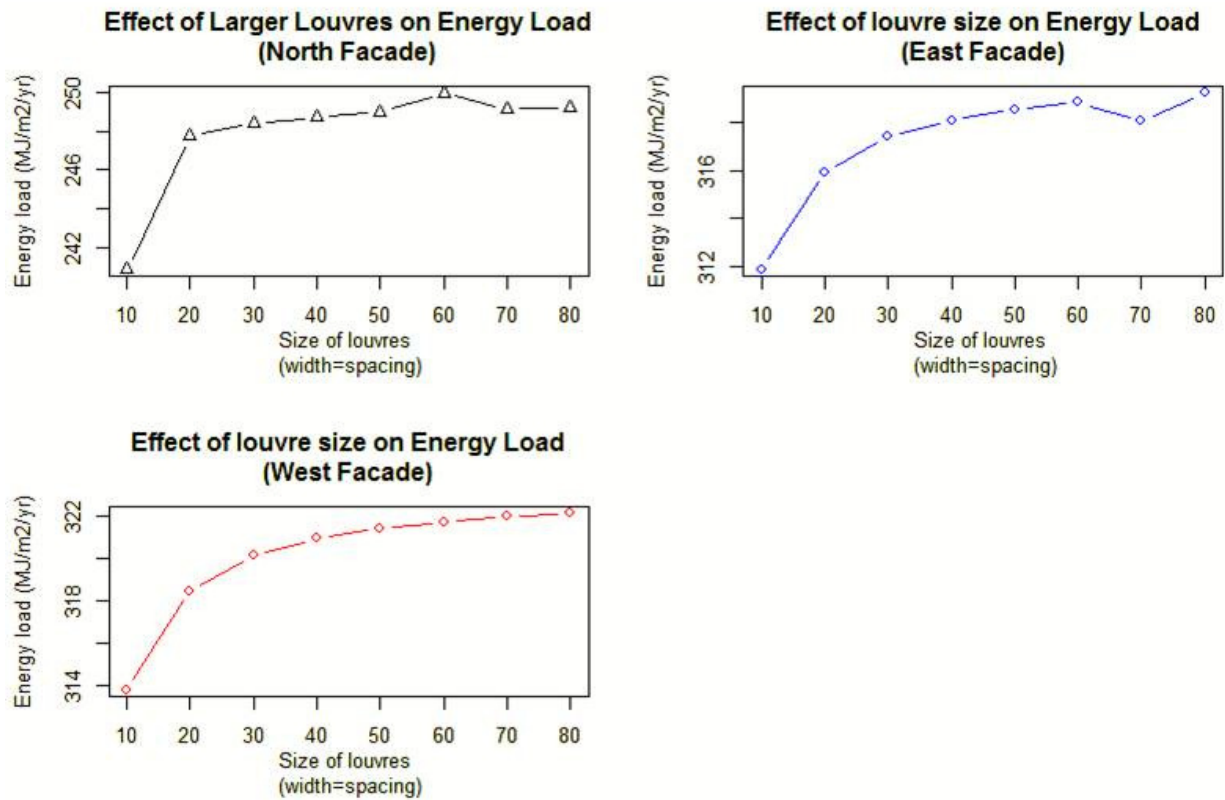


Figure 4.7: Plot showing the efficiency of larger louvres for each facade (Source: Author)

- 4 For further investigation, one façade can therefore be studied and the most optimal solution can then also be applied to the other facades

## Test 2: Determine optimal tilt angle and corresponding distance

### Selection of variables:

- 1 Incremental spacing will be applied in order to observe a range
- 2 Slat tilt greater than 90 degrees would move closer to being parallel with solar inclination, which would not be feasible
- 3 Slat tilt less than 45 deg would reduce total depth, while reducing visibility, which would not be feasible
- 4 Visibility is correlated to the relationship between tilt and slat spacing
- 5 At 45 degrees where 'distance' = 'slat width', horizontal visibility is zero
- 6 As tilt increases (i.e.<90 deg) slat spacing should increase relatively

### Variables

Table 4.13: Variable values (B) used for testing venetian blinds scenarios (Source: Author)

Description	Value	Symbol
Tilt	90 degrees	(a)
	85 degrees	(b)
	80 degrees	(c)
	75 degrees	(d)
	70 degrees	(e)
	65 degrees	(f)
	60 degrees	(g)
	55 degrees	(h)
	50 degrees	(i)
	45 degrees	(j)
Slat width	10	(x)
Slat spacing	4	_(1)
	6	_(2)
	8	_(3)
	10	_(4)
	12	_(5)
	14	_(6)
	16	_(7)
	18	_(8)
Orientation	North	N

## Results

Table 4.14: Results (B) from testing venetian blinds scenarios (Source: Author)

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
	X_a_1_N	<b>238.89</b>	150.05	88.84	22.12%	
	X_a_2_N	<b>234.3</b>	157.2	77.1	23.62%	B
	X_a_3_N	<b>236.52</b>	166.04	70.48	22.89%	B
	X_a_4_N	<b>240.9</b>	174.31	66.59	21.47%	
	X_a_5_N	<b>253.17</b>	188.84	64.33	17.47%	
	X_a_6_N	<b>259.06</b>	196.2	62.86	15.55%	
	X_a_7_N	<b>264.62</b>	202.73	61.89	13.73%	W
	X_a_8_N	<b>269.04</b>	207.93	61.11	12.29%	W
	X_b_1_N	<b>239.23</b>	148.75	90.48	22.01%	
	X_b_2_N	<b>234.06</b>	155.12	78.94	23.70%	B
	X_b_3_N	<b>234.36</b>	162.39	71.97	23.60%	B
	X_b_4_N	<b>238.26</b>	170.36	67.9	22.33%	
	X_b_5_N	<b>249.74</b>	184.28	65.46	18.59%	
	X_b_6_N	<b>255.76</b>	191.93	63.83	16.62%	
	X_b_7_N	<b>260.83</b>	198.08	62.75	14.97%	W
	X_b_8_N	<b>265.65</b>	203.73	61.92	13.40%	W
	X_c_2_N	<b>234.06</b>	153.37	80.69	23.70%	B
	X_c_3_N	<b>233.1</b>	159.34	73.76	24.01%	B
	X_c_4_N	<b>235.83</b>	166.51	69.32	23.12%	
	X_c_5_N	<b>246.58</b>	179.86	66.72	19.62%	
	X_c_6_N	<b>252.46</b>	187.46	65	17.70%	
	X_c_7_N	<b>257.65</b>	193.88	63.77	16.01%	W
	X_c_8_N	<b>262.39</b>	199.44	62.95	14.46%	W
	X_d_3_N	<b>232.95</b>	157.18	75.77	24.06%	B
	X_d_4_N	<b>234.53</b>	163.27	71.26	23.54%	B
	X_d_5_N	<b>243.92</b>	175.61	68.31	20.48%	
	X_d_6_N	<b>249.45</b>	183.06	66.39	18.68%	
	X_d_7_N	<b>254.61</b>	189.55	65.06	17.00%	W
	X_d_8_N	<b>259.41</b>	195.26	64.15	15.43%	W
	X_e_3_N	<b>233.22</b>	155.26	77.96	23.97%	B
	X_e_4_N	<b>233.6</b>	160.35	73.25	23.85%	B

X_e_5_N	<b>236.77</b>	166.59	70.18	22.81%	
X_e_6_N	<b>247.25</b>	179.17	68.08	19.40%	
X_e_7_N	<b>252.06</b>	185.48	66.58	17.83%	W
X_e_8_N	<b>256.72</b>	191.2	65.52	16.31%	W
X_f_3_N	<b>233.71</b>	153.47	80.24	23.81%	B
X_f_4_N	<b>233.32</b>	157.8	75.52	23.94%	B
X_f_5_N	<b>235.73</b>	163.47	72.26	23.15%	
X_f_6_N	<b>239.44</b>	169.45	69.99	21.94%	
X_f_7_N	<b>249.67</b>	181.35	68.32	18.61%	W
X_f_8_N	<b>254.27</b>	187.17	67.1	17.11%	W
X_g_4_N	<b>233.46</b>	155.6	77.86	23.89%	B
X_g_5_N	<b>235.32</b>	160.66	74.66	23.29%	
X_g_6_N	<b>238.55</b>	166.39	72.16	22.23%	
X_g_7_N	<b>248.02</b>	177.7	70.32	19.15%	
X_g_8_N	<b>252.34</b>	183.41	68.93	17.74%	W
X_h_5_N	<b>235.24</b>	158.04	77.2	23.31%	B
X_h_6_N	<b>238.27</b>	163.66	74.61	22.32%	
X_h_7_N	<b>241.73</b>	169.17	72.56	21.20%	
X_h_8_N	<b>245.34</b>	174.37	70.97	20.02%	W
X_i_6_N	<b>238.39</b>	161.14	77.25	22.29%	B
X_i_7_N	<b>241.82</b>	166.78	75.04	21.17%	
X_i_8_N	<b>245.26</b>	172.02	73.24	20.05%	W
X_j_7_N	<b>242.5</b>	164.71	77.79	20.95%	B
X_j_8_N	<b>245.84</b>	170.09	75.75	19.86%	W

## Observations

- 1 A correlation exists between 'spacing' and heat transfer, where smaller spacing translates to less heat transfer. See figure 4.8.

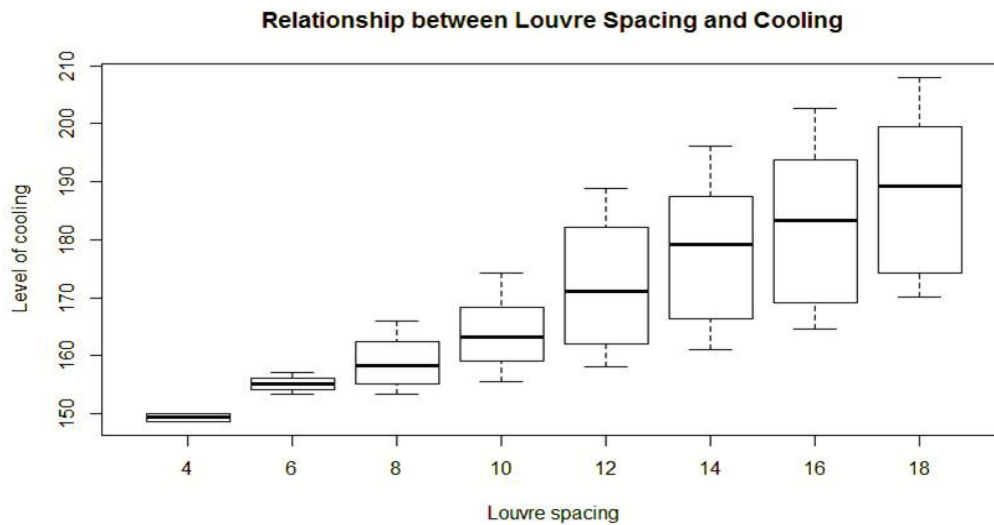


Figure 4.8: Box plot showing the relationship between louvre spacing and cooling (Source: Author)

- 2 Closer louvre spacing reduces visibility, especially where tilt is greater
- 3 In addition, closely spaced louvres require more material per area translating to higher cost
- 4 The scenario producing lowest energy transfer is therefore not necessarily the most cost effective. This aspect is further investigated below.

### TEST 3: Determine material quantity relative to energy transfer

#### Capital cost ratios

Table 4.15: Material quantity relative to energy transfer as a proxy for relative capital cost (Source Author)

Slat spacing	# slats / m	Material required	Difference
4	250.00	100.00%	0.00%
6	166.67	66.67%	33.33%
8	125.00	50.00%	50.00%
10	100.00	40.00%	60.00%
12	83.33	33.33%	66.67%
14	71.43	28.57%	71.43%
16	62.50	25.00%	75.00%
18	55.56	22.22%	77.78%

## Operating Cost ratios

Table 4.16: Material quantity relative to energy transfer as a proxy for relative operating cost (Source: Author)

Tilt	E-Reduction (W)	E-Reduction (B)	Performance difference
90	37.71	72.45	47.95%
85	41.10	72.69	43.46%
80	44.36	73.65	39.77%
75	44.36	73.80	39.89%
70	50.03	73.53	31.96%
65	52.48	73.43	28.53%
60	54.41	73.29	25.76%
55	61.41	71.51	14.12%
50	61.49	68.36	10.05%
45	60.91	64.25	5.20%
			<hr/> 28.67% Average

## Observations

- 1 Variable 8 represents a slat spacing of 18mm which in each instance performed the worst
- 2 For each increment 45 - 90 degrees, variable 8 performed on average 28.67% worse than the best case
- 3 However, variable 8 requires 77.78% less material than the best performing scenario
- 4 Potential material cost therefore significantly outweighs potential operational savings
- 5 In that sense, all worst performing scenarios (by energy) containing variable 8 will be used for further study
- 6 Among these worst performing scenarios (by energy):
  - 'Tilt 45' performs the best, only 5.2% worse than the best scenario, but has the lowest visibility

- 'Tilt 90' performs 47.95% worse than the best scenario, but has the greatest visibility

7 The full range will therefore be included for further study

### Best scenarios applied to east and west facades

### Results

Table 4.17: Results (C) from testing venetian blinds scenarios (Source: Author)

Orientation:		West				
ID	Combination	Total Energy	Cooling	Lighting	% opt	Observations
1	Base	<b>364.27</b>	317.91	46.36		
2	X_a_7_W	<b>346.12</b>	271.41	74.71	4.98%	
3	X_a_8_W	<b>353.35</b>	279.16	74.19	3.00%	W
4	X_b_7_W	<b>337.08</b>	261.85	75.23	7.46%	
5	X_b_8_W	<b>345.21</b>	270.53	74.68	5.23%	
6	X_c_7_W	<b>328.34</b>	252.41	75.93	9.86%	
7	X_c_8_W	<b>337.2</b>	261.85	75.35	7.43%	
8	X_d_7_W	<b>320.33</b>	243.53	76.8	12.06%	
9	X_d_8_W	<b>329.75</b>	253.6	76.15	9.48%	
10	X_e_7_W	<b>312.82</b>	235.02	77.8	14.12%	
11	X_e_8_W	<b>322.51</b>	245.43	77.08	11.46%	
12	X_f_7_W	<b>305.45</b>	226.49	78.96	16.15%	B
13	X_f_8_W	<b>316.06</b>	237.9	78.16	13.23%	
14	X_g_8_W	<b>309.91</b>	230.48	79.43	14.92%	
15	X_h_8_W	<b>304.41</b>	223.58	80.83	16.43%	
16	X_i_8_W	<b>299.81</b>	217.44	82.37	17.70%	
17	X_j_8_W	<b>295.95</b>	203.1	92.85	18.76%	B
Orientation:		East				
ID	Combination	Total Energy	Cooling	Lighting	% opt	Observations
1	Base	<b>352.46</b>	305.46	47		
2	X_a_7_E	<b>338.92</b>	263.52	75.4	3.84%	
3	X_a_8_E	<b>345.45</b>	270.6	74.85	1.99%	W
4	X_b_7_E	<b>330.7</b>	254.78	75.92	6.17%	
5	X_b_8_E	<b>337.76</b>	262.42	75.34	4.17%	
6	X_c_7_E	<b>322.93</b>	246.32	76.61	8.38%	
7	X_c_8_E	<b>330.51</b>	254.5	76.01	6.23%	
8	X_d_7_E	<b>315.7</b>	238.21	77.49	10.43%	
9	X_d_8_E	<b>323.8</b>	246.99	76.81	8.13%	
10	X_e_7_E	<b>308.59</b>	230.07	78.52	12.45%	
11	X_e_8_E	<b>317.4</b>	239.62	77.78	9.95%	
12	X_f_7_E	<b>302.67</b>	222.95	79.72	14.13%	B

13	X_f_8_E	<b>311.46</b>	232.57	78.89	11.63%	
14	X_g_8_E	<b>306.34</b>	226.15	80.19	13.09%	
15	X_h_8_E	<b>301.8</b>	220.17	81.63	14.37%	
16	X_i_8_E	<b>297.62</b>	214.39	83.23	15.56%	
17	X_j_8_E	<b>294.45</b>	209.42	85.03	16.46%	B

## Observations

- 1 A significantly increased load may be observed on both the east and west facades, where the base case increased from 306.75 MJ/m<sup>2</sup>/yr to 364.27 MJ/m<sup>2</sup>/yr on the West façade and to 352.46 on the East façade
- 2 Although ID 17 performed the best in both cases ID 12 may be better considering higher visibility (comparing how similar static scenarios behaved on different facades)

### 4.3.1.3 Mesh/Fabric screens

Mesh screens are fixed membranes that are applied and offset to a building façade with the purpose of reducing direct solar radiation. It usually comprises of a punched metal surface that are stretched to achieve a variety of spacing depending on the solidity required. The screens are not structural and require a sub-frame structure to keep it in place. (Haver & Boecker, 2016)

#### Fixed Values

Table 4.18: Fixed values used in testing mesh screen scenarios (Source: Author)

<u>Space</u>		
Orientation:	North Only	
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	with continuous control (by setpoints)
Equipment Load	8.07 W/m <sup>2</sup>	
<u>Device</u>		
Colour	Grey	
Solar reflection	0.1	R
Visible reflection	0.1	R
Emissivity	0.9	ratio
Conductivity	0.09	W/m-K
Movement	Static	

**TEST 1: Determine impact of equilateral sizing of both thread diameter and spacing (programme algorithm rule: thread diameter must be < spacing)**

**Variables**

*Table 4.19: Variable values (A) used in testing mesh screen scenarios (Source: Author)*

Description	Value (mm)	Symbol	
Thread diamtr	0.1	_(1)	_(2)
	0.2	_(3)	
	0.3	_(4)	
	0.4	_(5)	
	0.5		
Thread spacing	0.2	(a)	(b)
	0.3	(c)	
	0.4	(d)	
	0.5	(e)	
	0.6	(e)	

**Results**

*Table 4.20: Results (A) from testing mesh screen scenarios (Source: Author)*

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	S_1_a	<b>266.14</b>	153.02	113.12	13.24%	B
3	S_2_b	<b>267.79</b>	148.4	119.39	12.70%	
4	S_3_c	<b>269.18</b>	148.29	120.89	12.25%	
5	S_4_d	<b>270.63</b>	149.28	121.35	11.78%	
6	S_5_e	<b>271.94</b>	150.39	121.55	11.35%	W

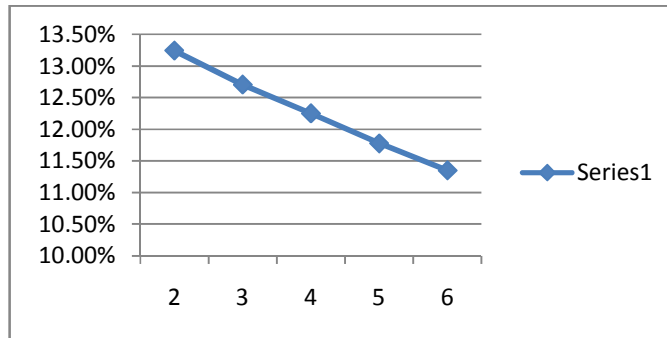


Figure 4.9: Degree of efficiency of each scenario based on the north façade (Source: Author)

### Observations

- 1 Screen efficiency decrease as thread diameter and thread spacing increase equilaterally

### Test 2: Determine impact of fixing thread diameter and increasing thread spacing (Algorithm rule: thread diameter must be < spacing)

### Variables

Table 4.21: Variable values (B) used testing mesh screen scenarios (Source: Author)

Description	Value (mm)	Symbol
Thread diamtr	0.1	_(1)
Thread spacing	0.2	(a)
	0.3	(b)
	0.4	(c)
	0.5	(d)
	0.6	(e)

## Results

Table 4.22: Results (B) from testing mesh screen scenarios (Source: Author)

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	S_1_a	<b>266.14</b>	153.02	113.12	13.24%	B
3	S_1_b	<b>266.44</b>	162.78	103.66	13.14%	B
4	S_1_c	<b>280.18</b>	182.71	97.47	8.66%	
5	S_1_d	<b>287.6</b>	194.44	93.16	6.24%	
6	S_1_e	<b>293.24</b>	203.16	90.08	4.40%	W

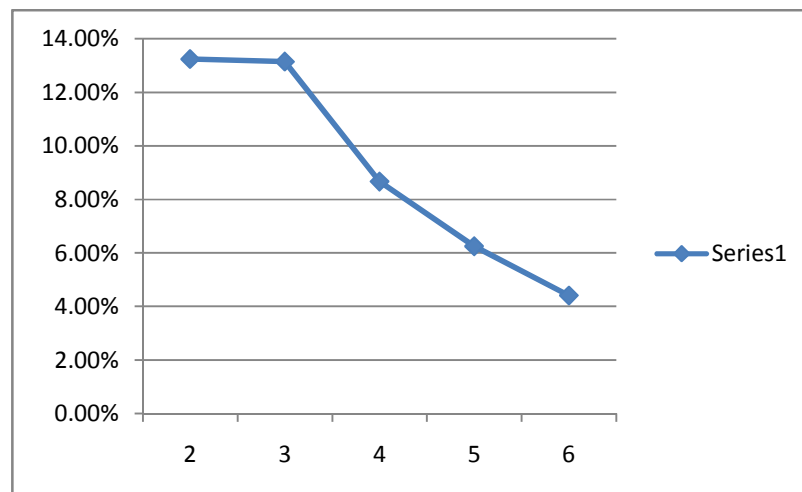


Figure 4.10: Degree of efficiency of each scenario based on the north façade (Source: Author)

## Observations

- 1 Screen efficiency decrease as spacing increase
- 2 There was a marginal difference in efficiency up to a 3:1 ratio ('spacing' : 'diameter')
- 3 ID3 is potentially the most ideal scenario where total number of threads would be significantly less. This aspect is further explored below.

**TEST 3: Determine impact of fixing thread diameter and decreasing thread spacing less than 2:1 (Algorithm rule: thread diameter must be < spacing)**

**Variables**

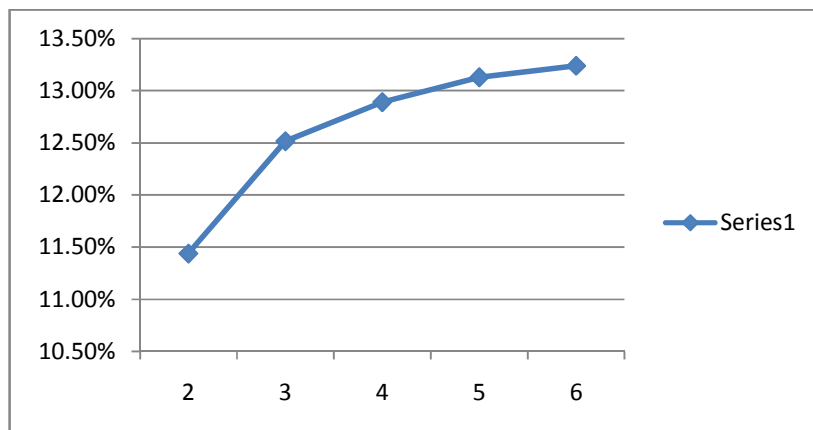
*Table 4.23: Variable values (C) used testing mesh screen scenarios (Source: Author)*

Description	Value (mm)	Symbol
Thread diameter	0.1	_(1)
Thread spacing	0.12	(a)
	0.14	(b)
	0.16	(c)
	0.18	(d)
	0.2	(e)

**Results**

*Table 4.24: Results (C) from testing mesh screen scenarios (Source: Author)*

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	S_1_a	<b>271.66</b>	150.11	121.55	11.44%	W
3	S_1_b	<b>268.36</b>	148.01	120.35	12.52%	
4	S_1_c	<b>267.21</b>	149.12	118.09	12.89%	
5	S_1_d	<b>266.48</b>	150.96	115.52	13.13%	
6	S_1_e	<b>266.14</b>	153.02	113.12	13.24%	B



*Figure 4.11: Efficiency of mesh screen scenarios 2-6 (Source: Author)*

## Observations

- 1 Interestingly, when thread spacing is reduced to less than 2:1, the efficiency drops
- 2 When results from test 2 and 3 are combined the results occur as displayed in the following section

## Results

Table 4.25: Results (D) from testing mesh screen scenarios (Source: Author)

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	S_1_1.12	<b>271.66</b>	150.11	121.55	11.44%	W
3	S_1_1.14	<b>268.36</b>	148.01	120.35	12.52%	
4	S_1_1.16	<b>267.21</b>	149.12	118.09	12.89%	
5	S_1_1.18	<b>266.48</b>	150.96	115.52	13.13%	
6	S_1_1.20	<b>266.14</b>	153.02	113.12	13.24%	B
8	S_1_1.30	<b>266.44</b>	162.78	103.66	13.14%	B
9	S_1_1.40	<b>280.18</b>	182.71	97.47	8.66%	
10	S_1_1.50	<b>287.6</b>	194.44	93.16	6.24%	
11	S_1_1.60	<b>293.24</b>	203.16	90.08	4.40%	W

## Observations

- 1 Marginal efficiencies exist between ID3 to ID8
- 2 ID3 is likely to be the better option due to its lower thread-count, translating to lower capital costs

## Best scenarios applied to East and West facades

Table 4.27: Summary table of best scenarios applied to East and West facades (Source: Author)

East

ID	Combination	Total Energy (MJ/m <sup>2</sup> /yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>352.46</b>	305.46	47		
2	S_1_1.14	<b>270.37</b>	152.41	117.96	23.29%	B
3	S_1_1.20	<b>286.82</b>	175.72	111.1	18.62%	
5	S_1_1.30	<b>314.88</b>	211.33	103.55	10.66%	W

West

ID	Combination	Total Energy (MJ/m <sup>2</sup> /yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>364.27</b>	317.91	46.36		
2	S_1_1.14	<b>262.48</b>	145.99	116.49	25.53%	B
3	S_1_1.20	<b>282.53</b>	172.75	109.78	19.84%	
5	S_1_1.30	<b>314.58</b>	212.16	102.42	10.75%	W

## Observations

- 1 East and West responds very differently compared to the North façade and shows an inverse relationship
- 2 Figure 4.12 shows that varying mesh spacing 14 - 30 had a very small effect on the Northern façade,
- 3 While the finer spacing made a much larger difference on the East and West facades
- 4 ID3 is best suited for the North façade, while ID2 is best for East and West

Table 4.27: Summary table of best mesh screen scenarios (Source: Author)

Scenario	E reduction		
	North	East	West
Base	306.75	352.46	364.27
<b>S_1_1.14</b>	<b>11.44%</b>	<b>23.29%</b>	<b>25.53%</b>
<b>S_1_1.20</b>	<b>13.24%</b>	<b>18.62%</b>	<b>19.84%</b>
<b>S_1_1.30</b>	<b>13.14%</b>	<b>10.66%</b>	<b>10.75%</b>

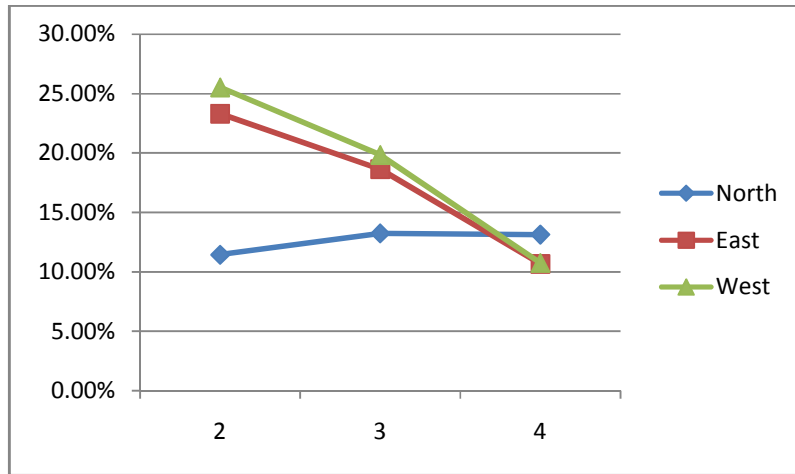


Figure 4.12: Summary graph of best mesh screen scenarios (Source: Author)

#### 4.3.1.4 Overhangs

Overhangs in the context of the research are basic horizontal projections that screen direct solar radiation from the façade's glazing elements.

#### Fixed values

Table 4.28: Fixed values (A) used in testing overhang scenarios (Source: Author)

##### Space

Orientation:	North, East, West	
Office workers:	18 pax	
Room dim's:	20 (W)x10(D)x3.5(H)	
Lighting load	10.76 W/m <sup>2</sup>	with continuous control (by setpoints)
Equipment Load	8.07 W/m <sup>2</sup>	

##### Device

Colour	Grey	
Solar reflection	0.1	
Visible reflection	0.1	
Emissivity	0.9	
Conductivity	0.09	W/m-K
Thickness	100	mm
Movement	Static	

## Test 1: Determine various overhangs at various depths and quantity

### Variables

Table 4.29: Variable values (A) used in testing overhang scenarios (Source: Author)

Description	Value	Symbol
Depth	1000	1
	750	0.75
	500	0.5
	250	0.25
Number spaced equally starting from top	1	x1
	2	x2
	3	x3
Orientation	North	N
	East	E
	West	W

### Results

Table 4.30: Results (A) from testing overhang scenarios (Source: Author)

North						
ID	Combination	Total Energy (MJ/m <sup>2</sup> /yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	O_1_x1_N	<b>189.29</b>	143.51	45.78	38.29%	
3	O_1_x2_N	<b>209.43</b>	130.27	79.16	31.73%	
4	O_1_x3_N	<b>208.41</b>	120.17	88.24	32.06%	
5	O_0.75_x1_N	<b>198.27</b>	153.44	44.83	35.36%	
6	O_0.75_x2_N	<b>213.47</b>	135.58	77.89	30.41%	
7	O_0.75_x3_N	<b>200.81</b>	120.4	80.41	34.54%	
8	O_0.5_x1_N	<b>214.41</b>	172.4	42.01	30.10%	
9	O_0.5_x2_N	<b>207.61</b>	145.29	62.32	32.32%	
10	O_0.5_x3_N	<b>162.49</b>	115.36	47.13	47.03%	B
11	O_0.25_x1_N	<b>253.97</b>	212.76	41.21	17.21%	W
12	O_0.25_x2_N	<b>236.39</b>	179.6	56.79	22.94%	W
13	O_0.25_x3_N	<b>177.86</b>	134.44	43.42	42.02%	B

East

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>352.46</b>	305.46	47		
2	O_1_x1_E	<b>259.55</b>	208.11	51.44	26.36%	
3	O_1_x2_E	<b>241.06</b>	166.68	74.38	31.61%	
4	O_1_x3_E	<b>213.08</b>	135.98	77.1	39.54%	B
5	O_0.75_x1_E	<b>275.22</b>	224.39	50.83	21.91%	
6	O_0.75_x2_E	<b>255.37</b>	182.02	73.35	27.55%	
7	O_0.75_x3_E	<b>215.55</b>	144.12	71.43	38.84%	B
8	O_0.5_x1_E	<b>291.99</b>	244.12	47.87	17.16%	W
9	O_0.5_x2_E	<b>251.42</b>	198.49	52.93	28.67%	
10	O_0.5_x3_E	<b>212.09</b>	158.83	53.26	39.83%	B
11	O_0.25_x1_E	<b>317.51</b>	270.16	47.35	9.92%	W
12	O_0.25_x2_E	<b>293.38</b>	237.22	56.16	16.76%	W
13	O_0.25_x3_E	<b>247.66</b>	198.06	49.6	29.73%	

West

ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>364.27</b>	317.91	46.36		
2	O_1_x1_W	<b>263.26</b>	210.95	52.31	27.73%	
3	O_1_x2_W	<b>240.19</b>	161.55	78.64	34.06%	
4	O_1_x3_W	<b>206.27</b>	122.15	84.12	43.37%	B
5	O_0.75_x1_W	<b>281.79</b>	230.36	51.43	22.64%	
6	O_0.75_x2_W	<b>256.42</b>	179.76	76.66	29.61%	
7	O_0.75_x3_W	<b>210.86</b>	134.29	76.57	42.11%	B
8	O_0.5_x1_W	<b>299.77</b>	252.17	47.6	17.71%	W
9	O_0.5_x2_W	<b>257.07</b>	201.03	56.04	29.43%	
10	O_0.5_x3_W	<b>203.12</b>	149.47	53.65	44.24%	B
11	O_0.25_x1_W	<b>327.81</b>	281.13	46.68	10.01%	W
12	O_0.25_x2_W	<b>298.34</b>	244.68	53.66	18.10%	W
13	O_0.25_x3_W	<b>247.47</b>	198.18	49.29	32.06%	

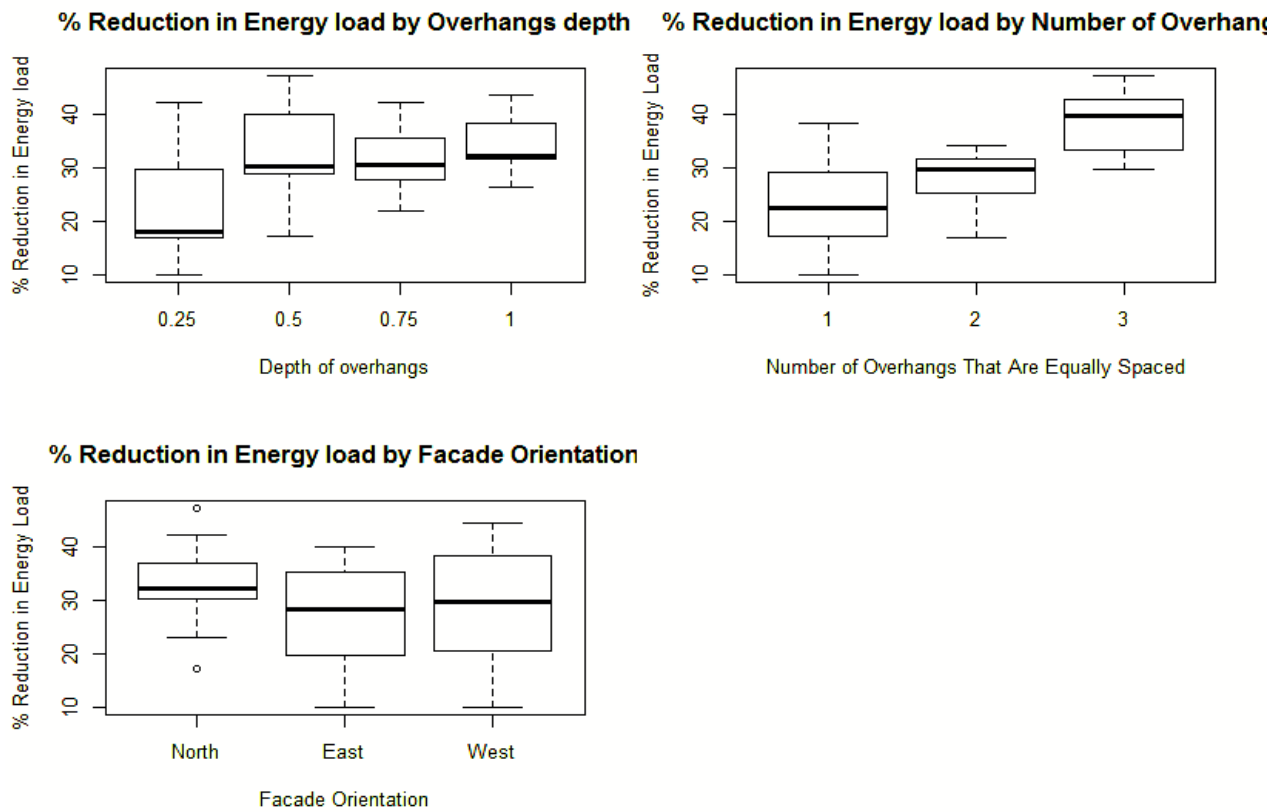


Table 4.31: Box plots showing the mean and distribution of energy optimization in various instances  
(Source: Author)

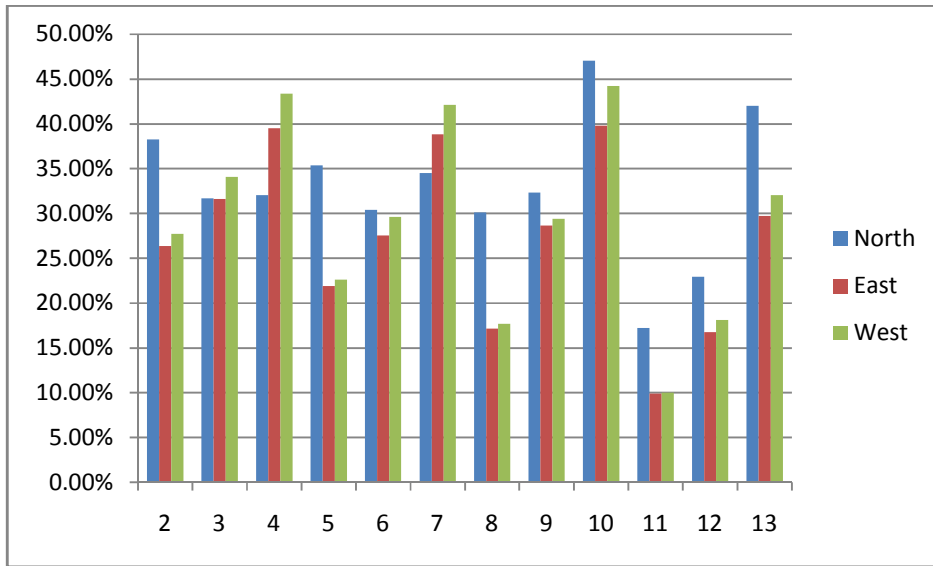


Figure 4.13: Bar chart showing energy reduction of each scenario applied to all facades(Source: Author)

### Observations

- 1 The worst scenarios on all facades have been ID11 and ID12, due to its short depth
- 2 However when an additional overhang was added it performed second best on the North façade and very well on East and West
- 3 Very deep overhangs especially when three are used, reduce lighting significantly and is therefore inefficient – refer to figure 4.14

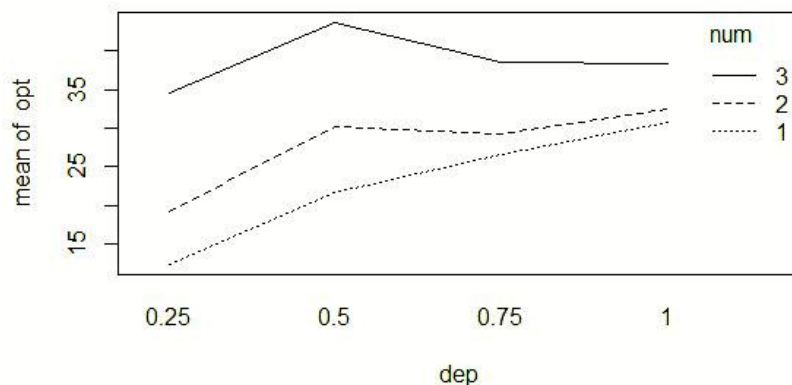


Figure 4.14: Interaction plot of depth and number of overhangs testing for efficiency (Source: Author)

- 4 Best performing overhang on all facades is ID10 with three overhangs at 500mm each, delivering:
  - 47.03% reduction on North façade
  - 39.83% reduction on East façade
  - 44.24% reduction on West façade
  
- 5 ID10 and ID13 require further comparison. ID10 requires double the material quantity compared to ID13, but with a less significant energy reduction
  
- 6 Further scenarios with less depth than 0.5 should be tested
  
- 7 The data shows that more overhangs (in quantity) deliver more optimal results - additional overhangs should therefore be considered (see figure 4.15 and 4.16)

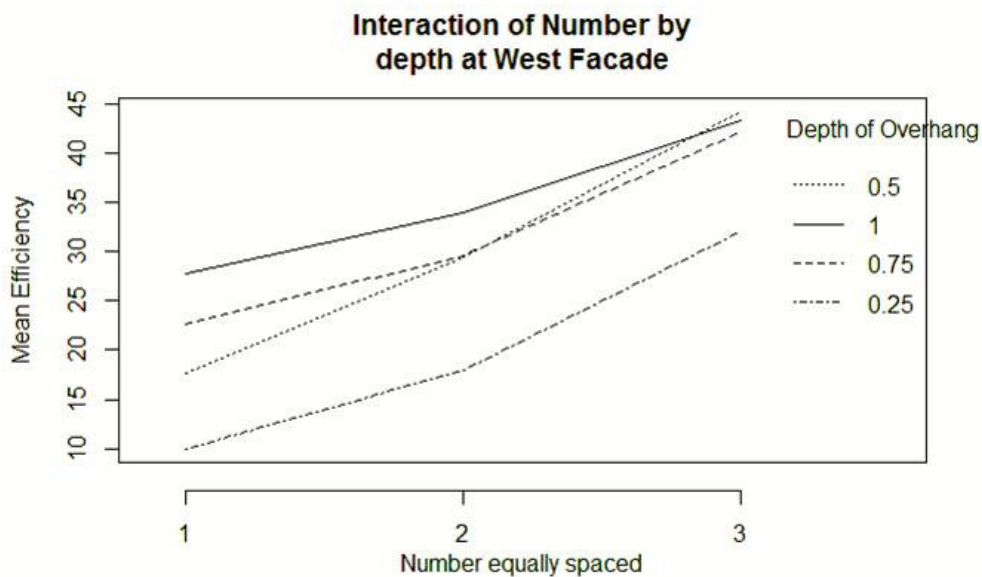


Figure 4.15: Interaction plots of depth and number of overhangs testing for efficiency; pertaining to west (Source: Author)

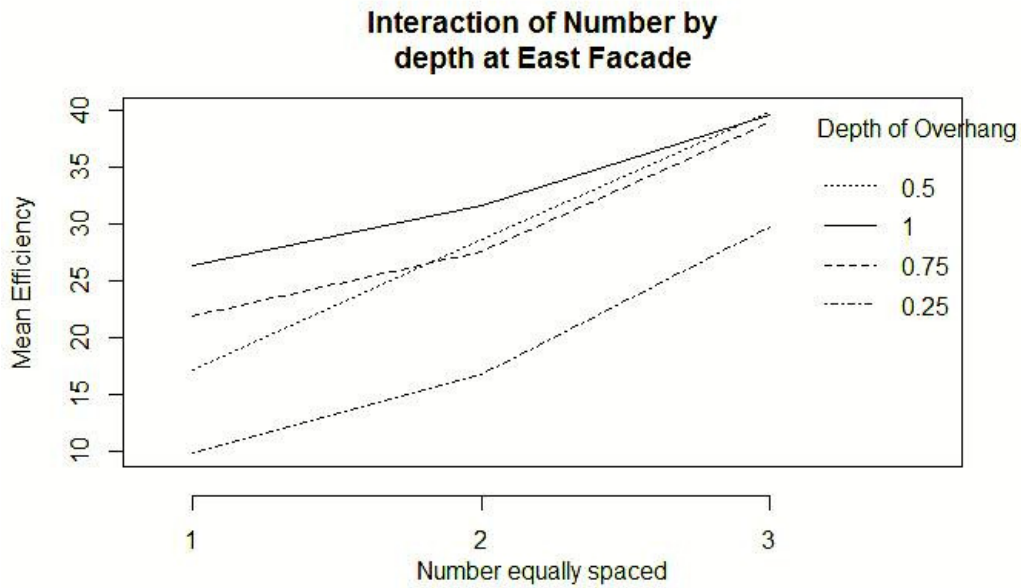


Figure 4.16: Interaction plots of depth and number of overhangs testing for efficiency; pertaining to east  
(Source: Author)

- 8 Additional overhangs will reduce visibility at 100mm thickness. Thickness will be reduced to 50mm

### Variables

Table 4.32: Variable values (B) used in testing overhang scenarios (Source: Author)

Description	Value	Symbol
Depth	200	0.2
	300	0.3
	400	0.4
Number spaced equally starting from top	3	x3
	4	x4
	5	x5
	Orientation	North

## Results

Table 4.33: Results (B) from testing overhang scenarios (Source: Author)

North						
ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>306.75</b>	266.04	40.71		
2	O_0.2_x3_N	<b>189.94</b>	146.87	43.07	38.08%	
3	O_0.2_x4_N	<b>206.86</b>	146.64	60.22	32.56%	W
4	O_0.2_x5_N	<b>185.29</b>	137.66	47.63	39.60%	
5	O_0.3_x3_N	<b>180.01</b>	134.44	45.57	41.32%	
6	O_0.3_x4_N	<b>198.15</b>	132.63	65.52	35.40%	
7	O_0.3_x5_N	<b>179.23</b>	128.17	51.06	41.57%	
8	O_0.4_x3_N	<b>169.47</b>	123.16	46.31	44.75%	B
9	O_0.4_x4_N	<b>176.23</b>	118.85	57.38	42.55%	B
10	O_0.4_x5_N	<b>209.25</b>	129.66	79.59	31.78%	W

## Observations

- 1 Previous results have shown that facades are correlated, no further testing of East and West is necessary
- 2 The results show that fewer overhangs with greater material quantity is not more efficient, as demonstrated by ID4
- 3 ID4 have slightly less material quantity than ID8 at  $(0.2 \times 5 = 1)$  vs  $(0.4 \times 3 = 1.2)$
- 4 A reduced overhang thickness have not affected results materially
- 5 Combination O\_0.4 x3\_N at 44.75% is slightly less efficient than O\_0.5\_x3\_N at 47.03% however,
- 6 Its material quantity is less at  $(0.4 \times 3 = 1.2)$  vs  $(0.5 \times 3 = 1.5)$  i.e 20% less
- 7 Best scenario for the North façade is therefore a combination of 3 overhangs at 400mm depth and 50mm thickness
- 8 The same scenario will be tested for the east and west facades

## Results

Table 4.34: Results (C) from testing overhang scenarios (Source: Author)

East						
ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>352.46</b>	305.46	47		
2	O_0.4_x3_E	<b>230.32</b>	178.29	52.03	34.65%	
West						
ID	Combination	Total Energy (MJ/m2/yr)	Cooling	Lighting	% opt	Observations
1	Base	<b>364.27</b>	317.91	46.36		
2	O_0.4_x3_W	<b>226.74</b>	174.24	52.5	37.75%	

## Observations

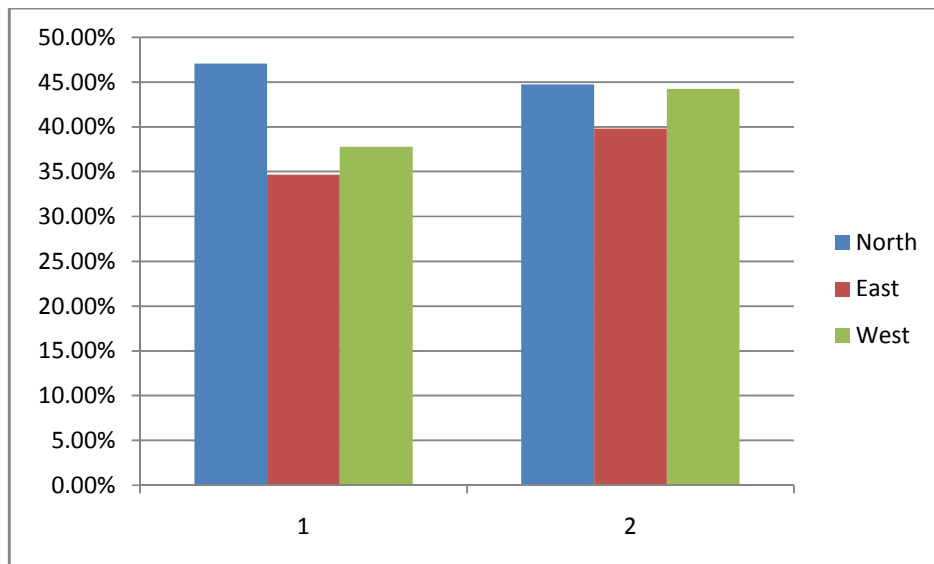


Figure 4.17: Comparison of optimal overhangs applied to all facades (Source: Author)

- 1 Combination O\_0.4 x3\_E at 34.65% is slightly less efficient than O\_0.5\_x3\_E at 39.83% however,
- 2 Its material quantity is less at (0.4x3=1.2) vs (0.5x3=1.5), i.e 20% less
- 3 Combination O\_0.4 x3\_W at 37.75% is slightly less efficient than O\_0.5\_x3\_W at 44.24% however,
- 4 Its material quantity is less at (0.4x3=1.2) vs (0.5x3=1.5) i.e 20% less

## 4.4 FINANCIAL ANALYSIS OF THE MOST OPTIMAL STRATEGIES

### 4.4.1 Energy costs

Energy costs have been derived from Eskom's annual published cost data. The rate is made up of an energy charge (c/kWh), an ancillary service charge (c/kWh) and a network demand charge (c/kWh). Business rate one has been selected since the network capacity charge and the service & administration charges are based on a daily rate and will not be affected by energy upgrades. Business rate 4 is designed for consumers who use less than 679kWh/month. (Eskom, 2016)

Table 4.35: Material Energy cost table for Eskom Business Rate 1 (Source: Eskom, 2016)

	Energy charge (c/kWh)		Ancillary service charge (c/kWh)		Network demand charge (c/kWh)		Network capacity charge (R/POD/day)		Service & administration charge (R/POD/day)	
	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.	VAT excl.	VAT incl.
Businessrate 1	88.51	100.90	0.33	0.38	12.27	13.99	R 17.60	R 20.06	R 15.07	R 17.18
Businessrate 2	88.51	100.90	0.33	0.38	12.27	13.99	R 29.67	R 33.82	R 15.07	R 17.18
Businessrate 3	88.51	100.90	0.33	0.38	12.27	13.99	R 51.27	R 58.45	R 15.07	R 17.18
Businessrate 4	238.19	271.54	0.33	0.38	12.27	13.99				

### 4.4.2 Supplier cost data analysis

This is a summary of the material supply and installation cost results obtained from suppliers and quantity surveyors. A break-down is presented in annexure 3.

Table 4.36: Material supply and installation cost summary (Source: Author)

1	<b>Roller shades</b>			
	Supply and Install (Fixed)	R 1,078.70	per sqm	incl vat
2	<b>Roller shades</b>			
	Supply and Install (Automatic)	R 2,396.21	per sqm	incl vat
3	<b>Louvres</b>			
	Supply and Install	R 2,972.46	per sqm	incl vat
4	<b>Woven mesh screens</b>			
	Supply and Install	R 2,972.46	per sqm	incl vat
5	<b>Overhangs</b>			
	Supply and Install	R 3,388.60	per sqm	incl vat

### 4.4.3 Payback

Annexure 4 elaborates on the payback calculations of all façade scenarios as it pertains to each façade.

### 4.4.4 Summary of results

#### 4.4.4.1 Years Payback if all facades are retrofitted

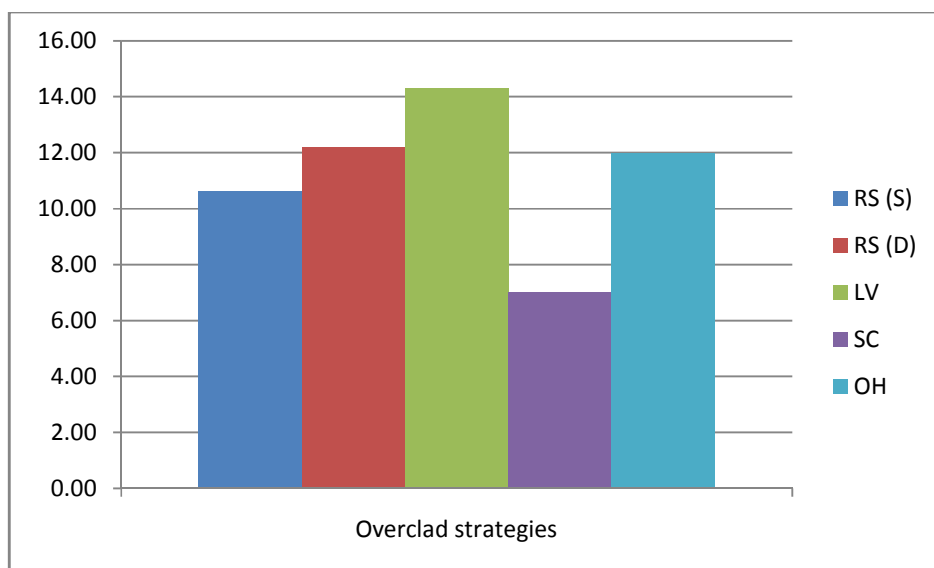


Figure 4.18: Payback period with all façades retrofitted (Source: Author)

Table 4.37: Payback period with all façades retrofitted (Source: Author)

	Payback in least amount of time	Payback		ROI
1	Mesh Screens	7.00	years	16.61%
2	Roller shades (static)	10.63	years	9.67%
3	Overhangs	12.00	years	8.36%
4	Roller shades (dynamic)	12.20	years	8.37%
5	Louvre screens	14.33	years	7.33%

Woven mesh screens present the best solution for façade over-cladding on all facades, followed by static roller shades. At a payback period of 7 years and 16,61% return on investment, mesh screens provide a feasible solution for façade retrofitting. This

compares well to the results published by Kok et al. (2012) who found that in 45.5% of the survey cases, payback was less than 5 years; 31.8% of cases had a payback of between 5 and 10 years; and in 9.1% of cases payback was more than 10 years. They noted that most of the upgrades involved high level retrofits, which consisted of basic, low cost changes, such as lighting upgrades, which typically produces a quicker payback period (Ibid). Considering the long term benefits of a DER, a 7 year payback period compares favorably.

#### 4.4.4.2 Years Payback if only the North façade is retrofitted

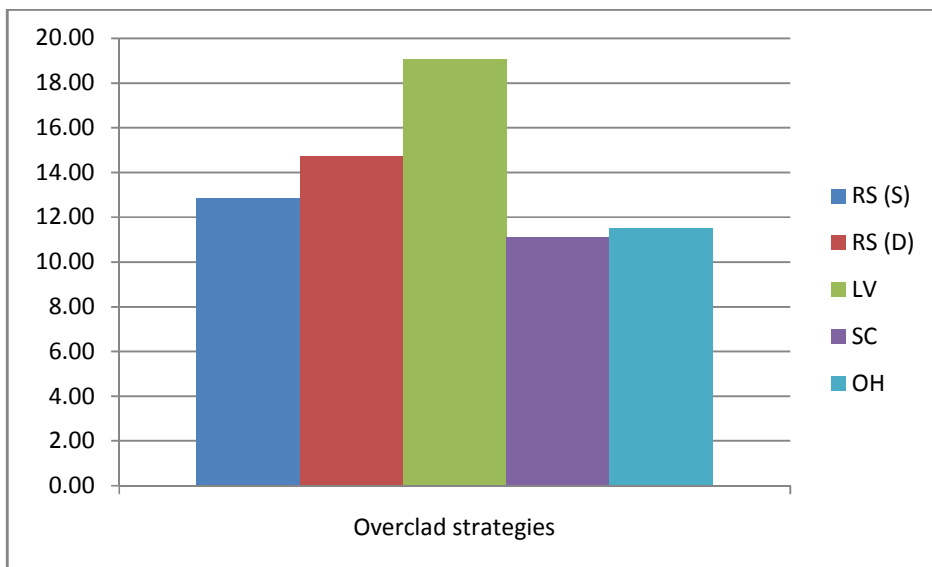


Figure 4.19: Payback period with only the north façade retrofitted (Source: Author)

Table 4.38: Payback period with only the north façade retrofitted (Source: Author)

	Payback in least amount of time	Payback		ROI
1	Mesh Screens	11.09	years	9.01%
2	Overhangs	11.53	years	8.67%
3	Roller shades (static)	12.85	years	7.78%
4	Roller shades (dynamic)	14.72	years	6.79%
5	Louvre screens	19.04	years	5.25%

The results have been isolated to determine how each solution compared to facades on an individual basis. On the north façade, mesh screens and overhangs show very

similar results. At a payback of 11 years and an ROI of 9% the results can still be considered feasible when compared to the findings of Kok et al. (2012). Some investors may not be willing to invest in upgrades with a payback period of more than 10 years, which suggests that a partial retrofit, which excludes the North façade could be considered.

#### 4.4.4.3 Years Payback if only the West façade is retrofitted

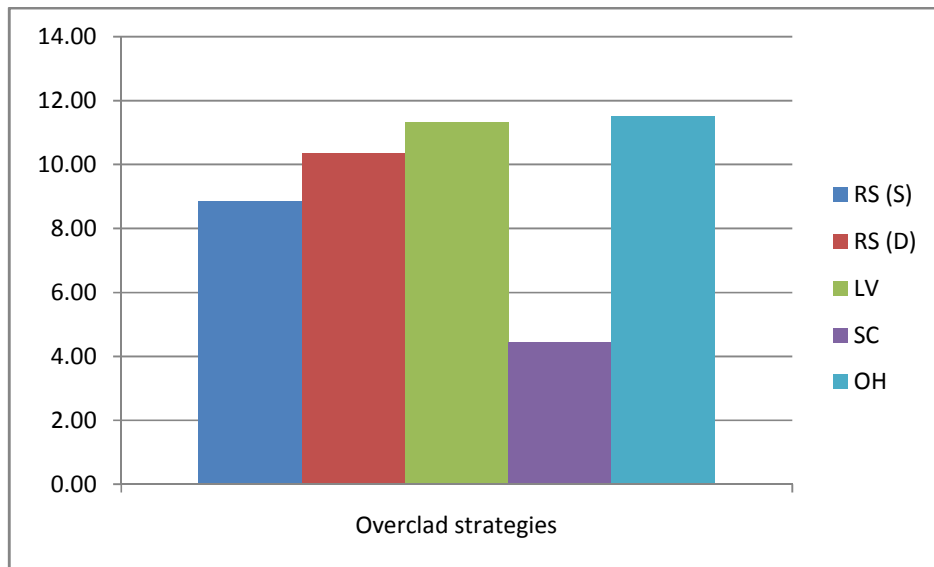


Figure 4.20: Payback period with only the west façade retrofitted (Source: Author)

Table 4.39: Payback period with only the west façade retrofitted (Source: Author)

	Payback in least amount of time	Payback		ROI
1	Mesh Screens	4.43	years	22.59%
2	Roller shades (static)	8.85	years	11.30%
3	Roller shades (dynamic)	10.35	years	9.66%
4	Louvre screens	11.33	years	8.82%
5	Overhangs	11.51	years	8.69%

Again, mesh screens have performed better than alternative over-clad strategies, and in this case by a significant margin. At a payback of 4.43 years and a ROI of 22.5%, property investors may find significant benefit in retrofitting their buildings at least

partially. Static roller shades presents another feasible option at a payback period of 8.85 years, with a ROI of 11.3%.

#### 4.4.4.4 Years Payback if only the East façade is retrofitted

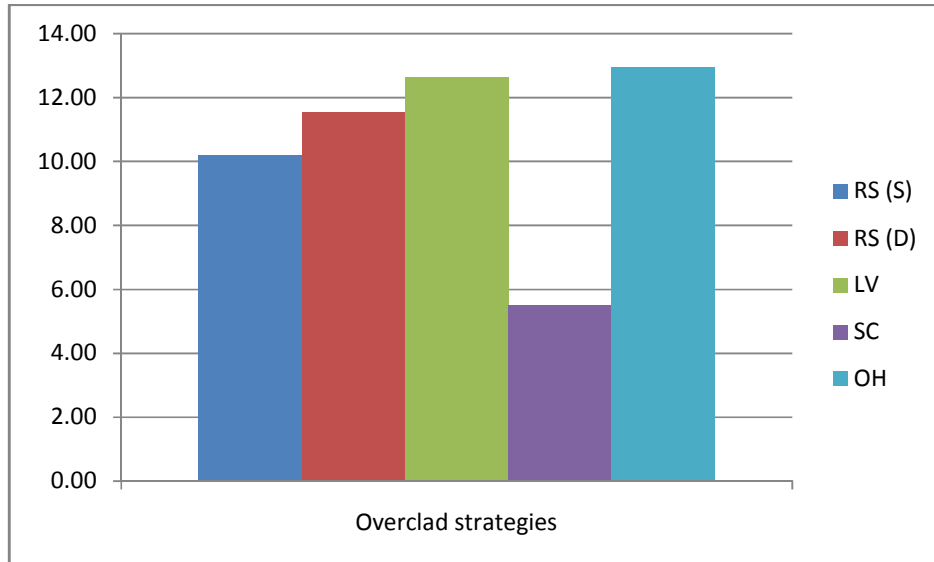


Figure 4.21: Payback period with only the east façade retrofitted (Source: Author)

Table 4.40: Payback period with only the west façade retrofitted (Source: Author)

	<u>Payback in least amount of time</u>	Payback		ROI
1	Mesh Screens	5.49	years	18.22%
2	Roller shades (static)	10.19	years	9.81%
3	Roller shades (dynamic)	11.53	years	8.67%
4	Louvre screens	12.63	years	7.92%
5	Overhangs	12.96	years	7.72%

Results for the East façade are correlated to those of the West façade, but with slightly longer payback periods.

## 4.5 SUMMARY

The iterative simulation analysis and cost inputs derived from the market suggest that DER projects that involve façade retrofits might be feasible from a financial perspective.

Considering the results published by Kok et al. (2012) there is sufficient evidence to suggest that developers are likely to show interest in long term upgrades that presents a payback period of 7 years and a return on investment of 16,6%, such as what was delivered by mesh over-cladding.

Whilst building overhangs produced a superior energy reduction compared to the other strategies, its relative cost reduced feasibility, however a payback of 12 years and ROI of 8.3% could still be considered feasible as compared to results published by Kok et al. (2012). Static roller blinds achieved a payback period of 10.6 years and ROI 9.7% when applied to all facades, which is also in line with Kok et al (2012) findings.

Upon considering the effects of each scenario as applied to each of the three facades, a more favorable outcome was achieved. When mesh screens are to be applied only to the east and west facades, a combined payback period of 5 years and a ROI of 20.4% resulted.

The cost data was gathered on an elemental basis and was applied to a hypothetical situation; also, respondents were made aware that they are not pricing for a real project and such the rates obtained can only be considered indicative. It is therefore likely that a degree of variability in results can be expected depending on the real life scenario.

The findings can therefore only be considered as indicative and further research regarding the costs of these strategies should provide valuable insight on its ultimate degree of feasibility. Furthermore, additional research of expected payback and market sentiment towards green initiatives, specifically in the Cape Town market will provide a more suitable benchmark to which these results may be tested.

As the cost of electricity continues to increase, façade over-cladding will become increasingly more feasible. When demand increases and the market becomes more

competitive, the cost of these initiatives will decrease, which is likely to lead to large scale implementation.

## **CONCLUSION AND RECOMMENDATIONS**

### **5.1 OVERVIEW**

This section will provide a short overview of the research objectives and research aim - and whether they have been met. The chapter concludes with recommendations for further research.

### **5.2 FINDINGS OF THE RESEARCH OBJECTIVES**

The objectives of the research were firstly to evaluate existing design strategies relating to building envelope design. Sufficient research was conducted, which concluded that over-cladding is likely to be the most efficient means of retrofitting the façade.

Secondly, with regards to the objective of understanding material parameters, such as performance, cost and availability; it was found through analysis, that window wall ratio and the degree of shading window openings was integral in reducing energy load. To that extent, wall cladding was not further investigated. Material parameters were tested in the simulation and cost and availability of materials was provided through market feedback.

The third aim was to investigate the physical implementation challenges embedded in envelope retrofitting. Existing tenancies, implementation challenges in CBD environments and project duration was found to be the most significant. These factors support the notion that over-cladding is more efficient than other methods, such as re-cladding or refurbishment.

Finally, the last objective was to conduct a simulation on a case study basis to implement and test the research assumption. It was found that façade retrofitting may potentially be a feasible investment, with payback periods between 5 and 19 years.

Key findings from the study show that there is sufficient evidence to suggest that developers may be motivated to invest in long term upgrades that presents a payback period of 7 years and a return on investment of 16,6%, as was demonstrated through

the application of mesh over-cladding, which is in line with the expected investment returns published by Kok et al. (2012)

The study further indicated that an overhang strategy produced superior energy reduction compared to all the other strategies. The relative cost of overhang devices however reduced its financial feasibility at a payback of 12 years and a cash-on-cash return of 8.3%. At these margins however, the result may still be considered feasible as compared to the results published by Kok et al. (2012). Additionally, static roller blinds achieved a payback period of 10.6 years and ROI of 9.7% when applied to all facades, which is also in line with Kok et al (2012) findings.

Upon considering the effects of each scenario as applied to each of the three facades, a more favorable outcome was achieved. When mesh screens are to be applied only to the east and west facades, a combined payback period of 5 years and a ROI of 20.4% resulted.

### **5.3 ACHIEVEMENT OF THE RESEARCH AIM**

The objectives of the research were:

1. To evaluate existing design strategies relating to building envelope design: Various strategies have been evaluated and through the literature, it has been determined that over-cladding is the most efficient means of facade retrofitting. Three popular methods of over-cladding have been studied further.
2. To understand material parameters, such as performance, cost and availability: These aspects have been researched and were used as variables in the simulation experiment.
3. To investigate the physical implementation challenges embedded in envelope retrofitting: These aspects have been researched and informed the notion of over-cladding being a more efficient means of facade optimisation.

4. To identify a hypothetical representative building through a case study and utilising a simulation design to implement and test the research assumption: A hypothetical building has been identified through a sampling exercise of Cape Town's medium to high-rise building stock. This model building has been used in the simulation to test the variables identified through the research.

#### **5.4 VALIDATION / REJECTION OF THE RESEARCH AIM**

The research questions that this study aimed to address were:

1. To what extent can operational savings from retrofitting the building envelope, justify the capital outlay as measured through payback required in the Cape Town market?

This question has been addressed and it has been shown that payback may be achieved in 5 years when mesh screens are applied to the east and west facades of a hypothetical building, which is representative of medium to high rise buildings in the Cape Town locale.

2. To what extent can operational savings from retrofitting the building envelope, justify the capital outlay as measured through return-on-investment required in the Cape Town market?

This question has been addressed and it has been shown that a return of investment of 20.4% may be achieved when mesh screens are applied to the east and west facades of a hypothetical building, which is representative of medium to high rise buildings in the Cape Town locale.

The research aim is therefore validated, but it is recommended that further research be conducted regarding the capital costs of façade retrofits, as well as market expectations with regard to payback periods.

#### **5.5 CONCLUSION**

The iterative simulation analysis and cost inputs derived from the market suggest that DER projects that involve façade retrofits may indeed be a valuable investment and

property owners and industry stakeholders should be encouraged to engage in such investments before considering the development of new Green Buildings. New Green Buildings may very well be energy efficient in terms of direct consumption, but the carbon footprint produced through its construction is not only damaging to the planet, but also resource inefficient on an economic level. In addition, the research have demonstrated that new Green Buildings may also yield lower returns compared to DER projects, which can potentially deliver a payback in as little as 5 years.

## **5.6 RECOMMENDATIONS**

Since the cost data that was gathered on an elemental basis and was applied to a hypothetical situation, it is likely that some degree of variability in results may be expected compared to a real life scenario. As such the findings can therefore only be considered as indicative and further market research regarding the costs of these strategies should provide valuable insight on its ultimate degree of feasibility. Furthermore, additional research of expected payback and market sentiment towards green initiatives, specifically in the Cape Town market will provide a more suitable benchmark to which these results may be tested. It is recommended that further studies be undertaken where retrofit projects are compared to new Green Buildings in a real life setting. In each case, operation costs should be recorded and tested against the project's capital outlay.

Another aspect that may affect project feasibility is a project's Green Star status and the potential effect this may have on rental income. A commercial property's value is linked to its Net Operating Income and therefore Rental Income. It is therefore recommended that further research be conducted to determine the ability of retrofitted projects to achieve Green Star status and what the potential rental premium may be. These results should be benchmarked to new Green Buildings to determine an even more calibrated comparison.

The literature revealed that Life Cycle Cost Analyses (LCCA) may indicate additional benefits when compared to an analysis which only assesses immediate return or Years Purchase. Since LCCA assesses a building's performance over a much longer term, it

considers the future benefits embedded in operational savings, maintenance savings and replacement and residual value. It was noted in the literature, that about 75% of the LCC of a building may be ascribed to its operation and maintenance stages, which highlights the significance of these studies. It is therefore recommended that further research include LCCA to determine what the total real returns of DER projects may be.

As the cost of electricity continues to increase, façade over-cladding will become increasingly more feasible. When demand increases and the market becomes more competitive, the cost of these initiatives will decrease, which will hopefully lead to implementation on a larger scale.

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# ANNEXURES

## ANNEXURE 1: CROSS-SECTIONAL OVERHANG ARRANGEMENTS

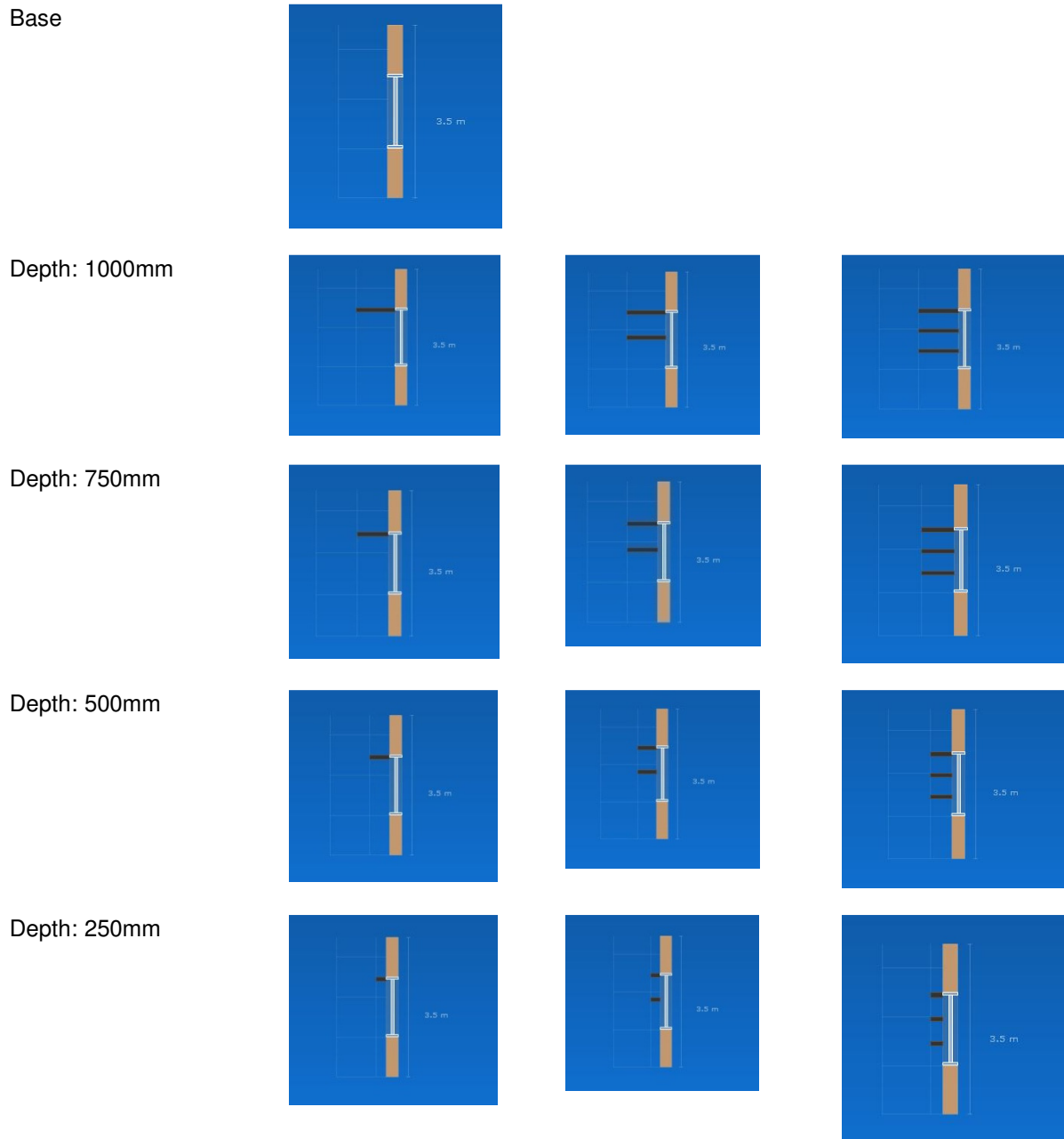
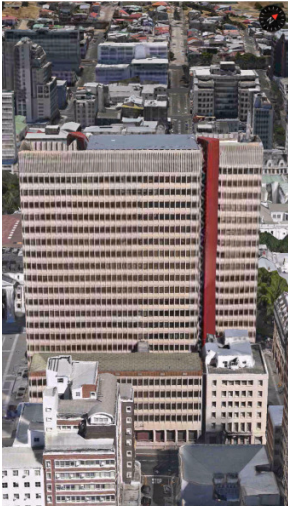


Figure 1 : Cross sectional overhang arrangements(Source: COMFEN - Energy Plus (2016) and author)

## ANNEXURE 2: CBD TALL OFFICE BUILDING, WINDOW-WALL RATIO SURVEY

1.



120 Plein Street  
COCT

WWR: 50%

2.



22 Hans Stijdom Avenue

WWR: 35%

3.



67 Strand Street

WWR: 70%

4.



9 Coen Steytler Avenue  
Metropolitan Plaza

WWR: 50%

5.



9 D.F. Malan Street  
Chevron

WWR: 40%

6.



2 Long Street

WWR: 65%

7.



20 Riebeeck Street

WWR: 35%-40%

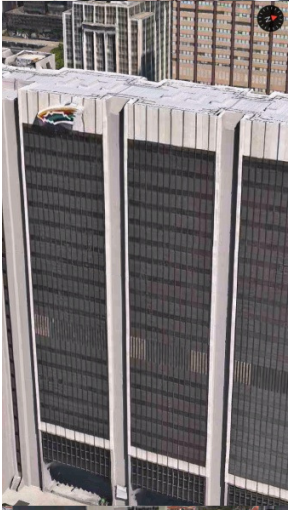
8.



44 Heerengracht Street  
Naspers

WWR: 55%

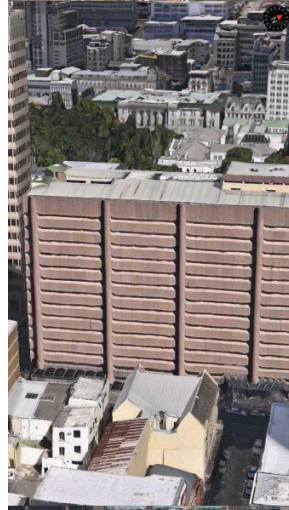
9.



12 Hertzog Blvd  
COCT

WWR: 65%

10.



0B Plein Street

WWR: 20%

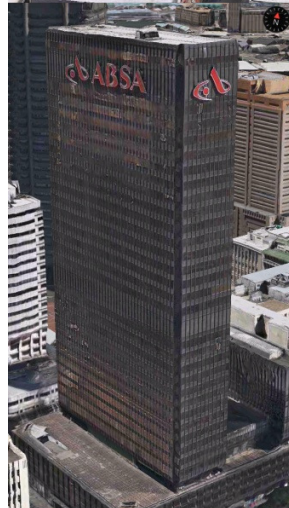
11.



17 Hans Strijdom Ave  
Standard Bank

WWR: 50%

12.



2 Riebeeck Street  
ABSA

WWR: 55%

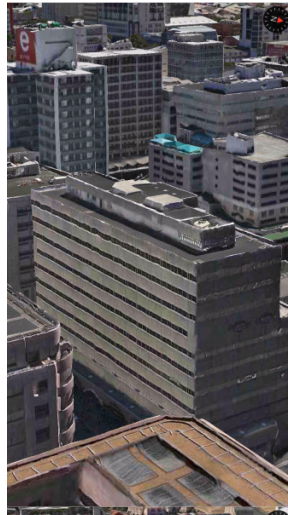
13.



2 Dorp Street (South)

WWR: 60%

14.



10 Long Street

WWR: 20%

15.



9 Riebeeck Street

WWR: 25%

16.



30 Hout Street

WWR: 0% - 45%

17.



1 Adderley Street

WWR: 35%

18.



81 Plein Street

WWR: 10% - 45%

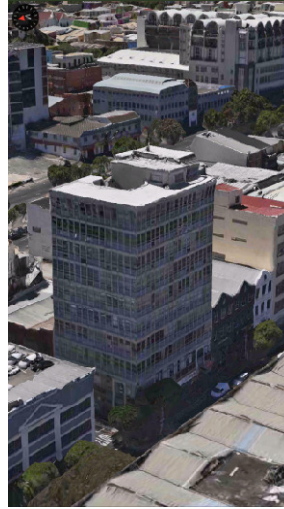
19.



2 Dorp Street (North)

WWR: 30%

20.



66 Bree Street

WWR: 45%

*Figure II: Aerial images of office buildings (Source: Google Images, 2016)*

Sampling Criteria:

Type: Office

Height: Greater than or equal to 10 storeys

Age: Older than 15 years

WWR Summary:

50%

35%

70%

50%

35% - 40%

65%

40%

55%

65%

20%

50%

55%

60%

20%

25%

0 - 45%

35%

10% - 45%

30%

45%

**Average WWR: 41%**

## ANNEXURE 3: MATERIAL COST DATA

### Roller blind rates Manual

#### Quantity Surveyor 1

General limit on roller shades is 2.5m (W) x 3.8m (H)

Price unlikely to vary if larger quantity

Cost incl Fabric, incllabour

(Spec. MermetSatine 5500, Bronze)

R 2,300.00 per sqm ex vat

(Spec. MermetSatine 5500, Pearl)

R 1,222.00 per sqm ex vat

Cost of motors (req 2/roll)

R 1,250.00 per motor ex vat

Thus 2 motors for 2.5x1.5 = 3.75

R 667.00 per sqm ex vat

#### Quantity Surveyor 2

Automatic External Roller shutter

Cost incl Fabric, incllabour

Roll-up Serranda

R 5,000.00 per sqm ex vat outlier

Manual External Roller shutter

Cost incl Fabric, incllabour

Roll-up Serranda

R 2,600.00 per sqm ex vat

#### Supplier 1

#### Supplier 2

Supply and Install (Fixed)	R 2,040.67	per sqm	incl vat
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Supply and Install (Automatic)	R 2,707.67	per sqm	incl vat
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### Louvres

#### Quantity Surveyor 1

Std size, custom will be more

Aluminium powder coated (incllabour)

R 2,500.00 per sqm ex vat

#### Quantity Surveyor 2

External Horizontal louvres (Gutco)

Aluminium powder coated (incllabour)

R 2,500.00 per sqm ex vat

#### Supplier 1

300x300	R 327.00	per unit	R 3,633.33	per sqm	incl vat	N.A
300x600	R 603.00	per unit	R 3,350.00	per sqm	incl vat	N.A
300x900	R 879.00	per unit	R 3,255.56	per sqm	incl vat	N.A

600x300	R 467.00	per unit	R 2,594.44	per sqm	incl vat	N.A
600x600	R 865.00	per unit	R 2,402.78	per sqm	incl vat	N.A
	R					
600x900	1,116.00	per unit	R 2,066.67	per sqm	incl vat	N.A
900x300	R 608.00	per unit	R 2,251.85	per sqm	incl vat	N.A
	R					
900x600	1,127.00	per unit	R 2,087.04	per sqm	incl vat	N.A
	R					
900x900	1,516.00	per unit	R 1,871.60	per sqm	incl vat	

Supply and Install	R 2,290.53	per sqm	incl vat
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### Woven Mesh Screens

#### Quantity Surveyor 1

Supply and Install	R 1,000.00	per sqm	ex vat
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#### Supplier 1

Angles	R 30.00	per meter	incl vat
1600 x 2100	R 3,203.00	per unit	incl vat
Inclusive rate	<b>R 1,020.00</b>	per sqm	incl vat

Supply and Install	R 1,010.00	per sqm	incl vat
--------------------	------------	---------	----------

### Overhangs

#### Supplier 1

##### Supply Only

	R					
NK152 profile	3,148.00	per 7.25m	R 434.21	per meter	excl vat	
Verticals at 5m CCS			<b>R 162.83</b>	per meter	excl vat	
1 horizontal at 1m depth			R 2,856.62	per meter	excl vat	
1 horizontal at 0.4m depth			R 1,142.65	per meter	excl vat	
3 horizontals at 0.4m depth			<b>R 3,427.95</b>	per meter	excl vat	
Total Supply only rate			<b>R 3,590.78</b>	per meter	excl vat	
			R 2,393.85	per sqm	excl vat	discard

##### Supply Only

NK Flat AB712 custom	R 389.14	per 6.5m	R 59.87	per meter	excl vat
Verticals at 2m CCS			<b>R 358.22</b>	per meter	excl vat
1 horizontal at 1m depth			R 1,348.37	per meter	excl vat
1 horizontal at 0.4m depth			R 539.35	per meter	excl vat
3 horizontals at 0.4m depth			<b>R 1,618.05</b>	per meter	excl vat
Total Supply only rate			<b>R 1,976.27</b>	per meter	excl vat

		R 1,317.51	per sqm	excl vat
<u>Installer 1</u>				
Labour	75% markup on cost	R 1,795.39	per sqm	excl vat
Supply and Install		R 3,548.71	per sqm	incl vat

*\*\* Rates supplied in March 2016*

## ANNEXURE 4: PAYBACK

### Static Roller Shades

Electricity rate (per Eskom)

Active Energy charge

Commercial Average R 1.15 per kWh

MJ to kWh conversion 1MJ = **0.277778** kWh

#### North Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 2,040.67

Total R 58,159.00

Additional costs R 0.00

Total cost R 58,159.00

Operational usage

Eskom rate R 1.15 per kWh

Base usage 85.21 kWh /m<sup>2</sup> / year

Revised usage 65.53 kWh /m<sup>2</sup> / year

Energy savings 19.68 kWh /m<sup>2</sup> / year

3935.56 kWh /200m<sup>2</sup> / year

Operational cost savings R 4,525.89

Payback 12.85 years

#### West Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 2,040.67

Total R 58,159.00

Additional costs R 0.00

Total cost R 58,159.00

Operational usage			
Eskom rate	R 1.15	per kWh	
Base usage	101.19	kWh /m2 / year	
Revised usage	72.62	kWh /m2 / year	
Energy savings	28.57	kWh /m2 / year	
	5713.33	kWh /200m2 / year	
Operational cost savings	R 6,570.33		
Payback	8.85	years	

---

### East Façade Only

Capital cost			
Area	28.5	m2	
Unit rate	R 2,066.67		
Total	R 58,900.00		
Additional costs	R 0.00		
Total cost	R 58,900.00		

Operational usage			
Eskom rate	R 1.15	per kWh	
Base usage	97.91	kWh /m2 / year	
Revised usage	72.78	kWh /m2 / year	
Energy savings	25.13	kWh /m2 / year	
	5026.11	kWh /200m2 / year	
Operational cost savings	R 5,780.03		
Payback	10.19	years	

---

### All facades

Payback	10.63	years	
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---

Table I: Static roller shades payback analysis (Source: Author)

## Dynamic Roller Shades

Electricity rate (per Eskom)

Active Energy charge

Commercial Average R 1.15 per kWh

MJ to kWh conversion 1MJ = **0.277778** kWh

---

### North Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 2,707.67

Total R 77,168.50

Additional costs R 0.00

Total cost R 77,168.50

Operational usage

Eskom rate R 1.15 per kWh

Base usage 85.21 kWh /m<sup>2</sup> / year

Revised usage 62.42 kWh /m<sup>2</sup> / year

Energy savings 22.79 kWh /m<sup>2</sup> / year

4557.22 kWh /200m<sup>2</sup> / year

Operational cost savings R 5,240.81

Payback 14.72 years

---

### West Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 2,707.67

Total R 77,168.50

Additional costs R 0.00

Total cost R 77,168.50

Operational usage			
Eskom rate	R 1.15	per kWh	
Base usage	101.19	kWh /m2 / year	
Revised usage	68.77	kWh /m2 / year	
Energy savings	32.42	kWh /m2 / year	
	6483.33	kWh /200m2 / year	
Operational cost savings	R 7,455.83		
Payback	10.35	years	

---

#### East Façade Only

Capital cost			
Area	28.5	m2	
Unit rate	R 2,707.67		
Total	<u>R 77,168.50</u>		
Additional costs	R 0.00		
Total cost	R 77,168.50		

Operational usage			
Eskom rate	R 1.15	per kWh	
Base usage	97.91	kWh /m2 / year	
Revised usage	68.81	kWh /m2 / year	
Energy savings	29.09	kWh /m2 / year	
	5818.33	kWh /200m2 / year	
Operational cost savings	R 6,691.08		
Payback	11.53	years	

---

#### All facades

Payback	12.20	years	
---------	-------	-------	--

---

Table II: Dynamic roller shades payback analysis (Source: Author)

## Louvres

Electricity rate (per Eskom)

Active Energy charge

Commercial Average R 1.15 per kWh

MJ to kWh conversion 1MJ = **0.277778** kWh

---

### North Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 2,290.53

Total R 65,280.25

Additional costs R 0.00

Total cost R 65,280.25

Operational usage

Eskom rate R 1.15 per kWh

Base usage 85.21 kWh /m<sup>2</sup> / year

Revised usage 70.30 kWh /m<sup>2</sup> / year

Energy savings 14.91 kWh /m<sup>2</sup> / year

2981.67 kWh /200m<sup>2</sup> / year

Operational cost savings R 3,428.92

Payback 19.04 years

---

### West Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 2,290.53

Total R 65,280.25

Additional costs R 0.00

Total cost R 65,280.25

Operational usage

Eskom rate	R 1.15	per kWh
Base usage	101.19	kWh /m2 / year
Revised usage	76.14	kWh /m2 / year
Energy savings	25.05	kWh /m2 / year
	5009.44	kWh /200m2 / year

Operational cost savings R 5,760.86

Payback 11.33 years

---

**East Façade Only**

Capital cost

Area 28.5 m2

Unit rate R 2,290.53

Total R 65,280.25

Additional costs R 0.00

Total cost R 65,280.25

Operational usage

Eskom rate	R 1.15	per kWh
Base usage	97.91	kWh /m2 / year
Revised usage	75.43	kWh /m2 / year
Energy savings	22.48	kWh /m2 / year
	4495.56	kWh /200m2 / year

Operational cost savings R 5,169.89

Payback 12.63 years

---

**All facades**

Payback 14.33 years

---

*Table III: Louvres payback analysis (Source: Author)*

## Overhangs

Electricity rate (per Eskom)

Active Energy charge

Commercial Average R 1.15 per kWh

MJ to kWh conversion 1MJ = **0.277778** kWh

---

### North Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 3,548.71  
R

Total 101,138.10

Additional costs R 0.00

Total cost R  
101,138.10

Operational usage

Eskom rate R 1.15 per kWh

Base usage 85.21 kWh /m<sup>2</sup> / year

Revised usage 47.08 kWh /m<sup>2</sup> / year

Energy savings 38.13 kWh /m<sup>2</sup> / year

7626.67 kWh /200m<sup>2</sup> / year

Operational cost savings R 8,770.67

Payback 11.53 years

---

### West Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 3,548.71  
R

Total 101,138.10

Additional costs R 0.00

Total cost R101,138.10

Operational usage

Eskom rate	R 1.15	per kWh
Base usage	101.19	kWh /m2 / year
Revised usage	62.98	kWh /m2 / year
Energy savings	38.20	kWh /m2 / year
	7640.56	kWh /200m2 / year

Operational cost savings R 8,786.64

Payback 11.51 years

---

**East Façade Only**

Capital cost

Area 28.5 m2

Unit rate R 3,548.71

R

Total 101,138.10

Additional costs R 0.00

R

Total cost 101,138.10

Operational usage

Eskom rate	R 1.15	per kWh
Base usage	97.91	kWh /m2 / year
Revised usage	63.98	kWh /m2 / year
Energy savings	33.93	kWh /m2 / year
	6785.56	kWh /200m2 / year

Operational cost savings R 7,803.39

Payback 12.96 years

---

**All facades**

Payback 12.00 years

---

Table IV: Overhangs payback analysis (Source: Author)

## Woven mesh screens

Electricity rate (per Eskom)

Active Energy charge

Commercial Average R 1.15 per kWh

MJ to kWh conversion 1MJ = **0.277778** kWh

---

### North Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 1,010.00

Total R 28,785.00

Additional costs R 0.00

Total cost R 28,785.00

Operational usage

Eskom rate R 1.15 per kWh

Base usage 85.21 kWh /m<sup>2</sup> / year

Revised usage 73.93 kWh /m<sup>2</sup> / year

Energy savings 11.28 kWh /m<sup>2</sup> / year

2256.11 kWh /200m<sup>2</sup> / year

Operational cost savings R 2,594.53

Payback 11.09 years

---

### West Façade Only

Capital cost

Area 28.5 m<sup>2</sup>

Unit rate R 1,010.00

Total R 28,785.00

Additional costs R 0.00

Total cost R 28,785.00

Operational usage

Eskom rate	R 1.15	per kWh
Base usage	101.19	kWh /m2 / year
Revised usage	72.91	kWh /m2 / year
Energy savings	28.28	kWh /m2 / year
	5655.00	kWh /200m2 / year

Operational cost savings R 6,503.25

Payback 4.43 years

---

**East Façade Only**

Capital cost

Area	28.5	m2
Unit rate	R 1,010.00	
Total	<u>R 28,785.00</u>	
Additional costs	R 0.00	
Total cost	R 28,785.00	

Operational usage

Eskom rate	R 1.15	per kWh
Base usage	97.91	kWh /m2 / year
Revised usage	75.10	kWh /m2 / year
Energy savings	22.80	kWh /m2 / year
	4560.56	kWh /200m2 / year

Operational cost savings R 5,244.64

Payback 5.49 years

---

**All facades**

Payback 7.00 years

---

*Table V: Woven mesh screens payback analysis (Source: Author)*

## ANNEXURE 5: STATISTICAL SIGNIFICANCE

### Roller shades

	Factors	p-values
1	auto	0.000525151
2	col	0.52472548
3	col:auto	0.631551645
4	col:dist	0.296844311
5	col:dist:auto	0.559667205
6	dist	0.060463657
7	dist:auto	0.309154825
8	thick	0.650125392
9	thick:auto	0.837421656
10	thick:col	0.357011622
11	thick:col:auto	0.688031516
12	thick:dist	0.495206026
13	thick:dist:auto	0.989830669

*Table VI: Significance of roller shade variables (Source: Author)*

\* Automation is the most significant variable, followed by distance

\*\* 3,4,5,7,9,10,11,12,13 shows significance of interaction

### Overhangs

	Factors	p-values
1	number	0.00000000247
2	depth	0.000001928578
3	depth:number	0.000600847511
4	orientation	0.005116940366
5	number:orientation	0.008673493933
6	depth:number:orientation	0.026480522143
7	depth:orientation	0.091362351540

*Table VII: Significance of over hang variables (Source: Author)*

\* Number is the most significant variable, followed by depth. All the factors in this table are significant at the 0.5% level

\*\* 3,5,6,7 shows significance of interaction

## Louvres

	Factors	p-values
1	width	5.06E-07
2	spacing	3.59E-18
3	width:orientation 0	6.4E-05
4	width:orientation 1	0.792405
5	width:spacing:orientation 0	0.523798

*Table VIII: Significance of louvre variables (Source: Author)*

\* Spacing is the most significant variable, followed by width

\*\* 3,4,5 shows significance of interaction