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Decision Support System for Sustainable Retrofitting of Existing Commercial Office Buildings

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Abstract

With more than 60% of the inventory being over thirty years old, commercial office buildings represent a substantial global energy consumer. The Australian government has attempted to lower greenhouse gas emissions through legislation, but the implementation of these efforts has only resulted in annual reductions of 1-3%. It is essential to focus energy-efficient interventions on the stock of current commercial buildings if we are to achieve net zero emissions by 2050. Energy performance, efficiency, and greenhouse gas emissions can all be improved in commercial buildings by reducing energy consumption. According to Climate Works Australia and the IPCC, there is a 30% chance of avoiding current energy use while still reaping net economic benefits. To lessen global warming, the IPCC has also recommended that developed nations, like Australia, reduce emissions by 45% by 2030. Buildings with passive technologies can have better energy efficiency without sacrificing comfort. One of the main tactics for lowering energy consumption and carbon emissions in already-existing commercial buildings is energy retrofitting.

"Providing a machine with a part, or a place with equipment which was not originally present when it was built" is what the Cambridge Dictionary defines as "retrofitting." However, in this context, it refers to any intervention activity that involves modernizing or repurposing the current structure to satisfy an appropriate requirement. Both cases deal with increasing a building's level of sustainability and energy efficiency through renovations.

Multiple combinations of applicable energy consumption-reducing measures that can be applied to retrofit a building present a major challenge to decision-makers in energy retrofit. The evaluation of life cycle cost (LCC) and life cycle analysis (LCA) during retrofits present additional difficulties. LCC and LCA are not used in tandem; additionally, selecting the most appropriate retrofitting strategy or set of measures can occasionally be challenging due to the inclusion of unqualified sustainable technology in listings and selections.

The current study intends to address the problems by creating a strong decision support system (RDSS) that integrates sustainable criteria, or triple bottom line TBLs (environmental, social, and economic benefits), in the energy retrofit decision-making process. This will lessen the difficulties encountered in making decisions that will lead to successful building appraisals. The predetermined objectives are meant to lead to the goal.

- Because of various technological alternatives, it may be vital to have a comparison to simplify sustainable technologies (STs) tools using SWOT/multiple criteria in TBL aspects.
- Providing an assessment method to merge LCA & LCC to balance environmental and economic performances and determine the impact of the building life cycle on the energy retrofit decision process.
- Address the challenges decision-makers encounter in dealing with changes due to building markets and regulations since legislation and public expectation drive sustainable buildings.
- To develop and validate a holistic optimum strategic decision model to select the best retrofit alternatives for a particular building which maximizes the sustainability ranking of the building.

Initial research focuses on conducting a life-cycle cost analysis of a commercial office car park building in Sydney, New South Wales. The evaluation includes assessing energy performance through retrofit measures

to determine long-term benefits. By using life-cycle cost analysis, the study aims to enhance decision-making in energy assessment.
To examine energy consumption intensity, lifecycle costing, CO_2 emissions, and cost efficiency, data will be collected from non-green buildings and one building's envelope will be simulated using the Energy Plus tool. Experimental measurements will be compared to validate simulated models.
The study includes a case study on a 12,000 square meter commercial office building used as a commercial parking facility. Retrofitting activities were initiated on three office rooms, focusing on HVAC, lighting, and equipment improvements, resulting in a 1.9-year payback period, 15% emissions reduction, 25% energy savings, and 23% cost savings.

The subsequent phase involves utilizing various methods such as concept mapping, focus groups, interviews, Questionnaire surveys, and statistical analysis (SPSS) to develop a robust decision support system (RDSS) for sustainable energy retrofits.

The overall goal is to establish a systematic decision support system to aid decision-makers and policymakers in improving energy efficiency in commercial office buildings by implementing passive technologies. The system will also recommend strategies to enhance financial outcomes through smart building operations and management implementations.

The research contributes to knowledge:

- To integrate the decision support process into sustainable impacts of buildings' energy retrofits (economics, environmental, and social).
- Propose a decision matrix to guide decision makers on objective functions to formulate an optimization problem to select the best strategies for energy retrofits concerning investors' benefits.
- Identify, map, and categorize economics and environmental criteria for improving energy in existing office buildings and finally,
- To develop a robust decision support system (DSS) for energy retrofits of building projects in integrating the above method of approach.

Decision-makers can apply the model that will be developed in this study to various building types to determine the optimal optimization strategy for energy retrofits to optimize both the financial and environmental benefits. The model is most appropriate for commercial existing office buildings where maximum benefits can be obtained, but homeowners can also use it for planning and evaluating retrofit strategies.

1.0 Research Introduction

1.1 Research Background

New sustainable development paradigms are needed for sustainable buildings, which are those that satisfy the needs of the global population today without compromising those of future generations. With fewer people and more effective use of natural resources, these will promote a more inclusive society in which the advantages of rising economic prosperity are shared widely (London Department of the Environment, 2000). The goal of the research is to develop a framework for decision-supporting energy efficiency upgrades in lower- to medium-rise commercial office buildings constructed prior to 2000. These structures, which are categorized as secondary B-grade structures, are usually of lower quality and lack energy efficiency in both design and construction. With the help of this study, commercial building managers will have more tools to maximize energy efficiency, financial returns, and occupant comfort. Buildings and the environment coexist, which contributes to greenhouse gas (GHG) emissions, which local and international governments are concerned about because of global warming. The construction industry in Australia, especially that of commercial office buildings, is a significant source of CO_2 emissions.
Researchers recommend lowering CO_2 equivalent emissions from existing buildings through sustainable maintenance and retrofitting to lessen the environmental impact of office buildings. Unfortunately, there are not enough reliable decision-making models available right now for retrofitting commercial buildings, which is essential for achieving sustainability and energy efficiency objectives. The absence of a framework

for long-term assessments may cause decision-makers to forgo upgrades because they require capital expenditures. In the absence of a framework, stakeholders might develop maintenance plans that fall short of the social, environmental, and financial requirements of the buildings over the course of their lifetime.
To assist stakeholders in improving their office buildings and lowering expenses and CO2 emissions, the research aims to develop a decision-support framework for building upgrades that incorporates sustainable criteria, including economic and environmental aspects. The Triple Bottom Lines (TBL) concept, which evaluates office buildings' long-term performance and the advantages of striking a balance between social justice, environmental quality, and economic prosperity, serves as the foundation for the framework. It lowers risk, increases societal wealth, protects the environment, and enables stakeholders to report their activities for sustainability development and make reasonable assessments prior to making decisions. Data gathered from the renovation of current office buildings will be modelled in a sustainable and ecologically friendly manner, and it will be published to motivate stakeholders to increase their understanding of upkeep and renovation.

1.2 Research Significance

This research is important because, according to Gutowski et al. (2013), existing buildings produce about 40% of the world's energy and contribute more than 50% of greenhouse gas emissions. Furthermore, energy, water use, and CO2 emissions accelerate resource depletion, ozone depletion, and global warming—all of which influence human health—according to Simonen (2014). Kat (2018) continued by stating that greenhouse gas emissions from the building's energy use may have an adverse effect on people and the environment. By 2050, carbon emissions from the building construction industry, especially from pre-existing structures, could potentially triple, according to some estimates (IPCC 2014).
According to observations made by Hohne et al. (2017) and CIE (2008), if action is not taken to minimize energy usage in existing buildings worldwide, CO2 emissions from the building industry would rise to 280MT in 2050, or an increase of 110% over 2005 levels. According to UNEP (2008), buildings account for one-third of greenhouse gas emissions worldwide, consuming roughly 40% of energy, 25% of water, and 40% of land resources.
Shipley (2016) draws attention to the building construction industry's substantial impact on energy consumption. But increasing the energy efficiency of already-existing structures is essential to lowering global energy use and fostering the ecosystem. The advantages of energy efficiency, including lower operating costs, higher asset value, and better occupant comfort, are recognized by organizational leaders. According to Muldavin (2017), adopting new behaviours can result in inclusive growth and the shift to a sustainable energy economy. Enhancing operational and maintenance activities, equipment retrofitting, occupant behavioural changes, and building envelope modifications are some of the opportunities for increasing energy performance in office buildings.
According to Elmani (2015), lowering greenhouse gas emissions from existing buildings is therefore essential to their successful energy retrofit. The negative consequences of buildings' interactions with the environment will be significantly reduced, according to research, with decision support for sustainable building maintenance management (Henderson 2006).

1.3 Problem Statement

Although retrofitting existing buildings can lower energy use and greenhouse gas emissions, there are several unknowns involved, including shifts in the building market, governmental regulations, consumer behaviour, budgetary constraints, and weather. When choosing sustainable technologies (STs) for building upgrades, these factors come into play. The choice of STs is a multi-objective optimization problem with limitations imposed by the building fabric, efficiency, budgets, target project, and particular building attributes. Other issues that stakeholders deal with include the neglect to identify and evaluate STs, which can result in poor decision-making.
As researchers have established decision-making tools for choosing dependable retrofit solutions and realized the benefits of planning retrofit projects, many initiatives have been launched. Sustainable technologies (STs) reduce the energy consumption of currently existing commercial office buildings, thereby increasing energy savings. However, despite their benefits to the environment and economy, the use of STs in building retrofits has been slow.
When modernizing commercial existing office buildings, a range of instruments and methodologies are

employed for the appraisal and analysis of the buildings, including the building habitability index (PIHI), TOBUS, LCA, LCC, and others. There are restrictions on these tools: For example, engineers and architects were the primary users of TOBUS and EPIQR, which were designed to evaluate building conditions like physical deterioration, functional obsolescence, indoor environmental quality, and energy efficiency. Comparing potential retrofit scenarios was another use for these tools (Rey 2004; Cavccavelli & Gugerli 2002; Balara et al. 2002; Caccavelli & Genre 2000). But neither of these tools has a decision support mechanism, and PIHI does not address acoustics, waste, lighting, or water use (Kasuda 2001). (Rasmussen and Brandt 2002).

1.4 Research Gaps

- Inadequate robust decision models for guiding the retrofit of existing commercial office buildings, although this is important to achieve energy efficiency and sustainability goals.
- Challenges with listing and screening of sustainable technologies STs not qualified.
- Issues with the integration of LCC and LCA during building retrofits. Due to different processing methods, it is necessary and will minimize related issues due to economic and environmental measures.
- Changes in government building regulations affect building markets and decision processes.

From the above problems, this research will address the following questions.

1.5 Research Questions

- How would the integration of robust decision support systems aid decision-makers in overcoming the challenges of rapid changes in building markets, regulations, and technologies?
- How to understand the modern technological characteristics to implement listing and screening of STs not qualified from a different angle, focusing on benefits, cost, and limitations when applied in existing office building appraisals?
- How to provide an assessment method to merge LCA & LCC to balance environmental and economic performances?
- How will developing a holistic optimum decision support model contribute to balancing social, economic, and environmental performances?

Addressing this question will establish the answer to the major research question of this research thesis.
How would the model to be developed in this project contribute to overcoming the challenges of rapid changes in market technologies faced by decision-makers during office building appraisals?

1.6 Research Aims and Objectives

The project's objective is to offer a strong foundation for a decision support model that will assist decision-makers in overcoming challenges encountered when carrying out fruitful life cycle assessments of sustainable office buildings. To achieve this, the study will investigate how stakeholders select the best strategies and green technologies to use when remodelling buildings. It will also evaluate the long-term effects on the environment, society, and economy. Thanks to the information gathered based on the research findings, stakeholders will be better equipped to select the most cost-effective techniques and procedures to improve energy efficiency and extend the life of the building. Thus, to accomplish the goal, the following specific research objectives will be addressed:

Specific Research Objective

- Integration of a robust decision support system to aid decision-makers in overcoming challenges of rapid changes in building markets, regulations, and technologies.
- Due to various technological alternatives, it may be vital to have a comparison to simplify ST tools using SWOT/multiple criteria in TBL aspects.

- Providing an assessment method to merge LCA & LCC to balance environmental and economic performances.
- To develop and demonstrate a holistic optimum strategic decision model to select the best retrofit alternatives for a building that maximizes the benefits of sustainability (economic, social, and environmental) performance for retrofitting existing office buildings over their life cycle span.

1.7 Research Scope

The study's scope is restricted to B-grade (also known as secondary class) commercial office buildings, which include structures constructed prior to 2000. These buildings range in height from lower to medium-high rise. The study focuses on building systems and their characteristics during decision-making when energy retrofitting buildings, rather than considering the occupants' behavioural energy usage.

The proposed model could be used for residential buildings up to a specific age limit as well as commercial office buildings. However, this case study uses commercial office buildings to illustrate the application.

2.0 The Interaction between Office Buildings and Their Environments: Literature Review

2.1 Introduction

The literature review included in this study places the research study's topic within the corpus of existing knowledge in the built environment field. It also demonstrates the significance of the decision-making process that stakeholders employ when deciding on guidelines and technology for preserving and updating pre-existing office buildings. It will help identify conventional methods that are still in use in the building and construction sector. It will provide additional clarity on the practices and procedures currently employed by the sector.

There are two parts to the review:

- The Interactions between existing commercial office buildings, their environments, and the concept of sustainable building developments to reduce the impacts buildings have on the environment.
- The theoretical foundation of building management and decision-making process and understanding the logic behind existing building refurbishments and how it can improve the environmental, economic, and social performances.

The study's information and data will help determine a conceptual model for additional research.

The relationship between current commercial office buildings and their surroundings, including sustainable building developments and strategies for maintenance and refurbishment, served as the foundation for these reviews. Using a theoretical framework based on the decision support model, life cycle analysis assessments of existing office buildings, and retrofitting strategies implemented through measures and assessment tools under the theory of triple bottom lines (TBL).

2.2 Existing Commercial Office Buildings' Interactions with Environment

Concerns regarding the future of energy applications and their effects on the environment have been raised by the rise in global energy consumption. The greenhouse gas emissions from existing buildings cause global warming, resource depletion, carbon emissions, and ozone layer depletion. Countries are concentrating on sustainable designs, energy optimization, and reduction regulations because this industry consumes a lot of energy. Due to GHG emissions from existing buildings, Australia has experienced a significant increase in climate change, with an estimated 1°C increase in average temperature since 1950. To solve these problems, energy optimization, reduction laws, and sustainable design are essential.

In Australia, new construction replaces existing buildings at a rate of one to three percent annually; however, the construction of new low-energy buildings has little effect on greenhouse gas emissions. Refurbishing existing buildings has been found to be an effective way to reduce emissions in studies. The stock of commercial buildings has considerable room to improve energy efficiency. According to the 'Low Energy High Rise' study, major technical refurbishments could only be used sparingly to avoid about 30% of commercial energy use. For non-residential buildings, the Zero Carbon Australia Buildings Plan found savings of 44%, mostly from technical renovation.

Therefore, energy-efficient retrofitting of already-existing buildings is required to reduce the environmental

impact of these buildings using more energy (Elmani 2015). According to (Clarke 2009; Kentwell 2007; Lynas 2007 and Stenberg and Raisanen 2006), climate change will continue to accelerate unless sufficient steps are taken to reduce global warming.
It's claimed that the majority of old buildings use more energy because they have inefficient appliances like HVAC systems and Halogen lighting. Australia, for instance, uses 15% more water and 40% more waste than other countries (Gluch and Stenberge 2006; Madew 2007). However, just 10% of GHG emissions come from commercial buildings, with offices and hospitals accounting for up to 40% of emissions (Wilson).
Building systems that are necessary to guarantee the comfort of the occupants require energy to run. This includes using the air conditioning, heating, and ventilation systems, which account for over 40% of total energy use. As can be seen in figure 4 from the case study in this report, the remaining energy is used for machinery, elevators, etc. By conserving energy, a building with effective energy management is said to preserve important natural resources (Rhoads 2010). Up to 30% of the world's resources are allegedly consumed by buildings worldwide (OECD 2003; cited in Wilson and Tagaza 2006).
For businesses, wellness is crucial, and productivity is one aspect of it. When unfavourable office conditions—such as inadequate lighting, uncomfortable temperatures, and poor indoor air quality—have a detrimental impact on worker health or productivity.
Green Building Councils recently established a standard that is attracting a lot of interest from the industry and allows buildings that are designed and operated to improve occupant wellbeing to be certified. The market demanded high building energy performances while the larger community adopted sustainable certifications, increasing the amount of money required to get higher building energy ratings (McArthur, et al. 2015). The energy consumption of buildings is higher in developed countries. Consequently, the building sector's energy use is greatly impacted by its development, suggesting that building efficiency becomes more crucial as nations grow. The need for energy efficiency in construction is especially felt in emerging nations because of the rapid pace of new development and the opportunity to use best practices and efficient materials.

2.0 Sustainable Building Management

3.1 Sustainable Building Developments

Sustainable development is "the improvement in the quality of human life while living within the carrying capacity of supporting ecosystems," according to the United Nations Environmental Program (UNEP, 1991). Conversely, a sustainable building is one that integrates design, construction, and operation activities that significantly reduce or eliminate the negative effects of development on the environment and the occupants. This is achieved through approaches such as energy efficiency, reducing greenhouse gas emissions, conserving water, reducing waste, preventing pollution, improving biodiversity, using fewer natural resources, creating productive as well as healthy environments, and creating flexible spaces. This definition was provided by the Green Building Council of Australia (Madew 2003).
Gladwin et al. (1993) reinterpreted sustainability as the set of actions necessary to address environmental impacts through a well-defined approach that balances the needs of humans with the impact they have on natural resources.
Nonetheless, "sustainable development" was defined by "The Vancouver Valuation Accord" as development that satisfies current needs without compromising the capacity of future generations to satiate their own needs (Chapell and Corps 2009). According to Lucuik (2005), a sustainable building has healthier interior spaces and incorporates measures to lessen its environmental impact. This is a significant distinction between a sustainable and conventional building.
The advantages of sustainable buildings for the environment, society, and economy have led to a significant shift in the market. Additionally, studies by Madew (2003) revealed that sustainable buildings increase occupant productivity and well-being at a lower cost. As a result, incorporating sustainable elements into a building is simple, even though there are certain obstacles, like retrofitting existing structures (Miller and Buys 2011).
Accordingly, a "sustainable building" is one that is planned to have as little of an adverse effect on the environment as possible, to maximize profits from health and safety, and to have low running costs because of reducing energy and waste (Carlson 2015).
It has been noted that one of the biggest users of energy and other natural resources is the building sector. It makes up 40% of waste use, 30% of emissions related to energy use, and 12% of water use. The

management of financial profit is difficult to maximize, and operating costs are high. The building industry's social impact includes risks to building occupants' health, disturbances to the community, and deterioration of aesthetics (Assefa and Frostell 2007).

According to Neumayer (2003), this kind of division allows for the replacement of the resources and environment that society depends on for economic development. According to Giddings, Hopwood, and O'Brien (2002), strategy "b" is the most effective since it eliminates intersections and creates subsets by connecting all of the branches from a single centre.

His perspective is consistent with the worries and points of view brought forth by Rees (1995), who argued that society and the economy are interdependent. There would be no society and, consequently, no economy without the environment. According to McGregor (2003), the primary sustainability process should be the pressure that human activity places on finite resources as a result of supply and demand.

Through increased biodiversity, water efficiency, and energy efficiency, sustainable building has been able to achieve good building performance through the integration of green technologies. The selection of green technology is a hierarchical process that begins with the installation of energy-efficient measures to lower energy demand and concludes with the installation of a building monitoring system that permits precise data collection on end-user energy consumption and energy performance monitoring (Atici and Ulucan 2011).

3.2 Office Building Strategies on Retrofits

When choosing a retrofitting strategy, one must balance the benefits of energy retrofitting against the initial outlay required to implement the plan (Ma, et al. 2012). Jafari et al. (2016) state that there may be social, economic, or environmental benefits. For instance, they might lower air emissions or enhance occupant health and comfort. In the building construction industry, fund decisions are usually based on initial cost rather than life-cycle cost (LCC) (Arditi and Messiha 1999; Salem, et al. 2003). According to Syal et al. (2014), the perception of high upfront costs and a general lack of reliable information about the benefits of retrofits are factors that have led to a decrease in the adoption of energy retrofits.

A project's retrofit measure selection is a challenging optimization problem with many constraints. Research has employed either singular or multiple objective methods to determine the optimal retrofit strategies for a building, considering factors such as reducing life-cycle expenses, optimizing indoor air quality, enhancing thermal comfort, and reducing payback duration. To arrive at the best compromise, decision-makers must weigh energy-related, financial, legal, regulatory, and social factors. An extensive review of decision support resources for energy retrofitting projects is given by Nielsen et al. (2016).

3.3 Potential Investors of Energy Retrofits

Energy-related retrofits offer multiple benefits for already-existing office buildings. Investors gain from building retrofits right away, and they eventually pay for themselves. But the initial outlay, or start-up capital, is a barrier that will prevent building owners from improving their structures as much as they should or from narrowing the scope of the retrofit project to something that might not be sufficient (Moder 2013). This kind of issue does not occur when new construction is being done and the development of green buildings is being overlooked. However, the initial cost of energy retrofitting buildings may affect the possibility of long-term savings (Jafari and Valentin 2016).

Energy retrofit initiatives are available to building owners as well as investors. There are four primary investor categories in this study

- **Owner-occupant:** Anyone or occupant of a building with the title of that property in residential or commercial buildings of a retrofit project is termed the owner-occupant and is also an investor of the project.
- **Absent Owner:** Is referred to anyone who owns a property but does not live in it. This property held by an absent owner can range widely—from an office building or apartment to a large property such as an apartment building or 7 eleven stores. And their main aim would be to generate returns from their buildings.
- **Leaser:** Someone who occupies a building/property and is required to pay rent to the owner of the building. An occupant of a property who does not own but occupies it by paying rent. The leaser maybe is a renter in a residential apartment or a leader of a commercial office building.

- **External Stakeholder:** Energy efficiency policies and programs enable the implementation of energy retrofit projects to lower building operations' energy consumption. The Australian federal and state governments, local councils, and financial incentives can assist building owners in implementing these projects by lowering costs using public benefits funds, grants, loans, property-assessed clean energy financing, personal, corporate, property, and sales tax incentives, as well as assistance in reducing permitting fees. The Australian government's Modern Manufacturing Initiatives (MMI) program has recently provided up to $1.3 billion in funding for recycling and clean energy projects. Resources for funding incentives for energy efficiency in the US are available through the Department of Energy's Database of State Incentives for Renewables and Efficiency (DSIRE).

They are referred to as decision makers because, as the prospective investors have demonstrated, they are able to contribute the initial funding or deposit for energy retrofitting projects in buildings. The advantages to investors are considered when choosing energy-efficient project components. To maximize their benefits, investors could be encouraged to invest in energy efficiency when implementing specific retrofitting activities.

3.4 Retrofitting of Existing Buildings and Activities

According to Kats (2018), retrofitting is the process of fusing new and modern building features or technologies with older systems. Johnston and Gibson (2018) state that there are numerous types of retrofits, like power retrofits, that are intended to reduce greenhouse gas emissions and improve the energy efficiency of existing buildings (Ruckert 2018). However, Jagarajan et al. (2017) confirmed that it is a helpful tactic for improving the sustainability of office buildings. Lathan (2016), however, concluded that it was an important process that raised the bar for pre-existing office buildings while lowering embodied energy using sustainable methods.

Building materials and whole building retrofitting are two different approaches to building repair, though there isn't a commonly agreed definition, according to Giebeler et al. (2009). Table 8 provides a list of possible retrofitting operations and, where practical, acts as a guide when retrofitting existing buildings. The need for retrofitting measures is derived from (Barlow and Fiala 2007; Juan Gao and Wang 2010). Therefore, retrofitting existing buildings could improve energy and water efficiency, reduce waste, and improve building operations, all while significantly lowering greenhouse gas emissions caused primarily by existing building operations.

Table 2 illustrates how the building industry is one of the main sources of CO2 emissions, according to Liang et al. (2018). Moreover, industrialized nations utilize about 40% of the world's energy, according to Gao & Wang (2010). Table 3 shows that there are no set regulations or actions for retrofitting. Since retrofitting old office buildings depends on the specific circumstances of each building, there is no one universal standard to follow and each structure is unique. The revision of existing retrofitting actions from previous studies serves as a guide for future office building retrofits.

Targeting the improvement of building services, the building envelope, or the technical aspects of the building fit-out in the areas where technical advancements are required can be accomplished through refurbishing. Energy efficiency improvements could result from replacing old technology with newer models that perform better, or from aging and repair issues that lead to inefficiencies. Studies on the effectiveness of technical retrofits have concentrated on five areas: HVAC (Graham 2009; Lancashire 2004; McIntosh 2014; Nicol & McCartney 2000; Saidur, et al. 2012), lighting (Aste & Pero 2013; Harvey 2009; Nelson 2010; OEH 2012), IT (Davis 2008; Kamilaris, et al. 2014), and building fabric (Huang, et al. 2012, 2013; Saidur 2009).

3.0 Life Cycle Assessment

4.1 Building assessment with Lifecycle Costing and Life Cycle Assessment

Life Cycle Analysis Systems

This type of analysis employs a conditioned and well-balanced methodology. There are four stages to it, as figure 25 shows: goal and definition, life inventory, life cycle impact assessments, and improvement assessments. The approach permits comparisons between goods and objects that have the same functional quality, claim Zavadskas and Kaklauskas (1999). Additionally, it assesses various operating conditions in respect to sustainable structures without considering the implications for society and the economy.

Life cycle assessments, also known as LCAs, are the main tool used by the building industry to analyze the degree of environmental impacts and to quantify those impacts (Li 2006; Zabalza Bribián, Aranda Usón, and Scarpellini 2009). Life cycle assessment (LCA), according to Jeswani et al. (2010), is a technique used in the building industry to assess how a building affects different environmental parameters, including potential acidification, CO2 emissions, waste management, ozone depletion, soil pollution, energy efficiency, and global warming potential.
The physical life cycle of a building determines the assessment period, which can be anywhere between 40 and 50 years. Depending on the material used, the service life of building components can vary from 20 years to 60 years in energy-efficient office buildings. It can be difficult to develop an LCC and LCA framework because it involves handling environmental and economic measures at the same time. As a result, developing evaluation techniques that incorporate social, economic, and environmental factors can yield results for economic efficiency that are more accurate. A more accurate and comprehensive framework for assessing a building's performance can be obtained by combining LCC and LCA.
Financial support, capital costs, residual disposal, refurbishment and service operational replacements, and other costs are the main costs and benefits associated with Life Cycle Costing (LCC).
The costs and benefits of modifying a building to achieve a green standard can be calculated over the course of the building's life cycle. In particular, when cost considerations and green building principles are incorporated from the outset of the design process, excellent results can be obtained (Kubba 2010). As a result, the building evaluation procedure that follows can be applied.

- **For economic assessment approach:** Most investors/owners prefer this process because of profit concerns. The method used for this assessment is Life Cycle Costing (LCC). During real-life situations using LCC will provide stakeholders with necessary assistance economically during the process of decision-making.
- **For environmental assessment approach**: The process is required for environmental protection. The method used for this assessment is Life Cycle Assessment (LCA). In practice, the LCA is a useful tool for stakeholders in decision-making on environmental performance
- **For social assessment approach:** The process demands developing societal wealth. The method used for this assessment is a framework to establish value for the community that would embrace minor impacts on organizational and national employment and people's health.

The traditional Life Cycle Costing (LCC) framework, as per ISO 15686, focuses on economic benefits and neglects environmental and societal damage to buildings throughout their life cycle. This approach is criticized for its focus on profits, while ISO 14040 (2006) emphasizes an environmental approach, ignoring economic connections. Both methods have their limitations and processing methods.
Net Present Value (NPV) is the result of LCC calculations, which use discounts to convert future cost and benefit values into present-day monetary amounts for investments. This straightforward method compares potential outcomes to assist in decision-making. In practical terms, LCC is applied to various refurbishment costs to ascertain whether a parameter is more or less costly and provides better value. In general, expensive original components yield greater value when refurbished and repaired. Revenues are included in the capital budget through NPV, and LCC is normally applied in cost estimates during the calculation process.

4.2 Building Performance Assessment and Diagnostics

The energy efficiency and thermal comfort of office buildings are frequently compromised by malfunctions, degradation, and unforeseen faults that necessitate performance upgrades. Energy usage benchmarks for sustainable building retrofits are established through performance assessments and diagnostics. Through the identification of operational problems and possible opportunities for energy conservation, these assessments enable the design of more sustainable and effective buildings. This method contributes to increased comfort and energy efficiency in office buildings.
Energy performance in buildings is assessed through diagnostics and building performance assessments, which are essential. There are now three established approaches: computational, measurement, and performance based. Every project has a different strategy, and choosing the most economical one calls for support in making decisions as well as taking client needs and business expertise into account. Major office building retrofitting should be the main focus. Measurement-based techniques using in-situ measurement procedures, computational-based techniques utilizing energy audit data, and performance-based approaches

evaluating building utility bills should all be used.

4.3 Existing Building Quantification and Energy Conservation Benefits

To construct retrofit sustainability, energy consumption benefits must be measured and estimated. Energy simulation and modelling are employed to assess retrofit strategies. During refurbishments, energy simulation packages such as ESP-r, eQUEST, BPS, TRNSYS, HVACSIM, BLAST, and DOE-2 are utilized. These packages support energy performance of retrofit measures and thermodynamic simulation. According to Bojnec and Papler (2011), additional simulation models can also be used to estimate energy performance measures.

To analyse retrofit performance measures, black models, gray box models, and physical models are crucial because they offer various uncertainty prediction reliabilities. These models aid in obtaining accurate estimates for the selection of buildings undergoing refurbishment. Determining the energy efficiency or cost-effectiveness of retrofit options is aided by analyzing the financial situation.

The most popular energy-efficient measure for building retrofits is the Net Present Value (NPV), an optimal building energy assessment technique. Applying retrofit measures helps in decision support for optimized building design, ensuring successful retrofit performance measures.

4.4 Assessment of Risk in Retrofitting Office Buildings

It is critical to ascertain the risk's quantitative and qualitative value in relation to a given area or situation. The decision-maker will be able to make an informed decision by assessing the threat's magnitude, which is crucial for decision-making (Higgins, et al. 2008). Weather forecasts, energy use data, changes in energy consumption patterns, savings estimates, and many other unknowns make building retrofitting a complex topic. To guarantee that decision-makers have the skills and knowledge necessary to choose the best options for building renovation, risk assessments are crucial.

Physical, black box, and grey box models are essential for evaluating retrofit performance metrics since they offer varying levels of prediction reliability and allow for the use of trustworthy approximations when choosing which buildings to renovate. Retrofit alternatives' cost-effectiveness or energy efficiency is determined by analyzing economic scenarios; the most widely used energy-efficient metric is Net Present Value (NPV). Successful retrofit performance measures are ensured by the application of retrofit measures, which support optimized building design.

The difference between the energy measured prior to refurbishments and after the retrofitting activities will be determined to calculate the savings. Certain obstacles prevent the identification and quantification of energy changes through measurement and validation practices due to non-energy retrofit measure factors (Haralambopoulos, et al. 2003). There are four methods available for estimating and verifying energy savings:

- Option A deals with retrofit isolation as an important measurement parameter
- Option B deals with retrofit isolation for all measurement parameters
- Option C deals with the whole facility
- Option D deals with the calibration of simulation (Cappers and Goldman 2010).

For a building of energy savings, measurements and verification are popular and vastly used and are said to be an effective method that can be applied for reporting the amount of energy (Trotta D) when implementing retrofit measures for building retrofits used in measuring, computing, and reporting the energy saved by implementing Energy Efficiency Measures (EEM).

4.5 Summary

By presenting the current state of sustainable development, the literature review provides a contextual framework for the study. This justification explains why the decision support process for retrofitting must be included, as well as why it is important and why accessible assessment tools and methods must be categorized and assessed. By carefully considering and fully understanding the relevant information provided in section 1, research questions and gaps can be identified, and the goal of the study can be made even clearer. This explanation can also assist in establishing clear boundaries and points of view for future research.

5.0 Establishing The Framework For Research Methodology And Design

5.1 Research Ethical Consideration

According to Saunders et al. (2009) and McNeill and Chapman (2005), ethical considerations must be considered when conducting research on humans in order to prevent harm or risk to participants who have given their consent. The participant receives an information sheet with the option to withdraw from the study at any time during the investigation. Participant confidentiality and data security are 100% guaranteed. The Australian Code for the Responsible Conduct of Research (2007:1.3) further supported this, stating that to conduct human research, researchers involved must be held accountable and follow certain reasonable and responsible guidelines.

- They must carry it out with integrity and honesty.
- There should be regard and respect for human research participants, animals, and the environment.
- To conduct the research, there should be good accountability/stewardship of public resources used.
- It is important to acknowledge appropriately the role others played during the research.
- There should be responsible communication of research results.

Human research guidelines require that all human research is approved by the Human Research Ethics Committee before any research of such kind is conducted. To abide by this regulation on completion of confirmation of my candidature (COC), WSU Human Research Ethics Committee approved the research study to conduct the research as it is a low risk research.

5.2 Research Approach

This research methodology integrates various research design approaches and supports data collection and analysis procedures. Research approaches come in three varieties: mixed, qualitative, and quantitative. Because of this, both quantitative and qualitative approaches are more widely used. The growing popularity of mixed methods can be attributed to philosophers' preference for a combination of two approaches rather than hegemony. The primary focus of this study is on the discussion of two basic research approach types: qualitative and quantitative, as well as additional research designs utilized within each design approach. A research methodology that unifies various research design approaches forms the basis of this study.

5.3 Quantitative Research Approach

The quantitative research approach, which is defined as a research problem with a defined solution that depends on a numerical answer, or something related to numbers, is associated with the positivist/realist paradigm (Dainty 2008). Dawson (2002) and Rugg and Petre (2007) provide examples of this. Jonker and Pennink (2010:65) explain why it contributes to the theory's development as an operational concept model that can be used to measure variables and queries. Writing, evaluating, and interpreting study data are also considered forms of quantitative research, according to Creswell (2002).

5.4 Qualitative Research Approach

The qualitative research approach, according to Dawson (2002) and Rugg and Petre (2007), is centered on research questions that can be addressed in terms of actions, thoughts, emotions, viewpoints, declarations, and so on. Stated differently, industry and organizational structure are typically understood through first-hand experience from real-world scenarios (Jonker and Pennink 2010:77). This has to do with the constructivism and interpretation paradigm (Dainty 2008). Qualitative research employs an alternative methodology for data collection, analysis, and report writing than standard quantitative procedures, which are similarly open-ended but subject to modification based on specific circumstances.

5.5 Mixed Research Approach

A hybrid approach blends quantitative and qualitative methods, per (Cameron, Sankaran, and Scales 2015; Creswell 2008; Dainty 2008). On the other hand, Creswell (2008, 2013) suggested that employing the research methodology will be advantageous to all study participants. How aggressively hegemony chooses one over the other is determined by the attempt to reconcile constructivist and positivist research paradigms as well as the methodological heterogeneity of mixed methodologies (Dainty 2008; Raftery, McGeorge and Walters 1997).

The researcher can examine and analyze the data using a variety of methodologies because the data is typically gathered in both qualitative and quantitative formats. With the aid of numerical analysis, the conceptual model will be built upon the hallmark of quantitative studies. In light of these, the research challenge is viewed more broadly (Cameron, Sankaran, and Scales 2015; Creswell 2008). A mixed method approach will be employed in this study because it is based on a decision support model for retrofitting building projects (Marnell 2016).

6.0 Data Collection

6.1 Proposed Method of Data Collection and Analysis

Collection of Data

The survey sample will be drawn from the databases of several well-known industry associations, including Master Builders Australia, the Green Building Council of Australia, and the Certified Institute of Builders (CIOB) to guarantee a wide range of representation. The Victorian Energy Upgrades Program Essential Services Commission, the NSW Department of Environment, and NABERS can all be used to gather data for a study on energy retrofit of existing buildings. Given that most buildings must go through the NABERS database, it is the greatest choice for quantitative data. After ethics approval, the study intends to make phone calls, emails, and in-person visits to NABERS management and other state energy programs, such as Victoria and NSW, in order to obtain the necessary data.

6.2 Survey Questionnaire

To collect questionnaire responses from across Australia, participants will be chosen from major capital cities with robust commercial real estate markets. Sydney, Melbourne, Brisbane, Adelaide, Perth, and Canberra will be among them. The survey will be conducted using a questionnaire in Sydney, NSW, and Melbourne, Victoria. We will select participants who have the necessary experience in the building and construction industry. There will only be an online version of the survey. The relevant parties will be identified and notified through phone conversations, corporate websites, and coworkers in the building and construction industries.

All the online survey participants will also be asked as a favor to pass on the survey questionnaire to any of their colleagues that might be interested in contributing their opinion the way more people will be aware of the survey.

The participants in the questionnaire survey will be classified into four groups as follows.

- Stakeholders, owners’ investors, developers
- Strata managers
- Building managers, facility managers
- Building consultants and construction managers
- Project managers and supervisors

Based on existing literature, the questionnaire survey that is planned is expected to involve approximately 150 participants and employ a mixed method approach that combines quantitative and qualitative methods. The selected participants will be the most appropriate for the study given their areas of expertise (Leedy and Ormond 2001). The survey would take ten to fifteen minutes to complete. All of the information and data acquired will be pertinent to current theories, expertise, and real-world experience regarding retrofitting already-existing office buildings. It will also go through the steps and methods involved, how different parameters are used, how to choose which parameters to use and why, and what the future holds for remodeling already-existing office buildings. The subsequent information is required :

- Their perspective, views, thoughts, professional experiences, and knowledge concerning energy retrofit of existing buildings and their rationale or worry regarding which proven method is used, if there is any, in the decision-making process during retrofitting.
- If they have any knowledge or concern for the buildings' impact on the environment or ecological system.
- What kind of constraints do they encounter during the process?

- What are the reasons for selecting which parameters to be used?
- Any advantages or disadvantages with the decision in making the selection?

6.3 Semi-Structured Interviews/Focus Group Discussion

Project managers, supervisors, building managers, and stakeholders are the target audience for semi-structured interviews. This enables the participants to contribute to the discussion in ways other than the pre-planned questions, which are subsequently refined to eliminate superfluous details. According to Wilson (2013), because semi-structured interviews allow participants to raise new concerns about the topics at hand, they are effective in eliciting attitudes and options. The interview will mostly take place in Sydney, New South Wales, if necessary. The state is actively involved in retrofitting existing buildings under energy-saving schemes, making this possible. The participants' privacy and confidentiality may be preserved during the interview process, which may take place in their offices or at another suitable location.

Before the interview starts, the purpose of the interview will be made explicit and participants' consent will be recorded via email. Handwritten notes will be used in the process, and with participants' consent, they may occasionally be recorded. If participants are willing to engage in both surveys and interviews, it is possible to use them for both.

About 25 to 32 people are expected to attend the interview, which will mostly concentrate on one-on-one conversations with important staff members. Their knowledge of the value of applying a decision support system to evaluate various aspects of retrofitting current office buildings for ecological sustainability, as well as their theoretical and practical expertise, will be the only bases for the information and data that are gathered. Depending on participation, the interview will last between 25 and 40 minutes. The listed interview data that needs to be collected is listed below.

During retrofitting of existing buildings, the kind of strategic design used to implement the process about:

- Current strategy used for refurbishments
- The cost and benefits that would be realized during and after renovations.
- What are the disadvantages and advantages of renovating?
- What are the reasons for choosing parameters?
- What are the constraints in proceeding with the retrofit?

Regarding financial planning and any other specific data required to carry out the project, like life cycle analyses and evaluations and the impacts of their operations on social, economic, and environmental evaluations. Additionally, what they believe about using decision support mechanism concepts soon when renovating the current office buildings.

7.0 Case Studies

Case studies provide the best answers to research questions about "how" or "what" because the investigator has little to no control over the circumstances. However, in some real-world scenarios, the focus is on the contemporary phenomenon (Yin 2017). One of the objectives of the case studies is to cross-examine two or three selected existing buildings in Victoria and New South Wales. Based on their prior history of maintenance, repairs, and excessive energy use—all of which are considered unsustainable and non-green due to their noncompliance with legal or green standards—the buildings are chosen (Aziz 2000). The information gathered from the building under investigation will be examined and identified in order to ascertain the problems or reasons behind the building's poor energy performance as well as the areas that need to be changed in order to improve the building's energy performance and ratings.

Additional numbers can be added to the sampling numbers in case the data collection results indicate that the numbers are insufficient. When everything is finished, the data collected will be merged with information from surveys, questionnaires, literature reviews, and transcripts of interviews to produce a sustainable model that will help with the decision-making process when it comes to retrofitting existing office buildings. The model will offer solutions to the issues raised in the first section of this study topic.

Below is the required data information for the individual case to be collected and examined.

- Interested to know any major retrofitting activities recently undertaken within the last 5 years to improve the buildings energy performance to become a sustainable building.

- Kind of programs or processes used for effective energy improvements.
- Any financial or other constraints during the improvements
- The costs and savings, if any, during repairs
- Life expectancy and assessments with the upgrade
- Any advantages and disadvantages during the process
- Any contributions to be made regarding sustainable means in improving deciding during retrofitting soon.

Case Study of a Commercial office building.

Energy Simulation

To simulate the annual energy consumption for the case study of the commercial office building used as a commercial office car park as previously mentioned in section 1 above, an energy simulation software known as Energy-Plus tool was used. The energy-plus tool was used to analyse the energy use intensity, Life cycle costing, C02 emissions, whether data details for the location under consideration (DOE2 2013), annual energy consumption... The outcome of energy simulation will be used as the baseline for the case study annual energy consumption, annual energy use intensity, lifecycle cost analysis. Figure 6. shows the output of the case study building with respect to annual energy use, CO2 emission, Lifecyle costing, energy use intensity electricity and natural gas consumption of the building.

This shows how the simulated models were validated by means of experimental measurements that determined the building's energy performance. From the analyses it indicates that the base run for the annual energy use intensity (EUI) is 438 MJ/M2/year, and lifecycle for energy is 189,599,430 KW, and that of the design alternative (EUI) is 438MJ/M2/year, and lifecycle for energy is, 150,611,250 KW. The base run annual energy cost is, $393,194 and that for life cycle cost is $5,355,307, while the design alternative for annual energy cost is $325,690 and the lifecycle cost is $4,435,904 as shown in figure 1.

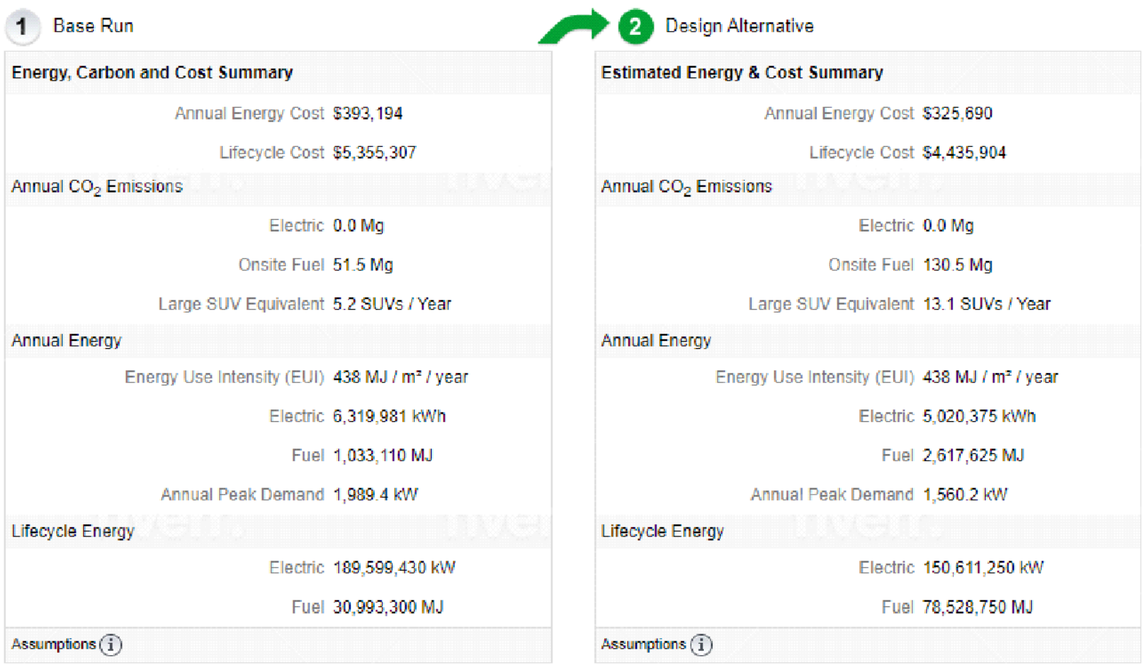


Fig 1. Energy, Carbon, And Cost Summary

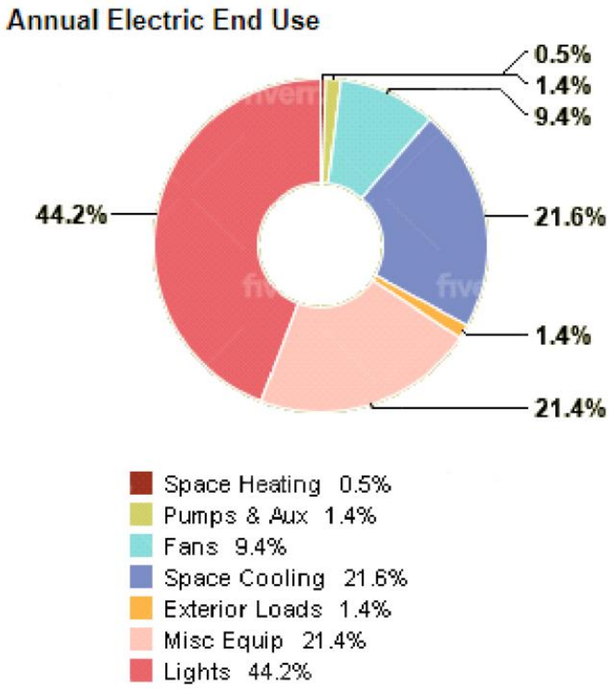


Fig 2. Annual Electric End Use

The "Annual Electric End Use" diagram illustrates the distribution of electricity consumption across various sectors, such as space heating, space cooling, light, fans and Exterior Load, over a one-year period.

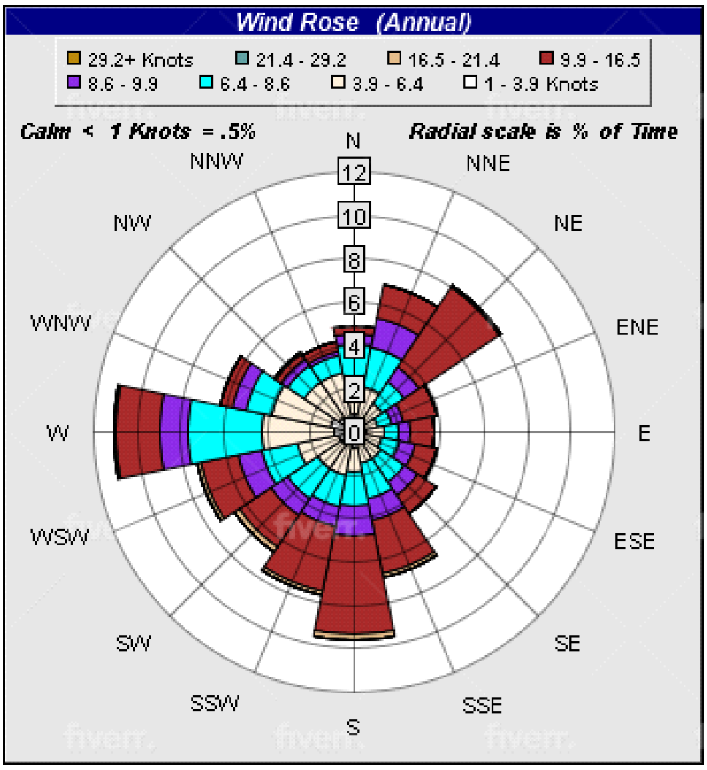


Fig 3. Wind Rose (Annual)

A "Wind Rose (Annual)" diagram illustrates the frequency and direction of wind over a year, with spokes representing wind directions and concentric circles indicating the frequency of winds from each direction.

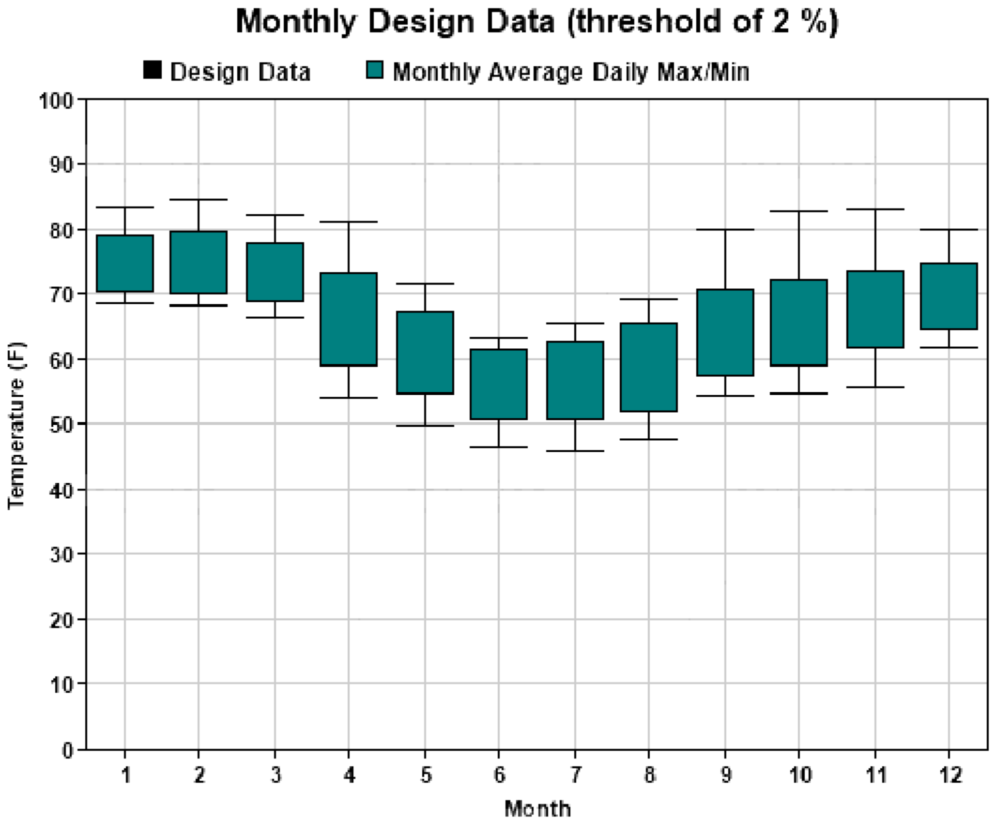


Fig 4. MONTHLY DESIGN DATA (Threshold Of 2%)

"MONTHLY DESIGN DATA (Threshold of 2%)" represents the critical design specifications that must be adhered to for 98% of the time each month. This threshold allows for a 2% margin of error, indicating that the design parameters may be exceeded or not met during only 2% of the month. The diagram typically includes metrics such as temperature, humidity, and other environmental or operational factors, ensuring the design remains functional and reliable within these constraints.

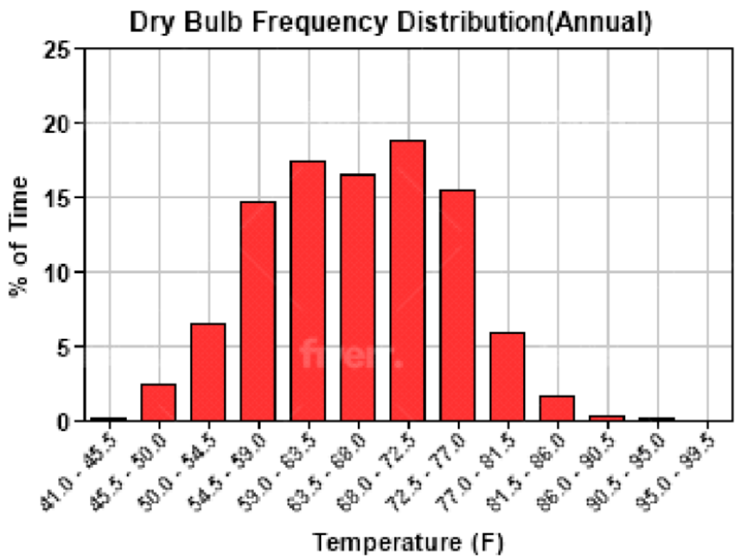


Fig 5. Dry Bulb Frequency Distribution (Annual)

"Dry Bulb Frequency Distribution (Annual)" is a diagram that illustrates the yearly distribution of dry bulb temperatures by showing how often different temperature ranges occur throughout the year. It provides a visual representation of the frequency and patterns of these temperatures, helping to understand climatic conditions and variations over an annual cycle.

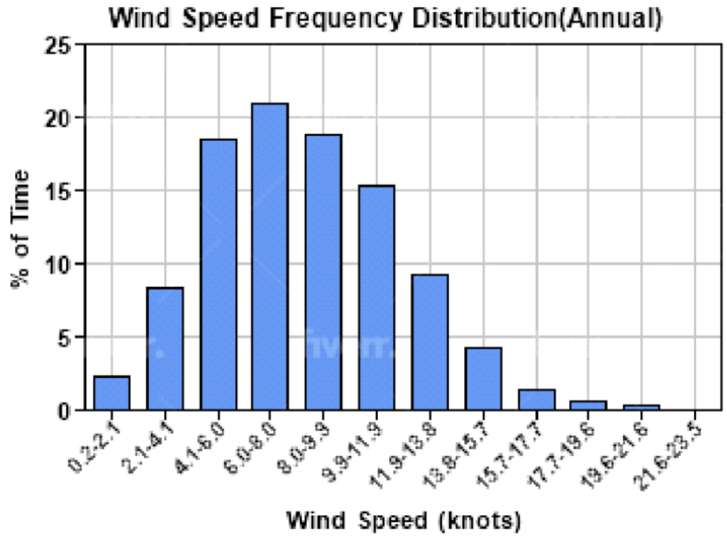
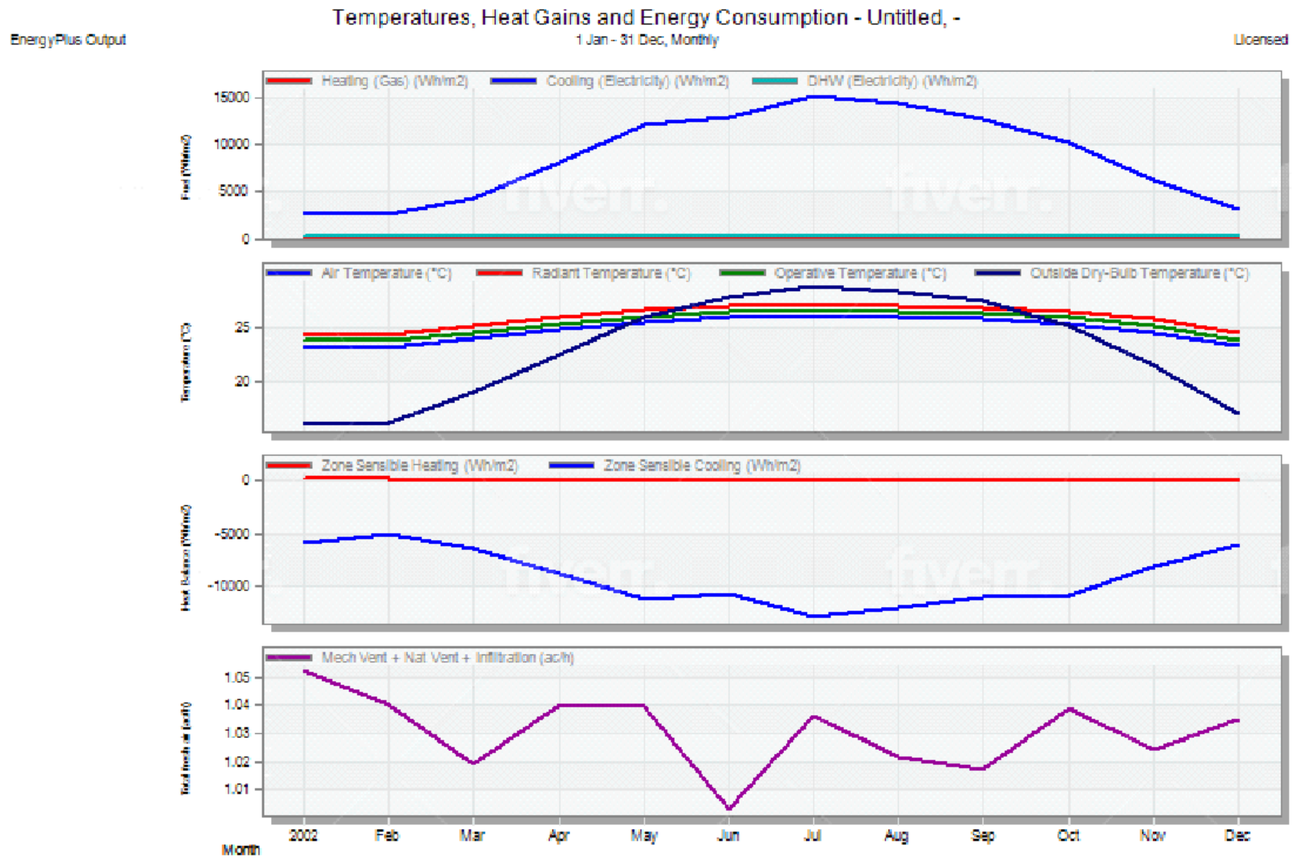


Fig 6. Wind Speed Frequency Distribution (Annual)

The diagram depicting "Wind Speed Frequency Distribution (Annual)" provides a comprehensive view of how often various wind speeds occur throughout the span of a year. It presents a detailed breakdown that allows for an understanding of the distribution pattern, highlighting the frequency with which different speeds of wind are observed over different periods within the year. This visual representation aids in discerning trends and patterns in wind behavior over time, crucial for various applications such as renewable energy planning, weather forecasting, and environmental monitoring.

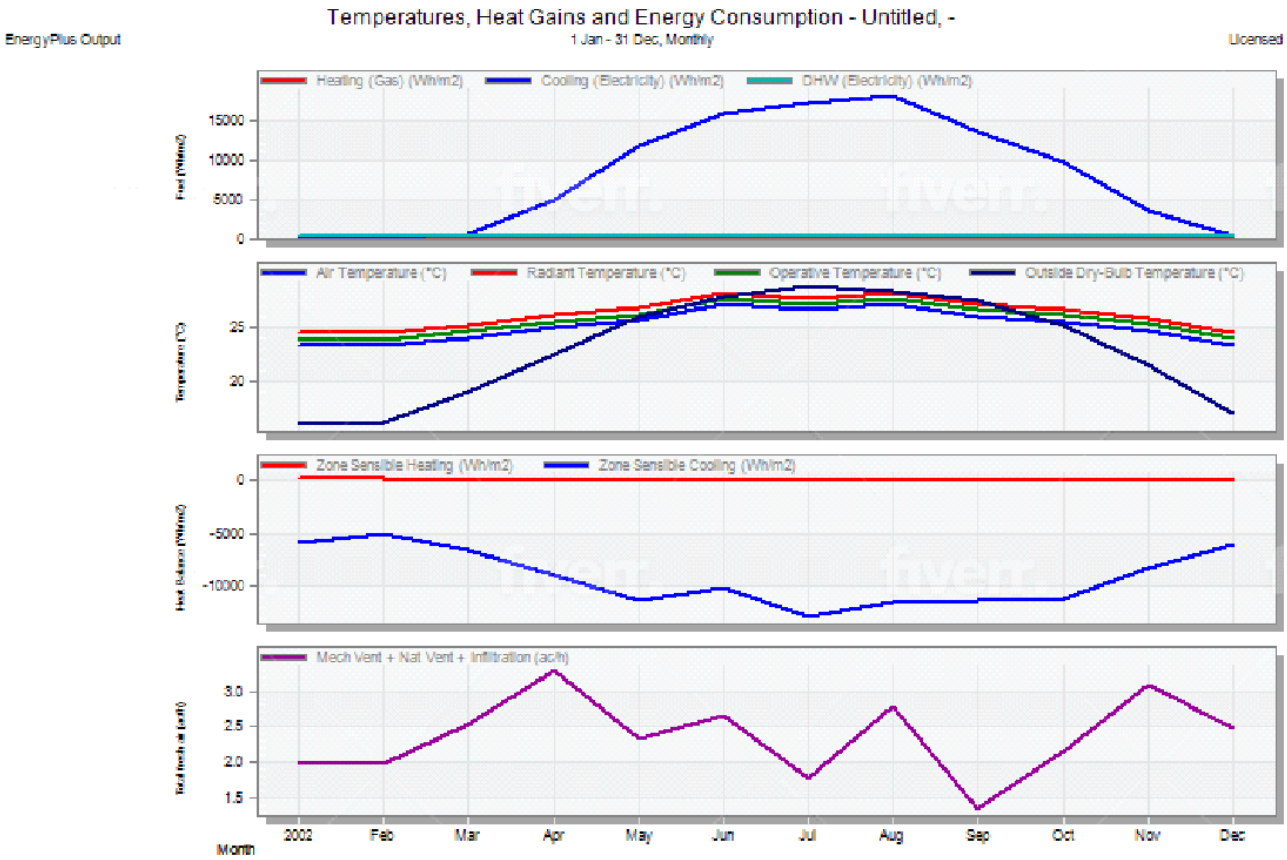
. The primary focus of these measures was on HVAC, lighting, and equipment. The outcomes showed that the retrofitting measures implemented had a 1.9-year payback period, 15% emissions reduction, 25% energy savings, and 23% cost savings.



	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating (Gas) (Wh/m2)	149.15	137.78	26.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	128.85
Cooling (Electricity) (Wh/m2)	2697.28	2534.90	4242.53	8160.19	12201.52	12964.74	15286.26	14397.30	12611.31	10239.83	6140.46	3177.92
DHW (Electricity) (Wh/m2)	345.60	300.52	315.55	330.58	345.60	300.52	345.60	330.58	315.55	345.60	315.55	330.58
Air Temperature (°C)	23.34	23.29	24.03	24.89	25.56	26.12	26.14	26.12	25.92	25.42	24.60	23.37
Radiant Temperature (°C)	24.52	24.41	25.16	26.07	26.71	27.08	27.22	27.13	26.97	26.62	25.82	24.49
Operative Temperature (°C)	23.93	23.85	24.60	25.48	26.14	26.60	26.68	26.63	26.45	26.02	25.21	23.93
Outside Dry-Bulb Temperature (°C)	16.12	16.30	19.03	22.59	26.07	27.92	28.85	28.44	27.54	25.32	21.53	17.11
Zone Sensible Heating (Wh/m2)	117.94	108.60	22.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	106.08
Zone Sensible Cooling (Wh/m2)	-5919.83	-5041.95	-6455.12	-8689.28	-11078.55	-10527.57	-12726.67	-11888.42	-10986.15	-10756.86	-8022.57	-6036.96
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.02	1.04	1.04	1.00	1.04	1.02	1.02	1.04	1.02	1.04

Fig 7. Temperatures, Heat Gain And Energy Consumption **(Before)**

The "Temperatures, Heat Gain, and Energy Consumption (BEFORE)" diagram illustrates how fluctuating outdoor temperatures affect indoor climate, leading to significant heat gain and increased energy consumption. The chart shows that as outdoor temperatures rise, heat gain peaks, causing the HVAC system to consume more energy to maintain stable indoor temperatures. This highlights the inefficiencies in the building's thermal management before any improvements or interventions.



Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating (Gas) (Wh/m2)	144.10	131.97	25.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	121.73
Cooling (Electricity) (Wh/m2)	5.34	40.60	550.28	4799.88	11669.04	15774.32	17130.63	18197.04	13460.84	9609.92	3586.37	230.17
DHW (Electricity) (Wh/m2)	345.60	300.52	315.55	330.58	345.60	300.52	345.60	330.58	315.55	345.60	315.55	330.58
Air Temperature (°C)	23.43	23.40	24.15	25.00	25.70	27.17	26.65	27.16	26.12	25.52	24.70	23.47
Radiant Temperature (°C)	24.63	24.53	25.31	26.24	26.92	28.21	27.80	28.22	27.26	26.80	25.98	24.62
Operative Temperature (°C)	24.03	23.97	24.73	25.62	26.31	27.69	27.23	27.69	26.69	26.16	25.34	24.05
Outside Dry-Bulb Temperature (°C)	16.12	16.30	19.03	22.59	26.07	27.92	28.85	28.44	27.54	25.32	21.53	17.11
Zone Sensible Heating (Wh/m2)	111.69	102.18	21.69	0.00	0.30	0.07	0.24	0.32	0.23	0.23	0.11	98.74
Zone Sensible Cooling (Wh/m2)	-5952.71	-5067.99	-6556.68	-8893.78	-11350.36	-10045.43	-12731.58	-11401.28	-11212.02	-11030.78	-8191.16	-6085.08
Mech Vent + Nat Vent + Infiltration (ac/h)	2.00	1.98	2.53	3.29	2.32	2.66	1.76	2.80	1.35	2.15	3.08	2.48

Fig 8. Temperatures, Heat Gain And Energy Consumption **(After)**

The diagram titled "Temperatures, Heat Gain, and Energy Consumption (AFTER)" illustrates the relationship between these factors in a building prior to improvements. It shows how internal temperatures fluctuate with external conditions and internal heat sources, highlighting significant heat gain from solar radiation, equipment, and occupancy during peak sunlight hours. Consequently, the HVAC system's energy consumption is high as it works to maintain comfortable internal temperatures, reflecting inefficient heat management.

Conclusion

The creation of an effective and strategic robust decision support model for the upkeep and improvement of commercial office buildings is a complex task that calls for an all-encompassing strategy that incorporates data collection, analysis, and the real-world application of theoretical insights gained from previous and current research. With a structured framework to help navigate the complexities of retrofitting projects, this model seeks to empower decision-makers, including building owners, engineers, architects, construction managers, facility managers, and consultants. The model combines practical knowledge with data-driven analytics to enable well-informed decision-making processes that are essential to attaining sustainable building outcomes.

This decision supports the model's strength lies in its capacity to make use of an abundance of empirical data regarding building performance, energy consumption trends, environmental effects, and economic factors. Stakeholders can evaluate office buildings in an efficient manner, pinpoint inefficiencies, and rank improvement strategies by utilizing these insights. Through scenario planning and predictive modeling made possible by the integration of sophisticated analytical tools and simulation techniques, stakeholders are provided with an outlook on the possible consequences of various retrofitting interventions.

Moreover, the model functions as a flexible instrument that conforms to the changing requirements and objectives of construction stakeholders. It encourages interdisciplinary communication and goal alignment amongst heterogeneous teams in order to attain sustainable building standards. The model improves reliability and applicability through iterative refinement and validation processes, guaranteeing that decisions are based on solid evidence and customized to particular environmental contexts and operational constraints.

When the decision support model is put into practice, it becomes an indispensable tool for building stakeholders, giving them the confidence to confidently navigate regulatory frameworks, financial considerations, and technological advancements. It facilitates the development of comprehensive plans for raising building efficiency, lessening environmental impact, and making the best use of resources throughout the building lifecycle. The model helps to achieve the more general objective of improving sustainability practices in the commercial real estate industry by endorsing a methodical approach to retrofitting.

The creation of a strong decision support model for retrofitting commercial office buildings is fraught with difficulties, but it also offers a chance for revolutionary change. This model not only fills in current research gaps but also establishes the foundation for future innovation and advancement in sustainable building practices by fusing data-driven insights with practical knowledge. As a result, it emphasizes the significance of ongoing investigation and improvement in this dynamic field, providing a rich environment for upcoming studies meant to mold the future of retrofitting commercial office buildings.

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