



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

**SUSTAINABLE FUTURES THROUGH THE USE OF CLIMATE  
ADAPTIVE BUILDING TECHNOLOGIES**

by

**Storm Sibisi  
U19176262**

**Supervisor: Abrie Vermuelen**

**Department of Architecture  
Faculty of Engineering, the Built Environment and Information Technology  
University of Pretoria  
South Africa**

**28 June 2024**



## Declaration of Originality

I declare that the mini-dissertation, **SUSTAINABLE FUTURES THROUGH THE USE OF CLIMATE ADAPTIVE BUILDING TECHNOLOGIES**, which has been submitted in fulfilment of part of the requirements for the module of **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: *Storm Sibisi*

Date: **28 June 2024**

## **Abstract**

There is a serious environmental catastrophe occurring right now that needs to be addressed. It is quite concerning how quickly the climate is changing across the globe. While global leadership on climate change will require an amalgamation of policy solutions, there are concerns that extreme weather shifts will disproportionately affect the developing world. Urban areas in South Africa must adjust to a changing climate and the resulting heat stresses that come with it. It is necessary to modify existing structures to meet these new needs and lessen their negative environmental impacts, highlighting the importance of adaptation rather than mitigation. Architecture plays a pivotal role in addressing environmental concerns. This study will investigate how we can enhance our existing building technology to achieve optimal building thermal efficiency while infusing innovation into our architectural thinking. This research paper forms part of a larger study that explores architectural building technologies that can be implemented as climate change adaptive strategies in multi-storey residential buildings in the city of Tshwane. The study follows a pragmatic approach and uses a desktop research method. The study aims to assess and comprehend the potential for thermal amelioration in both the current and projected climate conditions in Tshwane through the comparison of case studies and will draw conclusions on formulating a sustainable response to future climate changes.

**Key words:** Climate change adaptation, thermal response, building technologies, case studies, facade systems



## Table of Contents

<b>Declaration of Originality</b>	<b>i</b>
<b>Abstract</b>	<b>ii</b>
<b>List of Figures:</b>	<b>v</b>
<b>List of Tables:</b>	<b>v</b>
<b>List of Abbreviations:</b>	<b>v</b>
<b>1. Introduction and background</b>	<b>1</b>
1.1. Background	1
1.2. Research problem	3
1.3. Research Questions	4
1.4. Research objectives	4
1.5. Limitations, Delineation and Assumptions of the Study	4
<b>2. Literature review</b>	<b>6</b>
2.1 Background	6
2.1.1 Climate change	6
2.1.2 Climate change and the future	7
2.1.3 Urbanisation and Urban Heat Island Effect	8
2.1.4 The Impact of climate change on buildings	9
2.2 Solutions/ Response Context	10
2.2.1 Local Response:	10
2.2.2 International Response:	10
2.2.3 Resilient Futures	11
2.3 Facade Systems	12
<b>3. Research methodology</b>	<b>14</b>
3.1 Study approach / Paradigm	14
3.2 Study Area and Context	14
3.3 Data Collection	15
3.4 Data Analysis	17
3.4.1. Consideration of key variables	17
3.4.2. Köppen Geiger climate classification system	17
3.4.3. Present & Future Climate Classification (Cwa; Cwb; Bsh)	20
3.4.4. Design strategies for thermal comfort	21
3.5 Ethical considerations	22



<b>4. Results</b>	<b>23</b>
4.1 Case study description	24
4.1.1 Manuel Gea Gonzalez Hospital	24
4.1.2 KMC Corporate Office	24
4.1.3 Pearl River Tower	24
4.1.4 78 Corlett Drive Building	25
4.1.5 Council 2 House	25
4.1.6 Alexander Forbes Office	25
4.1.7 Kadoorie Biological Sciences Building	26
4.1.8 National Biodiversity Pavilion	26
4.1.9 Britam Towers	26
4.1.10 University of Pretoria Plant Science Complex	27
4.1.11 Podium AT Menlyn	27
4.1.12 The Grove	27
4.1.13 BMW Head office	27
4.1.14 The Lantern	27
4.1.15 Monash University Biomedical Sciences Buildings	27
4.2 Technicality	28
4.3 Methods of Assessing Effectiveness	36
4.4 Benefits and Constraints	36
4.4 Comparative analysis	44
4.5 Frequency of Use	46
4.6 Results Conclusion	46
<b>5. Discussion</b>	<b>47</b>
5.1 Discussion of results	47
5.1.1 Effectiveness of facade technologies	47
5.1.2 Trends and Similarities	47
5.2 Research question response	47
5.3 Gaps and recommendations	48
<b>6. Conclusion</b>	<b>49</b>
<b>References</b>	<b>50</b>
<b>Appendix A: The 32 Koppen Climate Classifications</b>	<b>55</b>
<b>Appendix B: The Data Capture</b>	<b>56</b>



## List of Figures:

<b>Figure 1:</b> Global warming chart projection.....	2
<b>Figure 2:</b> Earth beyond six of the nine planetary boundaries.....	6
<b>Figure 2:</b> Methodology data capturing process.....	16
<b>Figure 3:</b> A diagram illustrating the layout of research procedures used in the study.....	16
<b>Figure 4:</b> The 5 Köppen climate classification types.....	18
<b>Figure 5:</b> The 5 Köppen climate classification World map.....	18
<b>Figure 6:</b> World Map of the Köppen-Geiger climate classification updated.....	20
<b>Figure 7:</b> Case studies comparative analysis.....	45
<b>Figure 8:</b> Case studies frequency table.....	46

## List of Tables:

<b>Table 1:</b> Case studies description.....	23
<b>Table 2:</b> Case studies Technicality.....	28
<b>Table 3:</b> Case studies Benefits and constraints.....	36

## List of Abbreviations:

**IPCC:** International Panel for Climate Change

**CCA:** Climate Change Adaptation

**GHG:** Green House Gases

**WGI:** Worldwide Governance Indicator

**SPM:** Summary for Policy Makers

**AR:** Assessment Report

**NASA:** National Aeronautics and Space Administration

**RCP:** Representative Concentration Pathway

**NOAA:** National Oceanic and Atmospheric Association

**UHIE:** Urban Heat Island Effect

**INDC:** Intended Nationally Determined Contributions

**UNFCCC:** United Nations Framework Convention on Climate Change



## 1. Introduction and background

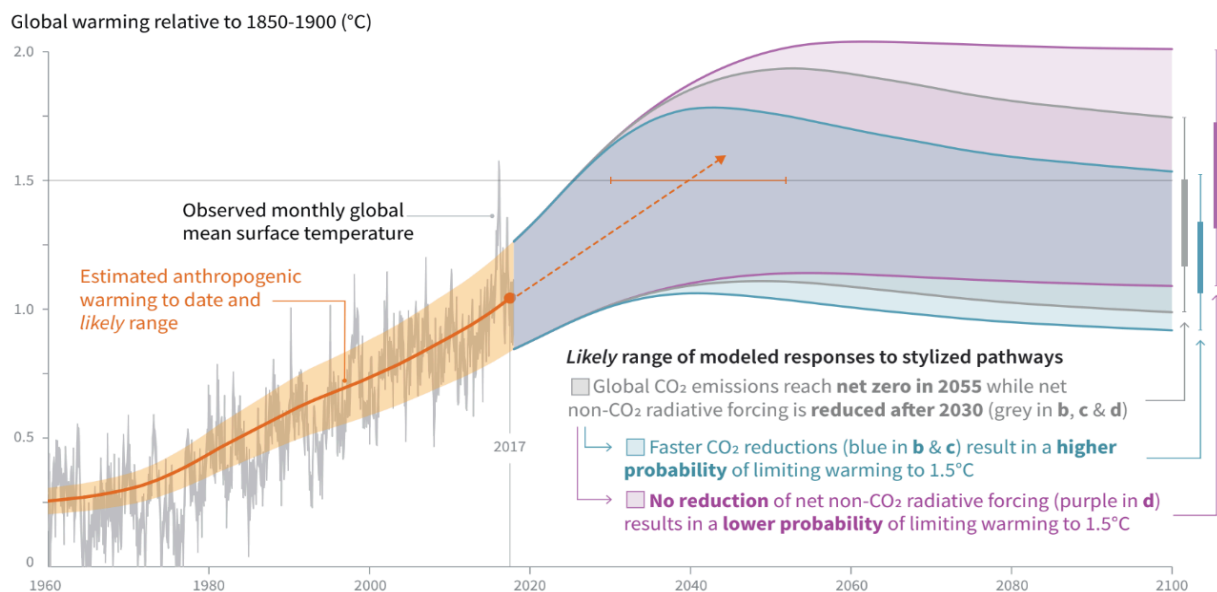
Most designers are oblivious on how architecture can alter peoples' lives on a daily basis. Its effect on our way of life, perspective, and attitudes makes it pertinent to ask: Can design alleviate the crisis of global warming? Considering the fact that the world is already engulfed by an environmental crisis, it is very important that we understand the dangers and effects of climatic change and why it is bad living in a society that neglects these concerns. The impacts of global warming are experienced everywhere in the world and are unsurpassed in terms of their extent and magnitude. Heatwaves, extreme weather events, and an increase in the average global temperature are the results of this. The impact of heatwaves on urban populations and natural ecosystems in large cities is intensified by the heat island effect (McCarthy, 2010). Urban centres in South Africa possess the capacity to tackle the persistent global trend of urbanisation and alleviate its detrimental impacts on the environment.

It is crucial to acknowledge that the majority of South African cities (such as Tshwane) are made up of pre-existing structures and built infrastructure that dates back decades ago, constructed from materials that followed design standards suitable and within the parameters of earlier local climate. It is also important to pinpoint that global warming and climate change breeds conditions where these parameters are exceeded, hence the design standards that were followed are typically no longer suitable for current climate conditions. This, then necessitates that architects explore innovative building technologies by utilising data collection and analysis to better understand the material and methods best suited for future conditions in urban spaces. While these factors can be considered during the design and development phases of new construction, upgrading existing buildings is required to improve their capacity to withstand these stresses and achieve thermal amelioration. This is crucial since the original climatic conditions for current buildings were altered and are still changing.

### 1.1. Background

Climate change is a complex issue that requires careful solutions. Reducing the impact of climate change as much as possible is one important strategy; the other is dealing with its ramifications by developing adaptation plans. Mitigation aims to stop the effects that are difficult to manage, while adaptation aims to deal with the effects that cannot be avoided (Liu, 2022). This highlights the importance of adaptation strategies as climate change is already happening before us and is set to worsen in the upcoming decades. Energy usage and emissions, the biggest contributors to climate change, may significantly increase by the middle of the 21st century (IPCC, 2021). Therefore, mitigation and adaptation strategies need to be prioritised.

According to (IPCC, 2018), An estimated 1.0°C of global warming has been attributed to human activities including farming, burning fossil fuels, and clearing forests, with a likely range of 0.8°C to 1.2°C. If global warming keeps increasing at its current rate, it is predicted to reach 1.5°C between 2030 and 2052. (refer to figure 1). Ever since the combustion of fossil fuels that was encouraged by the commencement of the industrial revolution, the chemical imbalances of the atmosphere have served as a catalyst towards the rapid change in climate conditions that threaten the planet (Altomente, 2008). The discovery of the industrial revolution had brought forth a new norm in the society's we live in today. The production of everyday products and the cycle of the modern-day city systems, have become fully dependent on the burning of these fossil fuels to stay functional. This creates a difficult transition to abruptly stop the emission of greenhouse gases into the atmosphere.



**Figure 1: Global warming chart projection (IPCC, 2018)**

Although current day leadership figures and policy makers have made attempts in reducing the production of greenhouse gases, these attempts are seemingly not enough. The IPCC (2018) states that due to the ever-increasing amount of anthropomorphic emissions released into the atmosphere, by the end of the century it is predicted that global average temperatures will increase by 4°C relative to the pre-industrial era (O'brein, 2014). Extreme weather events brought on by these temperature shifts around the world do serious harm to the built environment and densely populated areas (Kristl et al., 2020). As a result, the multiplicity of climate change's consequences at many sizes, from regional to micro settings, must be considered (Kosanovic et al., 2018). Due to



land use changes, urbanisation, and the built environment, buildings and urban areas endure higher temperatures than the surrounding rural areas. Therefore, in order to combat the consequences of heat-affected metropolitan areas and temperature surges, it becomes vital to reinvent cities using sustainable means of building (Li & Bou-Zeid, 2013).

Nonetheless, the building industry is thought to be potentially among the most adaptable and results-driven (Loonen, 2018). However, cities must adopt strategies to combat climate change in order to ensure their survival and prosperity. Without effective adaptation plans, urban areas are vulnerable to the impacts of climate change. This includes maintaining critical services, protecting public safety, and promoting sustainable practices as part of the growth and development process. By implementing measures to adapt and manage properly, cities can reduce their vulnerabilities, mitigate risks, and build resilience to future challenges (Oluoko-Odingo, 2019). New and old buildings must meet the standards to decrease emissions and save energy. This study focuses on methods and tools used in the construction industry to address climate change. Green buildings technology, zero-energy buildings and passive buildings form the new face of architecture in this era of design.

## 1.2. Research problem

Between 2015 and 2020, South Africa experienced protracted droughts and heat waves, which helped in creating the six hottest years on record for global average temperatures (WMO, 2020; 2021). In April 2022, KwaZulu-Natal experienced heavy rainfall that led to widespread structural and stormwater system failures in urban areas, showcasing the impact of climate change on human living conditions. A similar shift in Tshwane's climate may be seen in the quantity of days with extremely high temperatures. By 2050, there will likely be 48.54 days a year with temperatures exceeding 35°C (City of Tshwane, 2022). Alongside these exogenic forces are endogenic elements including the built-up density, present urban patterns, loss of vegetation, building materials, and anthropogenic heat sources (Seto and Shepherd, 2009),

According to the IPCC report, the primary reason (driver) for global warming is the increase in  $CO_2$  levels in the atmosphere since 1750 (IPCC, 2018). Even if emissions stop immediately, temperatures will continue to rise for centuries due to previously emitted greenhouse gases from human activities (IPCC, 2021).

The study aims to enhance our capacity to cope with heat stress amid urban development. As cities evolve to accommodate a growing population, buildings are being refurbished to withstand the increasing frequency and intensity of heat waves and other climate-related impacts. Southern



Africa is particularly vulnerable to climate variations and heat stress, putting the region in a precarious position. This study investigates how building technologies impact the regional climate, specifically in terms of improving thermal conditions. It will also be looking at how these technologies are evaluated for thermal adaptability and analysing the various factors related to their implementation. The goal is to provide useful insights for improving the resilience of multi-storey residential buildings in urban areas of South Africa, particularly in the Tshwane region.

### **1.3. Research Questions**

This study aims to record architectural interventions in the form of case studies that function as a form of building technologies implemented as systems for climate change adaptation. With a specific focus on facade systems, the study will look at the level of effectiveness that these interventions have on the ability to withstand heat stresses. By doing this, it seeks to further the theoretical discussion surrounding climate change adaptation. The aim of the study is to gain a better insight of the technical specifications needed to increase the thermal amelioration for multi-storey apartment complexes in South African cities (Vermeulen, 2023).

#### **1.3.1 Research Question:**

“How can/do architectural building technologies implemented in selected case studies, contribute to the local climate adaptation strategies that target thermal amelioration potential (Vermeulen, 2023)?”

#### **1.3.2 Sub Questions:**

01 “What methods are used to assess the thermal adaptive capacity of the building technology (Vermeulen, 2023)?”

02 “What are the reported outcomes/efficiencies/benefits/shortcomings of the building technology (Vermeulen, 2023)?”

### **1.4. Research objectives**

In the context of climate change, the goal is to analyse and comprehend the potential for thermal adaptation responses of selected adaptation solutions for use in current and future Tshwane climate conditions. The goal of this study is to collect and examine case studies that make use of facade system strategies situated in current and projected climate conditions in Tshwane. As a result, the findings will be used to develop a sustainable response for Tshwane's future climate change classification.



### **1.5. Limitations, Delineation and Assumptions of the Study**

Due to the numerous classifications and factors, the study will only examine the Köppen-Geiger climate classification of Tshwane, 2020–2100, which is currently classified as Cwa & Cwb. It is postulated that the future classification from 2040 will be Bsh; more details on this will be discussed in this paper. The scope of the study is the analysis of case studies within the climate classifications Cwa, Cwb & Bsh. Therefore, it limits the desktop study on climate change adaptation technologies as few countries fall under these classifications. Furthermore, the paper specifically looks at facade systems as a building technology, reducing the number of case study options. The study's results regarding the efficacy of adaptation tactics and technologies are based on the literature that is currently available on thermal amelioration.

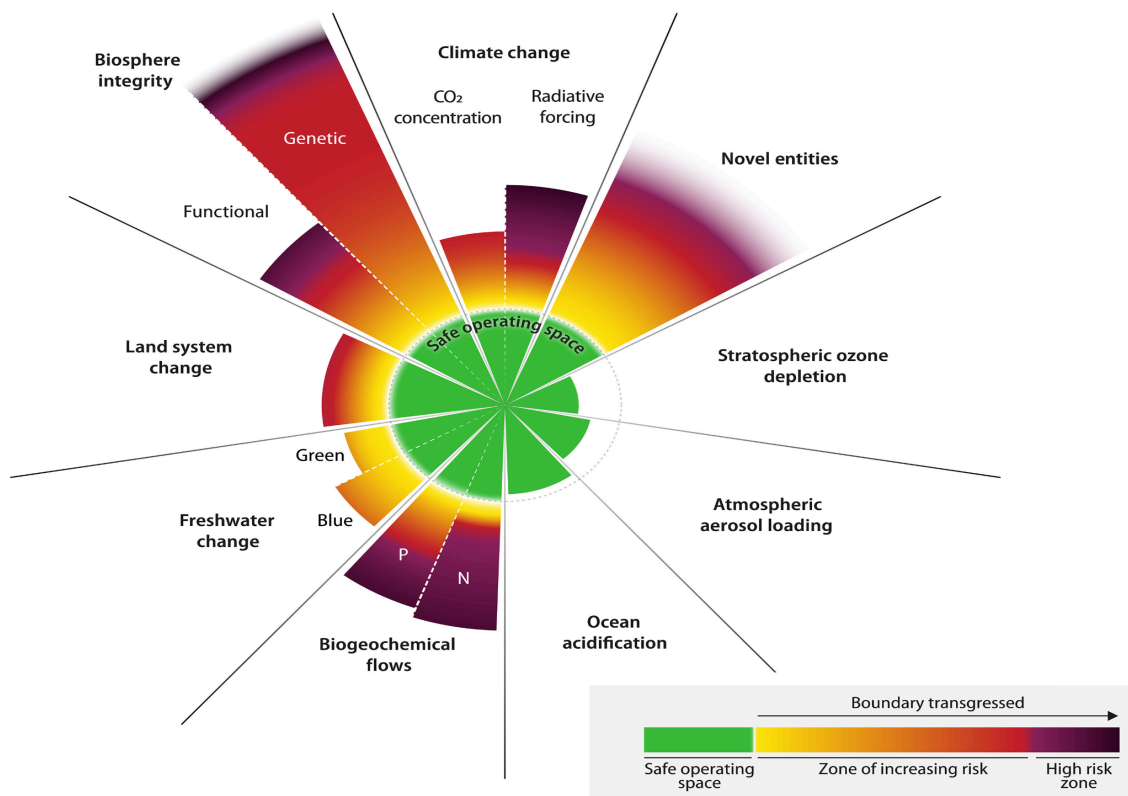


## 2. Literature review

### 2.1 Background

#### 2.1.1 *Climate change*

Over the last century, humans have had a significant impact on our environment, raising concerns about the limits of planetary systems. Rockström (2009) introduced the idea of nine planetary boundaries with specific thresholds to assess the overall effects of human activities on a global scale (see figure 2). Exceeding these limits could result in widespread alterations to earth's climate, upsetting the equilibrium of other systems and triggering irreversible environmental events. Human actions have already crossed one of the defined thresholds for climate change by emitting greenhouse gases into the atmosphere (Richardson et al., 2023). This has led to increases in both atmospheric and ocean temperatures, creating a state of uncertainty and heightened peril for us all (Rockström, 2009; IPCC, 2014). Scientists estimate that human activities have contributed to approximately 1.0°C of extra global warming, pushing temperatures to levels 0.8°C to 1.2°C higher than before the Industrial Revolution. Projections suggest that global warming will surpass pre-industrial levels, with a potential rise of 1.5°C by 2052 if current trends continue with human-caused global warming currently growing by about 0.2°C every ten years. Due to past and current emissions (IPCC, 2018).



**Figure 2: Earth beyond six of the nine planetary boundaries** (Richardson et al., 2023)

### **2.1.2 Climate change and the future**

To estimate how the climatic changes, projections for the future are studied with climate models. The Summary for Policymakers (SPM) provides an overview of the key findings from Working Group I (WGI) for the IPCC Sixth Assessment Report (AR6) on the current state of climate change as well as how it is changing. It builds upon previous reports like the Fifth Assessment Report (AR5) and integrates new scientific research from the 2018-2019 IPCC Special Reports in the AR6 cycle (IPCC, 2021). According to the Fourth Assessment Report (AR4) from the Intergovernmental Panel on Climate Change (IPCC), climate is described as the typical weather conditions in a certain area. It can be characterised by the average temperature, rainfall, and wind patterns over a specific timeframe. Recent studies have brought into question traditional definitions of current climate change knowledge terminology and understanding, with significant fluctuations in weather patterns being observed (NASA, 2005; Kosanovic et al., 2018).

Van Vuuren, (2011) introduced a globally recognized approach that initially includes four different representative concentration pathway (RCP) scenarios for assessing potential impacts of climate change in a similar manner. These situations consider various factors including greenhouse gas emissions, air pollution, land and energy usage, as well as social, economic, and technological changes to forecast future circumstances more accurately. The future climate scenarios for the



final stages of the 21st century is described by the four directions: RCP2.6, RCP4.5, RCP6.0, and RCP8.5, in terms of radiative forcing values ( $W/m^2$ ). The scenarios are labelled based on the expected radiative forcing levels, which correspond to the strength of the greenhouse effect. In RCP2.6, emissions are effectively reduced in the upcoming century, while RCPs 4.5 and 6.0 represent middle-ground scenarios, with RCP 8.5 symbolising a worst-case scenario (figure 1). If we were to proceed without attempting to reduce emissions, we would likely end up following pathways close to RCPs 6.0 and 8.5. (Van Vuuren, 2011; IPCC, 2014)

The global warming limit goal, set in the United Nations' Paris Agreement in 2015, aims to maintain the current increase in temperature within 1.5 degrees Celsius above pre-industrial levels. This legally binding pact, which addresses climate change, is a component of the United Nations Framework Convention on Climate Change (United Nations 2015). The RCP2.6 scenario is projected to meet the target of staying under 2 degrees Celsius, but the yearly CO<sub>2</sub> emissions linked to this path will surpass the planetary limit for climate change for an extended period. The limit for climate change was determined to be 350 ppm of atmospheric CO<sub>2</sub>, a level that has been exceeded since the last century.

The atmospheric CO<sub>2</sub> concentration at the end of 2020 was recorded at 413.95ppm by NOAA (2021). This means that as a result of climate change, the devastating weather occurrences including heat waves, torrential rains, storms, floods, and rising sea levels would occur more frequently and with greater severity, affecting both natural and human systems globally (IPCC 2014). The risks posed to these systems due to climate change are influenced by the speed, magnitude, and duration of global warming. The level of risk faced varies based on location, level of development, vulnerability, and the effectiveness of adaptation and mitigation measures implemented.

If global warming continues at the current pace, it is likely that we will reach a temperature increase of 1.5 degrees Celsius sometime between 2030 and 2052 as predicted by the IPCC (2018). Limiting the fluctuations in global temperatures to 1.5 degrees Celsius over pre-industrial levels is one of the primary objectives of the Paris Agreement. Other objectives are: improving the ability to deal with the results of climate change while also building climate resilience, encouraging the advancement of low-greenhouse gas emission technologies, and direct financial funds toward projects that reduce greenhouse gas emissions and enhance climate resilience. Notwithstanding this agreement, in ensuring that these objectives are met, was to be implemented while considering the unique situations of each country (United Nations, 2015).



### **2.1.3 Urbanisation and Urban Heat Island Effect**

The percentage of people living in urban areas has been rising, a phenomenon known as urbanisation. According to (Chen, 2013), people move from rural to urban areas in search of better economic opportunities. Economic growth in urban areas, especially in developing nations, often coincides with urban expansion (Chen, 2013). Urbanisation can be impacted by climate change in a number of ways. Apart from the apparent variations in temperature, where longer-term heat waves have negative effects on health, it also impacts the progress of urbanisation by altering the energy composition, modifying the pattern of precipitation in space, and triggering catastrophic weather events leading to natural disasters (Li, et al. 2022).

Because of human activity, the temperature in metropolitan areas is greater than in surrounding areas; this is called Urban Heat Island Effect (UHIE). The lack of trees and greenery together with the number of high-rise buildings and infrastructure contributes to the UHIE in urban areas. The temperatures in UHIE during the day can go up by up to 5°C higher than the areas surrounding them.

When looking ahead to ensure sustainability within the urban context, it's important to consider various factors. One critical factor that is often neglected, is the sheer number of people who are taking up these spaces. The world's population is expected to double from its present 8 billion people. Even with strict policies in place limiting the number of children per household, it will still take about 70 years for the population growth rate to significantly decrease. It's estimated that the population may plateau at around 13 billion individuals at that time (Rahbarianyazd and Raswol, 2018). Therefore, the effects of urbanisation and the impact it has on global warming will continue to persist in the next decades.

Urbanisation is a complex process that presents an amalgamation of challenges and opportunities for achieving sustainable development. Individuals' income levels can greatly influence their experiences and where they choose to stay. How do you plan to address this issue? Developing countries may approach urbanisation differently in distinct ways. Managing urban spaces is a complicated endeavour, but through the implementations of various strategies can be overcome

### **2.1.4 The Impact of climate change on buildings**

Although the precise magnitude of these effects is unknown and expected to vary across different places, it is anticipated that climate change will have a substantial effect on Architecture and the built environment as a whole. Climate change and severe weather, such as rising precipitation,



thawing permafrost, more frequent wildfires, strong storms, and flooding, can affect a lot of constructions (IPCC, 2018). According to IPCC (2018), this vulnerability will worsen if resilience isn't invested in. Furthermore, the location of built assets affects their susceptibility and predisposition. Since delays in construction projects are caused by significant rainfall, the construction industry is already directly impacted by climate change. (IPCC, 2018)

According to (Seto and Sheperd, 2009), the increase in frequency regarding severe weather events is causing more rebuilding and repair work which is a warning factor to officials regarding the impact of climate change in general. Heatwaves are becoming more frequent and intense, affecting how buildings are constructed. Higher temperatures will change energy demands due to climate factors. Due to rising temperatures, increased heat-related health concerns, stronger tropical storms, and increased damage from winds, soil erosion, and floods, the effects of climate change on buildings would result in higher energy use.

Buildings and infrastructure might be under risk from climate change (Knaack, 2009). According to (Vax, et al. 2018), storms, damage from snow or subsidence, water intrusion, poor indoor climate, and shorter building lifespans could all contribute to an increased danger of collapse, deteriorating health, and a large loss of value. In the areas of existing buildings that don't adhere to the building code's safety regulations, storms pose a risk to public safety.

## **2.2 Solutions/ Response Context**

### **2.2.1 Local Response:**

The impact of climate change becomes more evident nowadays, global communities have gathered response strategies to overcome its effects. According to Boschhoff and Meyl, (2020) South Africa's response to global warming has had a negative impact on humans and the environment surrounding them. Chersich and Wright, (2019) further credits this to the fact that South Africa waited on other nations' responses before acting. It is now evident that the shift is on coming up with strategies and mitigation efforts to counter or adapt to climate change.

In South Africa, the stakeholders together with the government have created numerous documents in recent years that send important policies and strategic facets of adjusting to climate change. The National Climate Change Response White Paper, published by the government in 2018, brought out the idea of various ways that climate change challenges can be incorporated into all areas. The 2011 White Paper on this subject has been updated in this publication. The National Climate Change Bill draft has been disseminated for public discussion and comment Source.

Furthermore, the general citizens were able to make remarks on the second draft of the South African National Adaptation Strategy in 2017 (Chersich and Wright, 2019). The significant strategies outlined in the ten-year plan should bring about quantifiable results. According to Boschoff and Meyl, (2020), with broad guidelines spanning all economic sectors, the strategy serves as a benchmark for all South African efforts to adapt to climate change. As a result, it aims to make sure that the private sector and various governmental levels incorporate and represent climate change adaptation.

According to Bosshoff and Meyl, (2020), after submitting its INDC by 25 September 2015, South Africa signed the Paris Agreement in 2016; its primary goals being reducing emissions between 2025 and 2030, dropping emission profile and that all economic sectors are included in the targets.

### ***2.2.2 International Response:***

Policy makers are increasingly acknowledging the significance of both adaptation strategies as well as mitigation strategies and reactions to the impacts of climate change (UNFCCC, 2006). The word "adaptation" is commonly used in the world of architecture to refer to the morphological and physical changes made to the architectural item. These morphological alterations usually result from the development of architecture as an industry, a social area, and a technology product.

In the course of history, various transformations have influenced the way people view and create architecture. The style of architecture evolves depending on the era in which buildings are designed and admired. These changes often arise from evolving social norms, economic circumstances, occupant needs, and environmental factors (Siew, 2024). Changes in the surrounding environment over a specific time period, like a day, can be seen as a factor that affects a building and results in local alterations. Year-round, long-term climate variations would necessitate alterations to architectural designs in order to sustain and safeguard the structure (Coursesidekick, 2023).

Adjustment is viewed as a lasting process in the realm of architecture, evolving and transforming over various periods and ages. Significant enhancements in human cognition, critical thinking abilities, technology, and financial backing supports the adaptable quality of architectural designs. Building envelopes consist of both horizontal and vertical components that serve as a shield for the building against external environmental impacts, ensuring the interior comfort levels are maintained, and ultimately providing structural support to the building. The outer layer of a building



plays a vital role in providing support, regulating air pressure, and protecting the interior from elements such as heat, sunlight, wind, and rain. Building skins are essential for studying adaptive architecture and integrating technology to help buildings adjust to different climates. effective building exteriors should be able to influence and manage thermal energy flow within the building envelope by enhancing, reducing, controlling, capturing, or excluding it (Sushant Verma 2013).

Adjusting to the anticipated effects of changes in temperatures is known as climate change adaptation (CCA). Modifications to procedures, customs, and frameworks are needed to prevent possible economic, environmental, and societal harm, adapt to changing circumstances, and capitalise on new opportunities (UNFCCC, 2006). One of the primary objectives of the Paris Agreement is for nations and their cities to create and implement adaptation solutions to enhance resilience and readiness for the future in line with the dangers and effects of climate change. Climate effects can be severe because they can happen quickly (like flash floods) or gradually increase over rising time (like temperatures and sea levels). For this reason, adaptation methods must include both general resilience and disaster readiness.

### **2.2.3 Resilient Futures**

Human-environment interactions are the basis of resilience, so it stands to reason that by taking steps to improve people's resilience as well as that of their living environments, we should be able to lessen the creation of hazards and respond to those uncontrollable natural disasters like earthquakes. According to this viewpoint, resilience emerges as a key idea for sustainable development and development methods (O'Brien, 2014).

The aim for resilient design is to effectively address both local dangers found on site as well as those found on an urban scale. It then becomes necessary to acknowledge the interconnectedness of projects and ensign as a whole at various scales and to optimise and integrate climate change resilience measures at the micro site level with resilient and sustainable urban planning and design measures (Kosanovic et al, 2018).

### **2.3 Facade Systems**

The most noticeable feature that determines a building's overall aesthetic appeal is its front. Facade is a term referring to generally the front part or exterior of a building. Facades adapt to various functional performances and design contexts. Life has been changing fast and this has had an impact on numerous aspects of the built environment including architecture (Lou and Chan, 2011)). Change has been a part of architectural design as society and architecture evolves. Issues

have been raised over the process of building design since existing structures or their parts cannot adjust with the changing temperature requirements. Researchers like Rahbarianyazd and Raswol, (2018) have embarked on studies that sought new ways to design façade that allow architecture to accommodate thermal changes.

For thousands of years people have alleged that the front face of the building is an immovable object which splits interior from exterior. However, it has many uses since it must meet user requirements, at the same time, also reduce the cooling load of the building and protect the structure from external factors (Schittich, Krippner & Lang, 2012). Despite their multiple uses, current facades rarely implement techniques that can adjust to changing weather patterns or users' needs. This is mainly due to an over dependence on a typical approach to facade design which requires a complete overhaul. This calls for developing new design strategies that are able to adjust themselves according to occurring changes instantly whenever they occur. The solution to this problem might come in the form of an innovative facade that responds accordingly (Drozdowski 2010).

Building envelopes with adaptive facades can adjust to shifting boundary circumstances, such as brief variations in the weather, daily cycles, or seasonal trends (Loonen, 2018). Adaptive facades can adapt to the surrounding environment without compromising the integrity of the building as a whole; this can be done by using advanced construction techniques and innovative building technologies that allow them to respond to environmental conditions in real time as opposed to conventional ones which don't always have this capability (Moloney 2011). Facades possess a unique characteristic that they can react to both the total energy usage of the structure and the conditions of indoor comfort (Favoino, Jin, & Overend 2014). It is possible to argue that adaptive facades have a beneficial effect on lowering the structures' energy requirements, which lessens this adverse effect and hence highlighting the need for such systems. (Knaack and Klein 2009).

Within recent decades, buildings seem to be evolving into an art that is more systematically integrated with its spatial, functional, and environmental context. Designs of some of the prominent adaptive facades have been described in this research report. Existing literature shows that evaluations of facade systems usually focus on their identification based on either material or their type of system.

To design new buildings which would need a different approach in the engineering and architecture profession, transforming from passive and static systems to dynamic and adaptable ones is

necessary. This will change how it affects the operation of a building and how user comfort is created. It also has some implications on how various elements of a building facade are related in space. The 1960s saw the development of the first established facade system that was weatherproof in architectural study and professional practice (Sandak et al., 2019). “A Home is Not a House” from 1969, which considered building envelopes, by Rayner Banham, identified the following three strategies of environmental modulation: conservative; selective as well as regenerative (Banham, 1969). The motorised sun blinds that Buckminster Fuller invented were initially displayed at the US pavilion Expo 67.

In general, when you say ‘adaptive facade’ you mean a system that performs certain operations or takes certain forms as well as behaves in a particular manner as outside conditions change (Sandak et al., 2019). The adaptable facade system is responsive and dynamic with the capacity to control insulation, daylighting, radiant heat exchange, solar shading, humidity, ventilation, and energy harvesting (Loonen, 2013). Szolomicki and Golasz-Szolomicka, (2019) refers to this system as a facade “which can react”. Shifting the facade profile physically (also called “kinetic facades”), regulating energy flow actively (which may involve opening/closing windows, lowering blinds) and energy harvesting like solar collectors/photovoltaic panels are some examples on how facade adaptivity can be achieved in different ways (Sandak et al., 2019). Certain environmental pressures will make some parts of these facades and subsystems have an ability to ‘vary in size, shape, volume, phase or colour and changes with fluctuating climatic variables (Chang, Huang & Datta, (2019).

### **3. Research Methodology**

#### **3.1 Study Approach / Paradigm**

The research methodology chosen follows a paradigm approach, focusing on practical philosophy that highlights the need for thorough analysis and understanding of real-world situations. By utilising a variety of methods, strategies, and theories in research translation, the goal is to produce impactful outcomes that are both rigorous and significant for stakeholders. This practical methodology ensures that research findings can be effectively applied to benefit the target audience. The main objective is to investigate different strategies for addressing climate change in Tshwane to enhance building resilience to temperature fluctuations (Vermeulen, 2024).



Pragmatism supports mixed methods research because it allows many study modes and procedures to be combined. Pragmatism makes it easier to produce knowledge that is beneficial to society by endorsing the use of mixed methods research and an ongoing cycle of abductive reasoning (Denzin, 2012). The pragmatic paradigm emphasises the necessity of a flexible and pragmatic approach to research by acknowledging the existence of numerous realities and the legitimacy of various worldviews and research approaches (Morgan, 2014). This method is especially useful in many studies where pragmatism encourages the integration of several research techniques, including qualitative and quantitative techniques, emphasising methodological issues above philosophical discussions (Johnson & Onwuegbuzie, 2004).

Case study research methods are also used in this study in the form of data collection. A useful strategy for delving deeply into complicated problems and offering a deeper understanding of occurrences in authentic settings is the use of case studies within research methods (Amerson, 2011). This strategy is especially helpful for analysing links, coming up with ideas, and investigating problems that previous research approaches might not have sufficiently addressed (Crasnow, 2012). Because case studies can yield detailed insights, it has become more and more popular among qualitative researchers, despite continuous discussions concerning its validity and limits in comparison to other techniques (Hyett et al., 2014).

### **3.2 Study Area and Context**

The study's main focus is on looking at thermal amelioration in Residential multi storey buildings in the city of Tshwane. A search was conducted to find and examine case studies, with an emphasis on the adaption technologies and techniques used in each. The Koppen-Geiger Climate Classification system was then utilised in order to classify these case studies into three distinct climate categories: Cwa, Cwb, and Bsh. Although Gauteng falls under Cwa/Cwb, the study focuses on dealing with adaptation measures to accommodate beyond the current climate state. It is claimed that Tshwane which also in Gauteng would be classified as Bsh throughout the ensuing 20 to 25 years.

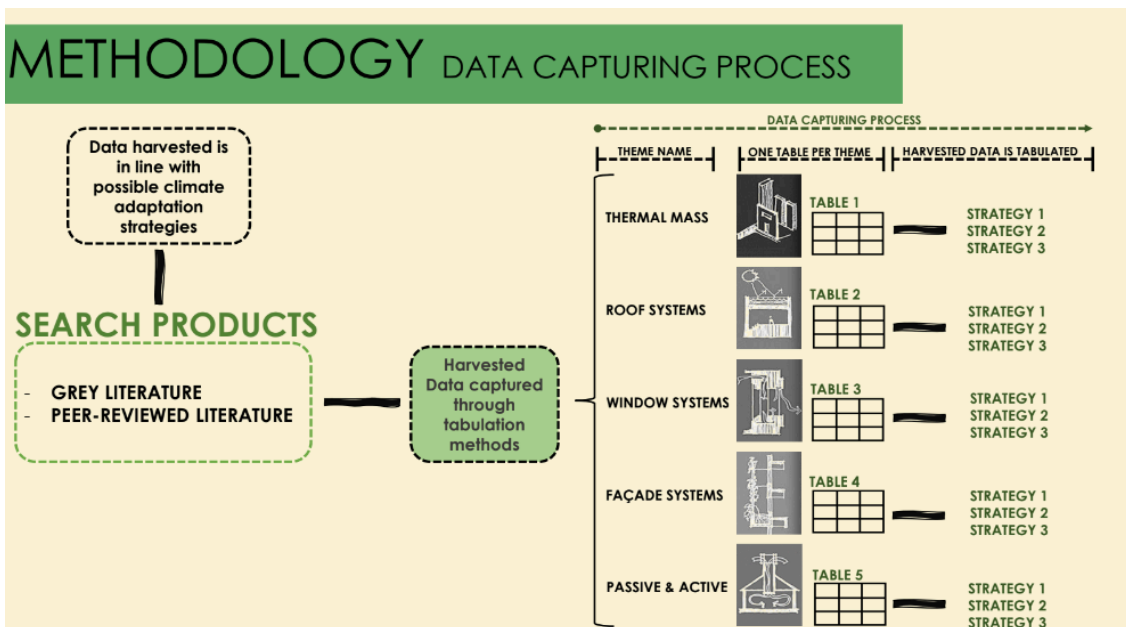
The current and future climate-like regions' interventions of climate change adaptation technologies are compared and analysed in this study. The goal of this documentation process is to showcase creative solutions and well-executed building technology applications that successfully handle the problems brought on by climate change. In addition, the documentation process aims to create a thorough database of case studies that will offer insightful analysis and important takeaways for

future study, decision-making, and application in the fields of sustainable design and urban planning.

### 3.3 Data Collection

Data capture forms an important part in research methodology as it forms the basis for analysis and assessment of the topic at hand. The process of obtaining and assessing data on relevant variables in a predetermined, methodical mode is referred to as data collection (Dovetail, 2024). Data collection helps in addressing the research question at hand, test hypotheses and assess results within the study. In this study, the data collection was done through a desktop research approach. The study therefore makes use of documentation such as surveys, literature and other studies obtained from various sources.

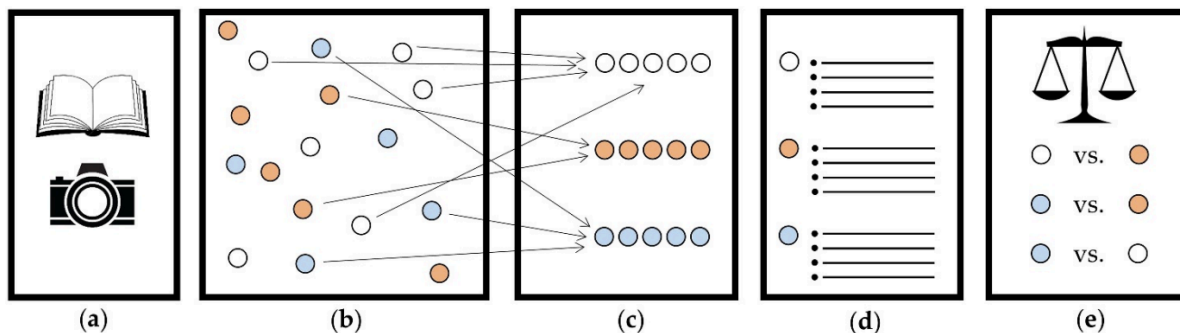
Because this study is part of a larger study, the set of adaptation technologies and strategies were already identified by a group of Architecture honours students (2022). The technologies and strategies were categorised to form basis on the different systems and systems type that the technologies come in (figure below). Furthermore, a group of 3 Masters students studying Architecture (2024) had chosen one of the 5 systems identified (being facade systems) to conduct desktop data capture.



**Figure 3: Methodology data capturing process** (Dos Santos, 2022)

In order to find a total of 15 case studies for this study, the Masters students conducted a search of 5 case studies each. Due to the selection of facade systems as a system type, each case study looks at a distinct instance where building technologies were used to improve the thermal

adaptability of buildings through its facade system located in areas with Köppen-Geiger climate classifications of Cwa, Cwb, and Bsh. The research procedure and data capture had a similar approach to (Brzezicki, 2021), where case studies were chosen through desk study and fieldwork (if local). A selection of the 5 case studies was carefully chosen on the basis of certain needs and requirements to fit the deliverables. After the 5 case studies were identified, they were added to a larger list of 15 where trends and differences can be identified for further analysis and comparison (refer to figure)



**Figure 4. A diagram showing the layout of study procedures in the study: (a) desk study (b) buildings selection; (c) trends conceptualisation; (d) summarising distinctive features; (e) comparative analysis and themes (Brzezicki, 2021).**

### 3.4 Data Analysis

In order to analyse the data for this study, a thorough desktop examination of case studies on building technology and thermal adaptation techniques was done. This section describes the procedures followed in the selection, analysis, and synthesis of the data from these case studies. This section highlights the various topics, trends and classifications considered when comparing the data. The goal of the research is to determine whether applications from other climate categories are suitable to Tshwane's future sustainable built environment, and if not, what the main distinctions in those applications are.

#### 3.4.1. Consideration of key variables

**Facade systems:** This study has a specific focus of facade systems as building technology, and so the case studies chosen will be analysed and compared on the functionality of those facade system types.

**Thermal control:** The analysis will be done on a basis that identifies the level of thermal amelioration achieved through the building technology.



**Köppen Geiger climate classification:** Utilising the Köppen Geiger climate classification system, climate conditions from several parts of the world that are comparable to Tshwane's climate conditions will be looked at. The focus will be on comparing the cases that fall under the climate classifications Cwa, Cwb and Bsh.

**High rise:** The studies focus is on the thermal amelioration for multi-storey buildings in Tshwane, and so the case studies that will be analysed will look into the thermal comfort achieved through multi story examples.

**Local vs International:** Due to case studies being extracted both locally and internationally. Differentiation in context and materiality will be considered.

#### ***3.4.2. Köppen Geiger climate classification system***

The Köppen Geiger climate classification system was developed by Wladimir Köppen and revised by Rudolf Geiger, its classification employs seasonal variations together with threshold values in precipitation and temperature. This approach categorises the world's climates into five groups: tropical, desert, temperate, cold, and polar (see figures 5 and 6). Each group is then further broken down into thirty specialised subgroups (refer to annexure A). The global biome map produced by the classification is a popular system for classifying climates according to temperature, precipitation, and vegetation features. It places comparable areas with comparable vegetation traits in the same group. This classification dates back to the late 1800s, it is still commonly used today for a variety of purposes and studies pertaining to climatic differences. Among these uses include ecological modelling and damage assessment related to climate change (Beck et al., 2018).

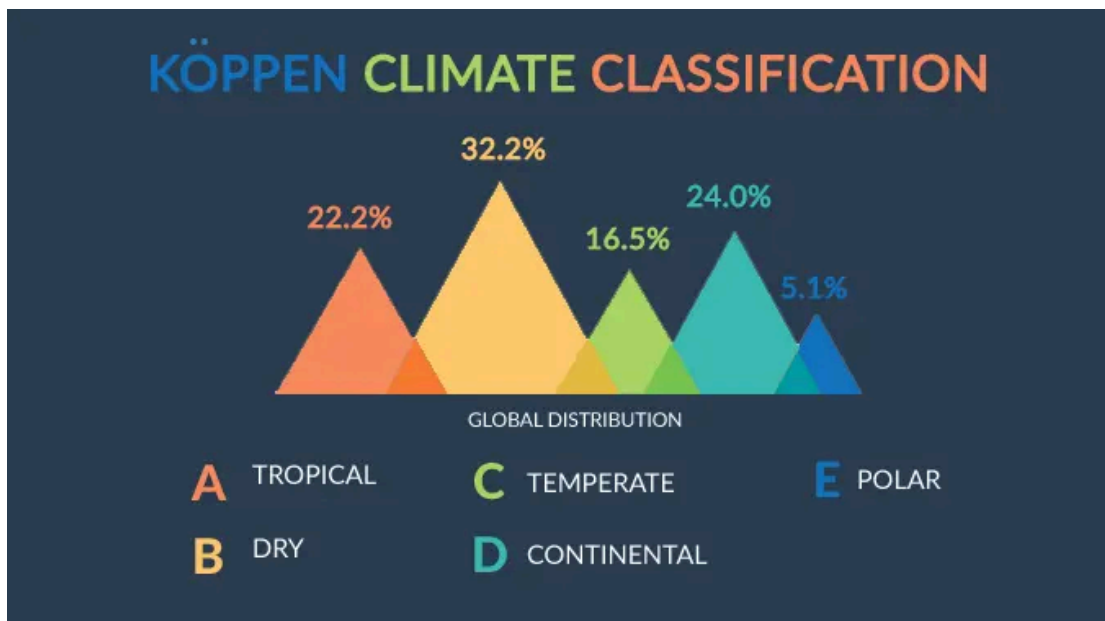


Figure 5: The 5 Köppen climate classification types (EarthHow, 2019)

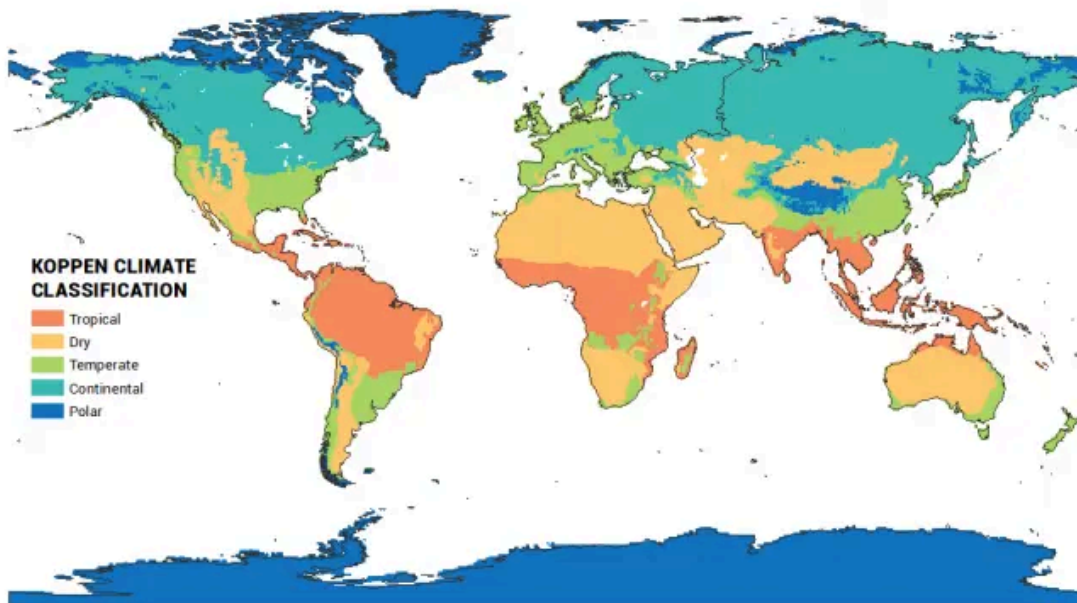


Figure 6: The 5 Köppen climate classifications world map (EarthHow, 2019)

Three recent global maps for the Köppen-Geiger climate classification are available; they are all based on distinct precipitation as well as temperature data sets with different results and station counts. Because of their poor resolution (0.1° or more), the maps may not adequately take into account the impacts of topography, especially in mountainous areas. Furthermore, certain maps' small number of stations may lead to incorrect classifications, particularly in regions with little

station coverage or noticeable climate fluctuations. Furthermore, there are no uncertainty estimates on these maps, which could give consumers a misleading sense of assurance.

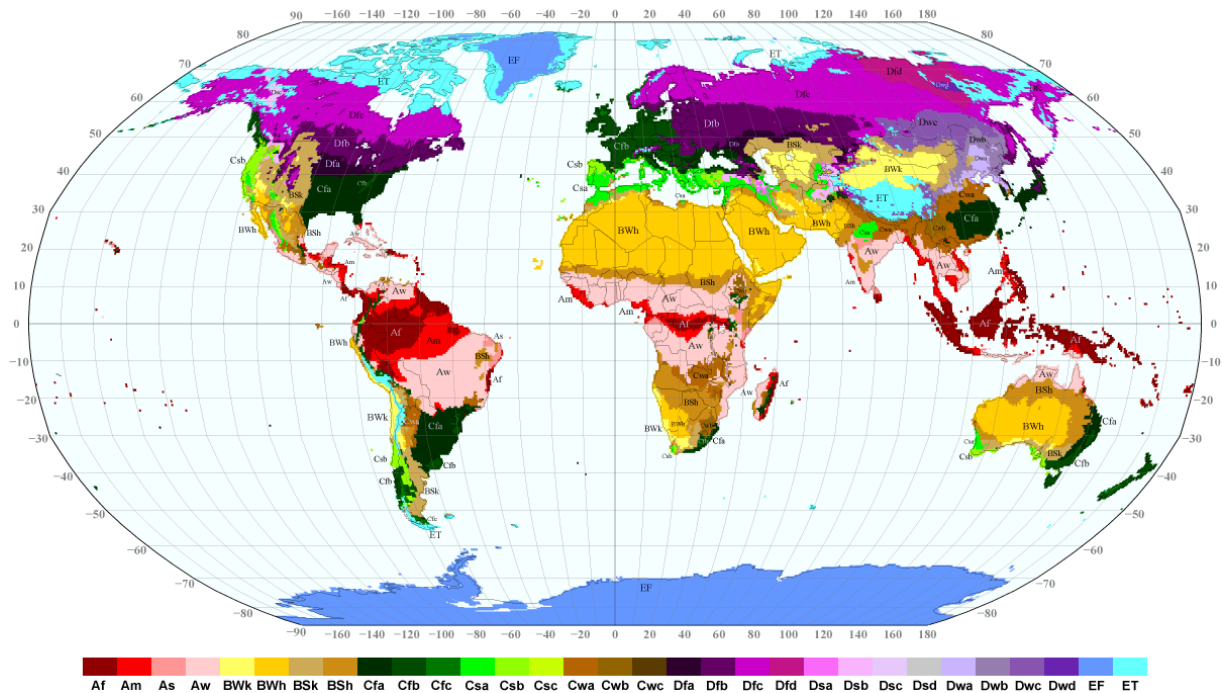
The fact that the Köppen-Geiger climate classification system is so widely used indicates that people recognize how much the climate influences the global distribution of plants. In species distribution models, climate variables are thought to be the main drivers that explain species distributions on larger scales, whilst habitat and terrain have a negligible effect on smaller ones. This categorization offers a useful method for breaking down intricate climate gradients into a system that makes sense ecologically. It is often applied in the analysis of species distribution, growth patterns, and dynamic global vegetation models.

The improved Köppen-Geiger climate classification map presented in the study (Figure 7) addresses earlier drawbacks. With its unmatched resolution of  $0.0083^\circ$  (about 1 km at the equator), this new map, which covers 1980 to 2016, enables a more accurate representation of various locales. To improve accuracy and account for uncertainties, the researchers combined a variety of independent data sources, such as WorldClim, CHELSA, and CHPClim, and they specifically adjusted for topographic effects. Because more stations are included in these datasets, it is possible to estimate the degree of uncertainty in the resulting climatic classifications. The study uses data from 32 climate change models to forecast future temperatures for the years 2071-2100 at the same spatial resolution.

Using past and upcoming precipitation as well as atmospheric temperature data preserved by CMIP5, the Köppen-Geiger classification for the future was developed. The RCP8.5 (Representative Concentration Pathway) scenario served as the basis for the data. Climate models that provided data for the 1980–2016 and 2071-2100 time periods were employed in the study. Historical data was gathered between 1980 and 2016 by combining past runs (up to 2005) with upcoming runs (starting in 2006). Every climate model was represented by a single initialization ensemble. Thirty-two models met the data requirements and were utilised to create the climatic categorization map for the future (Beck et al., 2018).

### **3.4.3. Present & Future Climate Classification (Cwa; Cwb; Bsh)**

The case studies selected had to have some form of incorporation of Facade type systems that help the building improve thermal quality. The case studies also had to be situated under the Köppen climate classifications listed Cwa, Cwb and/or Bsh.



**Figure 7: World Map showing Köppen-Geiger climate classification.** (Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel, 2006)

**Cwa** – Temperate, Hot Summer and Dry Winter (Tshwane)

A temperature above  $-3\text{ }^{\circ}\text{C}$  but less than  $+18\text{ }^{\circ}\text{C}$  is considered the coolest month. While the wettest month precipitation in winter is less, the wettest month precipitation in summer is more than ten times that of the driest month precipitation in winter. The highest recorded temperature in the warmest month was  $+22\text{ }^{\circ}\text{C}$  (Chen & Chen, 2013).

**Cwb** – Temperate, Warm Summer, Dry Winter (Johannesburg)

A temperature above  $-3\text{ }^{\circ}\text{C}$  but less than  $+18\text{ }^{\circ}\text{C}$  is considered the coolest month. While the wettest month precipitation in winter is less, the wettest month precipitation in summer is more than ten times that of the driest month precipitation in winter. At least four months had temperatures of more than or equal to  $+10\text{ }^{\circ}\text{C}$ , with the warmest month having a temperature of less than  $+22\text{ }^{\circ}\text{C}$  (Chen & Chen, 2013).

**BSh** – Hot, Semi-arid (Tshwane Future Classification)

There is more than five times as much precipitation in a given year than there is dryness. The annual mean temperature (Tann) in degrees Celsius is directly related to the dryness threshold, which is expressed in millimetres. It is ascertained in this manner: The dryness criterion is  $2\text{ Tann}$  if the winter precipitation is at least two thirds that of the summer precipitation;  $2\text{ Tann} + 28$  if the

summer precipitation is at least two thirds that of the winter precipitation; and 2 Tann + 14 otherwise. The average annual temperature is more than or equal to +18 °C. Chen and Chen (2013)

#### **3.4.4. Design strategies for thermal comfort**

**Facade systems:** Façade systems can contribute to a building's thermal performance, daylighting, and overall environmental sustainability (Drozdowski, 2010). Facade systems, which encompass a wide range of materials, technologies, and design approaches, are essential in determining how the built environment responds to local climate, user demands, and geographic context. A new level of adaptability and reactivity to shifting environmental circumstances is introduced by the incorporation of façade systems, such as electrochromic glass, phase-change materials, and responsive shading devices (Loonen et al., 2016). Real-time dynamic property adjustments by facade systems are made possible by these cutting-edge technologies.

**Daylight control:** Another essential component in design for thermal comfort is daylighting, which emphasises the value of natural light in enhancing occupant comfort, productivity, and health. Effective facade solutions make use of daylighting concepts to reduce solar heat gain and maximise natural light penetration. Among the many techniques used to maximise daylighting effectiveness, lessen dependence on artificial lighting, and promote a link between indoor inhabitants and the outer environment are glazed windows and exterior shade devices.

**Natural ventilation:** The process of letting outside air into a building to increase the uppermost limit of the comfort zone past what is practical in still air circumstances is referred to as "comfort ventilation." The movement of the outside air can have a physiological cooling effect, even when the outside air is fairly warm. When cross-ventilation is used throughout the day, the interior surfaces and air temperature almost exactly match the outside temperature. Therefore, midday ventilation should only be used when the temperature of the internal air is similar to that of the outside air.

**Passive cooling:** The term "passive cooling systems" describes methods & strategies for using natural energy sources to lower a building's interior temperature. The usage of mechanical air movement systems and technologies is not excluded when we refer to something as "passive," provided that their involvement improves the effectiveness of adaptation tactics (Givoni, 1994). The technologies and strategies found in the study should be used as a reference when developing buildings in areas classified as warm, humid, and semi-arid with seasonal precipitation

in the winter. When creating buildings for these particular climate types, architects and other built environment designers ought to be considering how to keep building occupants warm while using fewer traditional exhaustible energy sources (Drozdowski, 2010)

**Material consideration:** Materiality can play a big role in the thermal gain of indoor spaces. After long exposure to heat, material can absorb and transfer heat (Favoino, 2014)). Concrete, rock and earth are examples of dense materials that have various qualities that make them effective heat-insulators. Good thermal conductivity (the capacity to recover passive cooling), thermal lag (heat transmission is slower), low reflectivity (heat redistribution is less), and high volumetric heat capacity (capacity to store heat is more) are examples of these in reverse order of importance. These material properties become particularly strong when used in large quantities (Cao, 2019), for example multi storey buildings

**Incorporation of vegetation:** In addition to improving air quality and thermal efficiency, green facade systems—which include vegetated screens, living walls, and vertical gardens - also support urban greening, biodiversity, and biophilic design. These living facade systems demonstrate how natural ecosystems and built form can coexist peacefully by using plants' natural ability to control temperature, filter pollutants, and improve microclimate (Hugo, 2023). In the summer, green façades can encourage evapotranspiration and allow the structure to be physically shaded. In the winter, they can also improve the building's thermal insulation (Vax, 2018).

### 3.5 Ethical Considerations

This study was conducted in line with the University of Pretoria Ethics requirements. According to all social research, researchers are obligated to conduct research in an ethical manner (Dovetail, 2024). A code of ethics refers to moral principles that govern the research progress. The study used readily available information and material that does not require public participation. There was no classified or confidential material that required permission from individual bodies to investigate and analyse. The study did not require any involvement of individuals or members of the public. The study ensured that it did not make up data.

## 4. Results

The following table shows the case studies that were selected by the three Masters students.



**Table 1: Case studies description** (Author, 2024)

Case study No.	Project	Location	Climate classification	Program use
1	Manuel Gea Gonzalez Hospital	New Mexico, Mexico	Cwb	Commercial
2	KMC Corporate Office	Hyderabad, India	Bsh	Commercial
3	Pearl River Tower	Guangzhou, China	Cwa	Commercial
4	78 Corlett Drive	Johannesburg, South Africa	Cwa	Commercial
5	Council 2 House	Melbourne, Australia	Cwa	Commercial
6	Alexander Forbes Office	Johannesburg, South Africa	Cwa	Commercial
7	Kadoorie Biological Sciences Building	Hong Kong, Chi	Cwa	Mixed use
8	National Biodiversity Pavillion	New Mexico, Mexico	Cwa	Commercial
9	Britam Towers	Nairobi, Kenya	Cwb	Educational
10	University of pretoria Plant Science Building	Pretoria, South Africa	Cwb	Commercial
11	Podium AT Menlyn	Pretoria, South Africa	Cwb	Commercial
12	The Grove	Guangzhou,China	Cwa	Residential
13	BMW Head Office	Johannesburg, South Africa	Cwb	Commercial
14	The Lantern	Hanoi, Vietnam	Cwa	Commercial
15	Monash University Biomedical Sciences Building	Melbourne, Australia	Cwa	Institutional

**4.1 Case Study Description**



#### **4.1.1 Manuel Gea Gonzalez Hospital**

The structure uses prosolve tiles—plastic coated in titanium dioxide—for its biomimetic façade. Because of their de-polluting and anti-microbial qualities, these Prosolve tiles were selected. The Prosolve 370e skin let's natural light into the building while also serving as an urban filter. By blocking sunlight from entering the hospital, this biomimetic facade efficiently reduces the requirement for artificial lighting and climate control equipment. By slowing down wind flow, this facade system creates turbulence that disperses air pollutants across the panels and into the building (Architect Magazine, 2013).

#### **4.1.2 KMC Corporate Office**

The double skin green façade is used as an eye-catching and energy-efficient piece of architecture. This façade's twin skin concept enables the building to modulate how much light and air enters it. Incorporated into the aluminium trellis, the misting system cools the inside of the building while controlling and regulating the amount of water supplied to the plants and trays. Because so many different types of plants are used in the facade throughout the year, the exterior skin becomes a dynamic facade. This dynamic function, driven by nature, modifies the building's aesthetic all year long and modifies the interior temperature in accordance with the changing of the seasons. When the facade is fully covered in the summer, less sunlight enters the structure, resulting in a cool inside temperature. On the other hand, some plants (deciduous ones) will wither or die in the winter, resulting in an inner climate that is warmer and more appropriate for the season (Singh et al, 2023). In theory, this is an active facade with a dynamic function that is "powered by nature." The facade system not only improves the building's appearance but also provides acoustic insulation, shade from the sun, heat, and dust (Singh et al, 2023).

#### **4.1.3 Pearl River Tower**

The façade design was created with energy-saving guidelines, considering the city's sun and wind patterns (Selcuk et al, 2014). The outcome is a double skin facade system consisting of the outside layer that is insulated and the inside layer that has air space in between the two layers (Selcuk et al, 2014). The double skin curtain wall façade accommodates solar shading as well as venting devices inside (Frechette et al, 2008). The building benefits from the transparency of the façade in terms of both usefulness and aesthetics. The motorised sunshade devices inside the cavity carry out the façade system's operation by controlling glare and providing solar shading for the interior spaces (Selcuk et al 2014). Photocells that monitor the sun's position in relation to elevation trigger automatic controls for the sunshade systems. enabling control over the amount of natural light, moisture intrusion, and fresh air intake into the interior space (Selcuk et al 2014),enhancing the



building's thermal efficiency during seasonal variations by lowering solar heat gain at the building's perimeter, where areas are normally occupied (Frechette et al, 2008). In order to reduce solar heat, building management systems automatically adjust the solar shades' angle to counter sunlight extremity, solar azimuth as well as solar altitude (Selcuk et al, 2014).

Pearl River Tower's glass exterior skin and external solar shading system are merged with a photovoltaic system (Selcuk et al, 2014), serving the dual purpose of building cover and generators for power. Consequently, the Building Integrated Photovoltaics, or BIPV, serves as a solar shade for the building and a source of electricity. The double facade of the building collects solar energy, which is subsequently sent to the mechanical levels to heat the building's dehumidification system. An internally ventilated double wall system is provided by the double skin facade system. The low-E glass panel on the exterior may be opened for maintenance, completing the inner walls that allow each floor to be mechanically ventilated (Frechette et al, 2008). The envelope is therefore used as a thermal regulator.

#### **4.1.4 78 Corlett Drive Building**

The dynamic façade system at 78 Corlett Drive is made up of a very effective passive shading system. The inhabitants are shielded from the intense summer sun by the fixed modular shading devices that make up the passive shading system. The adjacent façades' sliding shutters provide an ever-changing visual element while also enabling the occupants to mechanically control how much heat, light, and glare enters the internal space (Arch daily, 2019).

#### **4.1.5 Council 2 House**

Nature served as inspiration for the building's expressive undulating concrete floor structure, tapering ventilation ducts that work with day lighting schemes, and climate-modulating façades. The building's double-skin façade is composed of an outer skin made of wood that provides shade and an inner layer of glass that lets in views and natural light. The building's interior temperature may be managed via natural ventilation since the façade is automatically operated (ArchDaily, 2013). As a result, the facade is dynamic in direct proportion to the outside environment. This skyscraper responds to its surroundings by moving and coming to life, demonstrating the pinnacle of biomimicry (MikePearce, 2016).

#### **4.1.6 Alexander Forbes Office**

The use of 22,000 square metres of windows has made possible the transparency of the building, which lets natural light meet 58% of lighting requirements and gives views to 64% of office spaces.



The Ferrari cloth used for the external sun shading blinds is regulated by a wind and sun sensor to provide shade without jeopardising structural integrity or safety. The west and east facades' S-shaped concrete scalloping look, which is intended to oxidise and age naturally over time. Rheinzink-clad German-imported wood was used to texturize these. In addition to its environmentally friendly qualities, such as its recyclable nature and low manufacturing energy usage. Rheinzink is a material that is very flexible, it makes it possible to create forms and shapes that would be challenging to achieve with other materials (Architizer, 2015)

#### **4.1.7 Kadoorie Biological Sciences Building**

This structure is the first in Hong Kong to use the environmentally friendly potential of a second skin fully, an exterior covered/glazed screen that is set back 2.5 metres from the outer wall. In addition to housing the building services, the area between the double skin serves as an exterior buffer zone between the two levels of glass. This buffer zone acts as a stack, channelling hot air upward for discharge into the air and lowering the structure's solar heat gain. Each floor has an open metal grille that serves as a pathway for maintenance access and permits free air circulation. By placing heat-emitting devices outside the building in the exterior part of the building services zone, the heat is released into the spaces instead of the inside, enabling the heat to decrease.

#### **4.1.8 National Biodiversity Pavilion**

In terms of façades, the lower level incorporates views of the nearby natural region within the structure, acting as a display for native species. The upper floor's double glass and multi-perforated aluminium façade regulates views and unfolds to meet the lighting and ventilation requirements of the interior rooms. The result is a wind-responsive façade made of thousands of aluminium pieces, each measuring 30 by 20 cm. This movement is a result of the site's climate, implying the site's importance in the survival and evolution of biodiversity and creating a living façade.

#### **4.1.9 Britam Towers**

A remarkable façade with an intriguing prismatic 3D geometric design is covered with solar shades that are shaped like egg crates and extend all the way up to the top of the building, giving it an incredibly regal appearance. The mentioned solar-shading systems accomplish the structure of the building's primary functions of heat regulation and daylighting, as well as allowing the offices to be adequately ventilated. On the outside of the structure, the glass façade is covered by ceramic rods in the shape of an egg, which serve as solar blinds. These permanent, fixed Egg-Crate ceramic rods allow the necessary quantity of solar radiation to pass through, thereby cooling the structure



throughout the year. The systems for solar-shading, which have historically utilised concrete fins for the solar-shades, have incorporated ceramic rods as a novel innovation (Ibse, 2011)

#### **4.1.10 University of Pretoria Plant Science Complex**

The building's design incorporates a number of energy-efficient and passive design elements to help with ventilation that is natural, heat gain reduction, solar control and electrical usage. The building's orientation and layout were purposefully designed to maximise passive temperature control and minimise heat gain through the use of thermal mass, screens, and reflectors. Plantation rock walls and walls covered in clay and stone pavers produce thermal mass (Architizer, 2014).

#### **4.1.11 Podium AT Menlyn**

The air gap between the main layers of a double façade that has an air corridor serves as insulation against extreme temperatures. The top and bottom of the external glass façade are open, which allows heat to be forced out as the cavity area warms up and allows a cool breeze to enter. a method and approach primarily employed in Europe (Boogertman, 2014)

#### **4.1.12 The Grove**

Improved air quality and thermal insulation are two advantages of integrating vegetation into building exteriors through the use of green facade technologies. The right plants must be chosen, structural support must be ensured, irrigation and drainage systems must be put in place, maintenance access must be made easy, the building's systems must be integrated, fire safety must be addressed, and long-term sustainability must be ensured by using durable materials and little maintenance (Cüce et al., 2021).

#### **4.1.13 BMW Head office**

In order to reduce the amount of intense sunlight that enters the building, the dynamic solar tracking louvres use mechanical mechanisms to rotate in the direction of the sun (Boogertman, 2012).

#### **4.1.14 The Lantern**

The building has a double façade, with the exterior façade allowing winds to circulate freely through the blocks to cool it down. The blocks' hollow shape minimises direct sunlight exposure while yet letting in enough light. This is a historical, customary technique used in Vietnam to cool buildings before the invention of air conditioning technology (Hoy & Hoy, 2021).

#### 4.1.15 Monash University Biomedical Sciences Buildings

The structure has a twin facade system, with vertical fabric screens on one side and an aluminium external façade on the other. Any heat that enters the building is directed through to a vertical core with an aperture at the top that permits hot air to be expelled out of the structure through vertical stacking. The external aluminium facade blocks direct sunlight from entering the building. The building's other side has screens that permit unrestricted entry and exit of fresh air, and the second-to-last floor's vent permits heat from the building to escape partially through the top entrance (Sung & Kim, 2019).

## 4.2 Technicality

**Table 2: Case studies technicality** (Author, 2024)

Case study No.	Facade system type	Active / Passive	Strategy and Technicality	Materiality
1	Ornate double skin biomimetic façade	Passive	A biomimetic façade composed of prosolve tiles, which are titanium dioxide-coated plastic. Because of their de-polluting and anti-microbial qualities, these Prosolve tiles were selected. The Prosolve 370e skin let's natural light into the building while also serving as an urban filter. By blocking sunlight from entering the hospital, this biomimetic facade efficiently reduces the requirement for artificial lighting and climate control equipment. This facade system creates turbulence by slowing down the wind flow that distributes air pollutants across the panels before entering the building(Architect Magazine, 2013).	White Prosolve 370e tiles are made up of 500 puzzle-like blocks that are arranged in three dimensions. The modules, which are fashioned like an X and an I, attach to a vertical steel foundation. Thermoformed plastic tiles that are lightweight are coated with titanium dioxide (TiO <sub>2</sub> ), a nanomaterial invented by Cristal Global that is photocatalytic and air-scrubbing when powdered (Architect Magazine, 2013).
2	Double skin green facade	Hybrid	""The double skin green façade is used as a visually striking and energy-efficient technology. This façade's	The inner skin of the building is a reinforced concrete frame with aluminium windows. The



			<p>twin skin concept enables the building to modulate how much light and air enters it. Incorporated into the aluminium trellis, the misting system cools the inside of the building while controlling and regulating the amount of water supplied to the plants and trays.</p> <p>Because so many different types of plants are used in the facade throughout the year, the exterior skin becomes a dynamic facade. This dynamic function, driven by nature, modifies the building's aesthetic all year long and modifies the interior temperature in accordance with the changing of the seasons. This dynamic function, powered by nature, changes the visual appeal of the building year round while adapting the interior climate according to the seasons. In summer, the facade will be full, limiting the amount of solar radiation into the building creating a cool interior climate. Adversely, in winter, some plants will lose their leaves (deciduous) or die out, creating a warmer interior climate suited to the season (Singh et al, 2023). This is an active facade in principle with a 'powered by nature' dynamic function. Along with enhancing the building's aesthetic, the facade system offers acoustic insulation, protection from direct sunlight, heat and dust (Singh et al, 2023). “</p>	<p>external skin of the façade comprises a hand assembled cast aluminium trellis with an integrated misting system and hydroponic trays. This aluminium trellis is made up of four modular panels which can be arranged in 16 different ways, adding a degree of flexibility to the assembly of the facade. The panels were made using dies and then cast, notched, welded, sanded, shot-blasted and anodized (Singh et al, 2023).</p>
3	Double skin dynamic facade with integrated	Active	"The façade design was created with energy-saving concepts in mind, accounting for the city's solar and wind	"Double skin curtain wall systems consist of a double-insulated glazed unit with integral spandrel



	photovoltaic panels on sunshade devices		<p>patterns (Selcuk et al, 2014). The result is a double skin facade system with air space positioned between the two layers and an insulated outer and inner layer (Selcuk et al, 2014).</p> <p>Venting and sun shading devices are accommodated within the cavity of the double skin curtain wall façade (Frechette et al., 2008). The building benefits from the transparency of the façade in terms of both usefulness and aesthetics. The motorised sunshade devices inside the cavity carry out the façade system's functioning by controlling glare and providing solar shading for the internal spaces (Selcuk et al 2014).</p> <p>Photocells that monitor the sun's position in relation to elevation trigger automatic controls for the sunshade systems. Reducing solar heat gain at the building's perimeter, where spaces are usually occupied, improves the building's thermal performance during seasonal changes, and allows control over the amount of daylight, moisture infiltration, and fresh air into the interior environment (Selcuk et al., 2014). (Frechette et al, 2008). In order to minimise solar heat, building management systems automatically adjust the sunshades' angle in response to solar intensity, solar altitude, and solar azimuth (Selcuk et al, 2014).</p> <p>A photovoltaic system is integrated into Pearl River Tower's external solar</p>	<p>panel in a 3,0 x 3,9m unitized panel (Frechette et al, 2008). Two hinged 1,5 x 2,8m single glazed leaves are fixed to the back face of the mullion to create a 200mm cavity with a small air gap at the base. Within the cavity is a motorised 50mm perforated silver venetian blind which is fully extended. This blind has 3 operation modes: open, closed to a 45 degree angle or completely closed. The exterior glazing of the curtain wall system is insulated, tempered glass with a low-E coating. The Inner glass skin is an operable clear glass panel which can be opened for maintenance. r with a triple-glazed façade (Frechette et al, 2008).</p> <p>“</p>
--	---	--	--	--



			<p>shading system and glass outer skin (Selcuk et al, 2014), serving the dual purpose of building skin (spandrel panels) and power generator (Frechette et al,2008). Therefore, the BIPV (Building Integrated Photovoltaics') provides an electrical supply whilst functioning as a solar shade for the building (Frechette et al, 2008). Solar energy is collected within the building's double facade and is then transferred to the mechanical floors to be used as the heating for the dehumidification system of the building (Frechette et al, 2008). The double skin facade system serves as an internally ventilated double wall system. The external skins glass panel with a low-E coating can be opened for maintenance, complementing the interior walls which mechanically ventilate every floor (Frechette et al, 2008). The envelope is therefore used as a thermal regulator .</p>	
4	Dynamic facade system	Active	<p>Dynamic façade system consisting of a highly efficient passive shading system. The passive shading system consists of fixed modular shading devices protecting the occupants from the harsh summer sun. The sliding shutters along the adjacent façades creates an ever-changing aesthetic while simultaneously affording the occupants the ability to mechanically adjust the amount of natural light, heat and glare that enters the interior space (Arch daily, 2019).</p>	<p>"The street interface façade consists of fixed shading louvres composed of modular aluminium panels fixed to an aluminium frame, implementing a clad-like construction method. This façade system is placed in front of a curtain wall system, adopting characteristics of a double-skin facade system (ArchDaily, 2019). The adjacent dynamic façade system comprises operable shading devices installed in the window</p>



				cavities of the building envelope (ArchDaily, 2019). “
5	Dynamic biometric double skin facade system	Active	Nature is used as inspiration for façades that moderate climate, tapered ventilation ducts integrate with day lighting strategies and an evocative undulating concrete floor structure that plays a central role in the building’s heating and cooling (ArchDaily, 2013). The buildings double-skin façade consists of a timber outer skin that provides shading and a glazed inner skin which allows in natural light and views. The façade is mechanically operated, allowing natural ventilation to regulate the building’s internal temperature (ArchDaily, 2013). The facade is thus animated in direct response to the external conditions. This is biomimicry at its very best – the building moving and becoming alive in response to the conditions surrounding it (MikePearce, 2016).	The façade consists of vertical timber slats covering a fully glazed curtain wall (MikePearce, 2016). The slates are mechanically operated and pivot vertically, opening and closing in response to the time of day and the angle of the sun (MikePearce, 2016).
6	Angled standing seam system	Hybrid	the sense of transparency has been achieved with the inclusion of 22 000 m2 of glazing which allows natural daylight to fulfil 58% of lighting needs and provides 64% of office areas with views. Externally the sun shading blinds are made from a Ferrari fabric controlled by a sun and wind sensor to ensure shading without compromising safety and structure. the concrete S-shaped scalloping effects on the west and east facades are	"The use of RHEINZINK-prePATINA BlueGrey angled screens along the Northern facade of the building, • Automated textile screens located on the West facade that change automatically through sun detection.. •The use of curtain wall systems throughout the entire site



			<p>created to age and oxidise naturally over time. These were texturised by a covering of German-imported pine, clad in Rheinzink. Aside from having environmental properties such as its recyclability and low energy consumption during manufacture, Rheinzink is an extremely flexible material allowing for the creation of shapes and forms that would be difficult</p>	
7	Double skin facade system	Passive	<p>This structure is the first in Hong Kong to fully utilise the environmentally friendly potential of a second skin, an exterior glazed screen that is set back 2.5 metres from the outer wall.</p>	<ul style="list-style-type: none"> <li>• The building is clad in a combination of silver grey ceramic tiles and glass and steel double skin.</li> <li>• The north and south facades are clad in ceramic tiles and the windows are protected by aluminium sun shading devices.</li> <li>• The east and west facades are clad in a double-skin glass curtain wall which serves several functions.</li> </ul>
8	Dynamic facade system	Active	<p>This structure is the first in Hong Kong to fully utilise the environmentally friendly potential of a second skin, an exterior glazed screen that is set back 2.5 metres from the outer wall.</p>	<ul style="list-style-type: none"> <li>• The façade is made up of thousands of 30x20 cm aluminium modules that move with the wind.</li> <li>• The walls of the building are built with cantera, a volcanic stone that is the most characteristic element of the local biodiversity. It was formed by the Xitle explosion that gave its name to Pedregal, the area where Ciudad Universitaria is located.</li> <li>• Aluminium fins run down along the facades adding an additional static facade system.</li> </ul>
9	Passive facade system	Passive	<p>A remarkable façade featuring prismatic 3D geometric shapes coated in ceramic rods shaped like egg crates that serve as solar shades all the way up</p>	<ul style="list-style-type: none"> <li>• For the Solar-Shading System Design, the building makes use of permanent fixed EggCrate External type of Solar Shading Systems. The option of using External Solar-Shading Systems was</li> </ul>



			to the top of the building, giving it an incredibly regal appearance.	<p>due to the fact that they perform better at thermal functionality than Internal Solar-Shading Systems.</p> <ul style="list-style-type: none"> <li>• The alternative of opting for the use of Terracotta Ceramic Rods designs for the Egg-Crate SolarShading Systems provides a more durable and distinct factor. Using a more durable material that is easily maintainable ensures the longevity of use.</li> <li>• Horizontal Venetian Blinds are a type of SolarShading Systems that are placed to the interior of Building Spaces to provide Solar-Shading.</li> <li>• The choice of using tinted blue glass as a Solar-Shading design</li> </ul>
10	Green facade system	Passive	A remarkable façade featuring prismatic 3D geometric shapes coated in ceramic rods shaped like egg crates that serve as solar shades all the way up to the top of the building, giving it an incredibly regal appearance.	<ul style="list-style-type: none"> <li>• Two steel-framed vertical rock walls with mesh baskets holding rocks and planters holding a variety of native plants</li> <li>• The use of screens made of steel cylinder elements with steel frame structure on the North and Western facades acknowledges and commemorates the heritage value of red Kirkness bricks used on and around the campus.</li> <li>• The choice of red brick paving used as cladding in a decorative panel on the southeast corner.</li> <li>• The use of concrete louvres supporting the northern façade with a steel frame;</li> <li>• The use of perforated textile reflectors with steel frame structures on the north and western facades.</li> <li>• Using walls made of perforated concrete.</li> </ul>
11	Double skin green facade system	Passive	Double façade with an air corridor, the air space between the main layer acts as insulation against harsh temperatures. Since the top	For the Glazing façade, 3 different types of coloured glass are used, the laminate glass with a vinyl in between 2 pieces of



			and the bottom of the outer glass façade are open, when the cavity space starts to heat, the heat is pushed out bringing in a cool breeze inside the cavity space. A technique and strategy mostly used in Europe (Boogertman, 2014)	glass (Boogertman, 2014).
12	Green facade system	Active	Green facade systems integrate vegetation into building exteriors, providing 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 long-term sustainability through durable materials and minimal maintenance requirements (Cüce et al., 2021).	Traditional plants that require less water (Xerophytes)
13	Dynamic facade system	Active	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 (Boogertman, 2012).	Smart building technology, Solar tracking louvres (Boogertman, 2012).
14	Double skin facade	Passive	Double façade, the external façade provides breezes to freely move through the blocks in order to cool the building, the hollow design of the blocks allows minimum exposure to direct sunlight but allows adequate light in. This is an old traditional method used in Vietnam to cool buildings before air-conditioning systems were invented (Hoy & Hoy,	Double façade system of Perforated Terracotta blocks and curtain wall



			2021).	
15	Double facade systems	Passive	The building incorporates a double facade system that utilises aluminium external facade on one side while using vertical fabric screens on the other side. The external aluminium facade prevents direct sunlight into the building, and any heat that enters the building is channelled through to a vertical core with an opening at the top that allows hot air to be released out of the building through vertical stacking. On the other side of the building screens allows free flow of fresh air in and out of the building while the second last top floor allows heat to escape through a vent while the rest of the heat escapes through the top opening (Sung & Kim, 2019).	<p>"Double façade</p> <ul style="list-style-type: none"> <li>• Aluminium façade</li> <li>• Vertical fabric screens"</li> </ul>

### 4.3 Methods of Assessing Effectiveness

The case studies represented perform in different ways. Since the projects have an amalgamation of facade technologies and strategies used, we can expect different performance outcomes from them. The effectiveness of the thermal control and success of the facade can be done in analytical, empirical and experimental ways. The literature found made evidence of this. Some of the designers and engineers involved with these case studies tested the performance of the buildings through computational simulations through energy models. Other methods include the incorporation of specialists to measure analytical data on the air quality post production.

### 4.4 Benefits and Constraints

**Table 3: Case studies benefits and constraints** (Author, 2024)

Case study No.	Benefits	Constraints
1	Improved air quality -Cleaner air introduced into the interior spaces of the building.	Material Constraints - TiO2 material is patented, the availability as well as feasibility are



	<p>-absorbing air pollutants, improving the exterior air quality surrounding the building. -Urban filter</p> <p>Thermal comfort - The facade system absorbs UV rays, decreasing the thermal gains of the building and decreasing the Urban Heat Island Effect of the surrounding urban areas (Architect Magazine, 2013). - Lowered temperature of internal spaces.</p> <p>Energy Efficiency - Filters natural light, decreasing the need for artificial light throughout the course of the day. - Lowered requirement for artificial cooling.</p> <p>Technical considerations - Lightweight panels which don't require heavy machinery for installation. - Individual panels are assembled like puzzle pieces on the ground and are later mounted to the vertical grid on the facade.</p>	<p>concerns which must be addressed. - the TiO<sub>2</sub> material sprayed onto the thermo plastic modules wears thin over time and needs to be reapplied - maintenance constraint.</p> <p>Technical constraints - the panels are calculated to absorb air pollutants equivalent to 1000 vehicles per day. If there are an increased number of vehicles in the vicinity, this will impact the internal air quality of the building due to the inability of these panels to handle the overload of pollutants. - The static nature of the double facade limits the facades' adaptability to future climate variations and changes.</p>
2	<p>Thermal comfort - decreases thermal gains into the building - limits direct sunlight exposure - The foliage absorbs UV rays without radiating heat into the building, limiting urban heat island effect - lowered temperature of internal spaces during summer - creates ambient internal temperature during winter months</p> <p>Energy Efficiency - Filters natural light, decreasing the need for artificial light throughout the course of the day. - Lowered requirement for artificial cooling.</p>	<p>Water usage constraints - The misting system used for irrigation, does not allow for the water runoff to be captured and filtered back into the system - resulting in water wastage.</p> <p>Vegetation concerns - Different plant species have different water requirements. This consideration must be made when grouping plants together.</p> <p>Maintenance concerns - Plants require regular maintenance (i.e.. pruning, pest control etc)</p>



	<p>Technical considerations</p> <ul style="list-style-type: none"> <li>- Offers acoustic insulation from external environment</li> <li>- The modularity of the individual aluminium panels, allows for flexibility in assembly and design.</li> <li>- The integrated misting system serves two function; 1, hydrates the vegetation, 2, cools down the building internal spaces</li> <li>- The aluminium panels are lightweight, two people are required to carry one panel.</li> </ul> <p>Air quality</p> <ul style="list-style-type: none"> <li>- The vegetation attracts the dust particles in the air, improving the internal area quality of the building.</li> </ul>	
3	<p>"Thermal comfort</p> <ul style="list-style-type: none"> <li>- Automated shading system reduces the solar heat gain for the interior space of the building</li> <li>- The air gap situated in the double skin facade system is mechanically ventilated, improving the thermal micro-climate of the interior spaces.</li> <li>- Reduction of heating and cooling loads at the perimeter of the building</li> <li>- Improved thermal performance during the winter months</li> </ul> <p>Energy Efficiency</p> <ul style="list-style-type: none"> <li>- Reduction of the extensive use of mechanical cooling equipment due to the active facade system.</li> <li>- Reduction of artificial lighting</li> <li>- The BIPV system integrated into the cavity of the double skin facade system, produces electrical energy for the building.</li> <li>- Energy savings due to the reduced airflow of the decoupled' ventilation system as well as the introduction of the radiant ceiling system. These systems reduce the need for persistent operation of mechanical ventilation systems.</li> <li>- Dehumidification system which uses heat collected from the double wall facade as an energy source to</li> </ul>	<p>Technical constraints</p> <ul style="list-style-type: none"> <li>- The 200mm cavity embedded in the double skin façade poses accessibility issues for maintenance.</li> </ul>



	<p>power the mechanised dehumidification system for the building (Frechette et al, 2008).</p> <p><b>Air quality</b></p> <ul style="list-style-type: none"><li>- The 'decoupled' ventilation system within the cavity, provides improved air quality and air exchange effectiveness, improving the indoor air quality of the building (Frechette et al,2008)</li><li>- Dehumidification system which uses heat collected from the double wall facade as an energy source to power the mechanised dehumidification system for the building (Frechette et al, 2008).</li></ul> <p><b>Daylight and glare</b></p> <ul style="list-style-type: none"><li>- Brings useful daylight into the interior space.</li><li>- Reduces direct glare into the building through an automated shading system.</li></ul> <p><b>Acoustic comfort</b></p> <ul style="list-style-type: none"><li>- Reduced noise transmission from the outside of the building to the inside (Frechette end al, 2008).</li></ul> <p><b>Ventilation</b></p> <ul style="list-style-type: none"><li>- The 'decoupled' ventilation system within the cavity provides improved air quality and air exchange effectiveness, improving the indoor air quality of the building (Frechette et al,2008).</li><li>- The cavity within the double skin facade system is mechanically ventilated, improving the air quality of the interior spaces.</li></ul> <p><b>Technical considerations</b></p> <ul style="list-style-type: none"><li>- The implementation of a building management system (BMI), automates the shading devices according to the solar intensity, angle and elevation. The BMI ensures that the building is thermally comfortable throughout the course of the day without human intervention.</li></ul>	
--	---	--



	<ul style="list-style-type: none"> <li>- The "'decoupled' ventilation system within the double skin facade system, reduced the 'floor-to-floor' height from 4,2m to 3,9m.</li> <li>- Integration of the shading system and active ventilation in the cavity of the double skin facade.</li> </ul>	
4	<p>"Thermal comfort</p> <ul style="list-style-type: none"> <li>- Decrease thermal gains into the building</li> <li>- Occupants can adjust the amount of natural light which enters the building</li> <li>- Decreases glare that enters the interior space</li> </ul> <p>Energy Efficiency</p> <ul style="list-style-type: none"> <li>- Decrease the amount of artificial light needed throughout the course of the day</li> <li>- Decrease the constant needed for artificial cooling of interior spaces</li> </ul> <p>Air quality</p> <ul style="list-style-type: none"> <li>- The passive shading system and the fixed modular aluminium-clad facade acts as an external skin for the curtain wall system, allowing for natural air to enter the building. This approach adopts passive design principles, improving the quality of air within the building without compromising the interior micro-climate (ArchDaily, 2019).</li> </ul> <p>Daylight and glare</p> <ul style="list-style-type: none"> <li>- The passive shading system allows for the occupants to mechanically adjust the amount of daylight and glare into the interior spaces based on their needs throughout the course of the day.</li> </ul> <p>Acoustic comfort</p> <ul style="list-style-type: none"> <li>- the fixed modular aluminium-cladded facade system, adjacent to the street interface, acts as an acoustic barrier to the street edge, allowing for the interior</li> </ul>	<p>Technical constraints</p> <ul style="list-style-type: none"> <li>- The static nature of a fixed modular facade limits the facades' adaptability to future climate variations and changes.</li> <li>- Due to the street façade being fixed, it makes it difficult to clean the inner skin curtain wall system.</li> </ul>



	<p>spaces to not be impacted by the street edge.</p> <p>Ventilation</p> <ul style="list-style-type: none"> <li>- The passive shading system and the fixed modular aluminium-clad facade acts as an external skin for the curtain wall system, allowing for natural air to enter the building and for stale air to exit the building. This approach adopts passive design principles relating to ventilation.</li> </ul> <p>Technical considerations</p> <ul style="list-style-type: none"> <li>- There are two facade types implemented on the building envelope (ArchDaily, 2019):</li> </ul> <ol style="list-style-type: none"> <li>1, The fixed modular aluminium-clad facade system is non-operable and acts as an aesthetic barrier between the street interface and the interior environment. This facade system comprises modular aluminium panels fixed to a framing system which is then fixed to the envelope of the building. This approach makes the installation process easier and more efficient as well as limits wastage of material.</li> <li>2, The passive shading system on the adjacent facades are automatically operated by the users and are 'fitted' into the window cavity, demonstrating characteristics of a double facade system.</li> </ol> <ul style="list-style-type: none"> <li>- The LED lighting embedded in the fixed modular panels of the facade, add an aesthetic appeal to the building.</li> <li>- Due to the modular nature of the facade system, maintenance and replacing panels of the facade is made easier.</li> </ul> <p>“</p>	
5	<p>Thermal comfort: The structure passively cools and regulates temperature throughout the day by absorbing heat using thermal mass (MikePearce, 2016).</p>	<p>Technical constraints</p> <ul style="list-style-type: none"> <li>- The use of thermal mass to absorb heat may necessitate specific materials and construction techniques, potentially increasing initial costs and</li> </ul>



	<ul style="list-style-type: none"> <li>- When the effects of the night purge wear off, chilled beams—copper pipes that release cool air later in the day—maintain acceptable temperatures (MikePearce, 2016).</li> <li>- The structure's engineering and architectural shape are intended to provide for sustainable thermal comfort in response to natural processes (MikePearce, 2016).</li> <li>- Through the active facade system, the building uses passive ventilation. By controlling the temperature differential between cold air and night air, the facade system promptly cools the structure (MikePearce, 2016).</li> </ul>	<p>construction complexity.</p> <ul style="list-style-type: none"> <li>- Integrating photovoltaic and thermal solar panels, along with a gas-fired cogeneration plant, involves significant upfront investment and requires sufficient rooftop/facade space.</li> <li>- The timber vertical slats system must be durable and weather-resistant, and its automated operation needs to be reliable to avoid malfunction.</li> <li>- Ensuring consistent and effective airflow throughout the building necessitates precise design and integration of various ventilation components, which can be technically challenging.</li> </ul> <p>Maintenance concerns</p> <ul style="list-style-type: none"> <li>- Incorporating plant life within the building requires ongoing maintenance, adequate light, and water supply, as well as proper pest control.</li> </ul> <p>Cost concerns</p> <ul style="list-style-type: none"> <li>- Using recycled wood and other sustainable materials may limit material availability and increase procurement costs.</li> <li>- Ensuring a fresh air change every half hour demands a highly efficient and possibly expensive HVAC system to maintain consistent air quality without excessive energy consumption.</li> </ul>
6	<p>Comfort: An effective facade design can improve indoor thermal comfort by minimising temperature fluctuations and drafts. This creates a more pleasant environment for occupants throughout the year, enhancing their satisfaction and well-being.</p>	<p>Due to high cost required to maintain the building, the facade systems such as the adaptive and adjustable West facade have been neglected and are no longer in use but stand stagnant rather than being able to accommodate for necessary external conditions.</p>
7	<ul style="list-style-type: none"> <li>•The outer skin is made of fritted glass, which is a cost-effective means of reducing solar radiation.</li> <li>• The security of the laboratories is</li> </ul>	<p>"•Climate Sensitivity: The performance of double skin facade systems is sensitive to climatic conditions such as temperature, humidity, and wind. Proper design and control</p>



	<p>further enhanced by the provision of access to the building services through external ducts and staircases.</p> <ul style="list-style-type: none"> <li>• Having the building services installed on the exterior means maintenance can be carried out without disturbing laboratory users and laboratories are less likely to be contaminated.</li> </ul>	<p>mechanisms are needed to optimise energy efficiency and indoor comfort under varying weather conditions.</p> <ul style="list-style-type: none"> <li>• Aesthetics: Designing a visually appealing double skin facade requires careful consideration of materials, proportions, and detailing. Balancing aesthetic preferences with functional requirements can be challenging.</li> <li>• Fire Safety: Double skin facade systems may present fire safety concerns, particularly in terms of fire spread between the layers and access for firefighting operations. Adequate fire protection measures and emergency evacuation plans must be incorporated into the design." </li></ul>
8	<ul style="list-style-type: none"> <li>• Climate Sensitivity: The building's wave of thousands of aluminium modules was created with thermal comfort in mind. It was intended to react to the internal environment by covering the glass facade when less light was needed.</li> <li>• Aesthetics: The live facade feature gives the design an eye-catching quality.</li> </ul>	<p>high cost required to maintain the building, the facade systems such as the adaptive and adjustable living facade need to be maintained to ensure effective performance</p>
9	<ul style="list-style-type: none"> <li>• Using the egg-crate devices enhances annual performance, lowers window solar incident radiation, promotes natural lighting, and uses less artificial lighting overall.</li> <li>• Since the building is situated in a warm, tropical climate all year round, the solar shading system does not need to be adjustable because the temperature will be</li> </ul>	<ul style="list-style-type: none"> <li>• The design follows a 50th percentile approach to the design, accommodating for the 'average user', leaving no room for adaptability options.</li> <li>• The technical approach alongside the scale of the building leaves concern for maintenance and cost.</li> </ul>
10	<p>mitigating the effects of urban pollution by breaking down several gaseous pollutants, recycling CO<sub>2</sub> and sequestering carbon, and capturing dust</p> <p>pollutants. • Reabsorbing a portion of the heat that is trapped in urban settings, so lessening the impact of the so-called "urban canyons" heat island effect.</p>	<ul style="list-style-type: none"> <li>• There are numerous obstacles when it comes to choosing the right building techniques, choosing plants, caring for them, and making green façades or living walls sustainable. Cameron</li> </ul> <p>Concerns about certain "green" wall systems not meeting other sustainability requirements, such as not wasting water, nutrients, or energy to pump irrigation water to the wall</p>



		planting, are voiced by et al. (2014: 199). •On the UP Plant Sciences wall, the constraints imposed by the limited resources accessible to cremnophytes on naturally existing cliff faces—such as restricted growth space and limited soil and moisture—have largely been overcome.
11	<p>Occupant's comfort and well-being.</p> <ul style="list-style-type: none"> <li>• The Double façade system that is open at the bottom and the top plays a significant role in providing passive cooling. since the warmer air moves out at the top and the cooler air comes in at the bottom. This natural ventilation strategy also minimises the need for mechanical means. By promoting more natural ventilation solutions this contributes towards energy efficiency and environmental sustainability.</li> <li>• The external facade also reduces the amount of direct sunlight from entering the building (minimises glare), by shading the interior from the direct sun's rays and it helps with the building.</li> <li>• The double facade act as a sound buffer in reducing the noise into the building, this is important for occupant comfort as well providing a more peaceful and serene indoor environment (Boogertman, 2014).</li> </ul>	<ul style="list-style-type: none"> <li>• Some notable constraints of using a double facade system are that the floor space required for the building is then occupied by this external facade.</li> <li>• 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.</li> </ul>
12	The green façade acts as an insulator that prevents the building heating up. Plants foliage blocks direct sun rays, keeps the interior quite cool (Cüce et al., 2021).	Green facades might be costly in certain instances and require regular maintenance, water maintenance.
13	They are adaptable, and innovative solar tracking technology and they adjust with the orientation of the sun in order to provide the building with best performance, they provide environmental sustainability to the building (Boogertman, 2012).	They are costly and require high maintenance. They consume power, depending on what type of power is used.
14	Provides Thermal benefits to	There maybe challenges with



	building. It provides energy efficiency means (Hoy & Hoy, 2021).	durability and there are design limitations as well. It is not compatible with a lot of other materials. It is costly
15	Cost saving, sustainable, natural ventilation, energy efficient and provides improved indoor air quality (Sung & Kim, 2019).	It is highly dependent on the existing climatic and weather conditions, there might be odour transmissions into the building and air quality concerns.

#### 4.4 Comparative analysis

A comparison matrix has been created based on the façades and facade systems type, since the different systems perform in different ways. Ten important aspects were identified and have been defined in the table. All 15 case studies were compared as individuals due to their specific locations; cost; maintenance aspects; aesthetics; etc. The score does not necessarily indicate the success of the project; rather, it serves as an indicator of how well the structure addresses the numerous aspects impacting thermal comfort. Presumably, a higher score denotes a better implementation of the strategy/technology employed and a better experience with thermal comfort. The selection of the system and technology in the built environment may be influenced by issues other than thermal comfort, such as cost, maintenance, and aesthetics.



Case study	Reduction of thermal gains	lighting control	Indoor Air Quality Control (IAQ)	Adaptable (YES/NO)	Sustainable material	Climate classification (Tshwane specific)	Maintenance	Ventilation	Aesthetic	Cost	Rating (-/10)	Percentage
1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5	50%
2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.5	55%
3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3.5	35%
4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.5	55%
5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6.5	65%
6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6.5	65%
7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.5	45%
8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7.5	75%
9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.5	55%
10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6	60%
11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.5	55%
12	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6	60%
13	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6.5	65%
14	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7.5	75%
15	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6	60%

0 Low rating    
 0.5 Medium rating    
 1 High rating

**Figure 8: Case studies comparative analysis** (Author, 2024)

The scoring system used is as follows: 0 (Low rating); 0.5 (Medium rating); 1 (High rating);

Through the rating table shown above we see that Case studies 5, 8, 13, and 14 were among the highest leaving an understanding that the overall attributes of these facades work best among the 15 case studies.

The Lantern (case study 14), was one of the best performing case studies, with consideration of the 10 key factors. The Lantern makes use of a double skin facade with an exterior brick screening device that allows for controlled light access and natural ventilation, making the facade diverse in its approach to target thermal amelioration.

The National Biodiversity Pavilion (case study 8) also achieved a 75% rating. The pavilion makes use of a kinetic facade that allows for wind to alter the direct sunlight access into the building whilst maintaining natural ventilation. This draws evidence that facade systems that incorporate both ventilation and shading strategies produce overall good building thermal performances.



### 4.5 Frequency of Use

In this paper, the frequency used calculation is the amount of times the building technology type has been implemented in a case study. It's important not to understand it as a final, or that the building technology used is successful. It can be implied that a specific technology of strategy is more popular with the selected case studies or has a somewhat greater influence on thermal comfort. The success of each strategy would be finalised in a further study, where the technical abilities will be measured.

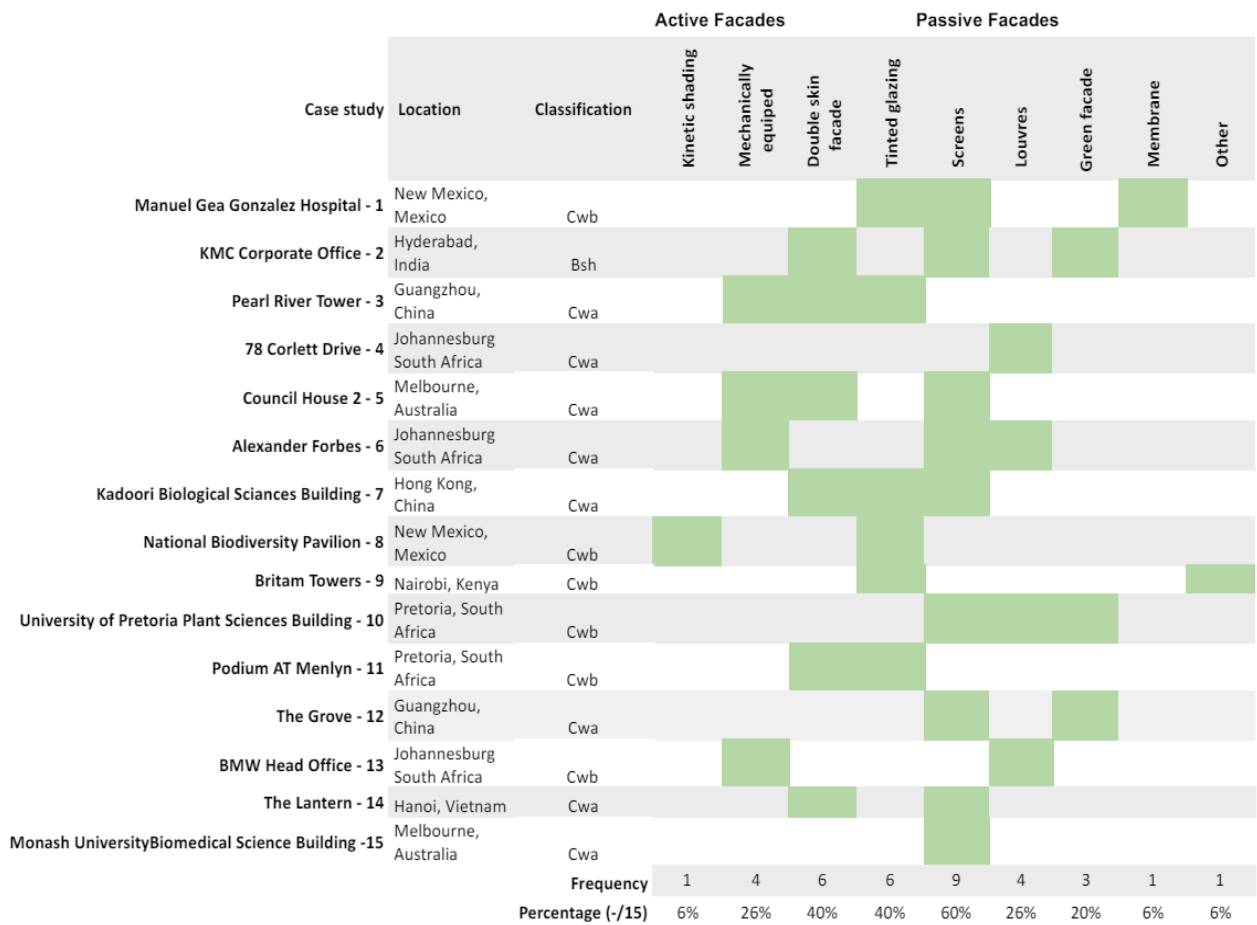


Figure 9: Case study frequency table (Author, 2024)

### 4.6 Results Conclusion

The use of fixed screens were the most used technology and face system among the fifteen cases studies with a 60% frequency use, meaning that the buildings within the climate classification tend implement fixed shading devices to reach thermal amelioration. It's also evident in the table that the fixed screens used in the buildings is classified under Cwa and Bsh, with the exception of one in Cwb, therefore making it evident that a warmer climate such as Tshwanes current and future classification requires the use of shading devices more in its thermal strategies approach to reduce



direct sunlight access within the building to lower the interior temperature and enhance thermal comfort.

## **5. Discussion**

### **5.1 Discussion of results**

#### ***5.1.1 Effectiveness of facade technologies***

Enhanced indoor air quality, reduction of natural light penetration, and general occupant well-being are the results of using innovative facade systems. There have been numerous case studies that document excellent occupant comfort and satisfaction from the sources gained. Energy Efficiency has also been achieved. Double skin façades and dynamic automated louvres have been demonstrated to significantly reduce energy use; in certain case studies. Techniques such as natural ventilation and thermal mass use have proven successful in preserving comfortable interior temperatures while lowering the need for mechanical cooling systems.

#### ***5.1.2 Trends and Similarities***

As seen in the data analysis on the case studies in chapter four, the use of fixed shading devices was a recurring pattern in use. This emphasises the need in reducing direct sun exposure to interior spaces in order to control thermal comfort in buildings. Most case studies made use of natural ventilation systems, which often included elements like air gaps in double skin facades, perforated screen walls (brick), and movable windows to control temperature and improve indoor air quality. A number of buildings had dynamic facade systems, such as double skin facades and solar tracking louvres, indicating a trend toward the use of responsive shading devices that move according to the building's needs, wrestling in thermal comfort and energy efficiency. A large number of the case studies included living walls and green facade features, highlighting the importance of nature inspired design concepts for sustainability and occupant well-being.

### **5.2 Research question response**

“How can / do architectural building technologies implemented in selected case studies, contribute to the local climate adaptation strategies that target thermal amelioration potential (Vermeulen, 2023)?”

The factors for choosing the ideal facade system in light of particular project needs are covered in detail in the discussion. The best facade system depends on a number of factors, including building orientation, energy efficiency objectives, climatic classification, and aesthetic



considerations. Built environment specialists can choose the best facade system to improve building performance by matching the selection criteria to the project goals and surrounding conditions.

**Double Façade System:** This design incorporates two building envelope layers separated by a void. The inner layer promotes natural ventilation, which increases energy efficiency, while the outer layer offers heat insulation and shade.

**Green Facade systems:** Multi Storey residential buildings in Tshwane can make use of green facade systems such as vertical gardens and green walls to enhance evaporative cooling within the buildings.

**Fixed shading systems:** With fixed shading being the most commonly used facade technology it proves to be an easy choice in helping the reduction of direct daylight into buildings, improving thermal comfort in a cost-effective way.

### **5.3 Gaps and recommendations**

The study dived into the identification of building technologies that contribute to thermal amelioration. The building technology that presented itself made use of high-tech examples and innovative use of materials. Due to limited local case studies, a large number of case studies were taken from developed international countries who are well equipped with access to innovative technologies. There are opportunities in additional study to investigate low tech strategies and developing technology, especially in the context of Africa. We learnt from Britam Tower (case study 9) that a low-tech approach is possible as they successfully managed to reduce thermal heat gain through the use of shading devices made from old egg cartons. Future research could concentrate on low tech, cost effective technologies that can be easily implemented in developing countries such as South Africa.

The study also mentions thermal amelioration, with results found on strategies that tackle heat stress scenarios due to the classifications in which Tshwane falls in. There is a possibility in enhancing the research further that looks at technologies that can both deal with thermal amelioration in the context of both heat stress in summer and 'cold stress' in winter. The identification and research of technology that can adapt and counteract heat access into the building in unexpected cold conditions.

## 6. Conclusion

This study investigates strategies for enhancing the thermal adaptation capability of buildings in South African cities by means of a thorough examination of architectural building technologies and interventions. Buildings can lower energy use, improve internal comfort, and lessen the impact of the urban heat island effect by putting in dynamic facade strategies, green systems, shading devices, and natural ventilation systems. The analysis on the case studies helped in identifying key technologies and strategies that can be implemented in adapting multistory buildings in Tshwane.

The significance of acknowledging the obstacles presented by climate change and the increasing urbanisation trend is emphasised in the paper. By 2030, a sizable fraction of the world's population is expected to live in cities, making the development of sustainable and climate-resilient urban ecosystems imperative. In particular, the study focuses on improving the thermal adaptable ability of existing buildings. It explores the pressing need for climate change adaptation in South African cities. Globally, people are already experiencing the effects of climate change, such as harsh weather and rising temperatures, and Southern Africa is particularly susceptible to these effects.

In conclusion, the study emphasises how urgent it is to improve South African cities' buildings' ability to adapt to climate change and increase their thermal capacity. For present and future generations, a prosperous and resilient future can be ensured by adopting sustainable building solutions and taking cues from adaptable natural systems. The research highlights how crucial it is for communities, professionals, and governments to work together to mitigate the effects of climate change and adapt to its difficulties in order to ensure a sustainable and prosperous future.



## References

- Architizer. (2015). University of Pretoria Plant Science Complex by KWP CREATE Architects. [online] Available at: <https://architizer.com/projects/university-of-pretoria-plant-science-complex/>.
- Attia S, Bilir S, Safy T, Struck C, Loonen R, Goia F. Current trends and future challenges in the performance assessment of adaptive façade systems. *Energy Build.* 2018; 179: 165-182.
- Banham, R. (1969). *The Architecture of the Well-Tempered Environment*. Architectural Press
- Bioenergy. Available from: <https://en.wikipedia.org/wiki/Bioenergy>.
- Boschoff, B., Meyl, C. (2020). The building emission reduction potential of South African residential building efficiency tools – A review. (2020). *Acta Structilia*, 27(2). doi: <https://doi.org/10.18820/24150487/as27i2.6>.
- Cao, L. (2019). *What Materials Keep Buildings Cool?* [online] ArchDaily. Available at: <https://www.archdaily.com/923445/what-materials-keep-buildings-cool>.
- Cameron, Ojembarrena, J.A., Chanampa, M., Rivas, P.V., Olivieri, F., Aragonés, R.G., González, F.J.N. & Frutos, C.B. 2013. 'Thermal and illuminance performance of a translucent green wall', in *Journal of Architectural Engineering* Vol. 19 No. 4: 256–264
- Chang, T.-W., Huang, H.-Y., & Datta, S. (2019). Design and fabrication of a responsive carrier component envelope. *Buildings*, 9(4), 84. <https://doi.org/10.3390/buildings9040084>
- Chersich, M.F. and Wright, C.Y. (2019). Climate change adaptation in South Africa: a case study on the role of the health sector. *Globalization and Health*, [online] 15(1). doi: <https://doi.org/10.1186/s12992-019-0466-x>
- City of Tshwane (2022), *City of Tshwane Climate Action Plan*, City of Tshwane, Tshwane.
- Coursesidekick, (2024). Available at: <https://www.coursesidekick.com/geography/3543903>.



Dovetail. (2024) *Data Collection 101: Examples, Steps, and FAQs*. [online] Available at: <https://dovetail.com/research/data-collection/>.

Dos Santos, F. (2022). Quarter 3 Honours RFS 701 Slides Submission, University of Pretoria

Drozdowski, Z. (2010). The Adaptive Building Initiative. *Architectural Design*, 118–123.

Favoino, F, Jin, Q., & Overend, M. (2014). Towards an ideal adaptive glazed façade for office buildings. *Energy Procedia*, 62, 289–298. <https://doi.org/10.1016/j.egypro.2014.12.390>

Hugo, J.M. and Sonnendecker, P.W. (2023), "Ground-level documentation of heat stress exposure and response strategies in informal settlements in Tshwane, South Africa", *Smart and Sustainable Built Environment*, Vol. ahead-of-print No. ahead-of-print.  
<https://doi.org/10.1108/SASBE-10-2022-0229>

Ibse.hk. (2001). *HKU Biological Sciences Building*. [online] Available at: [http://ibse.hk/sbe/case\\_study/case/hk/hku-bsb/bsb-index.html](http://ibse.hk/sbe/case_study/case/hk/hku-bsb/bsb-index.html).

Knaack U, Luible A, Overend M. (2015). Adaptive facade network Europe. 1. Lucerne, Switzerland: Lucerne University;

Knaack, U., Klein, T. (2009). *The Future Envelope 2: Architecture – Climate - Skin, Research*, in *Architectural Engineering Series*, Vol. 9.

Li, X., Stringer, L.C. and Dallimer, M. (2022), "*The impacts of urbanisation and climate change on the urban thermal environment in Africa*", *Climate*, Vol. 10 No. 11, p. 164, doi: 10.3390/cli10110164.

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. <https://doi.org/10.3390/ijerph192114470>

Loonen, R. C. G. M., Trčka, M., Cóstola, D., & Hensen, J. L. M. (2013). Climate adaptive building shells: State-of-the-art and future challenges. *Renewable and Brzezicki, Cogent Arts & Humanities* (2021), 8: 1960699 <https://doi.org/10.1080/23311983.2021.1960699> Page 27 of 29 *Sustainable Energy Reviews*, 25, 483–493. <https://doi.org/10.1016/j.rser.2013.04.016>



Loonen R. Approaches for Computational Performance Optimization of Innovative Adaptive Façade Concepts. Eindhoven: Technische Universiteit Eindhoven; 2018.

Lou, W., & Chan, E. (2011). Sustainable Construction: Waste Reduction by Prefabrication. *Journal of Construction Engineering and Management*, 137(9), 726-735.

Luthra, J. and Sundaram, A.M., 2023, July. Identifying external louver angle for residence opening to optimize the indoor environment for the composite climate of Delhi NCR. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1210, No. 1, p. 012003). IOP Publishing.

Lwasa, S. (2014). Managing African urbanization in the context of environmental change. *Inter Disciplina*, 2(2). <https://doi.org/10.22201/ceiich.24485705e.2014.2.46528>

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. <https://doi.org/10.21608/jesaun.2019.115119>

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. <https://doi.org/10.1051/shsconf/202110203003>

Mason, W., Morris, K., Webb, C., Daniels, B., Featherstone, B., Bywaters, P., & Scourfield, J. (2019). 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. <https://doi.org/10.1177/1558689819857972>

McCarthy, M., Best, M., & Betts, R. (2010). Climate change in cities due to global warming and urban effects. *Geophysical Research Letters*, 37(9). <https://doi.org/10.1029/2010gl042845>

McCusker, K. and Günaydın, S. (2014). Research using qualitative, quantitative or mixed methods and choice based on the research. *Perfusion*, 30(7), 537-542. <https://doi.org/10.1177/0267659114559116>



Mehrotra, D. and Mehrotra, R. (1995). Climate change and hydrology with emphasis on the Indian subcontinent. *Hydrological Sciences Journal*, 40(2), 231-242.

<https://doi.org/10.1080/02626669509491406>

Mello, C. R. d., 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*, 36(1), 53-59. <https://doi.org/10.1590/s1413-70542012000100007>

Moloney, J. (2011). *Designing kinetics for architectural facades: state change*. Taylor & Francis.

R.W.F., Taylor, J.E. & Emmett, M.R. 2014. 'What's "cool" in the world of green façades? How plant choice influences the cooling properties of green walls', in *Building and Environment*, Vol. 73: 198-207.

Rahbarianyazd, R., & Raswol, L. (2018). Evaluating energy consumption in terms of climatic factors: A case study of Karakol residential apartments, Famagusta, North Cyprus. *Journal of Contemporary Urban Affairs*, 2(1), 45 54. <https://doi.org/10.25034/ijcua.2018.3658>

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S., Donges, J.F., Drüke, M., Fetzer, I., Bala, G., Werner von Bloh, Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Willem Huiskamp, Matti Kummu, Mohan, C., Bravo, D. and Petri, S. (2023). Earth beyond Six of Nine Planetary Boundaries. *Science Advances*, [online] 9(37). doi: <https://doi.org/10.1126/sciadv.adh2458>.

Sandak, A., Sandak, J., Brzezicki, M., & Kutnar, A. (2019). *Bio-based Building Skin* (pp. 22). Springer

Schittich, C., Lang, W., & Krippner, R. (2006). *Building skins*. Birkhäuser.

Seto, K.C. and Shepherd, J.M. (2009), "*Global urban land-use trends and climate impacts*", *Current Opinion in Environmental Sustainability*, Vol. 1 No. 1, pp. 89-95, doi: [10.1016/j.cosust.2009.07.012](https://doi.org/10.1016/j.cosust.2009.07.012).

Sheweka, S. & Magdy, N. 2011. 'The living walls as an approach for a healthy urban environment', in *Energy Procedia* Vol. 6: 596–597



Siew, G. (2024). *The transformation of architecture in the era of climate change - Cogito COGITO*. [online] COGITO. Available at: <https://oecdcoigito.blog/2024/03/25/the-transformation-of-architecture-in-the-era-of-climate-change/> [Accessed 14 May 2024]

Szolomicki, J., & Golasz-Szolomicka, H. (2019). Technological advances and trends in modern high-rise buildings. *Buildings*, 9(9), 193. <https://doi.org/10.3390/buildings9090193>

Vax, G. Blanco, I. & Schettini, E. (2018). “*Green facades to control wall surface temperature in buildings*”, *Building and Environment*, Vol. 129, pp. 154-166, <https://doi.org/10.1016/j.buildenv.2017.12.002>

Vermeulen, A., 2023. *Climate Change Adaptation Technologies*

Wu, W. and H.M. Skye, Residential net-zero energy buildings: Review and perspective. *Renewable and Sustainable Energy Reviews*, 2021. 142: p. 110859. DOI: 10.1016/j.rser.2021.110859



## Appendix A: The 32 Koppen Climate Classifications

<b>Af</b>	Equatorial rainforest	No dry season. The driest month has at least 2.36" (60 <u>mm</u> ) of rain. Rainfall is generally evenly distributed throughout the year. All average monthly temperatures are greater than 64°F (18°C).
<b>Am</b>	Equatorial monsoon	Pronounced wet season. Short dry season. There are one or more months with less than 2.36" (60 mm). All average monthly temperatures are greater than 64°F (18°C). Highest annual temperature occurs just prior to the rainy season.
<b>As</b>	Equatorial savanna	Summer dry season. There are more than two months with less than 2.36" (60 mm) in summer. All average monthly temperatures are greater than 64°F (18°C).
<b>Aw</b>	Equatorial savanna	Winter dry season. There are more than two months with less than 2.36" (60 mm) in winter. All average monthly temperatures are greater than 64°F (18°C).
<b>BWk</b>	Mid-latitude desert	Mid-latitude desert. Evaporation exceeds precipitation on average but is <b>less than half</b> potential evaporation. Average temperature is <b>less</b> than 64°F (18°C). Winter has below freezing temperatures.
<b>BWh</b>	Subtropical desert	Low-latitude desert. Evaporation exceeds precipitation on average but is <b>less than half</b> potential evaporation. Average temperature is <b>more</b> than 64°F (18°C). Frost is absent or infrequent.
<b>BSk</b>	Mid-latitude steppe	Mid-latitude dry. Evaporation exceeds precipitation on average but is less than potential evaporation. Average temperature is <b>less</b> than 64°F (18°C).
<b>BSh</b>	Subtropical steppe	Low-latitude dry. Evaporation exceeds precipitation on average but is less than potential evaporation. Average temperature is <b>more</b> than 64°F (18°C).
<b>Cfa</b>	Humid subtropical	Mild with no dry season, hot summer. Average temperature of warmest months are <b>over</b> 72°F (22°C). Average temperature of coldest month is under 64°F (18°C). Year around rainfall but highly variable.
<b>Cfb</b>	Marine west coast	Mild with no dry season, warm summer. Average temperature of all months is <b>lower</b> than 72°F (22°C). At least four months with average temperatures over 50°F (10°C). Year around equally spread rainfall.
<b>Cfc</b>	Marine west coast	Mild with no dry season, cool summer. Average temperature of all months is <b>lower</b> than 72°F (22°C). There are one to three months with average temperatures over 50°F (10°C). Year around equally spread rainfall.
<b>Csa</b>	Mediterranean	Mild with dry, hot summer. Warmest month has average temperature <b>more</b> than 72°F (22°C). At least four months with average temperatures over 50°F (10°C). Frost danger in winter. At least three times as much precipitation during wettest winter months as in the driest summer month.
<b>Csb</b>	Mediterranean	Mild with cool, dry summer. No month with average temperature of warmest months are over 72°F (22°C). At least four months with average temperatures over 50°F (10°C). Frost danger in winter. At least three times as much precipitation during wettest winter months as in the driest summer month.
<b>Cwa</b>	Humid subtropical	Mild with dry winter, hot summer
<b>Dfa</b>	Humid continental	Humid with hot summer
<b>Dfb</b>	Humid continental	Humid with severe winter, no dry season, warm summer
<b>Dfc</b>	Subarctic	Severe winter, no dry season, cool summer
<b>Dfd</b>	Subarctic	Severe, very cold winter, no dry season, cool summer
<b>Dwa</b>	Humid continental	Humid with severe, dry winter, hot summer
<b>Dwb</b>	Humid continental	Humid with severe, dry winter, warm summer
<b>Dwc</b>	Subarctic	Severe, dry winter, cool summer
<b>Dwd</b>	Subarctic	Severe, very cold and dry winter, cool summer
<b>ET</b>	Tundra	Polar tundra, no true summer
<b>EF</b>	Ice Cap	Perennial ice
<b>H</b>	Complex zone	Can encompass any of the above classifications due to the mountainous terrain.








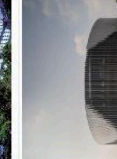



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

## Appendix B: The Data Capture





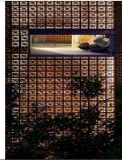



**Case Studies Table**

Case Study No.	Project	Location & Year	Köppen Climate classification	Facade Image	Type of system		Type of Facade				Facade Function		Response time			
					Passive	Active	External shading/curtain membrane	Curtain walls	Green facade	Daylight control	Thermal control	Airflow	Seconds	Minutes	Hours+	
1	Manuel Gaeonzalez Hospital	New Mexico, Mexico, 2013	Cwb		X						X	X				X
2	KMC Corporate Office	Hyderabad, India, 2012	Bsh		X	X			X			X	X			X
3	Pearl River Tower	Guangzhou, China, 2013	Cwa			X		X				X				X
4	78 Collett Drive Building	Johannesburg, South Africa, 2018	Cwa			X					X	X			X	
5	Council House	Melbourne, Australia, 2006	Cwa			X					X	X				X
6	Alexander Forbes Office	Johannesburg, South Africa, 2012	Cwa		X	X					X	X				X
7	Kadooni Biological Sciences Building	Hong Kong, China, 2000	Cwa		X				X			X	X			X
8	National biodiversity pavilion	New Mexico, Mexico, 2021	Cwa			X					X	X			X	
9	Britam Towers	Nairobi, Kenya, 2017	Cwb		X						X	X				X



**Case Studies Table**

Case Study No.	Project	Location & Year	Köppen Climate Classification	Facade Image	Type of system		Type of Facade			Facade Function		Response time				
					Passive	Active	External shading/ glazing membrane	Curtain walls	Green facade	Daylight control	Thermal control	Airflow	Seconds	Minutes	Hours*	
10	University of Pretoria Plant Science Complex	Pretoria, South Africa, 2012	Cwb		X		X		X	X	X			X		
11	Podium AT Meylyn	Pretoria, South Africa, 2012	Cwb		X			X		X						X
12	The Grove	Guangzhou, China, 2016	Cwa			X			X				X			X
13	BMW Head office	Johannesburg, South Africa, 2012	Cwa			X			X				X			X
14	The Lantern	Hanoi, Vietnam, 2016	Cwa		X					X						X
15	Monash University Biomedical Sciences Buildings	Melbourne, Australia, 2010	cwa		X						X					X