UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Building Resilience in Urban Areas: Exploring Climate Change Adaptation Strategies for Buildings in urban areas of Tshwane, South Africa

RESEARCH REPORT

Author: McClay Thikusho

u24028356

Supervisor: Abrie Vermeulen

Module co-ordinators: Dr Ida Breed, Dr Carin Combrinck

Department of Architecture

Faculty of Engineering, the Built Environment, and Information Technology

University of Pretoria

South Africa

28 June 2024

© University of Pretoria

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

DECLARATION OF ORIGINALITY

I declare that the mini-dissertation, Building Resilience in Urban Areas: Exploring Climate Change Adaptation Strategies for Buildings in urban areas of Tshwane South Africa, which has been submitted in fulfilment of part of the requirements for the module of Design Investigative Treatise (DIT 801), at the University of Pretoria, is my own work and has not previously been submitted by me for any degree at the University of Pretoria or any other tertiary institution.

I declare that I obtained the applicable research ethics approval in order to conduct the research that has been described in this dissertation.

I declare that I have observed the ethical standards required in terms of the University of Pretoria's ethic code for researchers and have followed the policy guidelines for responsible research.

Signature: ……

Date: 28 – 06 - 2024 ……

 © University of Pretoria

Abstract:

The issues pertaining to the changing climatic conditions on the landscape demand urgent measures to enhance resilience of new building infrastructure and already existing buildings, particularly in Tshwane, South Africa, which are vulnerable to extreme weather events. This research focuses on investigating building technologies as climate adaptation strategies for multi-story apartment buildings in Tshwane, South Africa, where regular and severe heat surges create substantial challenges. By addressing the research problem of enhancing thermal adaptive capacity, the study intends to recognize technologies and strategies that can serve as interventions towards adapting to the changes in climatic conditions. Through a thorough analysis of selected case studies, the research examines how these building technologies aid in local climate adaptation strategies, specifically targeting their potential for improving thermal amelioration.

The study examines the methods used to evaluate the thermal adaptive capacity of these technologies, analyses their reported outcomes, efficiencies, benefits, and shortcomings, and examines material and technical considerations associated with their implementation.

The findings from this investigation aim to provide valuable guidance for enhancing the resilience of multi-story residential buildings in South African urban areas, particularly within the context of Tshwane's climate conditions.

Keywords: Climate change adaptation strategies, building technologies, thermal comfort, thermal response, façade systems

 © University of Pretoria

Table of Contents

Chapter 1: Introduction 7
1.1 Background 8
1.2 Research problem 9
1.3 Research questions 9
Chapter 2: Literature Review 10
2.1 Introduction 10
2.2 The Global Crisis of Climate Change 11
2.3 Rapid urbanisation and growing susceptibilities 12
2.4 Approaches for Adapting to Climate Change Using Building Technology/Climate Change Adaptation Strategies 12
2.5 Implemented Climate adaptive building technologies and strategies 16
2.6 Methods for Assessing Thermal Adaptive Capacity 18
2.7 Reported Outcomes, Efficiencies, Benefits, and Shortcomings 19
2.8 Material and Technical Considerations 20
2.9 Summary of literature reviewed 21
Chapter 3: Research Methodology 22
3.1 Research paradigm 22
3.2 Study area 24
3.3 Data capture and collection 24
3.4 Data Analysis 25
Chapter 4: Results 31
4.1 Introduction 31
4.2 Descriptive Statistics of Case Studies 31
4.3 Thermal Comfort Strategies 56
4.4 Facade Systems 57
4.5 Climate Adaptation Strategies 61
4.6 Quantitative Analysis 62
4.7 Qualitative Analysis 65
4.8 Synthesis of Findings 68
Chapter 5: Discussion 69
5.1 Interpretation of Results 69
5.2 Comparison of Facade Systems 70
5.3 Performance Evaluation 70
5.4 Comparative Analysis and Performance Metrics 70

© University of Pretoria

5.5 Recommendations for Climate-Specific Facade Selection 70
5.6 Future Research Directions 71
5.7 Summary of discussion 71
Chapter 6: Conclusion 71
Chapter 7: References 73
Annexure 1....93

Table of Figures

Unless otherwise specified, all figures are created by the author.

Figure 1: Köppen-Geiger climate classification, map of Africa (Peel et al., 2007). 9
Figure 2: Climate classification criteria (Peel et al., 2007). 25
Figure 3: Köppen-Geiger climate classification of all regions (Peel et al., 2007). 26
Figure 4: Greef façade system section and plan view (Widiastuti et al., 2020). 57
Figure 5: Façade system performance in Cwa climate region (Author, 2024). 58
Figure 6: Façade system performance in Cwb climate region (Author, 2024). 59
Figure 7: Façade system performance in Bsh climate region (Author, 2024). 59
Figure 8: Façade system comparison in cwa, cwb and bsh climate region (Author, 2024). 60
Figure 9: Spider chart comparison (Author, 2024). 60
Figure 10: Types of green façade systems direct and DSF (Hunter et al., 2013). 63
Figure 11: Green façade Variations (Hunter et al., 2013). 63
Figure 12: Green Façades Microclimate parameters and its effects on the thermal environment (Hunter et al., 2013). 64
Figure 13: Newton's law of cooling (Convertino et al., 2019). 64
Figure 14: Green Façades testing and experiment (Convertino et al., 2019). 65
Figure 15: DSF setup (Ghaffarianhoseini et al., 2016). 66
Figure 16: Heat transmission and airflow and in a ventilated DSF system (Ghaffarianhoseini et al., 2016). 67
Figure 17: How heat is transferred when it circulates in a naturally ventilated DSF (Ghaffarianhoseini et al., 2016). 67

List of Tables

Unless otherwise specified, all tables are created by the author.

 © University of Pretoria

Table 1. Table summarising the key definitions (Author, 2024). 10
Table 2. Table summarising the research design (Author, 2024). 23
Table 3. Table summarising list of case studies (Author, 2024). 31
Table 4. Table of details of case studies (Author 2024). 32
Table 5. Table of detailed case study 1 analysis (DaEncarnacao, 2024). 34
Table 6. Table of detailed case study 2 analysis (DaEncarnacao, 2024). 36
Table 7. Table of detailed case study 3 analysis (DaEncarnacao, 2024). 39
Table 8. Table of detailed case study 4 analysis (DaEncarnacao, 2024). 41
Table 9. Table of detailed case study 5 analysis (DaEncarnacao, 2024). 44
Table 10. Table of detailed case study 6 analysis (Sibisi, 2024). 45
Table 11. Table of detailed case study 7 analysis (Sibisi, 2024). 47
Table 12. Table of detailed case study 8 analysis (Sibisi, 2024). 48
Table 13. Table of detailed case study 9 analysis (Sibisi, 2024). 49
Table 14. Table of detailed case study 9 analysis (Sibisi, 2024). 51
Table 15. Table of detailed case study 11 analysis (Author, 2024). 52
Table 16. Table of detailed case study 12 analysis (Author, 2024). 53
Table 17. Table of detailed case study 13 analysis (Author, 2024). 54
Table 18. Table of detailed case study 14 analysis (Author, 2024). 54
Table 19. Table of detailed case study 15 analysis (Author, 2024). 55
Table 20. Annexure table (Author, 2024). 92

List of Abbreviations

Alternative Building Technologies – ABTs

Analytical Hierarchy Process – AHP

Building Information Modelling – BIM

Building Integrated Photovoltaics – BIPV

Climate Adaptive Building Shells – CABS

Carbon dioxide – CO_2

Computational Fluid Dynamics – CFD

Double Skin Façade – DSF

Green Building Council of South Africa – GBCSA

Heating, Ventilation, and Air Conditioning – HVAC

Information and Communication Technology – ICT

 © University of Pretoria

Internet of Things – IoT

Intergovernmental Panel on Climate Change – IPCC

Leadership in Energy and Environmental Design – LEED

Life Cycle Assessment – LCA

Nationally Determined Contributions – NDCs

Degrees Celsius – ^{O} C

Phase Change Materials – PCMs

Republic of South Africa – RSA

Sandbag Building Technologies – SBTS

United Nations Framework on Convention on Climate Change – UNFCCC

United Nations Statistics Division – UNSD

 © University of Pretoria

Chapter 1: Introduction

The start of the Industrial revolution, in the 18th century indicated a significant turning point in mankind's history bringing forth a period known for technological progress, population growth and increased use of resources. As we enter new centuries there has been a growing awareness of how human actions have impacted the environment. This includes concerns such as pollution, improper disposal of waste, climate change, resource depletion, overflowing landfills and widespread deforestation (Johnston et al., 2016; Hong et al., 1994).

During the Industrial revolution the widespread utilisation of fossil fuels led to challenges like air and water pollution and soil degradation (Hong et al., 1994). The burning of these fuels resulted in the emission of greenhouse gases that changed weather patterns and contributed to global warming, which primarily is caused by human activities (Dally et al., 2022). Greenhouse gases become trapped in the atmosphere and affect temperatures. These gases include methane, CO_2, nitrous oxide and hydrocarbons (Meng et al., 2024). The impact of greenhouse gases on the climate system has had effects on factors such, as water availability, agricultural productivity and energy consumption (Mehrotra & Mehrotra, 1995).

Climate change is recognized as an issue, in today's world impacting both the environment and society (UNSD, 2016). It refers to changes in weather patterns caused by actions that affect the atmosphere over time (UNSD, 2016). While human actions have contributed to climate change and natural processes like solar radiation variations, volcanic eruptions and internal climate changes have also historically influenced the earth's climate (Jay et al., 2018). However, the rapid pace and severity of climate change are primarily accounted for by human made factors (Dally et al., 2022). This applies similarly in places like South Africa, where climate change has caused fluctuation in temperatures and rainfall patterns.

The repercussions brought about by climate change includes the increase of global temperatures, rainfall patterns which have adverse effects on crop yields, water availability and the quality of the soil posing significant challenges to agriculture productivity and food security (Arnell & Freeman, 2021), the rise in sea levels which is also mainly because of the melting of the polar ice caps with increased global temperatures (Thompson, 2010). Approximately one-third of the total sea level has risen since 1990 and is linked to ice caps melting (Baqi & Abbas, 2021).

The effect of climate change is worsening the occurrence of calamities and severe weather conditions. The increasing global temperatures are amplifying the strength and occurrence rate of phenomena, like hurricanes, forest fires and heatwaves (Spence et al., 2011). Such catastrophes have the potential to result in loss of lives, destruction of property, relocation of communities and disturbances, to infrastructure. Climate adaption technologies have been adapted to address challenges posed by rising temperatures, and climate effects.

Policies, agreements, regulations, and frameworks were developed to address the issues raised by climate change. Some of these were the UNFCCC, the Kyoto Protocol, which later was superseded by the Paris agreement, the IPCC, and the National Climate Change Response White Paper which outlines RSA's strategy for addressing climate change.

© University of Pretoria

1.1 Background

The city of Tshwane has tremendously transformed over time due to factors such as urbanisation and societal shifts. The growth and evolution of cities have been significantly impacted by industrialisation, technological advancements, and globalisation. During the expansion and advancement of cities it has been observed that the construction industry stands out as a consumer of energy resulting in notable environmental repercussions and contributing significantly to climate change. The sector's heavy reliance on renewable energy sources further amplifies its environmental impact (Burciaga, 2020). According to Chuai et al. (2015) the built environment accounts for 40% to 50% of utilisation of energy leading to heightened human induced emissions of greenhouse gases.

Throughout history cities have experienced changes as planning has adapted to tackle different challenges and possibilities. Majority of the world's population currently living in cities, the trend of urbanisation has been a rapidly developing phenomenon (Orsini et al., 2013). The shift of people from rural areas to urban environments is known as urbanisation (Sanyaolu & Sanyaolu, 2018). The rapid expansion of urban areas along with issues associated with changing climatic conditions present both challenges and opportunities for urban expansion. The impacts of warming and urban factors on climate change within cities are extensive as projections indicate a rise in city residents by 2050 due to urbanisation. Understanding phenomena like the heat island effect and aerosol dynamics in settings is crucial, in addressing these issues (McCarthy et al., 2010).

Human activities, particularly the emission of heat-trapping gases, have already led to a warming of the climate by approximately 1.1^{o} C, and within a few decades from worldwide yearly temperatures forecasted to increase or surpass the 1.5^{o} C, and this will affect all life on earth (IPCC, 2021).

Buildings and urban environments endure elevated temperatures in comparison with neighbouring rural areas, because of urbanisation, land use changes, and the built environment. Therefore, it becomes necessary to reinvent cities with sustainable means to tackle the effects of heat-affected urban areas and temperature surges (Li & Bou-Zeid, 2013).

Climate adaptation technologies therefore have become a very crucial aspect in dealing with issues of changing climatic conditions. Effective climate adaptation technologies and strategies could greatly advance the indoor climate efficiency of developments under both current and future climate conditions in Tshwane (Dodoo, 2020). With the increasing impacts of climate change, it is essential to enhance the resilience of buildings to severe changing weather patterns. Climate change adaptation in urban settings proves particularly challenging especially in severely congested areas, where adjustments and alterations to the urban structure is difficult compared to newly built areas (Tamminga et al., 2020). By adapting climate adaptation technologies to the conditions of the climate, an elevated amount of safety can be attained, by reducing the consequences of the changing climatic conditions (Milinković et al., 2020).

The changing climatic conditions is a reality, and it is actively taking place. To live comfortably in buildings and urban areas it is imperative to adapt to climate adaptation technologies to decrease high temperatures thereby benefiting public health (Arellano & Roca, 2022).

As a result of the obstacles stemming from the changing climatic conditions, this study will investigate building technologies that can be utilised as an adaptation strategy towards the

© University of Pretoria

changing climatic conditions to enhance capacity for adapting to the changing climates and enhancing the ability of buildings to effectively regulate temperature in Tshwane, South Africa. To identify building technologies for climate adaptation purposes, it is essential to examine areas with climate patterns similar to Tshwane. The Köppen Geiger classification system will be utilised for this purpose, as it groups regions with similar climates together and offers insights into the types of building technologies that can be employed to enhance the thermal adaptability of structures in Tshwane, South Africa.

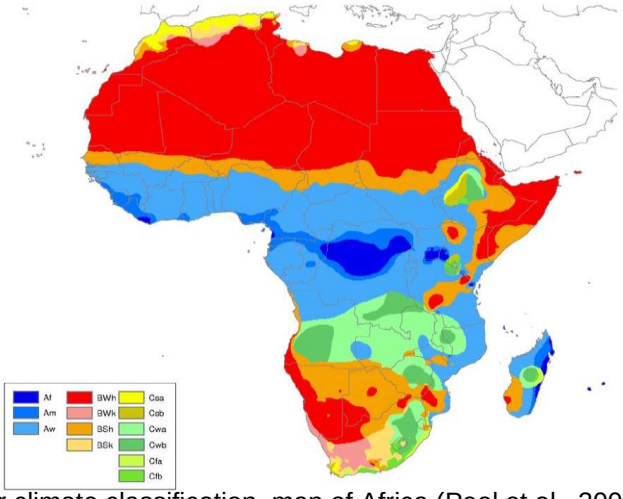


Figure 1: Köppen-Geiger climate classification, map of Africa (Peel et al., 2007).

1.2 Research problem

The study strives to tackle the challenges of enhancing multi story building apartment's thermal ability in cities in the South African region, particularly in efforts towards responding to the increasing variation and intensity of heatwaves and other issues of the changing climatic conditions. With Southern Africa being particularly vulnerable to variations in climate and heat stress, there is a pressing need to identify and document architectural interventions that serve as examples of building technologies employed for climate change adaptation.

This research problem seeks to investigate how these implemented building technologies contribute to local climate adaptation strategies, specifically targeting thermal amelioration potential. Additionally, the study aims to explore the techniques that are utilised to evaluate the thermal ability of technologies to analyse their achievements, advantages, efficacies, benefits, and weaknesses, and examine their material and practical considerations associated with their implementation. Through this investigation, the research seeks to provide insights into viable strategies for enhancing the resilience of multi-storey residential buildings in South African urban areas, particularly in the context of the Tshwane climate conditions (Vermeulen, 2024).

1.3 Research questions

How do architectural building technologies utilised in specific case studies aid local climate adaptation strategies focused on improving thermal comfort (Vermeulen, 2024)?

1.3.1 Sub questions

1. What techniques are employed to assess the thermal adaptive capacity of the building technology (Vermeulen, 2024)?

2. What are the reported results, efficiencies, advantages, and limitations of the building technology (Vermeulen, 2024)?

3. What are the material and technical factors to consider of the building technology (Vermeulen, 2024)?

© University of Pretoria

Chapter 2: Literature Review

2.1 Introduction

One of the most critical global challenges facing us today is the issue of climate change, associated with vast devastating consequences on the environment and human society. These actions mainly involve the burning of fuels, deforestation and industries releasing greenhouse gases into the Earth's atmosphere. This leads to warming as greenhouse gases trap heat in the air resulting in temperatures rising, melting ice caps and glaciers, increasing sea levels and intensified weather events like hurricanes and droughts (O'Brien, 2018). The consequences of changing climates on urban areas are considerable, affecting sectors such as urban settlement, biodiversity, agriculture, the health and well-being of people (Ziervogel et al., 2014). Climate change technologies are crucial for adapting to climate impacts, promoting sustainability, enhancing resilience, creating economic opportunities, and fostering global cooperation (Ziervogel et al., 2016).

Strategies for adaptation towards climate change, therefore, become crucial in enhancing urban spaces to withstand the impact of the changing climatic conditions. Without effective adaptation strategies, cities face difficulties in maintaining essential services, ensuring public safety, and promoting sustainable development (Scharf & Kraus, 2019). By implementing adaptation measures and proper planning, cities can reduce vulnerabilities, avoid risks, and build capacity to withstand future challenges (Oluoko-Odingo, 2019).

The building technologies that are used as climate change adaptation strategies are active and passive systems, façade systems, thermal mass systems, roof systems and window systems. For this discourse, however, we will be focusing on façade systems.

In the perspective of architectural building technologies and thermal adaptation strategies, it is important to define key concepts such as thermal comfort, building envelope, and facade systems.

Concept	**Definition**
Thermal Comfort	The feeling of contentment with the temperature conditions, which is affected by elements like air temperature, humidity, radiant heat, air movement, and the level of clothing insulation (Frontczak et al., 2011: 925).
Building Envelope	The physical barriers that isolate the indoor from the external conditioned environment, including walls, roofs, windows, and doors (Oral et al., 2004).
Facade Systems	They provide an essential function in regulating heat transfer and controlling daylight penetration. They include elements like ventilation strategies, insulation shading devices and glazing designed to optimise thermal performance and enhance occupant comfort (Romano et al., 2018).

Table 1. Table summarising the key definitions (Author, 2024).

© University of Pretoria

To construct a comprehensive national adaptation strategy, it is essential to integrate findings from climate science, impact and vulnerability assessments, and evaluation of diverse adaptation options (Ziervogel et al., 2014).

In structuring the literature review, it begins with an introductory paragraph that highlights the urgency in managing the global crisis of the changing climate. The subsequent sections address various aspects connected to the changing climate, including the global crisis of the changing climate, rapid urbanisation and growing susceptibilities, climate change adaptation strategies, the implemented climate adaptive building technologies and strategies in place, methods for assessing thermal adaptive capacity, reported outcomes, efficiencies benefits and shortcomings, material and technical considerations, and finally, the conclusion of the literature review. This structured approach presents a complete examination of adaptability to changes in climatic circumstances and seeks to provide an understanding on how building technologies can enhance thermal comfort amidst the changing climate.

2.2 The Global Crisis of Climate Change

2.2.1 The Present State of Climate Change

The present state of the changing climate is a matter of concern, closely linked to issues primarily caused by human actions (O'Brien, 2018). Human actions, particularly through the emission of greenhouse gases, have undeniably been attributed to the issue of climate change. Global greenhouse gas emissions have been on the rise due to practices in energy consumption, land management, and human consumption patterns (IPCC, 2023). According to Busch (2015) developed countries are significantly accountable for this crisis, responsible for 79% of carbon emissions. The continuation of these practices exacerbates disparities in emissions between nations, within nations, and among individuals (IPCC, 2023).

2.2.2 United Nations Framework Convention on Climate Change

The UNFCCC is one of the earliest efforts established to tackle combat climate change. Established in 1992, it primarily targets preventing high amounts of greenhouse gas emanations from disrupting the climate (UNFCCC, 1992). The UNFCCC has been pivotal in promoting the progression and utilisation of carbon capture technologies to tackle the concerns of the changing climate (Rimmer, 2019). Efforts within the UNFCCC have focused on enhancing adaptation strategies and handling the movement of people in the era of the changing climate (Warner, 2013).

2.2.3 The Kyoto Protocol

The Kyoto Protocol, as the first multilateral attempt to cap carbon emissions, has exerted a significant role in shaping global climate change governance (Aichele & Felbermayr, 2012). It includes specific obligations for industrialised nations to reduce the emissions of greenhouses compared to 1990 levels (Arrouays et al., 2006). The effectiveness of the Kyoto Protocol has been a subject of debate, with studies evaluating its impact on CO_2 emissions and global temperature (Grunewald & Martínez-Zarzoso, 2015).

2.2.4 The Paris Agreement

The Paris Agreement was adopted in December of 2015, encourages, and supports nations in transitioning towards carbon neutrality (Rogelj et al., 2016). Its main purpose is to reduce rising temperatures to lower than 2^{o} C above pre-industrial levels and to reduce its increment

© University of Pretoria

to 1.5^{o} C. The agreement stresses on the value of NDCs and global stock takes to review progress towards the goals (Paris Agreement, 2016).

2.2.5 Intergovernmental Panel on Climate Change

The IPCC offers evaluations of changes in climate sciences, effects, adaptation, and mitigation strategies (IPCC, 2021). It exerted a critical role in shaping climate strategies through its assessment reports, which underscore the pressing nature of dealing with climate change and the necessity for unified international efforts (Reckermann et al., 2008).

2.2.6 National Climate Change Response White Paper

The National Climate Change Response White Paper serves as a roadmap for RSA's approach to addressing the changes in climatic conditions and transitioning towards a climate-resilient economy and society (White Paper, 2011). It details the country's strategies for managing the issues of changes in climate and lowering CO_2 emissions.

2.3 Rapid urbanisation and growing susceptibilities

Urbanisation is a process marked by the expansion of cities in relation to their size, population density and diversity often accompanied by factors, like population mobility, segregation and industrial growth. It is mainly driven by economic growth and the shift towards service sectors (Kolimenakis et al., 2021).

Urbanisation has implications for strategies aimed at addressing climate change. As cities expand, they can worsen temperatures contributing to the heat island effect and impacting regional climate patterns (Solecki et al., 2005). The process of urbanisation can result in alterations to land cover, the release of pollutants and changes to ecosystem services, all of which are drivers to climate change (Mortoja & Yigitcanlar, 2020).

One key effect of urbanisation is its influence on CO_2 emissions. While higher urban density can bring cost efficiencies and lower pollution levels its overall impact on emissions is complex (Shahbaz et al., 2016). In terms of ecology urbanisation contributes to biodiversity loss resulting in declines in bird species diversity and disruptions in plant pollinator relationships (Sol et al., 2014). Economically urbanisation promotes development influencing productivity and business growth (Wu et al., 2022). It also leads to shifts in land usage patterns, fragmentation of open spaces and presents sustainability challenges (Yu, 2024; Anarfi et al., 2020).

Sustainable growth of cities is vital amidst their expansion, tackling challenges like environmental degradation, social disparities and economic uncertainties (Pongruengkiat et al., 2023). Managing urban areas requires attention to problems such as slums, traffic congestion, waste disposal and pollution (Syaodih, 2019). Government bodies and environmental organisations are crucial in promoting sustainable urban development (Iwan & Poon, 2018). With the rise of areas and shifting demographics it becomes imperative to implement sustainable strategies to counter the negative impacts of rapid urban growth (Lwasa, 2014).

2.4 Approaches for Adapting to Climate Change Using Building Technology/Climate Change Adaptation Strategies

2.4.1 Importance of thermal adaptive capacity in adapting to climate change

© University of Pretoria

The capacity for thermal adaptiveness is a pivotal aspect in adapting to the changes in climate in buildings and urban spaces. The deepening of these climatic changes requires an increasing degree of readiness and adaptation techniques to lessen societal susceptibility to excessive heat in urban areas (Wilhelmi & Hayden, 2010). Buildings that are designed to moderate temperatures and allow airflow between them in order to facilitate adaptability to greater temperatures while also maintaining density (Hamin & Gurran, 2009).

Urban green spaces can positively impact the microclimate environment by mitigating effects of the elevated urban temperatures, contributing to thermal amelioration potential and adaptation in urban settings (Yin et al., 2021).

Understanding and enhancing thermal adaptive capacity in buildings and urban spaces is essential for effectively addressing climate change challenges. By integrating climate-responsive design principles and urban greening strategies, cities can absorb, react, recover, adapt, and reorganise in response to climate phenomena, ultimately raising the resilience of the urban populations towards the changes in climate issues.

Optimising the thermal efficiency of urban planning and incorporating adaptation measures can help prepare urban areas to better cope with local climatic conditions and reduce risks associated with climate change consequences (Mahmoud & Ghanem, 2019).

The thermal adaptive capacity in adapting to the changes in climate in buildings and urban spaces lies in its ability to enhance resilience and improve thermal comfort in the face of changing climatic conditions. By Incorporating adaptive strategies, climate-responsive design, and urban greening initiatives, cities can better prepare for and address the issues posed by climatic changes, creating a more sustainable built environment.

2.4.2 The role of building technologies in improving thermal comfort

Building technologies are essential for improving thermal amelioration potential in buildings. Dear and Brager (2002) mention that incorporating adaptive comfort research findings into building standards to enhance thermal amelioration potential in naturally ventilated buildings is important. Additionally, Krawczyk and Krakowiak (2021) compares thermal amelioration tests in modern and traditional buildings, highlighting the role of design choices and building technologies in optimising thermal comfort.

Ismail (2021) discusses that Innovative approaches focus on integrating ICT-based solutions like BIM and the IoT to enhance thermal comfort practices in precast concrete building projects. Guichard et al. (2015) discusses that the utilisation of PCM’s in building envelopes demonstrate how advanced materials can improve thermal energy storage and enhance thermal comfort within buildings.

Moreover, Coley et al. (2012) discusses the importance of construction developments and behavioural adaptations in safeguarding buildings from elevated temperatures, emphasising the need for a holistic approach that combines technological advancements with user behaviours to ensure optimal thermal comfort in buildings. By leveraging building technologies such as advanced materials, ICT integration, and design strategies, it is possible to create built environments that prioritise thermal comfort, energy efficiency, and occupant well-being.

2.4.3 Range of Façade System Setups

2.4.3.1 Passive façade systems

© University of Pretoria

Passive facade systems are a fundamental element in building design especially in modern times. They are aimed at improving energy efficiency and occupant comfort. These systems utilise natural elements and design strategies to minimise the need for active mechanical systems. Passive facade systems encompass various approaches, such as passive shading systems like louvres and meshes (Mifsud et al., 2020), green facades acting through mechanisms like shadowing, insulation, and evaporative cooling (Coma et al., 2014), and DSFs passively absorb the vibrations produced by wind as efforts for reducing its effects (Santos et al., 2020; Pipitone et al., 2017). Additionally, passive solar design elements, such as window-to-wall ratios and shading systems, play a significant role in optimising energy efficiency (Kar, 2023).

Passive facade systems contribute to sustainable building practices by reducing cooling loads, controlling heating and cooling needs, and enhancing overall building performance. They also assist with reducing the direct sun's direct rays, reducing building temperatures, and improving occupant comfort (Ghafar et al., 2018; Heiz et al., 2018). Furthermore, the integration of passive systems in building envelopes can lead to a shift from merely acting as environmental barriers to becoming environmental mediators that optimise natural heating, cooling, and lighting effects (Holstov et al., 2017).

In the context of energy-efficient and sustainable building design, passive facade systems are essential components that work in conjunction with active systems like photovoltaic modules and solar collectors to achieve net-zero energy goals (Oh et al., 2017).

Passive facade systems represent a critical aspect of contemporary architectural and engineering practices, offering sustainable solutions to minimise energy usage, by improving user comfort, and optimising building performance. By leveraging natural elements and innovative design strategies, passive façade systems play an important part in the pursuit for environmentally conscious building designs.

2.4.3.2 Active façade systems

Active façade systems are an important aspect of modern building design, emphasising dynamic components that actively alter the building’s performance and inner ambient conditions. These systems include diverse technologies and tactics for integrating mechanical and electrical components to improve the user comfort, the efficiency of energy utilised, and overall building functioning (Athienitis et al., 2018; Bock 2019; Gracia et al., 2015).

BIPV, solar-thermal systems, and photovoltaic/thermal systems are examples of active façade systems that can harness energy from the sun and transform it to heat and energy needs for building usage (Athienitis et al., 2018; Bock 2019). These systems are intended to actively adapt to environmental conditions and occupant requirements, offering a dynamic approach to building performance optimisation (Bock, 2019; Gracia et al., 2015).

Active façade systems can include technologies like thermal energy storage systems, which actively control heat gains and losses inside building envelopes for the minimisation of the energy consumption requirements needed to cool or heat buildings. Incorporating adaptable facade systems may turn buildings into dynamic and responsive structures that adjust to changing environmental circumstances, improving both energy efficiency and occupant comfort (Bock, 2019; Gracia et al., 2015).

© University of Pretoria

Buildings that combine active façade systems with passive design methods can achieve better levels of energy efficiency and sustainability. Active facade systems are critical for decreasing energy consumption, enhancing interior environmental quality, and improving overall building efficiency (Gracia et al., 2015). The incorporation of active components into facade design marks a significant leap in building technology, providing novel answers to the issues of modern sustainable architecture.

2.4.4 The Performance Drivers of Facade Systems in Buildings

Facade systems in buildings represent crucial components that significantly impact various aspects of building performance. This explores the key performance drivers of facade systems such as:

- Energy efficiency
- Thermal comfort
- Daylighting
- Visual comfort
- Acoustic Performance.

One of the primary drivers of facade performance is energy efficiency, achieved through features such as thermal insulation and shading elements. These components mitigate heat transfer and the usage of energy that is used for lighting, cooling and heating purposes (Šadauskienė et al., 2015; Mortarotti et al., 2017)

Additionally, façade setups contribute towards thermal comfort by regulating indoor temperatures and optimising natural light penetration for daylighting (Yılmaz et al., 2022). This enhances occupant well-being and productivity, as supported by studies on indoor environmental quality (Fanger, 1972).

Visual comfort is another crucial aspect driven by facade systems, achieved by controlling glare, reflections, and visual distractions (Reinhart & Walkenhorst, 2001). Such control creates pleasant indoor environments conducive to various tasks (Frontczak et al., 2012).

Facade systems integrate sound insulation features to mitigate noise transmission, providing acoustic comfort for occupants. This is essential for maintaining a productive indoor environment (Humphreys, 2005).

The indoor air quality is facilitated by façade systems by supplying fresh air and removing pollutants. This improves occupant health and well-being (Sundell et al., 2011).

Aesthetic appeal is also a significant driver, as innovative facade designs enhance the visual aesthetics of buildings (Loonen et al., 2013). These designs reflect architectural identity and contribute to urban landscapes (Frampton, 2001).

Durable facade materials and construction techniques ensure the longevity of buildings. Sustainable design and maintenance practices minimise environmental impact (CIBSE, 2020).

Façade systems efficiency indicators include a variety of aspects that collectively influence the functionality, sustainability, and user experience of built environments.

© University of Pretoria

2.5 Implemented Climate adaptive building technologies and strategies

2.5.1 Climate Adaptation Innovative Facade Technologies

In tackling challenges of adaptation towards the changes in climate, technology plays a pivotal role in bolstering sustainability and resilience, particularly in urban contexts. Climate change technologies hold significant importance in enhancing energy efficiency and fortifying resilience against extreme weather occurrences (Ziervogel et al., 2016).

Martinez et al. (2021) discusses an educational facility project in Mexico that incorporates smart building technology, native vegetation, sustainable construction systems, and responsive architectural skin, to address extreme climate conditions and enhance indoor environmental quality. This illustrates how innovative architectural technologies Could be integrated to boost energy performance and thermal amelioration potential in educational developments.

Eltanboly and Afify (2022) discuss the impact of using responsive façades to interact with the external environment, enhance building physics, enhance thermal amelioration potential, and achieve energy efficiency in buildings. This highlights the significance of simulation software's in achieving architectural responses, the design of responsive envelopes, and climate data to enhance thermal amelioration potential and reduce environmental pollution.

2.5.2 Typical examples of facade technologies

The incorporation of smart technologies, responsive façades, and sustainable construction practices in architectural building technologies is pivotal in local climate adaptation strategies targeting thermal amelioration potential.

Adaptive facades are essential components of climate change adaptation technologies, offering innovative solutions to enhance building performance and sustainability, to tackle thermal amelioration potential. CABS or dynamic facades are adaptive façade systems that are designed to adjust with the environmental influences, like very brief climatic variations. These adaptive facades can optimise sunlight based on their angles and altitudes all through the day, optimising the energy usage and enhancing thermal amelioration potential (Attia et al., 2018; Kumar et al., 2022).

Hygromorphic facades, which inhibit unique characteristics and are known as a type of adaptive façade that innovatively utilise materials capable of responding to changes in humidity to create adaptive building envelopes. These facades have gained attention because they have the capacity to enhance energy efficiency, sustainability, and user comfortability in buildings (Holstov et al., 2015; Holstov et al., 2017).

Regenerative facades adjust to the variable climatic conditions. By integrating buildings with the landscape, these facades can transition indoor climates from 'manufactured' to 'mediated,' providing opportunities for high-performance building design (Loonen et al., 2013).

Morphing solar shadings are adaptive facades that can modify their properties to control heat and light based on environmental conditions. These systems offer a dynamic response to changing climate conditions, promoting energy efficiency and occupant comfort (Fiorito et al., 2016).

Biomimetic adaptive facades are biomimetic building skins that utilise adaptive approaches to respond to environmental changes. By imitating natural processes, these facades can

© University of Pretoria

optimise energy consumption and enhance building performance in various climate zones (Al-Obaidi et al., 2017).

Adaptive solar facades can modify their properties to maximise solar energy utilisation. These facades can improve environmental impact and energy efficiency, making them a valuable technology for climate change adaptation (Ghosh, 2020).

Solar chimneys are passive ventilation systems that utilise solar energy to improve circulation of air within buildings. Air circulation by the solar chimney could be used for the cooling of buildings. The rising warm air inside the chimney creates a suction effect, drawing in cooler air from the building's interior, providing passive cooling and ventilation (Nguyen & Wells, 2020).

Green facades are a type of climate adaptation technology that involves covering building facades with vegetation. Green facades can help enhance climate regulation by reducing heat gain in hotter seasons and minimising the heat that is lost during colder seasons and providing natural ventilation. They act as a barrier against direct sunlight, reducing the heat on the environment and improving thermal amelioration potential (Kabisch et al., 2016).

DSFs are building envelopes with double layered glass split by an air void. They offer insulation by creating this space, between the inner and outer glass layers. This gap acts as a barrier that limits heat transfer thus improving energy efficiency in buildings (Pomponi et al., 2016). The air gap within DSF can be utilised to manage heat gain, by adjusting the airflow in the cavity these facades are able to regulate the quantity of sunlight penetrating through into the building and helping it to maintain temperatures and reduce the need for cooling systems (Ahriz et al., 2022).

Moreover, DSFs support ventilation by allowing fresh air to flow through vents in the facade. This natural ventilation system enhances air quality but also reduces reliance on mechanical ventilation and enhances occupant's comfort (Barbosa et al., 2015). Additionally, these facades contribute to performance by acting as an additional shield against external noise. The airspace between the glass layers helps diminish transmission creating a peaceful indoor environment (Bossche et al., 2020).

2.5.3 South African Building Industry Sustainable Trends and Innovations

The aspect of climate adaptive building technologies has attracted some attention in South Africa over the past few years as efforts to deal with sustainability challenges are faced in the built environment. ABTs, such as SBTs, have emerged as viable solutions for building affordable housing that is sustainable (Adetooto et al., 2022; Adetooto & Windapo 2022). These types of technologies provide a faster way to build houses while also being a more environmentally friendly option (Adetooto et al., 2022). Despite providing numerous benefits, the acceptance and adoption of these technologies remain a challenge (Adetooto et al., 2022).

The construction sector in RSA has been slow to adopt sustainable practices like LCA (Kwofie et al., 2019). Nevertheless, there is a growing interest in green building initiatives motivated by economic considerations and ecological concerns (Windapo, 2014). The utilisation of innovative technologies has been identified as a key driver to enhance energy efficiency in commercial properties beyond standard building energy requirements (Moghayedi et al., 2022).

© University of Pretoria

Furthermore, both the academics and RSA government regard ABTs as a way of constructing robust sustainable low-income housing developments that are cost effective (Adetooto & Windapo, 2022). The industry has also begun to embrace green building rating tools such as LEED, albeit on a smaller scale. Additionally, the importance of using local building materials and involving the public in water resource management has been emphasised as critical factors in sustainable construction practices in South Africa (Windapo et al., 2014).

South Africa is progressively moving towards integrating climate adaptive building technologies to enhance sustainability in the construction sector. While challenges persist in the adoption of these technologies, there is an increasing recognition of the significance of green practices through initiatives such as the GBCSA and innovative solutions to address environmental concerns and promote sustainable development in the country.

2.6 Methods for Assessing Thermal Adaptive Capacity

To evaluate the thermal adaptive capacity in buildings and urban spaces, various methods and approaches can be utilised. Liu discusses (2022) a method that involves using digital simulation techniques to assess outdoor thermal amelioration potential in urban neighbourhoods. This approach can increase the performance of thermal comfortability in infrastructure developments by leveraging digital tools for simulation and analysis.

Li et al. (2019) discusses another method that focuses on evaluating the adaptive ability of urban morphology to climate tension. This approach allows for the evaluation of urban structures ability to withstand and adapt to climate challenges, providing insights into enhancing resilience in urban spaces.

Bre and Fachinotti (2017) discusses an experimental methodological proposal for analysing and optimising performance indicators related to thermal comfort and urban morphology. By employing parametric workflows and multicriteria optimisation, this method can contribute to improving urban comfort and thermal performance in outdoor spaces.

Battista et al. (2016) discuss the thermal impact of redeveloped areas on localised urban microclimates, emphasising the importance of assessing alterations in thermal conditions and implementing urban heat island countermeasures. This method enables the evaluation of the effectiveness of urban redevelopment projects in mitigating thermal impacts and improving outdoor comfort.

To assess how well adaptive facades or dynamic facades can adjust to changing temperatures researchers use computer simulation tools to model how these facades respond to conditions. This method helps them evaluate façade systems efficiency and the energy proficiency and thermal performance of facades (Ramírez-Balas et al., 2018). By creating models focused on performance, researchers can analyse how adaptive facades behave in terms of temperature control and energy efficiency. These models take part in refining the facades operation and design to enhance comfort levels and save energy (Favoino et al., 2014).

To study how adaptive facades perform in real world settings researchers conduct experiments to measure properties and performance metrics. Through this analysis they gauge how well these facades manage comfort and contribute to energy conservation (Fuliotto et al., 2010). The AHP is a tool for setting priorities regarding objectives and criteria for adaptive facade systems. This approach helps evaluate the impact of facades on achieving sustainability targets saving energy and enhancing thermal comfort (Yitmen et al., 2021).

© University of Pretoria

Thermal 3D CFD simulation is employed for assessing the efficiency of buildings featuring transparent facades. Felice et al. (2021) discusses an approach that enables an examination of heat transfer and thermal performance, in structures that feature dynamic facade systems.

To assess the Thermal Adaptive Capacity in DSFs, an evaluation could be employed to analyse the output over a duration of time of the features of DSF set up and their thermal performance under changing environmental conditions (Pasut & Carli 2012). CFD modelling strategies could be utilised in the prediction of temperature distribution, airflow patterns, and thermal performance in DSFs, providing insights into their adaptive capability (Pomponi et al., 2016).

Gupta et al. (2010) discusses assessing the thermal adaptive capability of green facades by introducing the method that can evaluate the intrinsic attributes of buildings through enabling their adaptive capability known as the Adaptive Capacity Wheel. This framework can be adapted to evaluate the adaptive capability of green facades in relation to their ability to respond to changing thermal conditions. Şık et al. (2021) employed parametric modelling based on optimisation algorithms to evaluate sustainable measures and tools for supporting choices about kinetic green facades. This approach could be used to assess the thermal amelioration potential and adaptive capacity of green facades. Moghaddam et al. (2021) used simulation tools for evaluating the viability of green facades with a façade with glazing.

In order to examine the adaptive capacity of biomimetic facades, digital simulation and mathematical modelling for analysing the thermal behaviour and energy performance of biomimetic facades is required. This approach can help evaluate the adaptive capacity of biomimetic facades in responding to changing thermal conditions across different climate zones (Webb, 2021).

Assessing thermal adaptive capacity in buildings and urban spaces necessitates a multidisciplinary approach that integrates digital simulation techniques, urban form analysis, performance optimisation, and green infrastructure assessments. By employing these methods, people can enhance thermal comfort, reduce urban heat island effects, and promote sustainable urban development amid changing climate patterns. Conduct experimental studies to examine the thermal performance and adaptive capacity of biomimetic facades in real-world conditions. By measuring thermal parameters and performance indicators, researchers can assess how biomimetic facades respond to varying thermal conditions (Webb, 2021). Implement integrated methodologies that combine mathematical modelling, simulation tools, and experimental studies to comprehensively evaluate the thermal adaptive capacity of biomimetic facades. This holistic approach can provide a thorough understanding of how biomimetic facades perform in different environments (Webb, 2021).

2.7 Reported Outcomes, Efficiencies, Benefits, and Shortcomings

Climate adaptation in building technology has been extensively researched to tackle the issues presented by the changes in climate. Studies have highlighted various outcomes, advantages, benefits, and shortcomings that are related to the implementation of climate adaptive measures for the built environment.

One key outcome identified is the potential for cost-effective solutions through simple modifications to occupant behaviour (Lim & Yun, 2017). This suggests that behavioural changes can significantly enhance building efficiency and reduce energy consumption. The

© University of Pretoria

use of CABS has been recognised as offering opportunities to optimise indoor climates and improve energy efficiency (Loonen et al., 2013).

Retrofitting existing buildings can significantly enhance building energy performance at a beneficial cost-effectiveness (Gremmelspacher et al., 2020). Retrofitting with smart and sustainable technologies not only reduces environmental impacts but also improves residents' quality of life. Incorporating appropriate green technologies in retrofitting strategies is crucial for adapting to the changes in climatic conditions.

One of the main benefits of green retrofitting is energy and cost reduction, along with improvements in building energy performance (Yang et al., 2023). Energy-efficient retrofitting is highlighted as a cheaper method to lower energy consumption and adapt towards the repercussions of climate change (Maheshwari et al., 2021). Informed decision-making in retrofit projects, considering future climate uncertainties, can lead to significant benefits in energy-efficient retrofits (Gremmelspacher et al., 2020).

Efficiencies in building technology for climate adaptations have been linked to the optimum utilisation of energy usage and the reduction of carbon footprints. Passive building design strategies, such as improving HVAC systems, have been shown to enhance building performance and contribute to energy savings (Rañeses et al., 2021). The application of smart technologies and control systems in non-domestic buildings has demonstrated increased efficiency and improved building automation (Buckman et al., 2014).

Despite the benefits of climate adaptive measures, some shortcomings have been identified. Constraints such as the lack of finance, knowledge about technology, and high adaptation costs have been reported as barriers to effective climate adaptation in buildings (Vijayasarathy & Ashok, 2015). The need for behavioural changes alongside technological advancements has been emphasised, highlighting the difficulty in achieving successful climate adaptation (Biagini et al., 2014).

While retrofit approaches in some places such as the UK focus on mitigation and adaptation of climate change, some shortcomings like increased insulation and airtightness in retrofitting may lead to indoor air quality issues (Jahed et al., 2018). Retrofitting historic buildings may face challenges related to indoor overheating risks due to the impacts in the changes in climate (Hao et al., 2022). Additionally, the lack of energy-efficient technologies during construction and design processes, coupled with rising refurbishment activities, poses challenges in achieving significant energy savings and adapting to climate change impacts through retrofit strategies (Özarısoy & Altan, 2017).

Retrofitting buildings with climate change adaptation technologies also offers numerous benefits such as energy efficiency, cost reduction, and improved environmental performance. However, challenges like indoor air quality issues, overheating risks, and the need for advanced technologies pose significant hurdles that need to be addressed in retrofitting projects.

2.8 Material and Technical Considerations

Addressing the issues of changing climate in buildings, materials and technical considerations are important in improving sustainability. Façade systems are key elements in this regard.

Regarding facade systems, the use of CABS has been recognised as a responsive solution that can dynamically react to climate changes using kinetic and flexible elements.

© University of Pretoria

Gronostajska and Berbesz (2018) discusses the significance of climatic properties in selecting materials, designing facades, and setting up systems to meet the adequate performance of indoor environments based on different climate types.

In terms of materials, mineral wool slabs are suggested to be ideal for ventilated hinged facade systems due to their thermal properties, resistance to temperature variations, and vapour permeability (Maltseva et al., 2019). Vertical greening walls are highlighted for regulating building temperatures in tropical climates, underscoring the importance of different facade types in managing heat transmission (Othman & Sahidin, 2016).

Integrating advanced facade technologies that respond to climate change is essential for improving building sustainability. Selecting appropriate materials, such as those with high specific insulating properties, is crucial in enhancing the performance of these systems in adapting to the issues of the changes in climate on buildings.

2.9 Summary of literature reviewed

Adapting to climate change in buildings necessitates innovative technologies and strategies to enhance sustainability and resilience, particularly in urban settings. Facade systems, including CABS, regenerative building envelopes, morphing solar shadings, and biomimetic adaptive facades, offer promising solutions to address thermal amelioration potential and improve building performance.

These adaptive facade systems can dynamically respond to changing environmental conditions, optimising energy consumption, enhancing thermal comfort, and promoting occupant well-being. Additionally, passive ventilation systems like solar chimneys and green facades contribute to natural cooling and ventilation, reducing the urban temperatures and improving thermal regulation.

Furthermore, DSFs provide insulation and ventilation benefits, while also acting as a shield against external noise. Integrating these climate adaptive technologies into building design and retrofitting projects can significantly enhance energy efficiency, reduce environmental impacts, and improve overall building performance.

However, despite the numerous benefits offered by climate adaptive building technologies, challenges such as high adaptation costs, limited knowledge, insights, and issues pertaining air quality need to be addressed. Overcoming these challenges requires collaborative efforts from key industry actors to promote the utilisation and application of sustainable practices.

In RSA, efforts to integrate climate adaptive building technologies are gaining momentum, driven by initiatives such as the white paper, green building council and innovative solutions like sandbag building technologies. Despite challenges in adoption, sustainable construction methods and green practices are gaining recognition in enhancing resilience to climate change and promoting sustainable development.

By embracing climate adaptive building technologies and implementing comprehensive assessment methods, we can effectively mitigate the implications of the changes in climate, improve the performance of buildings, and create more resilient and sustainable built environments for generations to come.

© University of Pretoria

Chapter 3: Research Methodology

To address the need for more empirical investigation into the discourse of building technologies that can be utilised as strategies for the changes in climate, this study centres on the pragmatism paradigm. The research employed a mixed method approach to explore the various types of facade systems that could be utilised as building technologies for the adaptation strategies towards the changes in climate, specifically focusing on improving the thermal amelioration potential for buildings in Tshwane, South Africa.

3.1 Research paradigm

The selected research methodology aligns with a paradigm approach. The pragmatic paradigm focuses on meaningful practical analysis and understanding of real-world scenarios, its measures, and models in research translation, highlighting the goal of producing results that are not only rigorous but also relevant to all parties (Kelly & Cordeiro, 2020). This pragmatic approach ensures that research findings can be effectively translated into practice to benefit the intended users (Glasgow, 2013).

Pragmatism is a significant factor in research due to its emphasis on practicality, flexibility, and the integration of diverse research methods to address complex research questions across disciplines. The pragmatic paradigm allows for the recognition of multiple realities and the validity of different interpretations of the world and research methodologies, highlighting the need for a flexible and practical approach to research (Morgan, 2014). This approach is particularly valuable in numerous studies, where pragmatism supports the integration of numerous research methods such as quantitative and qualitative research methods, focusing on methodological considerations over metaphysical debates (Johnson & Onwuegbuzie, 2004).

Since pragmatism enables the combination of different research methods and modes, a mixed method research then followed. By supporting the using a mixed-method approach and a continuous cycle of abductive reasoning, pragmatism facilitates the production of socially useful knowledge (Denzin, 2012).

Mixed method approach provides a holistic understanding of research problems. The approach allows for more exploration of research questions from multiple perspectives, leading to an extensive and nuanced analysis of the phenomena in question (Mason et al., 2020).

Mertens (2015) discusses that although mixed methods research offers a comprehensive analysis of research problems it also presents some challenges, namely, difficulties in using the method, technical issues, and the need for creativity when applying the mixed method approach in answering complicated issues.

The study makes use of various case studies. Case study as a research methodology is a valuable approach that makes provision for research teams to go in depth into complex issues, providing a rich understanding of phenomena within real-world contexts (Amerson, 2011). This method is particularly useful for generating hypotheses, understanding causal relationships, and exploring issues that may be inadequately addressed by other research approaches (Crasnow, 2012). Despite ongoing debates about its credibility and limitations compared to

© University of Pretoria

other methods, case study research has gained popularity among qualitative researchers due to its ability to provide in-depth insights (Hyett et al., 2014).

While taking into consideration case studies from international communities, the essence of the findings is to contribute to the theory surrounding climate adaptation in urban areas and buildings specifically in Tshwane, South Africa.

Additionally, on top of gathering information from secondary data, it is also crucial to ensure utilising statistical data of how climate changes have been changing from the past until the future to present more knowledge and understanding on different climate change adaptation technologies needed for Tshwane.

This report was conducted using a desktop research methodology. A crucial step in desktop study is the use of literature reviews and document analysis. This helps to discern the present state of knowledge in the subject matter to assist in building a foundation for the research.

By adopting a pragmatic perspective, this study on architectural interventions as climate change adaptation strategies takes a practical and solution-based strategy. The focus is on documenting selected building technologies that improve the thermal adaptive capacity of buildings, thereby contributing to practical solutions for urban development and enhancing community wellness. The research goal is to make beneficial contributions to the adaptation towards the changes in climate in the city of Tshwane.

The following table outlines important components of the methodology on architectural interventions as climate change adaptation strategies:

Aspect	**Description**
Paradigm	The study adopts a pragmatic paradigm, emphasising practical analysis and problem-solving approaches.
Methodology	A mixed methodology is employed, combining qualitative and quantitative approaches to gather comprehensive insights.
Data Collection Methods	Various data collection methods are utilised, including literature review, document analysis, and possibly on-site observations.
Instruments Used	Observational checklists may be employed to gather data effectively. Google scholar, Research gate.
Ethical Considerations	Ethical considerations are paramount, ensuring that research activities are conducted with integrity, respect, and confidentiality. This current study forms a component of a larger study and has received conditional ethics clearance.
Research Boundaries	The study focuses on identifying climate adaptation strategies that specifically target thermal adaptation responses applicable buildings in Tshwane, South Africa. The research boundary is limited to considering strategies within the same Köppen-Geiger climate classification as Tshwane.
Focus Areas	The study focuses on documenting selected architectural interventions as examples of building technologies for climate change adaptation.
Importance of Metrics	Metrics are utilised to measure and evaluate the effectiveness and impact of the documented building technologies.

© University of Pretoria

Table 2. Table summarising the research design (Author, 2024).

3.2 Study area

The study centres on the documentation of specific architectural interventions chosen as prime examples of building technologies that can be utilised as a strategy for climate change adaptation particularly in Tshwane RSA. Through this documentation process, the aim is to highlight innovative approaches and successful implementations of building technologies that are able to tackle issues of climate change.

These selected interventions serve as examples that show practical solutions and strategies for adapting built environments to changing climatic conditions. By thoroughly documenting these architectural interventions, the study seeks to contribute to the broader discussion of adaptation to climate change within built environment domains. Furthermore, the documentation process seeks to establish a comprehensive database of case studies, providing valuable insights and lessons learned for practice and future research.

3.3 Data capture and collection

Data collection is a crucial component of research methodology, involving the systematic gathering of information to address the research question. People undertaking research typically follow a structured process to ensure that the data collected is dependable and trustworthy (Kelley, 2003; McCusker & Günaydın, 2014; Cantrell & Lupinacci, 2007).

The collection of data was methodically done through a comprehensive desktop research approach. Data collection methods involve a wide range of approaches, including surveys, interviews, observations, and document analysis (Yanti et al., 2021).

A team of RFS 701 students from 2022, set out various adaptation strategies and technologies, forming the cornerstone of their investigation. These strategies were meticulously categorised and served as the bedrock for subsequent analysis. To align with the case studies under scrutiny and bolster the argument presented in this study.

Particularly, for this study a rigorous search was undertaken by a team of 3 Masters of Architecture 2024 students in order to identify a total of 15 case studies, each representing unique instances where building technologies were employed to enhance the thermal adaptability of buildings situated in regions characterised by Köppen-Geiger climate classifications of cwa, cwb, and bsh.

These case studies were selected to depict a diverse range of facade systems known to enhance the thermal amelioration potential in buildings in different climatic conditions. The selection process involved a thorough examination of various websites and journals renowned for their credibility and contributions to the field of Architecture and building science at large.

Through this rigorous methodological approach, a robust collection of case studies was obtained, ensuring that the data used was valid and reliable. This comprehensive exploration of reputable sources allowed for the identification of relevant examples that showcase innovative strategies to improve thermal amelioration potential and energy performance in buildings across different climatic zones.

© University of Pretoria

3.4 Data Analysis

Conducting the study required a detailed desktop review of existing case studies on building technologies and thermal adaptation strategies. This section outlines the methodology used to select, analyse, and synthesise data from these case studies.

3.4.1 Identification of Key Variables

- **Thermal Comfort Strategies**: Identified specific strategies used to enhance thermal comfort, such as passive cooling, natural ventilation, and thermal mass.
- Facade Systems: Focused on the types of facade systems employed, including their materials, technologies, and design features.
- Climate Adaptation: Examined how the building technologies and facade systems were adapted to specific climatic conditions (Cwa, Cwb, BSh) using the Köppen Geiger classification system.

3.4.2 Selection of building technologies from similar climatic regions using the Köppen Geiger classification system

3.4.2.1 Köppen Geiger classification system

To get climatic conditions from various regions around the world that are similar to Tshwane's climatic conditions, the Köppen Geiger climate classification system was used. It is a widely used method to categorise climates based on temperature, precipitation and vegetation characteristics.

This system groups the world's climates into five categories, namely:

- Tropical - A
- Arid – B
- Temperate – C
- Cold – D
- Polar - E

Each group further subdivided into specific subcategories as displayed in the figure below (Peel et al., 2007).

1st	2nd	3rd	Description	Criteria*
A			Tropical	$T_{cold} \geq 18$
	f		- Rainforest	$P_{dry} \geq 60$
	m		- Monsoon	Not (Af) & $P_{dry} \geq 100 - MAP/25$
	w		- Savannah	Not (Af) & $P_{dry} < 100 - MAP/25$
B			Arid	$MAP < 10 \times P_{threshold}$
	W		- Desert	$MAP < 5 \times P_{threshold}$
	S		- Steppe	$MAP \geq 5 \times P_{threshold}$
		h	- Hot	$MAT \geq 18$
		k	- Cold	$MAT < 18$
C			Temperate	$T_{hot} > 10$ & $0 < T_{cold} < 18$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Cs) or (Cw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a or b) & $1 \leq T_{mon10} < 4$
D			Cold	$T_{hot} > 10$ & $T_{cold} \leq 0$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Ds) or (Dw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a, b or d)
		d	- Very Cold Winter	Not (a or b) & $T_{cold} < -38$
E			Polar	$T_{hot} < 10$
	T		- Tundra	$T_{hot} > 0$
	F		- Frost	$T_{hot} \leq 0$

Figure 2: Climate classification criteria (Peel et al., 2007).

© University of Pretoria

Numerous researchers have utilised the Köppen-Geiger climate classification system within various fields. Its ability to offer an ecologically relevant description of conditions has proven valuable in climate change research, biodiversity assessments and ecosystem services evaluations (Naranjo et al., 2018).

The Köppen Geiger classification played a role in mapping climate zones evaluating and analysing the issues related to the changes in climatic conditions like heat related risks (Das et al., 2024). By categorising regions into distinct climate types, researchers can enhance their understanding of climate distributions, forecast shifts in climate patterns and evaluate how climate change impacts different geographical areas (Watson et al., 2020).

This climatic classification system known as the Köppen Geiger has enabled researchers to explore the connection between climate and various phenomena. When researchers integrate climate classifications into their research methods, they can uncover how climate impacts activities, human well-being and the spread of species in various climate regions.

The Köppen-Geiger climate classification was utilised in classifying and assessing climatic conditions worldwide by many researchers (Peel et al., 2007) as depicted by figure below and the aim is to identify strategies that can yield the most favourable outcome for maintaining a comfortable indoor temperature in Tshwane's buildings throughout an extended duration.

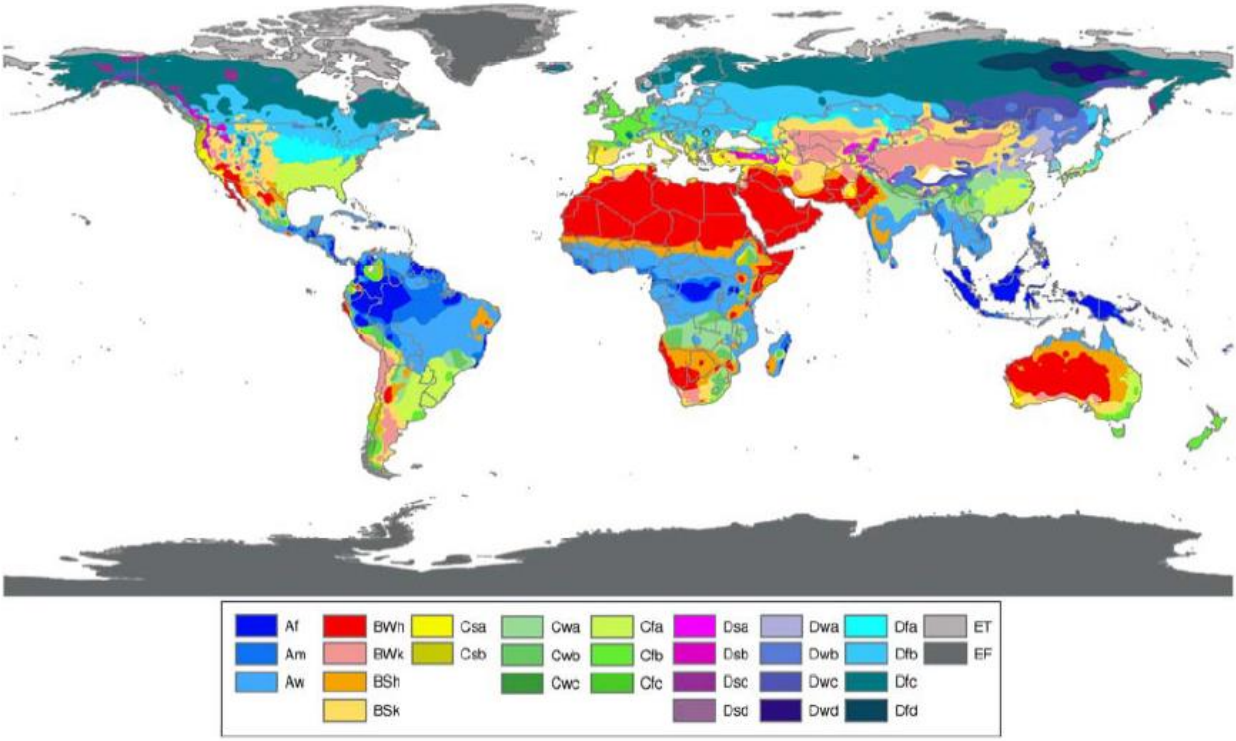


Figure 3: Köppen-Geiger climate classification of all regions (Peel et al., 2007).

© University of Pretoria

3.4.2.2 Current and Projected Climate Classifications:

(i) Cwa - (Dry winter, hot summer subtropical)

The Cwa climate classification, noted by the Köppen Geiger system, represents climatic conditions found in regions like Tshwane South Africa, characterised by dry winters and hot subtropical summers. This classification signifies a climate distinguished by moist summers along with arid winters typically receiving approximately 1,500 mm in yearly rainfall of (Bueno et al., 2016). Regions categorised under Cwa encounter changes show significant variations between summer and winter conditions. The Cwa climate type is commonly linked to characteristics indicating moderate temperature ranges throughout the year (Bueno et al., 2016).

Researchers have utilised the Cwa climate classification in studies related to agriculture, environmental science and climatology. Understanding the conditions associated with the Cwa classification is crucial for evaluating agricultural productivity, water resource management strategies and ecosystem dynamics in regions marked by this particular climate type. The classification of Cwa offers insights into temperature and precipitation trends that impact the overall environmental circumstances in different regions (Bueno et al., 2016).

The Cwa climate classification is crucial, for identifying areas with climates marked by dry winters and warm summers. Through the Köppen Geiger classification system, study patterns, leading to an understanding of improved insights into environmental dynamics and reactions in regions classified as Cwa.

(ii) Cwb - (temperate dry winter, warm summer)

Climates associated with Cwb climate classification, as stipulated by the Köppen-Geiger climate classification system, signifies a temperate dry winter, warm summer. This classification points to regions known for temperatures and distinct seasons with cold and dry winters alongside relatively warm summers, which are characteristics found in the City of Johannesburg. The Cwb climate category is linked to regions that experience a contrast between winter and summer conditions with varying levels of precipitation throughout the year (Mello et al., 2012).

Researchers have utilised the Cwb climate classification in studies related to agriculture, hydrology and environmental science. Grasping the traits associated with the Cwb classification is crucial for evaluating water availability, agricultural methods and ecosystem dynamics in regions falling under this climate type. The categorisation of Cwb offers insights into temperature and precipitation trends that impact soil characteristics, plant growth and overall environmental conditions in different regions (Mello et al., 2012).

The Cwb climate classification plays an important role in identifying regions characterised by temperate climates featuring dry winters. Using the Köppen Geiger system allows researchers to categorise and study conditions, which helps enhance our knowledge in different sustainability initiatives, in different regions identified as Cwb.

(iii) Bsh - (hot semi-arid climate)

The BSh climate classification represents a hot semi-arid climate which is associated with warm temperatures with limited precipitation. This classification indicates regions with distinct seasonal variations, featuring dry and hot conditions, especially in summer. The BSh climate

© University of Pretoria

type is associated with areas that experience arid to semi-arid conditions, with moderate temperature ranges and low humidity levels (Filho et al., 2020).

Researchers have utilised the BSh climate classification in various environmental science studies. Understanding the specific climatic characteristics associated with the BSh classification is essential for assessing water availability, crop suitability, and ecological dynamics in regions classified under the Bsh climate classification (Filho et al., 2020). The classification of BSh provides valuable insights into the temperature and precipitation patterns that influence land use, vegetation distribution, and overall environmental conditions in these regions (Filho et al., 2020).

The climate categorised by BSh provides valuable insight into categorising regions with hot semi-arid climates characterised by limited rainfall and warm temperatures. By utilising the Köppen-Geiger system, researchers can effectively classify and analyse climatic conditions, contributing to a better understanding of ecosystem responses in areas classified as BSh.

3.4.3 Selection of Sustainable Building Design Strategies for Climate Comfort: A Focus on Facade Systems

3.4.3.1 Sustainable Building Design Overview

In the realm of the built environment, particularly regarding energy efficiency, the selection of appropriate façade systems plays a pivotal role in regulating internal temperatures and reducing cooling loads. Various innovative technologies and strategies were made to optimise building performance, contributing to sustainability and occupant comfort.

The approaches, techniques and technologies that have been noted should be guiding principles for buildings in climatic regions classified as Cwa, Cwb and Bsh. Built environment professionals should be cognisant of producing buildings that consider inhabitants well-being and comfort through provision of thermal comfort.

The term "facade systems" refers to the elements of a building that serve multiple functions, then just aesthetic purposes. These systems consist of parts and technologies aimed at improving the building's functionality, performance, energy usage requirements and the comfortability of its users. They can incorporate elements such as passive and active HVAC systems (Prieto et al., 2017).

Sustainable building design strategies for climate comfort represent a critical approach in contemporary architecture and construction, aiming to mitigate and adapt towards the environmental impact of factors such as rising global temperatures due to climate change to ensure occupant comfort and well-being (Seyfang, 2010).

3.4.3.2 Recognition of Facade Systems

The pursuit of climate comfort through innovative design strategies has emerged as a paramount concern. Architects and designers are increasingly recognising the pivotal role of building facades in mediating the interaction between indoor and outdoor environments, thereby influencing occupant comfort, energy performance, and environmental sustainability. Façade systems act as integral components of climate-responsive architecture for sustainable building design (Nicol & Humphreys, 2002).

© University of Pretoria

3.4.3.3 Integration of Passive Cooling Strategies

At the forefront of sustainable building design is the imperative to reduce energy usage and CO_2 emissions linked to building operations. Passive cooling strategies, as integral components of sustainable design, harness natural elements such as solar radiation, airflow, and thermal mass to regulate indoor temperatures without relying extensively on mechanical systems. These strategies not only contribute to energy saving needs but also improve resilience of buildings to climate variability and reduce their ecological footprint (Habert et al., 2020).

3.4.3.4 Emphasis on Passive Solar Design

Passive solar design stands as a sustainable building practice that emphasises the strategic orientation of buildings and the optimisation of solar heat gain and loss throughout the year. By aligning building orientation with the path of the sun and incorporating features like windows that face the south direction and thermal mass materials, passive solar design maximises solar heat gain during colder months while minimising it during warmer periods. This approach ensures optimal thermal comfort for occupants while minimising the need for artificial HVAC systems, thus reducing the energy usage and operating costs (Fleer et al., 2017).

3.4.3.5 Enhancement Through Natural Ventilation Strategies

Natural ventilation strategies further complement passive solar design by providing means for free flow of fresh air through buildings, improving the interior air quality, and promoting thermal amelioration potential (Daisey et al., 2003). Through thoughtful building orientation, cross-ventilation, operable windows, and the utilisation of prevailing winds, natural ventilation systems harness the power of natural airflow to cool indoor spaces and reduce reliance on mechanical cooling systems (Földváry et al., 2017). By incorporating these approaches and techniques into building design, architects can create indoor environments that prioritise occupant comfort and well-being while minimising energy demand and environmental impact (Jabareen, 2006).

3.4.3.6 Utilisation of Thermal Mass

Using thermal mass elements like concrete, stone, or rammed earth serves as an effective means of stabilising indoor temperatures and reducing temperature fluctuations. These materials have significant thermal properties, allowing them to trap excess warmth that is released throughout the day, thus moderating indoor temperature extremes. By strategically integrating thermal mass into building envelopes and interior spaces, architects can enhance thermal comfort, optimise energy performance, and reduce the need for active heating and cooling systems (Saffari et al., 2017).

3.4.3.7 Integration of Shading Devices and Passive Cooling Techniques

Shading devices and passive cooling techniques further enhance the climatic responsiveness of sustainable buildings by mitigating solar heat gain and optimising natural ventilation (Lau et al., 2016). External shading elements such as overhangs, louvres, and vegetation provide effective protection against solar radiation, reducing the need for mechanical cooling and minimising energy consumption (Dakheel & Aoul, 2017). Moreover, the incorporation of greenery into building design through green roofs, living walls, and urban vegetation not only enhances aesthetic appeal but also improves thermal comfort, the quality of the air, and

© University of Pretoria

biodiversity, providing for the broader sustainability requirements of the built environment (Luthra, 2023).

3.4.3.8 Specialized Focus on Facade Systems

Facilitating the transition from broad principles to specialised applications, the discussion narrows mainly to façade systems on the thermal performance, daylighting, and overall environmental sustainability of buildings. Facade systems, include a diverse array of materials, technologies, and design strategies, that perform a significant task in influencing the construction industry's response to climatic conditions, geographical context, and user needs (Habitzreuter et al., 2019).

Sustainable building design strategies for climate comfort represent a holistic approach to architectural practice, integrating passive cooling techniques, passive solar design, natural ventilation, thermal mass, and shading devices to create environmentally responsive and energy-efficient built environments. By prioritising occupant comfort, environmental stewardship, and resource efficiency, these strategies pave the way for a future that aligns with sustainability practices that meets the current complex and changing times connected to the issues of the changes in climatic conditions and urbanisation (Fernandez-Antolin et al., 2019).

3.4.3.9 Innovations in Sustainable Facade Design

At the forefront of sustainable facade design lies the imperative to optimise thermal performance and mitigate heat transfer through the building envelope. High-performance facade systems integrate advanced insulation materials, air barriers, and thermal breaks to minimise thermal bridging and enhance the energy optimisation. By mitigating gaining heat in hotter seasons and losing heat in colder seasons, these facades minimise dependence on HVAC systems, in order to reduce the energy usage and costs (Hou et al., 2020).

3.4.3.10 Integration of Dynamic Facade Systems

The integration of dynamic facade systems, such as responsive shading devices, electrochromic glazing, and phase-change materials, introduces a new dimension of adaptability and responsiveness towards the fluctuation of environmental conditions (Loonen et al., 2016). These innovative technologies allow facade systems to dynamically adjust their properties in real-time, optimising daylight penetration, solar heat gain, and visual comfort while reducing energy demand and enhancing occupant well-being (Loonen et al., 2016).

3.4.3.11 Emphasis on Daylighting

Daylighting, another crucial aspect of sustainable facade design, underscores the importance of natural light in promoting occupant health, productivity, and comfort. Well-designed facade systems leverage daylighting principles to maximise natural light penetration while minimising glare and solar heat gain. Light-diffusing glazing, light shelves, and external shading devices are among the myriad strategies employed to optimise daylighting performance, reduce reliance on artificial lighting, and foster the correlation between interior and the exterior areas (Dabaj et al., 2022).

3.4.3.12 Incorporation of Vegetation Within Facade Systems

© University of Pretoria

The aesthetic and functional integration of vegetation within facade systems offers a holistic approach to sustainable design, blurring the boundaries between architecture and nature (Wong et al., 2010). Green facade systems, comprising vertical gardens, living walls, and vegetated screens, not only enhance thermal performance and air quality but also contribute to biodiversity, urban greening, and biophilic design. By harnessing the innate properties of plants to regulate temperature, filter pollutants, and enhance microclimatic conditions, these living facade systems exemplify the symbiotic relationship between built form and natural ecosystems (Coma et al., 2014).

3.4.3.13 Summary of Sustainable Building Design Strategies

The discussion sheds light on the significance of the different façade systems, on how they can contribute towards advancing the agenda of sustainable building design and climate comfort. By embracing a multidisciplinary approach that integrates architectural, engineering, and environmental principles, facade systems can serve as catalysts for transformative change in the built environment. From passive strategies to cutting-edge technologies, facade systems offer a myriad of opportunities to create buildings that are not only responsive to their climatic context but also resilient, resource-efficient, and conducive to occupant well-being (Şık et al., 2021).

Chapter 4: Results

4.1 Introduction

The relevance of the results is to shed light on the findings pertaining to the analysed data on the different case studies.

This section systematically outlines the key insights derived from the analysis, focusing on thermal comfort strategies, facade systems, and climate adaptation techniques. Through the exploration and examination of these areas, the results section aims to highlight effective building technologies and innovative approaches to enhancing thermal adaptability in different climatic conditions.

4.2 Descriptive Statistics of Case Studies

Case studies	Name of Place	Source
1	Manuel Gea Gonzalez Hospital / Elegant Embellishments / 2013	
2	KMC Corporate Office / RMA Architects / 2012	
3	Pearl River Tower /SOM / 2013	
4	78 Corlett Drive Building / Daffonchio Architects / 2018	

© University of Pretoria

5	Council House 2 / DesignInc / 2006	**(See Appendix 1)**
6	Alexander Forbes - Paragon Architects	
7	Kadoori Biological Sciences Building, university of Hong Kong	
8	National biodiversity pavilion	
9	Britam Towers,	
10	University of Pretoria Plant Science Complex (2012)	
11	Podium AT Menlyn / Boogertman + Partners 2012	
12	The Grove/ WOHA Architects 2016	
13	BMW Head office / Boogertman + Partners 2012/ refurbished again 2019.	
14	The Lantern / VTN Architects 2016	
15	Monash University 2nd phase of the science centre	

Table 3. Table summarising list of case studies (Author, 2024).

Case Studies of Façade Systems in Various Climate Regions

Case studies	Location:	Climate region:	Building Typology	Number of Storeys	Active or Passive façade system	Façade System Type
1	New Mexico / Mexico	Cwb	Commercial / hospital	Multistorey	Passive	Ornate Double Skin Biomimetic Façade.

© University of Pretoria

2	Cyber City, Hyderabad/ India	Bsh	Commercial	Multistorey	Hybrid	Double Skin Green Façade.
3	Guangzhou / China	Cwa	Commercial	Multistorey	Active	Double skin dynamic Façade system with integrated photovoltaic panels on sunshade devices.
4	Johannesburg / South Africa	Cwa	Commercial	Multistorey	Active	Dynamic Façade system
5	Melbourne / Australia	Cwa	Commercial	Multistorey	Active	Dynamic biomimetic double skin façade system
6	Johannesburg	Cwa	Commercial	Multistorey	Hybrid	Angled Standing Seam System (4,200 m² 31.2 t)
7	Hong Kong, China	Cwa	Mixed-use	Multistorey	Passive	DSF
8	New Mexico	Cwb	Commercial	Multistorey	Active	Dynamic Facade
9	Nairobi, Kenya	Cwb	Commercial	Multistorey	Passive	Passive Facade
10	Pretoria, South Africa	Cwb	Educational	Multistorey	Passive	Green façade
11	Pretoria/Tshwane / South Africa	Cwb	Commercial	Multistorey	Passive	DFS
12	Guangzhou / China	Cwa	Residential / commercial	Multistorey	Active façade	Green façade (Vertical Garden)
13	Johannesburg / South Africa	Cwb	Commercial	2/3 storey	Active façade	Dynamic Façade system
14	Hanoi / Vietnam	Cwa	Commercial	Multistorey	Passive	Dynamic Façade system
15	Melbourne / Australia	Cwa	Institutional	Multistorey	Passive	Double façade systems

Table 4. Table of details of case studies (Author 2024).

© University of Pretoria

CASE STUDY 1

Name of Place: Manuel Gea Gonzalez Hospital / Elegant Embellishments / 2013

Location:	Climate region:	Building Typology	Number of Storeys	Active or Passive façade system	Façade System Type
New Mexico / Mexico	Cwb	commercial / hospital	multistorey	Passive	Ornate Double Skin Biomimetic Façade
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The biomimetic façade made of prosolve tiles (plastic coated with titanium dioxide) was chosen for its anti-microbial and de-polluting properties. This prosolve370e skin acts as an urban filter and filters natural light into the building, serving as a solar blocker that reduces the need for artificial light and climate control. It also slows wind flow to generate turbulence, distributing air pollutants across the panels before entering the building (Architect Magazine, 2013).	White Prosolve370e tiles, shaped into 3D X and I modules, are attached to a vertical steel substructure with about 500 blocks arranged puzzle-like. Made of lightweight thermoformed plastic, these tiles are coated with powdered titanium dioxide (TiO2), a photocatalytic nanomaterial patented by Cristal Global, aiding in air purification (Architect Magazine, 2013).	The façade's efficacy was initially tested using a single panel and computational simulation. The completed façade's efficiency was then monitored by assessing nearby air quality levels. Monitoring indoor air quality changes indicates its air purification function, while temperature fluctuations throughout the day reflect the success of design strategies (Architect Magazine, 2013).	The results from third party testing of TiO2, the façade of the hospital should offset the quantity of NO emissions generated by 1000 vehicles travelling on the roads of Mexico City every day (Architect Magazine, 2013).	**Enhanced air quality:** • Bringing fresher air indoors. • Removing pollutants, improving air quality. • Serving as a filter, in city environments. **Comfortable temperature:** • Blocking UV rays, decreasing heat absorption and urban heat island effects (Architect Magazine, 2013). • Keeping indoor temperatures cooler. **Efficient energy usage:**	**Material constraints:** • The patented TiO2 material poses availability and feasibility issues. • TiO2 coating wears thin over time, requiring reapplication, which is a maintenance concern. **Technical constraints:** • Panels can absorb pollutants equivalent to 1,000 vehicles per day; higher vehicle numbers may affect internal air quality. • The static double façade limits adaptability to future climate changes.

© University of Pretoria

				• Filtering sunlight, decreasing reliance on artificial lighting. • Reducing the need for cooling systems. **Practical aspects:** • Panels are lightweight and simple to install.	

Table 5. Table of detailed case study 1 analysis (DaEncarnacao, 2024).

CASE STUDY 2

Name of Place: KMC Corporate Office / RMA Architects / 2012

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
Cyber City, Hyderabad/ India	Bsh	commercial	multistorey	Hybrid	Double Skin Green Façade
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The use of a green DSFs serves as both an energy-efficient feature and a visually striking element. This design concept involves a facade with two layers that control light and airflow within the	The building's interior showcases aluminium-framed windows, while its exterior facade boasts a meticulously crafted cast aluminium trellis. This trellis	Measuring the internal temperature and humidity. No computational simulation was done due to the hands on and handmade approach to the design therefore	Increased acoustic insulation from external noises. Decreased thermal gains in summer, creating cool internal spaces, decreasing the need for air-	**Thermal Comfort:** • Reduces thermal gains and limits direct sunlight exposure, maintaining comfortable internal temperatures	**Water Usage Constraints** • The misting system for irrigation doesn't capture and recycle runoff, causing water wastage. **Vegetation Concerns** • Different plant species have varying water needs, requiring careful grouping.

© University of Pretoria

structure (Singh et al., 2023). The integrated misting system, housed within the aluminium trellis, manages water flow to the plants and trays while contributing to cooling the building (Singh et al., 2023). The outer skin functions as a dynamic facade, with a variety of plants that change throughout the seasons. This natural dynamic function alters the building's visual appearance year-round and adjusts the interior climate according to the seasons. In summer, the foliage limits solar radiation, creating a cooler interior climate, while in winter, deciduous plants shed leaves or die out, allowing more sunlight and warmth into the building (Singh et al., 2023). This active facade, powered by nature, offers acoustic insulation, protection from direct sunlight, heat, and dust, in addition to enhancing the building's aesthetic (Singh et al., 2023).	incorporates a sophisticated misting system and hydroponic trays. Comprising four modular panels, it offers versatile assembly options. These panels undergo a precise manufacturing process involving casting, welding, and anodizing to ensure quality and durability (Singh et al., 2023).	a post-occupancy method for measuring the effectiveness of the façade system would be required (Singh et al., 2023).	conditioning during summer (Singh et al., 2023). Reduces the reliance, on lighting in daylight hours.	throughout the year. • Foliage absorbs UV rays without radiating heat into the building, mitigating heat in environments. • Maintains reduced temperatures inside during summer and creates ambient warmth during winter months. **Energy Efficiency:** • Filters natural light, reducing reliance on artificial lighting throughout the day. • Decreases the need for artificial cooling, enhancing energy efficiency. **Technical Considerations:** • Provides acoustic insulation from the external environment. • Modular design of aluminium panels allows for flexible assembly.	**Maintenance Concerns** • Plants need regular maintenance, such as pruning and pest control.

© University of Pretoria

				• Integrated misting system hydrates vegetation and cools internal spaces. • Lightweight aluminium panels facilitate easy handling and installation by two people. **Air Quality:** • Vegetation attracts dust particles, improving internal air quality.	

Table 6. Table of detailed case study 2 analysis (DaEncarnacao, 2024).

CASE STUDY 3

Name of Place: Pearl River Tower /SOM / 2013

Location:	**Climate region:**	**Building Typology**	**Number of Storeys**	**Active or Static façade system**	**Façade System Type**
Guangzhou / China	Cwa	Commercial	multistorey	Active	Double skin dynamic Façade system with integrated photovoltaic panels on sunshade devices
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The façade design follows	The double skin curtain wall	Computational simulation using	The building uses 30% less	**Thermal Comfort:**	Technical constraints

© University of Pretoria

energy-saving principles, considering the city's solar and wind patterns (Selcuk et al., 2014). It features a dual-layer system with an air gap between layers (Selcuk et al., 2014). The layered skin incorporates ventilation and sun shading mechanisms (Frechette et al., 2008). The transparency adds both aesthetic and functional benefits, with motorised sunshades in the cavity providing shading and glare control (Selcuk et al., 2014). These sunshades adjust based on sensors tracking the sun's position, controlling daylight, moisture infiltration, and fresh air (Selcuk et al., 2014), reducing solar heat gain and improving thermal performance during seasonal changes (Frechette et al., 2008). The building management system adjusts sunshades	system features a panel that is double glazed consisting of dimension 3000 by 3900mm (Frechette et al., 2008). 1500 by 2800mm single glazed leaves that are hinged x 2 behind the mullion, which provides a gap at the base. Inside this gap there is an automated 50mm silver venetian blind (perforated) with three modes: open, 45^{o} angle, or closed. The exterior glazing is insulated, coated with low E tempered glass coating, while the inner operable glass panel can be opened for maintenance (Frechette et al., 2008).	an energy model (Frechette et al., 2008)	energy compared to buildings of a similar magnitude. The building envelope produces 1% net energy of the total energy required for the building (Frechette et al, 2008)	• Automated shading systems reduce heat entering the building, enhancing thermal comfort. • Mechanically ventilated air gap within the DSF system improves indoor conditions. • Decreased heating and cooling demands at the building's perimeter reduce overall energy usage and enhance thermal efficiency during winter months. **Energy Efficiency:** • Active facade systems reduce reliance on cooling systems and artificial lighting. • BIPV system generates electricity. • Energy savings realised through reduced airflow in the 'decoupled' ventilation system and introduction of a ceiling system. • Dehumidification system utilities heat from the wall facade as an energy source	- The 200mm cavity embedded in the DSF poses accessibility issues for maintenance.

© University of Pretoria

according to sunlight intensity and angle, reducing heat (Selcuk et al., 2014). The Pearl River Tower integrates solar shading and power generation, with BIPV providing electricity and acting as a solar shade (Frechette et al., 2008). Energy harnessed through the façade is used for heating and dehumidification (Frechette et al., 2008). The double-skin system serves as an internally ventilated double wall, with external low-E glass panels that can be opened for maintenance, complementing mechanically ventilated interior walls (Frechette et al., 2008). This envelope functions as a thermal regulator.				(Frechette et al., 2008). • Daylight and Glare: • Automated shading systems bring useful daylight while reducing direct glare. **Acoustic Comfort:** • Reduced noise transmission from outside to inside the building. **Ventilation and Air Quality:** • 'Decoupled' ventilation system within the cavity improves air quality and exchange effectiveness (Frechette et al., 2008). • Mechanically ventilated cavity within the DSF system enhances interior air quality. **Technical Considerations:** • Building Management System (BMI) automates shading devices for thermal comfort without human intervention.	

© University of Pretoria

				• 'Decoupled' ventilation system reduces 'floor-to-floor' height. • Integration of shading system and active ventilation within DSF cavity.	

Table 7. Table of detailed case study 3 analysis (DaEncarnacao, 2024).

CASE STUDY 4

Name of Place: 78 Corlett Drive Building / Daffonchio Architects / 2018

Location:	**Climate region:**	**Building Typology**	**Number of Storeys**	**Active or Static façade system**	**Façade System Type**
Johannesburg / South Africa	Cwa	Commercial	multistorey	Active	Dynamic Façade system
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The dynamic exterior system incorporates passive shading with fixed devices shielding occupants from summer sunlight. Movable shutters on the walls offer both an evolving appearance and manual control over natural light, warmth, and glare (ArchDaily, 2019).	The street interface facade features fixed shading louvres made of modular aluminium panels on an aluminium frame, resembling a clad-like construction (ArchDaily, 2019). This system is positioned in front of a curtain wall, resembling a DSF (ArchDaily, 2019). The dynamic	The dynamic facade treatment was seamlessly integrated with the passive shading system through collaboration among lighting and facade experts, utilising advanced modelling software (Arch daily, 2019). This synergy created a	Improved quality of interior spaces (ArchDaily 2019).	**Thermal Comfort:** • Minimises thermal gains into the building. • Allows occupants to adjust natural light levels, reducing glare. **Energy Efficiency:** • Reduces reliance on artificial lighting throughout the day.	Technical constraints - The static nature of the fixed modular facade limits the facades' adaptability to future climate variations and changes. - Due to the street façade being fixed, it makes it difficult to clean the inner skin curtain wall system.

© University of Pretoria

	facade system adjacent to it consists of operable shading devices installed in window cavities (ArchDaily, 2019).	striking street presence, protecting occupants from summer sunlight while minimising waste through modular aluminium-clad construction, nearly achieving net-zero wastage (Arch daily, 2019).		• Decreases the need for constant artificial cooling of interior spaces. **Air Quality:** • Utilises passive shading and a fixed modular aluminium-clad facade to promote natural airflow, improving indoor air quality without compromising the micro-climate (ArchDaily 2019). Daylight and Glare Control: • Enables manual control of sunlight and glare levels throughout the day with the passive shading system. **Acoustic Comfort:** • Acts as an acoustic barrier to street noise, ensuring interior spaces are unaffected. **Ventilation:** • Facilitates airflow into and out of the building, following ventilation design concepts. **Technical Considerations:** • Two facade types are implemented: 1 Fixed modular aluminium-clad facade acts as a non-operable aesthetic barrier.	

© University of Pretoria

				2 Passive shading system, operated by users, is integrated into the window cavity. • LED lighting within the fixed modular panels enhances the building's aesthetic. • Modular facade system simplifies maintenance and panel replacement (ArchDaily, 2019).	

Table 8. Table of detailed case study 4 analysis (DaEncarnacao, 2024).

CASE STUDY 5

Name of Place: Council House 2 / DesignInc / 2006

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
Melbourne / Australia	Cwa	Commercial	Multistorey	Active	Dynamic biomimetic double skin façade system
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The building's design is inspired by nature, incorporating climate-moderating features like tapered ventilation ducts and daylighting	The front of the building is made up of slats that cover a glass wall completely (MikePearce 2016). These slats can be moved mechanically.	Computational simulation through generating an energy model of the building in the design stages (ArchDaily 2013).	The building achieves a 50% reduction in energy consumption, 87% in gas consumption, and 72% in main water supply. Innovative	The building incorporates several advanced strategies for energy efficiency and thermal comfort: **Thermal Regulation:** • Mass and Cooling: Heat is trapped by thermal mass,	**Technical Constraints:** • Utilising thermal mass for heat absorption may require specific materials and construction techniques, potentially increasing

© University of Pretoria

strategies. An undulating concrete floor structure helps control temperature. The DSF features a timber layer for shading and a transparent inner layer for light and views, operated mechanically for ventilation (ArchDaily, 2013). The exterior reacts to the environment, showcasing biomimicry at its finest, with the structure appearing alive based on surroundings (MikePearce, 2016).	Pivot up and down depending on the sun's position and time based on the time. (MikePearce 2016).		features are projected to recoup costs in five to ten years, driven by improved air quality and energy savings estimates (ArchDaily, 2013).	regulating temperature throughout the day. Chilled beams, comprising copper pipes that release cool air, help maintain temperatures after the night purge effect diminishes. • Ventilation System: The facade system enables efficient cooling by managing temperature differences between night and cooler air. **Energy Efficiency:** • Water Management: Water sourced from city sewage is filtered and used for toilet flushing, plant watering, and air conditioning. The AC water trickles down the structure's exterior via "shower towers" to cool commercial spaces. • Phase Change Cooling: A phase change device in the basement, using 10,000 stainless steel spheres filled with salts, cools water for distribution. • Shading System: Heat absorption is minimised by positioning glass panels behind an automated shading system. **Indoor Air Quality:** Oxygen Circulation: Plant-covered surfaces promote	initial costs and complexity. • Combining electricity and heat-generating panels with a gas-powered cogeneration plant requires significant upfront investment and sufficient rooftop or facade space. • The timber vertical slats system must be durable, weather-resistant, and reliably automated to avoid malfunction. • Ensuring consistent airflow throughout the building demands precise design and integration of ventilation components, posing technical challenges. **Maintenance Concerns:** • Incorporating plant life within the building necessitates ongoing maintenance, adequate light, water supply, and pest control. **Cost Concerns:** • Using recycled wood and sustainable materials may limit availability and raise procurement costs. • Maintaining air exchange every thirty minutes requires a high-performing HVAC system, potentially increasing energy consumption and operational costs.

© University of Pretoria

				oxygen circulation indoors and outdoors (Mike Pearce, 2016). • Air Exchange: The building undergoes an air exchange every thirty minutes, significantly enhancing air quality (Mike Pearce, 2016). • Wind Turbines: Installed at the top of the building, they enhance airflow and ventilation. **Glare Control:** • Dynamic Facade Systems: Adjustable slats pivot vertically based on sunlight angles to regulate daylight and minimise glare. • Glass Elements: Thoughtful placement reduces heat while allowing natural light to illuminate the interiors. **Ventilation:** • Fresh Air Vents: Fresh air ascends through floor vents, controlled by a phase change cooling system (Mike Pearce, 2016). • Hourly Air Exchange: This improves ventilation and air quality. **Sustainability and Engineering:** • Natural Processes**:** The design captures relationships seen in nature, employing timber slats, wind turbines, automatic wood shutters,	

© University of Pretoria

				shower towers, and a phase change system. **Strategic Design:** The strategic placement of windows and the use of chilled beams enhance energy efficiency and ensure comfort. Overall, the building's intricate systems aim to create a pleasant environment by aligning with natural processes and sustainability objectives.	

Table 9. Table of detailed case study 5 analysis (DaEncarnacao, 2024).

CASE STUDY 6

Name of Place: Alexander Forbes - Paragon Architects

Location:	**Climate region:**	**Building Typology**	**Number of Storeys**	**Active or Static façade system**	**Façade System Type**
Johannesburg	Cwa	Commercial	Multistorey	Hybrid	4,200 m² 31.2 t Angled Standing Seam System
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The building's openness is achieved with 22,000 metres of glass illuminating 58% of the space and offering views to 64% of the office areas.	• RHEINZINK-prePATINA BlueGrey angled screens on the Northern facade. • Automated textile screens on the West facade	Thermal factors and influences were thoroughly researched and discussed with clients and manufacturers.	The construction received a certification status of 4 stars from the GBCSA, ensuring a suitable interior space for users. It also achieves a 40% reduction in	Comfort: An effective facade design can improve indoor thermal comfort by minimising temperature fluctuations and drafts. This creates a more pleasant	High maintenance costs have led to neglect of facade systems like the adaptive and adjustable West facade, rendering them stagnant

© University of Pretoria

Sun shading blinds made from Ferrari fabric, controlled by sensors, provide shade while ensuring safety. The unique concrete design on the facades, weathers over time, enhanced with German imported pine and clad in Rheinzink for texture. Rheinzink's eco-friendly properties and flexibility make it an ideal material for creating shapes and forms.	that adjust based on sun detection. • Curtain wall systems across the entire site.		energy costs compared to similar-sized buildings.	environment for occupants throughout the year, enhancing their satisfaction and well-being.	and unable to accommodate external conditions as intended.

Table 10. Table of detailed case study 6 analysis (Sibisi, 2024).

CASE STUDY 7

Name of Place: University of Hong Kong, (the Kadoori Biological Sciences Building).

Location:	**Climate region:**	**Building Typology**	**Number of Storeys**	**Active or Static façade system**	**Façade System Type**
Hong Kong, China	Cwa	Mixed-use	Multistorey	Static	DSF
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
This structure in Hong Kong maximises eco-potential with unique design	• The building features a mix of tiles, glass panels and a steel exterior on the	To let in light, into the labs the engineer figured out the best angle, for	The building is projected to conserve around 53,360 kilowatt hours every year	• Each floor features open metal grilles for air circulation and	• **Climate Sensitivity:** DSF's effectiveness is influenced by climate elements like moisture levels, temperature and

© University of Pretoria

features, including an outer glass screen positioned 2.5 metres from the building's exterior wall. The gap between layers of the double skin houses building systems and facilitates natural ventilation, minimising solar heat absorption. Each floor has a metal grid for airflow and maintenance access. Heat-producing equipment is strategically placed to dissipate heat externally.	façade double skin system incorporating layers, for added depth. Ceramic tiles cover the walls, complemented by windows shielded by aluminium and sunshades. • Dual layer glass curtain walls, on the side serve practical purposes.	sunlight to come into the building. They then put in fritted glass and clear glass bands to help allow the daylight to go through.	adding, up to 2.67 million kilowatt hours, over five decades. Moreover, it aims to lower CO_2 emissions by 37.6 tonnes totalling 1.88 million tonnes across a span of 50 years.	maintenance access. • Heat-generating equipment is placed in the building's service area to expel heat outdoors (Author, Year). • Fritted glass in the screen wall blocks radiation, with the space between glass layers expelling air upward to reduce solar heat absorption. • Cost-effective fritted glass on the outer layer minimises solar radiation. • Laboratories' security is enhanced by external access to building services via ducts and staircases. • External installation of building services allows maintenance without disrupting laboratory operations, minimising contamination risks.	the air flow. Precise design and control mechanisms are crucial for maximising indoor comfort and energy efficiency in various weather conditions. • **Aesthetic Considerations:** Designing an aesthetically pleasing DSF requires meticulous attention to materials, proportions, and detailing. Balancing visual appeal with functional requirements can be challenging. • **Fire Safety Concerns:** DSF systems may pose fire safety issues, especially regarding fire spread between layers and accessibility for firefighting. Incorporating adequate fire protection measures and emergency evacuation protocols is crucial during the design phase.

Table 11. Table of detailed case study 7 analysis (Sibisi, 2024).

© University of Pretoria

CASE STUDY 8

Name of Place: National biodiversity pavilion

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
New Mexico	Cwb	Commercial	Multistorey	Active	Dynamic Facade
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The lower façade showcases endemic biodiversity by blending with the surroundings, while the upper levels feature a glass and perforated aluminium double skin façade (DSF) that adjusts lighting and ventilation. The unique façade consists of 300 by 200 mm aluminium panels that sway along with wind, reflecting the area's climate and symbolising its role in sustaining biodiversity and enlivening the building's exterior.	• 30x20 cm aluminium modules make up the façade, which moves in response to the wind. • The building's wall is constructed from cantera, a volcanic stone that is a prominent feature of the local biodiversity. This stone was created by the Xitle eruption, which was also named Pedregal, the region where Ciudad Universitaria is situated. • Aluminium fins run down along the facades adding an additional static facade system.	Measuring the internal temperature and humidity of the building can be done on a quantitative and qualitative approach.	Provides active and passive cooling while enhancing indoor air quality.	**Climate Sensitivity:** • The aluminium modules wave in response to the interior environment, covering the glass facade where less light is needed, ensuring thermal comfort. **Aesthetics:** • The living facade element enhances the design aesthetically.	Maintaining the building, especially the adaptive and adjustable living facade systems, comes with a high cost to ensure continued effective performance.

Table 12. Table of detailed case study 8 analysis (Sibisi, 2024).

© University of Pretoria

CASE STUDY 9

Name of Place: Britam Towers,

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
Nairobi, Kenya	Cwb	Commercial	Multistorey	Static	Passive Facade
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The building boasts a stunning 3D geometric shape with an exterior adorned by Egg Crate rod Solar shades extending to the peak. These shades enhance airflow, regulate temperature, and maximise natural light. Positioned on the glass facade, they aid in year-round cooling by regulating solar radiation, marking an advancement from traditional shading methods.	• The structure features a shading system designed in a fixed egg crate style. This design was chosen for its efficiency compared to internal systems. • Opting for terracotta rods, for the egg crate shading systems enhances durability and adds a unique touch. The use of this material ensures upkeep and prolonged functionality. • Within the building spaces horizontal Venetian blinds serve as a shading system to provide extra shade. • The solar shading design incorporates tinted blue glass.	The building's orientation was carefully chosen to suit its surrounding context and accommodate the prevailing climate conditions throughout the year.	• The egg crate external solar shading system maintains a steady 25°C temperature year-round by regulating sunlight entry. • Tinted glass ensures commercial buildings maintain 500 lux illumination levels.	By incorporating egg crate devices there is an improvement in the building's performance, through increased light and decreased solar radiation on windows and reduced dependency on artificial lighting. Since the building is in a tropical climate there is no need for a customisable solar shading system due to the stable temperature. While individuals do have to manually do adjustments, an option having a fixed design that caters to the needs of all users is seen as advantageous and well received.	• The design targets the 'average user,' lacking adaptability options. • Technical approach and building scale raise maintenance and cost concerns.

© University of Pretoria

Table 13. Table of detailed case study 9 analysis (Sibisi, 2024).

CASE STUDY 10

Name of Place: University of Pretoria Plant Science Complex (2012)

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
Pretoria, South Africa	Cwb	Educational	Multistorey	Static	Green façade
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The building design integrates energy-efficient strategies to enhance natural ventilation, control solar exposure, minimise heat gain, and reduce electricity usage. The positioning and layout were meticulously planned to optimise climate regulation and minimise heat absorption using screens, reflectors, and thermal mass. Thermal mass is achieved through rock walls and walls adorned with stone and clay pavers.	• Natural ventilation for the basement is achieved through openings in the ground floor slab and louvres around the building's base. • Strategic planting on plinths creates a temperate microclimate along the perimeter. • The design features vertical rock walls composed of steel frameworks with baskets filled with rocks and planters, showcasing plants. • Red brick paving and	The effectiveness of the facade was initially assessed by comparing it to green facade systems and evaluating its impact through research conducted by engineers. Assessing the temperature and humidity levels of the building can be approached from both qualitative perspectives.	In their research on the temperature and illuminance output of vegetated walls, Ojembarrena et al., (2013), Sheweka and Magdy (2011) found that incorporating vegetation on a building's façade can enhance indoor temperatures. This enhancement is attributed to the shading provided by the vegetation and the cooling effect of evapotranspiration from the leaves, which lowers the temperature of outdoor air entering the building and mitigates uncomfortable summer conditions.	• Enhancing urban environments through mechanisms such as dust capture, CO_2 recycling and sequestration, and the breakdown of various gaseous pollutants. • Reducing urban heat absorption by alleviating heat Island effect and cooling urban canyons where heat accumulates. • Research by Sheweka and Magdy (2011) demonstrated that vegetated building facades improve indoor temperatures. Vegetation provides shade and cools the air through evapotranspiration,	Green facades or living walls present several challenges, including proper construction techniques, plant selection, maintenance, and sustainability. Cameron et al., (2014) express concern that some green wall systems fail to meet sustainability standards due to excessive use of water, nutrients, and energy for irrigation. However, the limitations of resources that typically restrict

© University of Pretoria

	cladding on the corners pay tribute to the historical significance of the traditional red Kirkness bricks used around the campus. • The North and Western facades incorporate steel screens with cylindrical elements, textile reflectors with perforations supported by steel frames, and concrete louvres with steel frame support. • Perforated concrete walls are also part of the design.			reducing the temperature of outside air entering the structure and alleviating summer discomfort. • Boosting urban biodiversity. • Reducing noise pollution and providing sound insulation. Enhancing the visual and aesthetic appeal of urban buildings.	the growth of cremnophytes on natural cliff faces—such as limited space, soil, and moisture—have been largely addressed on the UP-Plant Sciences wall.

Table 14. Table of detailed case study 9 analysis (Sibisi, 2024).

CASE STUDY 11

Name of Place: Podium AT Menlyn / Boogertman & Partners

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
Pretoria/Tshwane / South Africa	Cwb	Commercial	Multistorey	Passive	DSF
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
A layered double skin façade, with	For the Glazing façade, 3 different	The architects sought a	Initially the strategy is quite	• The DSF promotes occupant comfort by	• Some notable constraints of

© University of Pretoria

an air corridor serves as insulation, against temperatures. The open top and bottom of the glass layer allow heat to escape from the cavity space bringing in a breeze. This technique is commonly employed in Europe. (Boogertman & Partners Architects 2014)	types of coloured glass are used, the laminate glass with a vinyl in between 2 pieces of glass (Boogertman & Partners Architects 2014).	strategy that maintained the facade's aesthetics while effectively cooling the building, drawing inspiration from successful European practices. This approach, proven effective through case studies, resulted in a seamless look. The building holds Green Star, LEED, and Net Zero certifications (Boogertman+Partners Architects 2014).	common in European buildings, so it has already been tried and tested and because of that it has also proven to work in some of the African climatic conditions as well (Boogertman & Partners Architects 2014).	facilitating airflow for cooling and reducing reliance on energy-consuming systems. • External shading minimises glare and direct sunlight entry, enhancing indoor comfort. • The DSF acts as a sound buffer, reducing noise for a peaceful indoor environment (Boogertman & Partners Architects, 2014).	using a double facade system are that the floor space required for the building is then occupied by this external facade. • Using the double facade would also mean more investments when it comes to the usage of materials. Since a second layer of facade has to be constructed on the outside.

Table 15. Table of detailed case study 11 analysis (Author, 2024).

CASE STUDY 12

Name of Place: The Grove/ WOHA Architects

Location:	**Climate region:**	**Building Typology**	**Number of Storeys**	**Active or Static façade system**	**Façade System Type**
Guangzhou / China	Cwa	Residential / commercial	Multistorey	Active façade	Green façade (Vertical Garden)
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
Green facade systems integrate	Traditional plants that require less	Using sensors for microclimate	Green facades can prevent	The green façade acts as an	Green facades might be costly

© University of Pretoria

vegetation into building exteriors, offering benefits like improved air quality and thermal insulation. Key considerations include selecting suitable plants, ensuring structural support, implementing irrigation and drainage systems, facilitating maintenance access, integrating with building systems, addressing fire safety, and ensuring sustainability with durable, low-maintenance materials.	water (Xerophytes)	monitoring around the building measures the green facade's effectiveness in reducing ambient temperatures. Thermal imaging can visualise temperature variations, showing that areas with plants are consistently cooler. Adaptive Capacity Wheel (Cüce et al., 2021).	solar radiation through evapotranspiration, and eventually lowers the surrounding temperature.	insulator that prevents the building heating up. Plants foliage blocks direct sun rays, keeps the interior quite cool (Cüce et al., 2021).	in certain instances and require regular maintenance, water maintenance.

Table 16. Table of detailed case study 12 analysis (Author, 2024).

CASE STUDY 13

Name of Place: BMW Head office / Boogertman + Partners

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
Johannesburg / South Africa	Cwb	Commercial	2/3 storey	Active façade	Dynamic Façade system
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**

© University of Pretoria

The dynamic solar tracking louvres utilise mechanical means to rotate to the direction of the sun to minimise the extreme sun from penetrating into the building.	Smart building technology, Solar tracking louvres.	The building is awarded 5-star certification status from GBCSA, and the rating tools cater for ensuring that the indoor environment is fit for people to use. It also nets certified and LEEDS certified. Also, LEEDS and Net zero certified.	Innovative and smarter technology have been proven to be more efficient.	They are adaptable, and innovative solar tracking technology and they adjust with the orientation of the sun to provide the building with best performance, they provide environmental sustainability to the building.	They are costly and require high maintenance. They consume power, depending on what type of power is used.

Table 17. Table of detailed case study 13 analysis (Author, 2024).

CASE STUDY 14

Name of Place: The Lantern / VTN Architects

Location:	**Climate region:**	**Building Typology**	**Number of Storeys**	**Active or Static façade system**	**Façade System Type**
Hanoi / Vietnam	Cwa	Commercial	Multistorey	DSF	Ventilated Façade system: Dynamic Façade system
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
DSF, the external façade provides breezes to freely move through the blocks to cool the building, the hollow design of the blocks allows minimum exposure to direct	Double façade system of Perforated Terracotta blocks and curtain wall.	Natural ventilation, energy efficiency	Using Perforated Terracotta blocks has displayed numerous benefits as it allows cool breezes to sip through and provide a cool	Provides Thermal benefits to building. It provides energy efficiency means	There may be challenges with durability and there are design limitations as well. It is not compatible with a lot of other materials. It is costly

© University of Pretoria

sunlight but allows adequate light in. This is an old traditional method used in Vietnam to cool buildings before air-conditioning systems were invented.			indoor environment for buildings.		

Table 18. Table of detailed case study 14 analysis (Author, 2024).

CASE STUDY 15

Name of Place: Monash University 2nd phase of the Science Centre.

Location:	Climate region:	Building Typology	Number of Storeys	Active or Static façade system	Façade System Type
Melbourne / Austrailia	Cwa	Institutional	Multistorey	DSF	Double façade systems
Façade system strategy and technical considerations	**Material considerations**	**Method for measuring effectiveness of system**	**Recorded achievements**	**Benefits**	**Constraints**
The building integrates a DSF system, featuring an aluminium external facade on one side and vertical fabric screens on the other. The aluminium facade blocks direct sunlight, while any heat entering is directed to a vertical core with an opening at the top for hot air to escape. The fabric screens facilitate the flow of fresh air, and on the second-to-last	**DSF System** • Aluminium façade • Vertical fabric screens	Through the analysis of the airflow dynamics in efforts to grasp an understanding of the stacking effect, and the impacts provided by the strategy in the building.	Provides passive cooling and a robust improved indoor air quality (Sung & Kim, 2019).	Cost saving, sustainable, energy-efficient, natural airflow, and enhances indoor air quality.	Its effectiveness varies significantly based on the prevailing climatic and weather conditions, there might be odour transmissions into the building and air quality concerns.

© University of Pretoria

floor, heat escapes through a vent, while the remainder exits through the top opening.					

Table 19. Table of detailed case study 15 analysis (Author, 2024).

4.3 Thermal Comfort Strategies

4.3.1 Common Strategies:

Across the case studies, some common thermal comfort strategies include:

1. Integration of passive design principles such as natural ventilation, solar control, and thermal mass to regulate indoor temperatures.
2. Use of dynamic façade systems that adjust to external conditions to minimise heat gain and optimise natural light penetration.
3. Incorporation of green façade elements like plants and greenery to enhance thermal comfort and air quality.
4. Utilisation of double skin façade systems with air corridors to provide insulation against extreme temperatures and promote natural ventilation.

4.3.2 Effectiveness:

These strategies have shown effectiveness in different climate classifications:

1. In **Cwa** regions like Johannesburg, strategies such as dynamic solar tracking louvres and double skin façades have been effective in minimising heat gain and enhancing occupant comfort.
2. In **Cwb** regions like Pretoria, the incorporation of passive design strategies and thermal mass has proven successful in minimising energy usage and maintaining an adequate thermal amelioration potential.
3. In **BSh** regions, innovative approaches like biomimetic façade systems have demonstrated effectiveness in reducing the need for artificial lighting and climate control systems while promoting a healthier indoor environment.

4.3.3 Innovative Approaches:

Some innovative strategies found in specific case studies include:

1. Biomimetic façade systems that can imitate ecological operations to improve sustainability and energy efficiency.

© University of Pretoria

2. Use of coloured glass and laminate glass in façade construction to improve aesthetics and filter air pollutants.
3. Implementation of chilled beams and night purging techniques for maintaining comfortable temperatures and enhancing indoor air quality.

These innovative approaches showcase the continuous evolution and adaptation of thermal comfort strategies to meet the diverse needs of different climate regions and building typologies.

4.4 Facade Systems

4.4.1 Types of Facade Systems:

1. Dynamic Facade Systems: These systems adjust to external conditions to maximise daylighting penetration and reduce heat intake. Examples include dynamic solar tracking louvres and double skin façades with air corridors.
2. Green Facade Systems: Incorporating plants and greenery into the facade design to enhance thermal comfort, air quality, and aesthetics. This type of system promotes sustainability and biophilic design principles as depicted by figure 4.

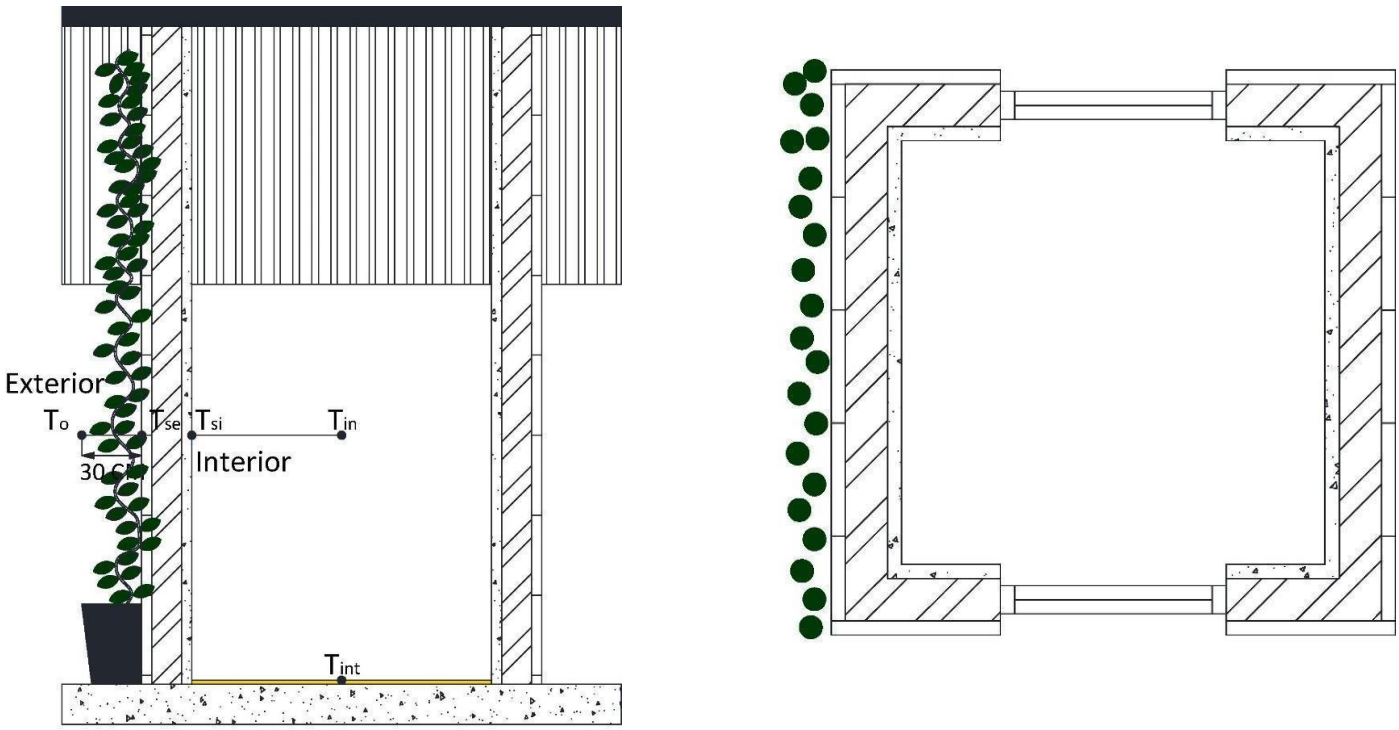


Figure 4: Greef façade system section and plan view (Widiastuti et al., 2020).

© University of Pretoria

3. Biomimetic Facade Systems: Mimicking natural processes to advance energy efficiency and reduce the need for artificial lighting and climate control systems. These innovative systems enhance occupant comfort while promoting sustainability.

4.4.2 Performance Metrics:

- Energy Efficiency: Facade systems such as dynamic solar tracking louvres and double skin façades have shown significant reductions in energy consumption, with some case studies reporting up to a 50% decrease in energy usage.

- Thermal Comfort: Strategies like natural ventilation, thermal mass utilisation, and chilled beams have been effective in maintaining comfortable indoor temperatures and minimising dependence on active cooling systems.

- Occupant Satisfaction: Implementing innovative facade systems has led to superior indoor air quality, increased natural light penetration, and overall occupant well-being. Many case studies have reported high levels of occupant satisfaction and comfort.

4.4.3 Comparative Analysis:

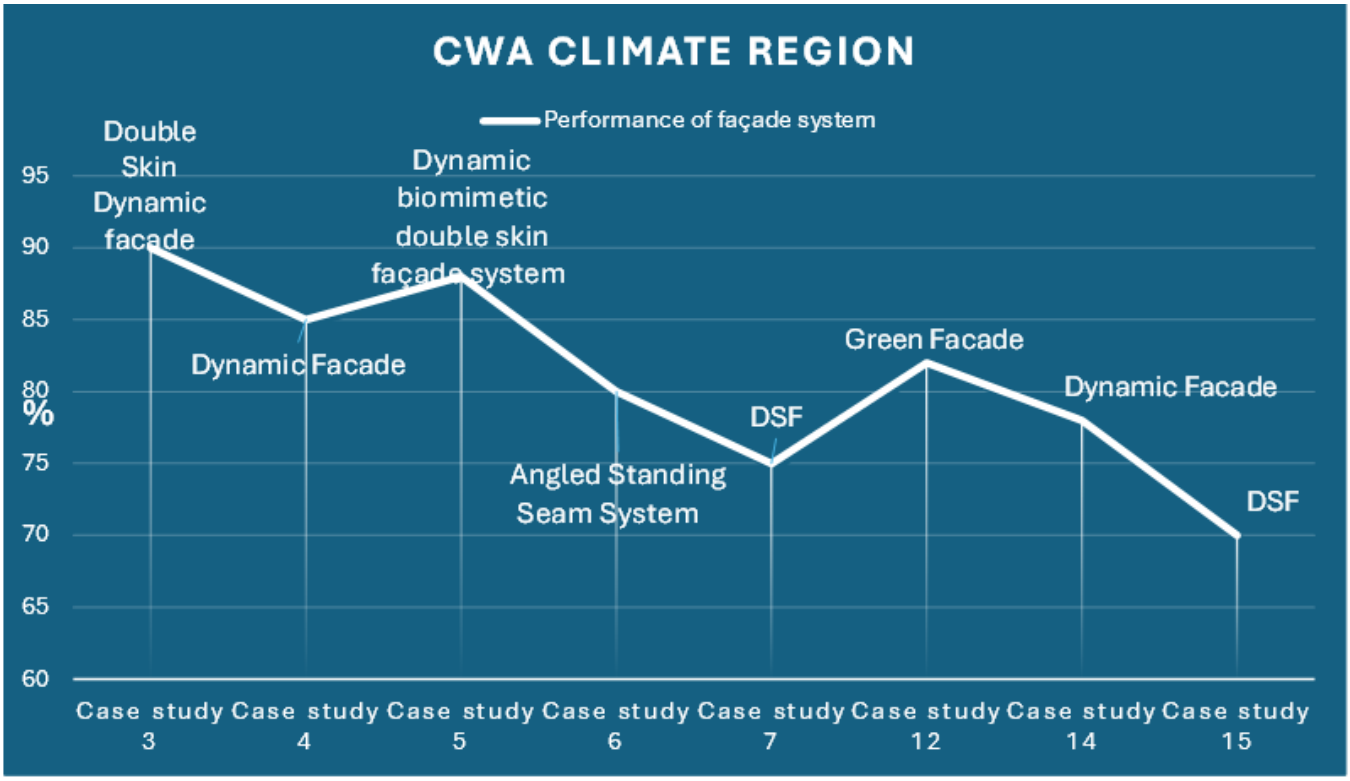


Figure 5: Façade system performance in Cwa climate region (Author, 2024).

© University of Pretoria

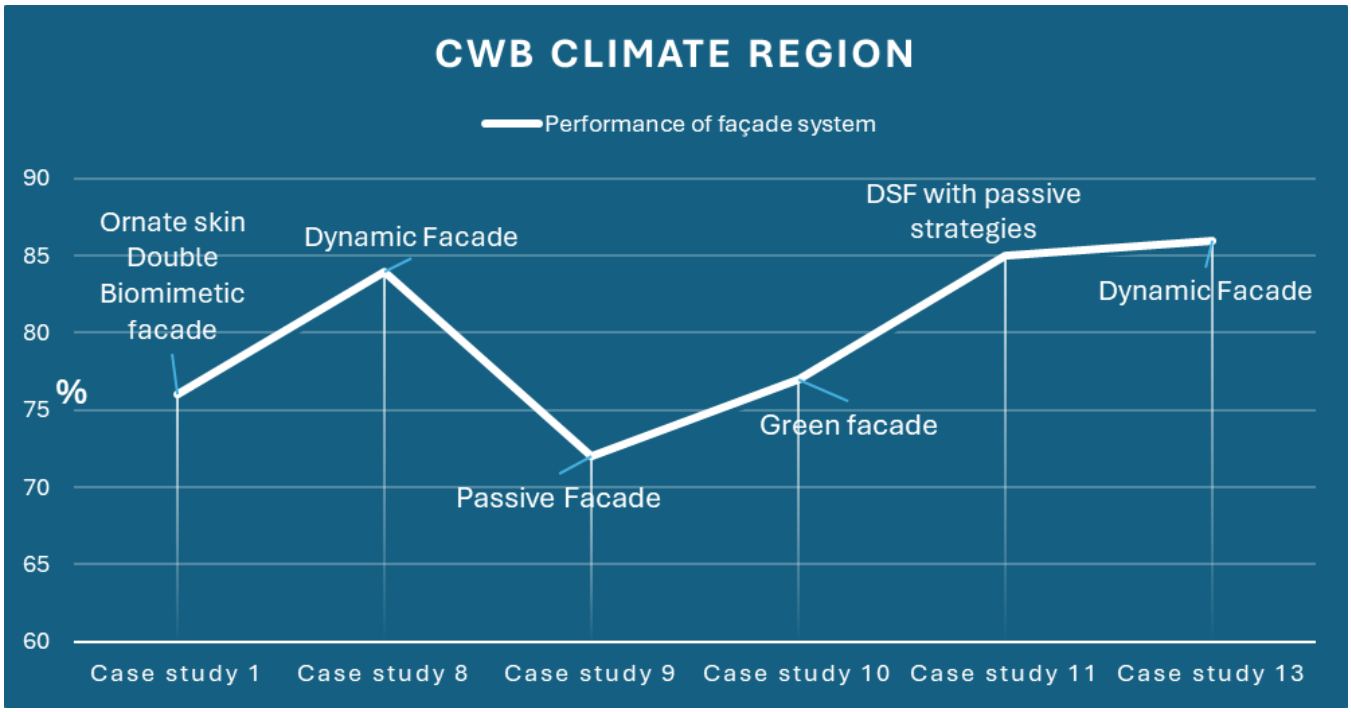


Figure 6: Façade system performance in Cwb climate region (Author, 2024).

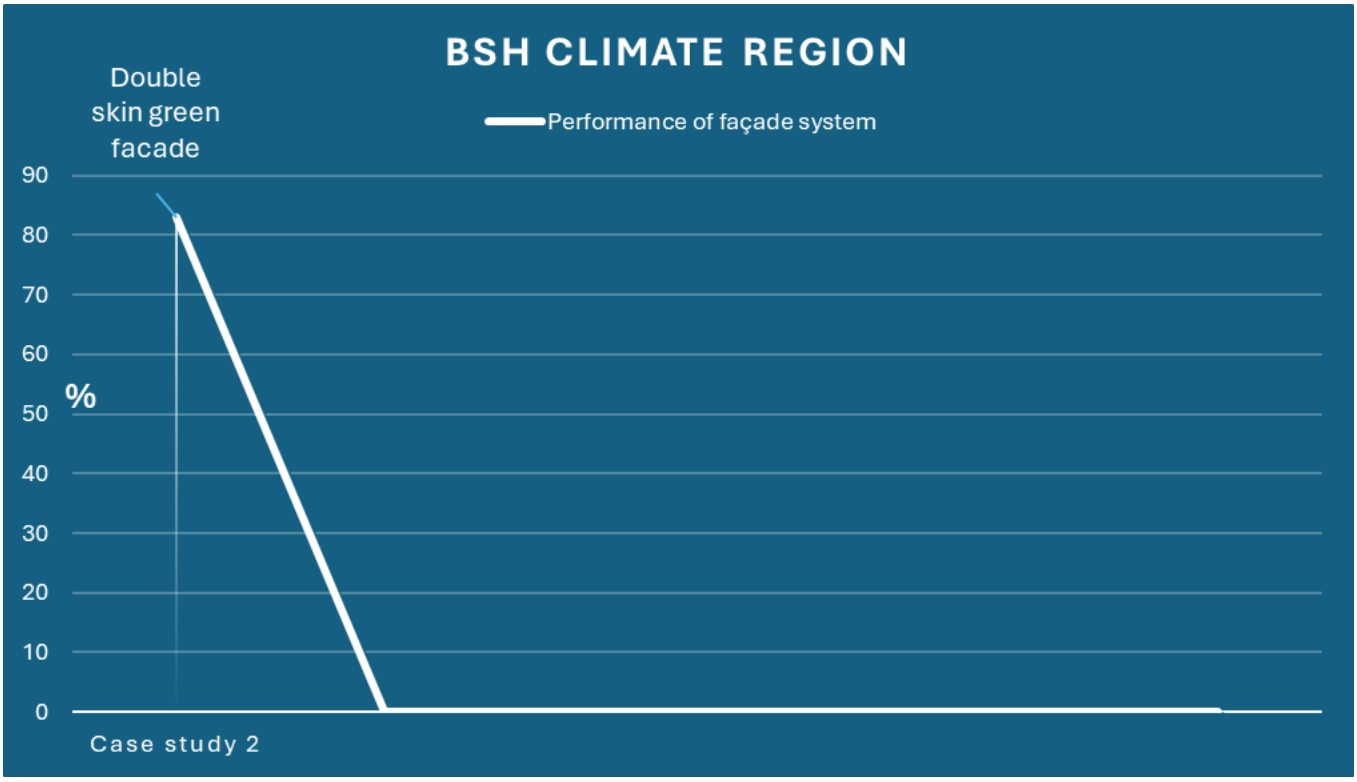


Figure 7: Façade system performance in Bsh climate region (Author, 2024).

© University of Pretoria

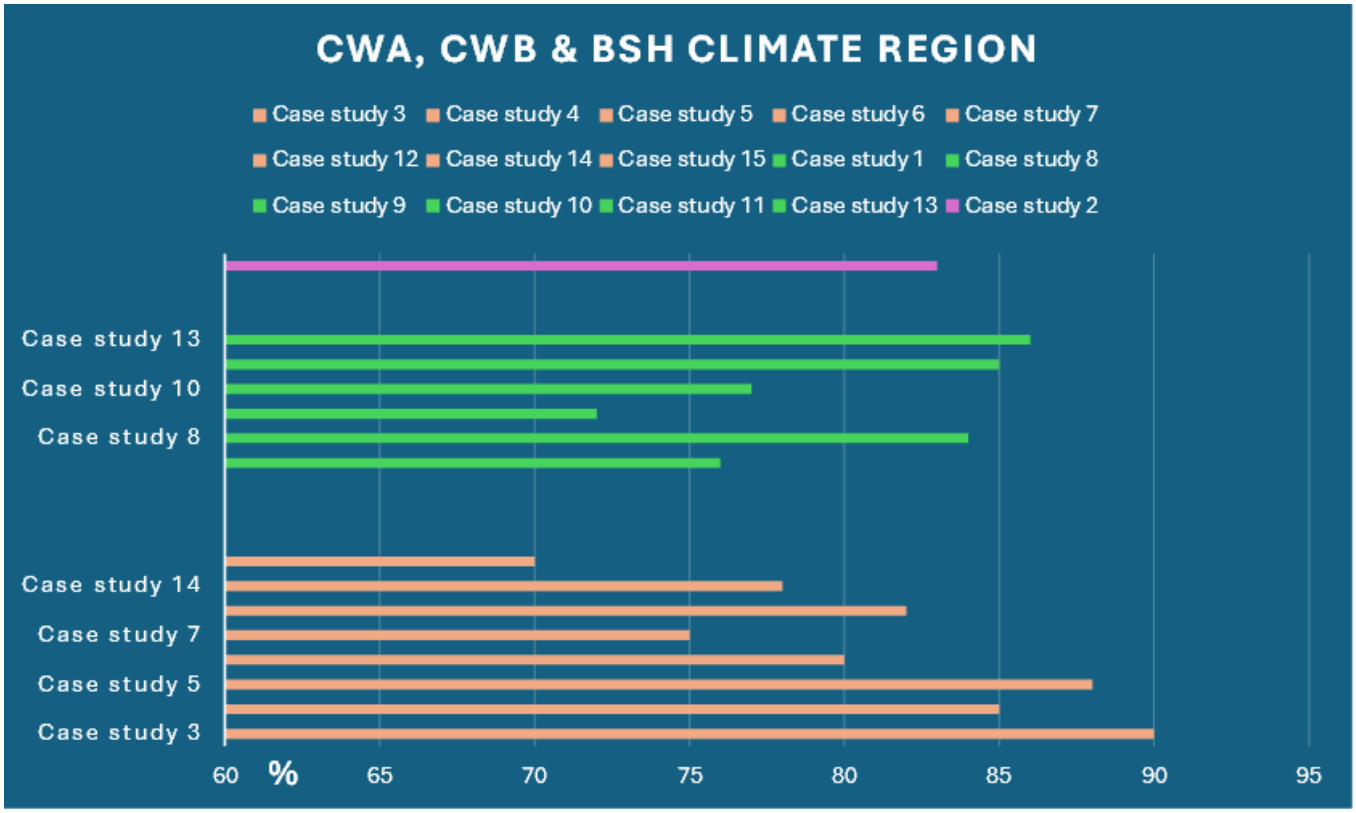


Figure 8: Façade system comparison in cwa, cwb and bsh climate region (Author, 2024).

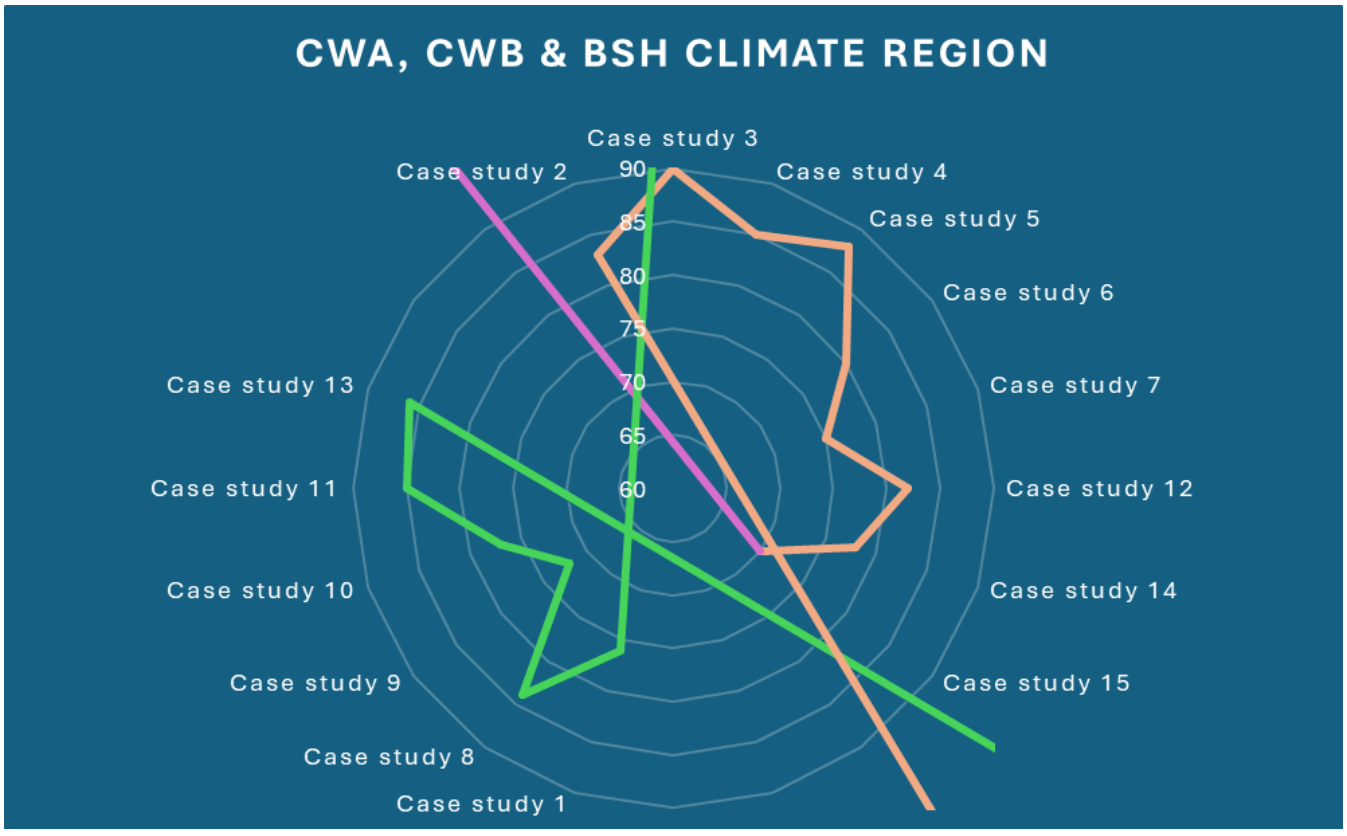


Figure 9: Spider chart comparison (Author, 2024).

© University of Pretoria

- In Cwa climate regions,

Dynamic facade systems have proven to have the greatest performance score ranging 78% to 90% as depicted in case studies 3, 4, 5, 6, 8, 13, and 14 as depicted in the figures above, depending on the extra functions or features added to it like integrated photovoltaic panels on sunshade devices or a biomimetic DSF system, which allows even greater performance. They have the capacity to effectively provide natural light, transparency, energy optimisation and drastically reduce the heat gain.

- In Cwb climate regions

Using DSF with the incorporation of passive design principles is quite ideal as shown by figures above especially for regions like Cwb especially in the context of Tshwane RSA associated with frequent power outages and DSF elements has shown success in minimising energy use while improving thermal comfort.

- In Bsh climate regions,

Biomimetic facade systems have proven to be innovative and effective in various climatic conditions especially bsh climates, offering a unique strategy that are able to efficiently utilise energy output and provide user comfort.

The comparative analysis shows the significance as to why the selection of facade systems that are tailored for specific climatic conditions and building requirements to attain adequate performance regarding thermal amelioration potential and energy efficiency, and occupant satisfaction is important.

4.5 Climate Adaptation Strategies

4.5.1 Adaptation Techniques:

1. Natural Ventilation: Using natural air flow approaches like operable windows, louvres systems, and air corridors to regulate indoor temperatures and improve air quality.

2. Solar Control: Implementing dynamic facade systems, shading devices, and sunshades to minimise heat gain, reduce glare, and optimise natural light penetration.

3. Thermal Mass: Indoor temperatures are stabilised, and the usage of mechanical cooling is reduced by Incorporating materials with elevated thermal mass properties to capture and store heat.

4. Green Infrastructure: Integrating green facade elements, living walls, and vegetation to improve thermal amelioration potential, air quality, and aesthetics while promoting sustainability.

© University of Pretoria

4.5.2 Impact on Thermal Performance:

- Natural ventilation approaches have had tremendous effects on minimising the reliance on active systems, improving the quality of air in interior spaces of buildings, and enhancing comfort for users.

- Solar control measures like dynamic facade systems and shading devices have significantly reduced heat gain, minimised glare, and optimised natural light penetration, leading to improved thermal comfort and energy efficiency.

- Thermal mass utilisation has helped stabilise indoor temperatures, reduce temperature fluctuations, and enhance overall thermal performance, contributing to energy savings and occupant comfort.

- Green infrastructure elements have positively impacted thermal performance by providing insulation, reducing heat island effects, and promoting a healthier indoor environment, thus enhancing overall building sustainability.

4.5.3 Best Practices:

1. Integration of Passive Design Principles: Incorporating strategies like thermal mass, natural ventilation, solar control and green infrastructure from the design inception to optimise the thermal performance and energy efficiency.
2. Climate-Specific Adaptation: Tailoring adaptation techniques to specific climatic conditions to maximise effectiveness and ensure optimal thermal comfort throughout the year.
3. Continuous Monitoring and Evaluation: Implementing systems to monitor and evaluate the performance of climate adaptation strategies to identify areas for improvement and ensure long-term sustainability and occupant satisfaction.

Following these best practices and incorporating climate adaptation techniques effectively, built environment professionals can create sustainable, energy-efficient, and comfortable indoor environments that respond to the challenges of varying climatic conditions.

4.6 Quantitative Analysis

4.6.1 Frequency of Technologies:

1. **Passive Cooling:** Passive cooling strategies were utilised in all case studies, with techniques such as natural ventilation, thermal mass utilisation, and shading devices being prevalent across the buildings.
2. **Natural Airflow (Ventilation):** Many of the case studies incorporated natural ventilation systems, with elements such as operable windows, louvres, and air corridors being common to enhance indoor air quality and regulate temperatures.
3. **Dynamic Facade Systems:** Dynamic facade systems, including solar tracking louvres and DSFs, were present in several buildings, demonstrating a trend towards utilising responsive building envelopes for energy efficiency and thermal comfort.

© University of Pretoria

4. **Green Infrastructure:** Green facade elements and living walls were integrated into a significant portion of the case studies, highlighting the importance of incorporating biophilic design principles for sustainability and occupant well-being (Figures 5, 6, 7, 8 and 9 display green facade information).

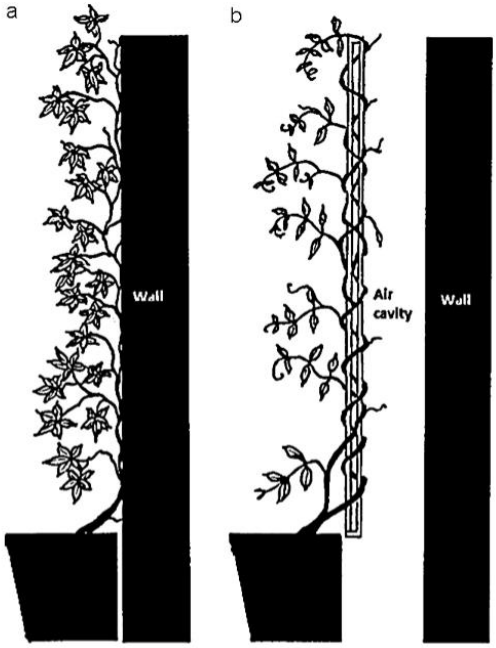


Figure 10: Types of green façade systems direct and DSF (Hunter et al., 2013).

Green façade type	Control-treatment	Method	Climate and location	Season	Building storeys and material	Aspect
DGF	BW	Obs	Humid sub-tropical (Sao Paulo)	W	2S; brick	SE
DGF	BW	Obs	Humid continental (Beijing)	S	2S; brick	W, S
DGF	BW	Obs, model	Humid continental (Beijing)	S	2S; brick	W, S
DGF	BW	Obs	Mediterranean (Greece)	S	5S; brick	E
DGF	BW	Exp	Hot, arid continental (Pretoria, SA)	S, W	1S; steel sheet	N
DGF	BW	Exp, model	Hot, arid continental (Pretoria, SA)	S, W	1S, fibro	N, W
DGF	BW	Obs	Humid sub-tropical (Japan)	S	2S; concrete	W
DGF	3W	Obs, model	Mediterranean (Greece)	S	1S; concrete	N, S, E, W
DGF	BW	Obs	Oceanic (Netherlands)	A	2S; brick	NW
DGF	BW	Obs	Oceanic (UK)	SP, S, A, W	nd	N, S, E, W
DGF	BW	Obs	Humid continental (IL, USA)	nd	3S; brick	S
DGF	BW	Obs, model	Humid continental (IL, USA)	Sp, S, A	1S; wall	nd
DS-GF	BW	Obs	Humid sub-tropical (Japan)	S	4S; concrete	SW
DS-GF	Bwin	Exp	Oceanic (Brighton, UK)	Sp, S, A	1S; window	SW
DS-GF	BW	Exp	Humid sub-tropical (Japan)	S	1s; wood/metal	S
DS-GF	BW	Obs	Dry Mediterranean (Spain)	Sp, S, A	nd	NW, SW, SE
DS-GF	4 spp	Exp	Dry Mediterranean (Spain)	S	1S; trellis	S
DS-GF	BW	Obs	Dry Mediterranean (Spain)	Sp, S, A	nd	NW, NE, SW, SE
DS-GF	BW, GW	Obs	Oceanic (Netherlands)	A	6S; brick	N-E
DS-GF	BW	Exp	Humid sub-tropical (MD, USA)	S	1S; timber	S, W
DS-GF	BW	Exp, model	Humid sub-tropical (MD, USA)	S	2S & 3S; timber	S, W
DS-GF	BW, LW	Exp	Laboratory	na	?S; timber	na
DS-GF	LW	Exp, model	Not specified	na	1S; window wall	S
DS-GF	BW	Exp	Tropical (Thailand)	S	1S, concrete	W
DS-GF	BW	Exp	Mediterranean (Greece)	S	Scale model: steel clad; ins	S?
DS-GF	BW	Exp, model	Mediterranean (Greece)	S	Scale model: steel clad; ins	S?
DS-GF	GW	Exp	Tropical/equatorial (Singapore)	M, intM	1S; concrete	nd

Figure 11: Green façade Variations (Hunter et al., 2013).

© University of Pretoria

Green façade type	Local weather station climate data			Microclimate in front of canopy			Microclimate within plant canopy			Microclimate behind plant canopy			Effect of green facade on building thermal environment			
	Rn (W/m^2)	Air temp (°C)	Wind speed (m/s)	Rn (W/m^2)▲	Air temp (°C)▲	Wind speed (m/s)▲	Rn (W/m^2)	Air Temp (°C)	Wind speed (m/s)	Rn (W/m^2)■	Air temp (°C)■	Wind speed (m/s)■	Ext. wall temp (°C)	Int. wall (°C) or (W/m^2)	Int. air temp	Energy savings
DGF					●	●							●	●	●	
DGF				●	●	●		●	●		●		●	●	●	
DGF				●#	●#	●#		●#	●#		●#		●#	●*	●#	●*
DGF	●		●		●			●					●	●	●	
DGF					●	●	●	●	●		●		●		●	
DGF					●#	●#		●#	●#		●#		●#		●*	
DGF				●	●	●	●	●	●				●	●	●	
DGF	●#	●#	●#		●#		●*	●#			?	?	●*	●*	●*	●*
DGF					●	●		●	●				●			
DGF													●			
DGF				●	●	●		●					●		●	
DGF	●#	●#	●#	●#	●#	●#							●*	●#*		
DS-GF				●	●	●				●	●	●	●		●	
DS-GF				●			●			●			●			
DS-GF				●	●	●	●						●			
DS-GF				●	●	●				●	●		●			
DS-GF				●						●						
DS-GF				●	●	●				●	●		●			
DS-GF					●	●		●	●		●	●	●			
DS-GF				●	●						●		●			
DS-GF				●#	●#		●#				●#		●#	●#	●#	●*
DS-GF				●	●		●	●			●		●			
DS-GF				●#	●#		●#				●*		●*			●*
DS-GF					●	●						●			●	
DS-GF				●	●	●						●	●		●	
DS-GF				●#	●#	●#						●#?	●*		●*	
DS-GF				●	●	●							●			
nd	●#	●#	●#			●#							●*	●*	●*	●*

Figure 12: Green Façades Microclimate parameters and its effects on the thermal environment (Hunter et al., 2013).

Suitable mathematical methods

The sensible convective heat flux in a green layer of a GF system is calculated by means of Newton's law of cooling:

$$CV = h_c(T_{ea} - T_{gl})$$

where: CV is the sensible convective heat flux [W m^{-2}], h_c is the convective heat transfer coefficient [W m^{-2} K^{-1}], and T_{ea} and T_{gl} are the external air and the green layer temperatures [K], respectively.

The evaluation of the h_c coefficient is the basis for the convective heat flux calculation. Different formulae, both analytical and empirical, can be used to calculate the h_c coefficient.

Figure 13: Newton's law of cooling (Convertino et al., 2019).

© University of Pretoria

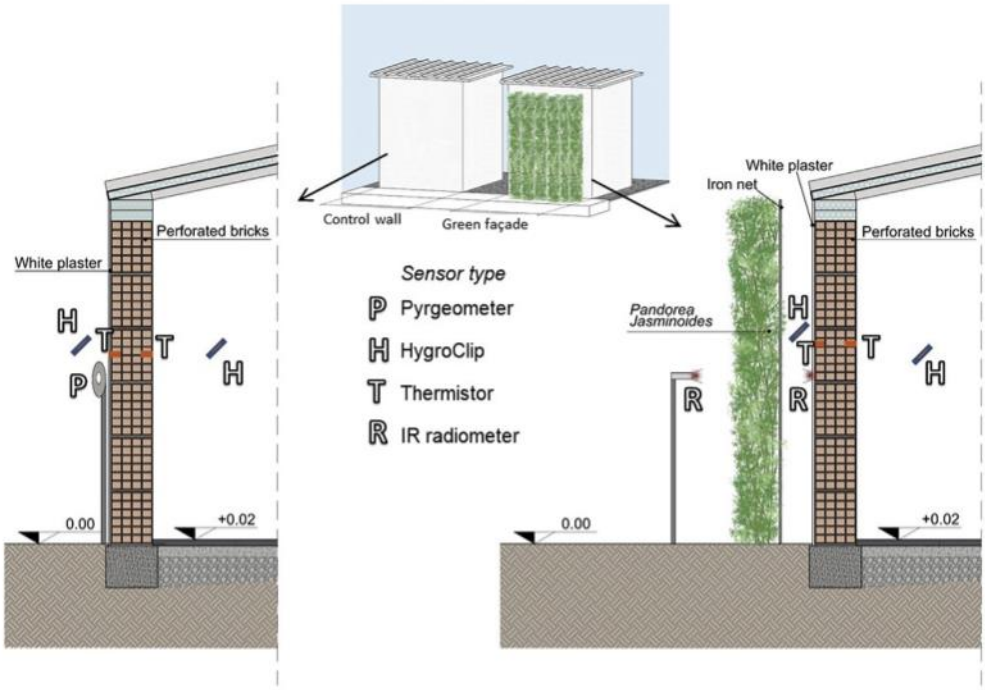


Figure 14: Green Façades testing and experiment (Convertino et al., 2019).

4.6.2 Performance Outcomes:

1. Energy Savings: The implementation of climate adaptation strategies resulted in notable energy savings across the case studies, with reported reductions in energy utilisation varying from 30% to 50% in contrast to conventional buildings.
2. Temperature Regulation: using thermal mass, natural air flow, and dynamic facades contributed to effective temperature regulation within the buildings, maintaining comfortable indoor temperatures and reducing the need for mechanical cooling.
3. Through promotion of natural air flow, green infrastructure, and sustainable materials, the case studies achieved improved indoor air quality, creating healthier and more comfortable environments for occupants.

The prevalence of passive cooling, natural ventilation, dynamic facade systems, and green infrastructure across the case studies underscores the importance of integrating these technologies and strategies to achieve significant performance outcomes regarding indoor environmental quality, energy efficiency, and thermal regulation.

4.7 Qualitative Analysis

4.7.1 Themes and Patterns:

1. **Sustainable Design Integration:** A prominent theme across the case studies is the integration of sustainable design principles, including passive cooling, natural ventilation, and green infrastructure, to enhance the thermal amelioration potential and energy efficiency.

© University of Pretoria

2. **Climate Specific Adaptation**: The case studies demonstrate the importance of tailoring adaptation strategies to specific climatic conditions, with buildings in different regions utilising unique technologies to optimise thermal performance and sustainability.
3. **Technological Innovation:** Dynamic facade systems, thermal mass utilisation, and advanced ventilation strategies emerge as key technological innovations that significantly impact building performance and environmental sustainability.
4. **Occupant Well-being Focus:** A consistent pattern is the emphasis on creating healthy indoor environments through improved air quality, natural light penetration, and thermal comfort, reflecting a commitment to enhancing occupant well-being.

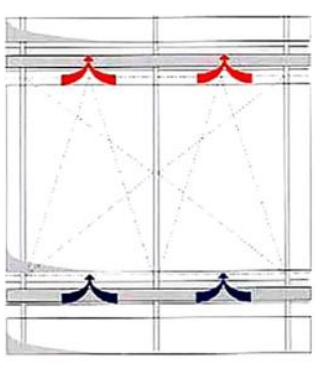
4.7.2 Case Study Highlights:

1. University of Pretoria Plant Science Complex (2012):

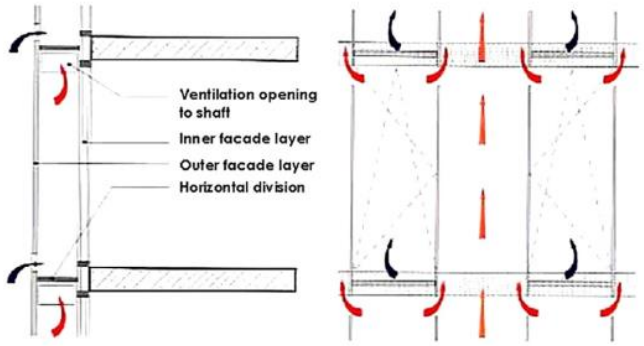
- Integrated passive design and energy-efficient principles to optimise natural ventilation, solar control, and thermal mass utilisation for reduced energy consumption and enhanced occupant comfort.
- Utilised a double facade system with open top and bottom sections to facilitate natural ventilation and minimise the need for mechanical cooling, showcasing a sustainable approach to climate adaptation.

2. Podium AT Menlyn by Boogertman + Partners (2012):

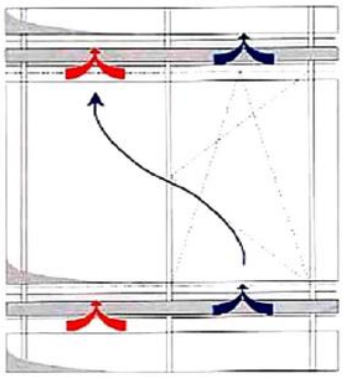
- Implemented a dynamic DSF system with air corridors to regulate indoor temperatures and enhance energy efficiency (Figures 10, 11 and 12 display how DSF function).



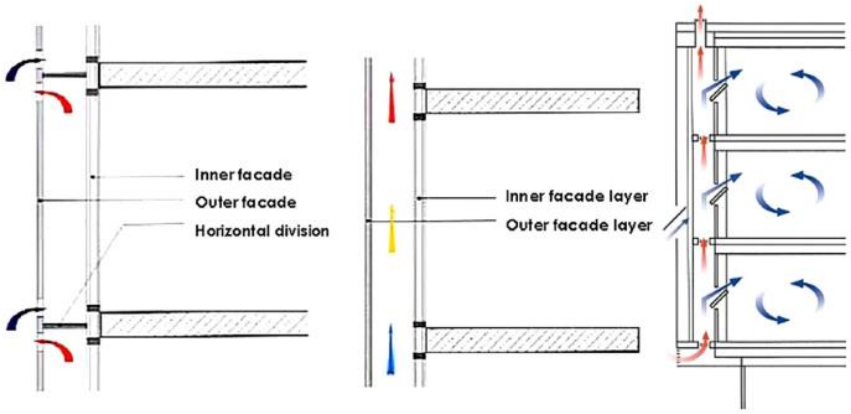
DSF – box window configuration, Source [14]



DSF – shaft box configuration, Source [14]



DSF – corridor configuration, Source [14]



DSF – Multi-storey (left) and twin façade (right) configurations, Source [14]

© University of Pretoria

Figure 15: DSF setup (Ghaffarianhoseini et al., 2016).

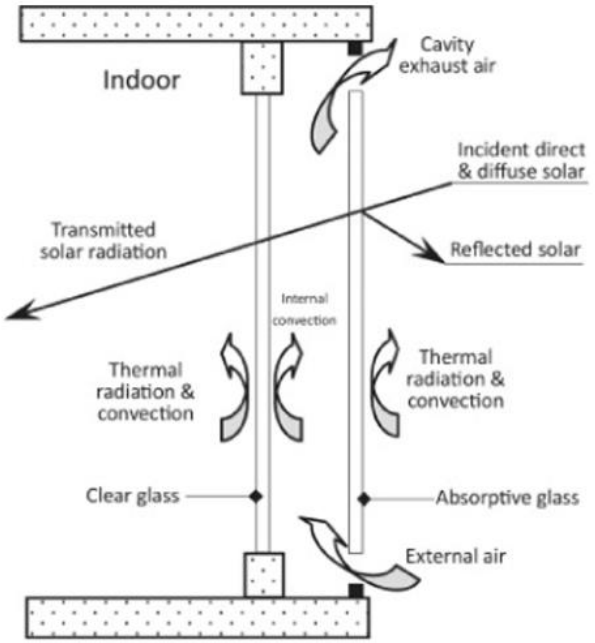


Figure 16: Heat transmission and airflow and in a ventilated DSF system (Ghaffarianhoseini et al., 2016).

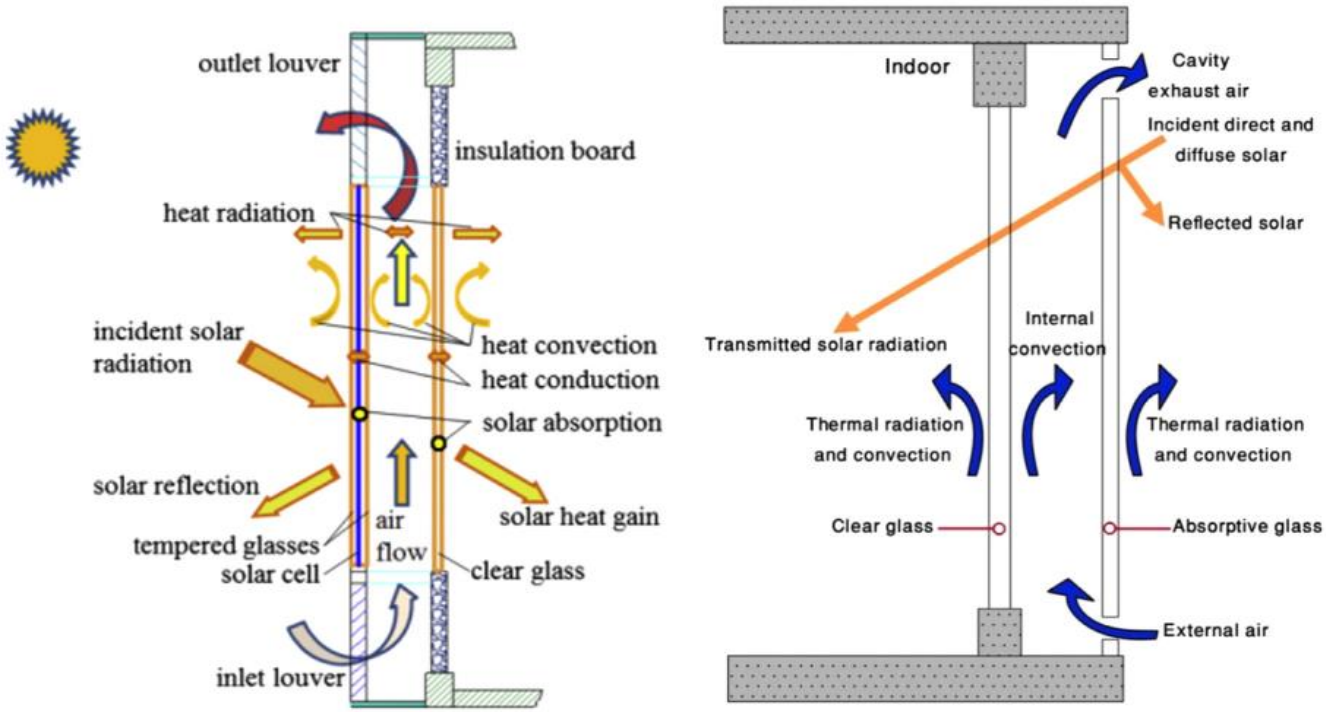


Figure 17: How heat is transferred when it circulates in a naturally ventilated DSF (Ghaffarianhoseini et al., 2016).

© University of Pretoria

- Utilised three types of coloured glass in the facade design to optimise natural light penetration while minimising heat gain, demonstrating a balance between aesthetics and performance.

3. Alexander Forbes by Paragon Architects in Johannesburg:

- Employed an angled standing seam system to achieve transparency and natural daylighting, fulfilling a significant portion of lighting needs and providing office areas with views.
- Demonstrated the effective use of glazing to enhance thermal performance, reduce energy consumption, and create a visually appealing and sustainable building design.

These case studies highlight the successful implementation of innovative technologies and sustainable design strategies to achieve energy efficiency, thermal comfort, and occupant well-being, showcasing best practices in climate adaptation and building design.

4.8 Synthesis of Findings

4.8.1 Cross-Case Synthesis:

1. Effective Building Technologies: The integration of passive cooling strategies, natural ventilation systems, and dynamic facade technologies emerged as effective strategies to improve thermal amelioration and energy efficiency across all case studies. In addition to improving the energy efficiency the technologies also improved indoor air quality and occupant well-being.
2. Thermal Adaptation Strategies: The utilisation of climate-specific adaptation strategies was crucial in optimising building performance in diverse climatic contexts. From dynamic solar tracking louvres in Johannesburg to double skin green facades in Pretoria, the case studies demonstrated the importance of tailoring thermal adaptation strategies to local climate conditions for maximum effectiveness.
3. Sustainable Design Principles: A common thread among the case studies was the incorporation of sustainable design principles such as green infrastructure, thermal mass utilisation, and natural ventilation to achieve long-term sustainability and resilience. By prioritising occupant comfort, energy efficiency, and environmental sustainability, the buildings showcased a holistic approach to thermal adaptation and climate-responsive design.

4.8.2 Contextual Adaptation:

1. Cwa: Buildings in cwb climate regions like in Johannesburg utilised dynamic facade systems like solar tracking louvres to improve thermal amelioration potential and minimise the solar heat gain in a climate characterised by hot summers and mild winters. The adaptive capacity of these technologies allowed for effective temperature regulation and energy savings in response to the region's climate demands.
2. Cwb: In cwb climate regions like in Pretoria, the integration of DSF systems and thermal mass utilisation played a key role in reducing heat gain and optimising natural

© University of Pretoria

ventilation. By leveraging passive cooling strategies tailored to the region's climate, buildings achieved significant energy savings and enhanced indoor environmental quality.

3. Climate-Responsive Design: The adaptation of facade systems to specific climatic contexts highlighted the importance of contextually relevant design solutions. By considering factors such as solar exposure, prevailing winds, and temperature fluctuations, the case studies demonstrated how tailored facade strategies can effectively mitigate thermal challenges and improve building performance in different climate regions.

The synthesis of findings shows the significance of integrating effective building technologies, climate-specific adaptation strategies, and sustainable design principles to achieve optimal thermal performance, energy efficiency, and occupant comfort in diverse climatic contexts. By contextualising facade systems and strategies to local climate conditions, buildings can enhance resilience, sustainability, and overall building performance.

Chapter 5: Discussion

5.1 Interpretation of Results

The case studies 1 to 15 depict various facade systems and how they perform successfully and efficiently in improving building performance and thermal amelioration potential. Through a detailed analysis of the different case studies, it is evident that different facade systems offer unique advantages related to sustainability, user comfort and energy efficiency and. The interpretation of results provides insights into the optimal facade system choices based on specific climatic contexts and building requirements.

5.1.1 Facade Systems in Different Climatic Conditions

The analysis of facade systems in varying climatic conditions, specifically in Cwa, Cwb, and BSh regions, reveals the effectiveness of different strategies in optimising building performance and occupant comfort. Each climatic context presents unique challenges and opportunities for facade system selection, emphasising the importance of climate-specific adaptation and sustainable design principles.

5.1.2 Cwa Regions

In Cwa regions characterised by hot summers and mild winters, dynamic facade systems like solar tracking louvres have demonstrated to efficiently reduce solar heat gain and enhance thermal comfort. The adaptability of these technologies allows for efficient temperature regulation and energy savings in response to the region's climate demands. Additionally, angled standing seam systems have demonstrated transparency, natural daylighting, and views while reducing heat gain, making them suitable for Cwa regions like Johannesburg.

5.1.3 Cwb Regions (e.g., Pretoria/Tshwane)

In Cwb regions with moderate temperatures and distinct seasons, the integration of DSF systems and thermal mass utilisation plays a key role in reducing heat gain and optimising

© University of Pretoria

natural ventilation. Passive design principles tailored to the region's climate have shown success in minimising the consumption of energy and enhancing indoor environmental quality. Strategies such as DSF systems facilitate natural ventilation and minimise demand for mechanical cooling, leading to energy efficiency and occupant comfort in Cwb regions like Pretoria.

5.1.4 BSh Regions (Future climate)

In BSh regions characterised by hot and arid climates, innovative approaches like biomimetic facade systems have demonstrated effectiveness in decreasing the demand for artificial lighting and climate control systems while promoting a healthier indoor environment. By mimicking natural processes to improve energy efficiency and occupant comfort, biomimetic facade systems offer a unique solution for sustainable building design in desert climates. Additionally, the use of coloured glass and laminated glass in facade construction can enhance aesthetics and filter air pollutants, contributing to improved indoor environmental quality in BSh regions.

5.2 Comparison of Facade Systems

Comparing the performance of different facade systems, including dynamic facade systems, DSF, green facade systems, and biomimetic facade systems, reveals distinct strengths and limitations. Dynamic facade systems, such as solar tracking louvres and DSFs, have shown effectiveness in minimising heat gain and optimising natural light penetration. Green facade systems, incorporating plants and greenery, enhance thermal comfort and air quality while promoting sustainability. Biomimetic facade systems, mimicking natural processes, offer innovative solutions for energy efficiency and occupant comfort.

5.3 Performance Evaluation

Facade systems performance in line with thermal comfort, energy efficiency, and occupant satisfaction provides an important outlook into the effectiveness of each system. Comparative analysis of energy savings, indoor temperature regulation, and indoor air quality improvement showcases the performance outcomes of different facade systems in diverse climatic conditions. By analysing the performance metrics, the discussion highlights the strengths and weaknesses of each facade system in achieving sustainable building design goals.

5.4 Comparative Analysis and Performance Metrics

The comparative analysis of facade systems in Cwa, Cwb, and BSh regions highlights the importance of selecting climate-responsive design solutions tailored to specific climatic conditions. Performance metrics such as energy efficiency, thermal comfort, and occupant satisfaction provides valuable information on the effectiveness of facade systems in different climatic contexts. By taking into cognizant solar exposure, prevailing winds, and temperature fluctuations, architects and designers can optimise building performance and occupant well-being through tailored facade strategies.

5.5 Recommendations for Climate-Specific Facade Selection

Based on the analysis of facade systems in Cwa, Cwb, and BSh regions, recommendations for climate-specific facade selection include:

- Prioritising dynamic facade systems in Cwa regions for solar heat gain reduction and thermal comfort enhancement.

© University of Pretoria

- Integrating DSF systems and passive design principles in Cwb regions to optimise energy efficiency and natural ventilation.
- Exploring biomimetic facade systems and innovative design approaches in BSh regions to address extreme climatic conditions and promote sustainability.

5.6 Future Research Directions

There are opportunities for further research to explore emerging technologies and innovative design approaches. Future studies could focus on the long-term monitoring of building performance with advanced facade systems, the integration of smart technologies for real-time energy management, and the evaluation of user satisfaction with different facade solutions. By addressing these research directions, additional knowledge can be gained on the selection and optimisation of facade systems to contribute significantly to global efforts in promoting sustainable building design and urban development. Facade.

5.7 Summary of discussion

The discussion on facade systems in Cwa, Cwb, and BSh climatic conditions shows the importance of contextually relevant design solutions and climate-responsive strategies in architectural design. By selecting facade systems that work well in specific climatic contexts and building requirements, architects and designers can enhance building performance, sustainability, and occupant comfort in diverse climatic regions (Attia et al., 2020; Attia et al., 2018). Through an integrative strategy towards selecting facades and design strategies, buildings can achieve optimal thermal performance and energy efficiency while responding effectively to the problems associated with climate change.

Chapter 6: Conclusion

The selection of facade systems stands as a pivotal decision, profoundly influencing building performance and occupant comfort, particularly in the face of diverse climatic conditions. Through an exhaustive examination of various case studies and meticulous analysis, this thesis emphasises the paramount importance of contextually tailored facade solutions, underpinned by sustainable design principles and climate-responsive strategies.

Architects navigating the complexities of climatic diversity must discern the optimal facade systems for specific contexts. For regions characterised by hot summers and mild winters, such as Cwa climates exemplified by locales like Johannesburg, dynamic facade systems are essential. Solar tracking louvres and angled standing seam systems effectively minimise solar heat gain while optimising natural light penetration, demonstrating high efficacy in these environments.

In moderate climates with distinct seasons, represented by Cwb regions like Pretoria, DSF systems integrated with passive design principles offer innovative solutions for climate adaptation. Utilising elements such as thermal mass, architects can create environments that mitigate heat gain and enhance natural ventilation, thereby improving both energy efficiency and indoor environmental quality.

© University of Pretoria

For hot and arid climates, represented by BSh regions, innovative biomimetic facade systems represent a paradigm shift in architectural design. These systems, inspired by natural processes, reduce reliance on artificial lighting and enhance occupant comfort, epitomising a comprehensive strategy for sustainable development and design.

The selection of optimal facade systems requires a judicious blend of technological innovation, sustainable design integration, and climate-specific adaptation. By advocating for dynamic facade systems in Cwa climates, DSF solutions in Cwb regions, and biomimetic approaches in BSh environments, architects can create sustainable, resilient, and occupant-centric architectural landscapes. This approach not only enhances the built environment against adverse climate impacts but also contributes significantly to global efforts in combating or adapting to the issues of the changing climate.

This research highlights the necessity of embracing innovative building technologies tailored to specific climatic contexts. These findings serve as a valuable resource for ongoing and future efforts to enhance urban resilience through thoughtful and climate-specific architectural design, thus fostering more sustainable and adaptable urban environments.

© University of Pretoria

Chapter 7: References

Adetooto, J.D. & Windapo, A. 2022. The use of alternative building technologies as a sustainable affordable housing solution: perspectives from South Africa. *Journal of Engineering, Design and Technology*. [Online] Available from: https://doi:10.1108/JEDT-05-2022-0257. [Accessed: 2024-03-03].

Adetooto, J.D. 2022. *An Investigation of the Utilisation and Barriers to the Social Acceptance of Alternative Building Technology in Housing Construction in South Africa.* Unpublished masters thesis. Cape town: University of Cape of Town [online] Available from: http://hdl.handle.net/11427/36968 [Accessed: 2024-03-15].

Ahriz, A., Mesloub, A., Djeffal, L., Alsolami, B., Ghosh, A. & Abdelhafez, M.H.H. 2022. The use of double-skin façades to improve the energy consumption of high-rise office buildings in a Mediterranean climate (csa). *Sustainability*, 14(10):6004. [Online] Available from: https://doi.org/10.3390/su14106004 [Accessed: 2024-04-07].

Aichele, R. & Felbermayr, G. 2012. Kyoto and the carbon footprint of nations. *Journal of Environmental Economics and Management, 63*(3):336-354. [Online] Available from: https://doi.org/10.1016/j.jeem.2011.10.005 [Accessed: 2024-03-18].

Al-Obaidi, K.M., Ismail, M.A., Hussein, H. & Rahman, A. 2017. Biomimetic building skins: an adaptive approach. *Renewable and Sustainable Energy Reviews*, 79:1472-1491. [Online] Available from: https://doi.org/10.1016/j.rser.2017.05.028 [Accessed: 2024-04-04].

Amerson, R. 2011. Making a case for the case study method. *Journal of Nursing Education, 50*(8):427-428. [Online] Available from: https://doi.org/10.3928/01484834-20110719-01 [Accessed: 2024-04-24].

Anarfi, K., Hill, R. A., & Shiel, C. (2020). Highlighting the sustainability implications of urbanisation: a comparative analysis of two urban areas in ghana. *Land*, 9(9):300. [Online] Available from: https://doi.org/10.3390/land9090300 [Accessed: 2024-06-16].

Arellano, B. & Roca, J. 2022. Effects of urban greenery on health. a study from remote sensing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLIII-B3-2022:17-24.

Arnell, N.W. & Freeman, A. 2021. The effect of climate change on agro-climatic indicators in the UK. *Climatic Change*, 165(1-2). [Online] Available from: https://doi.org/10.1007/s10584-021-03054-8 [Accessed: 2024-03-06].

© University of Pretoria

Arrouays, D., Deslais, W. & Badeau, V. 2006. The carbon content of topsoil and its geographical distribution in France. *Soil Use and Management, 17*(1):7-11. [Online] Available from: https://doi.org/10.1111/j.1475-2743.2001.tb00002.x [Accessed: 2024-03-18].

Athienitis, A., Barone, G., Buonomano, A. & Palombo, A. 2018. Assessing active and passive effects of façade building integrated photovoltaics/thermal systems: dynamic modelling and simulation. Applied Energy, 209:355-382. [Online] Available from: https://doi.org/10.1016/j.apenergy.2017.09.039 [Accessed: 2024-03-29].

Attia, S., Bilir. S., Safy, T., Struck, C.C., Loonen, R.R. & Goia, F. 2018. Current trends and future challenges in the performance assessment of adaptive façade systems. *Energy and Buildings*, 179, 165-182. [Online] Available from: https://doi.org/10.1016/j.enbuild.2018.09.017 [Accessed: 2024-04-03].

Attia, S., Lioure, R. & Declaude, Q. 2020. Future trends and main concepts of adaptive facade systems. *Energy Science & Engineering*, 8(9):3255-3272.

Baqi, A. & Abbas, A. 2021. Temporal variations in ice cap of Antarctica and Greenland. *Vol 3 Issue 2*, 3(2):52-58. [Online] Available from: https://doi.org/10.33411/ijist/2021030201 [Accessed: 2024-03-11].

Barbosa, S., Ip, K. & Southall, R. 2015. Thermal comfort in naturally ventilated buildings with double skin façade under tropical climate conditions: the influence of key design parameters. *Energy and Buildings*, 109:397-406. [Online] Available from: https://doi.org/10.1016/j.enbuild.2015.10.029 [Accessed: 2024-04-08].

Battista, F., Asfaw, S. & Lipper, L. 2016. Agricultural Technology Adoption under Climate Change in the Sahel: Micro-evidence from Niger. *Journal of African Economies, 25*:637-669.

Biagini, B., Kuhl, L., Gallagher, K.S. & Ortiz, C.C. 2014. Technology Transfer for Adaptation. *Nature Climate Change*. *4*(9):828-834.

Bock, M. 2019. A building integrated solar thermal collector with active steel skins. *Energy and Buildings*, 201:134-147. [Online] Available from: https://doi.org/10.1016/j.enbuild.2019.07.040 [Accessed: 2024-03-29].

Bossche, N.V.D., Brande, K.V., Bleecker, H.D. & Lori, G. 2020. Validation of a coupled pressure-equalization-thermal-mechanical model to study double-skin facades. *E3S Web of Conferences*, 172, 24001.

© University of Pretoria

Bre, F. & Fachinotti, V.D. 2017. A computational multi-objective optimization method to improve energy efficiency and thermal comfort in dwellings. *Energy and Buildings*, 154:283-294.

Buckman, A.H., Mayfield, M. & Beck, S. 2014. What Is a Smart Building? *Smart and Sustainable Built Environment*. *3*(2):92-109.

Bueno, E.O., Mello, C.R. & Alves, G.J. 2016. Evaporation from camargos hydropower plant reservoir: water footprint characterization. 21(3):570-575.

Burciaga, U.M. 2020. Sustainability assessment in housing building organizations for the design of strategies against climate change. *HighTech and Innovation Journal*, 1(4):136-147. [Online] Available from: https://doi.org/10.28991/hij-2020-01-04-01 [Accessed: 2024-03-16].

Busch. 2015 *Centre for Global Development,* [Online] Available from: https://www.cgdev.org/blog/climate-change-and-development-three-charts [Accessed: 2024-03-28].

Cantrell, M.A. & Lupinacci, P. 2007. Methodological issues in online data collection. *Journal of Advanced Nursing*, 60(5):544-549.

Chartered Institution of Building Services Engineers - CIBSE 2020. *Building Services Life Cycle Costing: A Best Practice Guide. Chartered Institution of Building Services Engineers*.

Chen, M., Liu, W, & Xiao-li, T. 2013. Evolution and assessment on China's urbanization 1960–2010: under-urbanization or over-urbanization? *Habitat International,* 38,25-33. [Online] Available from: https://doi.org/10.1016/j.habitatint.2012.09.007 [Accessed: 2024-03-20].

Chuai, X., Huang, X., Lu, Q., Zhang, M., Zhao, R. & Lu, J. 2015. Spatiotemporal changes of built-up land expansion and carbon emissions caused by the Chinese construction industry. *Environmental Science & Technology*, 49(21),13021-13030. [Online] Available from: https://doi.org/10.1021/acs.est.5b01732 [Accessed: 2024-03-10].

Coley, D., Kershaw, T. & Eames, M.E. 2012. A comparison of structural and behavioural adaptations to future proofing buildings against higher temperatures. *Building and Environment, 55*:159-166.

© University of Pretoria

Coma, J., Pérez, G., Solé, C., Castell, A. & Cabeza, L.F. 2014. New green facades as passive systems for energy savings on buildings. *Energy Procedia*, 57:1851-1859. [Online] Available from: https://doi.org/10.1016/j.egypro.2014.10.049 [Accessed: 2024-03-27].

Convertino, F., Vox, G, & Schettini, E. 2019. Convective heat transfer in green facade system. *Biosystems engineering*, 188:67-81.

Crasnow, S. 2012. The role of case study research in political science: evidence for causal claims. *Philosophy of Science, 79*(5):655-666.

Cüce, A. M., Cüce, E., Güçlü, T., & Demirci, V. 2021. Energy saving aspects of green facades: current applications and challenges. *Green Building & Construction Economics*, 1-11. https://doi.org/10.37256/gbce.2220211007

Dabaj, B., Rahbar, M. & Fakhr, B.V. 2022. Impact of different shading devices on daylight performance and visual comfort of a four opening sides' reading room in Rasht. *Journal of Daylighting*, 9(1), 97-116. [Online] Available from: https://doi.org/10.15627/jd.2022.7 [Accessed: 2024-05-18].

Daisey, J.M., Angell, W.J. & Apte, M.G. 2003. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air, 13(1):53-64.

Dakheel, A.J. & Aoul, K. 2017. Building Applications, Opportunities and Challenges of Active Shading Systems: A State-of-the-Art Review. *Energies* [Online], 10. [Online] Available from: https://doi.org/10.3390/en10101672 [Accessed: 2024-05-16].

Dally, M., Macaluso, F., James, K.A., Newman, L.S. & Sorensen, C. 2022. Addressing climate change in the workplace. *Workplace Health & Safety*, 70(7), 340-340. [Online] Available from: https://doi.org/10.1177/21650799221103767 [Accessed: 2024-03-10].

Das, S., Ossola, A. & Beaumont, L.J. 2024. Records of urban occurrences expand estimates of the climate niches in tree species. *Global Ecology and Biogeography*, 33(4):e13809.

Dear, R. & Brager, G. 2002. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. *Energy and Buildings, 34*(6):549-561. [Online] Available from: https://doi.org/10.1016/s0378-7788(02)00005-1 [Accessed: 2024-03-26].

Denzin, N.K. 2012. Triangulation 2.0. *Journal of Mixed Methods Research*, 6(2):80-88. [Online] Available from: https://doi.org/10.1177/1558689812437186 [Accessed: 2024-04-23].

© University of Pretoria

Dodoo, A. 2020. Energy and indoor thermal comfort performance of a Swedish residential building under future climate change conditions. *E3S Web of Conferences*, 172, 02001. [Online] Available from: https://doi.org/10.1051/e3sconf/202017202001 [Accessed: 2024-03-13].

Eltanboly, M.F. & Afify, M.M. 2022. The influence of using responsive façade as a tool for improving the built environment: case study: *attaba – opera square. IOP Conference Series: Earth and Environmental Science*, 992(1):012005. [Online] Available from: https://doi.org/10.1088/1755-1315/992/1/012005 [Accessed: 2024-04-03].

Fanger, P.O. 1972. Thermal Comfort: Analysis and Applications in Environmental Engineering. McGraw-Hill.

Favoino, F., Jin, Q. & Overend, M. 2014. Towards an ideal adaptive glazed façade for office buildings. *Energy Procedia*, 62:289-298. [Online] Available from: https://doi.org/10.1016/j.egypro.2014.12.390 [Accessed: 2024-04-11].

Felice, G., Fugger, R. & Gobbin, F. 2021. Overturning of the façade in single-nave churches under seismic loading. *Bulletin of Earthquake Engineering*, 20(2):941-962. [Online] Available from: https://doi.org/10.1007/s10518-021-01243-5 [Accessed: 2024-04-11].

Fernandez-Antolin, M., Río, J.M., Costanzo., V, Nocera, F. & Lezcano, R.G. 2019. Passive design strategies for residential buildings in different spanish climate zones. *Sustainability*, 11(18), 4816. [Online] Available from: https://doi.org/10.3390/su11184816 [Accessed: 2024-05-17].

Filho, C.M., Medeiros, R.M., Cavalcanti, N.L.L., Piscoya, V.C., Holanda, R.M., França, M.V., Araújo, W.R., Cunha, A.L.X., Moreira, G.R., Brito, C.C.R., Costa, M.L.L., Araújo Filho, R. N., Correa, M.M., Rocha, J.S., Freitas, J.R., Guerra, S.M.S. & Piscoya, T.O.F. 2020. Distribution of heat stroke in the Ipojuca/PE river basin, Brazil, *Research, Society and Development*, 9(10):e5599108708.

Fiorito, F., Sauchelli, M., Arroyo, D., Pesenti, M., Imperadori, M., Masera, G. & Ranzi, G., 2016. Shape morphing solar shadings: a review. *Renewable and Sustainable Energy Reviews*, 55:863-884. [Online] Available from: https://doi.org/10.1016/j.rser.2015.10.086 [Accessed: 2024-04-04].

Fleer, N.A., Pelcher, K.E., Zou, J., Nieto, K., Douglas, L.D., Sellers, D.G. and Banerjee, S., 2017. Hybrid nanocomposite films comprising dispersed vo2 nanocrystals: a scalable aqueous-phase route to thermochromic fenestration. *ACS Applied Materials & Interfaces*, 9(44):38887-38900.

© University of Pretoria

Földváry, V., Bekö, G., Langer, S., Arrhenius, K. & Petráš, D. 2017. Effect of energy renovation on indoor air quality in multifamily residential buildings in Slovakia. *Building and Environment*, 122, 363-372.

Frampton, K. 2001. *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*. MIT Press.

Frontczak, M., Schiavon, S., Goins, J., & Arens, E. 2012. Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. *Indoor Air*, 22(2):119-131. [Online] Available from: https://doi.org/10.1111/j.1600-0668.2011.00745.x [Accessed: 2024-03-30].

Frontczak. M. & Wargocki. P. 2011. Literature survey on how different factors influence human comfort in indoor environments. *Building and Environment*. 46(40), 922-937. [Online] Available from: https://doi.org/10.1016/j.buildenv.2010.10.021 [Accessed: 2024-05-12].

Fuliotto, R., Cambuli, F., Mandas, N., Bacchin, N., Manara, G. & Chen, Q. 2010. Experimental and numerical analysis of heat transfer and airflow on an interactive building facade. *Energy and Buildings*, 42(1), 23-28. [Online] Available from: https://doi.org/10.1016/j.enbuild.2009.07.006 [Accessed: 2024-03-12].

Ghafar, A.A., Abdulkarim, K.H., Said, I. & Jasmani, Z. 2018. Vertical greenery systems and its effect on campus: a meta-analysis. Journal of BIMP-EAGA Regional Development, 4(1), 42-56. [Online] Available from: https://doi.org/10.51200/jbimpeagard.v4i1.3113 [Accessed: 2024-03-28].

Ghaffarianhoseini, A., Ghaffarianhoseini, A., Berardi, U., Tookey, J., Li, D.H.W. & Kariminia, S. 2016. Exploring the advantages and challenges of double-skin façades (DSFs). *Renewable & Sustainable Energy Reviews*, *60*:1052–1065. [Online] Available from: https://doi.org/10.1016/j.rser.2016.01.130 [Accessed: 2024-05-32].

Ghosh, A. 2020. Potential of building integrated and attached/applied photovoltaic (bipv/bapv) for adaptive less energy-hungry building's skin: a comprehensive review. *Journal of Cleaner Production*, 276:123343. [Online] Available from: https://doi.org/10.1016/j.jclepro.2020.123343 [Accessed: 2024-04-05].

Glasgow, R.E. 2013. *What does it mean to be pragmatic? Pragmatic methods, measures, and models to facilitate research translation.* Health Education & Behavior, 40(3):257-265. [Online] Available from: https://doi.org/10.1177/1090198113486805 [Accessed: 2024-04-20].

© University of Pretoria

Gracia, Á., Fernàndez, C., Castell, A., Mateu, C., & Cabeza, L.F. 2015. Control of a pcm ventilated facade using reinforcement learning techniques. Energy and Buildings, 106, 234-242. [Online] Available from: https://doi.org/10.1016/j.enbuild.2015.06.045 [Accessed: 2024-03-29].

Gremmelspacher, J.M., Pizarro, R.C. & van Jarsveld, M. 2020. Sofiero park: A historic building renovation with optimising photovoltaics according to hourly load profile. in JM Cardemil, K Guthrie & R Ruther (eds), *Proceedings of the ISES Solar World Congress 2019 and IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2019*, 1791-1801.

Gronostajska, A. & Berbesz, J. 2018. Mobile structures in terrestrial and aquatic environments and the use of alternative energy sources. *E3S Web of Conferences.* 49:00038).

Grunewald, N. & Martínez-Zarzoso, I. 2015. Did the Kyoto protocol fail? An evaluation of the effect of the Kyoto protocol on CO2 emissions. *Environment and Development Economics, 21*(1):1-22. [Online] Available from: https://doi.org/10.1017/s1355770x15000091 [Accessed: 2024-03-19].

Guichard, S., Miranville, F., Bigot, D., Malet-Damour, B., Libelle, T. & Boyer, H. 2015. Empirical validation of a thermal model of a complex roof including phase change materials. *Energies, 9*(1):9. [Online] Available from: https://doi.org/10.3390/en9010009 [Accessed: 2024-03-27].

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., Van Den Brink, M., Jong, P., Nooteboom, S. & Bergsma, E. 2010. The Adaptive Capacity Wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy,* 13**,** 459-471.

Habert, G., Miller, S. A., John, V. M., Provis, J. L., Favier, A., Horvath, A. & Scrivener, K. L. 2020. Environmental impacts and decarbonization strategies in the cement and concrete industries. *Nature Reviews Earth & Environment,* 1(11)**:**559-573.

Habitzreuter, L., Smith, S.T. & Keeling, T. 2019. Modelling the overheating risk in an uniform high-rise building design with a consideration of urban context and heatwaves. *Indoor and Built Environment*, 29(5):671-688.

Hamin, E.M. & Gurran, N. 2009. Urban form and climate change: balancing adaptation and mitigation in the U.S. and Australia. *Habitat International, 33*(3):238-245. [Online] Available from: https://doi.org/10.1016/j.habitatint.2008.10.005 [Accessed: 2024-03-24].

© University of Pretoria

Hao, X., Hu, J., He, Y., Li, N., Su, Y. & Qu, H. 2022. Optimal temperature ranges considering gender differences in thermal comfort, work performance, and sick building syndrome: A winter field study in university classrooms. *Energy and Buildings*, *254*:111554.

Heiz, B.P.V., Su, L., Pan, Z. & Wondraczek, L. 2018. Fluid-integrated glass glass laminate for sustainable hydronic cooling and indoor air conditioning. *Advanced Sustainable Systems*, 2(10). [Online] Available from: https://doi.org/10.1002/adsu.201800047 [Accessed: 2024-03-28].

Holstov, A., Bridgens, B., & Farmer, G. T. 2015. Hygromorphic materials for sustainable responsive architecture. *Construction and Building Materials*, 98:570-582. [Online] Available from: https://doi.org/10.1016/j.conbuildmat.2015.08.136 [Accessed: 2024-06-17].

Holstov, A., Farmer, G. T. & Bridgens, B. 2017. Sustainable materialisation of responsive architecture. *Sustainability*, 9(3):435.

Holstov, A., Farmer, G.T. & Bridgens, B. 2017. Sustainable materialisation of responsive architecture. *Sustainability*, 9(3):435.

Hong, S., Candelone, J., Patterson, C. C. & Boutron, C. F. 1994. Greenland ice evidence of hemispheric lead pollution two millennia ago by Greek and Roman civilizations. *Science*, 265(5180),1841-1843. [Online] Available from: https://doi.org/10.1126/science.265.5180.1841 [Accessed: 2024-03-01].

Hou, K., Li, S. & Wang, H. 2021. Simulation and experimental verification of energy saving effect of passive preheating natural ventilation double skin façade. Energy Exploration & Exploitation, 39(1):464-487.

Humphreys, M.A. 2005. Quantifying Occupant Comfort: Are Combined Indices of the Indoor Environment Practicable? *Building Research & Information*, 33(4):317-325. https://doi.org/10.1080/09613210500161950 [Accessed: 2024-03-31].

Hunter, A., Williams, N., Rayner, J., Aye, L., Hes, D. & Livesley, S. 2013. Quantifying the thermal performance of green facades: A critical review. *Ecological Engineering*, *63*:102-113.

Hyett, N., Kenny, A. & Dickson-Swift, V. 2014. Methodology or method? a critical review of qualitative case study reports. *International Journal of Qualitative Studies on Health and Well-Being, 9*(1):23606.

© University of Pretoria

Intergovernmental Panel on Climate Change [IPCC] 2023. *Climate Change 2023: Synthesis Report Summary for Policymakers.*

Intergovernmental Panel on Climate Change [IPCC]. 2021. *Climate Change 2021: The Physical Science Basis. Summary for Policy Makers*.

Ismail, Z. 2021. Thermal comfort practices for precast concrete building construction projects: towards BIM and IoT integration. *Engineering, Construction and Architectural Management*. [Online] Available from: https://doi.org/10.1108/ecam-09-2020-0767 [Accessed: 2024-03-27].

Iwan, A. & Poon, K. 2018. The role of governments and green building councils in cities' transformation to become sustainable: case studies of Hong Kong (East) and Vancouver (West). *Sustainability and the City, 13*(04):556-570.

Jabareen, Y.R. 2006. Sustainable urban forms. *Journal of Planning Education and Research*, 26(1):38-52. [Online] Available from: https://doi.org/10.1177/0739456x05285119 [Accessed: 2024-05-10].

Jahed, N. 2018. *Performance based façades: retrofit strategies for energy efficiency and comfort in existing office buildings.* Unpublished masters thesis. Turkey: Middle East Technical University. [Online] Available from: https://hdl.handle.net/11511/27173 [Accessed: 2024-04-17].

Jay, A., Reidmiller, D.R., Avery, C.W., Barrie, D., DeAngelo, B.J., Dave, A., Dzaugis, M., Kolian, M., Lewis, K.L.M., Reeves, K & Winner, D. 2018. Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. *US Global Change Research Program*. pp. 33-71. [Online] Available from: https://doi:10.7930/NCA4.2018.CH1 [Accessed: 2024-03-07].

Johnson, R.B. & Onwuegbuzie, A.J. 2004. *Mixed methods research: a research paradigm whose time has come.* Educational Researcher, 33(7):14-26. [Online] Available from: https://doi.org/10.3102/0013189x033007014 [Accessed: 2024-04-22].

Johnston, F.H., Melody, S. & Bowman, D. 2016. The pyrohealth transition: how combustion emissions have shaped health through human history. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1696), 20150173. [Online] Available from: https://doi.org/10.1098/rstb.2015.0173 [Accessed: 2024-03-02].

Jurišić, D. 2022. The challenges of military operations in urban areas. *Vojno Delo, 74*(2), 75-94. [Online] Available from: https://doi.org/10.5937/vojdelo2202075j [Accessed: 2024-03-21].

© University of Pretoria

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Hase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K. & Bonn, A. 2016. Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society*, 21(2):39. [Online] Available from: https://doi.org/10.5751/es-08373-210239 [Accessed: 2024-04-06].

Kar, S., Kumar, N.S. & Bhatia, A. 2023. Use of genetic algorithm to optimize energy efficiency, construction cost, and daylight in building design. IOP Conference Series: Earth and Environmental Science, 1279(1):012029.

Kelley, K.D. 2003. Good practice in the conduct and reporting of survey research. *International Journal for Quality in Health Care*, 15(3):261-266. [Online] Available from: https://doi.org/10.1093/intqhc/mzg031 [Accessed: 2024-04-26].

Kelly, L.M. & Cordeiro, M. 2020. Three principles of pragmatism for research on organizational processes. *Methodological Innovations*, 13(2):205979912093724. [Online] Available from: https://doi.org/10.1177/2059799120937242 [Accessed: 2024-04-21].

Kolimenakis, A., Heinz, S., Wilson, M., Winkler, V., Yakob, L., Michaelakis, A., … & Horstick, O. 2021. The role of urbanisation in the spread of aedes mosquitoes and the diseases they transmit—a systematic review. *PLOS Neglected Tropical Diseases*, 15(9):e0009631. [Online] Available from: https://doi.org/10.1371/journal.pntd.0009631 [Accessed: 2024-06-13].

Krawczyk, N. & Krakowiak, J. 2021. The comparison of thermal comfort test results in selected traditional and modern buildings. *E3S Web of Conferences, 286*, 02008. [Online] Available from: https://doi.org/10.1051/e3sconf/202128602008 [Accessed: 2024-03-26].

Krentel, A., Fischer, P. & Weil, G.J. 2013. A review of factors that influence individual compliance with mass drug administration for elimination of lymphatic filariasis. *PLoS Neglected Tropical Diseases, 7*(11): e2447. [Online] Available from: https://doi.org/10.1371/journal.pntd.0002447 [Accessed: 2024-03-20].

Kumar, A., Kassa, M, Boity, A.K., Rana, A. & Behera, S. 2022. An analytical study of architecture design studios with respect to orientation and facade treatment. *ECS Transactions*, 107(1):9313-9325. [Online] Available from: https://doi.org/10.1149/10701.9313ecst [Accessed: 2024-04-03].

Kwofie, T.E., Aigbavboa, C.O. & Thwala, W.D. 2019. Measures to improve the adoption of life cycle assessment in the South African construction industry. *Journal of Engineering, Design*

© University of Pretoria

and Technology, *18*(2):480–494. [Online] Available from: https://doi.org/10.1108/jedt-05-2019-0141 [Accessed: 2024-04-09].

Lau, A.K., Salleh, E., Haw, L.C. & Sulaiman, M.A. 2016. Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: the case of malaysia. *International Journal of Sustainable Built Environment*, 5(2), 387-399. [Online] Available from: https://doi.org/10.1016/j.ijsbe.2016.04.004 [Accessed: 2024-05-12].

Li, D. & Bou-Zeid, E. 2013. Synergistic interactions between urban heat islands and heat waves: the impact in cities is larger than the sum of its parts. *Journal of Applied Meteorology and Climatology*, 52(9):2051-2064. [Online] Available from: https://doi.org/10.1175/jamc-d-13-02.1 [Accessed: 2024-03-12].

Li, X., Cui, S., Tang, J., Nguyen, M., Liu, J. & Zhao, Y. 2019. Assessing the Adaptive Capacity of Urban Form to Climate Stress: A Case Study on an Urban Heat Island. *Environmental Research Letters*.

Lim, J.H. & Yun G.Y. 2017. Cooling Energy Implications of Occupant Factor in Buildings under Climate Change. *Sustainability*, 9(11):2039. [Online] Available from: https://doi.org/10.3390/su9112039 [Accessed: 2024-04-09].

Liu, W. 2022. The evolution of cold adaptation technology within ancient buildings in Amur River Basin viewed from archaeology. *International Journal of Environmental Research and Public Health,* *19*(21), 14470. [Online] Available from: https://doi.org/10.3390/ijerph192114470 [Accessed: 2024-04-09].

Loonen, R., Favoino, F., Hensen, J. & Overend, M. 2016. Review of current status, requirements and opportunities for building performance simulation of adaptive facades. *Journal of Building Performance Simulation*, 10(2):205-223.

Loonen, R., Trcka, M., Cóstola, D. & Hensen, J. 2013. Climate adaptive building shells: state-of-the-art and future challenges. *Renewable and Sustainable Energy Reviews*, 25:483-493. [Online] Available from: https://doi.org/10.1016/j.rser.2013.04.016 [Accessed: 2024-04-01].

Luthra, J & Sundaram, M. 2023. July. Identifying external louver angle for residence opening to optimize the indoor environment for the composite climate of Delhi NCR. *IOP Conference Series: Earth and Environmental Science,* 1210(1):012003).

© University of Pretoria

Lwasa, S. 2014. Managing African urbanization in the context of environmental change. *Inter Disciplina,* *2*(2). [Online] Available from: https://doi.org/10.22201/ceiich.24485705e.2014.2.46528 [Accessed: 2024-03-23].

Maheshwari, J., Paliwal, P. and Garg, A. 2021. Assessing electricity and CO2 emission savings through energy efficiency measures in shopping malls in India: a feasibility study of appliance retrofit. *International Journal of Energy Sector Management*, *15*(3):697-718.

Mahmoud, H. & Ghanem, H. 2019. Urban geometry mitigation guidelines to improve outdoor thermal performance in Egyptian hot arid new cities. *JES. Journal of Engineering Sciences, 47*(2), 172-193. [Online] Available from: https://doi.org/10.21608/jesaun.2019.115119 [Accessed: 2024-03-25].

Maltseva, I.N., Elokhoz, A., Borisov, V. & Verkhovskiy, A. 2019. Optimization of insulation in ventilated hinged facade systems. *Matec Web of Conferences.*

Martinez, T., Duarte, M. & Garcia-Luna, A.C. 2021. How using smart buildings technology can improve indoor environmental quality in educational buildings. *SHS Web of Conferences*, 102:03003. [Online] Available from: https://doi.org/10.1051/shsconf/202110203003 [Accessed: 2024-04-2].

Mason, W., Morris, K., Webb, C., Daniels, B., Featherstone, B., Bywaters, P., Mirza, N., Hooper, J., Brady, G., Bunting, L. and Scourfield, J., 2020. Toward full integration of quantitative and qualitative methods in case study research: insights from investigating child welfare inequalities. *Journal of Mixed Methods Research*, 14(2):164-183.

McCarthy, M., Best, M. & Betts, R. 2010. Climate change in cities due to global warming and urban effects. *Geophysical Research Letters*, 37(9). [Online] Available from: https://doi.org/10.1029/2010gl042845 [Accessed: 2024-03-06].

McCusker, K. & Günaydın, S. 2014., Research using qualitative, quantitative or mixed methods and choice based on the research. *Perfusion*, 30(7):537-542. [Online] Available from: https://doi.org/10.1177/0267659114559116 [Accessed: 2024-04-26].

Mehrotra, D. & Mehrotra, R. 1995. Climate change and hydrology with emphasis on the Indian subcontinent. *Hydrological Sciences Journal*, 40(2):231-242. [Online] Available from: https://doi.org/10.1080/02626669509491406 [Accessed: 2024-03-06].

Mello, R., Norton, L.D., Curi, N. & Yanagi, S.N.M. 2012. Sea surface temperature (SST) and rainfall erosivity in the Upper Grande River Basin, Southeast Brazil. *Ciência E Agrotecnologia*,

© University of Pretoria

36(1):53-59. [Online] Available from: https://doi.org/10.1590/s1413-70542012000100007 [Accessed: 2024-05-06].

Meng, H., Liu, Z., Wang, X. & Feng, L. 2024. A fluorinated greenhouse gas sensor based on n-doped tin oxide materials. *Environmental Science: Nano*, 11(1):459-469. [Online] Available from: https://doi.org/10.1039/D3EN00679D [Accessed: 2024-03-06].

Mertens, D.M. 2015. Mixed methods and wicked problems. *Journal of Mixed Methods Research*, 9(1):3-6. [Online] Available from: https://doi.org/10.1177/1558689814562944 [Accessed:2024-04-24].

Mifsud, L., Pomponi, F., & Moncaster, A. 2020. Comparative life cycle analysis of façade passive systems in the mediterranean: comfort, energy, and carbon. *Renewable Energy*, 149:347-360. [Online] Available from: https://doi.org/10.1016/j.renene.2019.12.072 [Accessed: 2024-03-27].

Milinković, O., Brzaković, P., Milošević, O. & Brzaković, M. 2020. Property insurance and innovative building techniques: reducing the consequences of climate change. *Ekonomika Poljoprivrede*, 67(1):269-283. [Online] Available from: https://doi.org/10.5937/ekopolj2001269m [Accessed: 2024-03-14].

Moghaddam, F.B., Mir, J.M.F., Navarro, I. & Redondo, E. 2021. Evaluation of thermal comfort performance of a vertical garden on a glazed façade and its effect on building and urban scale, case study: an office building in Barcelona. *Sustainability*, 13(12):6706. [Online] Available from: https://doi.org/10.3390/su13126706 [Accessed: 2024-03-14].

Moghayedi, A., Awuzie, B., Omotayo, T., Le Jeune, K. & Massyn, M. 2022. Appraising the nexus between influencers and sustainability-oriented innovation adoption in affordable housing projects. *Sustainable Development*, *30*(5):1117-1134.

Morgan, D.L. 2014. Pragmatism as a paradigm for social research. *Qualitative Inquiry*, 20(8), 1045-1053. [Online] Available from: https://doi.org/10.1177/1077800413513733 [Accessed: 2024-04-21].

Mortarotti, G., Morganti, M. & Cecere, C. 2017. Thermal analysis and energy-efficient solutions to preserve listed building façades: the ina-casa building heritage. Buildings, 7(4), 56. [Online] Available from: https://doi.org/10.3390/buildings7030056 [Accessed: 2024-03-29].

Mortoja, M. G. and Yiğitcanlar, T. 2020. Local drivers of anthropogenic climate change: quantifying the impact through a remote sensing approach in brisbane. *Remote Sensing*,

© University of Pretoria

12(14):2270. [Online] Available from: https://doi.org/10.3390/rs12142270 [Accessed: 2024-06-14].

Naranjo, L., Glantz, M.H., Temirbekov, S. & Ramírez, I.J. 2018. El niño and the köppen–geiger classification: a prototype concept and methodology for mapping impacts in central america and the circum-caribbean. *International Journal of Disaster Risk Science*, 9(2):224-236. [Online] Available from: https://doi.org/10.1007/s13753-018-0176-7 [Accessed: 2024-05-01].

National Climate Change Response White Paper. 2011. *South African Government.*

Nguyen, Y. Q. & Wells, J. C. 2020. Effects of wall proximity on the airflow in a vertical solar chimney for natural ventilation of dwellings. *Journal of Building Physics*, 44(3):225-250. [Online] Available from: https://doi.org/10.1177/1744259120909515 [Accessed: 2024-04-06].

Nicol, J.F. & Humphreys, M.A. 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*, 34(6):563-572.

O'Brien, K. 2018. Is the 1.5°C target possible? Exploring the three spheres of transformation. *Current Opinion in Environmental Sustainability, 31*:153–160. [Online] Available from: https://doi.org/10.1016/j.cosust.2018.04.010 [Accessed: 2024-03-09].

Oh, J., Hong, T., Kim, H., An, J., Jeong, K., & Koo, C. 2017. Advanced strategies for net-zero energy building: focused on the early phase and usage phase of a building's life cycle. *Sustainability*, 9(12), 2272. https://doi.org/10.3390/su9122272 [Accessed 2024-03-28].

Oluoko-Odingo, A. 2019. Gender mainstreaming for the adaptation to weather and climate extremes in African cities. *Journal of Climate Change and Sustainability*, 15–27. [Online] Available from: https://doi.org/10.20987/jccs.2.02.2019 [Accessed: 2024-03-17].

Oral, G. Yener, A. & Bayazit, N. 2004. Building envelope design with the objective to ensure thermal, visual and acoustic comfort conditions. *Building and Environment,* 39(3):281-287 [Online] Available from: https://doi.org/10.1016/S0360-1323(03)00141-0 [Accessed: 2024-03-16].

Orsini, F. Kahane, R. Nono-Womdim, R. & Gianquinto, G. 2013. Urban agriculture in the developing world: a review. *Agronomy for Sustainable Development*, 33(4):695-720. [Online] Available from: https://doi.org/10.1007/s13593-013-0143-z [Accessed 2024-03-19].

© University of Pretoria

Othman, R.A. & Sahidin N. 2016. Vertical greening facade as passive approach in sustainable design. *Procedia - Social and Behavioral Sciences*, 222:845–854.

Özarısoy, B. & Altan, H. 2017. Energy Performance Development of Non-Regulated Retrofit Mass Housing Estates in Northern Cyprus. *The Design Journal*. 20(sup1):S1765-S1781.

Pasut, W. & Carli, M.D. 2012. Evaluation of various cfd modelling strategies in predicting airflow and temperature in a naturally ventilated double skin façade. *Applied Thermal Engineering*, 37:267-274. [Online] Available from: https://doi.org/10.1016/j.applthermaleng.2011.11.028 [Accessed 2024-04-12].

Peel, M.C. Finlayson, B.L. & McMahon, T.A. 2007. Updated world map of the Köppen-Geiger climate classification. *Hydrology and. Earth System Sciences*, [Online] Available from: https://doi.org/10.5194/hess-11-1633-2007 [Accessed: 2024-03-15].

Pipitone, G. Barone, G. & Palmeri, A. 2017. Optimal design of double-skin façades as vibration absorbers. *Structural Control and Health Monitoring*, 25(2):e2086. [Online] Available from: https://doi.org/10.1002/stc.2086 [Accessed: 2024-03-28].

Pomponi, F., Piroozfar, P., Southall, R., Ashton, P. & Farr, E.R.P. 2016. Energy performance of Double-Skin Façades in temperate climates: A systematic review and meta-analysis, *Renewable and Sustainable Energy Reviews*, 54:1525-1536. [Online] Available from: https://doi.org/10.1016/j.rser.2015.10.075 [Accessed: 2024-04-07].

Pongruengkiat, W., Tippayawong, K.Y., Aggarangsi, P., Pichayapan, P., Katongtung, T. & Tippayawong, N. 2023. Assessing sustainability of Chiang Mai urban development. *Research square,* [Online] Available from: https://doi.org/10.21203/rs.3.rs-3056904/v1 [Accessed: 2024-03-21].

Prieto, A., Klein, T., Knaack, U. & Auer, T. 2017. Main perceived barriers for the development of building service integrated facades: Results from an exploratory expert survey. *Journal of Building Engineering*, 13:96-106.

Ramírez-Balas, C., Fernández-Nieto, E.D., Narbona-Reina, G., Sendra, J. & Suárez, R. 2018. Thermal 3d cfd simulation with active transparent façade in buildings. *Energies*, 11(9):2265.

Rañeses, K., Chang-Richards, A., Wang, K. & Dirks, K.N. 2021. Housing for now and the future: a systematic review of climate-adaptive measures. *Sustainability, 13*:6744.

© University of Pretoria

Reckermann, M., Storch, H. & Isemer, H. 2008. Climate change assessment for the Baltic Sea Basin. *Eos, Transactions American Geophysical Union, 89*(17):161-162. [Online] Available from: https://doi.org/10.1029/2008eo170001 [Accessed: 2024-03-17].

Reinhart, C. & Walkenhorst, O. 2001. Validation of Dynamic RADIANCE-Based Daylight Simulations for a Test Office with External Blinds. *Energy and Buildings*, 33(7):683-697.

Rimmer, M. 2019. Beyond the Paris agreement: intellectual property, innovation policy, and climate justice. [Online] Available from: https://doi.org/10.31235/osf.io/fxhvm [Accessed: 2024-03-17].

Rogelj, J., Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K. & Meinshausen, M. 2016. Paris agreement climate proposals need a boost to keep warming well below 2°C. *Nature, 534*(7609):631-639. [Online] Available from: https://doi.org/10.1038/ [Accessed: 2024-03-20].

Romano, R., Aelenei L., Aelenei, D. & Mazzuchelli, E. 2018. Journal of Facade Design and Engineering. *What is an adaptive façade? Analysis of Recent Terms and definitions from an international perspective*.

Šadauskienė, J., Ramanauskas, J., Seduikyte, L., Daukšys, M. & Vasylius, A. 2015. A simplified methodology for evaluating the impact of point thermal bridges on the high-energy performance of a passive house. *Sustainability*, 7(12):16687-16702. [Online] Available from: https://doi.org/10.3390/su71215840 [Accessed: 2024-03-29].

Saffari, M., De Gracia, A., Ushak, S. & Cabeza, L. 2017. Passive cooling of buildings with phase change materials using whole-building energy simulation tools: A review. *Renewable and Sustainable Energy Reviews*, 80:239-1255.

Santos, F.A., Bedon, C. & Micheletti, A. 2020. Explorative study on adaptive facades with superelastic antagonistic actuation. *Structural Control and Health Monitoring*, 27(4). [Online] Available from: https://doi.org/10.1002/stc.2463 [Accessed: 2024-03-27].

Sanyaolu, P. & Sanyaolu, C. 2018. URBANIZATION 1. [Online] Available from: https://doi: 10.13140/RG.2.2.23495.96161 [Accessed: 2024-03-11].

Scharf, B. & Kraus, F. 2019. Green Roofs and Greenpass. *Buildings*, 206. [Online] Available from: https://doi.org/10.3390/buildings9090205 [Accessed: 2024-03-15].

© University of Pretoria

Selvanayagam, V. 2020. Contemporary Matale city: challenges and opportunities in urban development. *International Journal of Social Science and Economic Research, 5*(12), 3831-3855. [Online] Available from: https://doi.org/10.46609/ijsser.2020.v05i12.008 [Accessed: 2024-03-23].

Seyfang, G. 2010. Community action for sustainable housing: building a low-carbon future. *Energy Policy*, 38(12):7624-7633.

Shahbaz, M., Loganathan, N., Muzaffar, A. T., Ahmed, K. & Jabran, M. A. 2016. How urbanization affects co 2 emissions in malaysia? the application of stirpat model. *Renewable and Sustainable Energy Reviews*, 57:83-93. [Online] Available from: https://doi.org/10.1016/j.rser.2015.12.096 [Accessed: 2024-06-14].

Şık, C.S. Widera, B. & Woźniczka, A .2021. Sustainability-related parameters and decision support tools for kinetic green façades. *Sustainability*, 13(18):10313. [Online] Available from: https://doi.org/10.3390/su131810313 [Accessed: 2024-04-12].

Sol, D., González-Lagos, C., Moreira, D., Maspons, J. & Lapiedra, O. 2014. Urbanisation tolerance and the loss of avian diversity. *Ecology Letters*, 17(8):942-950. [Online] Available from: https://doi.org/10.1111/ele.12297 [Accessed: 2024-06-15].

Solecki, W.D., Rosenzweig, C., Parshall, L., Pope, G., Clark, M., Cox, J. & Wiencke, M. 2005. Mitigation of the heat island effect in urban new jersey. *Environmental Hazards*, 6(1):39-49.

Spence, A., Poortinga, W., Butler, C., & Pidgeon, N.F. 2011. Perceptions of climate change and willingness to save energy related to flood experience. *Nature Climate Change*, 1(1),46-49. [Online] Available from: https://doi.org/10.1038/nclimate1059 [Accessed: 2024-03-08].

Sundell, J., Levin, H., Nazaroff, W, Cain W., Fisk, W., Grimsrud, D., Gyntelberg, F., Li, Y., Persily A., Pickering, A., Samet, J., Spengler, J., Taylor S. & Weschler, C. 2011. Ventilation Rates and Health: Multidisciplinary Review of the Scientific Literature. *Indoor Air*, 21(3):191-204. [Online] Available from: https://doi.org/10.1111/j.1600-0668.2010.00703.x [Accessed: 2024-03-31].

Sung, U. & Kim, S. 2019. A study on the improvement of double-skin facade operation for reducing heating load in winter. Sustainability, 11(22):6238. [Online] Available from: https://doi.org/10.3390/su11226238 [Accessed: 2024-04-14].

© University of Pretoria

Syaodih, E. 2019. The challenges of urban management in Indonesia. In *Proceedings of the Social and Humaniora Research Symposium (SoRes 2018)*. [Online] Available from: https://doi.org/10.2991/sores-18.2019.111 [Accessed: 2024-03-22].

Tamminga, K., Cortesão, J. & Bakx, M. 2020. Convivial Greenstreets: a concept for climate-responsive urban design. *Sustainability*, 12(9):1-8. [Online] Available from: https://doi.org/10.3390/su12093790 [Accessed: 2024-03-13].

Thompson, L.G. 2010. Climate change: the evidence and our options. *The Behavior Analyst*, 33(2):153-170. [Online] Available from: https://doi.org/10.1007/bf03392211 [Accessed: 2024-03-08].

United Nations Framework Convention on Climate Change [UNFCCC]. 1992. United Nations.

United Nations Framework Convention on Climate Change [UNFCCC]. 2016. *The Paris Agreement.*

United Nations Statistics Division [UNSD]. 2016. *Sustainable Development Goals Report*.

Vermeulen, A. 2024. *Climate Change Adaptation Technologies*.

Vijayasarathy, K. & Ashok, K.R. 2015. Climate Adaptation in Agriculture Through Technological Option: Determinants and Impact on Efficiency of Production. *Agricultural Economics Research Review*. 28(1):103-116.

Warner, K. 2013. Enhancing adaptation options and managing human mobility in the context of climate change: role of the United Nations Framework Convention on Climate Change. In *Climate Change: International Law and Global Governance,* 761-784.

Watson, L., Straatsma, M.W., Wanders, N., Verstegen, J.A., De Jong, S.M. & Karssenberg, D. 2020. Global ecosystem service values in climate class transitions. *Environmental Research Letters*, *15*(2):024008.

Webb, M. 2021. Biomimetic building facades demonstrate potential to reduce energy consumption for different building typologies in different climate zones. *Clean Technologies and Environmental Policy*, 24(2):493-518. [Online] Available from: https://doi.org/10.1007/s10098-021-02183-z [Accessed: 2024-04-15].

© University of Pretoria

Widiastuti, R., Zaini, J. & Caesarendra, W. 2020. Field measurement on the model of green facade systems and its effect to building indoor thermal comfort. *Measurement*, *166*, 108212. [Online] Available from: https://doi.org/10.1016/j.measurement.2020.108212 [Accessed: 2024-05-01].

Wilhelmi, O. & Hayden, M.H. 2010. Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters, 5*(1), 014021. [Online] Available from: https://doi.org/10.1088/1748-9326/5/1/014021 [Accessed: 2024-03-24].

Windapo, A.O. 2014. Examination of green building drivers in the South African construction industry: Economics versus ecology. *Sustainability*, *6*(9):6088-6106. [Online] Available from: https://doi.org/10.3390/su6096088 [Accessed: 2024-04-09].

Wong, N.H., Tan, A.Y.K., Chen, Y., Sekar, K., Tan, P.Y., Chan, D.J.C., Chiang, K. & Wong, N.C. 2010. Thermal evaluation of vertical greenery systems for building walls. *Building and Environment*, 45(3):663-672.

Wu, L., Jiang, Y., Wang, L. & Qiao, X. 2022. The two faces of urbanisation and productivity: enhance or inhibit? new evidence from chinese firm-level data. *Asian-Pacific Economic Literature*, 36(1):126-142. [Online] Available from: https://doi.org/10.1111/apel.12352 [Accessed: 2024-06-15].

Yang, Y., Sun, R., Dai, J. and Zhu, M. 2023. Evolutionary analysis of stakeholder behavior in green retrofitting of traditional residential buildings based on dissemination and game models. *Plos one*, *18*(3):e0282314. [Online] Available from: https://doi.org/10.1371/journal.pone.0282314 [Accessed: 2024-04-16].

Yanti, S., Arafat, Y., & Wahidy, A. 2021. The influence of leadership and motivation on teacher work performance. *Advances in Social Science, Education and Humanities Research*. 1129-1135.

Yılmaz, Y., Şansal, K. E., Aşcıgil-Dincer, M., Kültür, S. & Tanrıöver, S. 2022. A methodology to determine appropriate façade aperture sizes considering comfort and performance criteria: a primary school classroom case. *Indoor and Built Environment*, 31(7):1874-1891. https://doi.org/10.1177/1420326x221080566 [Accessed: 2024-03-25].

Yin, C., Xiao, J. & Zhang, T. 2021. Effectiveness of Chinese regulatory planning in mitigating and adapting to climate change: comparative analysis based on Q methodology. *Sustainability, 13*(17), 9701. [Online] Available from: https://doi.org/10.3390/su13179701 [Accessed: 2024-03-24].

© University of Pretoria

Yitmen, I., Almusaed, A. & Yücelgazi, F. 2021. Anp model for evaluating the performance of adaptive façade systems in complex commercial buildings. *Engineering, Construction and Architectural Management*, 29(1):431-455. [Online] Available from:https://doi.org/10.1108/ecam-07-2020-0559 [Accessed: 2024-03-25].

Yu, P., Zhang, Y., Han, M., Yung, E. H. K., Chan, E. H. W. & Chen, Y. 2024. Spatial heterogeneity impacts of urbanisation on open space fragmentation in hong kong's built-up area. *Land*, 13(4):457. [Online] Available from: https://doi.org/10.3390/land13040457 [Accessed: 2024-06-16].

Ziervogel, G., Cowen, A. & Ziniades, J. 2016. Moving from Adaptive to Transformative Capacity: Building Foundations for Inclusive, Thriving, and Regenerative Urban Settlements. *Sustainability*, 8(9):955. [Online] Available from: https://doi.org/10.3390/su8090955 [Accessed: 2024-03-07].

Ziervogel, G., New, M., Archer, E., Midgley, G. F., Taylor, A., Hamann, R., Stuart-Hill, S., Myers, J. & Warburton, M. 2014. Climate change impacts and adaptation in South Africa. *WIREs Climate Change,* 5(5):605-620. [Online] Available from: https://doi.org/10.1002/wcc.295 [Accessed: 2024-02-26].

© University of Pretoria

Annexure 1

Case study 1	• Manuel Gea Gonzalez Hospital - Architectural websites Architect Magazine, 2013 https://www.architectmagazine.com/technology/architectural-detail/fighting-a-megacitys-pollution-with-mega-panels_o • website: Centre for public impact 2016 https://www.centreforpublicimpact.org/case-study/mexico-citys-manuel-gea-gonzalez-hospital-facade
Case study 2	• KMC Corporate Office - https://rmaarchitects.com/architecture/kmc-corporate-office/
Case study 3	• Pearl river tower – https://www.som.com/projects/pearl-river-tower/
Case study 4	• 78 Corlett Drive Building – https://www.archdaily.com/919164/78-corlett-drive-building-daffonchio-and-associates Architectural website ArchDaily, 2019
Case study 5	• https://www.designinc.com.au/project/council-house-2-ch2 • https://www.archdaily.com/395131/ch2-melbourne-city-council-house-2-designinc
Case study 6	• Alexander Forbes - https://paragon.co.za/content/alexander-forbes-115-west-street-sandton
Case study 7	• U. Hong Kong - http://ibse.hk/sbe/case_study/case/hk/hku-bsb/bsb-index.html
Case study 8	• National Biodiversity Pavilion - https://amazingarchitecture.com/pavilion/the-national-biodiversity-pavilion-mexico-city-mexico-by-fernanda-ahumada-free • https://www.dezeen.com/2023/07/17/national-biodiversity-pavilion-mexico-fernando-ahumada/ • https://www.archdaily.com/1005112/national-pavilion-of-biodiversity-fernanda-ahumada-plus-free
Case Study 9	• Britam tower - https://www.gapp.net/project/britam-tower/
Case study 10	• UP - https://www.kwpcreate.com/post/89/plant-sciences-complex/
Case study 11	• Podium at Menlyn | Boogertman + Partners Architects | Archello. https://archello.com/project/podium-at-menlyn • Boogertman+Partners Architects. (2014, April 4). Podium at Menlyn [Video]. YouTube. https://www.youtube.com/watch?v=ECV3Iy2oGFI

© University of Pretoria

Case study 12	• WOHA. (2024, April 2). The Grove – https://woha.net/project/the-grove/
Case study 13	• Caballero, P. 2023. BMW South Africa Head Office / Boogertman + Partners Architects. ArchDaily. https://www.archdaily.com/1001084/bmw-south-africa-head-office-boogertman-plus-partners-architects • Boogertman. 2012. BMW Head Office, Johannesburg, South Africa - Boogertman. https://boogertmanandpartners.com/portfolio/bmw-head-office/ • https://api.gbcsa.org.za/storage/uploads/Project-study-291/42-1-bmw-sa-head-office.pdf
Case study 14	• https://tileofspainusa.com/the-lantern-that-illuminates-hanoi-vietnam/ • https://www.dezeen.com/2016/11/25/the-lantern-vo-trong-nghia-perforated-brick-gallery-showroom-hanoi-vietnam/ • https://www.youtube.com/watch?v=GN9yh0owgJY
Case study 15	• https://www.wildeandwoollard.com/featured/monash-university-science-technology-research-and-innovation-precinct-strip-2-and-3/ • https://studentvip.com.au/monash/clayton/maps/122451 • https://www.archdaily.com/395214/monash-university-science-technology-research-and-innovation-precinct-stage-2-biomedical-sciences-buildings-designinc/51cc9ebfb3fc4be56b00009b-monash-university-science-technology-research-and-innovation-precinct-stage-2-biomedical-sciences-buildings-designinc-bioclimatic-section-c-designinc?next_project=no

Table 20. Annexure table (Author, 2024).

© University of Pretoria