FEASIBILITY STUDY OF EXTRA-LOW VOLTAGE DIRECT CURRENT POWER DISTRIBUTION

UNDERGRADUATE THESIS

SEMESTER 2 PROGRESS REPORT

by
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in the division of . . .

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Associate Professor Geoffrey Walker
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Dear Professor Walker,

In accordance with the requirements of the degree of Bachelor of Engineering / Bachelor of Finance (IX28) in the division of Computer Systems Engineering / Electrical and Electronic Engineering, I present the following thesis entitled Feasibility Study of Low Voltage Direct Current Power Distribution. This work was performed under the supervision of Associate Professor Geoffrey Walker.

I declare that the work submitted in this thesis is my own, except as acknowledged in the text with references, and has not been previously submitted for a degree at Queensland University of Technology or any other institution.

Yours sincerely,

DAVID PETRIE.

Acknowledgements

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Abstract

This design project aims to explore the issue of incorporating low or extra low voltage direct current (DC) power distribution systems to multi-residential and commercial buildings. Low voltage DC power is prevalent in telecommunications systems but has the possibility of being used for a variety of other applications to reduce electricity costs and improve efficiency. Due to the large costs involved in building power systems, the majority of this design project will be completed through software simulations and hand calculations. If successful, a more efficient and cheaper alternative to running simple electronics from Alternating Current (AC) mains will be created.

To complete this task, the project was separated into individual questions. These questions will cover finer details of the project including the chosen DC voltage level, whether photovoltatics can be used, if lighting requirements will be met, structural design and safety mechanisms for voltage loss reduction and finally whether DC could reasonably replace AC for portions of commercial building power systems.

The QUT data has been analysed and the results are positive. With the compared production and consumption curves that have been determined from the metering sources it appears certainly possible that the photovoltaic production will occur during times where the lighting based consumption occurs. This was expected however it was confirmed via these results. 48 V DC was chosen as the voltage level due to established applications in the real world, simple power calculations as well as commercially available products. The lighting models for the final commercial office floorplan design have been created however full analysis has not yet been completed. From initial calculations of expected lighting requirements, it confirms that at this stage of the project it remains feasible. Final calculations have not been completed at this stage.

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1 Introduction

In most Australian homes, power is consumed directly from the local distribution grid. All appliances are connected to one switchboard but can be separated over various circuits each with their own protective devices, usually circuit breakers. Generally, many modern Australian appliances will use Direct Current (DC) electricity but the outlets provide an Alternating Current (AC) source of 240 V at a frequency of 50 Hz. Each device therefore requires a converter that changes the AC source into the required constant DC voltage and current specific to that device.

This project will consider the feasibility of diverting a portion of power distribution from the standard 240 V AC sourced from the grid with an alternative solution. The considered option is utilising a low voltage direct current on a separate grid to power known low consumption devices such as LED lighting or electronics charging devices. An efficiency and financial analysis will be completed through hand calculations and software simulations.

This project will specifically focus on two aspects of this broader topic. These are whether alternative power generation systems will be utilised and whether the new possibilities for generation and distribution methods could be used in applications larger than residential homes. The additional locations for this application that will be analysed are apartment and commercial complexes. There will be a variety of design possibilities considered to find the optimal low voltage DC alternative implementation. To do this there will be a focus on cost, efficiency and usability comparisons of equivalent AC and DC systems.

2 List of Abbreviations

AC	Alternating Current
DC	Direct Current
W	Watts
kW	Kilowatts
kVA	Apparent Power
PV	Photovoltaic
DB	Distribution Board
MSB	Main Switch Board
MSSB	Mechanical Services Switch Board
SLD	Single Line Diagram
CAD	Computer Aided Design
NEW	NEW
SAM	System Advisor Model
PME	Power Monitoring Expert
QUT	Queensland University of Technology
GP	Garden's Point Campus
KG	Kelvin Grove Campus
Lux	Lumens per m^2
LED	Light Emitting Diode

Table 1: List of Abbreviations Table

3 Research Problems

The key problem that this research paper will be targeting is the feasibility of implementing a separate DC power distribution system for the specific purpose of powering LED lighting circuits and simple electronics. Additionally, the goal is to implement these systems into a commercial building and apartment setting within Australia. For a stronger understanding and case study, Brisbane city will be analysed due to high illuminance and numerous high rises. Designs will be tested predominately through software simulations however hardware will be used where it is technically and financially feasible. In order to answer this key question and complete the project, sub questions were separated and discussed.

1. Can direct current power be a suitable alternative to alternating current when efficiencies and costs are compared?
2. What is the optimal voltage level for a low voltage DC system when considering loads, costs and efficiencies?
3. If feasible, how can a photo-voltaic system be implemented to power these circuits?
4. Can lighting load and lux requirements be met through this system?
5. If feasible financially and technically, how can the proposed power distribution methods be implemented in commercial buildings effectively?

3.1 Initial Design Consideration

The research completed and discussions with the project supervisor has allowed for an initial concept for what could be a feasible design. The main design constraints are that cable lengths need to be short, the power generation should be with photovoltaic (PV) systems and due to load constraints, many micro-grids should be used. To do this, with tall and thin buildings it would be possible to use PV cells instead of shading or window awnings to generate electricity. Each floor has their own cells and generates electricity to power their lighting and simple electronics.

Utilising Steven Donohue's findings of 48 V DC being the most suitable voltage level for these forms of systems, the plan is to base calculations off the assumption he was correct [13]. The cables being run would follow Australian building standards at $2.5\,\mathrm{mm}^2$, two core and earth and would easily provide the necessary current carrying capacity. These cables would feed to separate, dedicated switchboards for a purely DC supply and then through to LEDs where a highly efficient DC-DC converter needs to be found or designed. Each floor would therefore have it's own switchboard to power an area between $50\,\mathrm{m}^2$ and $100\,\mathrm{m}^2$ although further calculations are required to confirm this. An office space is approximately $9\,\mathrm{m}^2$ requiring only 4 LEDs to provide necessary lux levels meaning the load for lighting should not exceed 40 W and at 48 V DC this equates to only 0.83 A. With multiple rooms such as this, the design should be feasible with further simulations.

These initial considerations have been expanded on throughout the investigation with more detailed analysis and simulations. Section 10.3 outlines the above calculations however with access to QUT data as well as technical knowledge from research more accurate designs and calculations were completed in Section 6.3.

4 Background & Literature Review

4.1 Literature Review

4.1.1 Power Systems

4.1.1.1 Existing Power Distribution Systems

Power systems consist of four major sections; generation, transmission, distribution and loads shown in Figure 1. AC electricity is generated in power plants and sent through high voltage transmission lines to substations and distributed to switchboards for use in residential, commercial and industrial areas [14]. In order to transport electricity over large distances (excess of 2km) without severe losses, very high voltage and low current is used [14]. This is voltage is lowered and current increased by a transformer at the substation and again at the residence. For electricity to reach the home and be utilised for devices there must be safety mechanisms installed to ensure damage is not done to the user or devices. The protective devices requiring consideration throughout this project will be fuses, circuit breakers and switchboards [15]. These devices are placed through the circuit to protect the more expensive equipment closer to the transformer and grid.

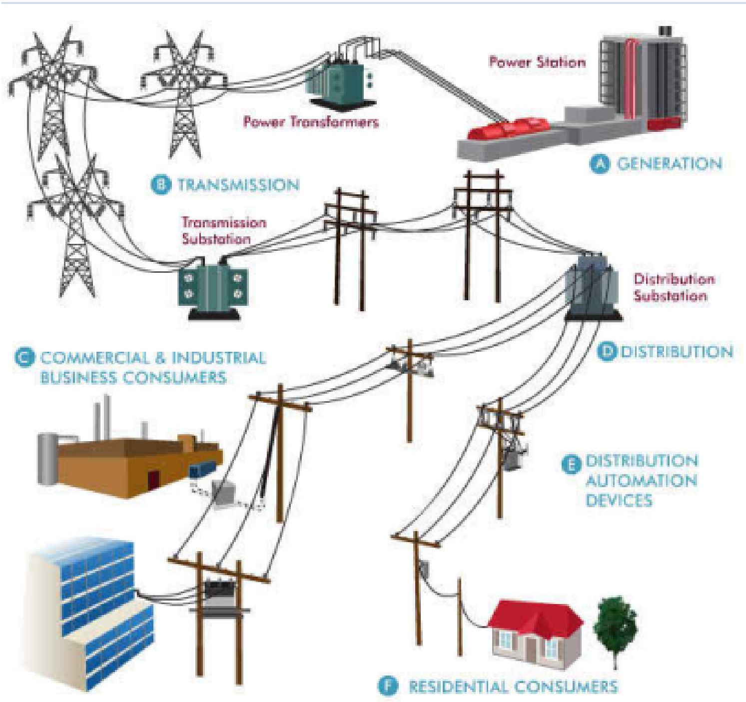


Figure 1: Existing Common Power Distribution Methods [1]

4.1.1.2 Commercial and Industrial Power Systems

There are relatively large differences between home and commercial power systems. A home application is fairly simple wih a transformer feeding electricity into one distribution board (DB) or switchboard (SB) that provides safety mechanisms along with circuit breakers for the home circuits. In a commercial setting, the loads are far higher and require a stable connection [16]. For an apartment complex, shopping centre or business building, the supplies are generally separated into buses in order to identify separate requirements or areas. The requirements could be essential items (including emergency lifts, safety equipment or machines that cannot be stopped) or non-essentials (tenancies or general equipment). Additionally it can be used to separate the entire building's load over towers or zones to minimise faults. Figure 2 represents a single line diagram showing the two separate buses for a design.

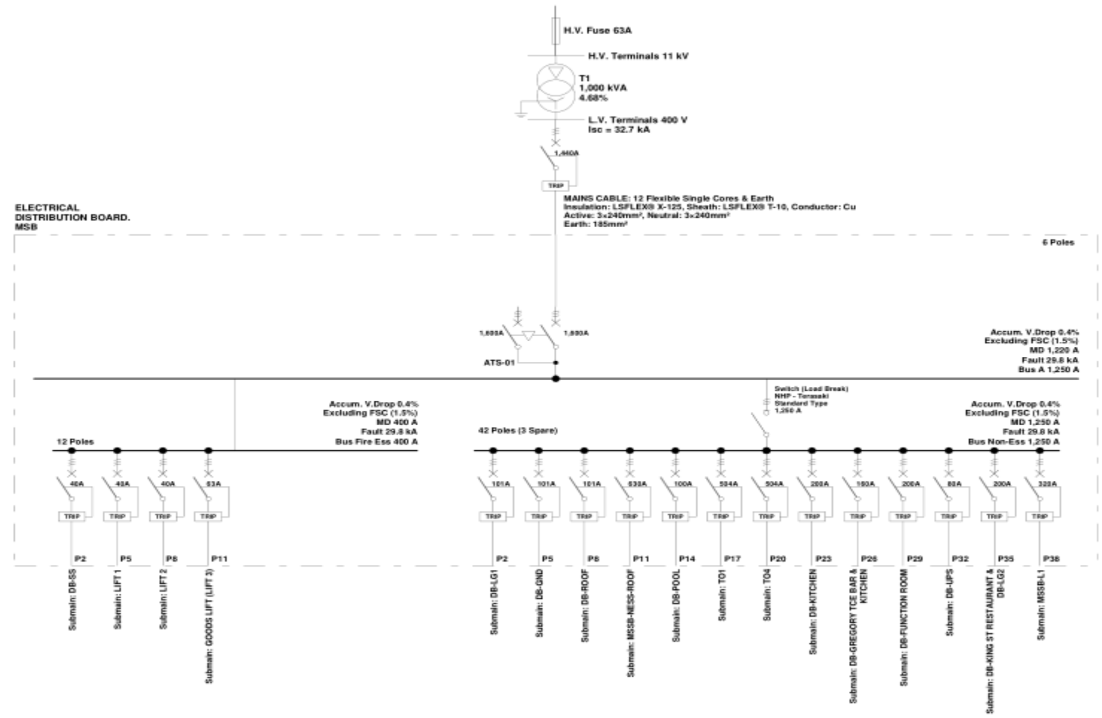


Figure 2: Example of Single Line Diagram - Hotel/Multi-Residential Building

4.1.1.3 Electrical Safety Mechanisms

For electricity to each the home and be utilised for devices there must be safety mechanisms installed to ensure damage is not done to the user or devices. The protective devices requiring consideration throughout this project will be fuses, circuit breakers and switchboards [15]. These devices are placed through the circuit to protect the more expensive equipment closer to the transformer and grid. A fuse is a simple device that acts as a sacrificial lamb for the protection of the more expensive devices. An internal wire will melt when too much current flows through therefore interrupting the connection [15]. A circuit breaker is a smarter and re-usable version of a fuse that is triggered by over current, overloads or shirt circuits to fulfil the same purpose [15]. The switchboard is a device that connects a home or building to the electrical grid and allows for individual circuits to be run for different purposes throughout the complex [15].

4.1.1.4 Summary of Power Systems

This section covered the main concepts of power distribution systems. This knowledge will be integral to understanding where the extra-low voltage design will begin and how to efficiently incorporate it with existing infrastructure. The safety mechanisms will have to be considered for a system that is not based on traditional AC concepts.

4.1.2 Regulations

4.1.2.1 Standards

Australian standards will be an integral part of this project. If the rules and regulations are not adhered to, the devised system will not be legally approved for installation. There are four standards that will be relevant to this report; AS3000, AS3008, AS1680 and AS3015. The AS/NZS 3000 covers the standards related to electrical installations or wiring rules within Australia and New Zealand [17]. These standards will be the main reference point. The AS/NZS 3008 which are the regulations specifically related to electrical installations and cable specifications will be vital [18]. An additional set of standards that will be used for initial calculations and estimation of building load requires is AS/NZS 1680 which are the lighting regulations and requirements for interiors and workplaces [12]. These standards outline the lux levels required by rooms depending according to their purpose allowing 3D models to be created. The AS/NZS 3015 specifically dictates the rules with regards to electrical installations of extra-low voltage direct current power supplies and services earthing within public telecommunications [19].

4.1.2.2 Voltage Levels as per Australian Standards

The Australian Standards (AS/NZS 3000: Wiring Rules) outline the specific voltage levels that distinguish circuits [17]. This information is required for both separate standards related to the design and distribution of each chosen voltage level. Extra-Low Voltage is any voltage that is either 50 V AC or 120 V DC ripple free [17]. Low Voltage is any level above Extra-Low Voltage but not exceeding 1000 V AC or 1500 V DC [17]. The final level is High Voltage which is anything exceeding Low-Voltage [17].

4.1.2.3 Tariffs

Tariffs will be an important consideration with the feasibility of this project due to the possibilities of cost reduction. In residential buildings, the financial benefit from PV installations is load shifting and for commercial buildings it is maximum demand reduction. Government policies have been put in place in order to prompt an increase in investment in renewable energy sources [20]. Users are able to sell their unused generated electricity back to the grid to reduce their overall electricity bills or possibly profit if consumption is low enough. In Queensland, different retailers practice competition through increasing the feed-in tariff for customers. The average price available is $0.06/kWh [21].By not connecting the photo voltaic panels to the grid, this tariff can not be received however the energy can be stored in batteries and discharged during non-production periods for possible increase efficiency [22]. The consideration will be whether the cost reduction in electricity bill will be worth the investment in the equipment and future cost reduction.

4.1.2.4 Summary of Regulations

There are a multitude of required standards that will be relevant to the designs created throughout this project. For the accurate feasibility of extra low voltage installations, all the above mentioned Australian standards will be referenced to find the appropriate lighting levels, voltage drop requirements, electrical installation spacings and any other design specific regulations. Although it is expected to be an extra-low voltage system, the standards will allow proper specifications if the level is above or below. The tariffs will be employed during financial calculations

4.1.3 Concepts

4.1.3.1 Direct Current vs Alternating Current

A very broad and contextual understanding must be made regarding the differences between DC and AC distribution systems. Compared with traditional AC designs, DC has the potential for effective power supply, smaller feeder loss, increased efficiency, more consistent power and direct access to renewable energy solutions [23]. Alternating current is run to outlets tests at 240 V AC, 50Hz and then devices are used to alter that source into device specific source requirements. Many household electronics such as computers, chargers, lighting and televisions operate internally at DC voltages meaning they each require either internal conversion circuitry or use a transformer between the powerpoint and device [24].

AC was originally chosen as the better choice for power distributions due to there being no method at the time for controlling DC electricity at the load causing large losses from the generator to device [25]. To remedy this, AC distribution was used due to efficient transformers being developed to boost the voltage. AC remains the fundamental power type but DC is growing in popularity with improved converters and increased quantity of DC energy sources [25]. Utilising DC generation systems could also fulfil the power industry's obligation to increase the sustainability of their systems and be more environmentally conscious [26]. The required converters to change the AC supply into DC for electronics reduces the efficiency (increasing voltage drop) of the overall system [25].

4.1.3.2 Alternative Electricity Generation Solutions

In order to increase efficiency of power systems through utilising a low voltage DC sub-system, alternatives to drawing standard AC electricity from the grid must be considered. In Australia, a strong option for the generation alternative is PV systems (known commonly as solar panels). These systems will convert the sun's rays into electricity and power devices via a regulator and a DC to DC converter [27]. This converter is designed to allow the panels to power varying DC loads. If the panels are being used for AC loads, an inverter will also be required and if the system is stand-alone a battery will also be required. For the purpose of this project, a vital aspect of DC distribution is the removal of the inverter allowing for the removal of losses caused by these circuits.

4.1.3.3 Summary of Concepts

A strong understanding of the differences in both physical electrons and their movement as well as the systems in place to operate both AC and DC power will be integral. Additionally with the investigation into DC systems, photovoltatic arrays will be investigated due to both efficiency financial benefits. Because the load will be DC, a converter will not be required.

4.1.4 Relevant Equipment

4.1.4.1 Large Scale Batteries

Due to photovolatic systems producing power during daylight but in the evenings will not produce, a solution needs to be established for power consumption during non-production hours. There are additional benefits of solar battery storage as well due to the financial markets associated with energy [2]. For example, if the spot price for energy is specifically high later in the evening due to increased demand, a user with battery storage from the day's production could export into the grid and make significant profit. It is not always a necessity to have battery storage however there are certainly benefits in particular situations. Figure 3 shows a broad, high-level view of PV system connection options [2].

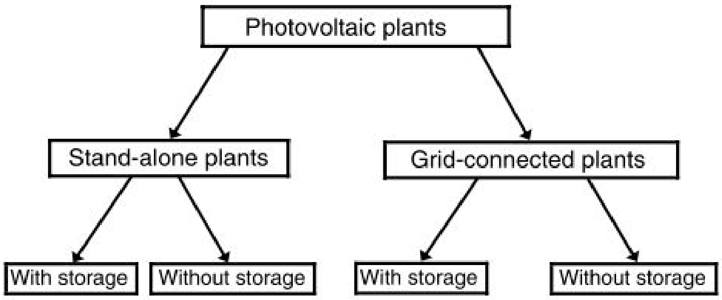


Figure 3: Photovoltaic Connection Options Pyramid [2]

Incorporating a battery into the design of the system is not extremely complicated. Figure 4 below shows a suggested connection option. The devices as per their numbered labels are:

1. Solar generator
2. Charge controller
3. Battery
4. Discharge controller
5. DC-DC converter
6. DC-AC converter
7. Consumers
8. Possible auxiliary generators (such as diesel or wind)

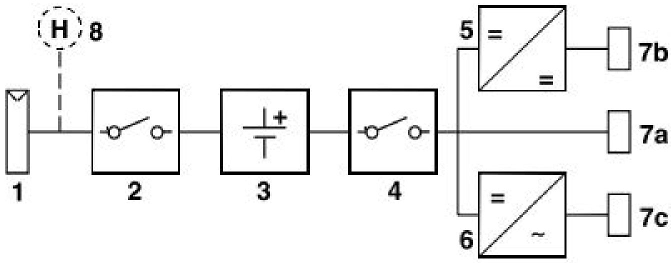


Figure 4: Photovoltatic System Model with Battery Integration [2]

The storage process occurs in item 3; the battery. The nominal voltage of this device in a stand-alone system should match the installation's system voltage [2]. There are voltage level alternatives depending on the design of the system such as 12 V, 24 V, 48 V or higher for larger installations [2]. In Australia, recent developments have seen lithium-ion battery solutions being used for solar storage far more than older technologies such as lead acid [28]. Lithium-ion has many advantages for hybrid storage applications. They have a higher energy density and have the ability to regularly discharge [28]. The estimated lifespan of these devices is a minimum of 15 years [28]. A popular development in this market is the Tesla Powerwall which incorporates the same batteries that Tesla uses in their cars but in a different application [29].

4.1.4.2 Converters

Converters are electrical devices designed and constructed to convert current between AC and DC [30]. Rectifiers are used to convert the voltage from AC to DC and inverters converter from DC to AC [30]. Although these are the technical terms for the two devices, in general the term "converter" can be used. A specific use for inverters is to convert the DC electrical generated from solar panels to AC for transfer back into mains or to the necessary switchboard. An additional use for these is in Uninterrupted Power Supplies (UPS) where DC battery power is stored and it is converted to AC when connected into existing power systems for to maintain power during grid errors [30].

4.1.4.3 Buck and Boost Converters

Buck and boost converters are a subset of the converter section above. These are used in DC to DC power systems where the voltage needs to be stepped up or stepped down

[31]. For smaller applications, chips such as the LM2575 buck converter are available to reduce voltages according to a feedback. Boost converters do the opposite and increase the voltage. These devices are frequently used with Photo-Voltaic systems depending on what loads they are feeding [31]. The panels generate electricity that is fed through a boost converter then into an inverter to convert the electricity to AC in order to be distributed throughout the circuit [31].

4.1.4.4 Direct Current Switchgear

Direct current devices will be required for a system that is not standard alternating current. With the increase in purely DC systems used for a variety of purposes, DC switchgear is readily available commercially. Eaton have a range of DC-DC Circuit breakers that are designed for energy storage, transportation and industrial DC circuits [32]. Specific design mechanisms were established in order to meet the protection requirements for PV systems.

For designs that use a large amount of DC devices, efficiency purposes suggest using a DC distribution board. There are commercially available products designed for such purposes. For example, Myers Power Products, Inc have designed a range of DC power solutions including traction power substations, DC switchgear, DC circuit breakers, rectifiers and inverters if required [3]. An example of a DC distribution room is shown in Figure 5.

Figure 5: Example of DC Main Switchboard Room [3]

4.1.4.5 LED Lighting

Table 2 below shows a technical comparison of three common lighting types. Improvements in LED lighting allow less power to be used for the same brightness. It is possible to design and create an energy efficient Low-Voltage DC (LVDC) grid powered LED lighting system with additional automation aspects and energy storage [10]. Typical lighting systems are fluorescent bulbs or tubes that are powered directly from standard 230 V AC due to the devices' high efficacy [10]. When comparing an AC fluorescent system and a LVDC LED system, the LVDC grid system requires significantly less power conversion which increases the overall efficiency [10]. The table below represents these factors. For applications, this means less physical lights are necessary for equivalent light reducing project costs [33].

Lighting Type (Bulbs)	*Incandescent*	*CFL*	*LED*
Average Lifespan (hours)	1,200	8,000	50,000
Wattage (at 800 lumens)	60	13-15	6-8
Lumens/Watt	13.3	53.3	114.3

Table 2: Comparing Efficiencies of Lighting Types (Bulbs) [10]

4.1.4.6 Summary of Equipment

Initial considerations make photovoltatic arrays a strong possibility for installation with batteries being considered if production is high enough. Additionally, batteries could be used to control load shifting if that is deemed beneficial. DC voltage regulation and level shifting will likely be required through buck and boost converters as well as rectifiers. There is DC switchgear available for purchase that specification sheets as well as drivers for LED luminaires. This further defends the hypothesis that the dedicated extra-low voltage system will be feasible.

4.2 Photovoltatic systems

4.2.1 Photovoltaic Arrays and DC Arcing

With the popularity of PV systems increasing, the risk of DC arc faults are being analysed further [34]. PV arrays and power systems are being designed with converters boosting voltages to 800 V DC and 1000 V DC. This is being done for efficiency and cost reduction purposes however it leads to large amounts of stress on insulation systems and arc faults developing [34]. This causes more safety concerns than traditional AC systems. There are three major causes of arc fault risk; high DC voltage, high DC current and large distribution of DC wiring [35].

Photovoltaic generators are non-linear sources that vary with intensity of sunlight and behave mainly as a DC current source [36]. There is an additional negative of PV systems than AC due to the occurrence of DC arc faults. The DC circuits that combine to form the PV power system distribution are able to generate and sustain arcs of considerable intensities. DC arcs have their uses in applications such as welding, but for a power system they are only a risk [36]. The risks of DC arcs can be reduced by incorporating proper safety equipment and reducing DC voltage levels [36].

4.2.2 Photovoltaic Mounting Solutions

4.2.2.1 Fixed Mounted

There are multiple options for fixing modules to the selected surface areas and each has their own merit. The most popular solution are frames specifically designed to mount an array of panels on a roof, ground or other surface and keep them still in place. This is known as a fixed mounting scheme [2]. Clips or conventional screws can be used to mount the modules to these frames. Two examples of this mounting scheme is shown in Figure 6 and Figure 7.

Figure 6: Photovoltaic System Mounting Example: Fixed [2]

Figure 7: Photovoltaic System Mounting Example: Roof Mounting [2]

4.2.2.2 Building Integration Mounting

There also exists creative solutions to mounting photovoltaic modules. This can be replacing roof material with modules or using them as window awnings. An example of this from the US Embassy in Geveva is shown in Figure 8.

Figure 8: Photovoltaic System Mounting Example: Window Awning [2]

4.2.2.3 Single and Dual Axis Tracking System

The yield of modules can be increased by implementing tracking systems in the modules' installations. These can be single or dual axis tracking systems. Single axis, as the name suggests, means that it will shift in one direction, back and forward, traditionally on a timer. The idea behind these is that as the day progresses, the module is able to shift to continually face the sun and receive the maximum luminance in order to increase production [2]. An examle of this installation is shown in Figure 9. Dual axis, again as the name suggests, shifts the module across two axes for even further increased production from the installed modules. These systems of course both require power to operate so it is possible to have a higher production than fixed axis however net production after operating the control systems could be lower.

Figure 9: Photovoltaic System Mounting Example: Single Axis [2]

4.2.3 Summary of Photovoltaic Systems

Photovoltaic modules will be a welcome addition to this project. Safety considerations will have to employed to prevent DC arcing in installations. For a commercial building it is likely that fixed mounting will be the ideal option due to single axis requiring larger surface areas to avoid self-shading.

4.2.4 Extra Low Voltage

4.2.4.1 Extra-Low Voltage Direct Current

DC power is currently restricted to special applications such as telecommunications, electric vehicles and high-voltage direct current (HVDC) transmission [37]. Low-voltage DC power systems at 48 V DC has been used fairly widely with telecommunications systems but is recently facing issues due to the high power requirements of computer system upgrades [37]. Studies have shown that the 48 V DC system still remains more efficient than a 270 V DC or 200 V AC but further investigation needs to be done into 230 V DC and 325 V DC through retrofitting existing low voltage AC installations [37]. PV generators are used frequently for these forms of power distribution systems as it can be powered directly or use simple DC to DC converters for different devices. Utilising a DC distribution system makes it easier to incorporate local power generation. This reduces costs and local power is unaffected by issues with power grid [26].

4.2.4.2 Extra-Low Voltage Direct Current in Telecommunications

Using low voltage energy distribution grids for high-speed communications networking can open up the possibility to utilities for expansions of widespread local area networks [38]. This could be services such as telephony and internet access without the necessity of additional cabling [38]. Firstly, this voltage level is chosen due to it being under the maximum for low voltage power and still considered a “safe low voltage”. Additionally, this voltage level could be backed up by battery systems with four 12 V batteries in series similar to Figure 10. Many data centres or communications rooms for corporate buildings will establish arrays of 48 V battery banks [4]. A solution for areas without large enough storage areas for are limited and power demands are low a single 12 V battery with a 12 V to 48 V boost converter can be used [4]. This setup is shown in Figure 10. Additionally, due to this nature of power telecomms, standalone systems are becoming a more suitable means of supply [36]. Photovoltaic arrays, due to their DC source nature, could be used with a DC to DC boost converter and regulator to power these systems.

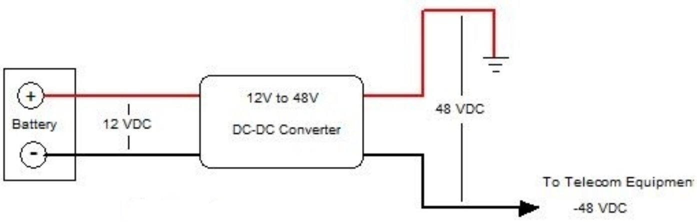


Figure 10: 12 V DC Battery Backup with 12 to 48 V DC Converter in Telecommunications [4]

4.2.4.3 Electrical Safety in Low Voltage DC

Fuses, mechanical and electronic safety switches / circuit breakers and their combinations operate the same in DC as they do in AC; detecting electric faults and switching off to isolate electrical equipment [39]. Plugs, sockets and safety equipment with nominal currents of 20 A are commercially available for pre-existing DC data centres [39].

4.2.4.4 Summary of Extra Low Voltage

Specific considerations are required for the use of extra-low DC voltage. Extra Low Voltage is deemed as voltage levels under 50 V. 48 V DC is a commonly used voltage level and has several successful case studies available. Due to the extensive research into these systems, commericially available products as well support the voltage level and data can be found on how to accurately model these systems.

4.3 Prior Art

For a thorough research project to be completed, devices that have already been designed, tested and created must be research and analysed. With the popularity of DC power systems increasing in recent years, there have been an many more academics assessing the possibilities. Due to the predominately theoretical design nature of this report and similar aspects of previous papers, a significant focus was made on previous project reports.

4.3.1 Past Academic Work

4.3.1.1 Donohue: Extra-Low Voltage In-Home Power Distribution and Storage

Donohue completed his undergraduate thesis at QUT in 2014 [13]. This paper assessed various aspects of the similar topic question but specifically focussed on using low voltage DC electricity in homes to power lighting systems. He also considered battery storage solutions and discovered that 48 V DC was the best option for voltage levels for this application [13]. He proposed that an installation model for low voltage distribution was uneconomical with current solar feed-in tariffs [13]. The final discussion of lighting application proved to be successful using LED lighting circuits in home. Donohue's project will be an asset to the completion of this thesis as the overall concept is very similar. It will be possible to make some assumptions and avoid investing time on smaller calculations due to Donohue's extensive research.

4.3.1.2 Foss: DC Supply In Buildings

From the University of Science and Technology in Norway, Aurora Bøhle Foss completed her master's thesis on incorporating DC supply into buildings with a larger focus on commercial buildings [40]. Her focus wasn't specifically on low voltage DC however it did incorporate some research and testing into the feasibility of these systems. Her research found that the most important aspect of incorporating DC supplies into power systems is a highly efficient Voltage Source Converter (VSC). She determined that if a load is requiring AC, it is more efficient to use an AC source. It has been found that higher power loads and cable lengths longer than 10 metres using 1.5mm^2 and 2.5mm^2 are impossible due to severe losses.

4.3.2 Conceptually Similar Applications

4.3.2.1 Remote Area Power Supplies

Remote are power supplies (RAPS) are utilised in situations where access to main power grid is either non-existent or untrustworthy [41]. They can be created in a variety of ways with gas and diesel generators being popular but expensive [41]. Specific to this project, recently renewable energy generation methods have been used to install power systems in these areas. By designing a successfully performing solar panel, battery and converter these locations can have access to much needed electricity [5]. Ahmad Zahedi from Monash University, Australia has designed a solar battery power supply for the purpose of helping nursing clinics and vital services in remote communities [5]. The structure of his system is as follows and is shown in Figure 11.

- PV generators with mechanical support and future plans for sun tracking system
- Battery storage in series
- Power conditioning & control including measurements and monitoring
- Buck-Boost regulator

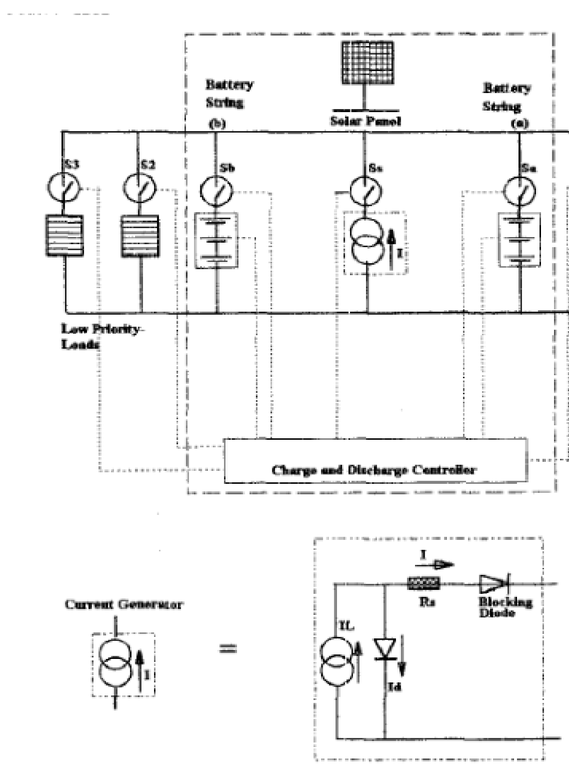


Figure 11: Block Diagram for Photovoltaic Remote Access Power System [5]

4.3.2.2 DC Data Centre

Interest in 400 V DC power systems has also been increasing in recent years for applications in telecommunications and data centres [6]. Lisy and Smrekar from Emerson Network Power produced a paper with three case studies of DC powered telecommunication buildings with one case being how an existing −48 V DC large telecom site is powered by 400 V DC distribution [6]. This application has 400 V DC cabinets that distribute power over long cables to 400 V DC to 48 V DC converters located near the −48 V DC load [6]. This was done to minimise the amount of copper used by converter an entire 48 V DC system to a 400 V DC and 48 V DC combination.

The site supports an 80 kW load. Initially, two 120 kW 400 V DC power systems will be installed to support a maximum of 2000 A of −48 V DC end loads. Each system is built up of eight, 15 kW modular rectifiers and expansion is made possible in future. Each side has four, 336 V DC battery strings comprising of 28 12 V DC cells connected to the power system for up to 4 hours of backup in the event of AC failure. This is shown in Figure 12.

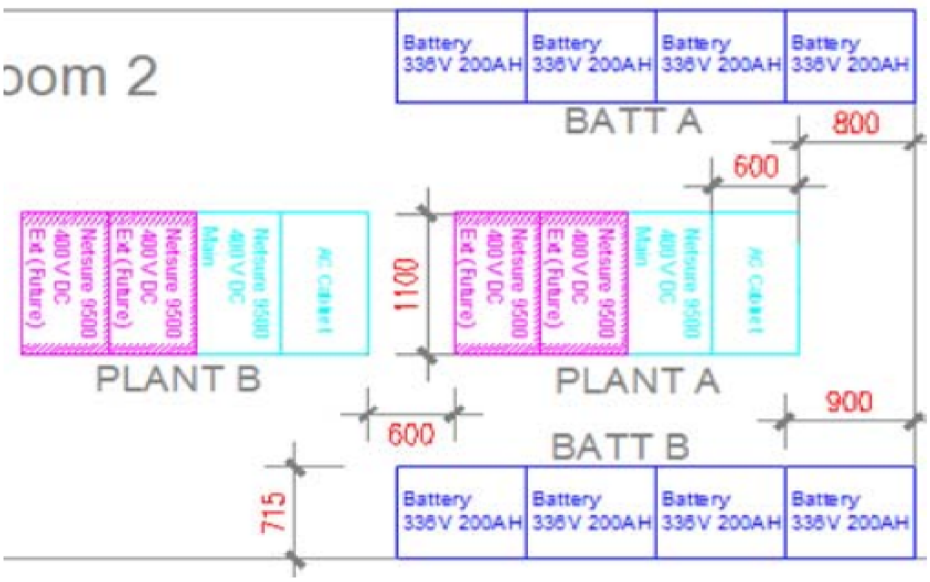


Figure 12: Example Floor Plan of DC Backup Data Centre [6]

4.3.2.3 Low Voltage Substations DC for Mining Sites

Low Voltage DC distribution is used in some mining sites including underground mines [42]. This is used for a variety of purchases but predominately at 550 V DC or 250 V DC for machinery [42]. These machines are locomotives and face equipment and generally a polyphase rectifier circuit is employed for the AC mains [42].

A related design system launched in 2015 is the ABB's prefabricated DC rail system [43]. These are modular substations designed to save time and money when working in both the real estate and mining sector within Australia [43]. These modular power systems offer flexible, adaptable and portable solutions to supplying DC power to devices. Each unit comes with pre-assembled with 11, 22 or 44 kV switchgear with a rectifier for 750 V DC to 1500 V DC [43]. They are self-contained and include an integrated power supply which reduces risk of power loss overall [43].

4.3.3 Relevant Commercial Products

4.3.3.1 Enphase Micro-Inverters

A competitor to the system that will be designed throughout this thesis will be recent developments in micro-inverter technologies by Enphase [44]. These products are designed to be efficient, small and affordable to allow for the DC electricity generated by photo-voltaic cells to be converted to 240 V 50Hz AC for the mains. A wide range of fittings are possible depending on the PV cells and switchboard distribution. They have a rated efficiency of 95.7% [44].

4.3.3.2 Existing Extra Low Voltage DC in Commercial LED Ballasts

There are already products in existence that are designed to drive (another term for power in this instance) LED luminaires from DC rather than AC. An example of this are the Tridonic dimmeable and fixed output DC/DC LED drivers [45]. This model takes 12-24 V DC at 700 mA with a maximum DC input of 29 V. The maximum DC output is 22V with output current of 0.7 A and output power of 16 W [45]. Additionally, the datasheet provides the maximum power loss of 0.65 W therefore the device has 96% efficiency.

5 Program and Design

5.1 Objectives

The objective of this research project is to attempt to answer the overall question of whether a low voltage DC power distribution system could be implemented to power low load devices such as lighting, simple electronics and charging devices. Secondly, it must be determined whether this is a more efficient solution than existing AC installations. The final objective is to relate this project directly to renewable energy generation and a commercial setting.

5.2 Methodology

In order to complete this task within a timely manner and ensure all aspects are thoroughly considered and discussed, a clear guideline of tasks musts be followed. Additionally, these tasks will need to specifically address the objectives that the research proposal addresses. As will be further discussed in Section 3, there are five broad questions that are being addressed throughout the two semesters of this thesis. The methodology of the thesis is predominately theoretical and simulation based with the possibility of some physical testing if time permits. A reliance on previous research and design recommendations will be important [14]. Although research into improving DC systems has increased, this project will be focusing on an area that has not been sufficiently researched and analysed [7].

The five separate questions are related to the same solution. Initial stages of the project require extensive research on the possibilities and theories behind a purely DC system. Once a strong idea of the possibilities and previous papers were analysed a general analysis of whether or not 48 V DC is the ideal voltage level is secondary. To do this, it will be predominately theoretical with voltage drop calculations over standard cable lengths and areas. Additionally research will be used to back up findings. Software and research will be used to assess the options with solar panels and the best method of implementing them into the solution. Queensland University of Technology's Building Management Services provided access to power production and consumption data with both historical and current graphs. Additionally, schematics and floor plans for P and Y Blocks have been given which will assist in the creation of an approximate floor plan for modelling and feasibility. studies.

SMART goals will be used to measure the progress. This framework is based off having goals that are specific, measurable, attainable, realistic and timely. These goals are the milestones that are described. By doing so, tasks can be achieved and a regular logbook of activities maintained for process improvements. Spreadsheets and in-built software data storage will be used to record the findings. These findings will be analysed either through additional hand calculations or Matlab. Figure 13 below shows the methodology behind technical design tasks.

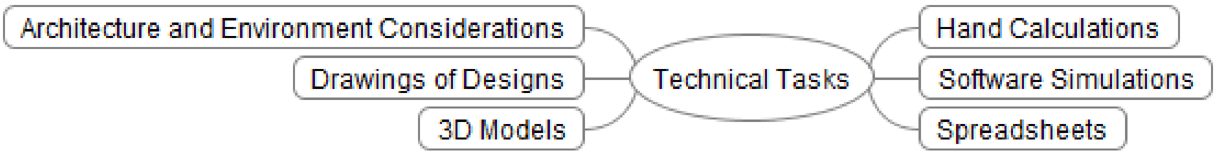


Figure 13: Technical Design Task Considerations Mind Map

5.3 Research Plan

A majority of the project will completed through simulations and calculations utilising Dialux4.12, AutoCAD, Microsoft Excel and System Model Advisor. This is due to power systems electronics being expensive and large scale testing out of the financial scope of this project. Ideally, a full system would be built with Photovoltaic cells, battery, controller, DC-DC converters and connections to appliances, however finances will not allow this. Figure 14 below shows a basic PV DC system and the areas requiring consideration.

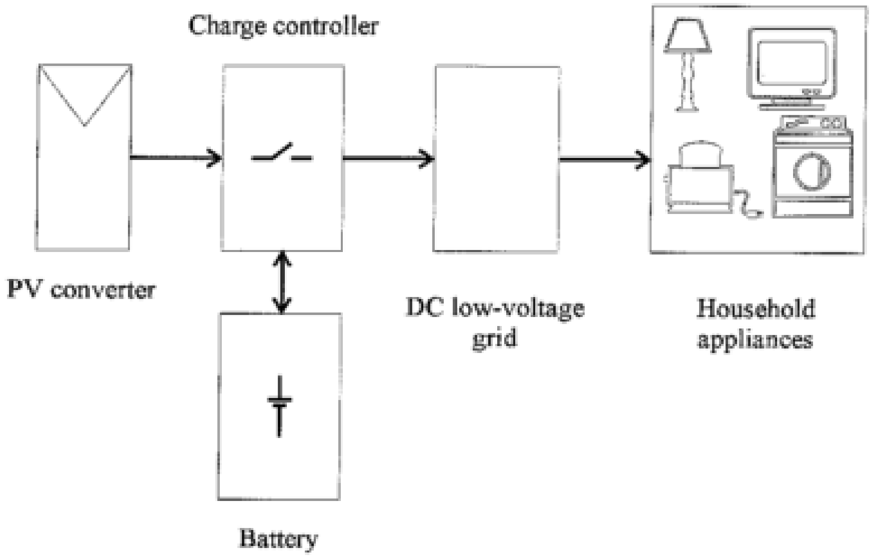


Figure 14: Initial Design Consideration System Diagram for DC Home Power System [7]

The software will allow for data collection and spreadsheets used to track and assess. The benefit of using spreadsheets and Matlab is that formulas can be input and optimisation simulations run. If simulations are not being used and physical tests are required, a multimeter or computer interfaces will be utilised. If testing cannot be performed or simulated, additional research will be completed to find the closest solution possible. If this method needs to be done, it will explicitly stated in the final report that not all aspects could be physically tested.

5.4 Resources and Funding

The design and construction of this project would require a substantial amount of resources. Due to this, computer assisted design (CAD) programs will be used as the main design calculation feasibility analysis mechanism. The University facilitating this research project will allocate $50 for each student through purchase order applications. This value will be taken into consideration when designing possible testing mechanisms or models for the presentation. It is unlikely that anything other than computer simulations and rendered images will be used to compliment calculations in the presentation.

5.5 Project Team

As previously stated, this project is being solely undertaken. Although this is the case, there are three undergraduate engineers undertaking topics that are interrelated. In addition to the task discussed within this project report focusing on low voltage DC systems in larger applications, the other two undergraduates are analysing sub-issues in the same broad topic of DC electricity. There will be discussions between the three undergraduates on relevant articles, journals and standards that each individual finds.

5.6 Progress and Remaining Tasks

Appendix item 10.2 shows a more detailed and up to date set of timelines with milestones and the dates they were reached or plan to be reached. This section will be a brief description of progress made to this point including specific additions in the most recent 6 months.

5.6.1 Completed

The project has progressed into its final stages with the majority of initial analysis having been completed. Sufficient background research and literature review has been completed and the knowledge and information gained from this utilised to complete the report. Skills with the chosen software have been improved in order to effectively model and comment on data. The feedback from the project supervisor has been implemented throughout as it was received. Due to the extensive research, data analysis and draft modelling, the final design phase of the project should progress without delays or failures.

5.6.2 Discussion

In the previously mentioned Appendix 10.2 it is outlined where siginficant delays were faced. Specifically, further technical calculations and design simulations were completed past pre-planned deadlines. Time was allocated during the summer break for further technical calculations but due to personal travel and commencing full time work immediately upon returning this deadline moved forward. Additionally, meeting and receiving feedback became far more complicated with conflicting schedules. Finally, the initial financial calculations have not been completed due to prioritising design over those calculations. There is no doubt that the finance will be simple to complete once design is finalised.

5.6.3 Remaining Tasks

Throughout the report, there are sections that remain incomplete with notes suggested specifying the intended blank space. Although this documentation process appears incomplete it is to outline more specifically intended discussion and calculation points for the remainder of the project. The final tasks remaining are all part of the final design phase.

- Design
  - Complete custom design of Brisbane corporate building
  - Commercial building max demand calculations
  - Commercial building cable length and voltage drop table
  - Quantity of photovoltaic modules required
  - Roof area required to install required modules
  - Detailed consumption vs production analysis to determine storage or supplementary power requirements
  - Efficiency comparison
- Finance
  - Capital investment
  - Lighting upgrades
  - Energy savings
  - Return on investment
  - Payback period
- Documentation
  - Tabulate necessary data

- Re-work document for flow and remove redundant sections or information
- Ensure all acquired data is organised in the appendix

- Additional (time permitting)
  - Brief room layout for apartment complex
  - Proposed design for DC distribution in apartment complex
  - Similar design methodology to the list above

6 Analysis and Discussion

This section will be the initial discussion of testing, calculations and analysis. Progress made will be discussed here however Section 7 is where the questions are specifically answered. Firstly, this section was used for a draft model to be created for initial testing and current demand expectations. This was to be a temporary estimation until more accurate information was acquired or calculated. The model will break down a custom designed small office floor plan to estimate lighting loads. The creation of this model was from basic square office shapes, hallways and a kitchen. Sizes were estimations based off approximate office sizes from experience viewing offices in Brisbane buildings.

After the production of the draft model access to QUT schematics, floor layouts and metering data was obtained. Section 6.1 will be a breakdown of available data and an analysis of what this means for the remainder of the project. The photovoltaic systems installed also have a secondary metering system that allows for specific monitoring of production curves and comparison to the consumption of the campus. Using this data, production and consumption curves can be estimated and compared so a DC to DC design can be created for feasibility and simulated. This stage will be close to the final model for answering the overall project question of whether this concept is feasible for commercial buildings.

6.1 QUT Electricity Consumption and Generation Data

To design a feasible commercial building incorporating low voltage DC electricity an approximate building size and layout was required. QUT's Building Management Services department kindly provided access to building schematics and metering data. Operation and maintenance manuals including electrical drawings, single line diagrams, architectural drawings and electrical specifications were received. These were integral to designing an accurate, "real world" model to test the feasibility of the proposed system.

6.1.1 Meteo Control

The first data management system that QUT has installed is Meteo Control Energy & Weather Services. This system connects and monitors the four separate PV arrays that QUT has installed throughout the Garden's Point Campus; P Block Level 10, P Block Pergola, P Block Solar Trees and Y Block Level 11. Figure 15 below shows an exert from Google Maps with mark-ups of these sections in practice. This monitoring system provides enormous quantities of useful data including:

- Technical data
- Info Center
- Data analysis
- Monitoring
- Reporting
- Metering management
- Solar Account (Finances)
- Environment (Carbon Footprint)

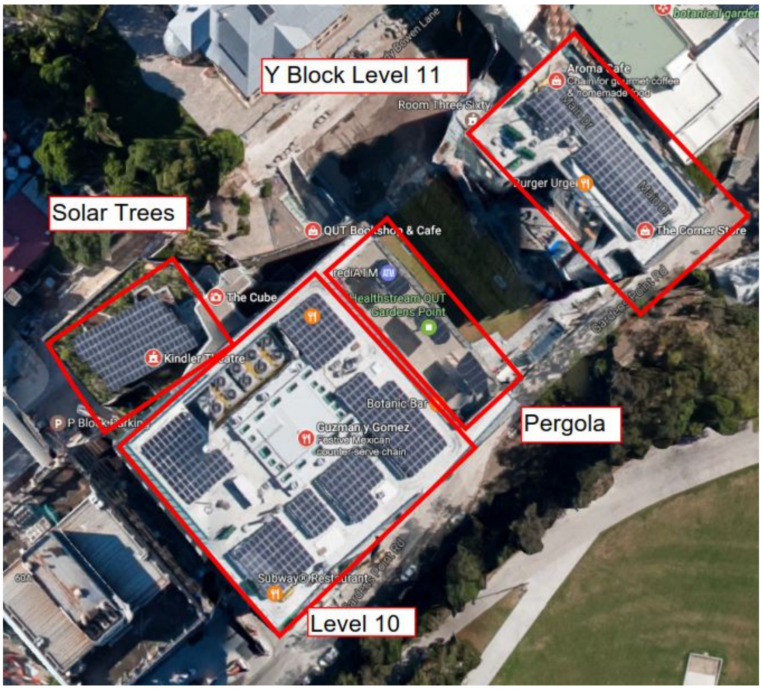


Figure 15: QUT Garden's Point Geographical Satellite Image with Markup of PV Sections

The main page provides an intuitive summary of the modules to provide information on the life of the installation shown below in Figure 16. This image was taken at May 15, 2017 for the P Block Level 10 and shows the existing returns that the specific installation has provided. It also breaks down the production curve for the day and daily production for the month and year so far. Although the financial information is useful, installations of PV will vary in the financial benefits.

The reasoning behind is that different energy providers will allow certain benefits and installations for varying costs. For example, if a client wishes to back-feed (also known as feeding electricity to the grid) certain agreements are required to be made with providers in order to be considered a generator. Additionally, depending on the size of the installation, module manufacturers or distributors may give different discounts per unit reducing the overall capital outlay and reducing the return on investment.

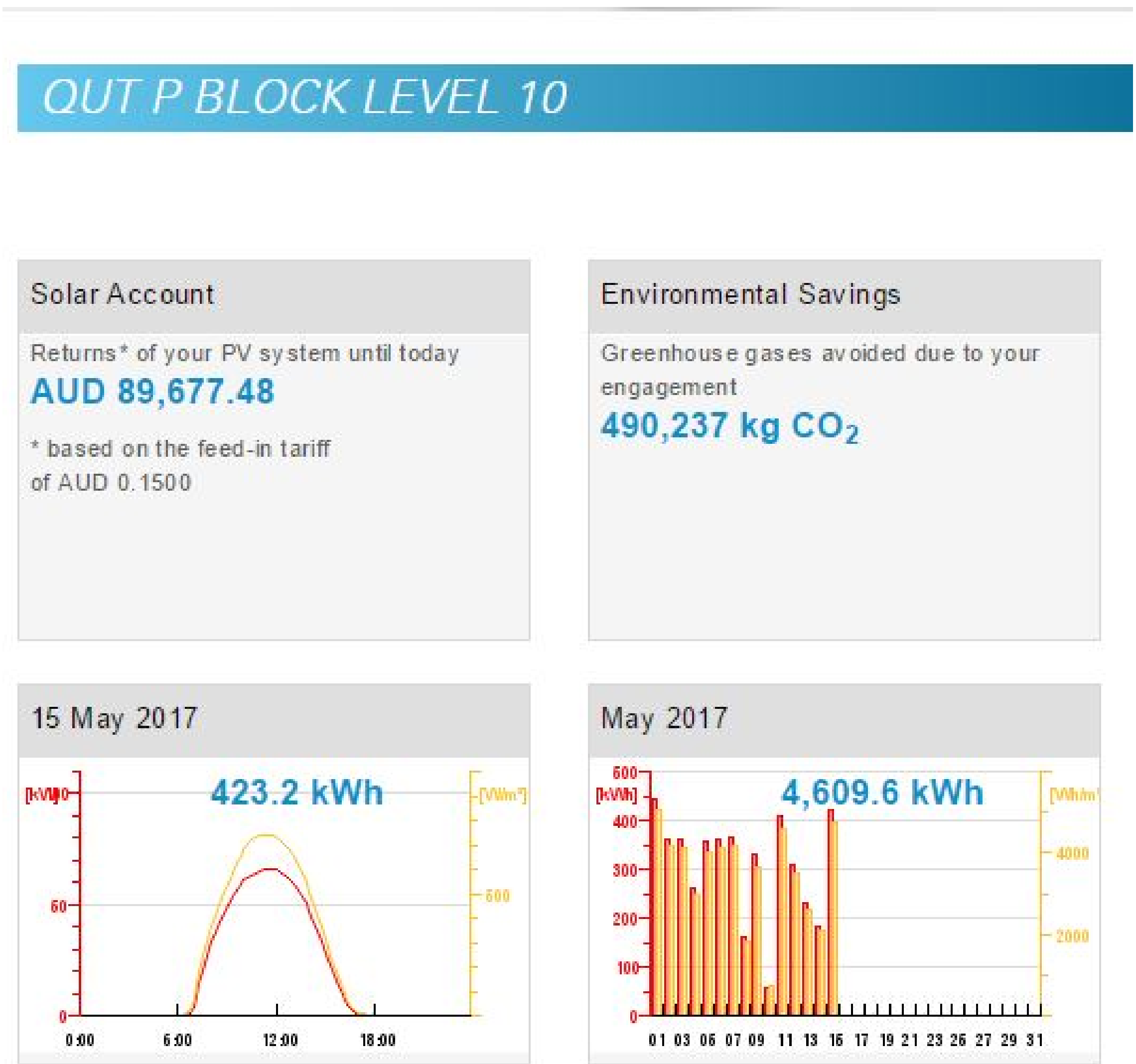


Figure 16: QUT Garden's Point Data: P Block Level 10 Meteo Photovoltaic Summary

6.1.2 Power Monitoring Expert

The second monitoring software that QUT Facilities Management allowed access to is Power Monitoring Expert v8.0. This will be used to provide an insight into the load demands of the building that would impact design. Figure 17 outlines the Garden's Point Electricity Metering system. The data is access through a interface closely linked with the single line diagrams of buildings including main switchboards (MSBs), distribution boards (DBs) and transformers. This information is critical to understanding optimal power system design.

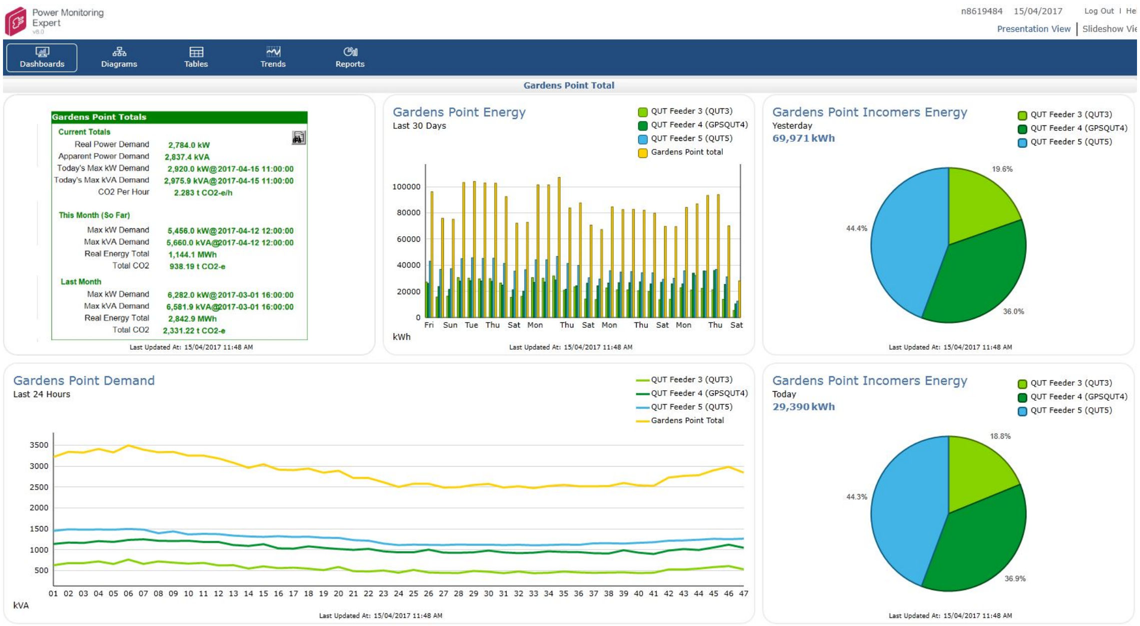


Figure 17: QUT Garden's Point Data: Power Monitoring Expert Dashboard

The EMS system additionally outlines how the PV system at QUT operates and what power it generates. The solar panels act as a load reducing generator rather than direct appliance powering. During the day the panels generate electricity and with a regulator and converter combination the DC generated power is converted to AC and fed into the University's power systems. The benefit of utilising the equipment in this way is that it reduces peak consumption which is when electricity prices are highest. The major difference between this design and the one which this project seeks to design is the panels will be directly powering loads.

6.1.3 Useful Data Interpretation

This section outlines the collation, analysis and interpretation of acquired data. Due to the quantity of data, the scope of the project was carefully considered during analysis.

6.1.3.1 Photovoltaic Breakdown

QUT P Block Level 10 (the same as Figure 16) was chosen as a model to analyse the modules, inverters and power quantities produced. Table 3 shows the breakdown of the 405 panel, 101.31 kWp installation. The specific model of module that was installed were the Suntech STP250-20/Wd which are a commercially available and average priced mono-crystalline 250 W panel. Additionally, there were two variants of the same model inverter installed. These are the 3.6 kW and 10 kW versions of the Power-One PVI OUTD/S. The sections on the physcial rooftop are outlined in Figure 18.

Section	**Area** (m^2)	**Peak Power (kWp)**	**Inverter**	**Arrays and Size**
1	25	3.75	1 x PVI-3.6	1 x 15
2	50	7.5	1 x PVI-10.0	2 x 15
3	139	21.02	1 x PVI-10.0	1 x 56 & 1 x 28
4	330	50.04	5 x PVI-10.0	1 x 140 & 1 x 60
5	38	5.75	1 x PVI-5000	1 x 11 & 1 x 12
6	41	6.25	1 x PVI-6000	1 x 12 & 1 x 13
7	46	7.00	1 x PVI-6000	2 x 14
TOTAL	**669**	**101.31**		**405**

Table 3: QUT P Block Level 10 Photovoltaic Array Installation

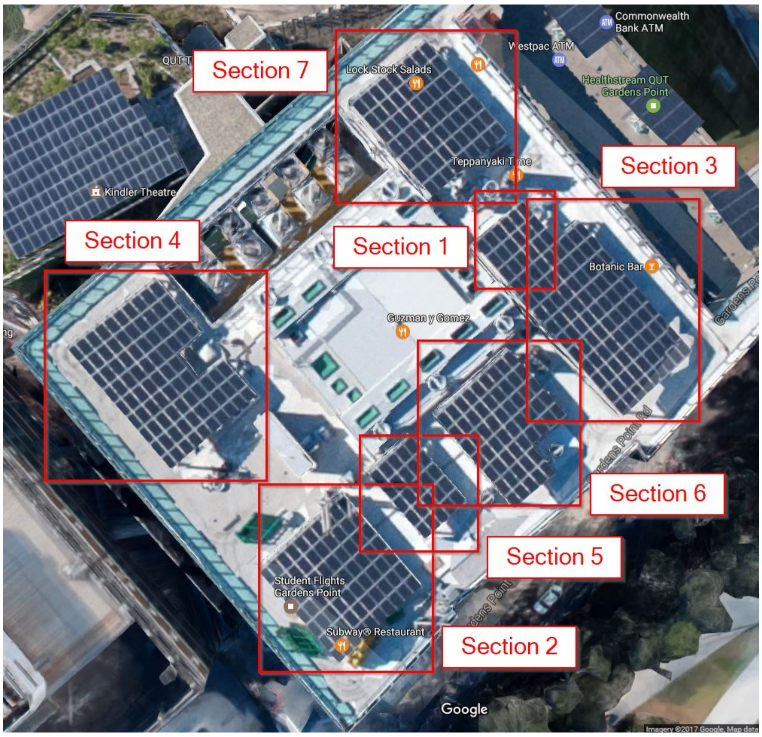


Figure 18: QUT Garden's Point P Block Geographical Satellite Image with Markup of PV Sections with reference to Table 3

6.1.3.2 Photovoltaic Production Data

Without production data, module quantities and associated inverters is of limited use. This monitoring system can provide and graphically represent the production over custom periods. To get accurate readings for Brisbane, Queensland (the location of the proposed system) the year of 2016 was assessed to give an accurate represented of predicted production capabilities. Table 4 outlines the figures exported by Metero and Figure 19 shows the graphical representation of the output as well as irradiance.

Table 3 shows that the peak power of the entire system is 101.31 kWp. Annually, the system generated 157,331 kWh of power equating to 1,522 kWh / kWp / year. To analyse whether this is a typical production expectation, the University of Queensland provides free access to their solar production data [8]. The output of this system is shown in Figure 20 with a 2,250 kWp system producing 2,428,422 kWh in 2016 [8]. This equates to 1,080 kWh / kWp / year which was surprisingly low. An industry rule of thumb is that in Brisbane with tilt angles close to the lattitude and north-east facing, production from a PV installation can receive 1,500 kWh / kWp / year. It should be noted that this assumption is reinforced by QUT's production data and will be used for future modelling assumptions.

Month	**Energy Per Month (kWh)**	**Energy Per Day (kWh)**	**Irradiance (kWh/**m^2**)**
January	15,360.13	495.49	179.68
February	14,491.13	499.69	170.18
March	12,987.95	418.97	151.04
April	11,976.68	399.22	137.84
May	10,820.50	349.05	126.70
June	7,869.84	262.33	87.05
July	9,704.54	313.05	107.52
August	12,199.19	393.52	136.48
Setpember	12,817.71	427.26	145.39
October	15,481.07	499.39	196.98
November	17,327.80	577.59	203.86
December	16,294.04	525.61	193.98
TOTAL	**157,331**		1,837

Table 4: QUT Data: P Block Level 10 2016 Production Summary Table

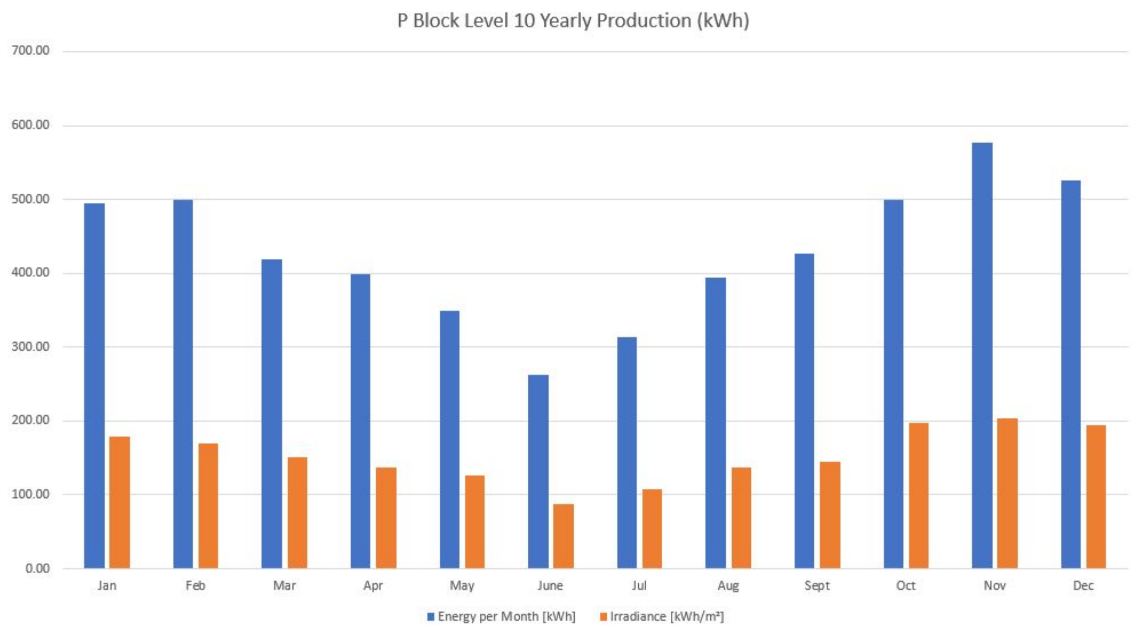


Figure 19: QUT Garden's Point Data: P Block Level 10 2016 Production Summary Graph

Figure 20: UQ Solar Data: St Lucia 2016 Production Summary [8]

6.1.3.3 Useful Conclusions

An important conclusion to make from this data is that the 405 panel installation with a 101 kWp over 1 year can produce 157,331 kWh. A simple calculation therefore gives us a loose approximation that each panel, in Brisbane over 1 year will produce 388 kWh. This can be used to calculate the demand required for the power systems to establish a system for AC powering and then conversions for DC. There are a few key characteristics and assumptions that will be required:

- Real Power = Apparant Power * Power Factor
- kWh is the measurement energy providers charge against (quantity of kW consumed within a one hour period)
- kVA is the measure that maximum demand is charged against
- DC Power Production is approximately 7% higher than AC from these modules (from System Advisor Model)

6.1.3.4 Power Monitoring Expert

Similar to the photovoltaic metering system, the Power Monitoring Expert (PME) product that QUT uses provides a large amount of data that needs to be analysed. PME also shows summary pages of the separate locations on both the Garden's Point as well as breakdowns to electrical infrastructure as represented in Figure 21.

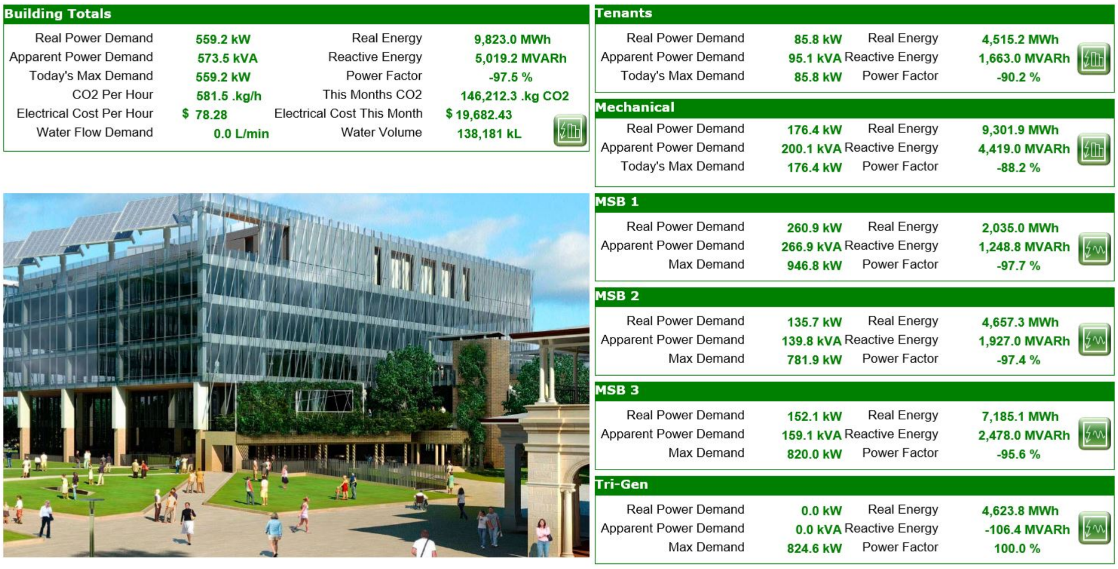


Figure 21: QUT Garden's Point Data: P Block Power Summary (12AM - April 16 2017)

6.1.3.5 Data Extraction

What data needs to be exported? To solve this the model for Level 7 of P Block as levels 7, 8 and 9 have the highest density of office rooms per level for the building. Figure 22 shows the lighting layout for level 7 and the quantity of luminaires installed. Additionally, it separates the floor plan onto the different distribution boards DB-P-7A, DB-P-7B and DB-P-7C. Following the floor plan, the building's power systems must be separated to understand where the power for the lighting comes from so the correct infrastructure can be observed within the metering system. The extract from the single line diagram is also shown in Figure 23 showing that each DB is split to separate power and lighting metering units. This will be integral to estimating the required electricity for lighting loads.

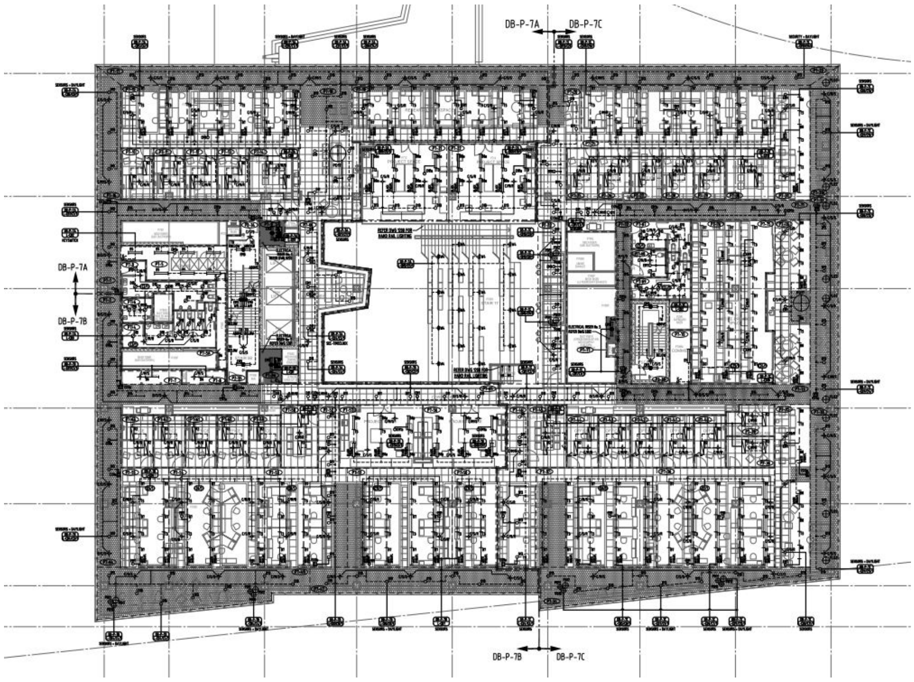


Figure 22: QUT P Block Floor Plan: P Block Level 7 Lighting Layout

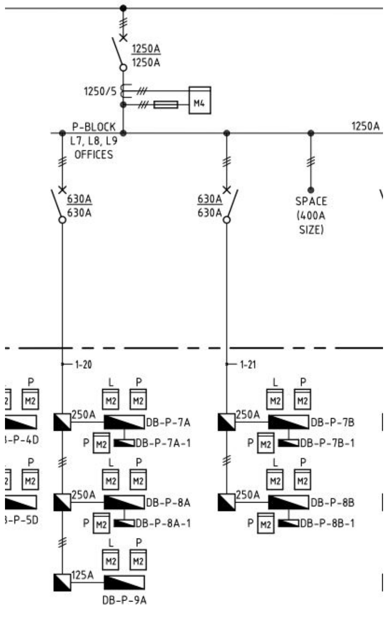


Figure 23: QUT P Block Electrical Schematics: P Block Level 7 Single Line Diagram Extract

The three DBs were found in Power Monitoring Expert for both the power and lighting meters. This was exported into a 600 page report and excel spreadsheet.

The metering system produced data in 15 minute increments which was totalled and aggregated into relevant intervals. Figure 24 is the graph of the average monthly lighting demand for level 7 over all three DBs. It can be seen that there are only minor differences along each month drawing the conclusion that time of year has a negligible effect on the lighting consumption of this floor.

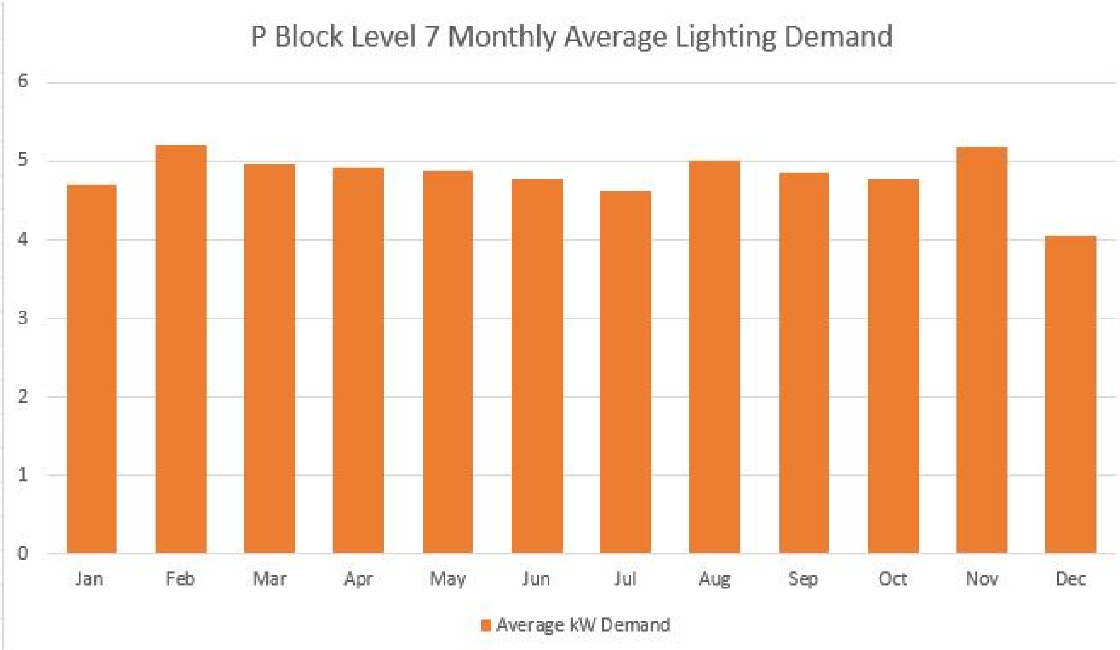


Figure 24: QUT Garden's Point Data: P Block Level 7 Lighting Demand (kW)

Although this information is useful for the production vs consumption curves the kwH are required for financial information. The graph shown in Figure 25 shows the monthly breakdown of the calculated kWh values. It should ne noted it is just a scaled down replication of the kW graph.

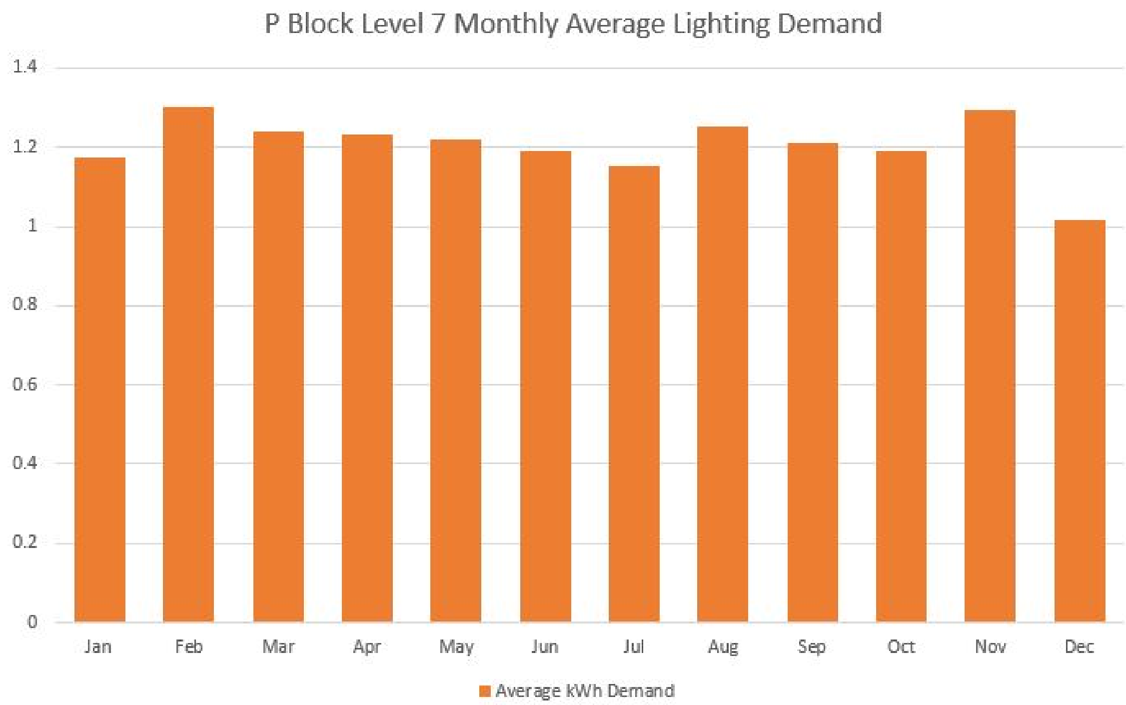


Figure 25: QUT Garden's Point Data: P Block Level 7 Lighting Demand (kWh)

Due to this finding, it was beneficial to model the average daily lighting consumption over each metering period. Figure 26 below shows the consumption curve and can be used to compare against production to determine feasibility.

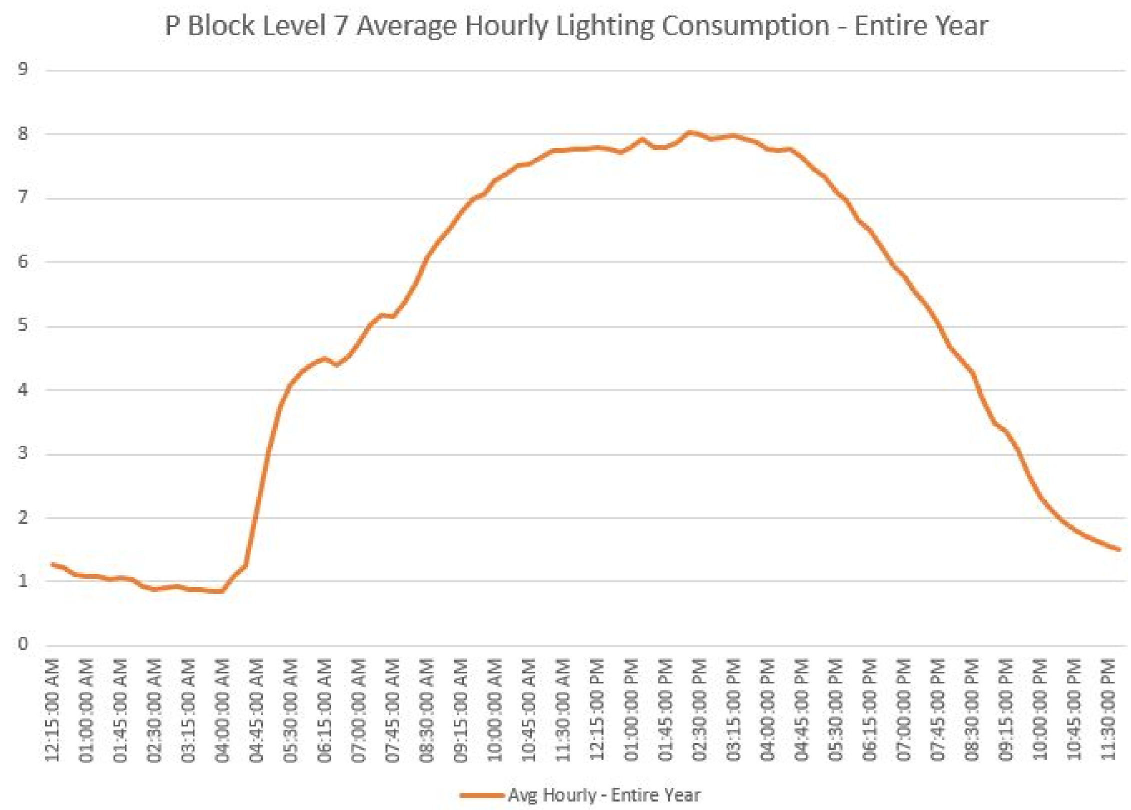


Figure 26: QUT Garden's Point Data: P Block Level 7 15-Minute Interval Lighting Demand (kW)

6.1.3.6 Lighting Considerations

6.1.3.7 Sensors

In this scenario, the building is within a University requiring different demands. For example, standard business hours in Brisbane are between 8:30 AM and 5:30 PM but Figure 26 shows that consumption begins earlier than this and finishes later. Additionally, lighting consumption never hits zero implying that there are always lights on. Additionally, upon analysis of the building documentation, P Block has lighting control systems including personnel sensors, light level sensors and illuminance sensors indicating that people are likely in the room at all hours driving the average consumption above zero. Additionally, as a public space it is unlikely that every light in the building is turned off at any stage.

6.1.3.8 Emergency Lighting

An additional consideration relevant to the consumption not lowering to zero is emergency lighting. These decides are generally left on at all times for the purpose of directing human traffic in the event of an emergency where general lighting is not available. Emergency lighting will be relevant to any commercial building within Australia as per Australia Standards AS 2293.1 Emergency lighting and exit signs [46].

6.1.3.9 Annual Periods

In addition to the sensors, a University building will have varied consumption depending on the time of year. This is due to:

- During study period (In-Semester)
- Out of study period (Non-Semester)
- Weekday
- Weekend

All these factors must be considered in the final design. The assessed data could be potentially useless if the varying periods of increased people traffic within the building. Figure 27 represents the new graphical representation of consumption comparing various yearly period factors and finding the 15 minute average. Additionally, standard business hours have been marked by the two vertical red lines. This area begins at 8:30 AM and finishes at 5:30 PM.

- Average In-Semester (Dark Blue)
- Average Entire Year (Orange)
- Average Weekend (Grey)
- Average Weekday (Yellow)
- Average Out of Semester (Light Blue)

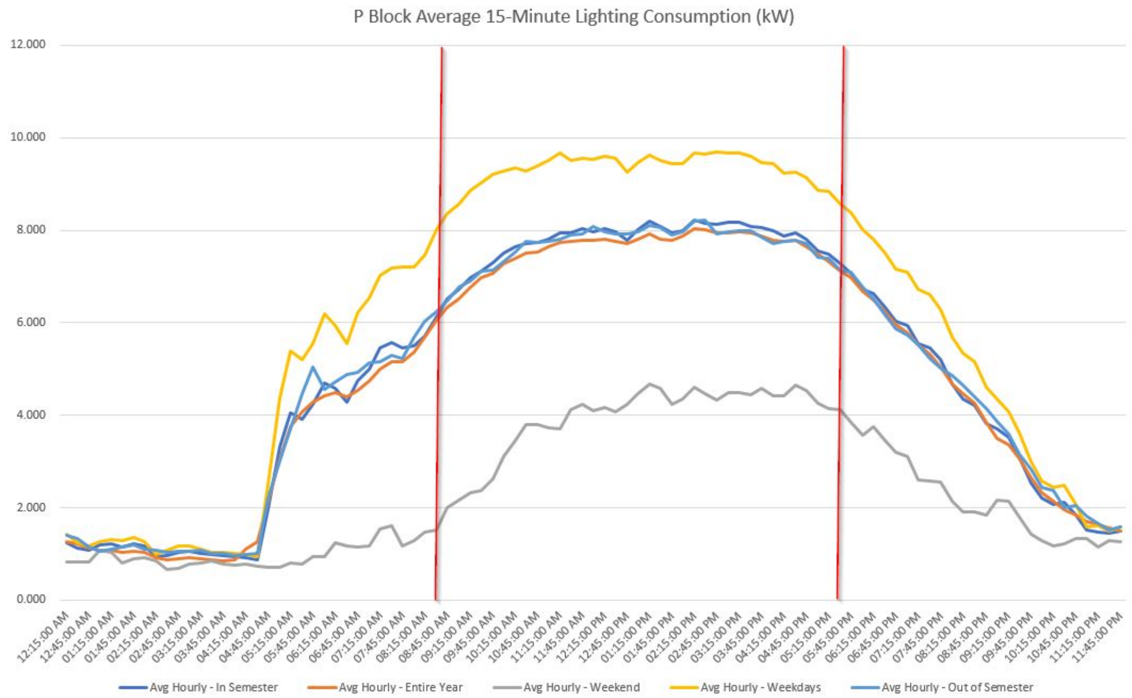


Figure 27: QUT Garden's Point Data: P Block Level 7 Detailed 15-Minute Interval Lighting Demand (kW)

6.1.3.10 Useful Conclusions

Analysing the graph above, the only variables that impact the consumption significantly is whether it is during the week or a weekend. It can be seen that weekend consumption does not increase at the same rate and the maximum is approximately 50% less. Because this data is being used for the modelling of a "real world" corporate building, the spikes of consumption at 5 AM will be reduced so the gradiant of the curve begins increasing at 6:30 AM and shifts to minimum at 7 PM. The extended hours are to account for employees who arrive at work early and leave later. Additionally, offices generally do not consume on the weekends meaning that the Yellow line from Figure 27 is the most accurate.

6.2 Calculations and Modelling of Photovoltaic Systems

This section is intended to outline the possible calculation methods for appxoimating and modelling expected PV generation. This section will conclude with an approximated production curve to check against the QUT Data and future project model discussed in Section 6.3. There are many ways that industry professionals use to predict and model photovoltaic production from installations however there will always be unknowns and sensitivities causing inaccuracies. Variables such as the weather and luminance can be inconsistent day to day or year to year reducing the accuracy of calculated predictions.

6.2.1 System Advisor Model

The software package that will be utilised for modelling and testing purposes is known as System Advisor Model (SAM). It is a free software package produced through photovoltaic module and inverter manufacturers funding the programmers. Weather, specific module information, specific inverter information as well as array size and orientations can all be input into the software package and run. This is an incredibly useful tool and will be utilised within the project. Although this is a very useful modelling tool it is unreasonable to rely on one method for caluclations when more are available.

6.2.2 Industry Approximation Ratio

From industry experience within Brisbane City, Queensland, there is an estimation ratio of production of 1,500 kWh/kWp/Annum. What this implies is that for every additional kilowatt peak that the pv array contains, over the year there will be 1,500 additional kilowatt hours of production. This is the first check for designing as the system can be assessed against this value and if it is within plus or minus 20% sensitivity.

6.2.3 Hand Calculation

After simple estimations utilising the industry approximation ratio are completed more accurate hand calculations are also possible. The variables related to this process are related to solar irradiance. The SI units for this value is watts per square meter (W/m^2). It is known that solar panels will perform at their peak production capability when the irradiance is equal to 1 SUN which is again equal to $1000\,W/m^2$. Irradiance can tell us the number of Peak Sun Hours (PSH) as well. For example, if we know that the irradiance of January is $160{,}000\,W/m^2$ then we know that over one day there is $5{,}161\,W/m^2$ or $5.161\,kW/m^2$. This represents the fact that over the average day in January the illuminance comes to approximately 5.1 PSH. With these values slightly more accurate approximations can be done specific to geographic locations when irradiance data is made available.

6.3 Project Test Model

This section outlines the test model that was created after the draft model stage, QUT data access and initial photovoltaic systems analysis. In order to create the test model of a "real-world" Brisbane based commercial building to structure the analysis around, the QUT schematics and personal experience within Brisbane's built environment were integral.

6.3.1 Lighting Loads

To calculate approximate lighting loads to be expected for a floor, level 7 of QUT P Block was marked up to count the number of luminaires installed. A full floor plan is shown in Appendix 10.4 but an image export is below in Figure 28.

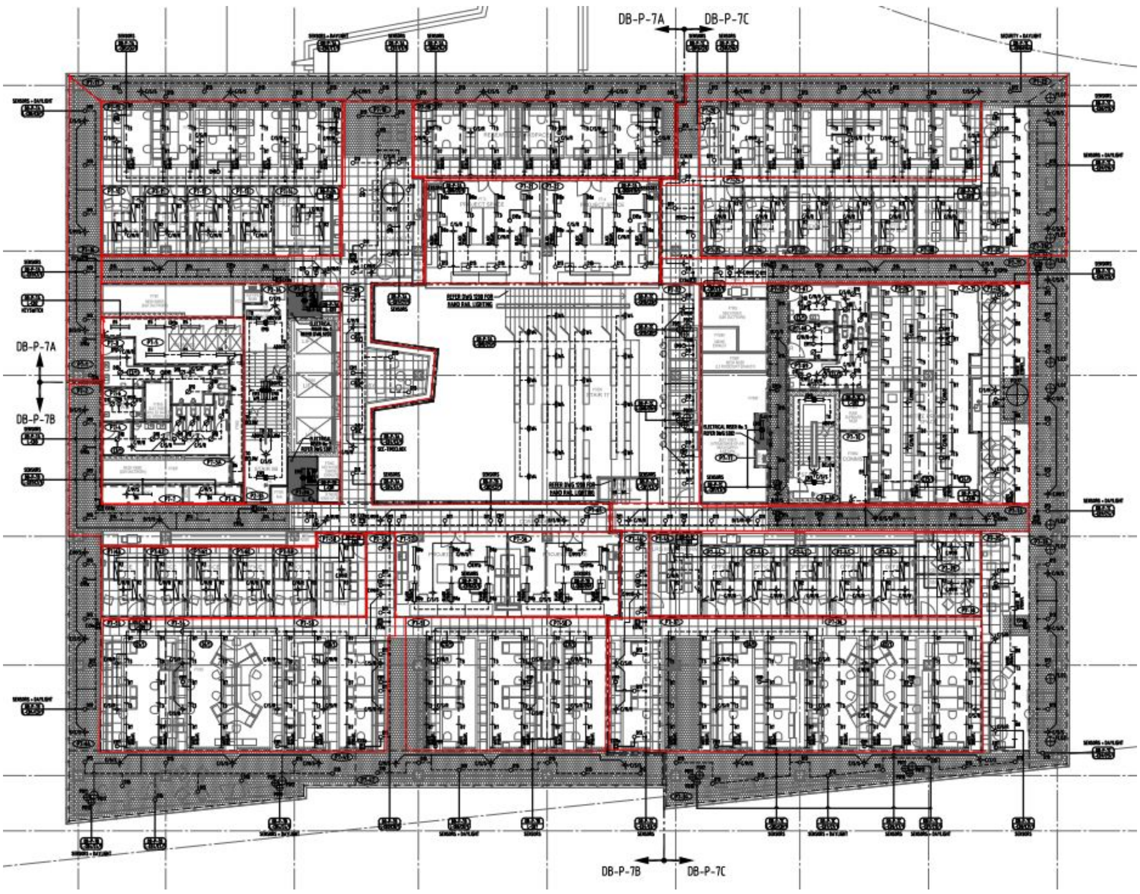


Figure 28: QUT Garden's Point Floor Layouts: P Block Level 7 Lighting Markup

Table 5 below outlines the counts from the markup. These were then used to calculate total loads for the floor plan. With these values, a test model can be based with an approximate light load that can be separated over dedicated DC distribution boards over the floor once further calculations and photovoltaics layouts are designed. This model will be utilised in Section 7 for deep analysis and simulation. This is the reasoning behind utilising the QUT provided floor plans to attempt to create an accurate "real world" example of DC distribution implementation.

Fitting	Wattage (W)	Voltage (V)	Count	Demand (A)
2 x 18W Fluorescent	18.0	230.0	220	0.08 & 17.2
2 x 28W Fluorescent	28.0	230.0	448	0.12 & 54.5

Table 5: QUT: P Block Level 7 Lighting Count and Calculations

6.3.2 Floor Size

The same floor plan layout was loaded into AutoCad to calculate the area and average room size. The entire floor plan was measure to be approximate 65 m by 47 m providing an area of approximately 3000 m^2. The average office size of 22 m^2.

6.3.3 Photovoltaic Modules

This information is elaborated on further in Section 7.2.1 however to briefly preface, the test model will be based on utilising the average photovoltaic module of 265 W of assumed size 1600 mm by 1000 mm by 35 mm. This value will be used in analysisng PV quantities with available spacings as well as power production simulation with System Advisor Model.

6.3.4 Electrical Infrastructure

The assumption for this project is that separate DC electrical infrastructure will be installed to power the chosen devices. At this stage, devices cannot be selected because loads have to be analysed first after photovoltaic modelling. Ideally, reputable brands for electrical equipment such as Eaton or NHP will be selected with preference to affordable but safe models. Eaton products are generally more affordable and will likely be chosen for the switchboards and circuit breakers. Additionally, it is generally far easier to alter settings to remove faults when the same manufacturer is used for the complete circuits.

7 Project Questions

The following section will technically analyse the five questions that this project will analyse. Due to the fact this is a progress report and not the final, there are not solutions to all answers however mechanisms put in place so that the solutions can be found. If a question has not been solved and discussed below, there will be milestones in place within the time line and discussions on reaching the goals in Section 8.

7.1 What Is The Optimal Voltage Level When Considering Loads, Costs and Efficiencies?

To determine what voltage level would be optimal for the suggested distribution systems, research was enlisted over technical tests. The previous QUT Student Donohue did extensive research on this aspect of the solution in 2014 for his 2014 project Extra Low Voltage In-Home Power Distribution and Storage 48 V DC. For the purpose of investing time more efficiently, this project relies on the quality of his research for the basis of this question.

With battery storage implementations, there are some restrictions on that voltage level for the solution. Batteries may or may not be implemented into this project's solution, however it is important to understand the fundamentals behind the voltage level decisions. There is a large amount of literature suggesting that 48 V DC is the best option due to the efficiency levels with standard loads. When a 240 V AC home power system was compared with DC it was found that the 48 V DC system used 22% less and a 120 V DC used 18% less [13].

An additional factor that is arguably more important is current differences affecting cable sizing requirements. As the voltage level is increased, the current required to power loads will be decreased following the relationship Power = Voltage * Current (P=VI). The table below represents brief calculations using 24, 48 and 96 V DC with two different loads to calculate approximate cable sizing. Although reducing cable sizes is important, an alternative comparison method is the distance that cables can be run. By using less current, cables of the same size can be run further distances without suffering from too high voltage drops. The voltage drop is the factor that affects a system's efficiency level. Therefore, when the voltage drop can be reduced from a 24 V DC system to 48 V DC system, the efficiency is being increased. Table 6 below shows the DC resistances from

TriCAB cable suppliers [11] and Table 7 shows approximate cable areas required for different DC voltages and loads.

Conductor DC Resistance		
Cable Size (mm^2)	**Ohm/Km**	**Ohm/m**
0.5	39	0.039
0.75	26	0.026
1	19.5	0.0195
1.5	13.3	0.0133
2.5	7.98	0.00798
4	4.95	0.00495

Table 6: TriCAB Catalogue DC Resistance Cable [11]

Load (Watts)	**Voltage (Volts)**	**Current (A)**	**Approximate Cable Size** (mm^2)
100	24	4.16	1
100	48	2.08	1
100	96	1.041	1
500	24	20.83	5
500	48	10.42	2
500	96	5.21	1

Table 7: Cable Sizing As Per Voltage Level

With these factors considered and the extensive literature review supporting the choice of 48 V DC, at this stage of the project this voltage level will be chosen. Simulations of this level will be run in further questions and analysis applications to determine if it is suitable when applied to commercial buildings.

7.2 Can Photovoltaic Systems Be Used Effectively for this Application?

Photovoltaic systems are considered for this project due to their nature to produce electricity in DC form. By doing so this negates the need for converting the power from DC to AC or vice versa. As discussed, this reduces inefficiencies and allows for the opportunity to produce an overall increased efficiency system compared to those traditionally used in commercial buildings today.

Generally in residential buildings, PV is used as a means to load shift to different periods where tariffs are reduced. In commercial buildings there are different motives and max demand reduction is the goal due to the significant financial benefits of completing this.

To quantify the benefits of PV systems when considering the application of Extra Low Voltage DC power Distribution.

- Photovoltaic panel options
- Brisbane solar production curve analysis
- Approximate losses of Photovoltatic system

7.2.1 PV Panel Overview

There are two main types of Photovoltaic cells; monocrystalline and polycrystalline [2]. They are both based on crystalline silicon. Crystalline silicon is silicon that has solidified into atoms that are arranged in a crystal lattice [2]. From this definition, it is intuitive from their names that monocrystalline is when the silicon has solidified into a large single crystal and polycrystalline is many crystals in various orientations. Production of a monocrystalline crystal is energy intensive and pulling a complete single crystal is time consuming [2].

The efficiency of to two main variations of solar panel are fairly equivalent in efficiency in modern times. Overall when comparing costs and efficiencies, it is generally the best option to choose a monocrystalline panel [2].The additional factors to consider are mounting systems, control system incorporation, direction of tilt and azimuth [2].

7.2.2 Brisbane Solar Modelling

As Brisbane, Queensland, Australia is the test location for this thesis the solar curve must be understood. These graphs can also be known as solar potential and outline the times of day in an area. This is an important factor when considering where and how to mount photovoltaic panels for optimal production efficiency. This graph will change throughout the year as seasons change the the timing of the sunrise and sunset alters.

To produce an accurate estimate of solar production in Brisbane, System Model Advisor (SAM) was used. SAM is a free piece of software for simulating photovoltaic systems. The model was established with Brisbane as a location and it automatically importants and caluclates with appropriate data. This is shown in Figure 29.

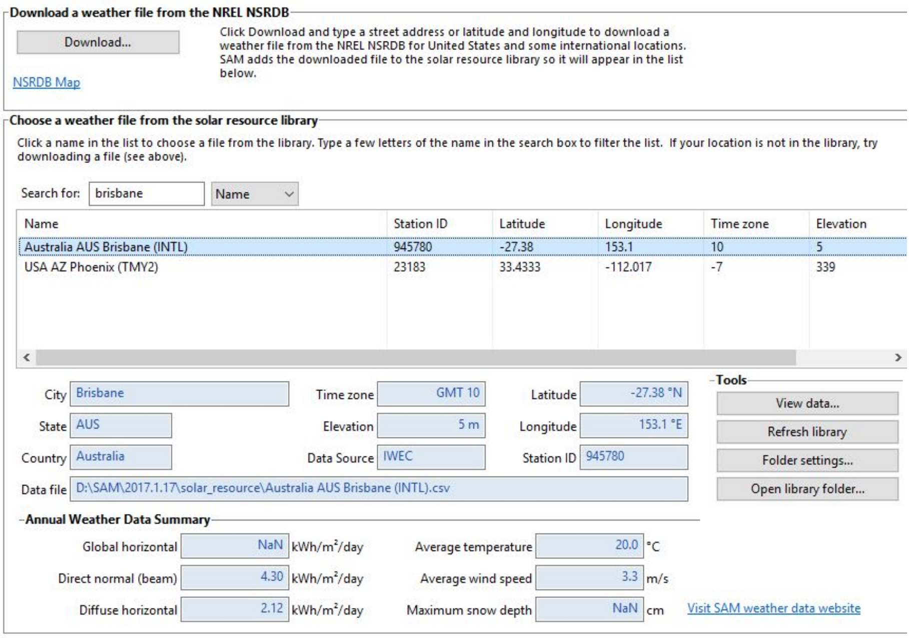


Figure 29: SAM System Design: Geographic & Weather Settings

For module testing, a Suntech Power STP250-20/Wd was chosen for two reasons. These reasons are firstly, that the QUT Project in P Block uses these same modules so the comparison of sites will be more accurate and provide a more detailed analysis. Secondly, 250 W panels are an average size in the industry as well as monocrystalline being considered the best overall option as discussed [2]. Similarly, the Power-One PVI-3.6-OUTD-US because these are used throughout QUT. In events where 3.6 kW AC or 3.7 kW DC is insufficient, the larger model Power-One PVI-10-OUTD-US will be used for modelling. This test was purely for weather data so the system design is fairly insignificant.

As discussed, during the year the solar curve will change as Figure 30 below. To provide a more detailed look, SAM exported hourly data for irradiance over an entire year which was averaged out to display a yearly average irradiance curve in Figure 31. These two images outline how Brisbane is a strong contender for installations of photovoltatic systems due to high irradiance levels for the majority of the year.

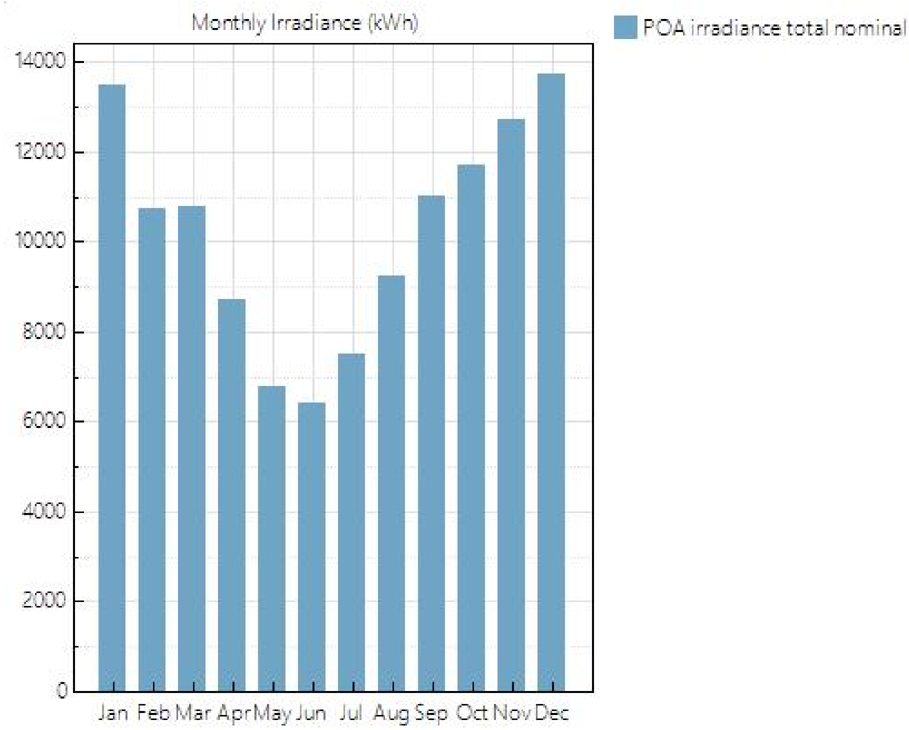


Figure 30: SAM System Design: Brisbane Monthly Irradiance

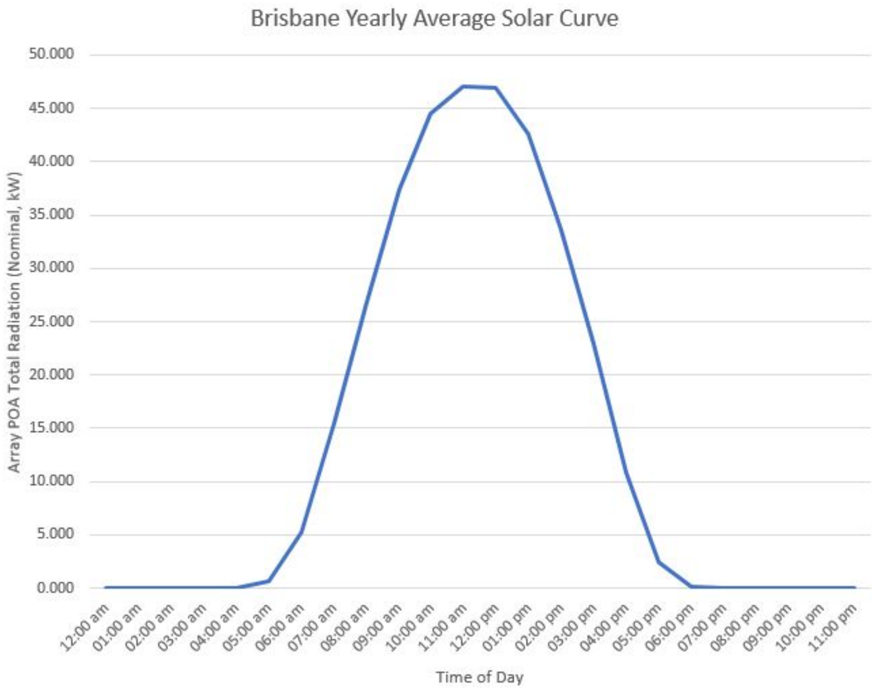


Figure 31: SAM System Design: Brisbane Monthly Irradiance

7.2.3 Losses

Within a power system there are multiple stages of losses. To approximate these losses for a traditional AC Photo-Voltaic system with inverters included, a non-commercially free software package called System Model Advisor (SAM) is available. This program allows the user to input the chosen panels, inverters, tilt angle, shading factors and the azimuth.

To model the test system, a standard module of 250 W Peak was chosen from the SAM module selector. Specifically, a SunPower SPR-250NX-BLK-D with a maximum power production of 249.952 W and nominal efficiency of 20.09 % was selected. This module is intended to represent an average system to give a reasonable quantity to losses to expect for future analysis.

For this level of analysis, again an average inverter requires select to calculate the approximate losses expected from an AC PV system. Because this installation is expected to be incorporated into a commercial building, a 20 kW inverter was selected. A standard inverter was chosen over micro-inverters due to the increased efficiency they generally provide in larger than residential installations [47]. The specific model selected is the SMA America:SB3800TL-US-22 with a 96.2 % weighted efficiency and of course a 240 V AC nominal AC output for feeding into existing power infrastructure.

For the test model, strings were made of 234 panels with 26 strings of 9 modules to simulate a 60 kWp system. There are a variety of assumptions that were made in order to model and approximate losses including those listed below. These losses are represented in Figure32.

- Location of Brisbane, Australia with automatically imported weather data
- Tilt of 27 degrees (Brisbane lattitude)
- Azimuth of 0 degrees (North facing)
- Ground Coverage Ratio (GCR) of 0.6 assuming tightly packed panels
- Fixed mounted onto roof

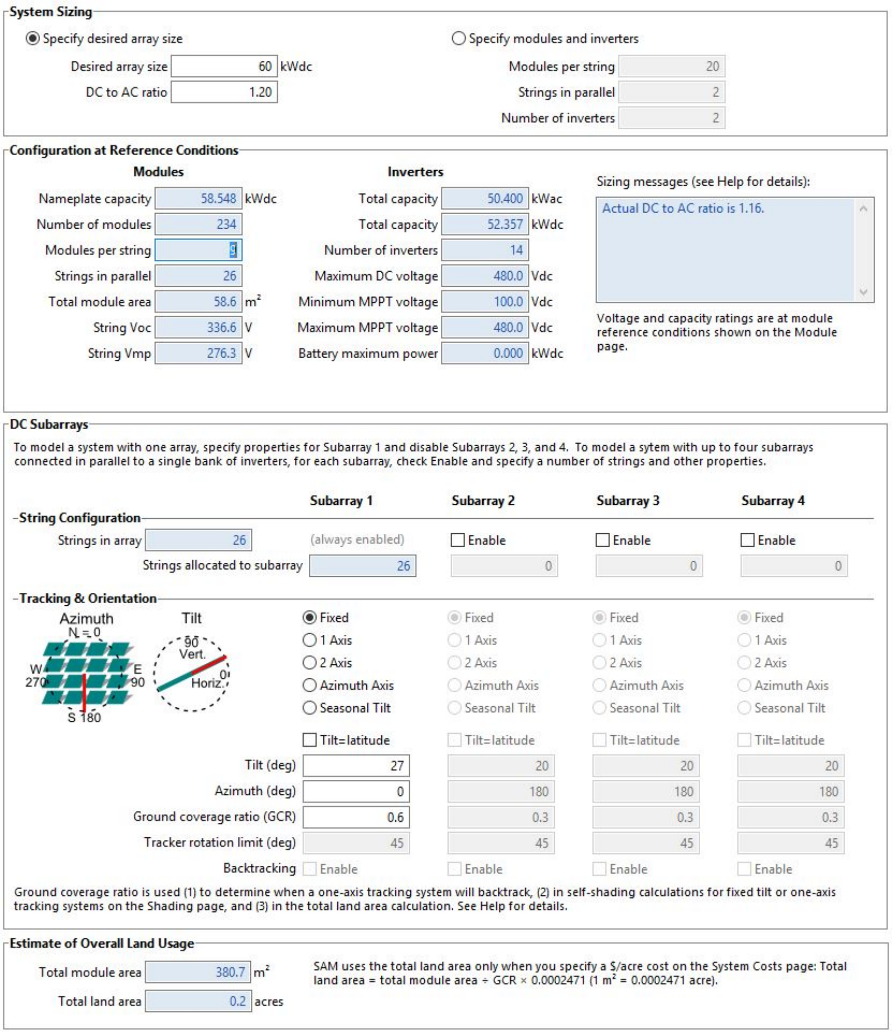


Figure 32: SAM System Design: Test Model 1

SAM results indicate the losses approximated over one year of data and simulations. As can be seen from Figure 33, the major losses are from soiling, the module, inverter clipping and DC wiring. Of those, the proposed DC system could remove the 4.365% loss from the inverters and incorporate a more efficient DC to DC converter.

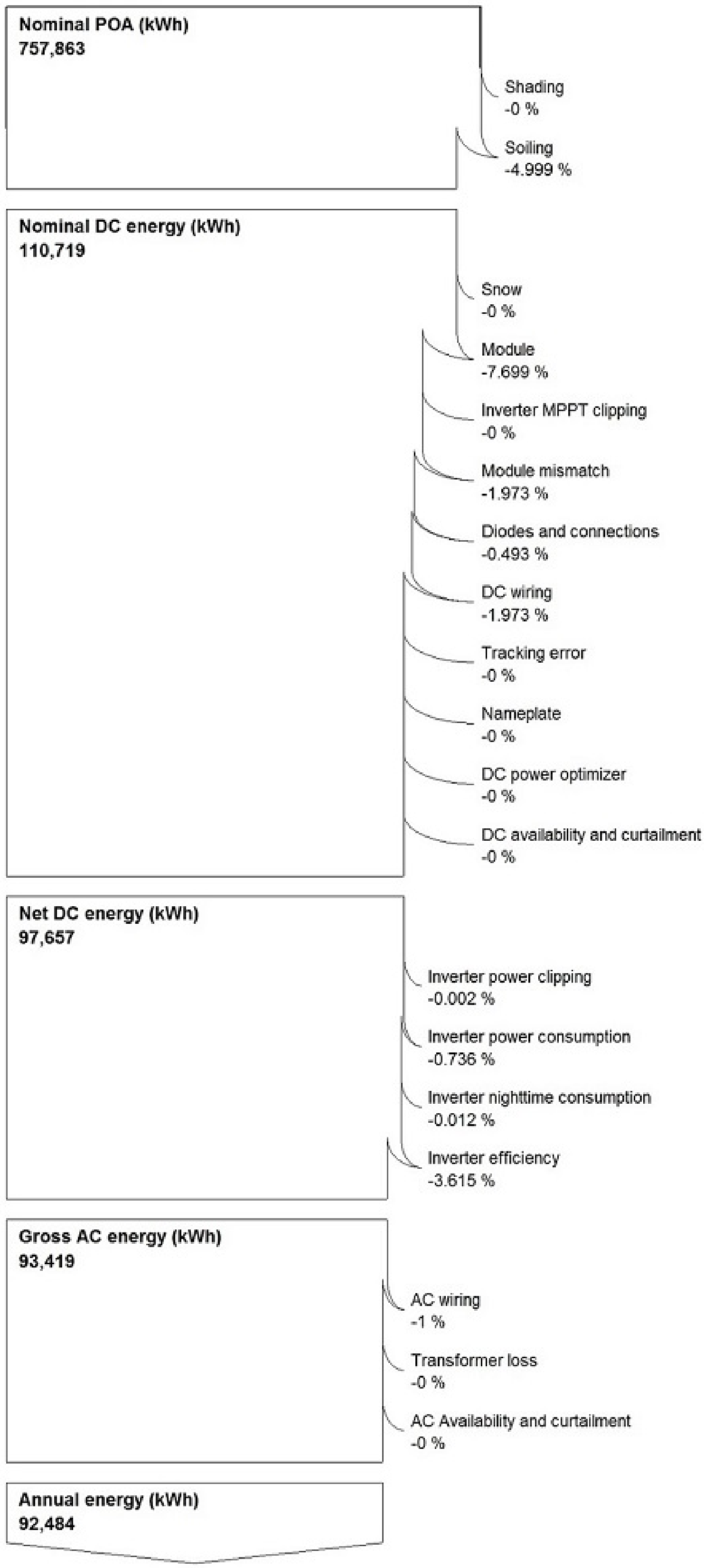


Figure 33: SAM System Design: Test Model 1 Losses

7.2.4 Converters

To successfully install the proposed system by adding DC electricity into a power distribution system, the voltage and current produced will require regulation. In existing AC installations, the inverter that converts from produced DC to appropriate AC operates as a regulator and voltage level control system. Because that device is no longer a consideration, there are additional efficiency benefits. Unfortunately an alternative device is required that will add partial inefficiencies. The STP250-20/Wd used for analysis has a production curve represented by below in Figure 34 [9].

Figure 34 displays the curve representing voltage, current and power.

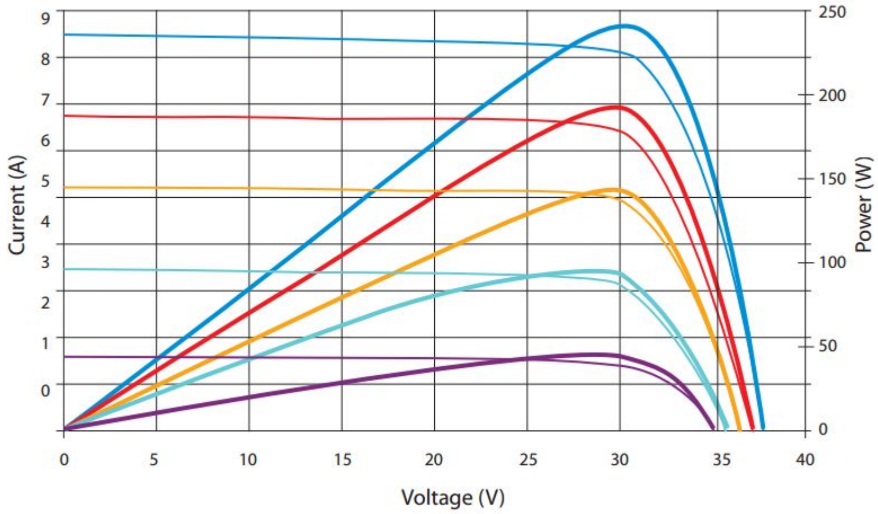


Figure 34: SAM System Design: PV Module Current Voltage Power Graph [9]

7.2.5 Mounting of Modules

As discussed in the Section 4.2.2 there are multiple options for PV mounting. The finalised chosen method will be discussed further in Question 4. For initial calculations, fixed mounting is assumed and the tilt should be targeted towards the latitude of the location wherever possible. For Brisbane, this means the optimal tilt would be 27 degrees.

7.2.6 Suitability

The general question for this section is whether or not photovoltatics could be employed to power an extra-low voltage DC power distribution system for a commercial building.

Summarising the information discussed above, it is certainly feasible that this is possible due to photovoltatic's ability able to produce DC electricity naturally and the losses being reduced. A test model must be produced and a comparison between AC and DC completed to test the differences.

7.3 Can Lighting Requirements Be Met Through the Proposed System?

For lighting requirements, as previously discussion in Section 10.3 there are Australian standards that impact the quantity and types of luminaires. Table 18 outlines the lux requirements expressed in AS/NZS 1680.2.2 explaining that the target for a standard office should be between 200 lux and 300 lux unless technical work is required (a minimum of 320 is required in this case) [12].

To begin the analysis, the project test model standard office was modelled in the lighting simulation software package Dialux. As discussed in Section 6.3 the floor plan is based off of QUT Garden's Point Campus P Block level 6. The reason this was chosen is that it is a real world application of a commercial office floor that access to the schematics and design plans was made available. This was the most accurate method for producing a model that could be applied to industry.

7.3.1 Office Room Lighting Model

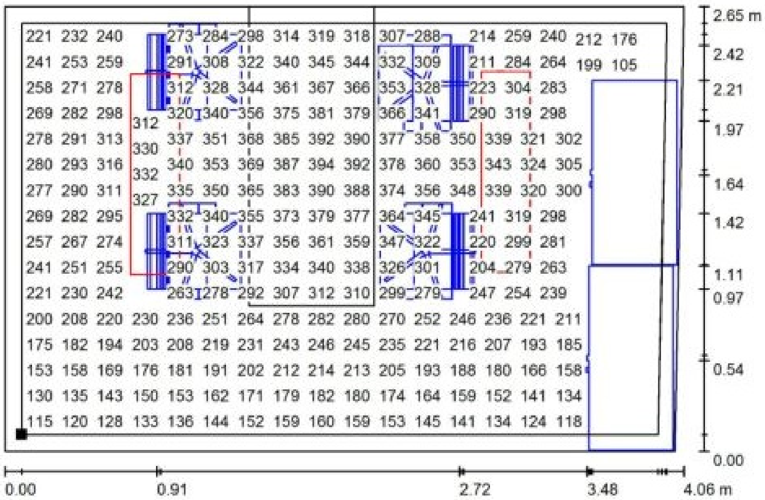
The large floor plan shown in Section 10.3 was loaded into Dialux and an office separated out for modelling. The room was approximation shows that offices on this are $22\,\text{m}^2$ and this lighting simulation displays this. The fittings modelled were luminaires with the same specifications outlined in the QUT design documents. Specifically, this is the Futcha LED 27.5 W fitting from Pierlite [48]. The DWG file additionally outlined some architectural objects including a table which was included in the modelling.

Utilising Table 8 below, the assumptions were input into Dialux to complete accurate modelling.

Assumption	**Value**
Roof Height	2.7m
Workplane	0.75m
Boundaries	0.1m
Ceiling Reflectance	70%
Wall Reflectance	50%
Floor Reflectance	20%

Table 8: QUT: P Block Level 7 Office Lighting Simulation Assumptions

The calculation completed in Figure 35 was to ensure that the inputs received from the schematics were correctly understood. Appendix 10.5 shows the complete Dialux output however the important aspects are the lux values of the workplace shown in Figure 35 and the 3D render shown in Figure 36.



Values in Lux, Scale 1 : 30

Not all calculated values could be displayed.

Position of surface in room:
Working plane with 0.100 m
Boundary Zone
Marked point:
(73.574 m, 63.408 m, 0.750 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
269	46	395	0.172	0.117

Figure 35: QUT: P Block Level 7 Office Lux Analysis

Figure 36: QUT: P Block Level 7 Office 3D Render

7.3.2 Lighting Model Discussion

Comparing Figure 36 to the lighting standards requirements in the below Table 9, it can be seen that the room is above standard with the average of 269 lux provided that it's a general office not requiring technical work or visually difficult applications. Table 5 has the total luminaires count and therefore the total demand for the office level, this will be scaled for the size of a project building.

Area or Application	**Lux Requirement**
Rarely Visited	40
Storage Rooms or Change Room	80
Machine Work or Waiting Room	160
Food Preparation Room	240
Technical Office Room	320
Visually Difficult Work	500

Table 9: Lighting Requirements as per AS/NZS Standards [12]

7.3.3 Equipment Improvements

As discussed in Section 4.1.4.4 of the Literature review, with the growth of DC distribution more devices are becoming available. For the project model, LED devices will be used for higher efficiency and of course the ballasts will be required to receive 48 V DC and output specific LED fitting requirements.

7.4 Structural Design and Safety Mechanisms to Minimise Cable Losses

This section will be answering design specific questions such as how the building will be structured electronically including PV mounting and locations as well as general building size limitations. Once building size and PV requirements are determined, electrical infrastructure sizing including switchboard and circuit breakers will be suggested. Finally, a summary of cable lengths with losses and efficiencies will be produced to determine the maximum distance between the PV array and luminaires before the system loses its value.

7.4.1 Safety and Design

Safety is integral to any design and specifically with electricity as it is difficult to see visual risks. If safety requirements are ignored, there can be severe consequences ranging from damage to property, loss of career or death. A variety of protective devices are installed in power systems in order to ensure safety design including circuit breakers, fuses and residual current devices. An initial requirement with the installation of DC systems over AC is the increased possibility of an arc flash. During installation, considerations must be made to ensure that the end point does not remain energised upon disconnection from the supply.

7.4.2 Mounting of Panels

Section 4.2.2 within the literature review outlines the possible mounting options that could be employed for the project model. Due to commercial buildings having a limited amount of roof area, single axis tracking modules are not as suitable due to the ground coverage ratio (GCR) being higher to reduced self-shading. The ground coverage ratio outlines a percentage of land required for the array based on the spacings in the design. GCR is used to calculate total required area following the formula:

$$Total\ Required\ Area = Module\ Area\ /\ GCR + Laneway\ Allowance$$

Due to these reasons, to maximise the efficiency and production potential a fixed mounting system will be utilised. As discussed in Section 7.2.2, modelling will be completed on the assumption of tilt being equal to the latitude and the modules facing directly North. In QUT P Block, the panels are facing North-East but that is also due to the location of the building specifically.

7.4.3 Location

The location of the building is, as discussed, assumed to be within Brisbane city. During design and construction it must be considered that the location should not have tall buildings surrounding the roof section causing shadowing. For this project, it will be assumed that this is possible.

7.4.4 Electrical Safety Devices

As in Section 4.1.4.2 of the literature review there are a variety of commercially available DC to DC converters and switchgear on the market. Fraunhofer electronics have designed low and extra low voltage converters with efficiency levels of 98% [49]. Protection devices such as solid-state circuits and hybrid breakers are now technically feasible as a solution for power systems [50]. Devices with 12, 24 or 48 V DC nominal inputs and outputs at a variety of current limites are commercially available. An example system that could be used is the NewMar DC Power Distribution Panel with Plug-In Circuit Breakers to operate as a mini dedicated ELV switchboard [51].

7.4.5 Cable Lengths and Efficiencies

Minimising the length of cables is a method of control to reduce the losses of the system and therefore the overall efficiency. What lengths of cable will be possible before the losses become too high. AS/NZS 3000 states that the voltage drop between the point of supply for the LV installation and any other point cannot exceed 5 % [17]. There is however an exception where the point of supply substation is location on premises that is dedicated to the installation, the permissible voltage drop is 7 % [17]. The voltage drop over a conductor is calculated using Ohm's Law and will indicate the efficiency possible. The lighting circuits will not require large cables. To expand,

$$\textit{Voltage Drop} = \textit{Length} * \textit{Current} * \textit{Milivolts Per Ampere Metre}[11]$$

To do a simple efficiency comparison of standard cable runs, appropriate assumptions were made for a loss comparison of an example cable run from the supply board to the device driver. This comparison ignores the losses that would be seen in the AC luminaire driver converting from 240 V AC to 48 V DC. Two cable sizes were compared as they are used within industry for simple power and lighting circuits with specifications gathered from TriCab [11]. As per Figure 35, this calculation is based off one room's lighting circuit with eight, 36 W luminaires installed. As expected, the losses in the DC system are higher for the same cable length. The results are shown in Table 10.

	Cable (mm^2)	**R (Ohms/km)**	**W**	**V**	**I**	**Length**	**Drop (%)**
AC	1.5	13.3	288	240	3	50	0.8
DC	1.5	13.3	288	48	3	50	4.0
AC	2.5	7.98	288	240	0.6	50	0.5
DC	2.5	7.98	288	48	0.6	50	2.4

Table 10: AC vs DC Simple Cable Voltage Drop Comparison

As discussed previously, according to AS/NZS 3000, a power system with a localised supply has a maximum voltage drop of 7% from point of supply to load [17]. According to AS/NZS 5033 which regulates the installation and safety requirements for photovoltaic arrays, the maximum allowable voltage drop should not exceed 3% of the maximum operating voltage (Vmp) for low voltage, photovoltaic arrays [52]. This is measured from the most remote PV module in the array to the input of the power converter.

The proposed design will be an extra low voltage system rather than low voltage. The specified modules are Suntech 265 W monocrystalline panels with a maximum operating voltage of 31 V. Become modules are run in series, the voltages will add and then the 3% voltage drop will be analysed against that figure. Therefore, there is required to be a balance between cable lengths increasing the drop to an acceptable level without exceeding the limit imposed by Australian Standards. Table 11 outlines a simple comparison of losses vs length for a 2.5 mm^2 cable run and the same loads as used for Table 10.

Cable Length (m)	AC Losses (%)	DC Losses (%)
25	0.24	1.20
50	0.48	2.39
75	0.72	3.59
100	0.96	4.79
125	1.20	5.99
150	1.44	7.18
175	1.68	8.38
200	1.92	9.58
225	2.15	10.77
250	2.39	11.97
275	2.63	13.17
300	2.87	14.36
325	3.11	15.56
350	3.35	16.76
375	3.59	17.96
400	3.83	19.15

Table 11: AC vs DC 2.5 mm^2 Cable Losses vs Length Breakdown

From Table 11 it can be seen that the DC losses are far more significant. This was of course expected due to the lower voltage level requiring a higher current level than the AC counterpart. Assuming a PV array with modules in strings of approximately ten units, the maximum operation voltage will total to 310 V. 3% of this value is 9.3 V. 9.3 V is 19% of 48 V allowing for a much larger allowable drop than AC. Table 11 is an exageration however does provide insight. AC system's maximum voltage drop is from the supply to the load with a variety of conversion devices in between whereas the DC will have less distance and no required inverter.

7.5 Is DC a Feasible Alternative to AC in Commercial Lighting Systems?

This section to answer the overall question of the project. The previous four questions will be summarised and the information combined to form an overall design conclusion.

7.5.1 Assumptions

The following assumptions have been made to propose a design:

- Location is Brisbane, Queensland, Australia
- PV tilt at Brisbane's latitude of 27 degrees
- Specified modules are the Suntech 265W monocrystalline [53]
- Ground Coverage Ratio of 0.5
- QUT P Block is an accurate test case for building scaling

7.5.2 Building Energy Specifications

7.5.2.1 Maximum Lighting Demand

As previously analysed in Section 7.3, a simple office room was modelled with lighting requirements based on QUT P Block. The table from this section is reproduced below in Table 12. The total loads are from a full corporate building level.

Fitting	**Wattage (W)**	**Voltage (V)**	**Count**	**Demand (A)**
2 x 18W Fluorescent	18.0	230.0	220	0.08 & 17.2
2 x 28W Fluorescent	28.0	230.0	448	0.12 & 54.5

Table 12: QUT: P Block Level 7 Lighting Count and Calculations

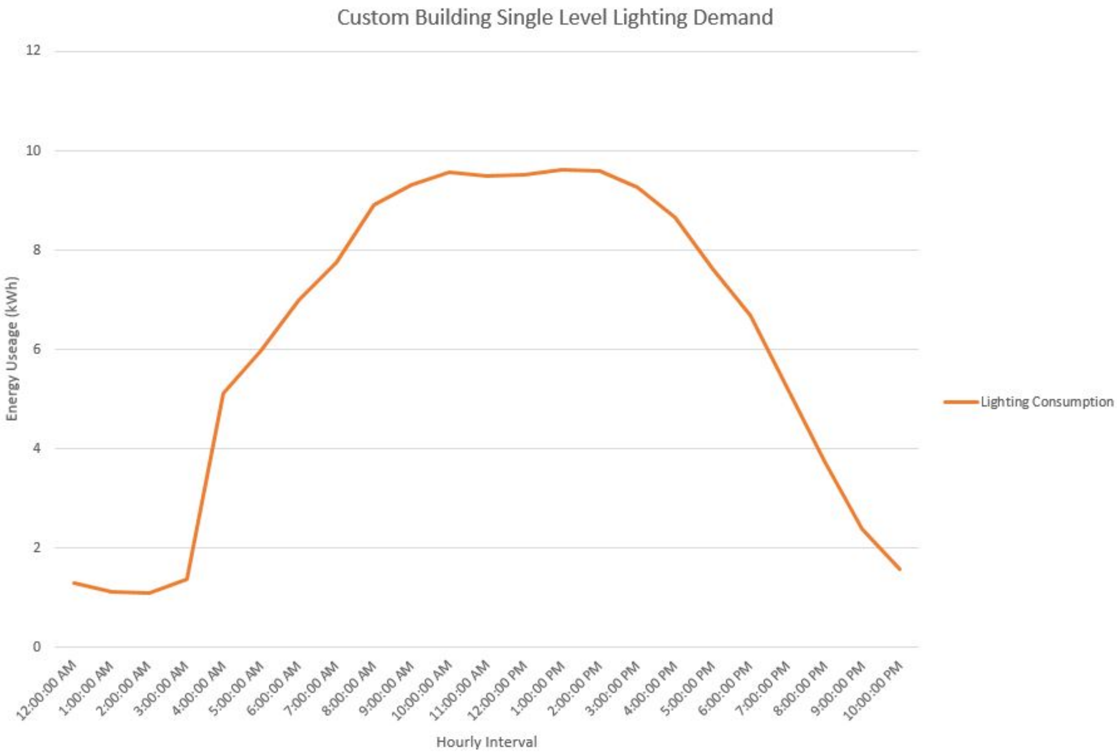


Figure 37: Custom Building: Predicted Single Level Lighting Demand

Figure 37 shows the predicted lighting energy demand in kilowatt hours. This curve can be used to size the photovoltaic array required for one level.

7.5.2.2 Required Photovoltaic Array

Over a year, the metering data shows that there will be 42,243 kWh of single level lighting consumption. In order to supply enough energy to power the lighting for one of the proposed levels, the array must produce a minimum of 42,243 kWh per year with the production curves ideally fitting the consumption curves to ensure that the connection to the grid is unnecessary. Utilising the assumptions stated in Section 7.5.1, an array was modelling that could produce the required electricity. Again, using System Model Advisor, 44,047 kWh DC/Year will be produced with 95 modules from 5 strings of 19 modules.

Design Variable	Value
Nameplate Capacity	25.21 kW
Number of Modules	95
Modules Per String	19
Strings in Parallel	5
Module Area	154.6 m^2
Annual DC Energy	44,047.4 kWh/yr

Table 13: Custom Building: Single Level Array Design Table

To calculate the required array for this array, the equation from Section 7.4.2 can be utilised. This considers the assumed spacings between modules to allow for an accurate estimation of the total area required.

$$\textit{Total Required Area} = \textit{Module Area} \,/\, \textit{GCR} + \textit{Laneway Allowance}$$
$$\text{Total Required Area} = 154.6 \,/\, 0.5 + 5\%$$
$$\text{Total Required Area} = 325\,\mathrm{m}^2$$

This calculation allows their to be the conclusion that to power one level of a commercial building, 325 m^2 will be required on the building's roof for PV mounting.

7.5.2.3 Demand vs Production Curve

The next stage of the feasibility study is whether the consumption vs production curve of energy match. In this instance, due to PV producing during daylight the system will not be capable of producing energy at all times consumption is occurring. Figure 38 below represents this situation.

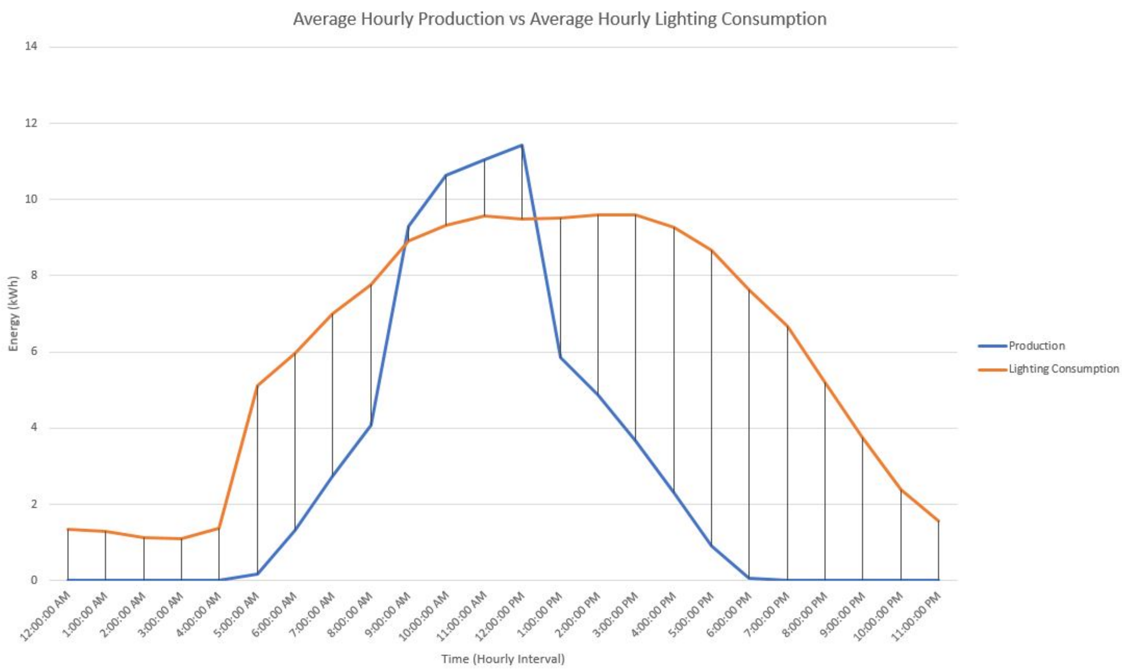


Figure 38: Custom Building: Production vs Consumption Curve

It should be noted that the modelled system produces enough energy annually but the curves do not match as mentioned previously. This can be explained by the time periods from 9 AM to 1 PM that, on average over one year, producing higher than required energy. Due to this, as predicted earlier in the report, a battery is required. At this stage there are a two main design options:

1. Install a battery to discharge from approximately 2 PM through to 9 AM the following day
2. Oversize the system so that 5 AM through to 5 PM is covered by immediate production and install a battery for overproduction
3. Separate from the original proposal and employ a dual connection with two drivers. When no direct DC connection is available, the device switches back to AC

The risk with option 1 is that during lower production periods such as winter, the additional production may not be enough to support the darker hours. Since June is a worst case, the system must be modelled to properly perform at this period. Figure 39 compares

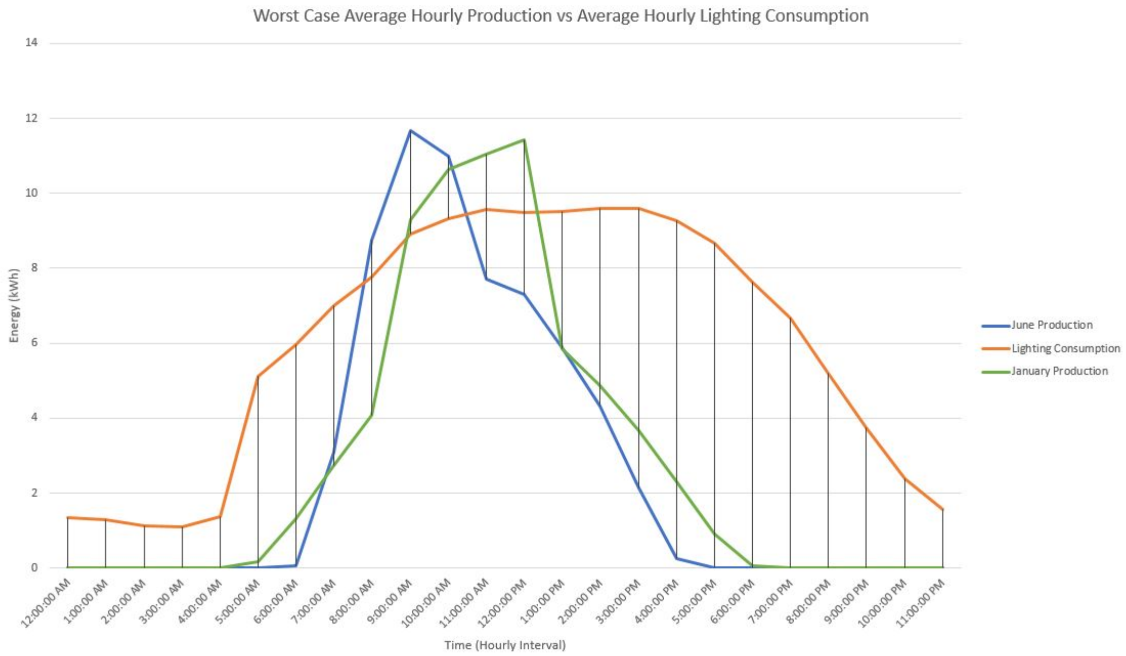


Figure 39: Custom Building: June and January Production vs Consumption Curve

As seen in Figure 39, the major difference between Summer and Winter appears to be the time shift rather than maximum production. Additionally, as expected the winter production time line has shrunk by one hour either side to 6 AM to 4 PM. This conclusion again leads to the conclusion that a small battery will be required on site. Due to altering weather conditions, it is suggested that the system be slightly oversized to allow for poor production periods as the luminaires will not have an AC connection.

7.5.3 Efficiency Comparison

7.5.3.1 Losses in AC and DC Systems

A simple way to model some of the losses of the AC system will be through System Advisor Model that was already created to predict production. These losses are represented in Figure 40. As can be seen, the losses are separated into soiling and shading, DC losses and AC losses. The total losses for the AC portion of PV modelling is:

$$\text{PV Array Losses} = 4.999 + 7.504 + 1.973 + 0.493 + 1.973 + 0.275 + 0.263 + 0.018 + 2.309 + 1$$

$$\text{PV Array Losses} = 20.807\%$$

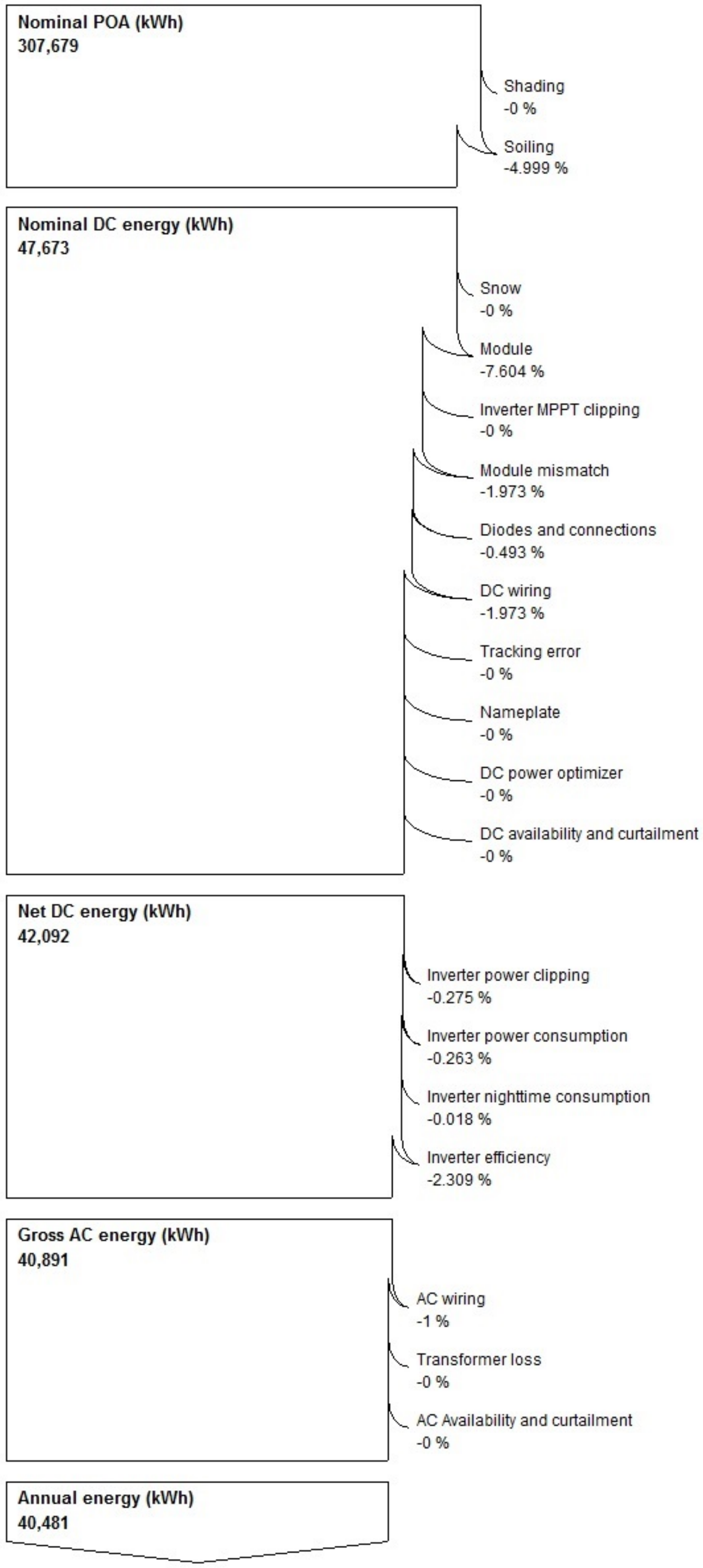


Figure 40: Custom Building: Modelled System Losses

Traditional AC system losses will be different due to each separate stage. This includes general cable losses, load losses but more specifically the converter losses. From Figure 40 it can be seen that this accounts for 3.9% of system losses. To model the comparison, a test system was modelled in Table 14 below. This system compares an AC and DC system with PV production, AC and DC coupled batteries respectively, an assumed 100 m cable run of 2.5 mm^2 cable, and an example ballast for LED luminaire. The PV system values were sourced from System Model Advisor. The batteries that were assumed for efficiency values were the Enphase AC battery [57] and the Tesla Powerwall [56]. The cable runs were calculated as per Table 11 and the ballasts were researched to find the average efficiency model.

Approximate Energy Losses Modelling AC vs DC				
Variable	**AC %**	**AC Energy (kWh)**	**DC %**	**DC Energy (kWh)**
PV System	20.81%	40,481	17.00%	42,092
Battery	4.00% [57]	38,862	7.50% [56]	38,935
100m Cable Run	0.96%	38,489	4.79%	37,070
Ballast	15.00% [54]	32,715	3.00% [55]	35,958
Total Loss	19.18%		14.57%	

Table 14: Approximate Energy Losses Modelling for AC vs DC

7.5.3.2 Losses Discussion

Provided that the assumptions made to calculate 14 and the modelling system was accurate, there is a 4.61% improvement in efficiency by using this proposed, extra-low voltage system. It should be noted that there will be various cable lengths throughout the built system so this can not simply be scaled to the size of the system. Additionally, this calculation was based off one building level however this does not effect the percentage values, only the kWh values.

7.5.4 Financial Analysis

This section outlines the approximate costs involved with the installation of the proposed extra low voltage DC power distribution system. It should be noted that the expectation is that this system would be installed in a new building. This is due to the expectation that energy cost savings will take a substantial amount of time to break even financially. That is, the additional costs of PV and battery installation will not be recovered from financial benefits from energy savings for a substantial time frame. Due to this, it is unlikely to be financially feasible to remove existing AC infrastructure in place for ELV DC. All financial information should be interpreted as approximations from research and industry experience.

7.5.4.1 Luminaire Cost Comparison

****

This section is intentionally blank. The report is a work in progress and this part of future works.

7.5.4.2 New Infrastructure Costs

****

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7.5.4.3 Capital Expenditure

****

This section is intentionally incomplete. The report is a work in progress and this part of future works.

- Panel Costs
- Installation Costs
- Battery Costs
- Cable Costs
- Luminaire cost difference
- New infrastructure costs

7.5.4.4 Energy Savings

****

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7.5.4.5 Monthly Costs or Savings

****

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7.5.4.6 Return on Investment

****

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7.5.4.7 Payback Period

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7.5.5 Finalised Design

8 Future Work

Now that this report is close to answering the initial questions proposed in the beginning there is interest in progressing the research further. With the previously discussed increase in both renewable energy device efficiency and installations of DC systems for data centres and mining sites it would be worth furthering the research in utilising purely DC systems in more applications.

The first suggestion would be to power more devices in small apartment buildings. The suggested layout from experience gained through this research project would be to power constant high loads such as fridges, freezers and air conditioning with the existing AC but all other devices could be powered off DC. To reduce consumption from the grid, renewables can be used for at least partial consumption reduction and a dedicated DC switchboard can be installed for each apartment.

If the system proves successful for small scale homes such as apartments there is cause to see it implemented in areas where reliable electricity is not available. Further analysis into a new supplementary form of micro-grid for essential services such as lighting, cooking and heating should be completed.

9 Conclusion

The project being undertaken plans to design and confirm the feasibility of a DC power distribution for commercial buildings to power low load electronics such as lighting and simple devices with an array of photo-voltaic cells. The completion of this task will require extensive research, time, calculations and computer simulations. Milestones that have been set meet the SMART criteria which will allow for tracking and maintaining progress throughout the project. A literature review and analysis of the task has been completed. Additionally, through testing and simulations initial calculations and test modelling have been completed.

Computer simulations are the main design solution due to the large costs involved in commercial power system implementation. By simulating designs and providing visual aids through 3D rendered images, the presentation will be show not only calculation data but designs implemented on a visual model. In the event that an experimental test can be financially and physically completed and it would benefit the task, it will be done.

As of the submission of this progress report (April 2017) calculations have been completed and some conclusions made. The remaining tasks have been outlined in Section 5.6.3 but are focused around the final stages of the design phase. Thus far, 48 V DC has been deemed the most appropriate voltage level for the system and remaining calculations based off that value. Additionally upon analysis of QUT data and further design and testing initial predictions are that this project should be feasibly. The consumption curves from lighting and production curves from feasible levels of photovoltaic installations appear to be in line such that they could outweigh each other within a DC installation. The created lighting models at this stage also represent consumption suitable for this installation.

Overall it is expected that this research project will be completed with a feasible design. If it is found that no solution will be suitable, a strong justification and possible future areas of discussion will be brought forward. A finalised design will be created in the next stage and final calculations of both efficiencies and finances completed. After these items are completed, all questions will be answered and a final conclusions drawn.

References

[1] A. S. Active and P. Filter, "Transmission and Distribution Components," *Quadrennial Technology Review 2015*, no. January, pp. 1–22, 2015.

[2] H. Haberlin, *Photovoltaics System Design and Practice*, H. Peel, Ed. Switzerland: John Wiley & Sons Ltd, 2012.

[3] I. Myers Power Products, "Myers power products, inc dc switchgear," 2017, http://www.myerspowerproducts.com/index.php?option=comcontentview=categoryid=173Itemid

[4] E. Herz, "48v dc for telecommunications: Powering an industry," 2016, http://resources.secamerica.com/48v-dc-for-telecommunications-powering-an-industry.

[5] A. Zahedi, "Solar Battery Power Supply: A Reliable Power Supply System for Nursing Clinic in Australia's Remote Areas," pp. 1911–1914.

[6] S. M. Lisy and M. Smrekar, "Three Case Studies of Commercial Deployment of 400V DC Data and Telecom Centers in the EMEA Region," pp. 6–11, 2015.

[7] J. Pellis, "The DC Low-Voltage House," Ph.D. dissertation, Eindhoven University of Technology, 1997.

[8] U. of Queensland, "Uq solar photovoltaic data: St lucia 2016," 2017.

[9] Suntech, "Suntech stp250-20/wd," 2012, http://www.energymatters.com.au/images/suntech/STP

[10] L. H. Koh, Y. K. Tan, Z. Z. Wang, and K. J. Tseng, "An energy-efficient low voltage DC grid powered smart LED lighting system," *IECON Proceedings (Industrial Electronics Conference)*, vol. 2, no. 11, pp. 2883–2888, 2011.

[11] TriCAB, "Triangle flexible lszh cables issue 13.1 australia," 2009, http://innovath.com/download/TriCAB

[12] Standards Australia, "Interior and workplace lighting Part 1 : General principles and recommendations," 2006.

[13] S. Donohue, "Extra Low Voltage In-home Power Distribution and Storage (48vdc)," Undergraduate Thesis, Queensland University of Technology, 2014.

[14] M. Amin, Y. Arafat, S. Lundberg, and S. Mangold, "Low voltage DC distribution system compared with 230 V AC," *2011 IEEE Electrical Power and Energy Conference, EPEC 2011*, pp. 340–345, 2011.

[15] United States Department of the Interior, "Methods for Coordinating System Protective Equipment," *Facilities Instructions, Standards, and Techniques*, vol. 3-9, no. December 1991, 2000.

[16] M. Baran and N. Mahajan, "DC distribution for industrial systems: opportunities and challenges," *IEEE Transactions on Industry Applications*, vol. 39, no. 6, pp. 1596–1601, 2003.

[17] Standards Australia, "AS/NZS 3000: Wiring Rules," pp. 1–21, 2007.

[18] ——, "AS/NZS 3008: Electrical Installations," pp. 1–136, 2010.

[19] ——, "AS/NZS 3015: Electrical Installations of Extra Low Voltage DC Power Supplies and Service Earthing Within Public Telecommunications Networks," pp. 1–61, 2004.

[20] T. Nelson, P. Simshauser, and S. Kelley, "Australian Residential Solar Feed-in-Tariffs: Industry Stimulus or Regressive Form of Taxation," *Economic Analysis and Policy*, vol. 41, no. 2, pp. 113–129, 2011. [Online]. Available: http://www.eap-journal.com/archive/v41{_}i2{_}01-nelson.pdf

[21] SolarChoice.net, "Which electricity retailer is giving the best solar feed in tariff?" 2016, http://www.solarchoice.net.au/blog/which-electricity-retailer-is-giving-the-best-solar-feed-in

[22] S. Antoniou, A, Tzimas, A, Rowland, "Transition from AC to DC Low-Voltage Distro Networks," *IET Generation, Transmission & Distribution*, vol. 9, no. 12, pp. 1391–1401, 2015.

[23] Z. Liu and M. Li, "Research on Energy Efficiency of DC Distribution System," *AASRI Procedia*, vol. 7, pp. 68–74, 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2212671614000328

[24] P. Paajanen, T. Kaipia, and J. Partanen, "DC supply of low-voltage electricity appliances in residential buildings," in *20th International Conference and Exhibition on Electricity Distribution (CIRED 2009)*, no. 0692, 2009, pp. 1–4. [Online]. Available: http://digital-library.theiet.org/content/conferences/10.1049/cp.2009.0925

[25] M. Starke, L. M. Tolbert, and B. Ozpineci, "AC vs. DC distribution: A loss comparison," *Transmission and Distribution Exposition Conference: 2008 IEEE PES Powering Toward the Future, PIMS 2008*, vol. 1, no. 1, pp. 1–7, 2008.

[26] M. Starke, F. Li, L. M. Tolbert, and B. Ozpineci, "AC vs. DC distribution: Maximum transfer capability," *IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century, PES*, pp. 1–6, 2008.

[27] L. Pillay and K. S. Karimov, "Photo-Voltaic System," in *3rd International Conference on Electrical & Computer Engineering*, no. December. Dhaka, Bangladesh: ICECE, 2004, pp. 28–30.

[28] O.-G. E. Australia, "Batteries," 2015, http://www.offgridenergy.com.au/batteries/.

[29] Tesla, "Powerwall," 2017, https://www.tesla.com/en_AU/powerwall.

[30] Diffen.com, "Converter vs inverter," 2016, http://www.diffen.com/difference/Converter-vs-Inverte

[31] H. Abu-Rub, M. Malinowski, and K. Al-Haddad, *Power Electronics For Renewable Energy Systes, Transportation and Industrial Appliactions.* West Sussex, UK: John Wiley & Sons Ltd, 2014.

[32] Eaton, "Eaton general dc circuit breakers," 2014, http://www.eaton.com/Eaton/ProductsServices/Electrical/ProductsandServices/CircuitProtectio

[33] EcoRevolution, "Lumens and light output," 2016, http://www.eco-revolution.com/lumens-and-light-output/.

[34] E. D. Spooner and N. Wilmot, "Safety issues, arcing and fusing in PV arrays," in *3rd International Solar Energy Society*, no. November, 2008, pp. 1–9. [Online]. Available: http://auses.org.au/wp-content/uploads/425.pdf

[35] M. Dargatz, "Dc arc faults and pv system safety," 2009, http://www.renewableenergyworld.com/articles/2009/12/dc-arc-faults-and-pv-system-safety.html

[36] E. F. F. Ribeiro, A. J. M. Cardoso, C. Boccaletti, and A. M. S. Mendes, "Photovoltaic DC-DC converter for telecommunications energy systems," *2009 International Conference on Clean Electrical Power, ICCEP 2009*, pp. 433–438, 2009.

[37] D. Salomonsson and A. Sannino, "Low-voltage DC distribution system for commercial power systems with sensitive electronic loads," *IEEE Transactions on Power Delivery*, vol. 22, no. 3, pp. 1620–1627, 2007.

[38] T. Waldeck, M. Busser, and K. Dostert, "Telecommunication Application Over The Low Voltage Power Distribution Grid," pp. 1–5, 1998.

[39] P. Meckler, F. Gerdinand, R. Weiss, U. Boeke, and A. Mauder, "Hybrid switches in protective devices for low-voltage DC grids at commercial used buildings," *27th International Conference on Electrical Contacts, June 22 – 26, 2014, Dresden, Germany*, pp. 120–125, 2014.

[40] A. B. Foss, "DC Supply in Buildings," Masters Paper, Norwegian University of Science and Technology, 2014.

[41] N. Mendis, K. Muttaqi, S. Sayeef, and S. Perera, "Application of a hybrid energy storage in a remote area power supply system," *Energy Conference and Exhibition (EnergyCon), 2010 IEEE International*, pp. 576–581, 2010. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs{_}all.jsp?arnumber=5771747

[42] L. A. Morley, *Mine Power Systems.* United States Department of the Interior: Bureau of Mines, 1990, vol. 1, no. 1.

[43] P. Process and C. Engineer, "Abb launches prefabricated dc rail substation," 2015, http://search.proquest.com.ezp01.library.qut.edu.au/docview/1692146095/fulltext/55E8DAA0D3

[44] Enphase, "Enphase microinverters: What's underdeanth the panels makes all the difference," 2016, https://enphase.com/en-au/products-and-services/microinverters.

[45] Tridonic, "Tridonic fixed output dc/dc led drivers," 2017, http://www.tridonic.com/com/en/products/led-talexx-converter-dc-dc-fo.asp.

[46] Standards Australia, "AS 2293.1: Emergency escape lighting and exit signs for buildings," pp. 1–56, 2005.

[47] A. Ranganatha, M; Sastry, "Solar Micro Inverter Modeling and Reliability," Ph.D. dissertation, Arizona State Univeristy, 2015.

[48] Pierlite, "Futcha led," 2016, http://www.pierlite.com/au/90221/futcha-led.

[49] F. I. o. I. S. (IISB) and D. Technology, "The power electronics innovators," pp. 1–28, 2014.

[50] M. Sechilariu, F. Locment, and B. Wang, "Photovoltaic electricity for sustainable building. Efficiency and energy cost reduction for isolated DC microgrid," *Energies*, vol. 8, no. 8, pp. 7945–7967, 2015.

[51] N. P. the Network, "Dc power distribution panel with plug-in circuit breakers," 2017.

[52] Standards Australia, "AS/NZS 5033:2014 Installation and safety requirements for photovoltatic (PV) arrays," pp. 1–101, 2014.

[53] A. N. Energy, "Suntech stp265-20/wem," 2012, http://www.allnaturalenergy.com.au/shop/solar-panels/suntech-solar-panels/suntech-265-watt-20

[54] L. C. Australia, "Led fact sheets: Energy efficiency of white leds," 2010.

[55] L. Supply, "Ldd-h series mean well step-down mode cc dc-dc led drivers," 2017.

[56] Telsa, "Powerwall rev 3.3," 2017.

[57] Enphase, "Enphase ac battery," 2017.

10 Appendices

10.1 Semester 2 Supervisor Meetings

2017 Supervisor Meeting Summary		
Date	*Time*	*Discussion Points*
31 Jan 2017	1200-1230	- Feedback from 2016 reports - Research shortcomings - My plan for remaining tasks - Explained where I was wrong with terminology
17 Apr 2017	1300-1400	- Report structure changes - Different PV calculation techniques - Necessary additions to PV section - Incorrect assumptions during calculation - Discussed remaining tasks - Discussed oral presentation
9 May 2017	1200-1400	- Checked over full report - Received grade for progress report 2 - Agreed on remaining tasks - Discussed presentation requirements - Provided tips on technical writing - Provide guidance final building model

Table 15: Supervisor Meetings of 2017 Summary

10.2 Timeline Analysis

10.2.0.1

The tasks were be split into days and University weeks. It was ensured to include the holidays during periods where University is not run. This project does not simply end upon the completion of this semester. BEB801 is concluded on November 4th at the end of Week 14, however BEB802 is the subject allocation to complete the second half of this project. The task table will allocate SMART milestones. Additionally, the benefits of completing the subjects during this period is that there is the additional time from summer holidays to account for.

10.2.0.2

Table 16 on the following page shows the milestones of this project. The University assigned submissions are represented as bold text. The four major deliverables for the first half of this project are the library assessment, project proposal, oral presentation and progress report. These four deliverables are what have outlined how the remaining tasks have been created and the time periods allowed for. Earlier due dates are set to allow for editing or possible difficulties to occur without major repercussions.

10.2.0.3

Table 17 represents the revised timeline with completed times. This is for the benefit of both the creator of this project as well as any future students who wish to progress the project and extend its scope. There are a variety of reasons as to why there were extensions of time for completing milestones. It is not an irregular occurrence that project plans are extended and this project is no different. As previously discussed, deadlines were set at least 1 week early with the intention of ensuring proper preparation is done and deadlines are not missed.

Initial Timeline

Initial Project Timeline	
Milestone	**Deadline**
Project Definition	Sem 1 Week 3
Library Assessment	**Sem 1 Week 4**
Initial Research Phase	Sem 1 Week 6
Project Proposal	**Sem 1 Week 7**
Initial Design Phase	Sem 1 Week 9
Initial Prototype Design Finalised	Sem 1 Week 11
Initial 3D Modelling for Presentation	Sem 1 Week 12
Initial Oral Presentation	**Sem 1 Week 14**
Written Report	**Sem 1 Week 14**
Implement Feedback From Report	Summer Break
Complete Research Shortcomings	Summer Break
Complete Further Technical Calculations	Summer Break
Initial Finance Analysis	Sem 2 Week 2
Design Simulations	Sem 2 Week 6
Progress Report	**Sem 2 Week 7**
Finalised Design	Sem 2 Week 10
Finalised Simulations & 3D Modelling	Sem 2 Week 11
Finalised Financial Analysis	Sem 2 Week 12
Final Presentation	**Sem 2 Week 14**
Final Report	**Sem 2 Week 14**

Table 16: Initial Project Timeline

Revised Timeline

Milestone	Original Deadline	Actual Completion
Project Definition	Week 3	Week 3
Library Assessment	**Week 4**	Week 4
Initial Research Phase	Week 6	Week 6
Project Proposal	**Week 7**	Week 7
Initial Design Phase	Week 9	Week 10
Initial Prototype Design Finalised	Week 11	NA
Initial 3D Modelling for Presentation	Week 12	Week 11
Initial Oral Presentation	**Week 14**	Week 14
Written Report	**Week 14**	Week 14
Implement Feedback From Report	Summer Break	Summer Break
Complete Research Shortcomings	Summer Break	Summer Break
Complete Further Technical Calculations	Summer Break	Week 8
Initial Finance Analysis	Week 2	TBC
Design Simulations	Week 6	Week 8
Progress Report	**Week 8**	Week 8
Finalised Design	Week 10	TBC
Finalised Simulations & 3D Modelling	Week 11	TBC
Finalised Financial Analysis	Week 12	TBC
Final Presentation	**Week 14**	TBC
Final Report	**Week 14**	TBC

Table 17: Initial Project Timeline Analysis

10.3 Draft Floor Plan

Before the schematics and floor plans for QUT's buildings were made available, an approximate small office area was modelled in AutoCAD with offices of 5m^2 represented in Figure 41. The purpose of this simulation was to analyse approximate lighting loads for the environment. It was only used as a preliminary design approximation until more time was allocated to design.

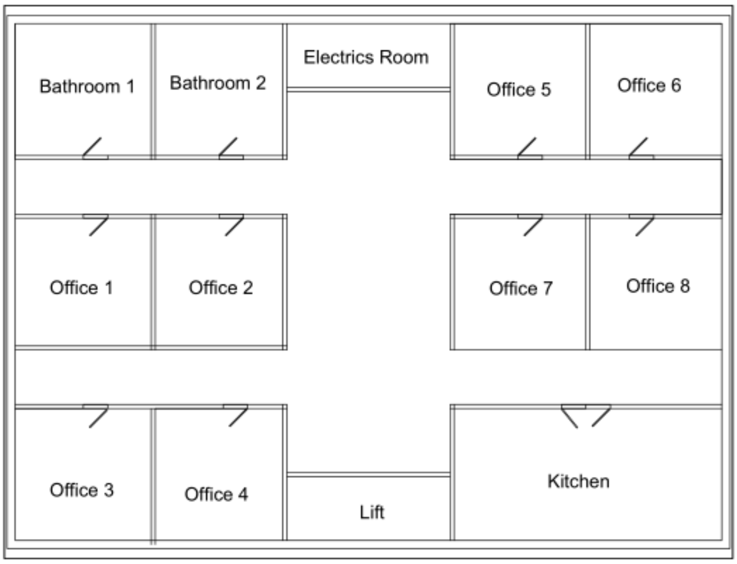


Figure 41: Initial Draft Floor Plan Design

10.3.1 Draft Floor Plan Lighting Simulation

After the initial room plans were created, the Australian Standards AS/NZS 1680.2.2 Interior and Workplace Lighting were consulted to produce a table of required lux values depending on room use. The standards is replicated and simplified below in Table 18.

Area or Application	**Lux Requirement**
Rarely Visited	40
Storage Rooms or Change Room	80
Machine Work or Waiting Room	160
Food Preparation Room	240
Technical Office Room	320
Visually Difficult Work	500

Table 18: Lighting Requirements as per AS/NZS Standards [12]

These two data points were used for the initial draft planning of designs. This is not an accurate representation of a building, it was a starting point to work from to beginning analysis load requirements. Once the more accurate schematics and plans are created, a stronger assessment can be created and feasibly power system construction plans created. To estimate load requirements for this smaller, draft area, the simple floor plan CAD file was imported into Dialux4.13. This is a lighting design software solution to model options and predict approximate load demands that the LVDC system will be required to power.

Through personal experience in building services design, I had an approximate idea of what amounts of lighting would be required for a $5\,\mathrm{m}^2$ room. I also knew that I would use LED down lights for simplicity and affordability. The difficult part is finding commercially available products that operate at a voltage level at either 48 V DC when the voltage drop over cabling is removed or at another level where an efficient DC to DC converter could be used. My goal was to have the average lux between 300 lux to 400 lux. This value was chosen as a technical office is an accurate assessment of most corporate buildings. As seen in Table 19 below, seven 20 W LED down lights reaches this specification. The way this was completed was through multiple tested and rendering of designs. It can be a tedious process but photometric files (also known as IES files) are also imported into Dialux and can be placed throughout the 3D model. This 3D model is shown in Figure 42. To find the optimal solution, the simplest method is to remove and add lights of varying wattage and test the lux distribution. An example of the lux distribution is shown in Figure 43. Appendix 10.6 shows the full report of the final working model.

Down Light Wattage	Quantity	Max Lux	Min Lux	Average Lux
11	6	114	3.8	73
11	10	180	7	114
20	8	680	16	383
20	7	677	12	344

Table 19: Dialux Outputs of Initial Draft Floor Plan

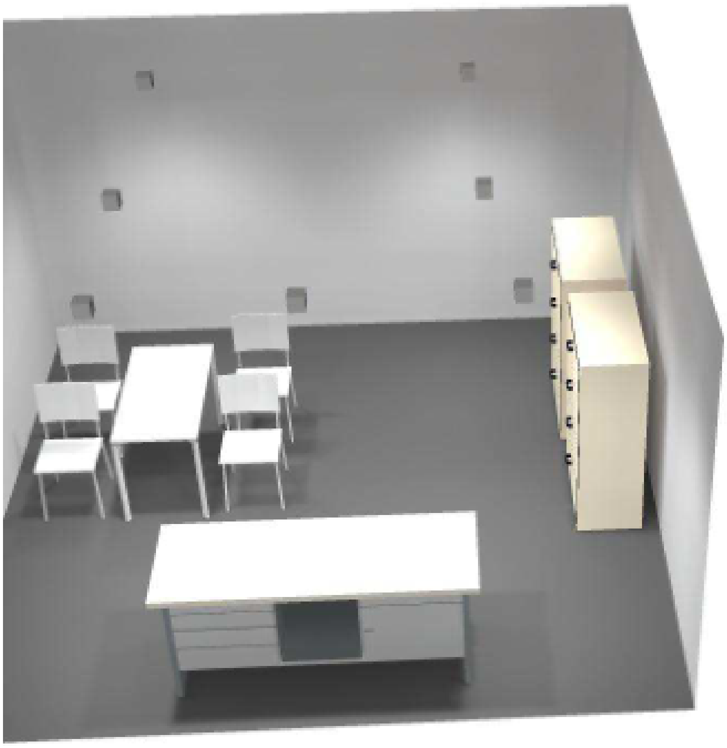


Figure 42: Initial Draft Floor Plan Lighting Test 3D Render

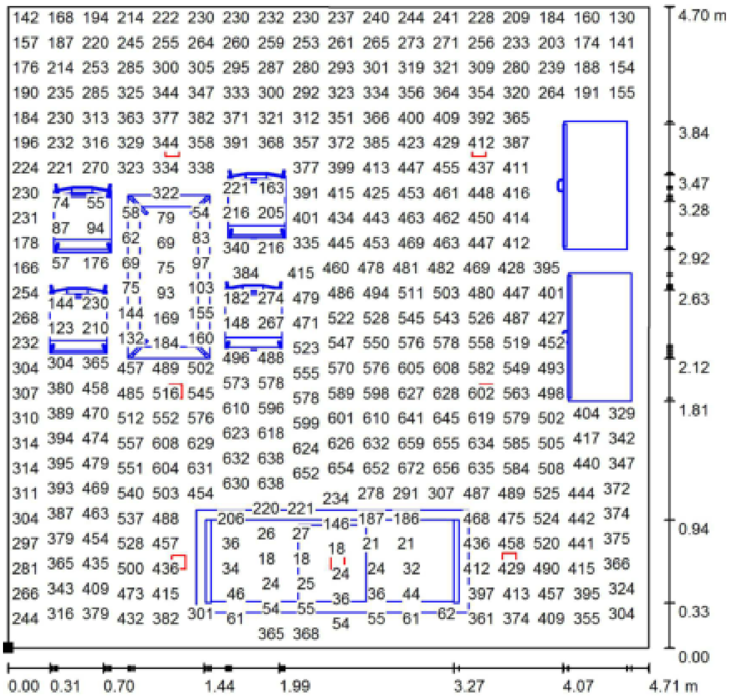
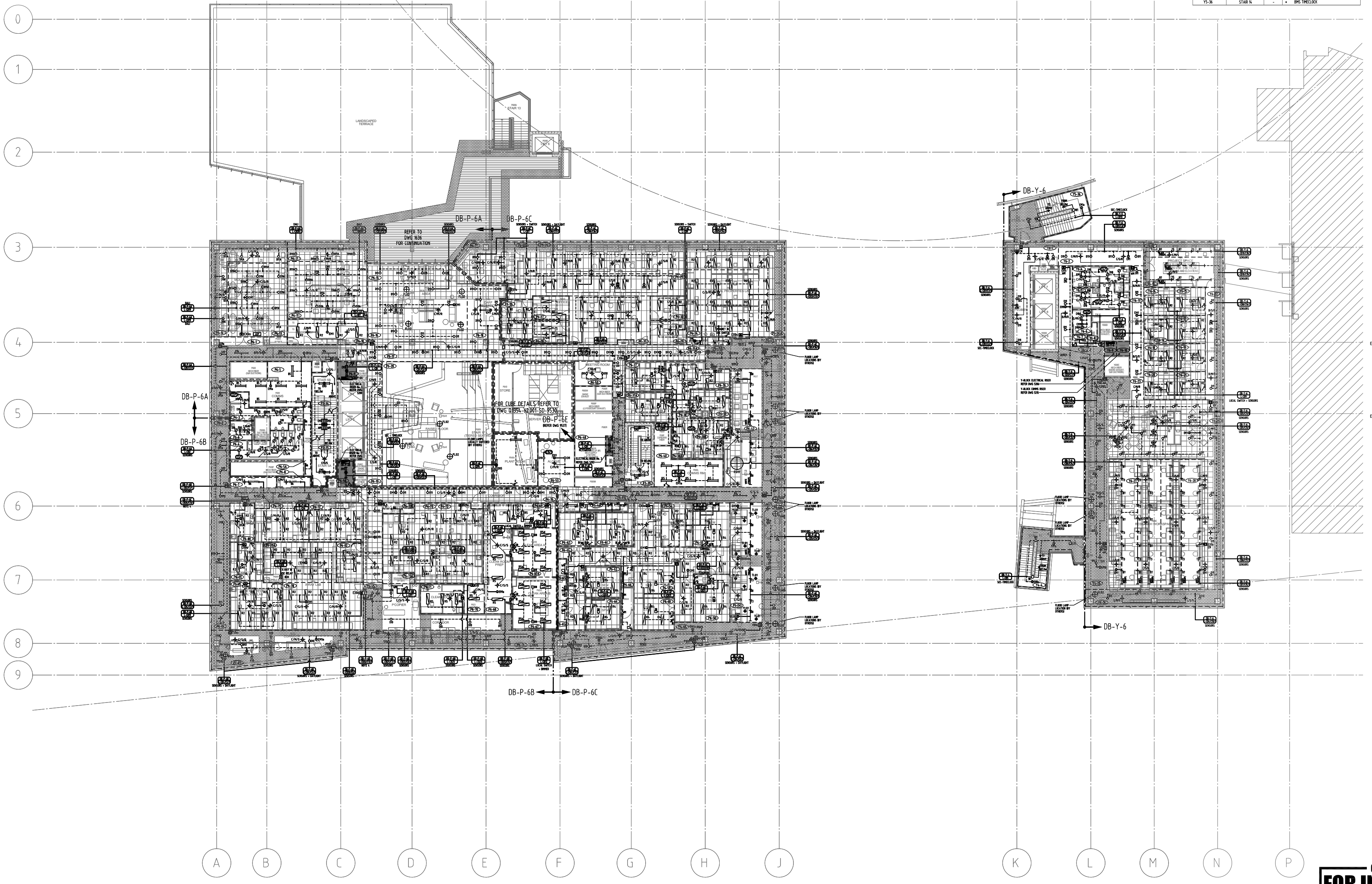


Figure 43: Initial Draft Floor Plan Lighting Test Lux Output

Continuing from this example, the total lighting load of an office room would therefore be 140 W (20 W * 7 lights). To approximate the total demand for the entire draft floor plan, there are bathrooms, kitchen and hallways that all require less light. If the offices' load is approximately 1.1 kW it can be expected that the total area lighting load would approach 1.8 kW. This is a good starting point and more accurate modelling can now be done with QUT's provided power data.

10.4 QUT P Block Level 6 Office Markup

QEEC-LAST UPDATED:
20-11-2012



LEVEL 6 Y-BLOCK - LIGHT SWITCHING SCHEDULE

LIGHTING SWITCHING ZONE NUMBER	USE OF AREA	AREA (m²)	LIGHT SWITCHING METHODOLOGY
Y6-1	LIFT LOBBY	46m²	• MASTER/SLAVE SENSORS, 30min • SEC-TIMECLOCK
Y6-2	PERIMETER WALKWAY CORRIDOR	26m²	• MASTER/SLAVE SENSORS, 30min
Y6-3	CORRIDOR	31m²	• MASTER/SLAVE SENSORS, 30min
Y6-4	FEMALE AMENITIES	14m²	• MASTER/SLAVE SENSORS, 30min
Y6-5	MALE AMENITIES	16m²	• MASTER/SLAVE SENSORS, 30min
Y6-6	PWD	6m²	• MOTION SENSOR
Y6-7	CLEANERS	2m²	• MOTION SENSOR
Y6-8	PLANT ROOM	3m²	• KEY SWITCH
Y6-9	ELECTRICAL DB ROOM	2m²	• KEY SWITCH
Y6-10	COMMS ROOM	2m²	• KEY SWITCH
Y6-11	CORRIDOR	20m²	• MASTER/SLAVE SENSORS, 30min
Y6-12	PERIMETER LIGHTING	16m²	• MASTER/SLAVE SENSORS, 30min
Y6-13	PROJECT SPACE	31m²	• MASTER/SLAVE SENSORS, 30min
Y6-14	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-15	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-16	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-17	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-18	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-19	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-20	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-21	SMALL OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-22	PERIMETER WALKWAY	26m²	• MASTER/SLAVE SENSORS, 30min
Y6-23	KITCHEN AREA	90m²	• MASTER/SLAVE SENSORS, 30min
Y6-24	PERIMETER WALKWAY	37m²	• MASTER/SLAVE SENSORS, 30min
Y6-25	PERIMETER WALKWAY	59m²	• MASTER/SLAVE SENSORS, 30min
Y6-26	PERIMETER WALKWAY	30m²	• MASTER/SLAVE SENSORS, 30min
Y6-27	WORK AREA	90m²	• MASTER/SLAVE SENSORS, 30min
Y6-28	WORK AREA	77m²	• MASTER/SLAVE SENSORS, 30min
Y4-4	STAIR 15	-	• BMS TIMECLOCK
Y5-36	STAIR 14	-	• BMS TIMECLOCK

LEVEL 6 P-BLOCK - LIGHT SWITCHING SCHEDULE

LIGHTING SWITCHING ZONE NUMBER	USE OF AREA	AREA (m²)	LIGHT SWITCHING METHODOLOGY
P6-1	CORRIDOR	53m²	• MASTER/SLAVE SENSORS, 30MINS
P6-2	CORRIDOR	41m²	• MASTER/SLAVE SENSORS, 30MINS
P6-3	MALE AMENITIES	19m²	• MASTER/SLAVE SENSORS, 30MINS
P6-4	FEMALE AMENITIES	23m²	• MASTER/SLAVE SENSORS, 30MINS
P6-5	COMMS ROOM	36m²	• KEY SWITCH
P6-6	PWD	6m²	• SENSOR, 30min
P6-7	STORE	6m²	• SENSOR, 30min
P6-8	CLEANERS	5m²	• SENSOR, 30min
P4-9	ELECTRICAL DISTRIBUTION CUPBOARD	4m²	• KEY SWITCH
P4-9A	ELECTRICAL DISTRIBUTION CUPBOARD	5m²	• KEY SWITCH
P6-10	SERVERY	26m²	• MASTER/SLAVE SENSORS, 30MINS
P6-11	MEETING ROOM	59m²	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-12	MEETING ROOM PERIMETER	20m²	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-13	FLEXIBLE MODELLING SPACE	56m²	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-14	FLEXIBLE MODELLING SPACE PERIMETER	36m²	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-15	PERIMETER AREA	22m²	• MOTION SENSOR, (30min)
P6-16	CARF LOUNGE	79m²	• MOTION SENSOR, (30min)
P6-17	WALKWAY	39m²	• MOTION SENSOR, (30min)
P6-18	MEETING ROOM	23m²	• MOTION SENSOR, (30min)
P6-19	LIFT LOBBY	36m²	• MASTER/SLAVE SENSORS, 30MINS SECURITY FITTINGS ON BMS TIMECLOCK
P6-20		165m²	
P6-21	DIRECTIONS OFFICE	29m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-22	OFFICE	9m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-23	OFFICE	15m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-24	CARF ADMIN	62m²	• MASTER/SLAVE SENSORS, 30MINS
P6-25	CARF ADMIN	51m²	• MASTER/SLAVE SENSORS, 30MINS
P6-26	MEETING ROOM	16m²	• MOTION SENSOR, (30min)
P6-27	OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-28	OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-29	OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-30	OFFICE	11m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-31	OPEN PLAN OFFICE	50m²	• MASTER/SLAVE SENSORS, 30MINS
P6-32	(ZONE DELETED)		
P6-33	(ZONE DELETED)		
P6-34	PHYSICAL PROP LAB	65m²	• MASTER/SLAVE SENSORS, 30MINS
P6-34A	PHYSICAL PROP LAB PERIMETER	55m²	• MASTER/SLAVE SENSORS, 30MINS
P6-35	WALKWAY	30m²	• MASTER/SLAVE SENSORS, 30MINS
P6-35A	ELECTRICAL DB	3m²	• KEY SWITCH
P6-35B	EQUIPMENT ROOM	3m²	• KEY SWITCH
P6-36	OPTICS PREP 1	25m²	• MASTER/SLAVE SENSORS, 30MINS
P6-37	OPTICS LAB 3	18m²	• MASTER/SLAVE SENSORS, 30MINS
P6-37A	OPTICS LAB 2	18m²	• MASTER/SLAVE SENSORS, 30MINS
P6-38	OPTICS PREP 2	30m²	• MASTER/SLAVE SENSORS, 30MINS
P6-39	OPTICS LAB 1	15m²	• MOTION SENSOR, (30min)
P6-40	COMMS ROOM	28m²	• KEY SWITCH
P6-41		m²	
P6-42	OPEN AREA	53m²	• MASTER/SLAVE SENSORS, 30MINS
P6-43	PERIMETER WALKWAY	48m²	• MASTER/SLAVE SENSORS, 30MINS
P6-44	PERIMETER WALKWAY	40m²	• MASTER/SLAVE SENSORS, 30MINS
P6-45	PERIMETER WALKWAY	42m²	• MASTER/SLAVE SENSORS, 30MINS
P6-46	CORRIDOR/WALKWAY	38m²	• MASTER/SLAVE SENSORS, 30MINS
P6-47	CORRIDOR/WALKWAY	34m²	• MASTER/SLAVE SENSORS, 30MINS
P6-48	ELECTRICAL CUPBOARD	3m²	• KEY SWITCH
P6-49	CORRIDOR/WALKWAY	54m²	• MASTER/SLAVE SENSORS, 30MINS
P6-50	MEETING ROOM	12m²	• MOTION SENSOR, (30min)
P6-51	RESEARCH CAVE	18m²	• MOTION SENSOR, (30min)
P6-52	SERVER ROOM	24m²	• KEY SWITCH
P6-53	RESEARCH CAVE	22m²	• MOTION SENSOR, (30min)
P6-54	OPEN AREA	29m²	• MASTER/SLAVE SENSORS, 30MINS
P6-55	ESEM LAB	18m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-56	FUME CUPBOARD	18m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-58	ESEM LAB	23m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-59	SEM LAB	15m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-60	SEM LAB	15m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-61	TEM LAB	17m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-62	TEM LAB	17m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-63	SEM LAB	15m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-64	SEM LAB	15m²	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-65	MICROSCOPY LAB WALKWAY	31m²	• MASTER/SLAVE SENSORS, 30MINS
P6-65A	EQUIPMENT ROOM	3m²	• KEY SWITCH
P6-65B	EQUIPMENT ROOM	4m²	• KEY SWITCH
P6-65C	EQUIPMENT ROOM	5m²	• KEY SWITCH
P6-66	EQUIPMENT ROOM	10m²	• KEY SWITCH
P6-67	CLEAN ROOM B	31m²	• MASTER/CLAVE SENSOR, 30min AND SWITCH (AUTO/OFF) • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-67A	CLEAN ROOM A	28m²	• MASTER/SLAVE SENSOR, 30min AND SWITCH (AUTO/OFF) • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-68	CLEAN ROOM PREP	47m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-69	AIRLOCK	7m²	• MOTION SENSOR, (30min)
P6-70	AIRLOCK	8m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-71	CLEAN ROOM	16m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-72	ANALYTICAL CHEM LAB	44m²	• MASTER/SLAVE SENSORS, 30MINS
P6-73	ANALYTICAL CHEM LAB	61m²	• MASTER/SLAVE SENSORS, 30MINS
P6-73A	EQUIPMENT ROOM	4m²	• KEY SWITCH
P6-73B	EQUIPMENT ROOM	4m²	• KEY SWITCH
P6-74	PERIMETER WALKWAY	47m²	• MASTER/SLAVE SENSORS, 30MINS
P6-75	CIRCULATION AREA	54m²	• MASTER/SLAVE SENSORS, 30MINS
P6-76	CORRIDOR/WALKWAY	66m²	• MASTER/SLAVE SENSORS, 30MINS
P6-77	OFFICE	27m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-78	X-RAY LAB	50m²	• MASTER/SLAVE SENSORS, 30MINS
P6-78A	X-RAY LAB	38m²	• MASTER/SLAVE SENSORS, 30MINS
P6-79	OFFICE	26m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-80	SAMPLE PREP C	12m²	• MASTER/SLAVE SENSORS, 30MINS
P6-81	SAMPLE PREP B	17m²	• MASTER/SLAVE SENSORS, 30MINS
P6-82	OFFICE	14m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-83	PERIMETER WALKWAY	60m²	• MASTER/SLAVE SENSORS, 30MINS
P6-84	PERIMETER WALKWAY	30m²	• MASTER/SLAVE SENSORS, 30MINS
P6-85	BULK ANALYSIS LAB	33m²	• MASTER/SLAVE SENSORS, 30MINS
P6-86	STORE	10m²	• MASTER/SLAVE SENSORS, 30MINS
P2-34	STAIR 5B	19m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P2-35	STAIR 5A	19m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P3-39	STAIR 10	24m²	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)

OVERALL DRAWING ISSUED
FOR INFORMATION ONLY
THIS DRAWING WILL NOT BE LEGIBLE AT A3 SIZE
FOR A3 PRINTS REFER TO QUADRANT DRAWINGS

ELECTRICAL SERVICES

Qelectrical
commercial and industrial solutions

RPD: LOT 651 ON SURVEY PLAN 141435
County of STANLEY,
Parish of NORTH BRISBANE

2009 BCA IS USED FOR ASSESSMENT OF THIS BUILDING

NOTES:

CONSULTANTS

Architect - Donovan Hill + Wilson Architects, 112 Bowen Street, Spring Hill 4000 | (07) 3831 3255
Acoustic - Vipac , Suite 6, Rialto Building 524 Milton Road, Toowong 4066 | (07)3377 0400
Certifier - PLP Surveyors, 8 Prospect St, Fortitude Valley 4006 | (07) 3252 9733
Civil Engineer - Aurecon, L14, 32 Turbot St, Brisbane 4000 | (07) 3173 8000
DDA - Access All Ways Consultants, 23 Missing Link Rd, Bisley 4554 | (07) 5457 3189
Environmental - EMF Griffiths , 82 Arthur St Fortitude Valley 4006 | (07) 3254 2788
Electrical Engineer - Aurecon, L14, 32 Turbot St, Brisbane 4000 | (07) 3173 8000
Food + Beverage - FSDA, 270 Halls Rd, Luscombe, 4207 | (07) 5546 4600
Hydraulic Engineer - Floth, 42 Doggett St, Fortitude Valley, 4006 | (07) 3252 0977
Fire Engineer - Aurecon, L14, 32 Turbot St, Brisbane 4000 | (07) 3173 8000
Mechanical Engineer - Floth, 42 Doggett St, Fortitude Valley, 4006 | (07) 3252 0977
Quantity Surveyor - Rider Levett Bucknall | Level 3, 179 Ann Street, Brisbane 4000 | (07) 3009 6933
Structural + Facade Engineer - Aurecon, L14, 32 Turbot St, Brisbane 4000 | (07) 3173 8000
Swimming Pool Consultant - Leisure Engineering, 4/ 49 Jijaws St, Sumner 4074 | (07) 3376 8500
Traffic - TTM Group, Level 1, 129 Logan Rd, Woolloongabba 4102 | (07) 3327 9500
Vertical Transport - Aurecon, L14, 32 Turbot St, Brisbane 4000 | (07) 3173 8000
Clients Representative - Thinc Projects, Level 7, 333 Ann St, Brisbane 4000 | (07) 3221 8425

ARCHITECTURAL DRAWING REFERENCE
DWG: Q1354-OV-DWAR-1470
REV: WDL DATE: 05.06.12
DWG: Q1354-OV-DWAR-1670
REV: WDF DATE: 16.12.11

QUT
LEIGHTON

PROJECT
SCITECH

LOCATION
GARDENS POINT CAMPUS
QUT PROJECT No. C0000721
GP140 P-BLOCK /GP141 Y-BLOCK

PROJECT
TRUE

1:100

ISSUE	DATE	DESCRIPTION
F	20.11.12	AS BUILT
E	29.06.12	AMENDMENTS AS CLOUDED
D	01.06.12	AMENDMENTS AS CLOUDED
C	13.03.12	CLEAN ROOM LIGHTS UPDATED
B	30.01.12	FOR CONSTRUCTION (AS CLOUDED)
A	13.10.11	FOR APPROVAL

QUT PROJECT No: P Block GP140/Y Block GP141
PROJECT No: LCPN:Q1234 QES:523
SCALE @ B1: 1:200 SCALE @ A3: -
CAD FILE: Q1354-62.001-SD-1070
DRAWN BY: G.L.
CHECKED BY: B.L.

SHEET TITLE
ELECTRICAL SERVICES
Lighting Layout Plan
Level 6

Q1354-62.001-SD-1070 ABF

10.5 QUT P Block Level 6 Office Lighting Simulation

QUT Level 6 Office Lighting Simulation Rev 3

Project: Undergraduate Thesis
University: Queensland University of Technology
Creator: David Petrie
Contact: david.petrie@connect.qut.edu.au

Date: 08.04.2017
Operator: David Petrie

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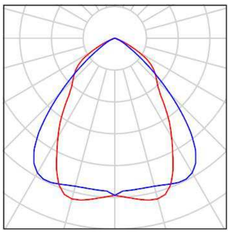
QUT Level 6 Office Lighting Simulation Rev 3 / Luminaire parts list

2 Pieces

Gerard Lighting F-LED_1234U1 Pierlite Futcha LED 300x1200 4000K 27W DALI
Article No.: F-LED_1234U1
Luminous flux (Luminaire): 2940 lm
Luminous flux (Lamps): 2940 lm
Luminaire Wattage: 27.5 W
Luminaire classification according to CIE: 100
CIE flux code: 70 96 100 100 100
Fitting: 1 x Samsung S4 (Correction Factor 0.800).

See our luminaire catalog for an image of the luminaire.



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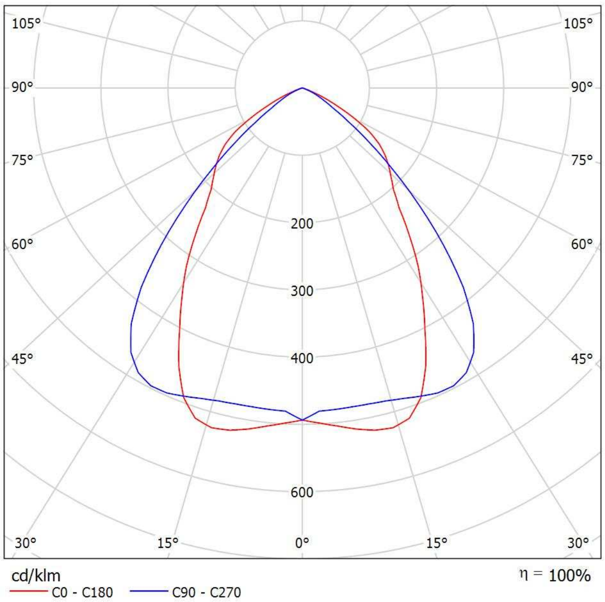
Gerard Lighting F-LED_1234U1 Pierlite Futcha LED 300x1200 4000K 27W DALI / Luminaire Data Sheet

See our luminaire catalog for an image of the luminaire.

Luminous emittance 1:



Luminaire classification according to CIE: 100
CIE flux code: 70 96 100 100 100

Luminous emittance 1:

Glare Evaluation According to UGR

ρ Ceiling		70	70	50	50	30	70	70	50	50	30
ρ Walls		50	30	50	30	30	50	30	50	30	30
ρ Floor		20	20	20	20	20	20	20	20	20	20
Room Size X	Y	Viewing direction at right angles to lamp axis					Viewing direction parallel to lamp axis				
2H	2H	13.0	14.0	13.3	14.2	14.4	7.6	8.6	7.8	8.8	9.0
	3H	13.0	13.9	13.4	14.2	14.4	7.6	8.5	7.9	8.7	9.0
	4H	13.0	13.8	13.3	14.1	14.4	7.5	8.4	7.8	8.6	8.9
	6H	12.9	13.7	13.3	14.0	14.3	7.5	8.2	7.8	8.5	8.8
	8H	12.9	13.6	13.2	13.9	14.2	7.4	8.2	7.8	8.5	8.8
	12H	12.9	13.5	13.2	13.9	14.2	7.4	8.1	7.8	8.4	8.7
4H	2H	12.8	13.7	13.2	13.9	14.2	7.7	8.5	8.0	8.8	9.0
	3H	12.9	13.6	13.3	13.9	14.2	7.7	8.4	8.1	8.7	9.0
	4H	12.9	13.5	13.3	13.8	14.2	7.7	8.3	8.1	8.6	9.0
	6H	12.8	13.3	13.2	13.7	14.1	7.6	8.1	8.0	8.5	8.9
	8H	12.8	13.2	13.2	13.6	14.0	7.6	8.0	8.0	8.4	8.8
	12H	12.7	13.1	13.2	13.6	14.0	7.5	8.0	8.0	8.4	8.8
8H	4H	12.8	13.2	13.2	13.6	14.0	7.6	8.0	8.0	8.4	8.8
	6H	12.7	13.1	13.1	13.5	13.9	7.5	7.9	8.0	8.3	8.8
	8H	12.7	13.0	13.1	13.4	13.9	7.5	7.8	8.0	8.2	8.7
	12H	12.6	12.9	13.1	13.3	13.8	7.4	7.7	7.9	8.2	8.7
12H	4H	12.7	13.1	13.2	13.5	14.0	7.5	8.0	8.0	8.4	8.8
	6H	12.6	13.0	13.1	13.4	13.9	7.5	7.8	7.9	8.2	8.7
	8H	12.6	12.9	13.1	13.3	13.8	7.4	7.7	7.9	8.2	8.7
Variation of the observer position for the luminaire distances S											
S = 1.0H		+1.1 / -0.9					+1.7 / -4.2				
S = 1.5H		+1.0 / -2.9					+3.2 / -8.2				
S = 2.0H		+2.3 / -7.8					+5.0 / -12.1				
Standard table		BK00					BK00				
Correction Summand		-8.5					-8.9				
Corrected Glare Indices referring to 2940lm Total Luminous Flux											

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Standard Office / Photometric Results

Total Luminous Flux: 5879 lm
Total Load: 55.0 W
Light loss factor: 0.80
Boundary Zone: 0.100 m

Surface	Average illuminances [lx]			Reflection factor [%]	Average luminance [cd/m²]
	direct	indirect	total		
Workplane	221	49	269	/	/
Floor	91	32	123	20	7.81
Ceiling	0.00	46	46	70	10
Wall 1	34	39	73	50	12
Wall 2	5.05	18	23	50	3.63
Wall 3	72	42	114	50	18
Wall 4	66	41	107	50	17

Uniformity on the working plane
u0: 0.172 (1:6)
E_{min} / E_{max}: 0.117 (1:9)

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.263, Ceiling / Working Plane: 0.171.

Specific connected load: 5.16 W/m² = 1.91 W/m²/100 lx (Ground area: 10.67 m²)

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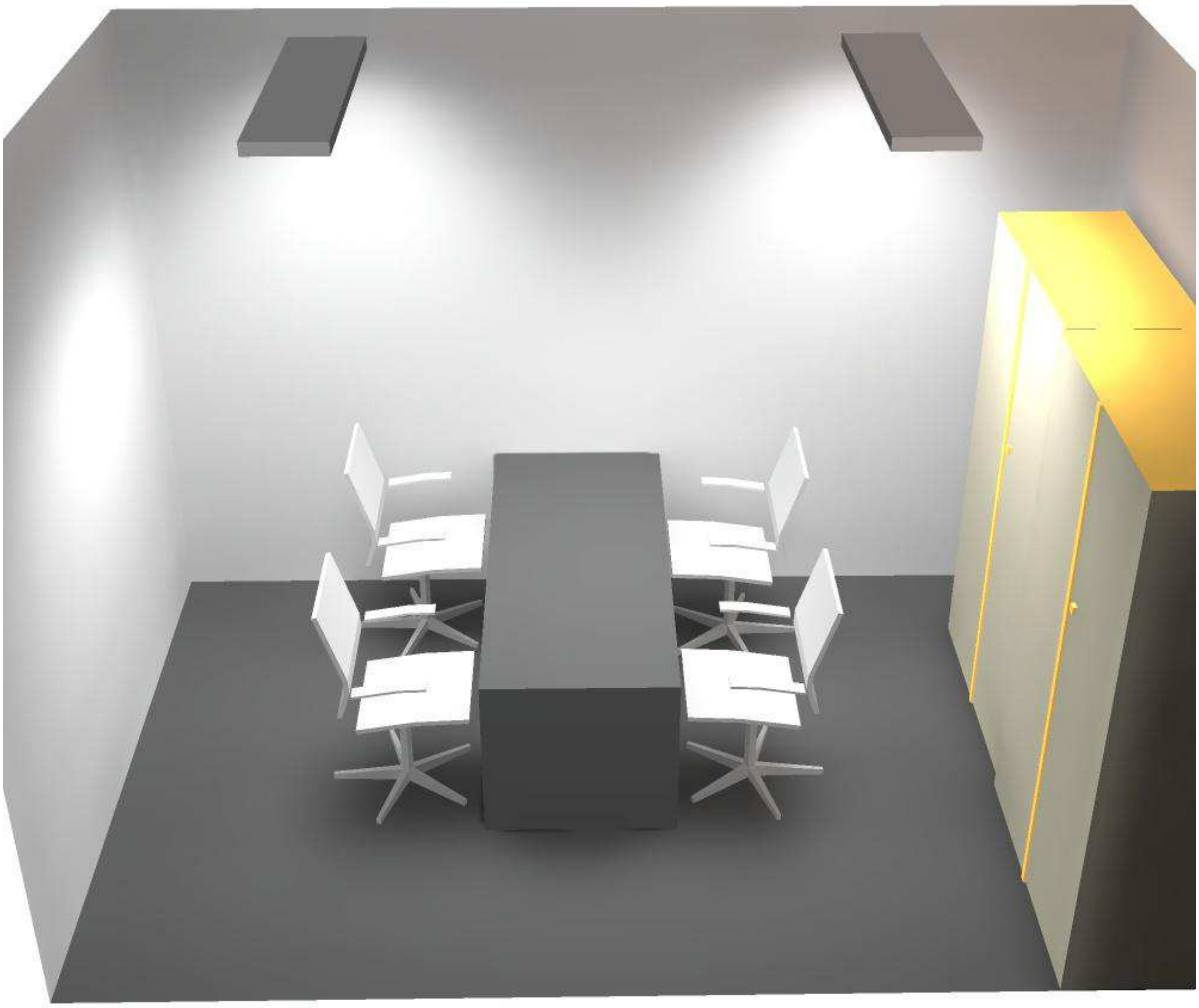
Standard Office / 3D Rendering



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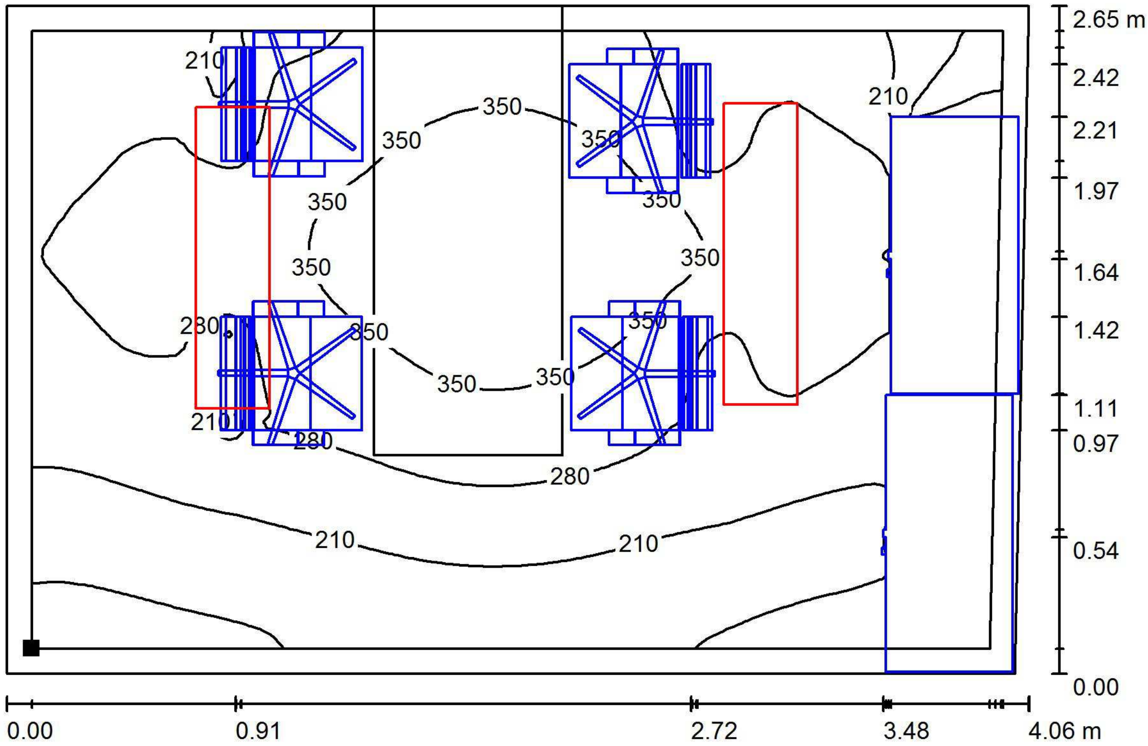
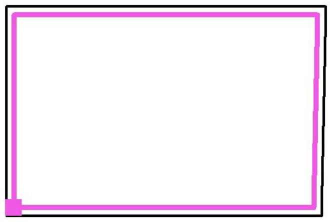
Standard Office / Workplane / Isolines (E)



Values in Lux, Scale 1 : 30

Position of surface in room:
Working plane with 0.100 m
Boundary Zone
Marked point:
(73.574 m, 63.408 m, 0.750 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
269	46	395	0.172	0.117

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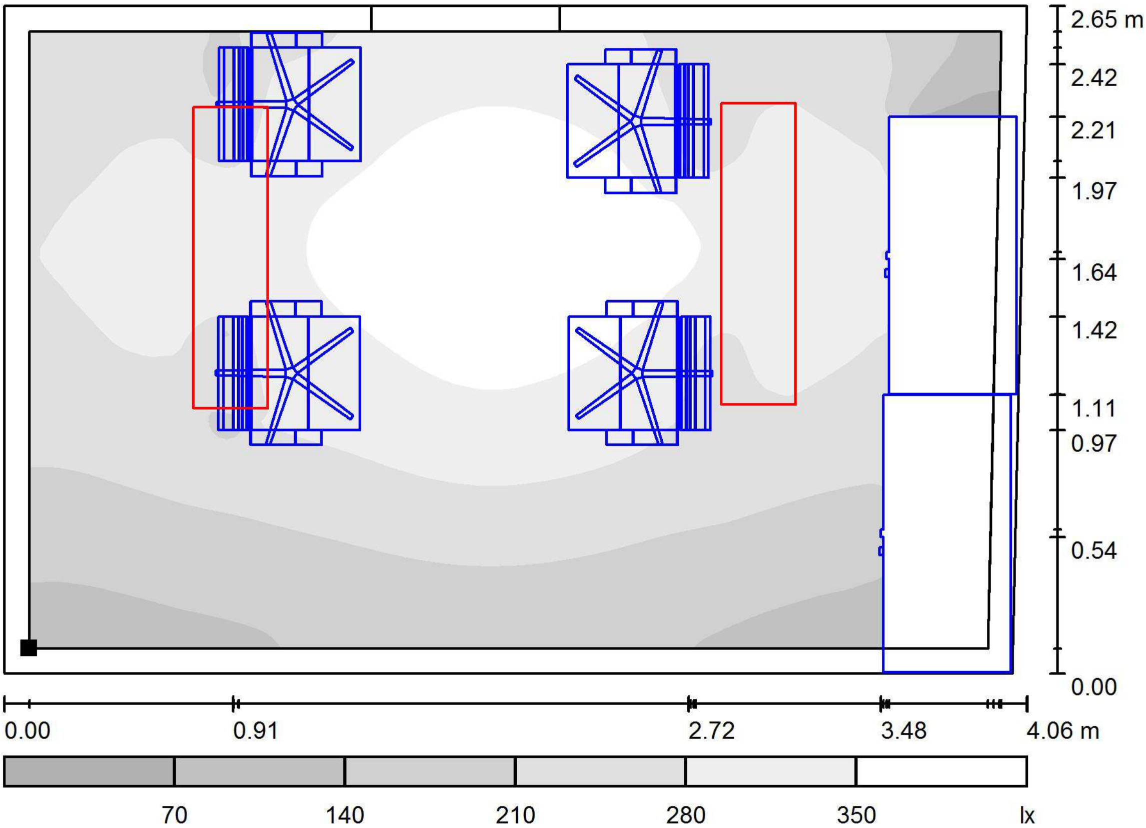
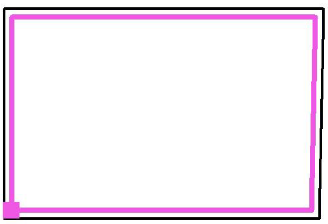
Standard Office / Workplane / Greyscale (E)



Scale 1 : 30

Position of surface in room:
Working plane with 0.100 m
Boundary Zone
Marked point:
(73.574 m, 63.408 m, 0.750 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
269	46	395	0.172	0.117

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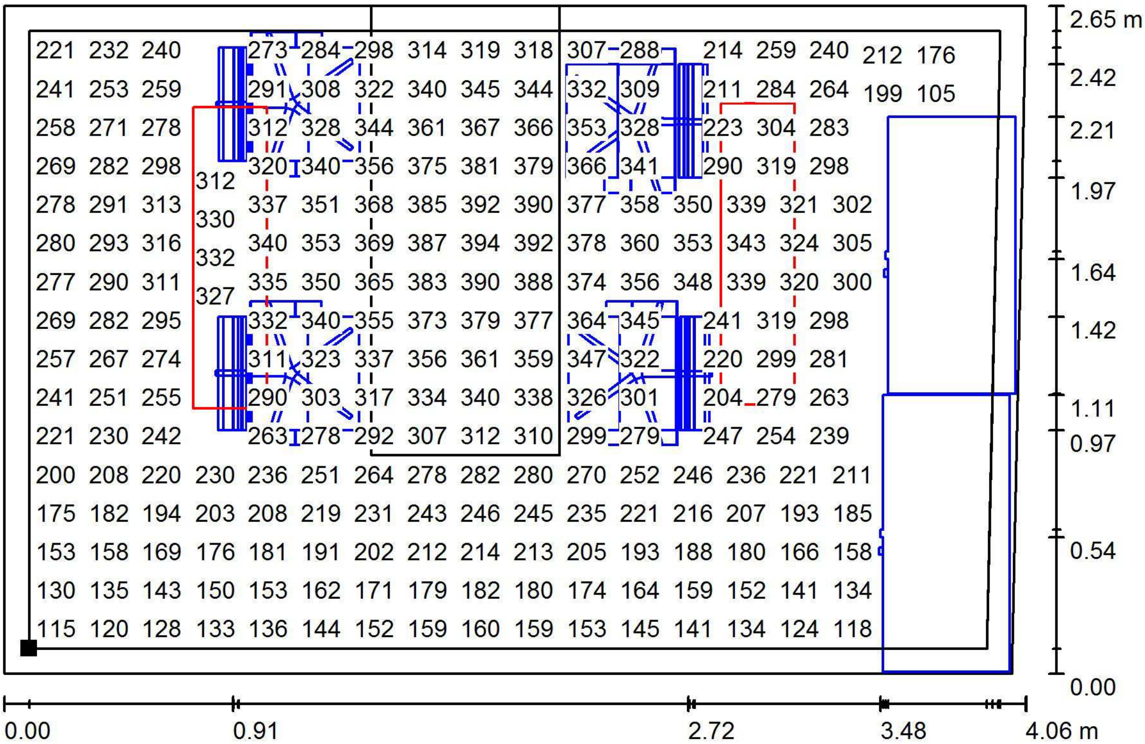
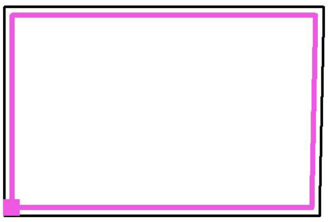
Standard Office / Workplane / Value Chart (E)



Values in Lux, Scale 1 : 30

Not all calculated values could be displayed.

Position of surface in room:
Working plane with 0.100 m
Boundary Zone
Marked point:
(73.574 m, 63.408 m, 0.750 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
269	46	395	0.172	0.117

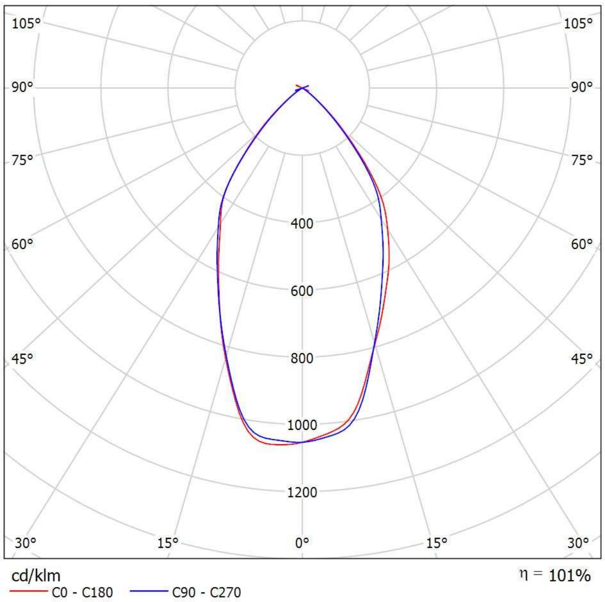
10.6 Draft Floor Plan Lighting Analysis Report

Operator
Telephone
Fax
e-Mail

onok 530 LED / Luminaire Data Sheet

Luminous emittance 1:

See our luminaire catalog for an image of the luminaire.

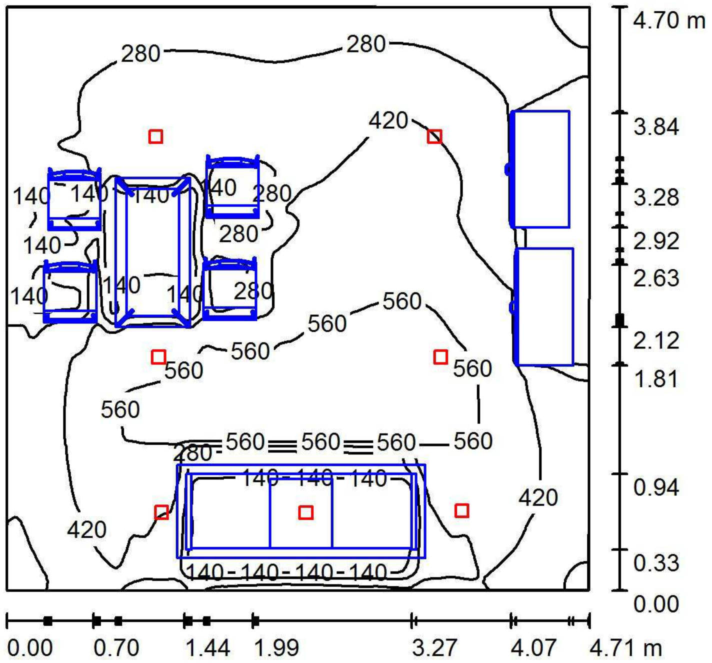


Luminaire classification according to CIE: 100
CIE flux code: 87 100 100 100 101

Due to missing symmetry properties, no UGR table can be displayed for this luminaire.

Operator
Telephone
Fax
e-Mail

Typical Office / Summary



Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80

Values in Lux, Scale 1:61

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	344	12	677	0.036
Floor	20	323	3.43	658	0.011
Ceiling	80	87	47	130	0.536
Walls (4)	50	132	7.64	457	/

Workplane:

Height:	0.100 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.386, Ceiling / Working Plane: 0.254.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	7	onok 530 LED (1.000)	2011	1985	0.0
			Total: 14075	Total: 13895	0.0

Specific connected load: 0.00 W/m² = 0.00 W/m²/ lx (Ground area: 22.10 m²)

Operator
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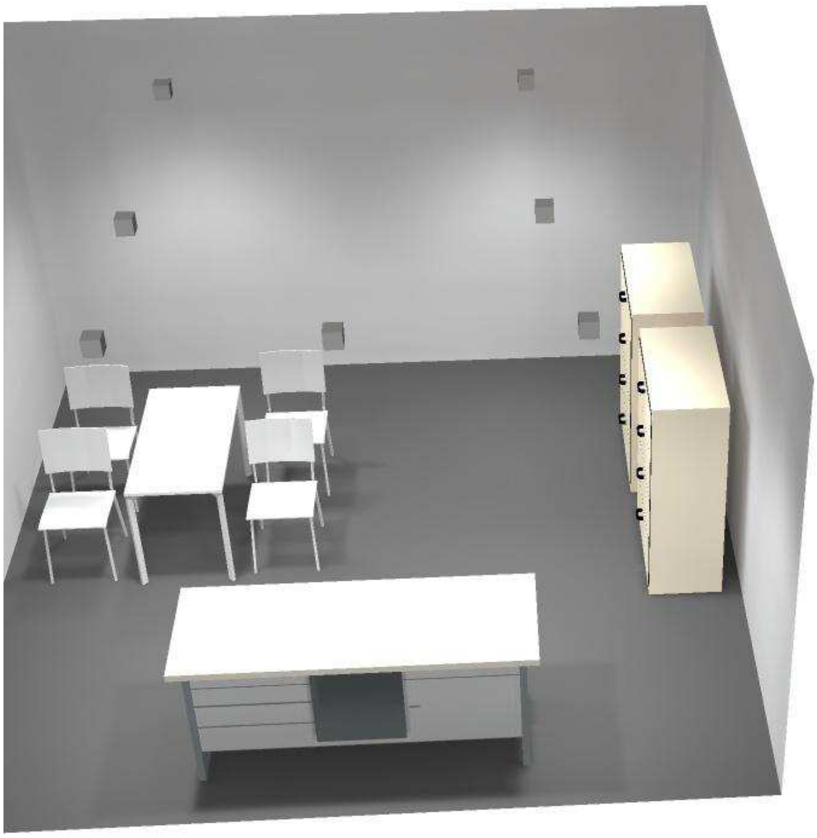
Typical Office / 3D Rendering



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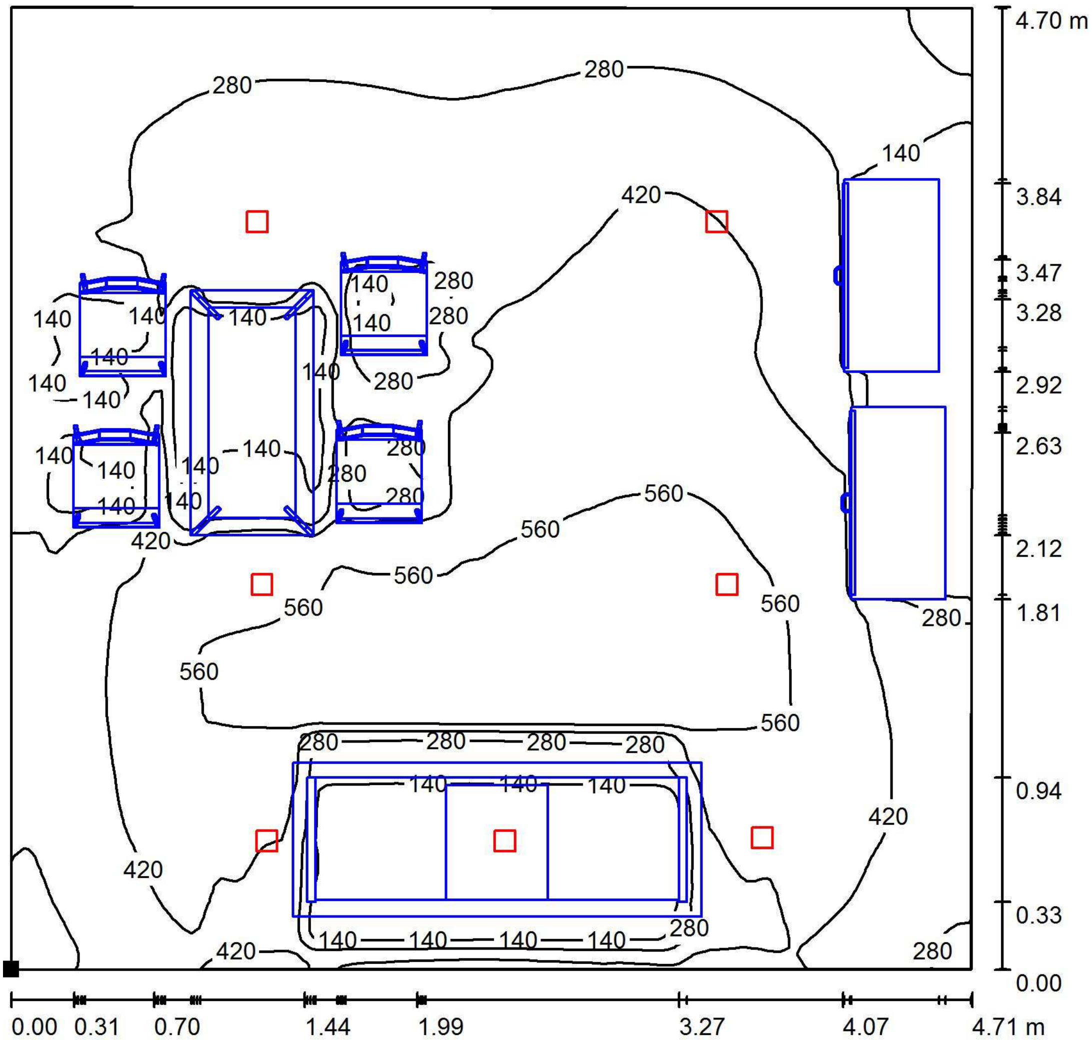
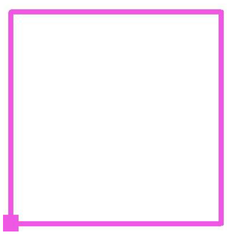
e-Mail

Typical Office / Workplane / Isolines (E)



Values in Lux, Scale 1 : 37

Position of surface in room:
Marked point:
(5.451 m, 7.447 m, 0.100 m)

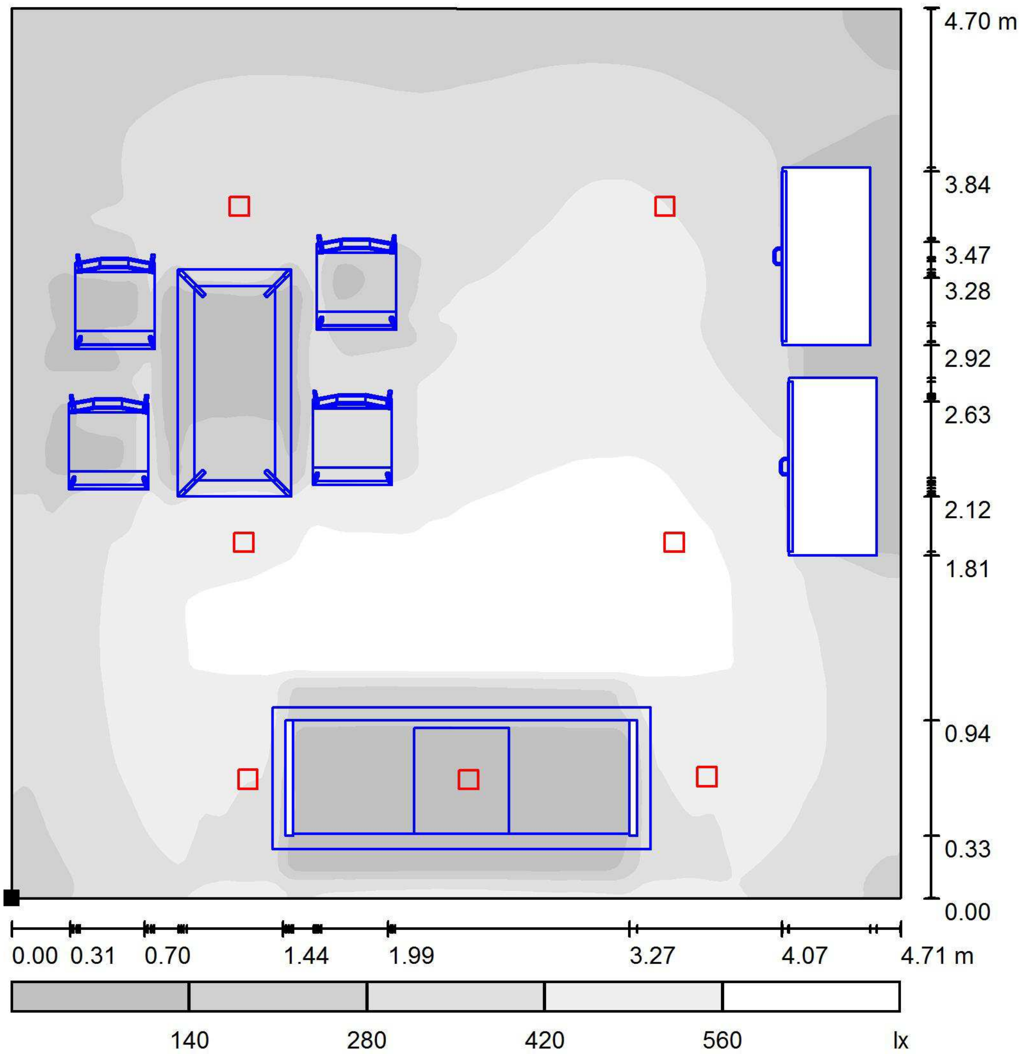


Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
344	12	677	0.036	0.018

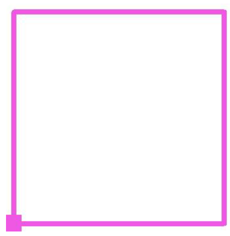
Operator
Telephone
Fax
e-Mail

Typical Office / Workplane / Greyscale (E)



Scale 1 : 40

Position of surface in room:
Marked point:
(5.451 m, 7.447 m, 0.100 m)

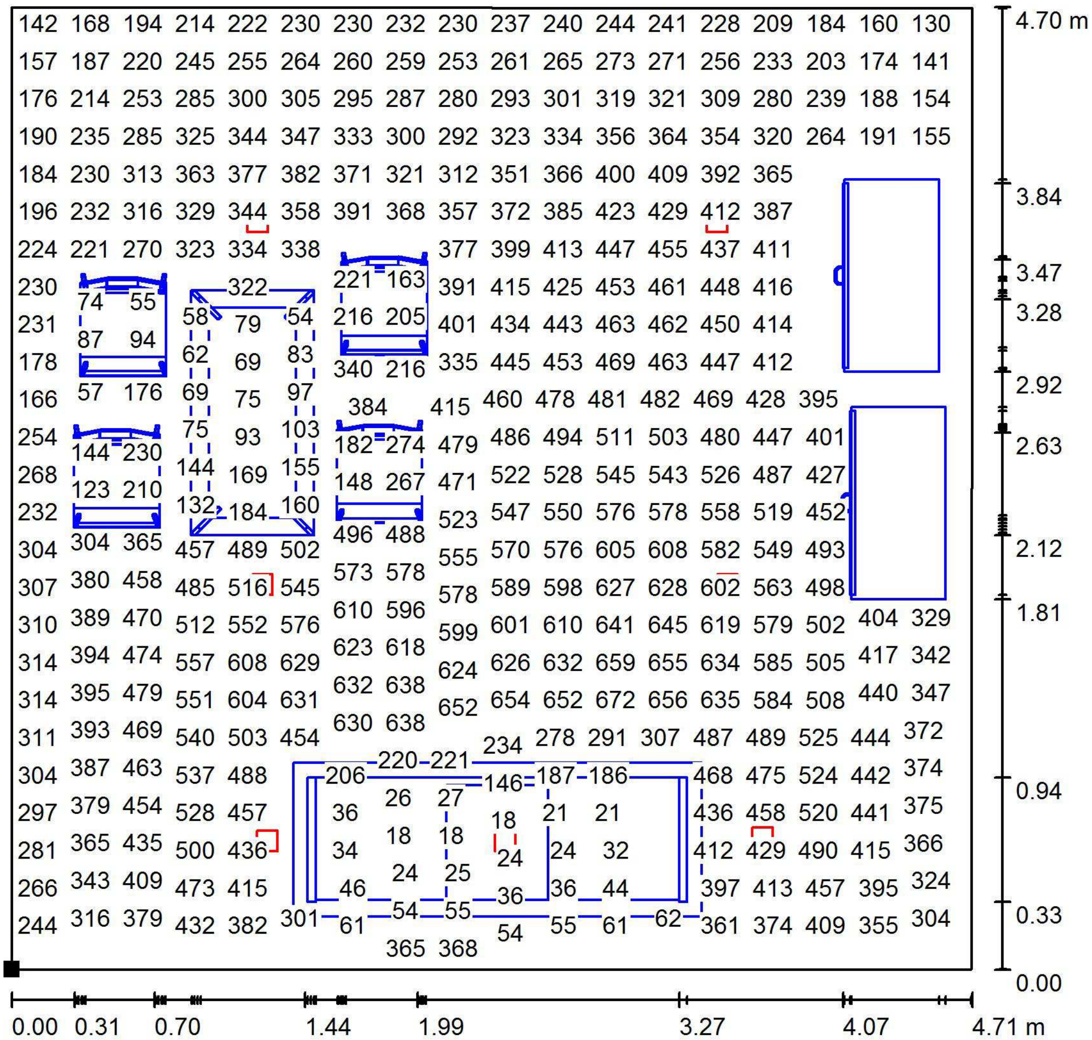


Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
344	12	677	0.036	0.018

Operator
Telephone
Fax
e-Mail

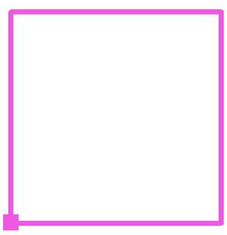
Typical Office / Workplane / Value Chart (E)



Values in Lux, Scale 1 : 37

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(5.451 m, 7.447 m, 0.100 m)

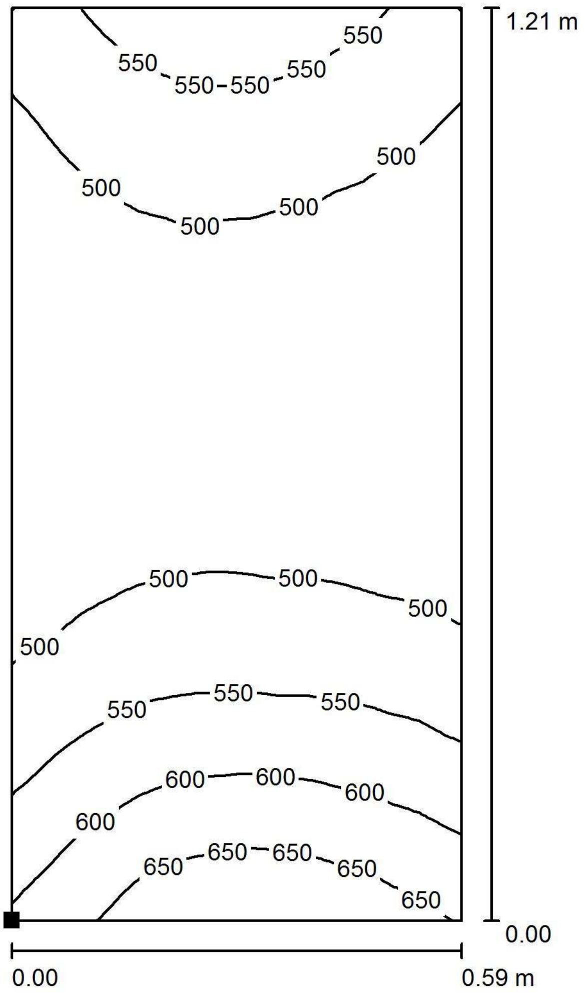


Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
344	12	677	0.036	0.018

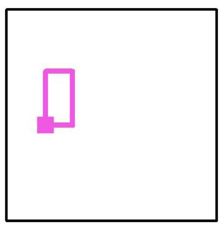
Operator
Telephone
Fax
e-Mail

Typical Office / Table Calc Surace / Isolines (E, Perpendicular)



Values in Lux, Scale 1 : 10

Position of surface in room:
Marked point:
(6.338 m, 9.569 m, 0.760 m)

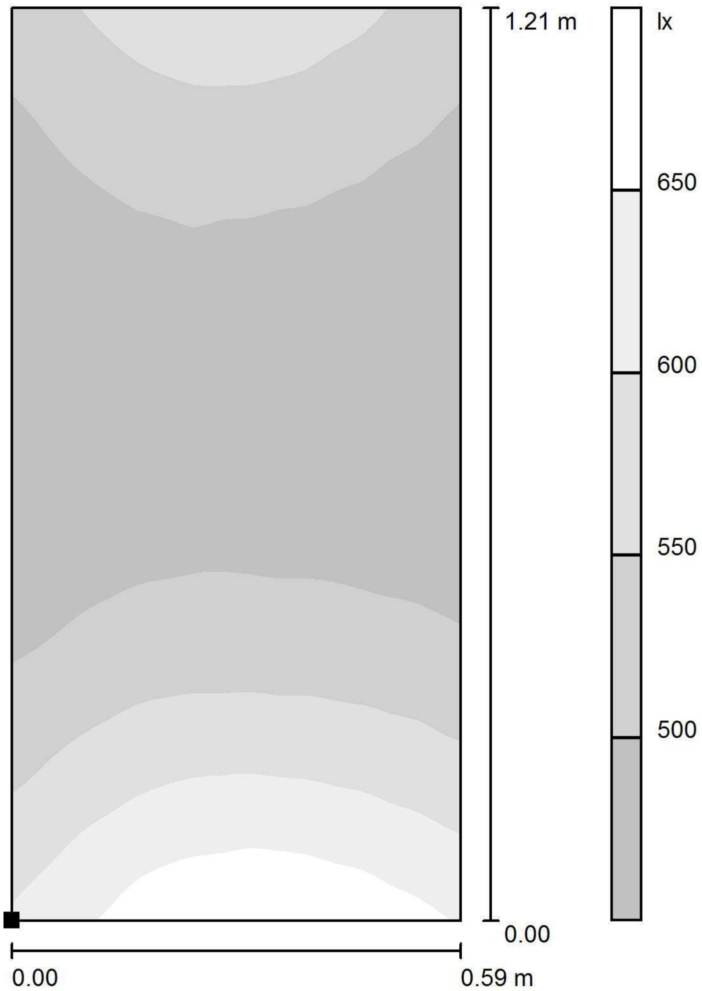


Grid: 32 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
524	451	680	0.861	0.664

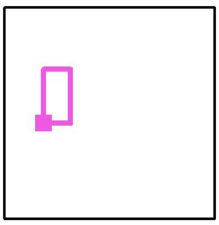
Operator
Telephone
Fax
e-Mail

Typical Office / Table Calc Surace / Greyscale (E, Perpendicular)



Scale 1 : 10

Position of surface in room:
Marked point:
(6.338 m, 9.569 m, 0.760 m)



Grid: 32 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
524	451	680	0.861	0.664

Typical Office / Table Calc Surace / Value Chart (E, Perpendicular)

1.21 m

521	543	561	571	570	561	546	529
506	525	542	549	548	540	528	513
498	515	530	535	534	527	517	505
485	500	511	515	513	508	500	489
476	492	501	505	502	498	492	483
467	480	489	493	490	487	481	474
464	471	483	484	482	480	478	470
453	466	471	479	477	475	466	465
453	464	471	475	474	472	467	464
456	465	473	477	475	473	470	466
461	472	479	482	482	480	477	474
462	474	482	484	484	482	479	475
469	485	494	497	497	495	491	487
484	499	509	508	511	507	503	500
495	511	522	526	526	525	519	514
512	529	541	546	546	544	538	531
528	549	562	569	570	568	560	552
548	570	586	597	599	595	586	575
566	594	614	625	627	623	613	599
585	616	640	650	655	651	639	625
606	639	661	676	680	677	670	649

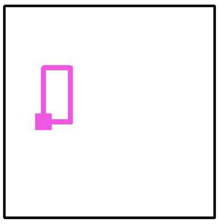
0.00

0.00 0.59 m

Values in Lux, Scale 1 : 10

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(6.338 m, 9.569 m, 0.760 m)

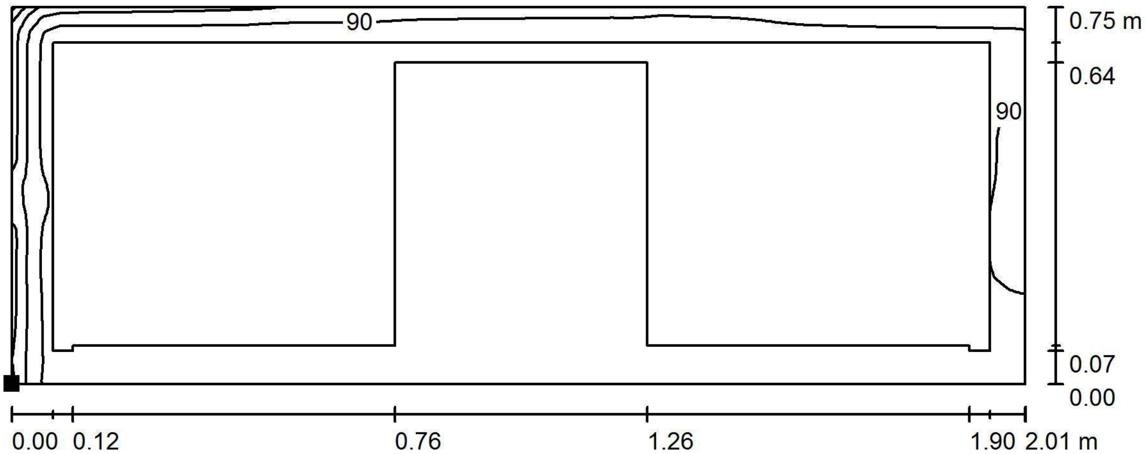


Grid: 32 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
524	451	680	0.861	0.664

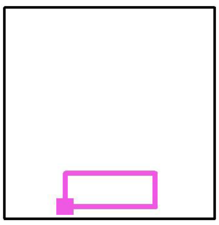
Operator
Telephone
Fax
e-Mail

Typical Office / Work Desk / Isolines (E, Perpendicular)



Values in Lux, Scale 1 : 15

Position of surface in room:
Marked point:
(6.819 m, 7.712 m, 0.760 m)

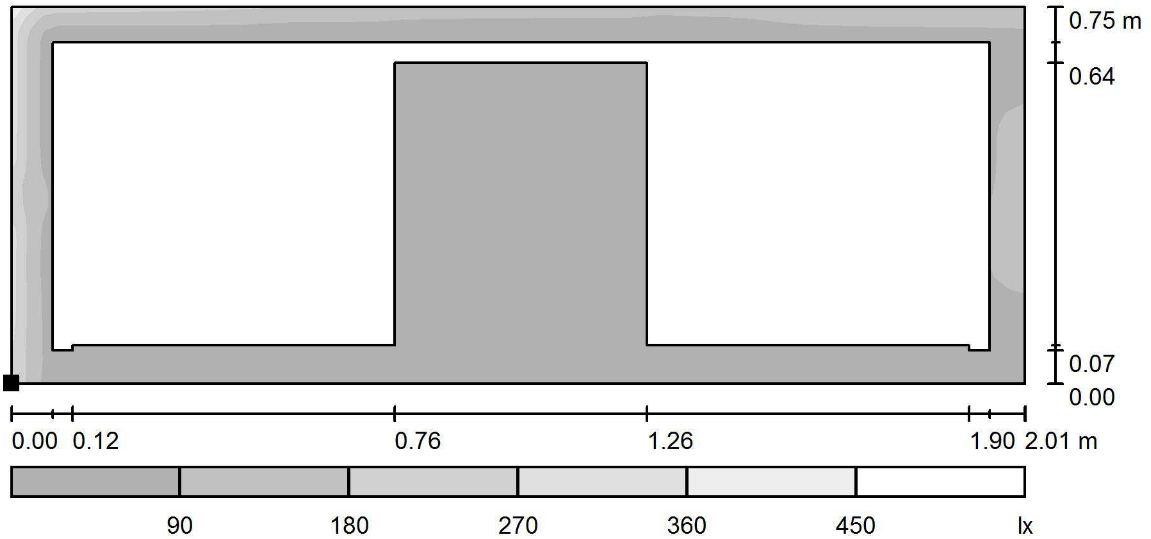


Grid: 64 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
60	11	418	0.186	0.026

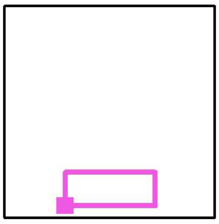
Operator
Telephone
Fax
e-Mail

Typical Office / Work Desk / Greyscale (E, Perpendicular)



Scale 1 : 15

Position of surface in room:
Marked point:
(6.819 m, 7.712 m, 0.760 m)

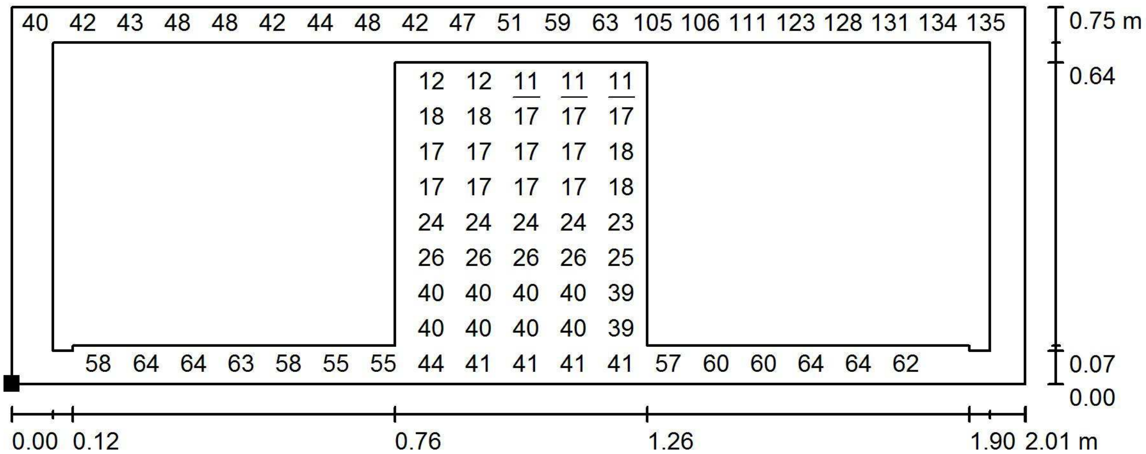


Grid: 64 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
60	11	418	0.186	0.026

Operator
Telephone
Fax
e-Mail

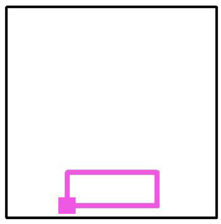
Typical Office / Work Desk / Value Chart (E, Perpendicular)



Values in Lux, Scale 1 : 15

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(6.819 m, 7.712 m, 0.760 m)



Grid: 64 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
60	11	418	0.186	0.026