Investigation of building energy consumption and the effect of energy efficient interventions in a commercial building

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Declaration

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Name: Akhil Biji Jacob

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Terms of Reference

AC – Alternating Current
DC – Direct Current
HVAC – Heating Ventilation and Air Conditioning
Hz - Hertz
IEA- International Energy Association
kHz – kilo Hertz
kW – kilo Watt
kWh – kilo Watt hour
NZEB – Net Zero Energy Building
UCT – University of Cape Town
VRF – Variable Refrigerant Flow
VRV – Variable Refrigerant Volume

Acknowledgements

അനുഭവം ഗുരു

The above text translates from Malayalam to ‘experience is the teacher’. My experience at University of Cape Town was not an easy one and I could not have done it without the love and support of my family. I learnt a lot about myself and grew as an individual during this degree to a version of myself I never thought would be possible. Just knowing that I am not alone in whatever I face is an incredible feeling and I know that no matter what happens, I can depend on them to provide guidance. Thank you, Appa, thank you Amma, thank you, Joyan.

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Abstract

Globally there has been a transition into the use of more renewable energy sources and the development of new climate conscious infrastructure. A cost-effective and realistic path that can be taken in South Africa to fast track this transition is research on the ways in which existing infrastructure can be adapted to be more energy efficient. This research aimed to find interventions that would significantly lower the energy consumption in an existing commercial building, namely G. H. Menzies- a commonly used engineering building, on the upper campus of the University of Cape Town. Data was collected through a building audit, building plans from Properties and Services Department at UCT and current energy consumption readings (from June 2021 to July 2022) in the Menzies building presented in an excel sheet supplied by the Department of Sustainability at UCT. Based off this data, two interventions were proposed to lower consumption. These suggested interventions were an upgraded lighting system and the installation of PV systems. Simulations were run, using *DesignBuilder* and *EnergyPlus*, for each intervention method. Each intervention was first implemented separately, to identify individual impact, and then together to see overall impact. The results showed that the two chosen intervention methods together decreased the overall energy consumption in the G. H. Menzies building by up to 46%.

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1. Introduction

1.1 Background to the study

In a world where climate change is no longer a myth nor a conspiracy theory, the global reliance on non -renewable energy needs to decrease drastically before the planet reaches a point of no return. With concerns for climate change rising, in 2015, governments all over the world came together in what is known as the Paris Agreement. This was a global treaty that committed each country to being more climate conscious through increasing resilience and the capacity for climate change adaptation, coordinating financial resources with a strategy that led to reduced greenhouse gas emissions and development that was climate resilient, with the joint goal of keeping the average global temperature from rising by more than 2°C [1].

While newer developments and infrastructure are being designed with this treaty in mind (i.e., designed to be environmentally sustainable and produce less emissions), existing infrastructure does not align with the updated environmental policies and regulations. In South Africa the need for energy conscious infrastructure is specifically relevant both because of climate change, and the inability of existing energy production methods to meet the demands of the public. Therefore, it is important to find cost effective, minimally invasive interventions that lead to existing infrastructure decreasing their energy consumption. Applying these interventions to commercial buildings is the first step to creating a more energy conscious society.

Objectives of this study

1.1.1 Problems to be investigated

South Africa is one of the many countries who have made a commitment to reducing their carbon emissions. Although attempts have been made to secure sources of renewable energy (through wind farming, solar power etc), existing infrastructure continues to function without environmentally conscious adaptations. In addition, the primary supplier of electricity in South Africa, Eskom, cannot keep up with the country's demand for electricity. Planned supply interruptions are carried out when the demand for power exceeds the supply that is available. This is called load shedding. This makes it crucial to find ways to decrease the load for Eskom to meet. There are many possible solutions to these problems but the most immediate and cost-effective is to decrease energy consumption in existing infrastructure and increase renewable energy generation.

1.1.2 Purpose of the study

Research shows that buildings absorb 40% of all energy consumed worldwide, making them the biggest energy consumers overall. Buildings that are energy efficient significantly lower energy consumption and greenhouse gas emissions. This report aims to investigate the energy consumed by a chosen commercial building (G. H. Menzies on the University of Cape Town's upper campus) and then will propose two intervention methods that would decrease the levels of energy consumption.

1.2 Scope and Limitations

The report highlights the impact of the two chosen intervention methods on a particular building's energy consumption. The level of savings discovered in this report may not translate accurately to all buildings. This could be due to multiple factors such as, building size, structure, location, occupation density etc.

1.3 Plan of development

1. Introduction
   The reader will be introduced to the subject and any potential issues that may occur during the study

2. Literature review
   This section forms as the theoretical foundation for the study. It is a detailed summary of journal articles and online resources that are relevant to the study.

3. Methodology
   The characteristics of the chosen building will be discussed here. Followed by an analysis of the building's energy consumption. After which a few possible intervention methods will be proposed and then two of the most suitable proposed intervention methods will be applied to the building.

4. Simulations
   This section will detail how the calibration model was simulated to match the raw data. Then the model will be simulated, and the results of the calibration model will be compared to the raw data

5. Results
   This section will contain the results of the intervention methods, highlighting their individual impact and then their combined impact on the energy consumption of the chosen building.

6. Discussion
   This section will elaborate on the results and their relevance to the real world.

7. Conclusion
   This chapter summarises the literature review, the interventions discussed and their results and then concludes the report by briefly speaking to the significance of the research.

8. Recommendations
   In this section, further adjustments that can be made will be suggested.

9. References
   A list of references used throughout the entire study will be found here.

10. Appendices
    All extra documents, information and findings will be added to the appendix

2. Literature Review

2.1 Energy consumption in buildings

Buildings make up a large percentage of the energy used globally. Within this category (commercial sector vs. residential sector), energy consumption varies between buildings. As mentioned previously, steps have been taken to increase the use of non-renewable energy sources, specifically in relation to powering buildings. In the commercial sector, statistics show that buildings reduced their use of coal from 21% in 1980 to 3% in 2010 and their use of oil from 28% to 15%. However, they maintained their use of natural gas at about 23-25% and their use of renewable energy at only about 2%. Finally, there was a huge increased in the use of electricity and heat from 26% in 1980 to 44% in 2010.

In the residential sector, the use of coal decreased from 10% in 1980 to 4% in 2010; the use of oil decreased from 15% to 10%; the use of natural gas increased from 7% to 20%; and the use of renewables remained constant at about 41% to 42%. In contrast to the commercial sector, the use of electricity and heat in the residential sector increased only slightly from 16% in 1980 to 25% in 2010 [2]. It can be observed that in 2010, the energy consumption of buildings throughout the world was fairly divided among different final energy carriers (with natural gas predominating, renewables, electricity, and heat, and renewables being very little) [2].

Below is a pie chart of different forms of energy use in residential and commercial buildings.

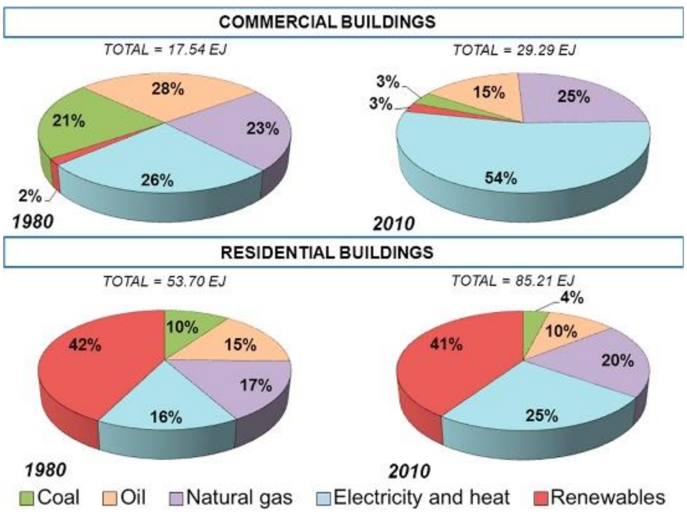

Figure 1: Energy consumption in residential and commercial buildings [1]

Both these sets of statistics, displayed by Figure 1 from the IEA (International Energy Association), show that while residential buildings have increased their energy consumption by almost 60%, they have managed to maintain similar percentages of the different sources of energy. Commercial buildings, on the other hand, have more than doubled their use of electricity and heat. It is evident that targeting commercial buildings would act as a significant first step in reducing overall energy consumption. It is an urgent matter to decrease our carbon footprint to help mitigate rising temperatures, rising sea levels, the change of precipitation patterns and ocean acidification [3]. Using renewable energy, energy efficient heating and cooling, monitoring standby losses, accurate appliance labelling, passive design, retrofitting and green buildings are just a few of the many interventions that can be applied to buildings to decrease the carbon footprint, that will be discussed in this literature review.

2.2 Building envelope

2.2.1 Windows and Shading

In summer when building interiors become extremely hot people frequently try to cool down by opening windows. This does not work as air outside will still be as hot as the air inside. In actuality, well installed windows and superior insulation make it easiest to keep the heat out. External horizontal shading, such as overhangs and louvres, are quite effective in the summer during the middle of the day because of how high the sun is. Windows that face east and west are more challenging to cover as the sun is lower during winter, which would require the overhangs to be much more extended. External shutters, such as those that are frequently seen on antique houses in France and Italy, are therefore preferred [4].

2.2.2 Paints and Glazes

It is normal practice to paint roofs with specialized pigments that are intended to reflect solar energy in both the visible and infrared spectrums. These can lower surface temperatures by more than 10°C, compared to traditional paint [4]. High performance solar glazing on windows have "spectrally selective" coatings — which means they keep the heat of the sun outside but let daylight in—also help [4]. Additionally, there is thermochromic glazing, which gets darker in the heat, and photochromic glazing, which alters transparency based on the brightness of the light (like certain sunglasses). There are even thermochromic paints that are being created, which will reflect heat and light in the heat and absorb them in the cold [4].

2.3 Building HVAC

2.3.1 Efficient heating

Heating large spaces can be extremely challenging. They not only need more energy to be produced, but also require that the heat it generates be dispersed evenly over a greater surface, which isn't always simple to execute [5]. Radiant heating and warm air heating are the two main methods for heating warehouses. For tall open buildings, using warm air heating—of which there are various types—is typically the most effective choice, as will be detailed below [5].

2.3.2 Warm Air Heating

A warm air heater does exactly what its name implies: it supplies warm air to the room, which in turn warms the occupants. This is accomplished by forcing air across a heat exchanger to raise its temperature. A fan then moves the heated air throughout the room. To maintain constant temperatures, the chosen heating system must make sure that the warmed air is spread evenly throughout the space [5]. Warm air heaters have a variety of options for heat sources. These include an internal gas or oil burner that powers the heater (direct-fired), hot water that is piped to the heater from a boiler or other central heating plant (indirect-fired), or an electric element [5].

Condensing versions of modern direct-fired warm air heaters are now available; they function similarly to condensing boilers and offer extremely high energy efficiency [5]. Warm air heaters can stand on the floor, be fixed on a wall, or be suspended from the roof. It is crucial to be aware that floor-standing versions will take up some floor space that could be put to better use for other things. However, because of their location, upkeep is simpler [5].

There won't be much temperature variance from one location to another thanks to a well-designed warm air heating system that distributes heat evenly throughout the room. The arrangement of the warm air heaters is crucial in doing this because it allows the warmed air to circulate easily throughout the area, preventing "cold patches" from forming [5].

2.3.3 *Radiant Heating*

Radiant heating is often provided by suspended radiant tubes or, less frequently, by wall - or ceiling - mounted radiant plaque heaters. Infrared radiation, which is emitted by heated surfaces in all types of radiant heating, heats people and other objects. The air that is heated by radiant heat is not warmed [5]. People must be in "direct line of sight" to be warmed by radiant heating, which is one of its drawbacks. This may be challenging to do in a building with tall structures since they will effectively "shade" individuals from the heat source. However, if there aren't any such towering structures, radiant heating could be appropriate. Additionally, it could be the ideal choice for locations that are constantly exposed to outdoor air [5].

2.3.4 *Efficient cooling*

More people turn on the air conditioning when the temperature rises. The usage of air conditioners is increasing globally. By 2050, it's expected that two thirds of all houses will have one, and the amount of energy needed to cool buildings would triple. Unfortunately, all that increased demand will result in greater greenhouse gas emissions, which contribute to global warming and, therefore, hotter summers, unless the energy is produced from renewable sources. It's a never-ending cycle. However, buildings may be designed to keep the heat out without adding to global warming [4].

2.3.5 *Water Evaporation*

Cooler air is forced downward when water evaporates after absorbing heat. This common occurrence prompted the creation of cooling systems, which employ water and natural airflow to lower indoor temperatures [4]. Sprayers, atomizing nozzles (to produce a mist), wet pads, or porous materials, such as ceramic evaporators filled with water, are some of the methods used to evaporate water [4]. Any structure that creates a channel where hot air and water vapour may ascend while cold air sinks can be used to evaporate water, including towers, wind catchers, and double-skinned walls [4]. When the weather is sufficiently dry, and the system is well regulated, such systems may be quite successful; temperatures as low as 14°C to 16°C have been recorded in various buildings [4].

2.4 Renewable Energy

The energy consumed for heating, cooling, lighting, cooking, appliances, and providing hot water is referred to as a building's operational energy. Nearly 300 net zero or nearly net zero energy buildings (NZEB), including both residential and commercial structures, have been built across the world. It was discovered that roughly one-third of these buildings used 60% less energy than nearby conventional buildings [6]. A building is more likely to reach net-zero energy usage if it has a large enough roof (for installing PV arrays and wind turbines) and site area (for drilling geothermal wells and erecting methane digesters). As a result of the high occupant density and restricted urban land space, NZEBs are more challenging to construct in urban locations [6].

2.4.1 Solar Energy

Buildings primarily use three different forms of solar energy technology: solar PV, solar thermal, and photovoltaic-thermal (PV-T) technology. The characteristics of solar irradiation, the size of the building roof, the number of occupants, and the ownership of the property all have an impact on the applications of solar energy technology in buildings [6]. Before using solar energy in buildings, decision-makers must carefully consider these factors. Additionally, because buildings last a very long time, it is important to consider how readily available solar energy will be throughout building operations in the coming decades to fully comprehend the energy, environmental, and financial advantages of this technology [6]. The resource potential of solar energy may be impacted by the effects of climate change brought on by rising levels of greenhouse gases (GHGs) in the atmosphere on atmospheric water vapour concentration, cloud cover, rainfall, and turbidity. Additionally, the declining air quality might sharply reduce solar irradiation [6].

2.4.2 Solar Photovoltaics

Solar panels are the main component of the solar PV system that absorbs and transform sunlight into power. To change the electrical production from direct current to alternating current, a solar inverter is installed [6]. To build up a functioning system, other electrical accessories, typically containing wiring and switches, a battery bank, and a mounting system, are also required [6]. At the heart of PV technology is the solar cell. Solar cells might be categorized into three generations as a result of the development of photoelectric materials [6]. Crystalline silicon PV, encompassing monocrystalline silicon (mono-Si) and polycrystalline silicon, is referred to as the first-generation solar cell (poly-Si). Amorphous silicon (a-Si), copper indium gallium selenium (CIGS), cadmium telluride (CdTe), dye-sensitized (DSSC), and organic solar cells are among the main thin-film materials used in second-generation solar cells. Due to their low economic cost and high conversion efficiency—which may reach as high as 23.3% and 22.1%, respectively—CIGS and CdTe are already commonplace products on the market. The third-generation PV cells have not yet been used commercially and are currently only conceptual products, like perovskite solar cells [6].

PV technology installations for buildings are often made on their rooftops. The bulk of these systems is made up of solar cells that are installed using racking gear off the surfaces of roofs [6]. Building-integrated photovoltaics (BIPV), a new market category for solar energy, calls for the deployment of PV materials in various building envelope components, such as the roof, skylights, or facades, to generate power. The energy payback period GHG emissions of technologies are typically used to measure the efficiency of implementing PV technology in buildings [6].

2.4.3 Solar Thermal

Solar thermal systems utilise energy from the sun to heat buildings in a variety of ways, most often domestic hot water. The provision of hot water requires a significant amount of energy, and the rising demand for hot water in buildings is a significant contributor to a nation's energy consumption, particularly in emerging economies where rapid urbanization and steadily rising living standards are occurring and will continue to occur [6]. For instance, in China, the energy required to heat urban residential hot water climbed from 1.6 million metric tons of coal equivalent (MTCE) in 1996 to 14.5 million MTCE in 2011, almost 10% of the nation's overall energy used to operate buildings; In comparison to the energy used for water delivery and treatment, water heating uses more energy in the United States [6]. To lessen their reliance on non-renewable energy sources, buildings might employ solar thermal technology to pre-heat their fresh water to the minimum temperature of 40°C to 65°C. A solar collector, pipes, and storage tank are the minimum components of a building's solar thermal system. Additional parts, such as a controller, pumps, and valves, are typically included as well. Three types of collectors are frequently used for lower-temperature (up to 100°C) heat provision: evacuated tube collectors, flat plate collectors, and unglazed absorbers [6].

2.4.4 Wind Turbines

Building owners and architects are considering mounting or integrating wind turbines inside buildings to capture the energy of the wind to advance the transformation of our built environment in a more sustainable direction. Micro wind turbines are often placed due to space constraints and the surrounding region of the construction site [6]. The nacelle and rotor are parts of the technology used in wind power. The rotor contains the components of the turbine that rotate in the wind, including the hub and blades, and for pitch-regulated wind turbines, the blade pitch mechanisms, and bearings. The nacelle houses all the internal parts of the turbine, primarily including the gearbox, generator, controller, and yaw drive [6].

Not all wind turbines have gearboxes; others can have a distinct "direct drive" generator type. The rotor is where wind energy is converted to mechanical energy, which rotates the wind turbine's main shaft. The hub is fastened to the blade root [6].

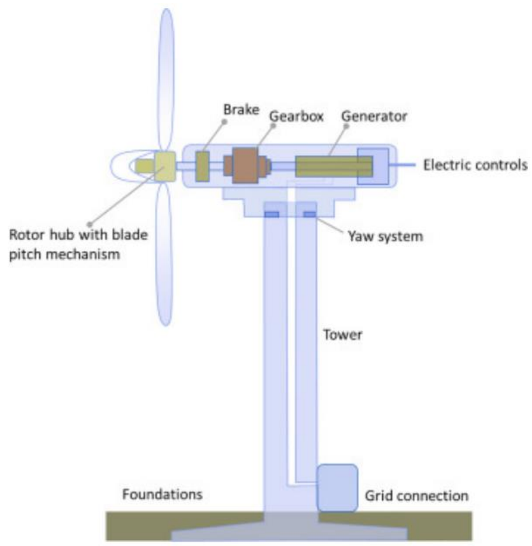

Figure 2: Components of a wind turbine [6].

2.5 Additional design techniques

2.5.1 Passive Design

One of the core concepts of passive design is solar gain. Since the sun's energy may supply most of the light and heat required in a Passive House, the passive design uses it to create a comfortable interior atmosphere [7].

A crucial idea in maximizing solar gain is orientation. The sun's path is from East to West, angling towards North in the Southern Hemisphere. A passive home should be oriented so that its long facade faces North to maximize solar gains. Minimal glazing should be used on the North-facing facade [7].

The layout should be long and thin and rectangular in shape so that the sun may shine deeply into the home and provide energy. The living room, kitchen, and other frequently used rooms should be placed on the North side of the floor plan for comfort, while the bathrooms and other rooms used less frequently, should be placed on the South side [7]. We now have a basic grasp of how to position a passive home to make use of the sun's energy; we need to understand the sun's trajectory during the day and the impact it may have on how well a passive house performs [7].

In the illustration below, we can see how a passive home can employ an overhang to reduce overheating by preventing the entry of the hot afternoon sun.

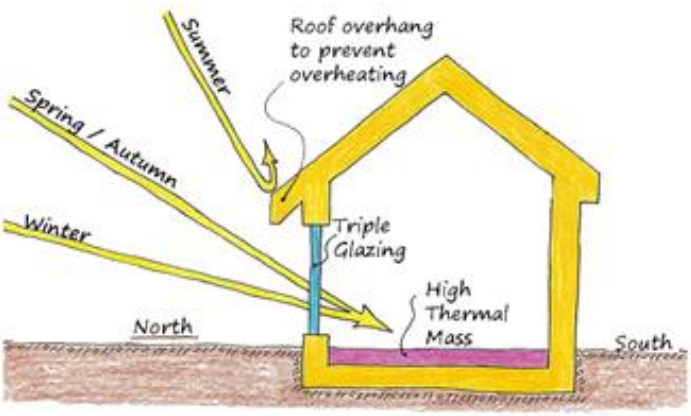

Figure 5: Suns trajectory and how light enters a building during summer and winter [7]

2.5.2 Retrofitting

Most buildings that will exist in 2030 and even in 2050 in certain countries already exist now, therefore considerable effort will need to be focused on existing structures to achieve significant reductions in the overall energy usage by buildings. Even long-lasting structures need substantial renovations from time to time, and between now and 2050, at least one such restoration will be necessary. During these renovations, significant energy consumption reductions of between 50% and 75% can be made [8].

Upgrades to the thermal envelope, replacement of heating and cooling equipment, reconfiguration of HVAC systems, implementation of better control systems, lighting improvements, and measures to reduce the use of hot water are just a few of the actions that can be taken to reduce energy consumption in existing commercial buildings [8].

The amount of money that may be saved by taking various actions relies on the building's specific pre-existing qualities, climate, internal heat loads, and occupancy pattern. However, worldwide retrofits of commercial buildings have resulted in significant energy consumption reductions (50–70% or more) [8].

It is important to note that complete building retrofits are typically carried out for a variety of reasons in addition to lowering energy expenses [8]. By replacing existing curtain walls or improving existing insulation and windows, existing buildings have a tremendous potential to reduce their energy usage. If significant reductions in heating and cooling energy usage are to be accomplished, upgrading present glazing systems and curtain walls will be a crucial future activity given the current craze for creating practically all-glass structures without even adopting high-performance windows [8].

Complete curtain wall replacements on high-rise office buildings appear to not present any significant technical challenges based on the recent replacement of the curtain walls on the 24-story 1952 Unilever building in Manhattan. Construction of a second glass façade over the first one, forming a double-skin façade, is one option for brick or cement facades [8]. This creates the potential for passive ventilation and lowers cooling loads through the supply of movable exterior shade devices. In Europe, this has frequently occurred. The Telus corporate offices in Vancouver serves as an example of a second façade built atop the first façade in North America. In this instance, adding a second façade to the structure was done so that it would be more earthquake-resistant [8]. Another option for protecting existing facades that are deteriorating due to moisture issues brought on by flaws in the original construction is to build a second façade [9].

2.5.3 *Green buildings*

Landlords in South Africa are looking for advice and tools to enable them to capitalize on the advantages of well-designed, well-built properties in tandem with rising power prices and expanding environmental consciousness [10]. Tenants are also seeking more "green" space to benefit from the healthier and more conducive interior conditions that green buildings provide. Improved quality of life, more staff productivity and retention, better asset performance, decreased vulnerability to regulatory changes, lower operating costs, reputational enhancement, and compliance with stricter corporate reporting standards are just a few advantages of green buildings [10].

According to the Green Building Council of South Africa, some of the advantages associated with green buildings will help renters, while others will benefit landlords [10]. There will also be some benefits provided. To their mutual advantage, however, all are interconnected and rely on the intention and behaviour of both parties, as well as those of their agents, contractors, and workers. This delicate balance is explained in the Green Lease Toolkit, which also introduces the idea of "spilt incentives" between owners and tenants [10].

2.6 Appliances

2.6.1 Standby losses

It is estimated that 10% of a building's energy bills are due to standby losses. A common misconception is that devices do not use electricity when turned off. TVs and stereos are the common culprits of high standby losses as they are remote-controlled and must be ready to turn on as soon as they receive the signal from the remote [11].

A handy little gadget that shows how much energy each electrical appliance is consuming is the Kill-a-Watt energy monitor. To receive the reading, plug it into the wall and then the appliance into the monitor. The device's purpose is to calculate how much using that electrical appliance will cost if it were left plugged in (on or off). This tool will truly quantify the amount of money wasted on each device. It also provides information as to how much CO2 is produced [11]. A controllable surge protector that enables you to decide whether the TV's accessories are receiving power. Simply plug your TV into the control outlet, and if it is off, it turns off standby power to the other outlets to prevent them from using energy even while the TV is off. It activates standby power if it is on. This could also function on computers [11].

2.6.2 Appliance labelling

It can be challenging for customers to stay informed about which appliances, brands, and models are more energy efficient given the rapid rate of technological advancement. By clearly displaying educational and user-friendly labels on appliances, the Energy Efficiency Standards and Labelling Programme in South Africa, strives to enlighten consumers and help them visualize energy use so they can make decisions with ease. [12]. Due to our nation's substantial reliance on coal to produce energy, South Africa ranks as the 14th greatest worldwide emitter of greenhouse gases, with considerable CO_2 emissions. Washer-dryer sets, tumble dryers, washing machines, electric ovens, fridge-freezer sets, freezers, electric water heaters (geysers), refrigerators, dishwashers, air conditioners, TVs, and audio-visual equipment are among the appliances that must display and use the South African Energy Efficiency Label. Soon, several other devices will be added to this initial collection of appliances, enhancing our capacity to mitigate the adverse energy and environmental effects mentioned above [12]. Below is an image of what an appliance label looks like.

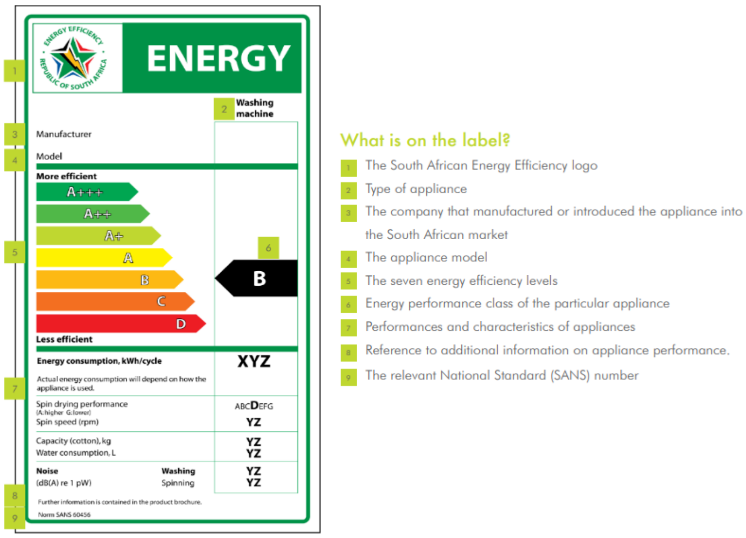

Figure 3: Appliance Label

2.7 Payback period

Having reviewed some of the possible energy saving interventions that can be applied to commercial building, it is important to determine their viability. The payback period is a tool that assists in this regard. The payback period is the amount of time that it will take for the cash inflows produced by an investment to recoup its initial outlay. It is among the easiest methods for valuing investments. The payback period is a sign of project risk because it only considers initial inflows and ignores cash flows after the initial investment is recovered [13]. This is because cash flow estimates are quite accurate for periods soon and relatively inaccurate in the distant future due to economic and operational uncertainties. When projects are evaluated with payback time, those with bigger cash inflows in the initial periods often score higher than those with larger cash inflows in the later periods [13].

$$Payback\ Period = \frac{Initial\ investment}{Net\ cash\ flow\ per\ period}$$

The risk of a project increases with its payback duration. The investment should be made in the project with the shortest payback period if two mutually incompatible projects with equivalent returns are available. A choice based on payback duration is somewhat difficult when selecting whether to invest in a project or when comparing projects with varying yields [13]. The management's willingness to take on risk determines whether to accept or reject a project depending on its payback duration. Depending on whether management is risk-averse or risk-taking, it will decide on an acceptable payback period for each investment. Since more risk equates to higher returns, various projects may have different targets, with lucrative ventures being willing to endure longer payback periods [13].

Table 1: Advantages and disadvantages of payback time [12]

Advantages	Disadvantages
Calculating the payback period is relatively straightforward.	A significant disadvantage of the payback period is that it disregards the time worth of money, which can result in poor judgments. Discounted repayment time technique is a payback method variant that tries to fix this flaw.
It may serve as a gauge for project risk. The payback period reveals how certain project cash inflows are, which is important because later-occurring cash flows are thought to be more unpredictable.	The cash flows that take place beyond the payback period are not included. This implies that a project with excellent cash flow that is past its payback time may be overlooked.
It offers a decent assessment of initiatives that would repay money early for businesses with liquidity issues.	

3. Methodology

3.1 Introduction

The objective of this research is to determine how well energy-efficient measures may lower a commercial building's energy usage. This section will go through the energy usage of the building, investigate the systems and practices in place that led to the consumption levels obtained and look at two distinct strategies for potentially reducing energy usage.

3.2 Data collection

3.2.1 Building information

G.H. Menzies is a building on the upper campus of the University of Cape Town. It is primarily used for the electrical engineering department and its students. Other departments and faculties also use the venues and facilities, but it is considered the 'home of electrical engineering'. It is a seven-storey building; however, the second floor is not accessible by the public and is only half a floor in height because it houses many ducts for the building. The building plans were sourced from the Properties and Services department and will be used to model the building accurately.

The floor areas are as follows:

- Floor 1: 1625.37 m^2
- Floor 2: 2139.36 m^2 (unoccupied)
- Floor 3: 2111.89 m^2
- Floor 4: 1920.36 m^2
- Floor 5: 1884.92 m^2
- Floor 6: 1444.09 m^2
- Floor 7: 649.97 m^2

Giving a total floor area of 13 696,85 m^2 but 11557.49 m^2 of occupiable space.

G.H Menzies is a combination of 2 buildings rectangular in shape, both are in an east-west orientation meaning majority of its face is exposed to morning and afternoon sun. However, the building is somewhat sandwiched between other buildings. The Electromechanical building (E.M. Building) is a three-storey building on the east side of the G.H. Menzies building, meaning that the chosen building's bottom 3 floors do not receive direct sunlight until around 10:00am – 11:00am. Additionally, there is a taller building on the west side of the G.H Menzies building called the Snape Building, resulting in the lower floors being in the shade after mid-afternoon. Depending on the time of year and the position of the sun, the building does still get direct sunlight after mid-afternoon, but not for long as the University of Cape Town's Upper campus is situated at the foot of a mountain range, so the sun goes over the mountain resulting in the entire campus being in the shade well before sunset.

Due to the G.H. Menzies building's unique location it only receives approximately 6-7 hours of direct sunlight. This results in the lower half of the building taking time to heat up naturally in the morning and begin the cool down in the afternoon well before some of the other buildings in the area. The building has single glazing which lets unfiltered light enter the building, thus heating the building quicker and providing more natural light.

There are four main entrances to the building, two on the first floor and two on the third floor. Usually, three of the four entrances have their doors always open for easy access into and out of the building. There is a fifth method of entry to G.H. Menzies on the fifth floor but that is an access corridor from the Snape building and there are no doors that lead to outside nearby.

3.2.1 Building occupancy

Since the building chosen is part of an academic institution, its occupancy levels are not evenly distributed throughout the year. Students tend to fill up the spaces and use the facilities during the months of the academic calendar where teaching takes place, i.e., March, April, May, August, September, and October. June and November are usually when examinations are held which means the buildings occupancy is less as there are no lectures taking place thus not requiring all students to be on campus. However, there are many students who work on campus during all hours of the day and use the study spaces in the building. This means that the occupancy levels will be around 50% - 60% during the examination period. This leaves July, December, January, and February as the remaining months of the year. During these months, occupancy would be at its lowest as it is not during the academic calendar and only a limited number of staff members will be using the buildings facilities.

Below is a graphical representation of the average monthly occupancy.

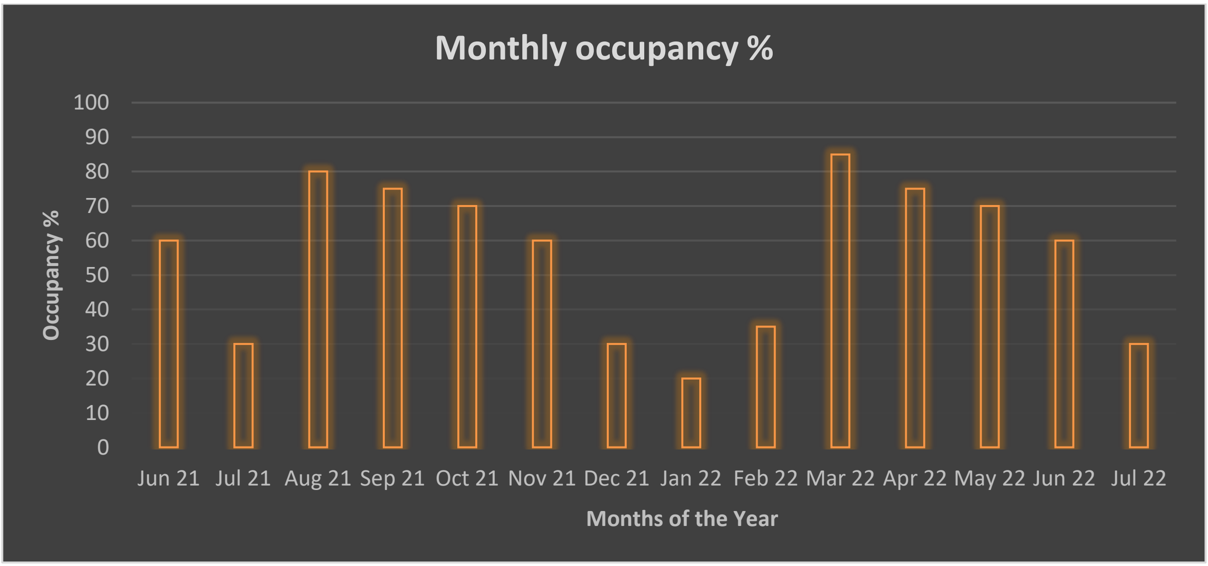

Figure 4: Monthly occupancy of G.H. Menzies

3.2.1 Building audit

A building audit was necessary as it revealed the systems in place and the primary consumption drivers. The main focus of the building audit was to collect data that will be used when initially simulating the building. A member from the university's maintenance team was called as a guide for the building audit.

The building has approximately 250 fluorescent lightbulbs for floors 1 through to 6, excluding floor 2 as the second floor is used to house the ducting system for the building and is only accessible to maintenance personal. The 7th floor is smaller but still has approximately 150 fluorescent light bulbs.
Of the approximately 1 400 light bulbs, there were a combination of OSRAM G13 58W, OSRAM G13 36W, Phillips G13 TL-D 58W and Philips G13 TL-D 36W fluorescent tubes.

A major part of the building audit was detailing the type of HVAC system in place in G. H. Menzies. The building has 14 split units spread across the building used for the smaller rooms and uses the Daiken VRV HVAC system, which is just the trademark name and is equivalent to a VRF HVAC system that other companies use, for the larger spaces. VRV is a system that modifies the refrigerant volume in a system to precisely meet the demands of a building. A system just has to use a minimal amount of energy to maintain fixed temperatures and make sure that it turns off on its own when no one is present in a room. Long term energy savings and a decrease in carbon emissions are what make this novel method more sustainable for end users [14]. There is a chiller on the bottom floor that works with the cooling tower on the roof to regulate the inside temperature of the building. The HVAC systems were noted to be one of the best systems and one of the more popular systems used in commercial buildings. It has been maintained properly and working well to keep the occupants in G.H. Menzies comfortable.

3.3 Analysis of building energy consumption

3.3.1 Monthly consumption

The university's director of environmental sustainability provided the data necessary to conduct this research. From the tables and graphs below, the monthly energy consumption data of the G.H. Menzies building can be analysed

Below is a table showing the energy consumption of G.H. Menzies for 13 months (June 2021 – July 2022)

Table 2: Monthly energy consumption of G.H. Menzies Building

Month	Energy Consumed (kWh)
Jun 21	123 808
Jul 22	122 306
Aug 21	119 569
Sep 21	123 353
Oct 21	122 092
Nov 21	108 836
Dec 21	106 133
Jan 22	119 331
Feb 22	117 432
Mar 22	133 379
Apr 22	125 855
May 22	131 673
Jun 22	120 360
Jul 22	116 318

Below is a graphical representation of the information in Table 2

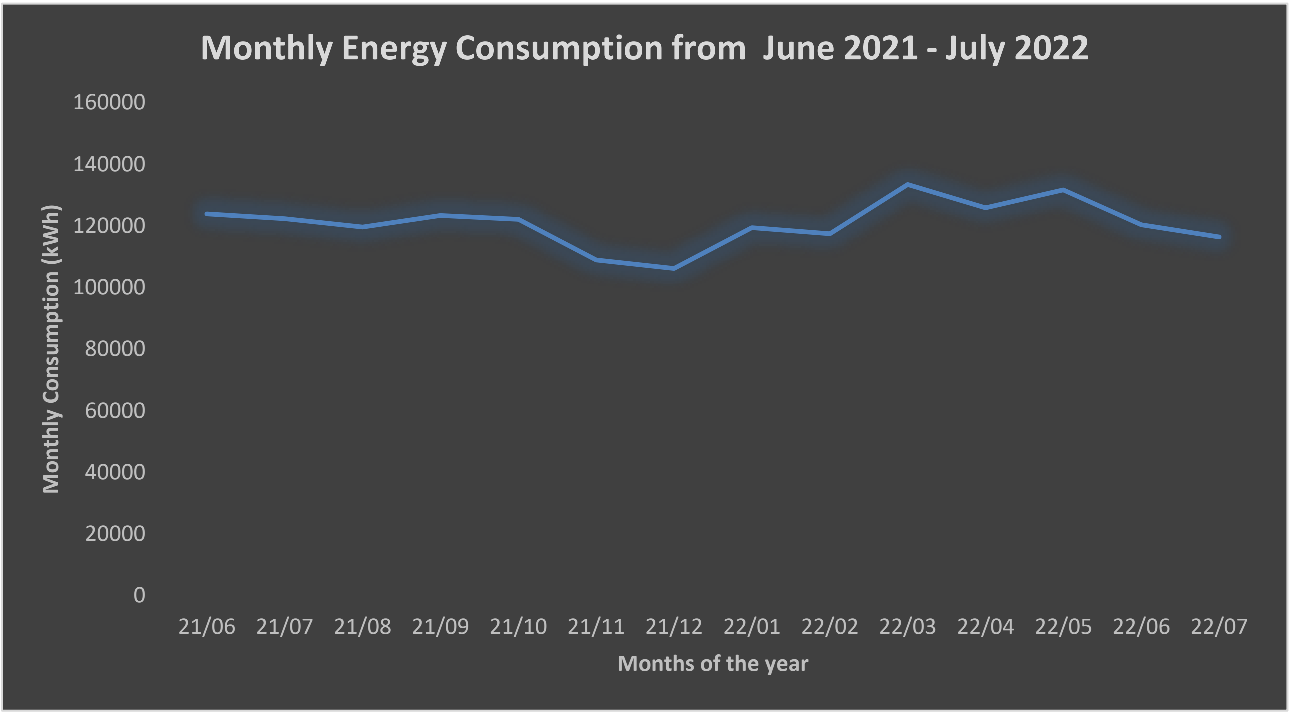

Figure 5: Monthly energy consumption from June 2021 to July 202

Lowest month

Table 2 shows the monthly consumption of G.H. Menzies in December 2021 to be the lowest. This is because for most of December every year, the University runs with skeleton staff. Only essential workers remain on campus to keep things running and majority of staff have less work to do during the day as the academic year is over. Usually there is a Summer-school that is conducted during the first half the month, but due to the COVID-19 pandemic, Summer- school was conducted online. The official closing date for the University of Cape town was the 23rd of December, meaning the week after had very little change in energy consumption as only the essentials were kept running.

Below is a graphical representation of the daily consumption for December 2021.

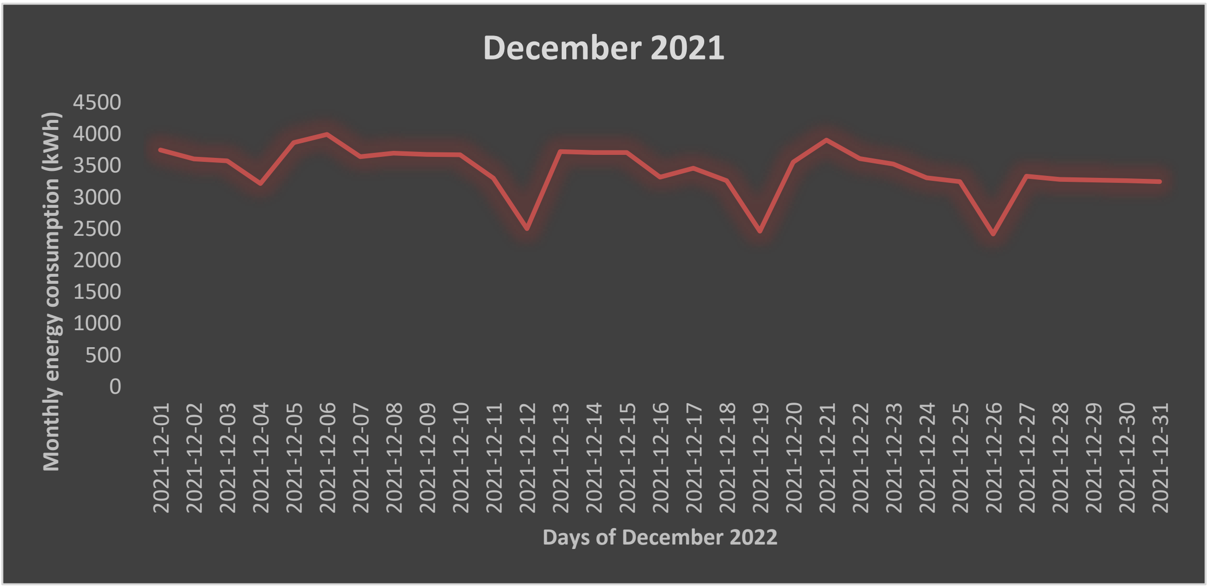

Figure 6: Daily energy consumption for December 2021

Highest month

Table 2 also shows March 2022 has the highest energy consumption. March is still in the beginning of the academic year at the University of Cape Town. Students are quite likely to attend lectures and use all the buildings facilities in the beginning of the semester even if teaching began in the second week of February, students tend to attend campus at least until mid-March, then students will come to study as the third week of March was test week. Many students also use campus as a workspace after hours to do work or will attend classes as their respective tests approach. The energy consumption for the last week of March is seen to be flat and this is because it is the week of the mid-semester vacation. During this period, majority of students go home

Below is a graphical representation of the daily energy consumption of March 2022.

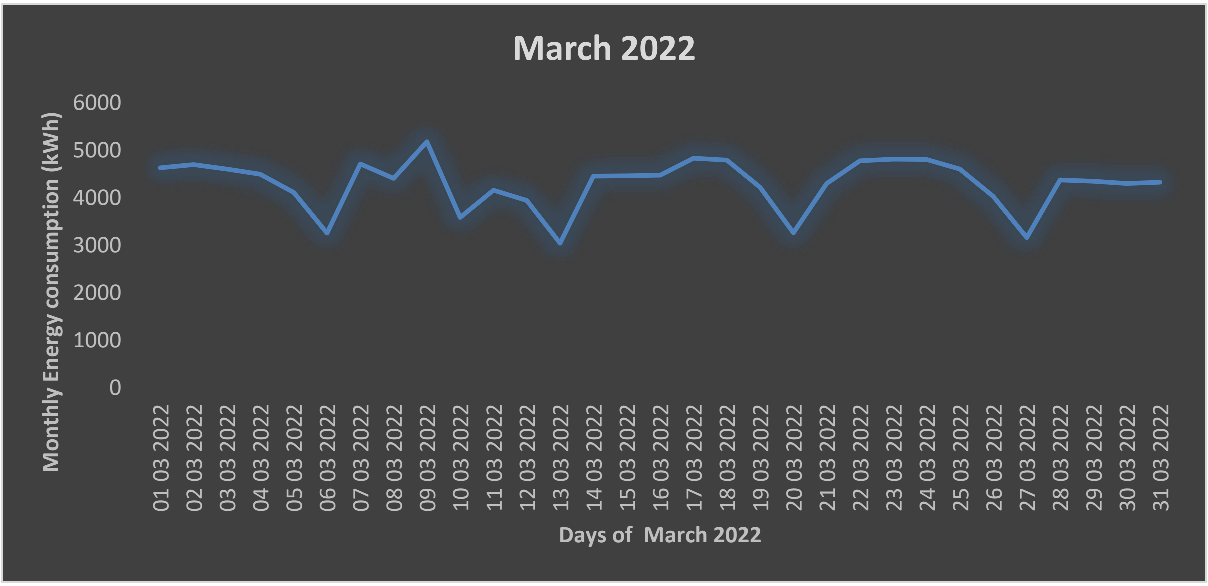

Figure 7: Daily energy consumption for December 2021

Highest vs lowest month

Below is the highest and lowest month on the same axis.

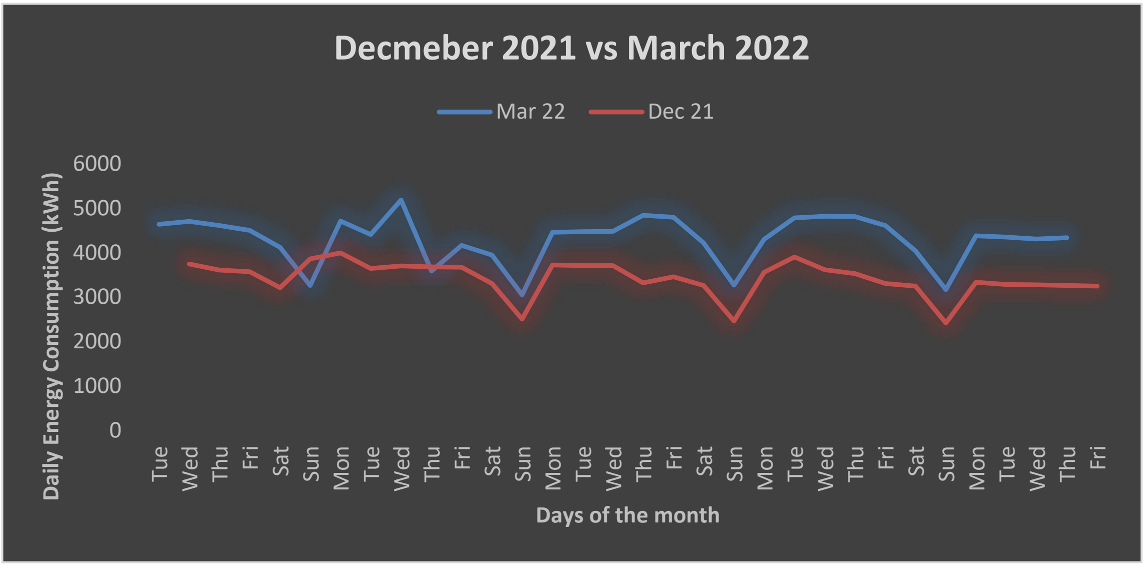

Figure 8: Daily energy consumption of December 2021 vs March 2022

The average daily energy consumption of G.H. Menzies for December 2021 is 3 424 kWh. And the average daily energy consumption of the building for March 2022 is 4303 kWh. In March, there is an average of just over 25% increase in energy consumption over December and this is expected from the occupancy densities of G.H. Menzies as well as the machinery, computers, and office equipment in use during these periods.

Daily energy consumption

To get the best understanding of energy consumption in G.H. Menzies, the daily data should be examined. It is observed that during the academic months (March – mid-June & August to November) the energy consumption on average, should be higher than the months of vacation. The fluctuations in the graph below are caused by the differences in the energy consumption during the week compared to the weekend.

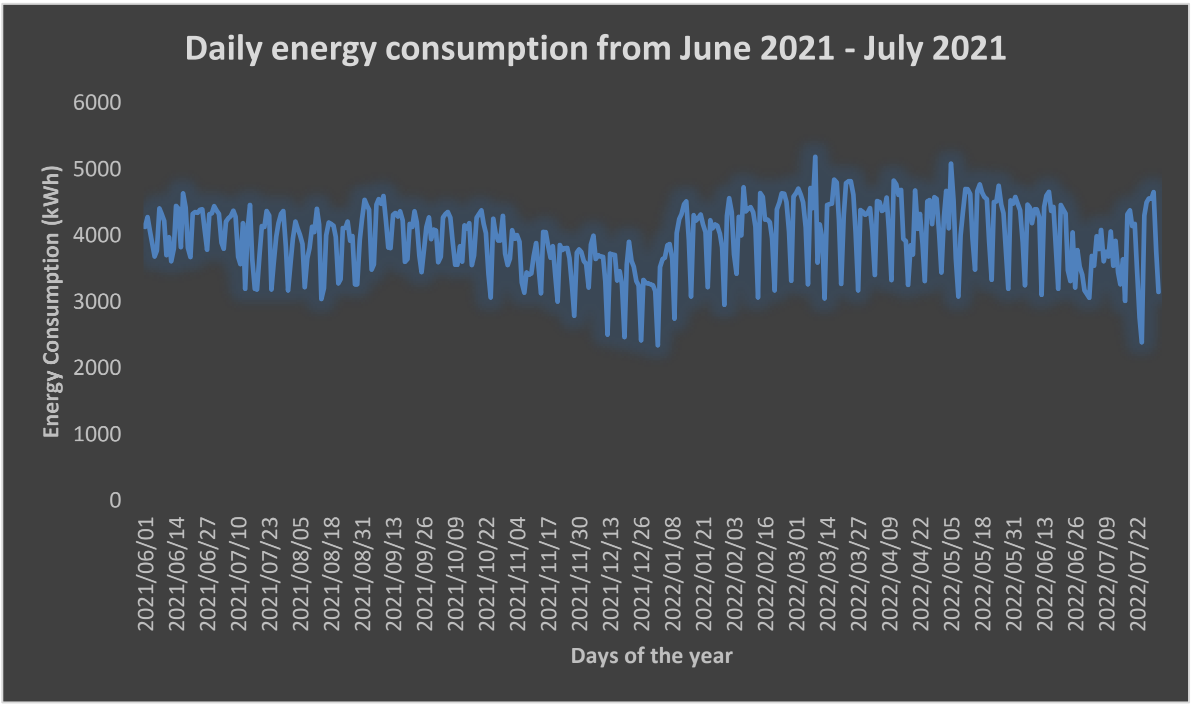

Figure 9: Daily energy consumption

Weekday vs weekend

Generally, academic buildings will have higher hourly energy consumption during the week compared to the weekend because of the occupancy rates during these parts of the week. Comparing the hourly energy consumption of the building during the weekday and weekend will give the graph below.

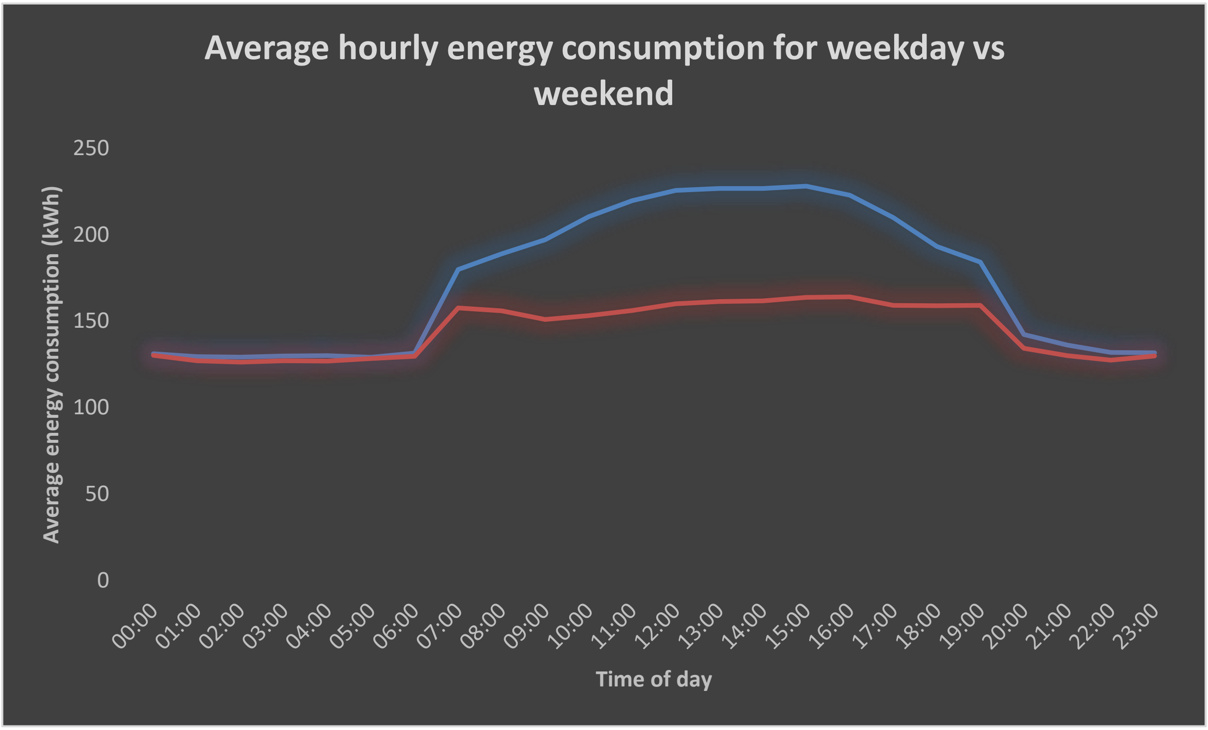

Figure 10: Average energy consumption for weekday vs weekend

The graph shows almost identical energy consumption during the night from 20:00 to 06:00. This is because there is less demand during these times and the machinery in the labs are not really used. During these hours, majority of the energy is used by the lights in hallways or common spaces where students are working or lights that have not been switched off. During the day however, energy consumption increases due to the number of people using the facilities and from the HVAC system that runs from 6am – 6pm via a BMS.

On average, during the weekday, the G. H. Menzies building uses almost 200 kWh and during the weekend, the building uses just over 150 kWh on average. This means that during the day, over 28% of energy is consumed compared to the night.

Yearly maximum vs minimum energy consumption

From the daily data, we can see the day that the most energy is consumed is the 9th of March 2022 and the day that consumed the lowest energy during the year is the 2nd of January.

The 9th of march being the day that consumes the most energy is understandable as it is in the month that consumed the most energy as well. It is also in the middle of the week; therefore, students will be using the facilities and all machinery and appliances will be running during the day. In contrast, the 2nd of January is a public holiday during a time when the University of Cape Town is closed for business. This means that it is possibly the day with the least amount of people on campus premises every year and therefore only a little amount of energy is consumed consumption levels stay quite stable throughout the day.

Below is a graphical representation of the hourly energy consumption for the 9th of March 2022 and the 2nd of January 2022 on the same set of axes.

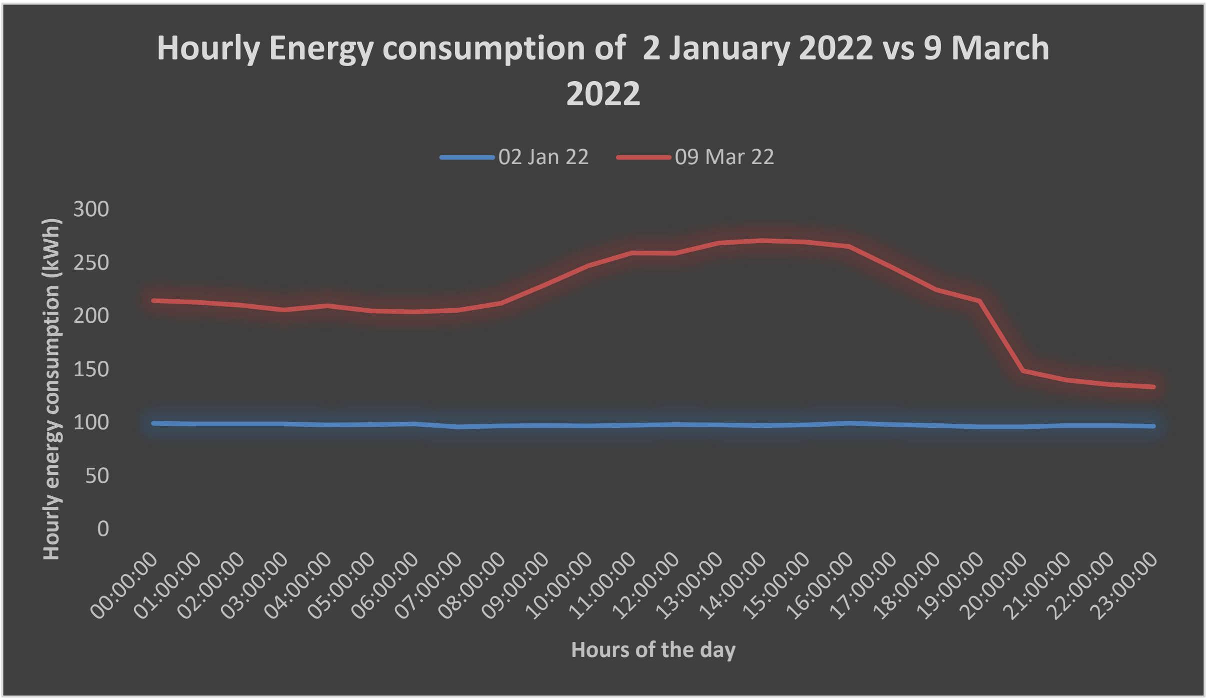

Figure 11: Hourly energy consumption for 2 January vs 9 March

Data Analysis

According to the figures in table 1, the yearly energy consumption (calculated from 1 August 2021 to 31 July 2022) is 1 444 331 kWh. G.H. Menzies building has a total floor area of 13697 m^2. Using these values, we can calculate the amount of energy consumed per square meter.

$$\frac{1\ 444\ 331 \text{ kWh}}{13\ 697\ m^2} = 105.45\ kWh/m^2$$

After achieving a baseline number to work with, methods of interventions will be proposed and the two most appropriate will be selected and used in the modelling section of the research project.

3.4 Possible intervention methods

3.4.1 Electronic ballasts

The building uses old fluorescent lighting that uses magnetic ballasts. An inductive coil is used in a magnetic ballast. With copper wire coiled over a core substance, it essentially has a transformer-like appearance [15]. Typically, inductors are used to resist changes in the current that passes through them. Electronic ballasts are now replacing magnetic ballasts since they are more efficient and have fewer disadvantages. Light sockets, or the area between the plug for the light bulb and the power cord, use magnetic ballasts [15].

Before reaching the light bulb, the electricity in magnetic ballasts passes via the copper coils. Only a small quantity of electricity is transmitted to the light bulb; the majority is captured in the magnetic field created. The copper coil's thickness and length determine how much current flows through it. The light bulb flickers and makes that familiar buzzing sound because of the erratic current flow through it [16]. A lighting device's starting voltage and operational currents can be controlled by electronic ballasts. The typical A.C source used for electronic ballasts is 220V, 50–60 Hz. The rectifier in the electronic ballast transforms the AC input into the D.C. output. Capacitors filter the D.C. current that is produced in this way. A high frequency oscillator is then fed with this filtered current after it has passed through several induction coils. As a result, the output current has an extremely high frequency (around 20-80 kHz) [16]. Electronic ballasts alter the current's frequency without affecting voltage. While electronic ballasts operate at a higher frequency of around 20 kHz, magnetic ballasts operate at a frequency of about 60 Hz. Because of this, fluorescent lights powered by electronic ballasts don't flicker or make buzzing noises [16].

The size and weight of electronic ballasts are likewise considerably less. They are far more energy-efficient than magnetic ballasts. Lamps that are linked in parallel or series can employ electronic ballasts. In this scenario, the performance of other lights utilizing the same ballast won't be impacted if one bulb fails [16].

3.4.2 LED Lighting

LED lighting is becoming more and more commonly used. A gas comprising mercury vapour plus argon, xenon, neon, or krypton is used to fill fluorescent tubes. Mercury vapour is excited by an electric current in the gas, producing short-wave ultraviolet light, which illuminates a phosphor coating within the lamp. The current passing through the lamp is then controlled by a ballast inside the lamp holder. Fluorescent lights are disposed of using specialized services like Interwaste since they are also considered hazardous trash and require decontamination if they break [17].

Traditional magnetic or electronic ballasts are required to operate T5, T8, and T10 fluorescent bulbs. For tube fluorescents in general, ballasts consume a lot of energy. They generate a flicker when they first turn on, cost a lot to replace if they break, and need to be taken out and replaced by a qualified electrician. As solid-state lighting is now produced by transformer and LED driver circuits, they are no longer essential for this sort of illumination [17].

The normal fluorescent bulb has a life expectancy of roughly 9000 hours, and it goes without saying that throughout that time, there will be significant light loss however, LEDs can have a lifespan of more than 100,000 hours [17].

3.4.3 Lighting control

Many lights are left on during the day throughout the building. This results in unnecessary energy consumption. If there was a way to detect whether an office or open space has people in it needing light, and if not, automatically turn the lights off when no one is detected, energy consumption could be considerably less [18]. A draw back for this is that if a person in an office stays in one position for an extended period, the motion detectors may not pick up anything and signal the lights to turn off. This would mean anyone in the office would have to wave their hands or move around regularly to keep the lights from turning off.

Perhaps if the motion sensor was placed at the entrance to the office space on the door frame, it can be programmed to detect when someone enters or exits the office [18]. Placing the sensors here would allow for the lights to turn on automatically when someone enters the room and turn off automatically when they leave the room. This however could be unfavourable when more than one person enters the room. The lights may be triggered to turn off when the second person walks in resulting in them manually flipping the switch to turn the light on. This will mean that when the two people leave the office, as the first-person leaves, the lights will turn off but as the second person leaves, it may trigger the lights to turn on and unless physically turned off they will remain on [18].

The lights in some spaces could also be connected to a timer such that they turn off during the day and turn back on in the evening. Alternatively, the lights in the building could be connected to a Light Detected Resistor. The resistance will be far too high during the day due to the amount of sunlight detected and the lights will not automatically turn on. If the light outside decreases, then the resistance in the lighting circuitry will decrease and turn the lights on.

3.4.4 Photovoltaic systems

PV systems are a very possible intervention method. Using photovoltaic systems to generate electricity will reduce its need for electricity from the grid. Unfortunately, making a building solely dependent on solar energy is unrealistic and not a good idea. Some days with uninterrupted sun will produce more than enough energy and some days that are cloudy could result in not being able to produce enough energy to sustain the buildings need. The occasional cloudy day may not cause a significant problem but when there is a string of days with poor weather, the building will not be able to meet the load requirements. Therefore, using PV systems in tandem with electricity from the grid is the key to successfully lowering the building's energy consumption while still meeting load requirements.

3.4.3 Chosen interventions

Out of 4 possible intervention methods discussed above, a combination of intervention method 2 & 3 can be used to decrease the load of the lighting system currently in place. Using LED lighting on a controlled schedule could be a solution to the increased energy consumption inefficiencies of fluorescent tubes.

The sun is a powerful source of energy if harnessed correctly, photovoltaic systems will be used to generate electricity for the building to use. While this method doesn't exactly decrease the energy consumption of the building, it does decrease the amount of money spent on electricity. It is also apt that the electrical engineering building uses renewable energy.

4. Simulations

4.1 Simulation software

There are many simulations that need to be run before the final results are assessed. Firstly, the building's current energy consumption must be modelled, for the year, for March and then for December. This is to calibrate the model to match the raw data. After which the intervention methods are added and then modelled, for yearly consumption, to see the impact. To do this, DesignBuilder v7.02.004 will be used with EnergyPlus v9.4 to model the energy consumption.

The DesignBuilder simulation tool was selected because of its user-friendliness and widespread acceptability in the world of energy modelling software. EnergyPlus is integrated with the DesignBuilder simulation tool very well. This software can model and simulate the thermal loads and gains the building experiences, lighting loads, electronic equipment, and appliances, building occupancy, on-site electricity generation by photovoltaic (PV) panels and wind turbines, construction materials and the building's properties, HVAC systems, as well as many other properties.

Below are some screenshots of the modelled building.

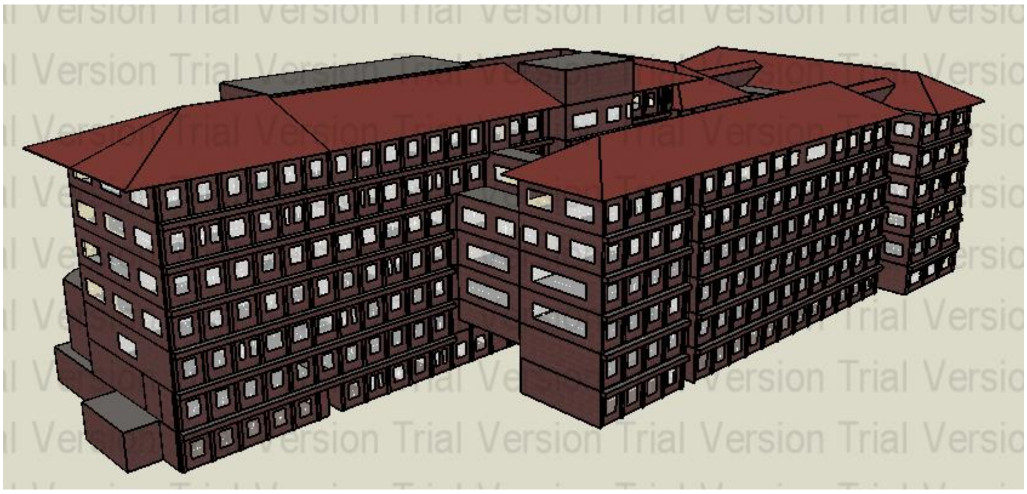

Figure 12: G.H. Menzies from the East

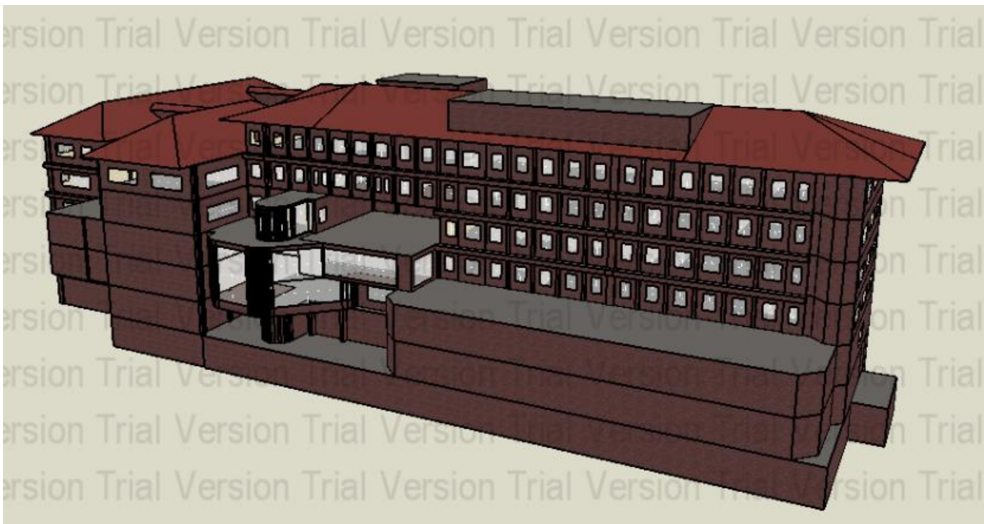

Figure 13: G.H. Menzies from the West

4.2 Calibrating building model

The model was used to simulate the yearly electricity usage of G.H Menzies. The goal of the first round of simulations was to get values and figures that correspond with the raw data provided by the Department of Sustainability of UCT. Three different simulations were run. A simulation for March 2022 as it was the month where the most energy was consumed and one for December as it was the month where the least energy was consumed. Lastly the buildings energy consumption was simulated over the period of one year with accurate weather data for all three simulations.

To achieve the same result in the simulations, many factors were taken into consideration such as occupancy density, lighting, the HVAC system, the consumption of office equipment, computer labs and machine labs.

4.2.1 Yearly simulation

Over 12 months, the building consumed almost 1 444 331 kWh of electricity.

<u>Occupancy density</u>

G.H. Menzies building is the main building for all electrical engineering students and many other departments and faculties use the spaces in the building for lectures and tutorials. This means at any given time there are at least 900 people including teaching, administrative and cleaning staff. This gives us an occupancy density of approximately 0,065 people/m^2

<u>Lighting</u>

During the building audit, the building was estimated to have approximately 150 x 58W light bulbs and 100 x 36W lightbulbs on the 1st, 3rd, 4th, 5th, and 6th floor and approximately 100 x 58W light bulbs and 50 x 36W lightbulbs on the 7th floor. With an occupied building area of 13 696,85 m^2. This comes to a normalised power density of approximately 5W/m^2. The building also does not have controlled lighting in place, so this option was deselected.

<u>HVAC System</u>

The VAV, Dual duct, Air-cooled Chiller model in the DesignBuilder library match the properties of the HVAC system in place in the building. The zones of the building where the HVAC operates were selected.

<u>Office equipment and computers</u>

Each floor has a different office equipment and a different number of computers, therefore making each floor consume different amounts of energy in these categories. These values were adjusted accordingly and then simulated.

After simulating the building with the appropriate settings, the simulation gave a yearly consumption of 1 446 406 kWh. This value is over 99% accurate when compared to the value from the raw data.

Table 3: Simulated yearly energy consumption

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	1446405.94	105.60
Net Site Energy	1446405.94	105.60
Total Source Energy	4546305.08	331.92
Net Source Energy	4546305.08	331.92

The report generated by the simulations included a table detailing the subcategories that use energy in the building. Below is a table showing the end uses for 1 year.

Table 4: End Uses

	Electricity [kWh]
Heating	4.72
Cooling	178982.89
Interior Lighting	213670.88
Exterior Lighting	0.00
Interior Equipment	928219.04
Exterior Equipment	0.00
Fans	107710.56
Pumps	1273.19
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00

The generated report indicated 213 671 kWh were consumed by the interior lighting. This is verified by the calculations below.

$$\big((58W \ \times 150) + (36W \ \times 100)\big) \times 5 + \big((58W \ \times 100) + (36W \ \times 50)\big) = 69,1\ kW$$

One year has 8 760 hours. Assuming on average that all the lights are on for 8 hours a day:

$$69{,}1\ kW\ \times \left(\frac{1}{3} \times 8760\right)\ hours = 201{,}8\ kWh$$

The calculated value is over 94% accurate and the minimal discrepancy is most likely due to the fact that not all lights are switched off when not in use or left on during the day.

928 219 kWh were consumed by all the interior equipment. This includes computers, office and staff room appliances, and machines in the labs that are used by the students and those conducting research.

The remainder of the energy consumed can be seen to be used by the HVAC system of the building. This energy was used regulate the inside temperature of the building throughout the year.

Below is the detailed EnergyPlus output of the simulation for 1 year.

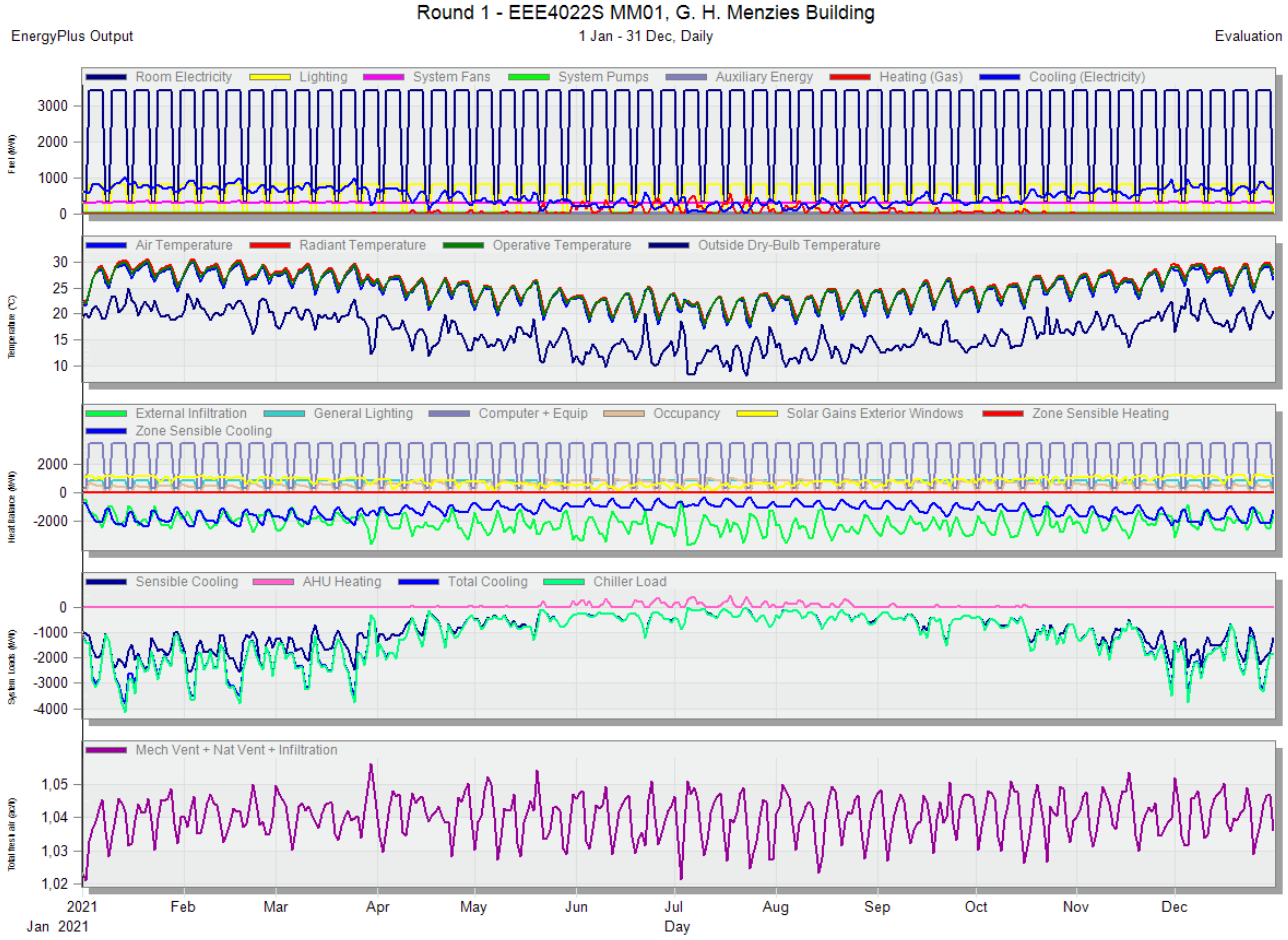

Figure 14: Simulation output for yearly consumption

4.2.2 March simulation

During March 2022, the building consumed almost 133 379 kWh of electricity.

<u>Occupancy density</u>

Since March is still the beginning of the academic calendar, the occupancy density will be higher than the average for the rest of the year. An occupancy density of 0,11 people/m^2 was calculated based on the number of students enrolled in courses that have booked the venues in G.H. Menzies.

<u>Lighting</u>

The same normalised power density of approximately 5W/m^2 was used again to simulate the lighting. Controlled lighting was deselected as the building does not have this system in place.

<u>HVAC System</u>

The same VRF, Dual duct, Air-cooled Chiller model in the DesignBuilder library that matches the properties of the HVAC system in place in the building was selected when simulating the energy consumption for March 2022. The zones of the building where the HVAC operates were selected.

<u>Office equipment and computers</u>

Each floor has a different office equipment and a different number of computers, therefore making each floor consume different amounts of energy in these categories. These values were adjusted accordingly and then simulated again for March 2022.

After running the simulation for the building with the appropriate settings, the generated report gave a consumption of 133 327 kWh for March 2022 which is over 99% accurate when compared to the value from the raw data.

<u>Table 5: Simulated energy consumption for March 2022</u>

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	133326.77	9.73
Net Site Energy	133326.77	9.73

The end uses for the building during March 2022 are as follows.

Table 6: End uses for March 2022

	Electricity [kWh]
Heating	0.07
Cooling	26147.05
Interior Lighting	18901.65
Exterior Lighting	0.00
Interior Equipment	75387.74
Exterior Equipment	0.00
Fans	11690.76
Pumps	179.99
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00

The generated report indicated 18 902 kWh were consumed by the interior lighting. This is verified by the calculations below.

March has 744 hours. Assuming on average that all the lights are on for 8 hours a day:

$$69{,}1\ kW\ \times\left(\frac{1}{3}\times 744\right)\ hours = 17{,}1\ kWh$$

The calculated value is over 90% accurate and the discrepancy is most likely due to the fact that not all lights were switched off when not in use or left on during the day. As there are more people in the building during this month, more venues and offices may have the lights on during the day.

75 383 kWh were consumed by all the interior equipment. This includes computers, office and staff room appliances, and machines in the labs that are used by the students and those conducting research

The remainder of the energy consumed can be seen to be used by the HVAC system of the building. This energy was used regulate the inside temperature of the building throughout the year. During March 2022 the cooling load is higher than the average because it is still the warmer season in Cape Town and staff and students would use the aircon and fans to remain comfortable.

Below is the detailed EnergyPlus output of the simulation for March 2022.

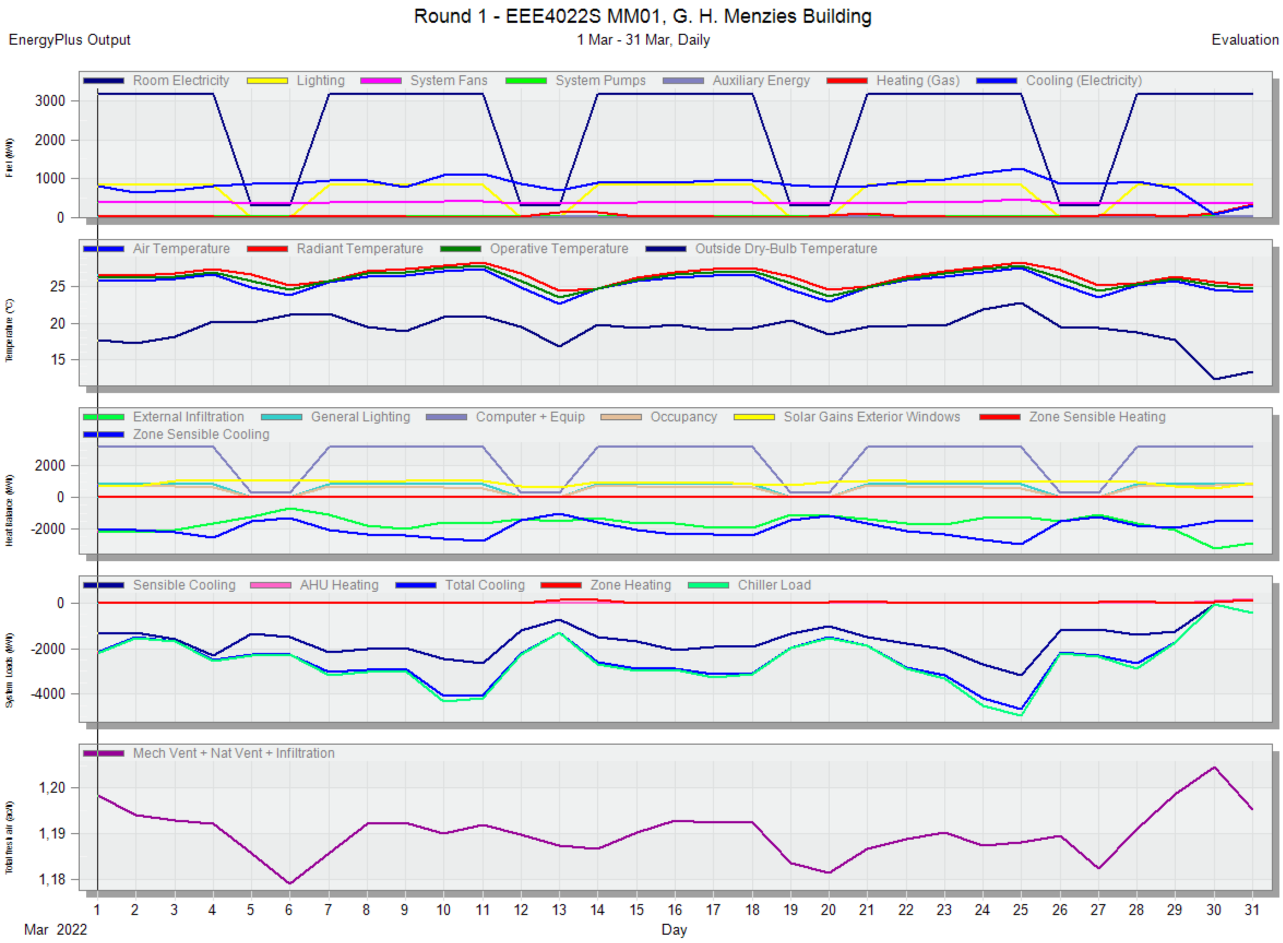

Figure 15: Simulation output for March 2022 energy consumption

4.2.3 *December simulation*

During December 2021, the building consumed 106 133 kWh of electricity.

Occupancy density

December falls outside the academic calendar, with only skeleton staff remaining on campus for maintenance purposes. A summer school is run during this period but none of the venues in G.H. Menzies are used for those classes. The occupancy density will be much lower than the rest of the year. An occupancy density of 0,007 people/m^2 was calculated based on the number of students and staff that may still use the buildings facilities

Lighting

Since there is minimal activity on in the building during this time, a normalised power density of approximately 3,5W/m^2 was used again to simulate the lighting. This value decreases from 5W/m^2 because some offices and private spaces such as staff rooms and research labs will be closed. The lights in those spaces will be off for the entire period their occupants are away. Controlled lighting was deselected as the building does not have this system in place.

HVAC System

The same VRF, Dual duct, Air-cooled Chiller model in the DesignBuilder library that matches the properties of the HVAC system in place in the building was selected when simulating the energy consumption for December 2022. The zones of the building where the HVAC operates were selected.

Office equipment and computers

Each floor has a different office equipment and a different number of computers, therefore making each floor consume different amounts of energy in these categories. These values were adjusted accordingly and then simulated again for December 2022.

After running the simulation for the building with the appropriate settings, the generated report gave a consumption of 106 477 kWh for December 2022 which is over 99% accurate when compared to the value from the raw data.

Table 7: Simulated energy consumption for December 2021

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	106476.65	7.77
Net Site Energy	106476.65	7.77

The end uses for the building during December 2021 are as follows.

Table 8: End uses for December 2022

	Electricity [kWh]
Heating	0.00
Cooling	20706.31
Interior Lighting	12853.13
Exterior Lighting	0.00
Interior Equipment	63939.95
Exterior Equipment	0.00
Fans	8843.98
Pumps	133.29
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00

The generated report indicated 12 853 kWh were consumed by the interior lighting. This is verified by the calculations below.

December has 744 hours. Assuming on average that all the lights are on for 8 hours a day:

$$69{,}1\ kW\ \times \left(\frac{1}{3} \times 744\right)\ hours = 17{,}1\ kWh$$

But since many offices and private spaces will be locked and not in use, the lights in those offices and private spaces will be off as well. A decrease of 1,5W/m² is a 30% decrease in the energy consumed by lighting in the building. Therefore:

$$17{,}1\ kWh\ \times 70\% = 12\ kWh$$

The calculated value is over 93% accurate and the discrepancy is most likely due to the fact that not all lights were switched off when not in use or left on during the day in the common spaces.

Almost 64 000 kWh were consumed by all the interior equipment. This includes computers, office and staff room appliances, and machines in the labs that are mainly used by the students and staff conducting research during this period.

The remainder of the energy consumed can be seen to be used by the HVAC system of the building. This energy was used regulate the inside temperature of the building throughout the year. During December 2021 the cooling load is higher than the average because it is the middle of Summer in Cape Town and staff and students who are in the building would use the aircon and fans to remain comfortable.

Below is the detailed EnergyPlus output of the simulation for March 2022.

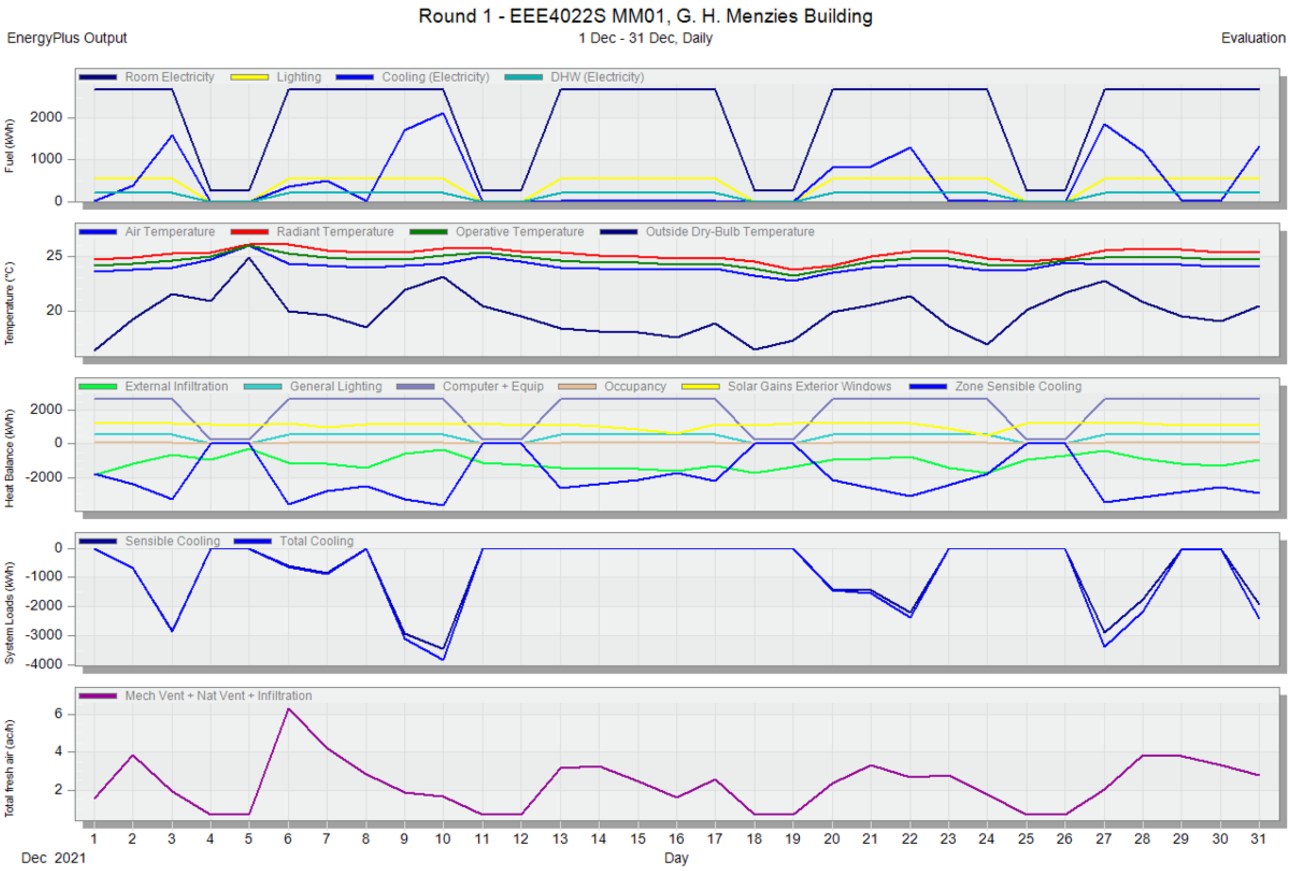

Figure 16: Simulation output for December 2021 energy consumption

5. Results

5.1 Intervention method 1: Upgrading the lighting system

During the building audit, it was noted that there were much more lightbulbs than necessary. By conducting a process called de-lamping, where every 1 out of 3 lighting fixtures were removed in places where it is not necessary, we can cut costs without even changing the type of lightbulb used. Currently the building uses a combination of 58W and 36W fluorescent lightbulbs. Replacing the 58W lightbulbs with OSRAM ST8PROU 23W LED tube lights and the 36W lightbulbs with OSRAM ST8-EM 20W LED tube lights, will decrease the amount of energy consumed while still providing almost exactly the same amount of light. Applying the above-mentioned changes bring the normalised power density from approximately 5W/m^2 to 1,5W/m^2.

In addition, having a lighting control system in place that automatically switches off the lights inside the rooms where enough daylight is detected and also turns the lights off automatically in some spaces at a certain time will drastically decrease the amount of energy consumed.

The building model was simulated once more, and the results are as follows:

Table 9: Simulated Energy consumption after upgrading lighting system

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	1267957.06	92.57
Net Site Energy	1267957.06	92.57

Table 10: End uses after upgrading lighting system

	Electricity [kWh]
Heating	6.84
Cooling	154779.08
Interior Lighting	64101.26
Exterior Lighting	0.00
Interior Equipment	928219.04
Exterior Equipment	0.00
Fans	98276.42
Pumps	1122.37
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00

According to the data in Table 4, interior lighting accounts for 213 671 kWh during the course of the year. After applying the first intervention, the new lighting system consumes 64 101 kWh during the entire year. This is a very large decrease of 70% and brings the yearly energy consumption down by over 12%. A simple calculation can be used to determine the validity of the simulated output. The basic equation remains the same, but the new lightbulbs and the de-lamping process must be considered. Substituting the 58W fluorescent bulb for the 23W LED and the 36W fluorescent bulb for the 20W LED and multiplying the whole equation by $\frac{2}{3}$ as 1 in every 3 lightbulbs will removed.

$$\frac{2}{3}\left[\left((23W \times 150) + (20W \times 100)\right) \times 5 + \left((23W \times 100) + (20W \times 50)\right)\right] = 20{,}3kW$$

One year has 8 760 hours. Factoring in that all the lights are on for strictly 8 hours a day:

$$20{,}3\ kW \times \left(\frac{1}{3} \times 8760\right)\ hours = 59\ 471\ kWh$$

The simulated value is over 92% accurate. The discrepancy can be caused by certain zones in the building not being on a controlled timer as they are public spaces.

The plot below is generated by the EnergyPlus simulation tool. It is clear in the top graph that lighting (yellow) has decreased drastically. The other graphs are to show that no other interventions were applied and remain consistent with the simulated output from Figure 14: Simulation output for yearly consumption

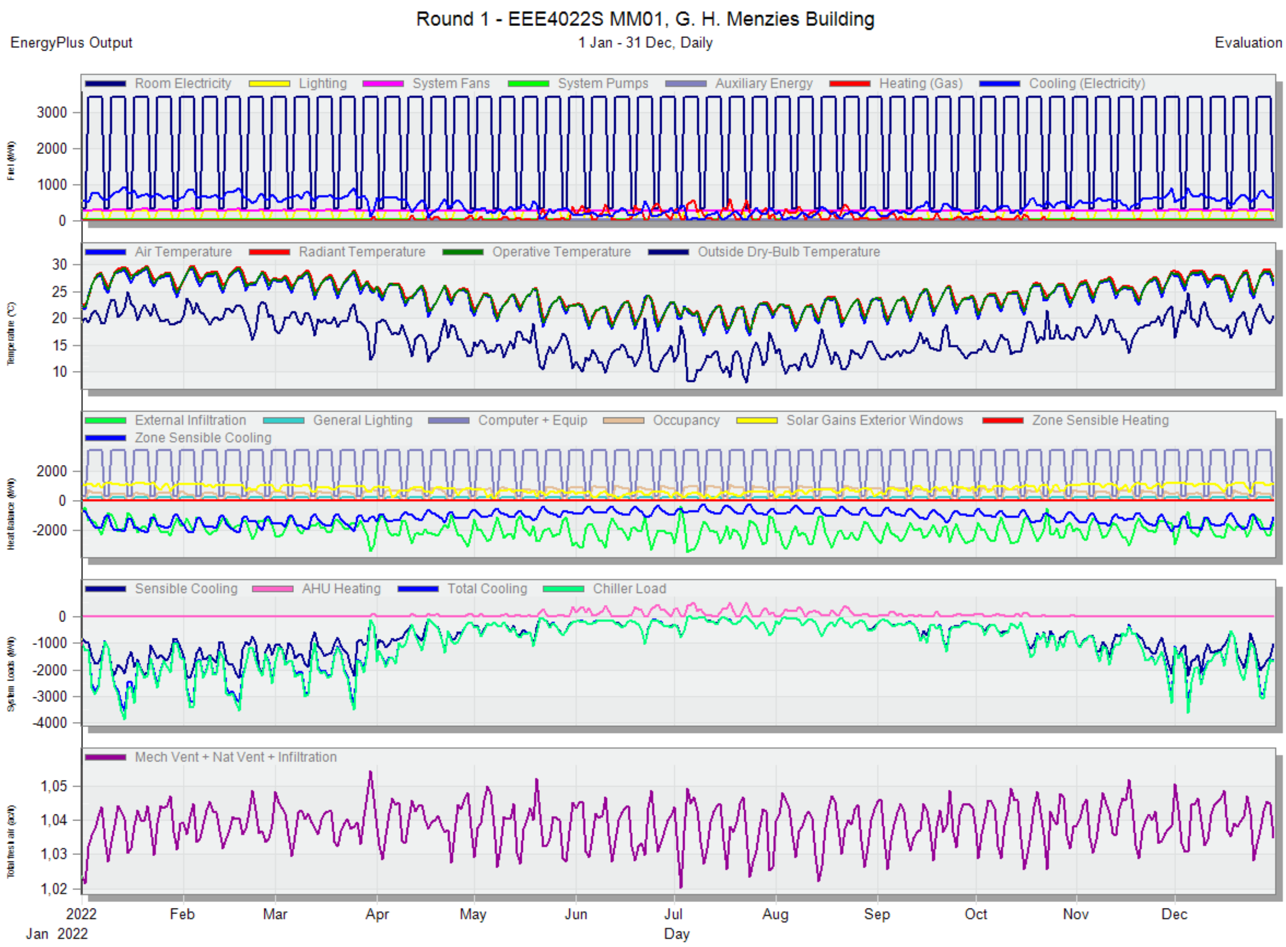

Figure 17: Simulated output for upgraded lighting system

5.2 Intervention method 2: Installing a photovoltaic system

Since the G. H. Menzies building sits on the foot of a mountain, it is elevated above the residential area of Rondebosch which is to the buildings East. The roofs of the building remain unobstructed until the late afternoon when the sun sets behind the mountain and direct sunlight is blocked. This is usually between 1-2 hours before the sun sets in the evening.

Strategically placing solar panels on the roofs of the building will help generate electricity for the building to use. The solar panels will be on the East, West and North facing roofs. The solar panels on the East and West facing roofs will ensure electricity is being generated in the morning and afternoon respectively. The solar panels on the North facing roofs will generate electricity throughout the day all year as the building is in the Southern Hemisphere and the suns path tends to angle towards north.

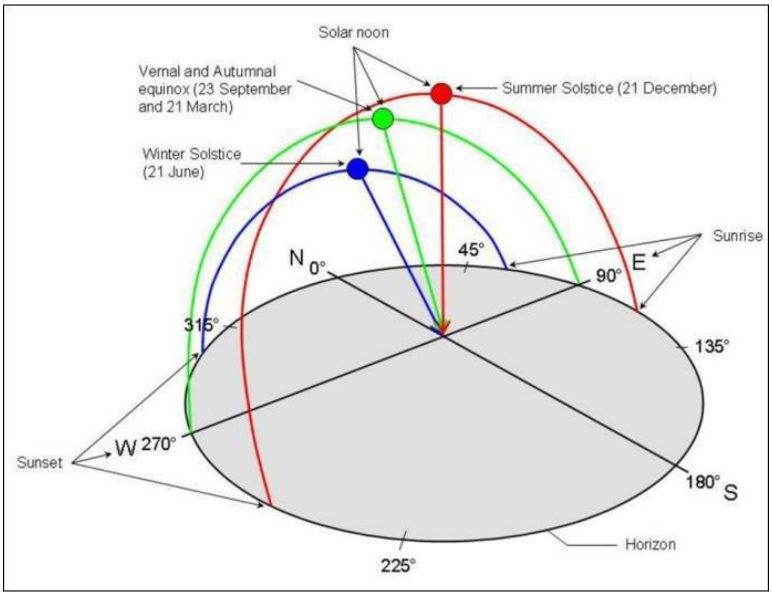

Figure 18: The suns path from the southern hemisphere

The PV module that will be used is the SunModule SW100POLYRGP from SolarWorld. The SW100POLYRGP is a polycrystalline module with 72 cells per module. Each cell is 52mm x 156mm.

To calculate the active area: $(52mm \times 156mm) \times 72\ cells = 0{,}584m^2$

Each solar panel has an active area of 0,584m^2 and many solar panels can be connected in series to form what is called a photovoltaic array. Using the information from the data sheet of the SW100POLYRGP PV module, a PV generator of the type of Equivalent One-Diode was created. Each PV array was configured with these specifications and then linked to a load centre that can hold up to 30 PV arrays. Configuring the load centres required creating a new inverter model in the DesignBuilder library with a 96% efficiency.

For this intervention method, 4 load centres are used to their full capacity as 120 solar panel arrays were placed on the roofs of the G. H. Menzies building. Thus totalling 1 422 m^2 of solar panels. While this intervention method does not decrease the amount of energy consumed, it does decrease the amount of electricity bought from the grid and therefore saving the University in costs.

After adding the PV system, the building model was simulated, and the results are as follows

Table 11: Simulated output after PV system intervention

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	1446417.31	105.60
Net Site Energy	1036616.95	75.68

As mentioned above, installing a PV system does not mean that the building will consume less energy. This is corroborated by the 'Total Site Energy' in the table above. This figure is the same as the annual consumption from the calibration simulation. But the 'Net Site Energy' is observed to be over 30% less than the 'Total Site Energy'. This is shown in further detail in the table below.

Table 12: Electrical loads satisfied

	Electricity [kWh]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	413939.757	30.39
Wind Power	0.000	0.00
Power Conversion	-4139.40	-0.3
Net Decrease in On-Site Storage	0.000	0.00
Total On-Site Electric Sources	409800.360	30.09
Electricity Coming From Utility	1023087.594	75.12
Surplus Electricity Going To Utility	70955.005	5.21
Net Electricity From Utility	952132.589	69.91
Total On-Site and Utility Electric Sources	1361932.949	100.00
Total Electricity End Uses	1361932.949	100.00

Upon closer inspection of the first graph at the top, the amount of electricity generated can be seen. It is seen that the amount of energy decreases during the winter months when there is less sun, while more energy is generated from late October to February which are the summer months.

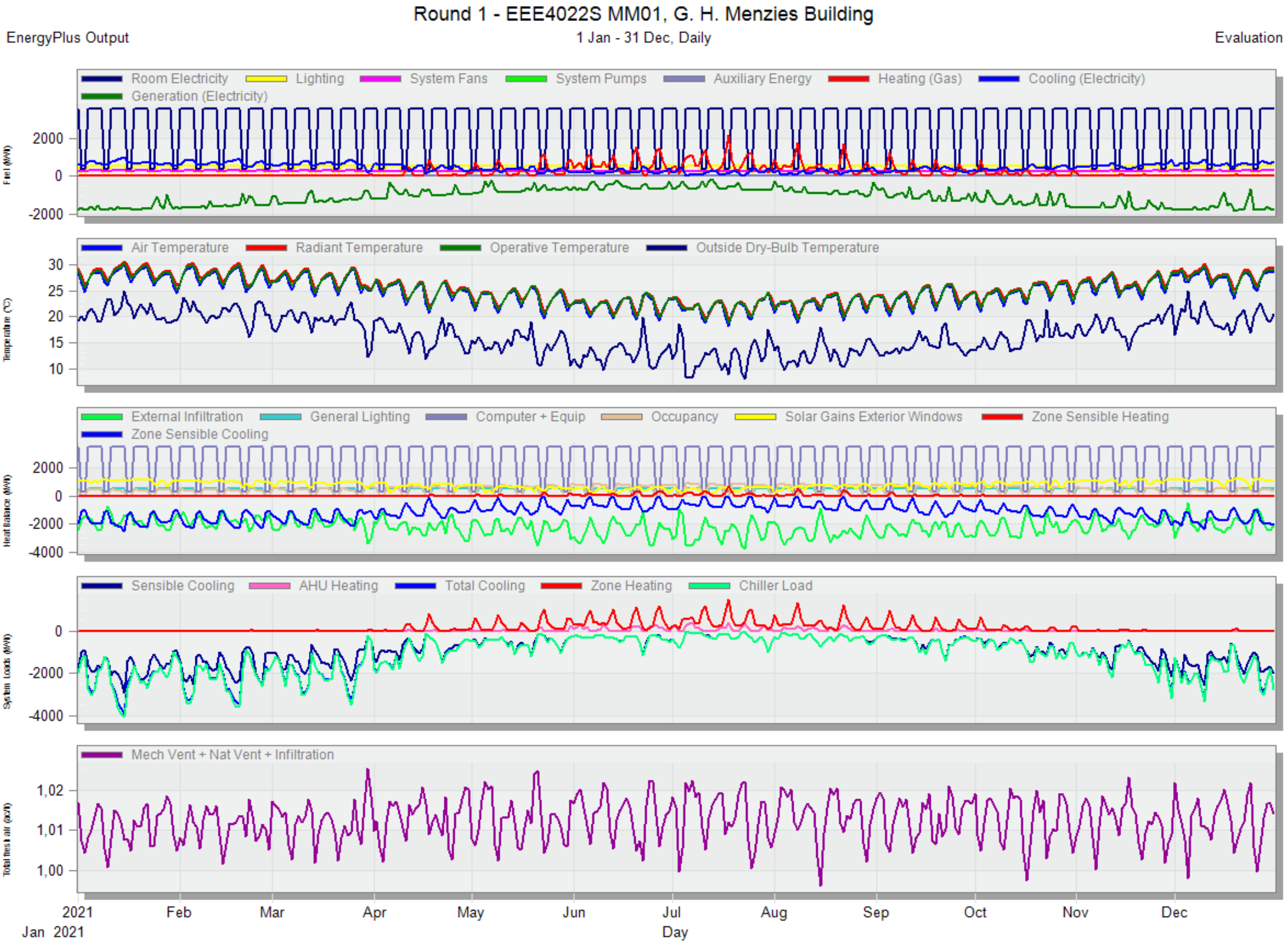

Figure 19: Simulated output for PV system

5.3 Overall impact of intervention methods

5.3.1 Effect of both intervention methods combined

In Intervention method 1: Upgrading the lighting system and Intervention method 2: Installing a photovoltaic system , the effect of each intervention method is seen separately to assess their individual impact. Upgrading the lighting system improved the overall yearly energy consumption by almost 12% and the installed PV system generated 30% of the yearly energy consumption. These two intervention methods alone have brought down the energy consumption of G. H. Menzies by a considerable factor.

The final simulation was run with both intervention methods applied to the building model, as seen below:

Table 13: Simulated output of both interventions

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]
Total Site Energy	1258276.06	91.87
Net Site Energy	786432.45	57.42

Table 14: Yearly end uses after both intervention methods are applied

	Electricity [kWh]
Heating	9.55
Cooling	151514.16
Interior Lighting	64347.81
Exterior Lighting	0.00
Interior Equipment	953866.45
Exterior Equipment	0.00
Fans	92814.73
Pumps	1197.14
Heat Rejection	0.00
Humidification	0.00
Heat Recovery	0.00
Water Systems	0.00
Refrigeration	0.00
Generators	0.00

From the tables above, it is observed that the 'Total Site Energy' is less than the calibration simulation results found in Table 3: Simulated yearly energy consumption Table 3 and the 'Net Site Energy' being lower indicates that the PV systems are working well and generating electricity throughout the year. This is confirmed in the table below showing the satisfied electrical loads.

Table 15: Electrical loads satisfied after both intervention methods were applied

	Electricity [kWh]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	476609.708	39.75
Wind Power	0.000	0.00
Power Conversion	-4766.10	-0.4
Net Decrease in On-Site Storage	0.000	0.00
Total On-Site Electric Sources	471843.611	39.35
Electricity Coming From Utility	825783.435	68.87
Surplus Electricity Going To Utility	98611.784	8.22
Net Electricity From Utility	727171.651	60.65
Total On-Site and Utility Electric Sources	1199015.262	100.00
Total Electricity End Uses	1199015.262	100.00

The table above shows that the installed PV system successfully generates almost 40% of the annual energy consumption. Below is the final simulated output by EnergyPlus. In the first graph it is seen that the effect of lighting(yellow) is almost minimal due to the efficiency of the LED tubes. It shows the Generation (green) generating more energy in the summer months than the winter months.

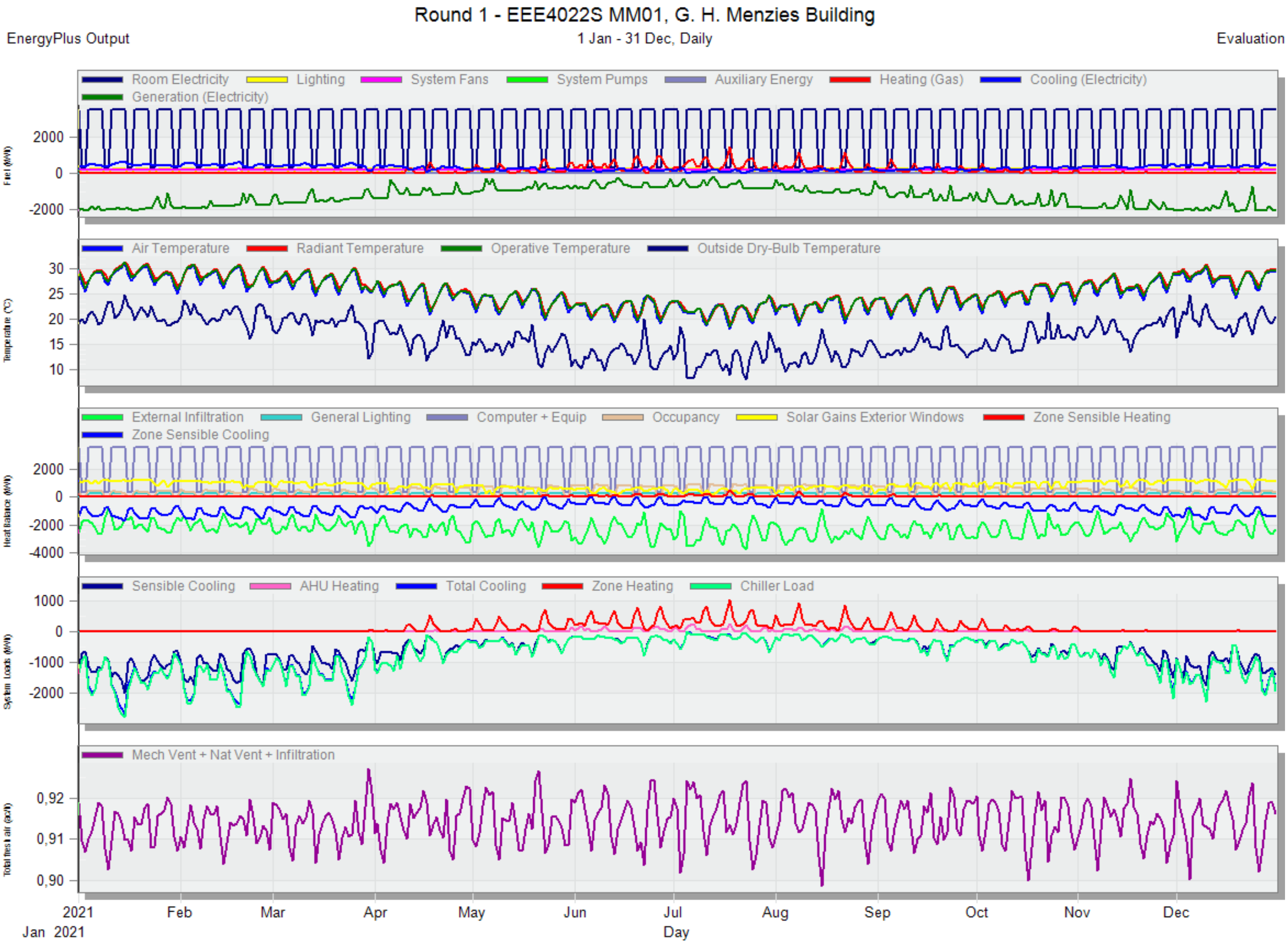

Figure 20: Simulation output for yearly energy consumption

5.3.2 *Comparison of all simulated results*

Table 16: Comparison of all simulation outputs

	Calibration (kWh)	Upgraded lighting (kWh)	PV Systems (kWh)	Both intervention methods (kWh)
Total site energy	1 446 405	1 267 957	1 446 417	1 258 276
Net site energy	1 446 405	1 267 957	1 036 617	786 432
Interior lighting	213 671	64 101	213 671	64 348
Generated energy	-	-	413 940	476 610

The above table is a brief summary of what was achieved after simulations. The baseline consumption value to work with was the 'Net Site Energy' in the calibration model, 1 446 405 kWh. The final simulated consumption value is the 'Net Site Energy' of the model with both intervention methods applied, 786 432 kWh. This shows a 46% decrease in the annual energy consumption of the G. H. Menzies building.

6. Discussion

6.1 Payback period for upgrading the lighting system

According to the Builders warehouse website,

The OSRAM 23W LED tubes cost R135 each [19]
The OSRAM 20W LED tubes cost R 115 each [19]

Therefore, the total cost of purchasing the LED tubes will be:

$$\frac{2}{3}\left[\left((R135\ \times 150) + (R115\ \times 100)\right) \times 5 + \left((R135\ \times 100) + (145\ \times 50)\right)\right] = R\ 118\ 667$$

A typical labour charge of R50 is expected per lightbulb fitted when replacing fluorescent tubes with LED tubes. This charge can be expected for the de-lamping process as well.

$$R50\ \times \left((150\ +\ 100) \times 5 + 100 + 150\right) = R70\ 000$$

The costs associated with installing a lighting control system can vary between R150 000 to R200 000 depending on the system required. For the calculation purposes, R200 000 will be used.

The total cost of upgrading the lighting system come to almost R 390 000.

Using a tariff of R1,83 per kWh, the amount of money saved per year by the new lighting system is:

(213 671 kWh – 64 101 kWh) x R1,83/kWh = R273 714

The payback period for the new lighting system alone is:

$$Payback\ Period = \frac{Initial\ investment}{Net\ cash\ flow\ per\ period}$$

$$Payback\ Period = \frac{R390\ 000}{R273\ 714}$$

$$Payback\ Period =\ 1{,}42\ years$$

This is just under 18 months.

6.2 Payback period for PV system

A 1MW solar plant is enough to generate the amount of energy that has been simulated.

However, the PV system has been d=designed to be roof mounted and this will add additional costs. Combining the PV, system and installation could cost up to R 10 million in South Africa [20].

The amount of energy generated in one year is 476 610 kWh.

This generation of energy annually saves:

$$413\ 940\ kWh\ \times R1{,}83\ per\ kWh =\ R872\ 196$$

The payback period for the PV system alone is:

$$Payback\ Period = \frac{Initial\ investment}{Net\ cash\ flow\ per\ period}$$

$$Payback\ Period = \frac{R10\ 000\ 000}{R872\ 196}$$

$$Payback\ Period =\ 11.5\ years$$

6.3 Combined Payback period

To calculate the actual pay pack period, both interventions energy savings need to be calculated together.

Total cost: R390 000 + R10 000 000 = 10 390 000
Total savings per year: R273 714 + R872 196 = 1 145 910

$$Payback\ Period = \frac{10\ 390\ 000}{1\ 145\ 910}$$

$$Payback\ Period = 9.07$$

This means that if the University of Cape Town were to spend R 10,4 million on these two intervention methods to save the money spent on electricity for the G.H Menzies building, it would make that money back in just over 9 years. This is a short payback period for projects of this scale and should encourage the university to conduct these renovations to decrease its consumption.

7. Conclusions

The purpose of this specific study was to find cost-effective, minimally invasive interventions that would lower the energy consumption of a commonly used commercial building, namely, G.H. Menzies on UCT's upper campus. The literature showed that a large percentage of energy use globally is by buildings. Within in this category, commercial buildings were determined as the highest consumers due to their increased use of electricity. Based on these findings, a number of possible interventions that could be applied to commercial building to lower their energy consumption were then narrowed down, reviewed and discussed, out of these, upgrading the lighting system and installing PV systems, were chosen as the most suitable options. Simulations were run, based on raw data collected from the building management, to see the impact of each intervention individually and together on energy consumption in the G.H. Menzies building. The results show a significant decrease in energy consumption by the building when both intervention methods were applied together. The payback period of each individual intervention was analysed to support their viability, showing that UCT would have a return on their investment within 9 years. This implies that cost-effective, climate conscious intervention methods can be seamlessly applied to existing buildings with meaningful results. It also indicates that there are ways to relieve the pressure put on South Africa's electricity grid, which is especially relevant in the age of load-shedding.

Although this research may be considered small scale, it shows the very real steps that can be taken in spaces that are frequented by larger groups of people (i.e., a university) to reduce energy consumption. While new climate conscious infrastructure is being built. The current infrastructure in these environments, that has been around for decades, does not function in a manner that is as environmentally friendly as it could and they continue to consume large amounts of energy, stunting any progress made in other areas. It, therefore, becomes imperative to adapt older buildings such that they align with new environmentally conscious policies.

8. Recommendations

To get more accurate results, the building chosen can be modelled with greater detail. Considering accurate shading from overhangs and the surrounding structures. Again, since only the lighting system was changed within the building itself, all other properties remained untouched but conducting a thorough investigation into the building with the simulation model in mind, allows for more of the options in the simulation tool to be customized to fit the exact building specifications.

This report was constrained by the fact that only 2 intervention methods were to be proposed. Both these intervention methods were required to be of an electrical nature but there are many other intervention methods that could be applied with minimal effort. In the real world, any number of intervention methods are welcomed provided the payback period is as low as possible and the intervention method is realistic and attainable.

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10. Appendices

The raw data, simulation files and the extensive reports each simulation generated, can be found using the GitHub link below:

[akhiljacob24/EEE4022S (github.com)]

Screenshots of G.H. Menzies, after intervention methods have been applied.

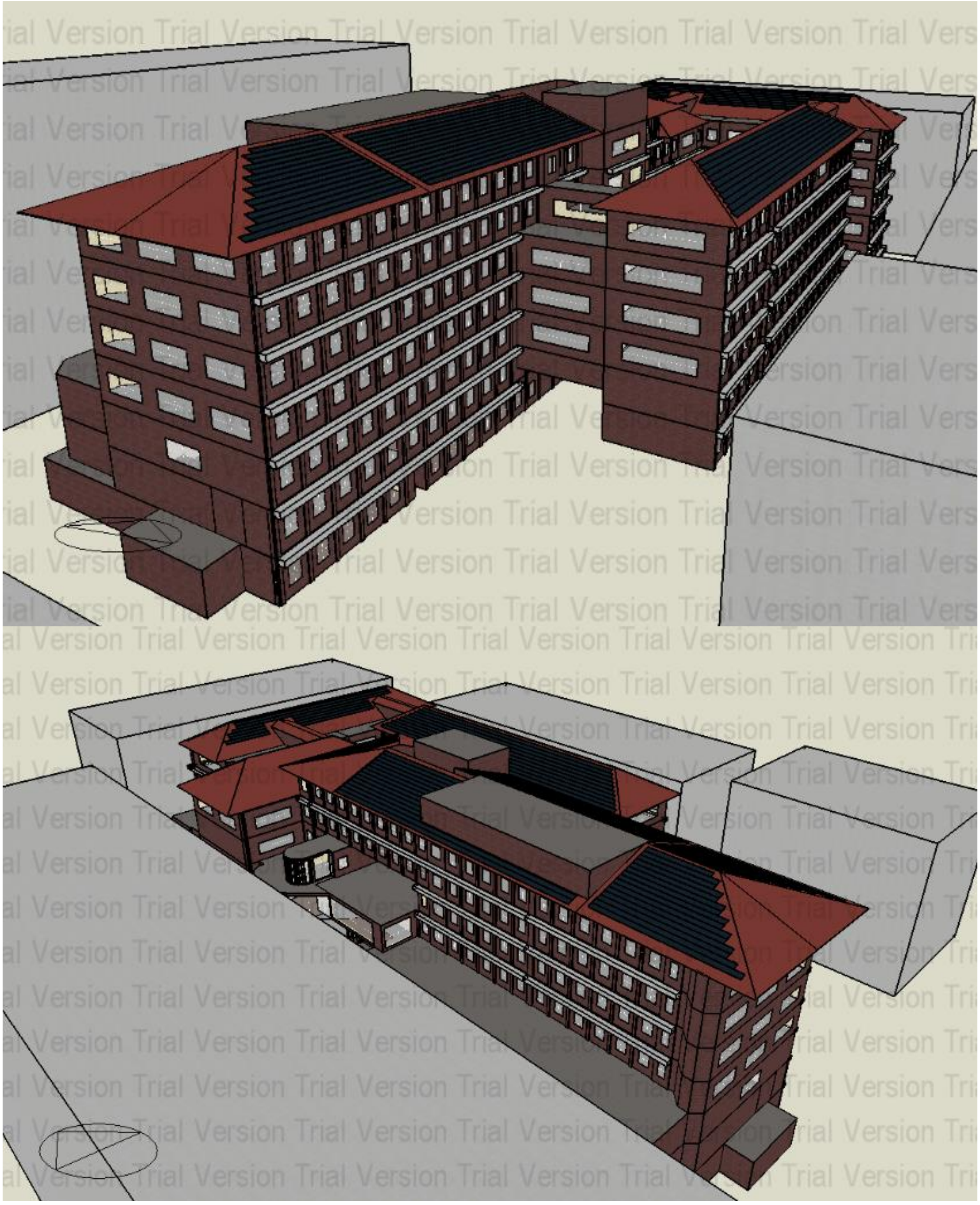

Figure 21: 3D rendering of G.H. Menzies after intervention methods

Screenshots of each floor showing each office space as a separate zone used for thermal calculations.

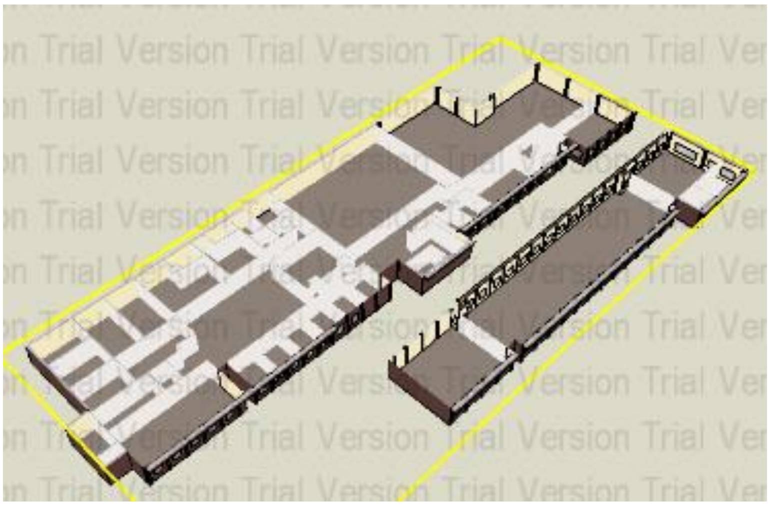

Figure 22: 1st floor of G.H. Menzies

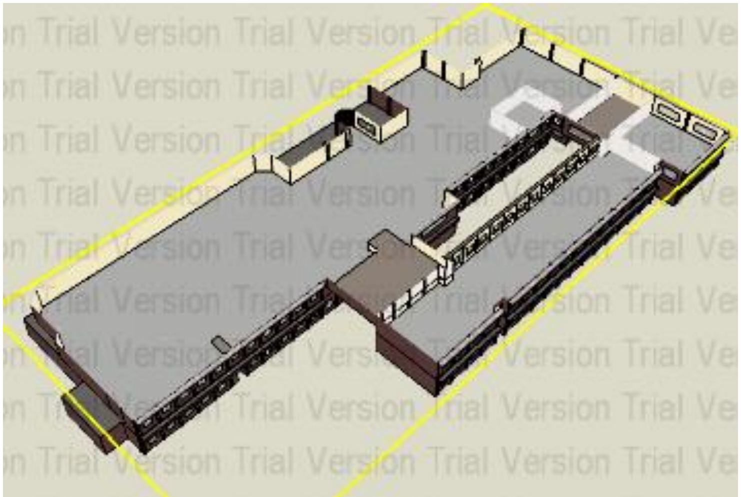

Figure 23: 2nd floor of G.H. Menzies

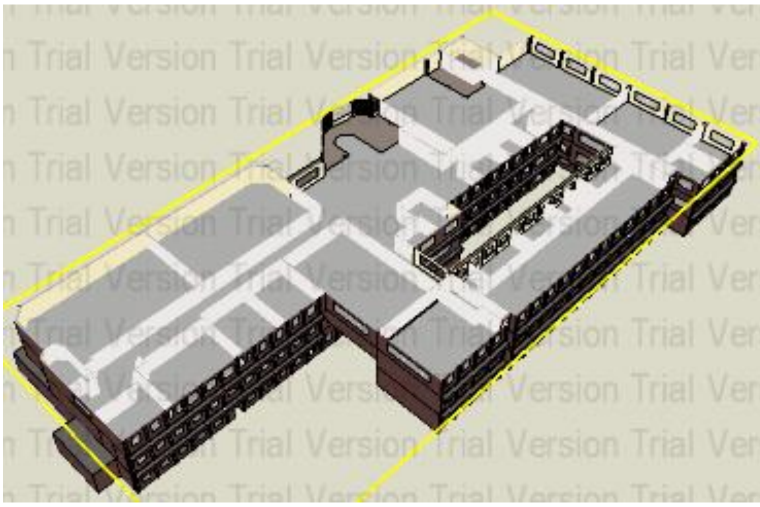

Figure 24: 3rd floor of G.H. Menzies

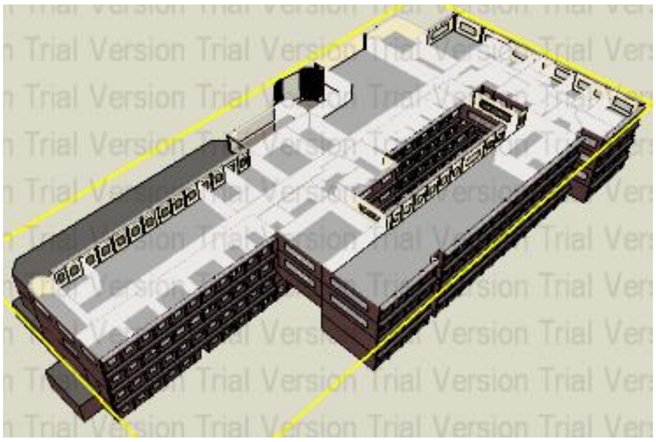

Figure 25: 4th floor of G.H. Menzies

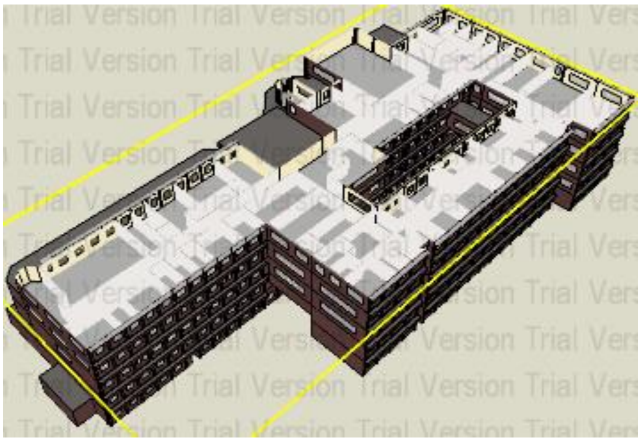

Figure 26: 5th floor of G.H. Menzies

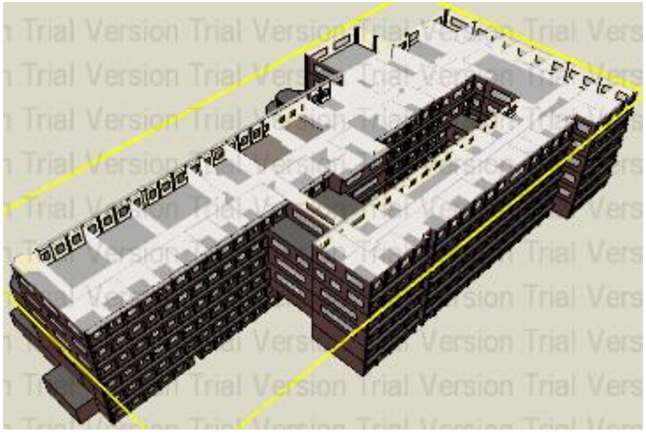

Figure 27: 6th floor of G.H. Menzies

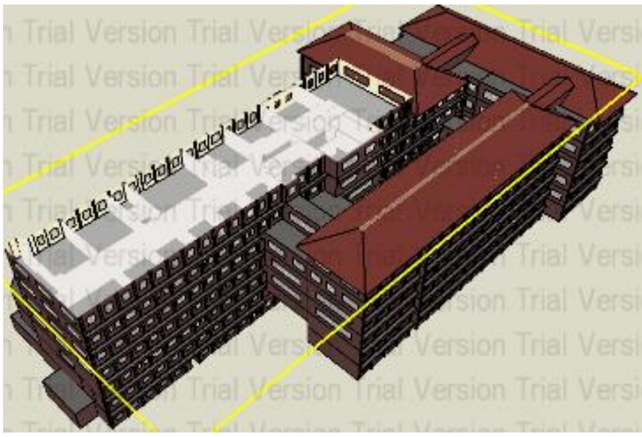

Figure 28: 7th floor of G.H. Menzies

Options selected for Calibration simulation

Below is a screenshot of the activity for the building over 1 year

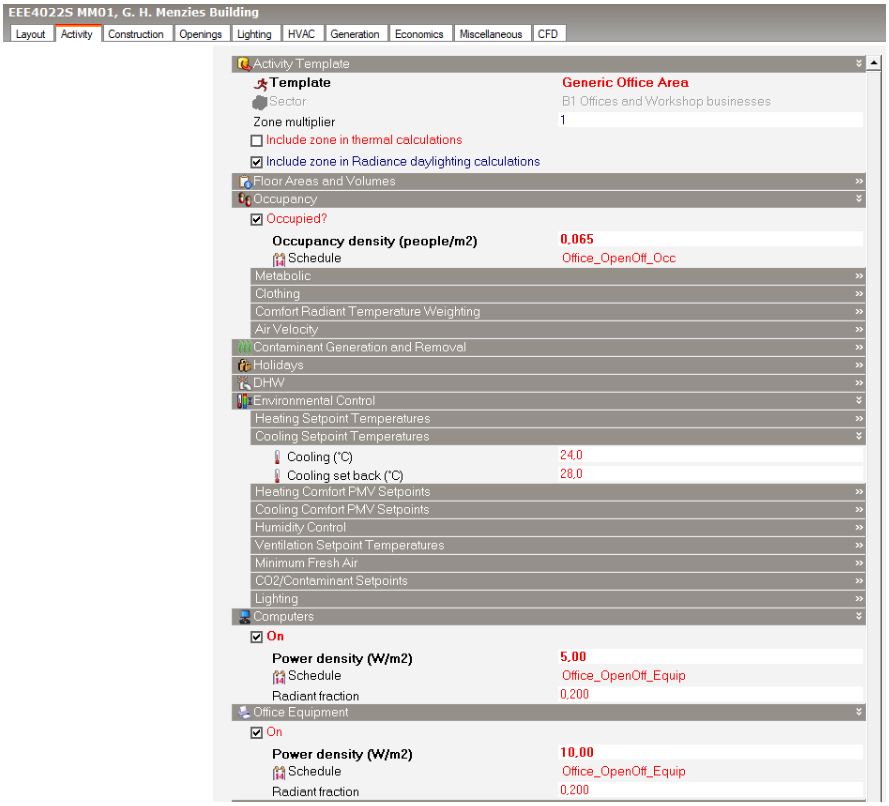

Figure 29: Activity details for calibration model for 1 year

Below is a screenshot of the activity for the building for March 2022

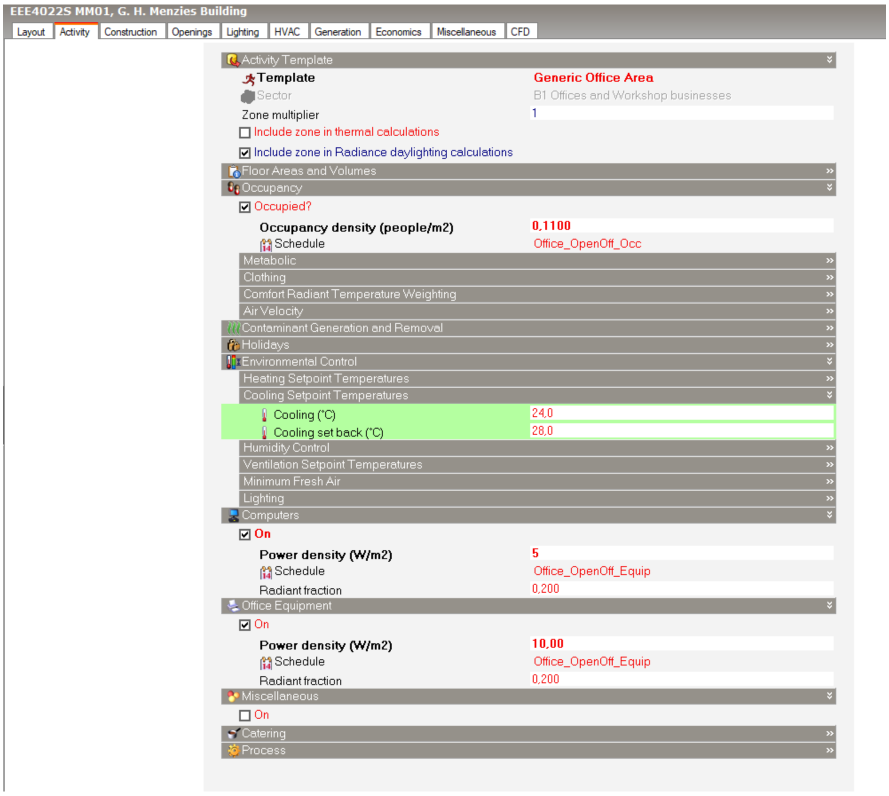

Figure 30: Activity details for calibration model for March 2022

Below is a screenshot of the activity for the building for December 2021

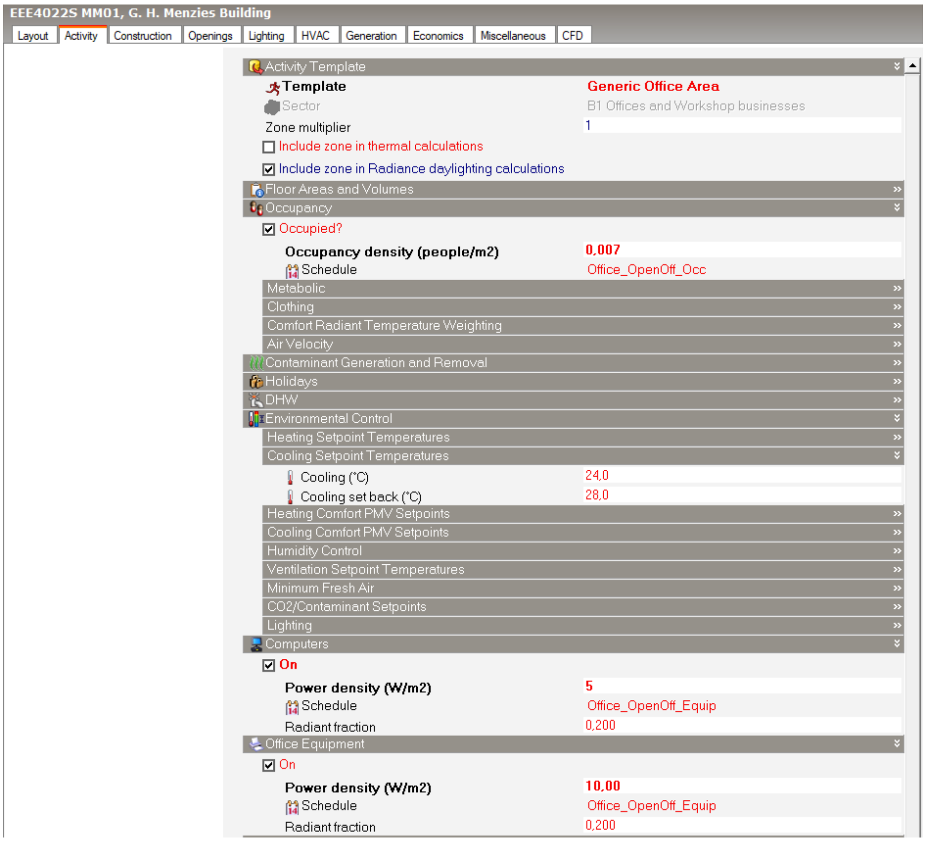

Figure 31: Activity details for calibration model for December 2021

Below is a screenshot of the lighting options selected.

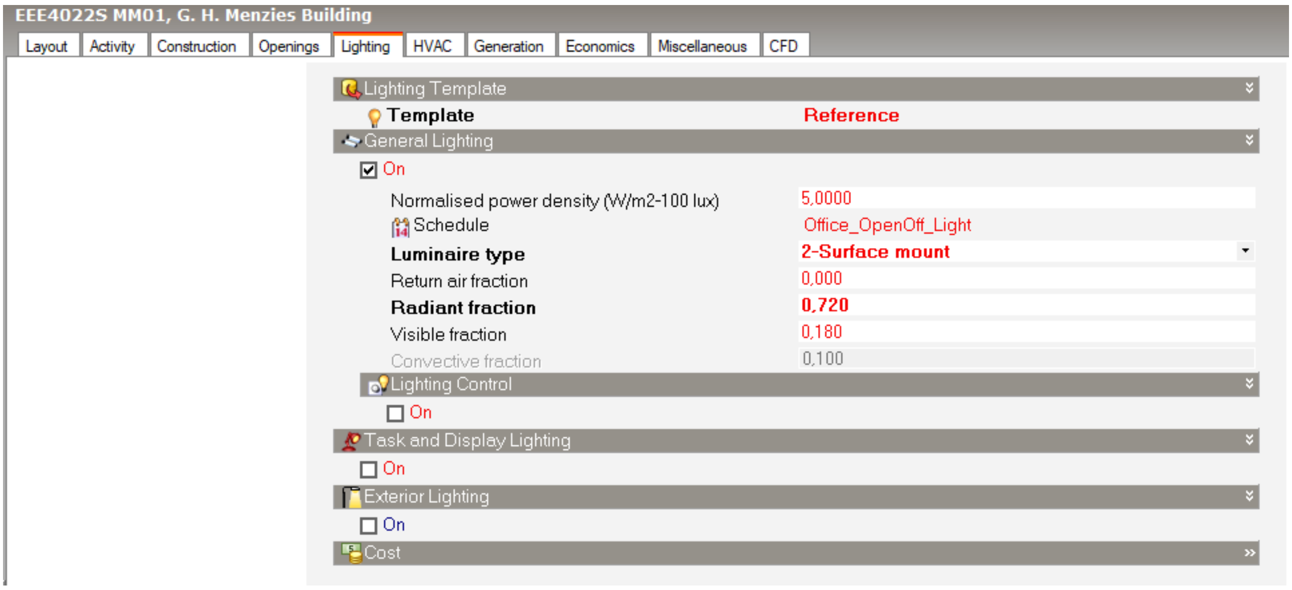

Figure 32: Lighting details for calibration model

Below is a screenshot of the HVAC options selected.

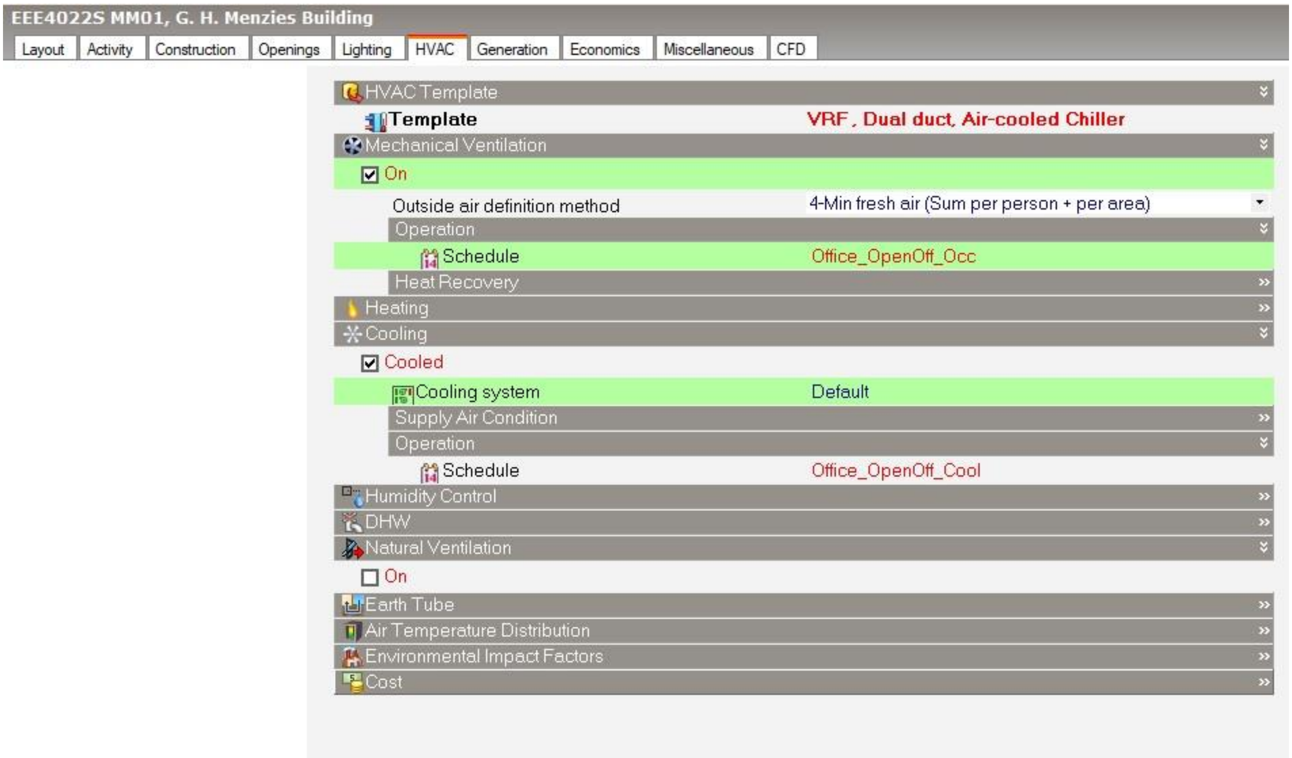

Figure 33: HVAC options selected for calibration model

Options selected for intervention method 1: Upgrading lighting system

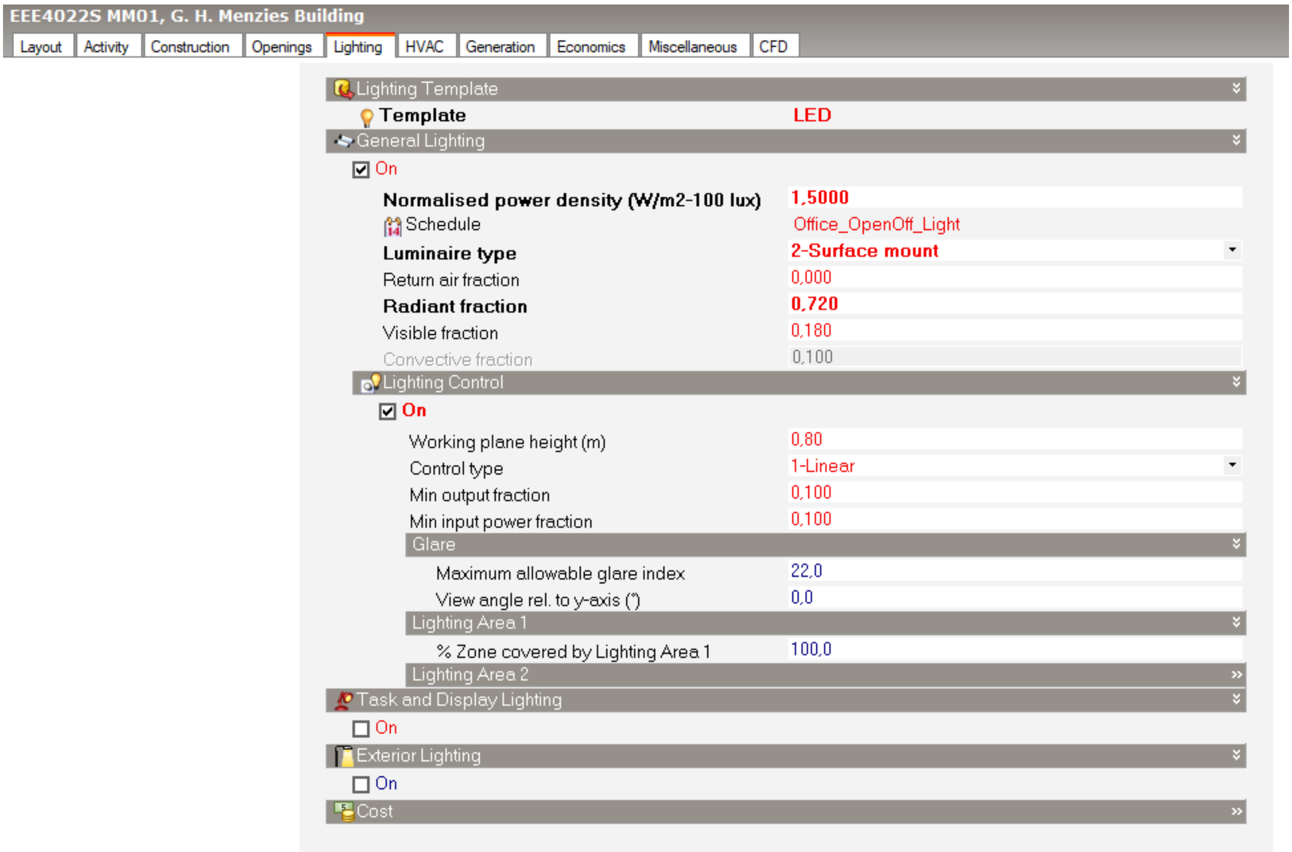

Figure 34: Lighting details for upgraded lighting system

Options selected for intervention method 2: PV Systems

Below are screenshots of the specifications of the PV system

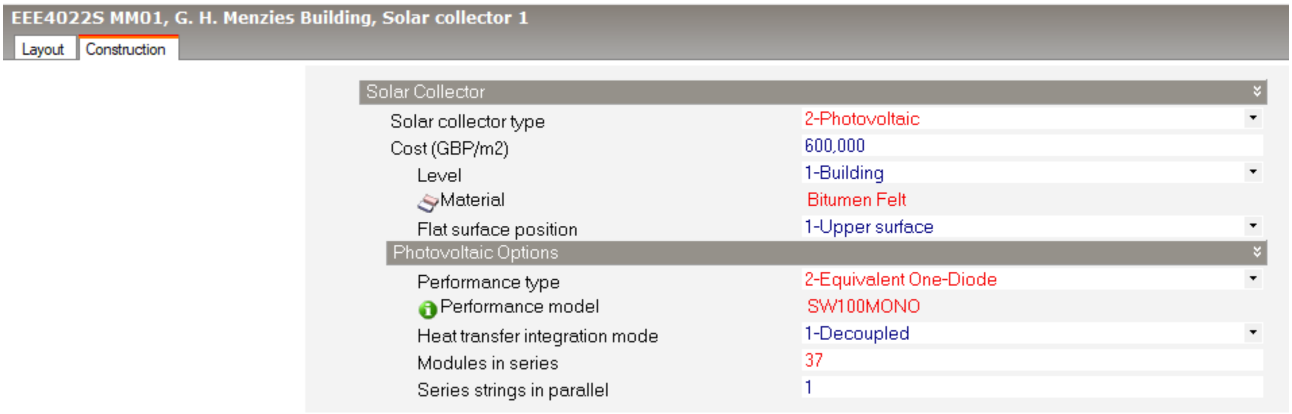

Figure 35: Details of the PV system

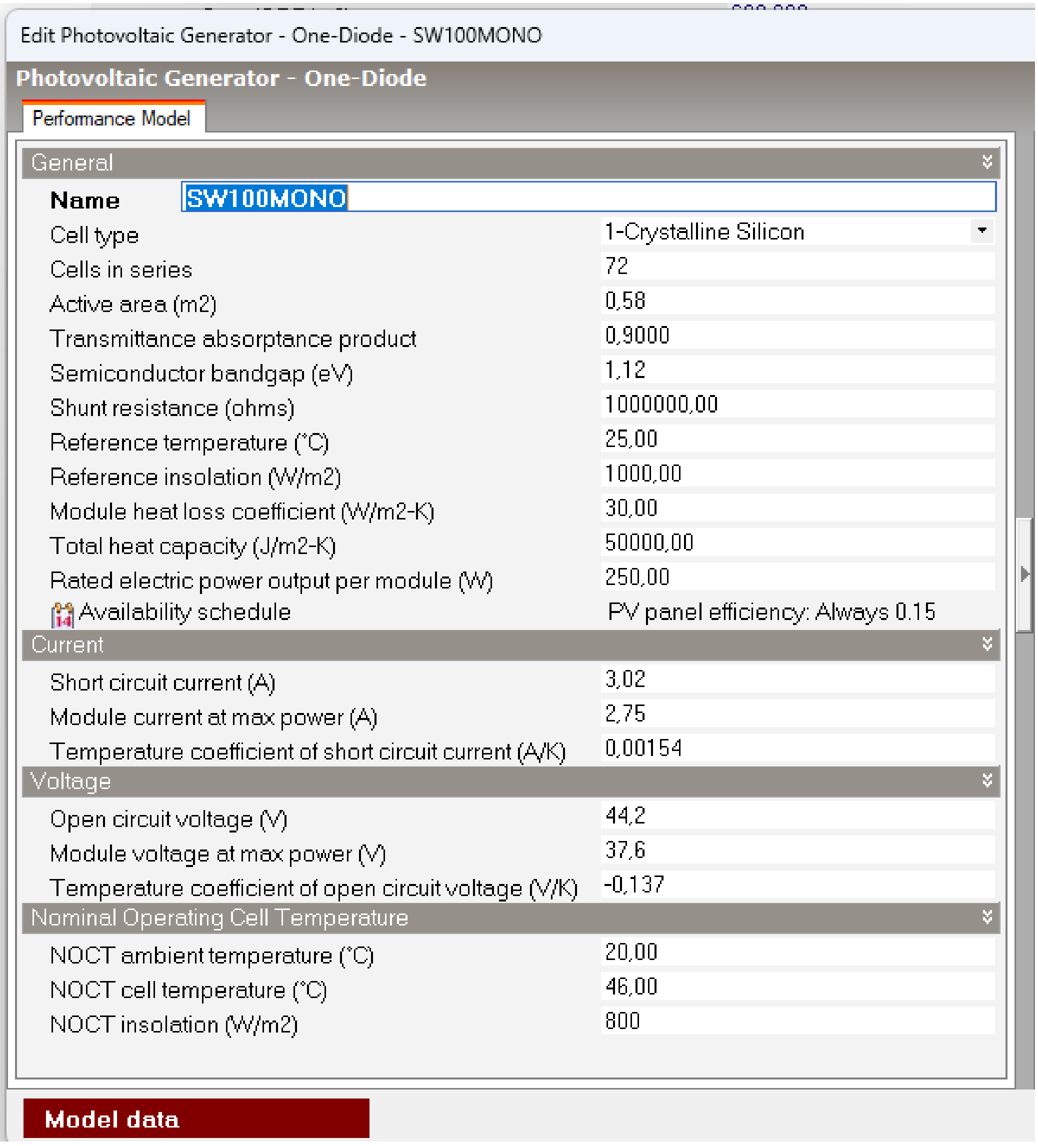

Figure 36: Details of the Equivalent One-Diode performance model

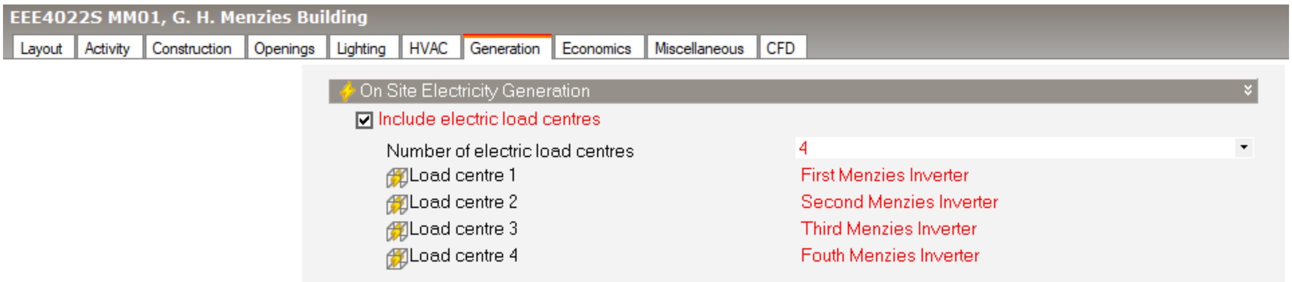

Figure 37: Screenshot showing the 4 load centres used for the PV system

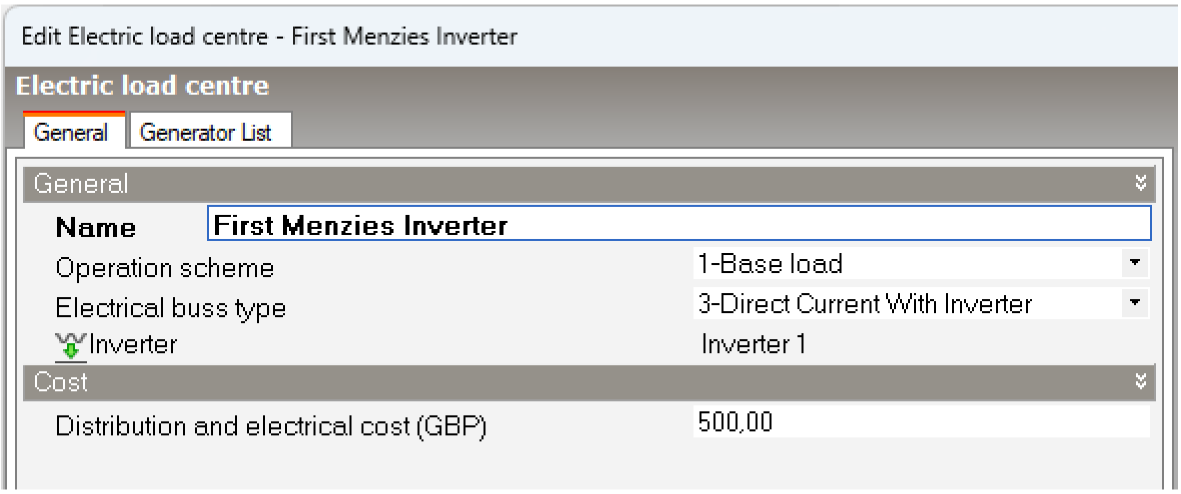

Figure 38: Details of the inverter model used by PV system

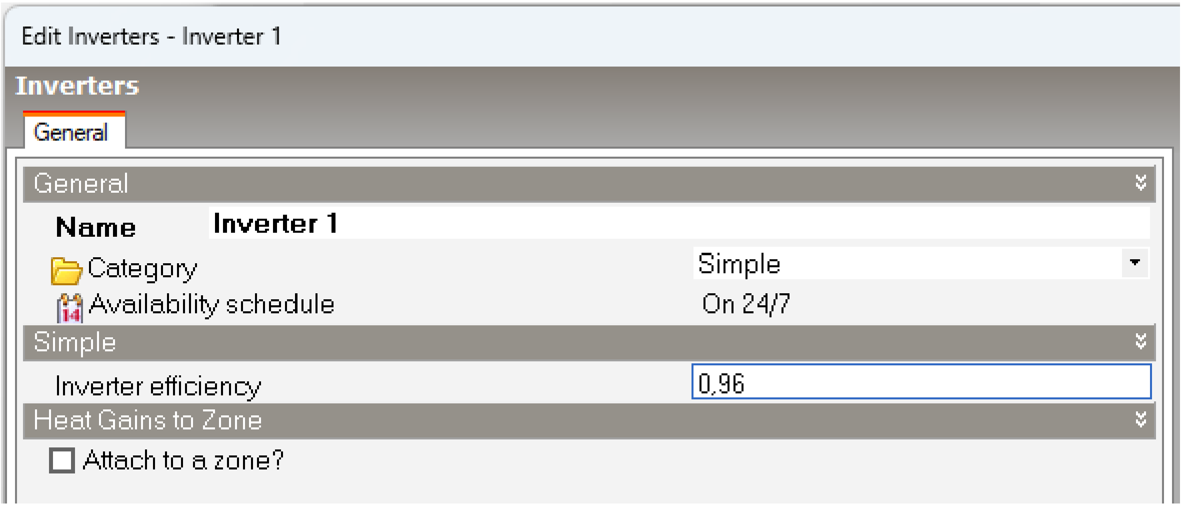

Figure 39: Further details of the inverter model used for the PV system

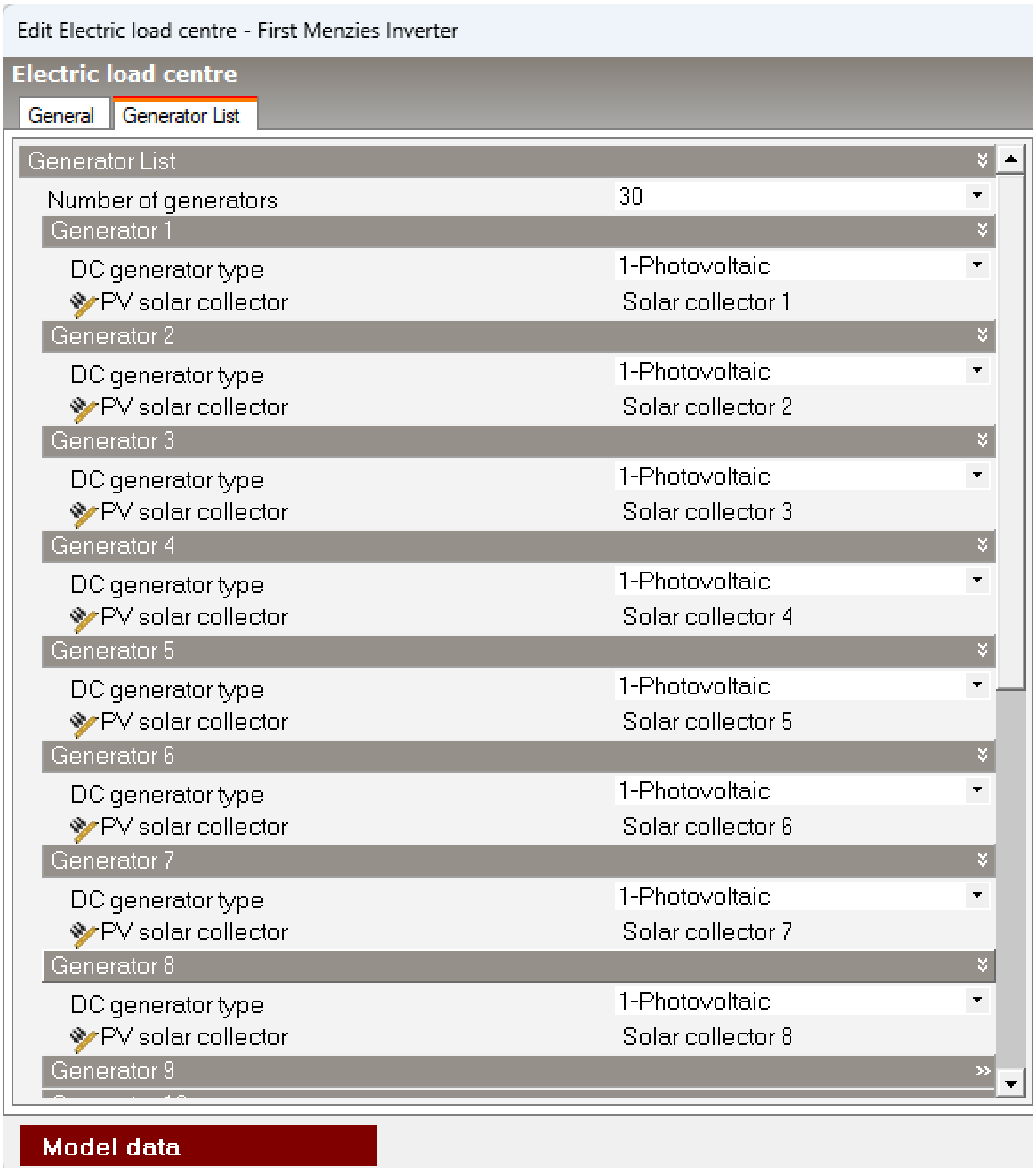

Figure 40: Screenshot showing PV arrays attached to one load centre

Drone footage was captured to assist with modelling the roofs of G.H. Menzies building as the plans provided were not clear.

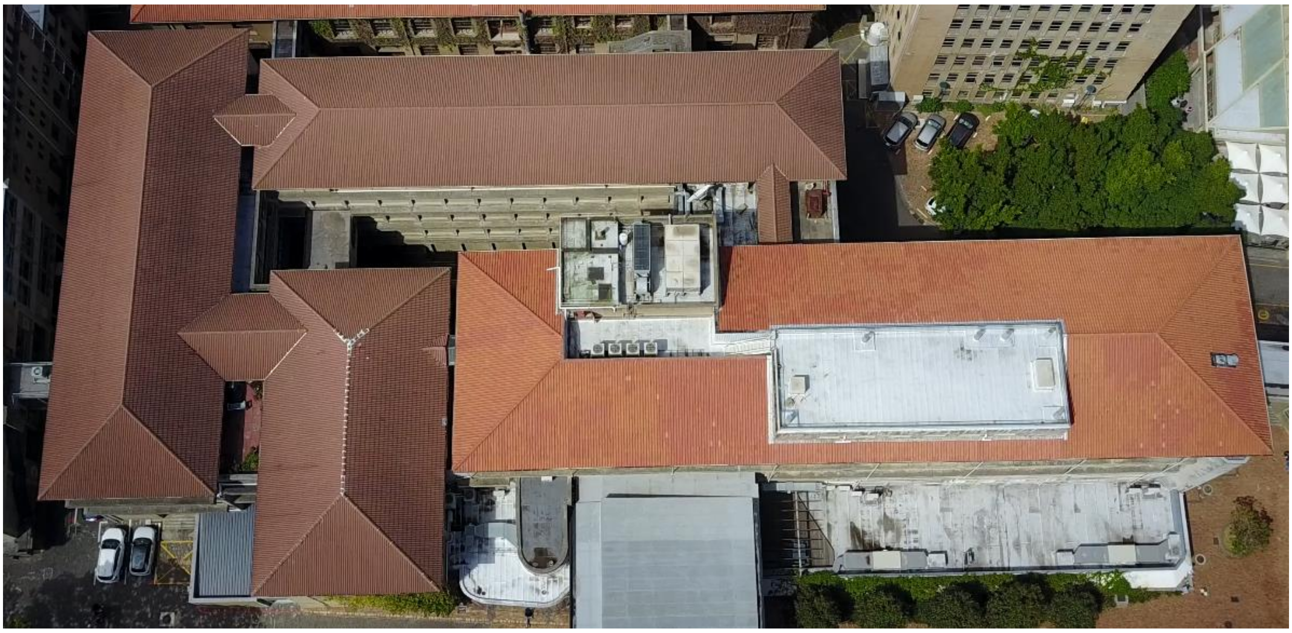

Figure 41: Screenshot of drone footage

11. EBE Faculty: Assessment of Ethics in Research Projects

Any person planning to undertake research in the Faculty of Engineering and the Built Environment at the University of Cape Town is required to complete this form before collecting or analysing data. When completed it should be submitted to the supervisor (where applicable) and from there to the Head of Department. If any of the questions below have been answered YES, and the applicant is NOT a fourth year student, the Head should forward this form for approval by the Faculty EIR committee: submit to Ms Zulpha Geyer (Zulpha.Geyer@uct.ac.za; Chem Eng Building, Ph 021 650 4791).Students must include a copy of the completed form with the final year project when it is submitted for examination.

Name of Principal Researcher/Student:	Akhil Biji Jacob	Department:	ELECTRICAL ENGINEERING
If a Student: YES	Degree: BSc (Eng) Mechatronic Engineering	Supervisor:	Mascha Moorlach

If a Research Contract indicate source of funding/sponsorship:

Research Project Title: Investigation of building energy consumption and the effect of energy efficiency interventions in a commercial building.

Overview of ethics issues in your research project:

Question 1: Is there a possibility that your research could cause harm to a third party (i.e. a person not involved in your project)?	YES	☒
Question 2: Is your research making use of human subjects as sources of data? If your answer is YES, please complete Addendum 2.	YES	☒
Question 3: Does your research involve the participation of or provision of services to communities? If your answer is YES, please complete Addendum 3.	YES	☒
Question 4: If your research is sponsored, is there any potential for conflicts of interest? If your answer is YES, please complete Addendum 4.	YES	☒

If you have answered YES to any of the above questions, please append a copy of your research proposal, as well as any interview schedules or questionnaires (Addendum 1) and please complete further addenda as appropriate.

I hereby undertake to carry out my research in such a way that

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

Signed by:

	Full name and signature	Date
Principal Researcher/Student:	Akhil Biji Jacob	06 November 2022

This application is approved by:

Supervisor (if applicable):	Masha Moorlach	06 November 2022
HOD (or delegated nominee): Final authority for all assessments with NO to all questions and for all undergraduate research.	Janine Buxey	06 November 2022
Chair: Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above		

ETHICS APPLICATION FORM

Please Note:

Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Akhil Biji Jacob
Department		Electrical Engineering
Preferred email address of applicant:		jcbakh001@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	BSc. (Eng)
	Credit Value of Research: e.g., 60/120/180/360 etc.	40
	Name of Supervisor (if supervised):	Mascha Moorlach
If this is a research contract, indicate the source of funding/sponsorship		
Project Title		Investigation in building energy consumption and the effect of energy efficienct interventions in a commercial building.

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University.
- the stated objective will be achieved, and the findings will have a high degree of validity.
- limitations and alternative interpretations will be considered.
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Akhil Biji Jacob		18 Aug 2022
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	MFC Moorlach		19 Aug 2022

APPROVED BY	Full name	Signature	Date
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).			
Chair: Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the questions in Section 1.			