FEASIBILITY STUDY OF EXTRA LOW VOLTAGE DIRECT CURRENT POWER DISTRIBUTION

UNDERGRADUATE THESIS

SEMESTER 2 PROGRESS REPORT

by
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Submitted for the degree of
Bachelor of Engineering &
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in the division of ...

April & 2017.

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April 17, 2017

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

Associate Professor Geoffrey Walker for your guidance, support and patience through the completion of this project.

My fellow students **Ash Abdullrabzak** and **Niroj Gurung** for their valuable discussions throughout our three projects.

Disa, for her constant love and support through not only this project but my entire degree.

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Abhishek Bhasin and **Isaac Linett** from Q Electrical for their technical assistance in the first half of my project.

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 these methods cannot be utilised, either physical testing or research will be completed as substitute. If successful, a more efficient and cheaper alternative to running simple electronics from Alternating Current (AC) mains will be created. This will allow for a portion of building's electricity demands to be self sufficient and not rely on the grid for continual supply.

To complete this task, the project was separated into individual questions that are interrelated and help to conclude whether the project will be successful or not. 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. Simulations were completed using System Advisor Model (SAM) for photovoltaics, Dialux4.12 for lighting, AutoCad for structural layouts and Microsoft Excel for all calculations and efficiency modelling.

FILL WITH RESULTS SUMMARY

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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 m2
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 the large amounts of sun and numerous high rises. Designs will be tested predominately through software simulations and hardware 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 [10]. The cables being run would follow Australian building standards at $2.5\,\text{mm}^2$, 2 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.

4 Background & Literature Review

4.1 Literature Review

4.1.1 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 [11]. 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 [12].

AC was originally depicted 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 [13]. 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 [13]. Utilising DC generation systems could also fulfil the power industry's obligation to increase the sustainability of their systems and be more environmentally conscious [14]. The required converters to change the AC supply into DC for electronics reduces the efficiency (increasing voltage drop) of the overall system [13].

4.1.2 Voltage Levels as per Australian Standards

The Australian Standards (AS/NZS 3000: Wiring Rules) outline the specific voltage levels that distinguish circuits [15]. 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 [15]. Low Voltage is any level above Extra-Low Voltage but not exceeding 1000 V AC or 1500 V DC [15]. The final level is High Voltage which is anything exceeding Low-Voltage [15].

4.1.3 Low Voltage Direct Current

DC power is currently restricted to special applications such as telecommunications, electric vehicles and high-voltage direct current (HVDC) transmission [16]. 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 [16]. 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 [16]. 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 us unaffected by issues with power grid [14].

4.1.4 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 [17]. This could be services such as telephony and internet access without the necessity of additional cabling [17]. 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 1. Many data centres or communications rooms for corporate buildings will establish arrays of 48 V battery banks [1]. 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 [1]. This setup is shown in Figure 1. Additionally, due to this nature of power telecomms, standalone systems are becoming a more suitable means of supply [18]. Photovoltaic arrays, due to their DC source nature, could be used with a DC to DC boost converter and regulator to power these systems.

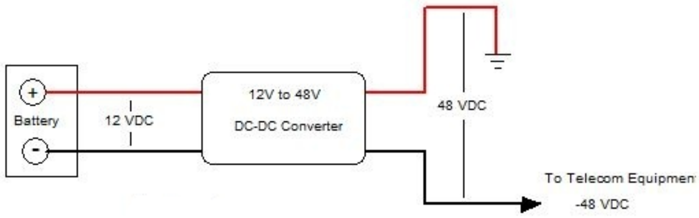

Figure 1: Single Battery Communications Room [1]

4.1.5 Existing Power Distribution Systems

Power systems consist of four major sections; generation, transmission, distribution and loads shown in Figure 2. 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 [19]. In order to transport electricity over large distances (excess of 2km) without severe losses, very high voltage and low current is used [19]. 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 [20]. These devices are placed through the circuit to protect the more expensive equipment closer to the transformer and grid.

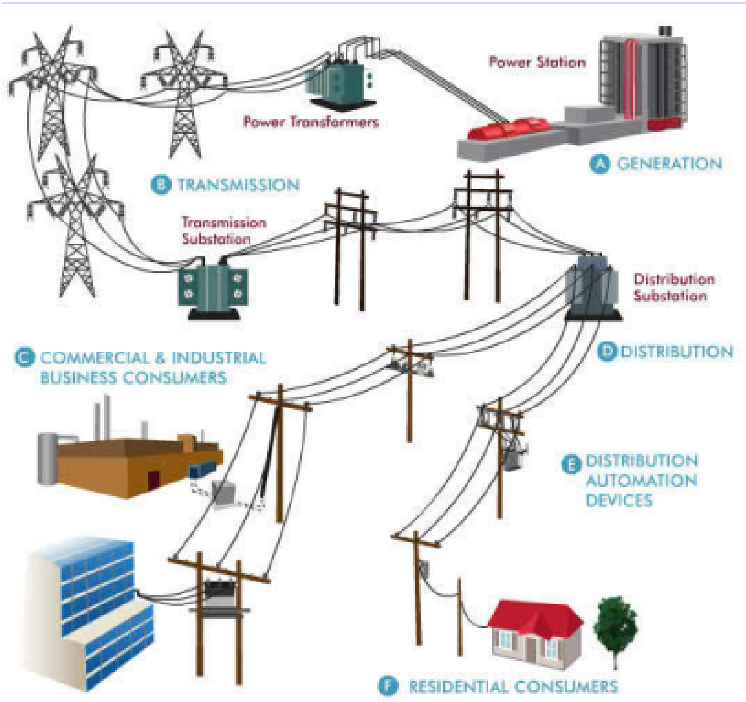

Figure 2: Existing Power Distribution Methods [2]

4.1.6 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 [21]. 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 3 represents a single line diagram showing the two separate buses for a design.

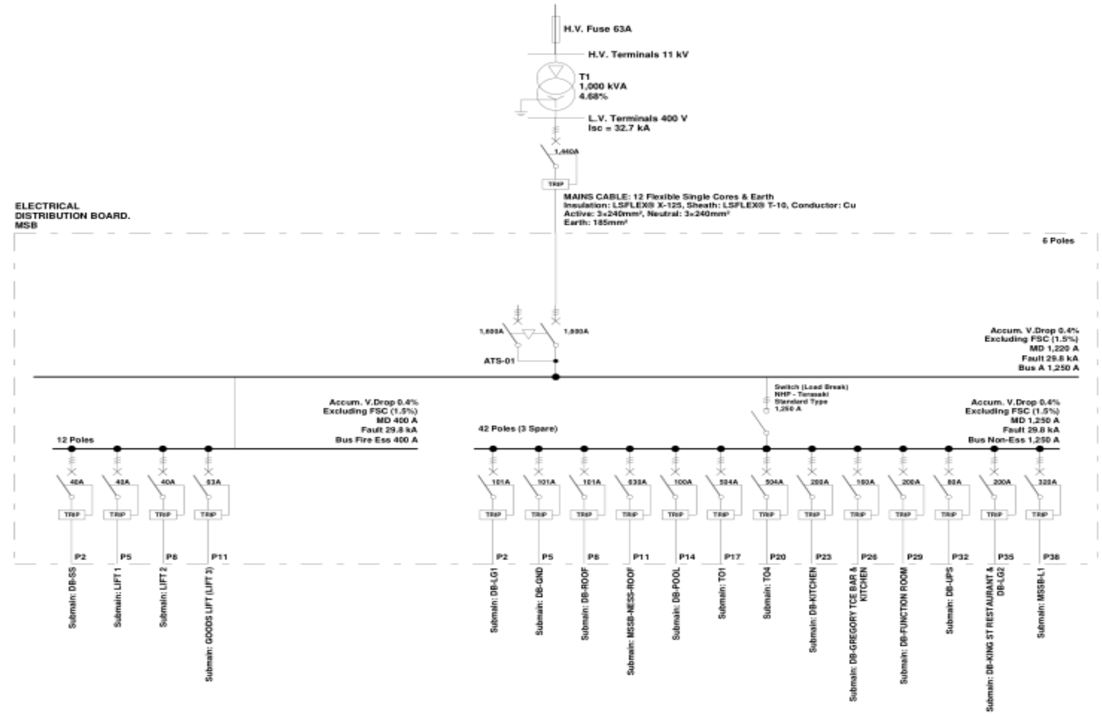

Figure 3: Hotel Single Line Diagram

4.1.7 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 [22]. 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.

4.1.8 Photo-Voltaic Arrays and DC Arcing

With the popularity of PV systems increasing, the risk of DC arc faults are being analysed further [23]. 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 [23]. 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 [24].

Photovoltaic generators are non-linear sources that vary with intensity of sunlight and behave mainly as a DC current source [18]. 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 [18]. The risks of DC arcs can be reduced by incorporating proper safety equipment and reducing DC voltage levels [18].

4.1.9 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 [20]. 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 [20]. 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 [20]. 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 [20].

4.1.10 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 [25]. Plugs, sockets and safety equipment with nominal currents of 20 A are commercially available for pre-existing DC data centres [25].

4.1.11 Converters

Converters are electrical devices designed and constructed to convert current between AC and DC [26]. Rectifiers are used to convert the voltage from AC to DC and inverters converter from DC to AC [26]. 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 stored DC battery power [26].

4.1.12 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 [27]. 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 [27]. 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 [27].

4.1.13 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 [15]. 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 [28]. 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 [8]. 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 [29].

4.1.14 Tariffs

Tariffs will be an important consideration with the feasibility of this project due to the possibilities of cost reduction. User expenses could theoretically be reduced by implementing a system off the grid. Government policies have been put in place in order to prompt an increase in investment in renewable energy sources [30]. 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, according to the SolarChoice website a feed-in tariff of $0.06/kWh can be earned [31]. By not connecting the photo voltaic panels to the grid, this tariff can not be received however there is the possibility that it is more efficient and will produce less energy loss by storing in local batteries and running simple circuits rather than feeding the grid [32]. The consideration will be whether the cost reduction in electricity bill will be worth the investment in the equipment and future cost reduction.

4.1.15 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 [7]. Typical lighting systems are fluorescent bulbs or tubes that are powered directly from standard 230 V AC due to the devices' high efficacy [7]. 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 [7]. 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) [7]

4.2 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.

4.2.1 Previous Thesis: Extra-Low Voltage In-Home Power Distribution and Storage

Steven Donohue completed his undergraduate thesis under Geoffrey Walker in 2014 [10]. 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 [10]. He proposed that an installation model for low voltage distribution was uneconomical with current solar feed-in tariffs [10]. 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.

4.2.2 Previous Thesis: 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 [34]. 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.

4.2.3 Concept: 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 [35]. They can be created in a variety of ways with gas and diesel generators being popular but expensive [35]. 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 [3]. 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 [3]. The structure of his system is as follows and is shown in Figure 4.

- 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

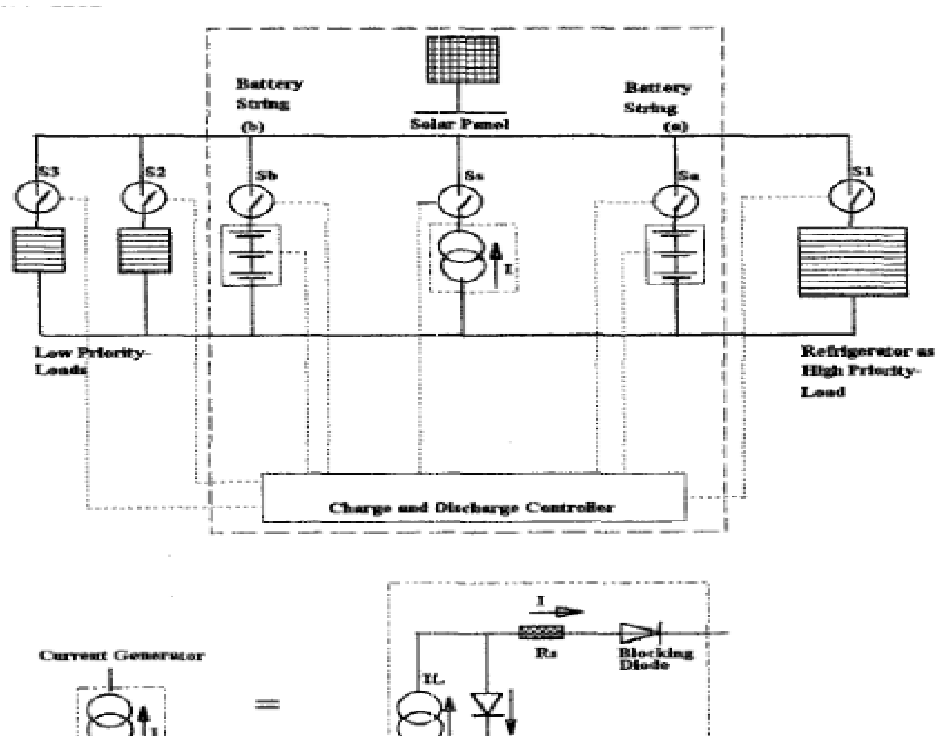

Figure 4: Block Diagram for Photovoltaic RAPS System [3]

4.2.4 Concept: DC Data Centre

Interest in 400 V DC power systems has also been increasing in recent years for applications in telecommunications and data centres [4]. Sara Lisy and Mirna 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 [4]. 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 [4]. 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 ill 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 5.

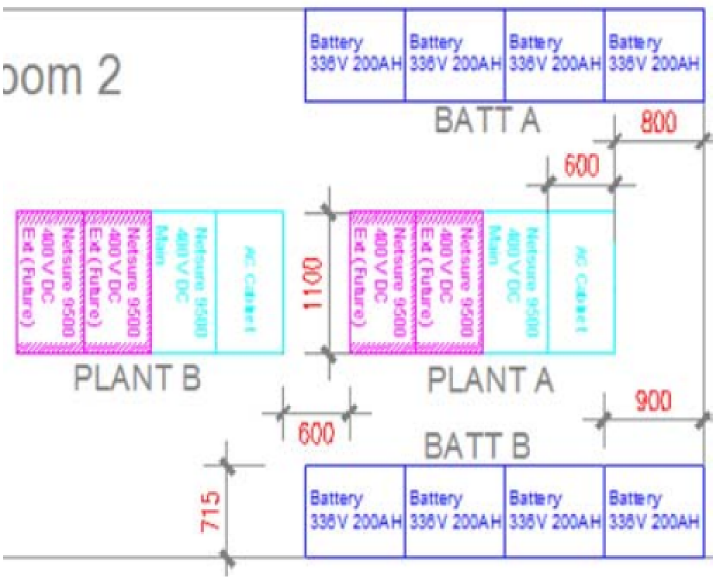

Figure 5: Floor Plan of DC Backup Data Centre [4]

4.2.5 Concept: Low Voltage Substations DC for Mining Sites

Low Voltage DC distribution is used in some mining sites including underground mines [36]. This is used for a variety of purchases but predominately at 550 V DC or 250 V DC for machinery [36]. These machines are locomotives and face equipment and generally a polyphase rectifier circuit is employed for the AC mains [36].

A related design system launched in 2015 is the ABB's prefabricated DC rail system [37]. These are modular substations designed to save time and money when working in both the real estate and mining sector within Australia [37]. 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 [37]. They are self-contained and induce an integrated power supply which reduces risk of power loss overall [37].

4.2.6 Product: 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 [38]. 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% [38].

4.2.7 Product: Existing Extra Low Voltage DC in Commercial LED Ballasts

TO BE COMPLETED

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. A secondary 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 [19]. Although research into improving DC systems has increased, this project will be focusing on an area that has not been sufficiently researched and analysed [5].

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 6 below shows the methodology behind technical design tasks.

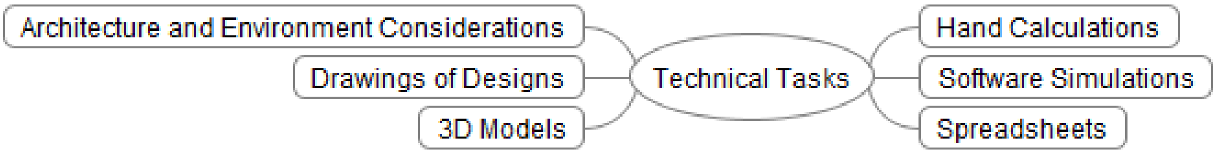

Figure 6: Considerations for a Technical Design Task

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 Photo-Voltaic cells, battery, controller, DC-DC converters and connections to appliances, however finances will not allow this. Figure 7 below shows a basic PV DC system and the areas requiring consideration.

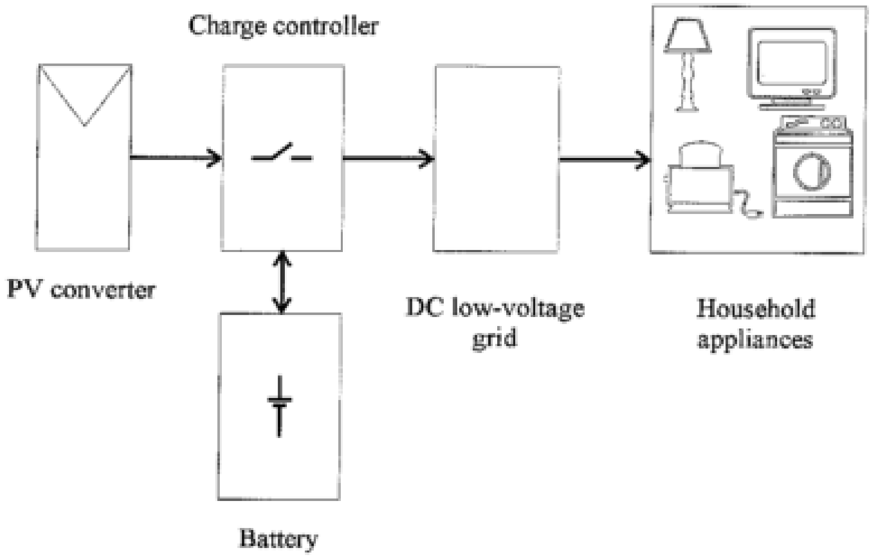

Figure 7: Initial Design Consideration for DC Home Power System [5]

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.

6 Project Timeline

This project will be predominately based on two major resources; software availability and personal time. Software will be available at all times due to the University providing paid software packages and already having installed free ones. Personal time will be the major difficulty as it will be balanced between other University classes, full-time work, and personal responsibilities. To balance this specific time periods will be allocated each week to work exclusively in this project.

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.

Table 3 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.

The assessed deliverables for Semester 2 are similar to the first. The major difference predicted is that the task should be very well understood by the beginning of semester. By having this advantage as well as the additional time during summer break, it allows for a very strong foundation for the final design. This is why the non-assessed milestones are predominately finalisation throughout the entire semester. The summer break will be utilised to reduce the required work during the University period. In the final 6 months I have worked full time at studied 2 subjects

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 3: Initial Project Timeline

6.1 Stage 1: Sem 1 Week 14 Analysis of Timeline

This section outlines the initial analysis of the originally projected timeline. Table 4 above will be replicated with additional analysis of whether or not milestones have been reached and if they were delivered on time. Additionally, if aspects of the project has changed and the time line needs to be re approached, this will be done.

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	TBC
Complete Research Shortcomings	Summer Break	TBC
Complete Further Technical Calculations	Summer Break	TBC
Initial Finance Analysis	Week 2	TBC
Design Simulations	Week 6	TBC
Progress Report	**Week 7**	TBC
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 4: Initial Project Timeline Analysis

6.1.1 Stage 1 Revised Timeline

The first major change from the first revised time line is that the initial prototype design is now NA. The reasoning behind this is due to the slight change in planning for the project since the initial proposal submission. Since creation of the time line, the scope has been re-approached and instead of ensuring a prototype converter is built by the end of the project, the questions have been refocused and more specific simulations will be reached. The design of a converter is a secondary if time allows.

The next milestone was initial 3D modelling of the building design for the presentation. This was completed but not as extensively as I would have liked. The access to Queensland of University's power consumption, floor plans, lighting plans and PV system configuration. This data was only made available in Week 11 which was later than possibly to fully utilise it before the presentation of progress. Due to this, the summer break tasks will be required to be extended to make up for the loss of time during Semester 1. This data will be used to finalise a floor plan that can be analysed and the concept of a low voltage DC distribution system proven feasibly or not.

Revised Timeline for Remaining Tasks	
Milestone	**Deadline**
Implement Feedback From Report	Summer Break
Complete Research Shortcomings	Summer Break
Finalise Floor plan and Load Demand	Summer Break
Complete Further Technical Calculations	Summer Break
Initial Product Decisions	Week 3
Initial Finance Analysis	Week 4
Design Simulations	Week 6
Progress Report	**Week 7**
Finalised Design	Week 10
Finalised Simulations & 3D Modelling	Week 11
Finalised Financial Analysis	Week 12
Final Presentation	**Week 14**
Final Report	**Week 14**

Table 5: Revised Timeline for Milestones

6.2 Stage 2: Sem 2 Week 8 Analysis of Timeline

TO BE COMPLETED

6.2.1 Stage 2 Revised Timeline

TO BE COMPLETED

7 Analysis and Discussion

This section will be the initial discussion of testing, calculations and analysis. Progress made will be discussed here however Section 7 will be where the questions are specifically answered. Firstly this section was used for a draft model to be created for initial testing and demand expectations. This was to be a temporary estimation until more accurate information was acquired. 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.

After the production of the draft model access to QUT schematics, floor layouts and metering data was obtained. Section 7.2 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.

7.1 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 8. 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.

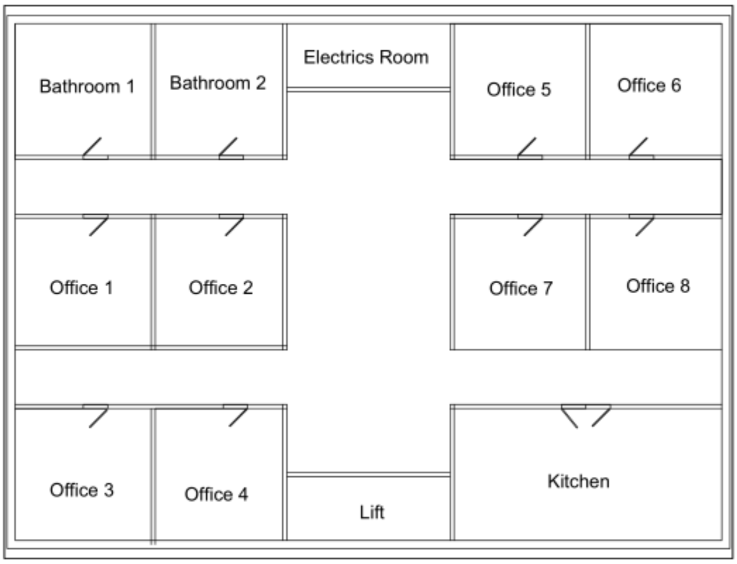

Figure 8: Temporary Office Floor Plan Design

7.1.1 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 6.

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 6: Lighting Requirements as per AS/NZS Standards [8]

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 7 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 9. 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 10. Appendix 11.3 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 7: Dialux Outputs of Draft Floor Plan

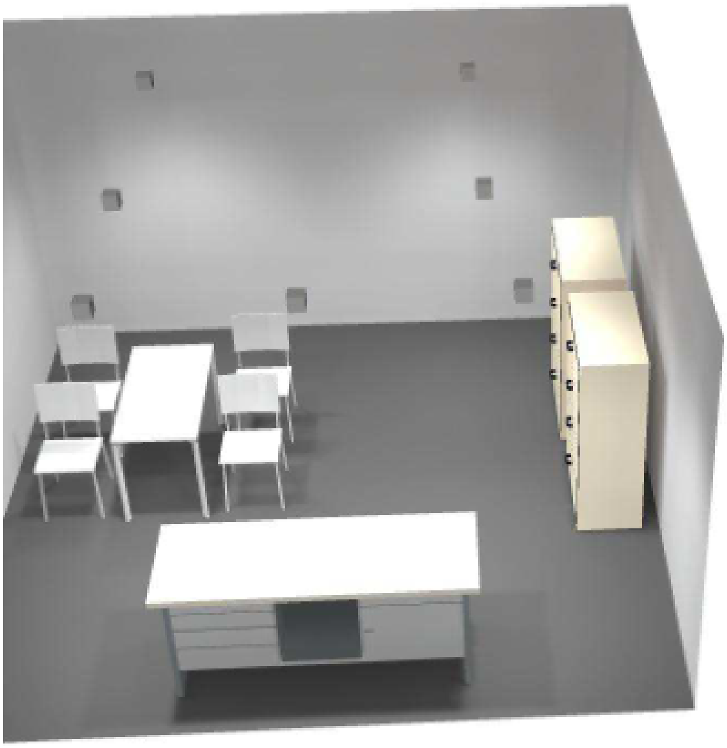

Figure 9: Draft Lighting Test 3D Render

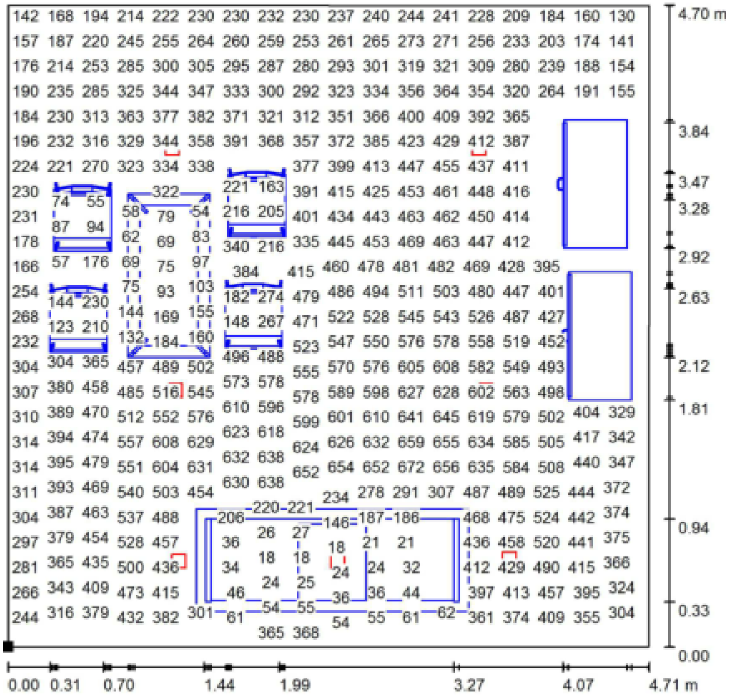

Figure 10: Draft Lighting Test Lux Output

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.

7.2 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. Through liaising with Geoff he suggested contacting QUT's Building Management Services department who have access to building schematics and load data. Geoff Woods and Norman Higgins provided electrical drawings, single line diagrams, architectural drawings and electrical specifications for analysis. These were integral to designing an accurate, "real world" model to test the feasibility of the proposed system.

7.2.1 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. 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)

The main page provides an intuitive summary of the modules to provide information on the life of the installation shown below in Figure 11. This image was taken at April 15, 2017 for the P Block Level 10 and shows the existing returns that the specific installation has provided. 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.

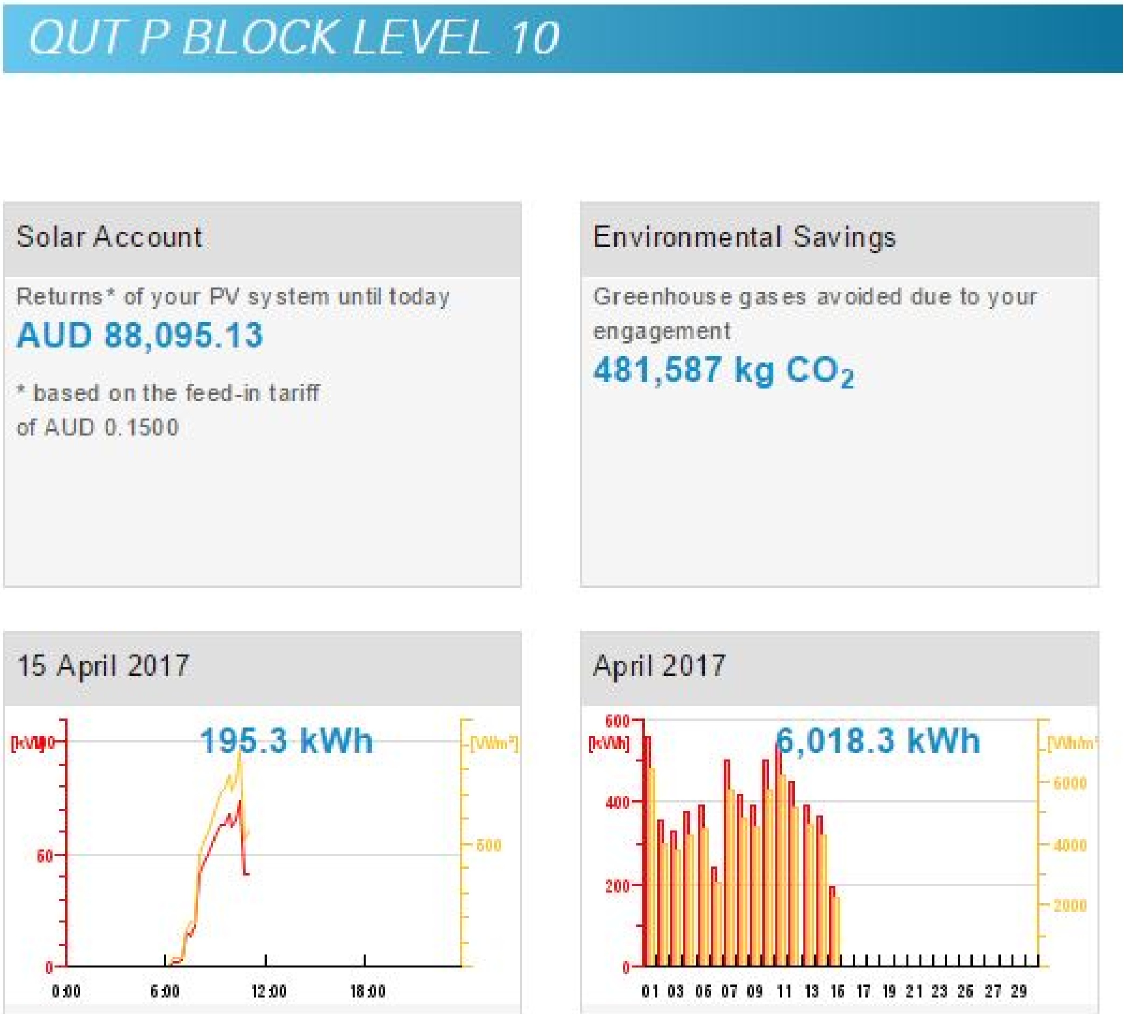

Figure 11: QUT Data: P Block Level 10 Meteo Photovoltaic Summary

7.2.2 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 12 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.

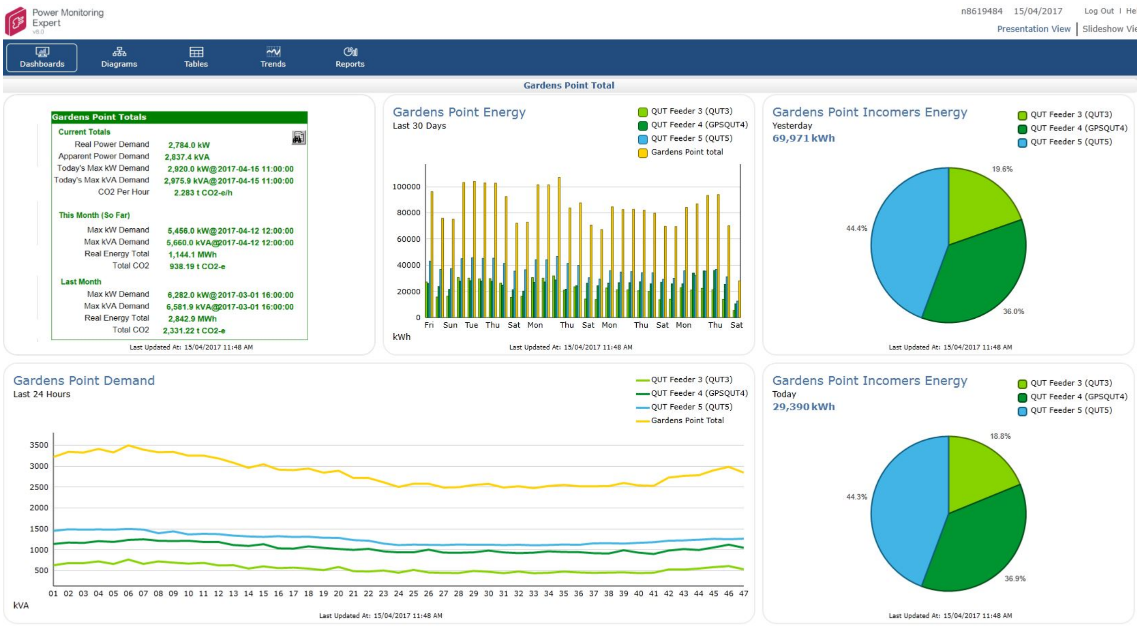

Figure 12: QUT Data: Power Monitoring Expert Dashboard

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.

7.2.3 Useful Data Interpretation

This section outlines the useful data extracted from the two metering systems. The initial task was to analyse all that was available and collate what can be used to produce a more accurate design. With the quantity of data available it was vital to ensure the scope was kept in mind in order to avoid analysing data for no useful reason.

Photovoltaic Breakdown

QUT P Block Level 10 (the same as Figure 11) was chosen as a model to analyse the modules, inverters and power quantities produced. Table 8 shows the breakdown of the 329 panel and 82.25 kWp installation. The specific models 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.

Section	**Area**	**Peak Power (kWp)**	**Inverter**	**Arrays and Size**
1	25	3.75	1 x PVI-3.6	1 x 15
2	50	7.50	1 x PVI-10.0	2 x 15
3	139	21.02	2 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

Table 8: QUT P Block Level 10 Photovoltaic Array Installation

Photovoltaic Production Data

This information is essentially useless without the production data. 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 entire year of 2016 was assessed to give an accurate represented of predicted production capabilities. Table 9 outlines the figures exported by Metero and Figure 13 shows the graphical representation of the output as well as irradiance.

Date	**Energy (kWh)**	**Irradiance (Wh/m2)**
January	15,360.18	179,680.91
February	14,491.13	170,175.99
March	12,987.95	151,039.79
April	11,976.68	137,836.65
May	10,820.50	126,695.90
June	7,869.84	87,047.60
July	9,704.54	107,522.56
August	12,199.19	136,475.33
September	12,817.71	145,385.42
October	15,481.07	196,983.92
November	17,327.80	203,855.62
December	16,294.04	193,980.84
Total Production	157,330.63	

Table 9: QUT Data: P Block Level 10 2016 Production Summary Table

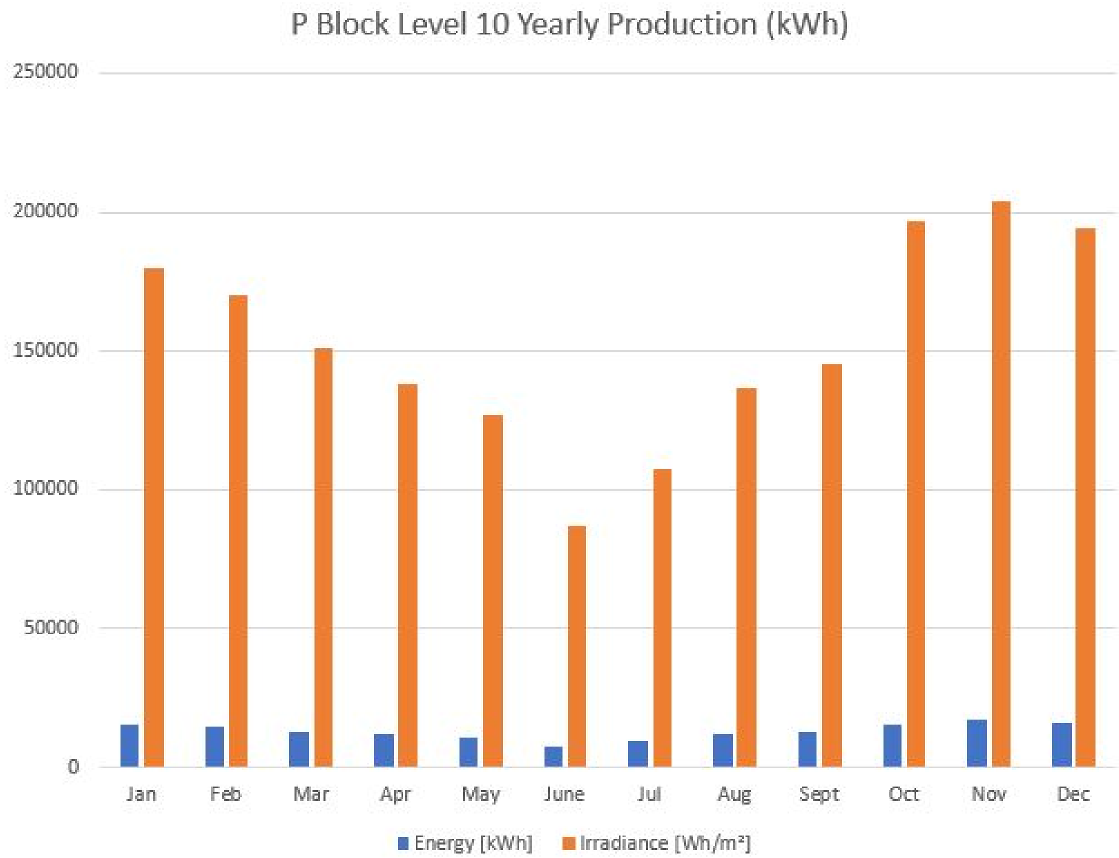

Figure 13: QUT Data: P Block Level 10 2016 Production Summary Graph

Useful Conclusions

An important conclusion to make from this data is that the 329 panel installation with a 82.25 kWp over 1 year can produce 157,330.63 kWh. A simple calculation therefore gives us a loose approximation that each panel, in Brisbane over 1 year will produce 478.2 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 what electricity bills are charged in
- kVA is what max demand calculations are based on
- DC Power Production is approximately 7% higher than AC from these modules (from System Advisor Model)

Metering System

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 14.

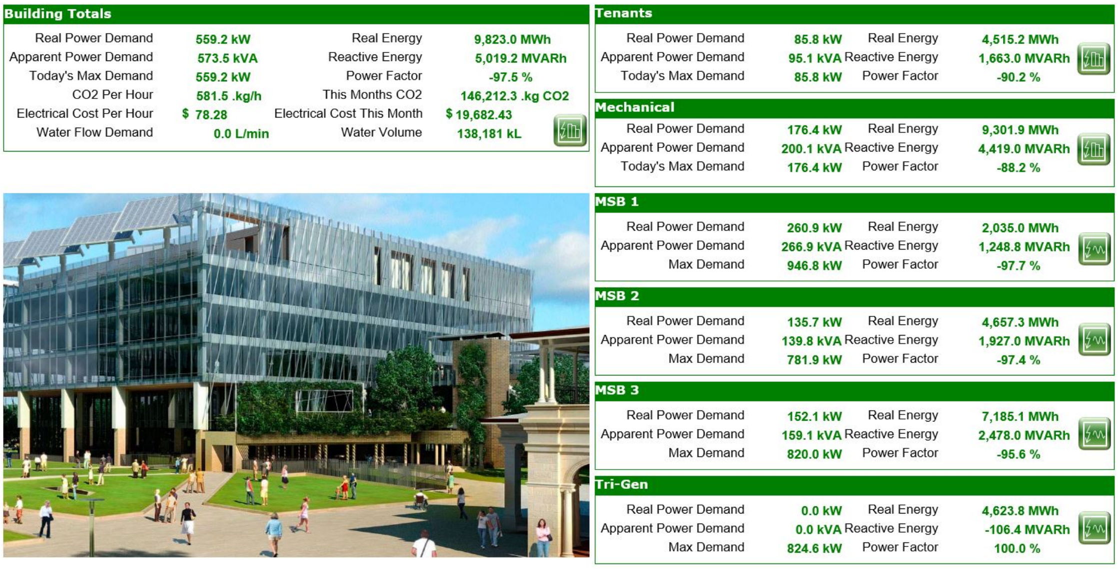

Figure 14: QUT Data: P Block Power Summary (12AM - April 16 2017)

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 for the building. Figure 15 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 16 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.

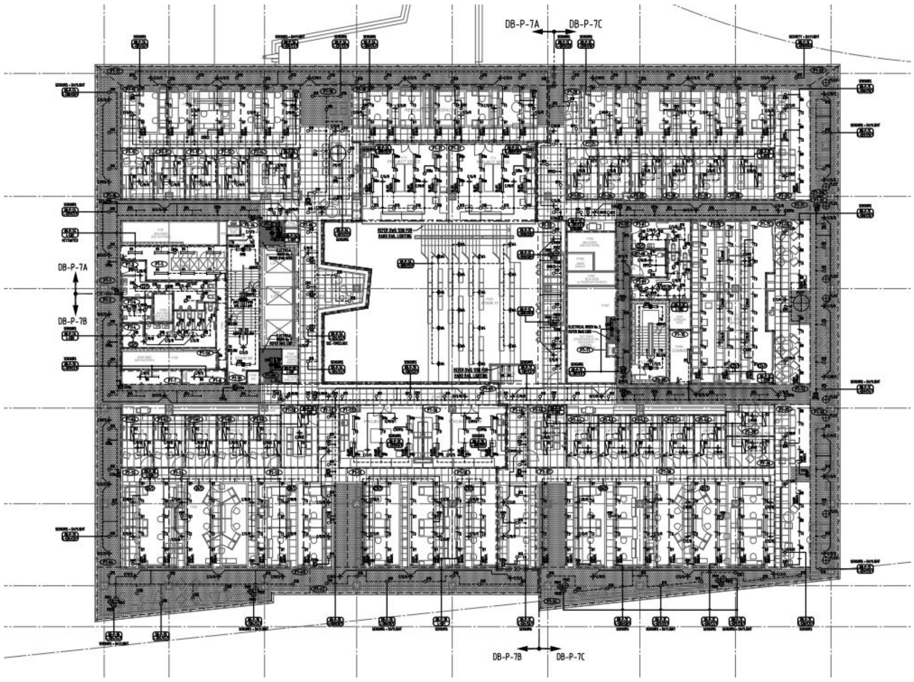

Figure 15: QUT Layout: P Block Level 7 Lighting Layout

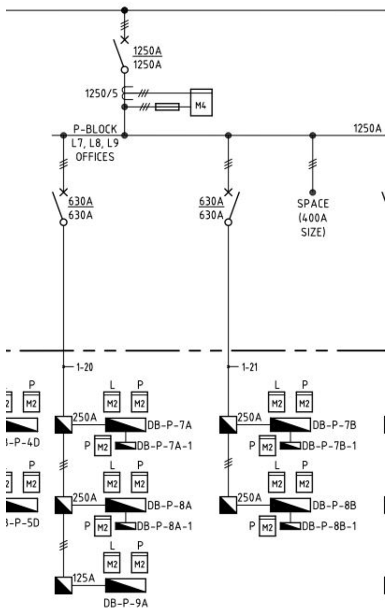

Figure 16: QUT Layout: P Block Level 7 Single Line Diagram Extract

The three DBs were found in Power Monitoring Expert for both the power and lighting meters. This was exported into a report and excel spreadsheet. The report is not attached with this paper due to the additional 600 pages it would require. Instead, the data is analysed and summarised below. The metered produced data in 15 minute increments. This means manipulation was required in order to remove a useful conclusion. Figure 17 is the graph of the average monthly lighting demand for level 7 over all 3 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.

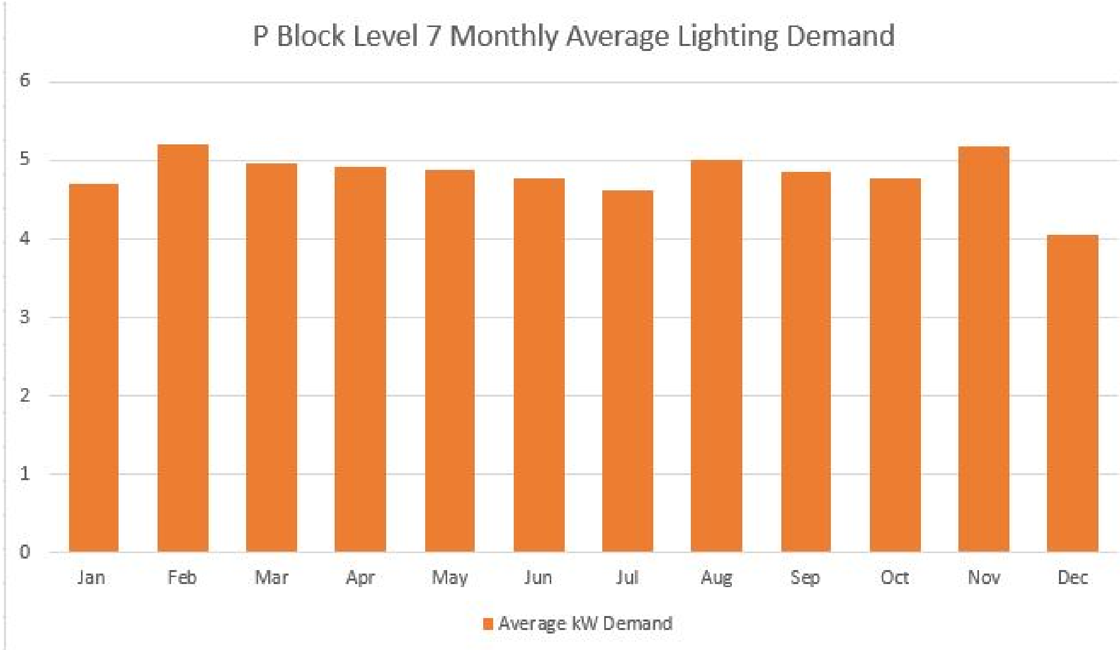

Figure 17: QUT Data: P Block Level 7 Lighting Demand (kW)

Although this information is useful for the production vs consumption curves however from a energy billing perspective, the kWh needs to be known rather than kW since this is what energy providers charge for. This will also allow for further financial analysis to be completed. Thankfully it is a very simple conversion of P(kWh) = P(kW) * time(h). Because the data is being provided in 15 minute intervals, the kW value must be multiplied by 0.25 to solve for kWh. The graph shown in Figure 18 shows the monthly breakdown of the calculated kWh values. It should ne noted it is just a scaled down replication of the kW graph.

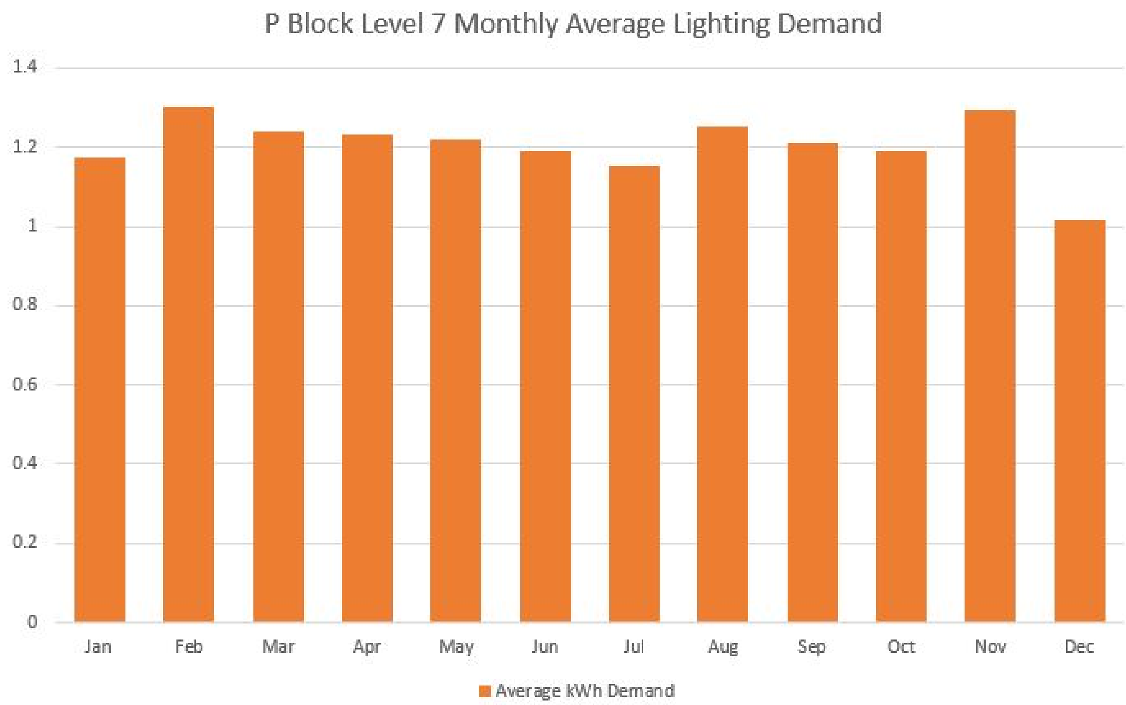

Figure 18: QUT Data: P Block Level 7 Lighting Demand (kWh)

Due to this finding, it was beneficial to model the average daily lighting consumption over each metering period. Figure 19 below shows the consumption curve and can be used to compare against production to determine feasibility.

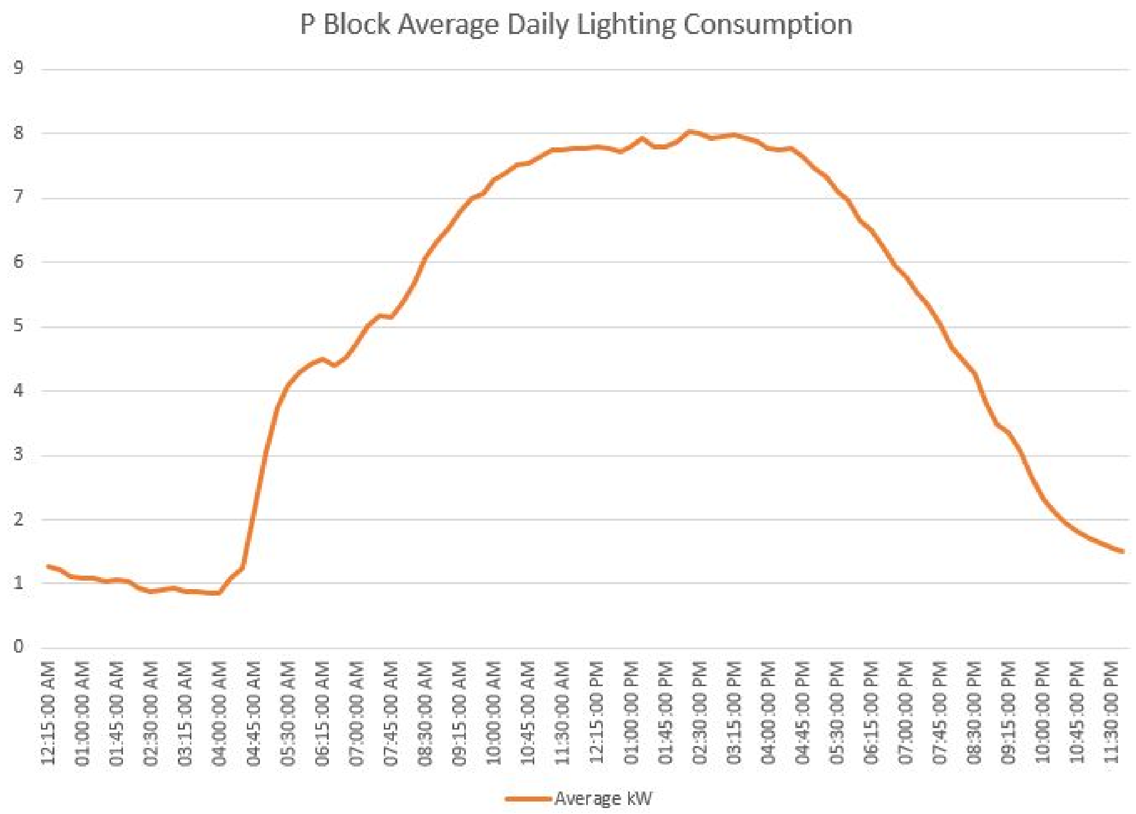

Figure 19: QUT Data: P Block Level 7 15-Minute Interval Lighting Demand (kW)

7.3 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.

7.3.1 Lighting Loads

To calculate approximate lighting loads to be expected for a floor, level 6 of QUT P Block was marked up to count the number of luminaires installed. A full floor plan is shown in Appendix 11.1 but an image export is below in Figure 20.

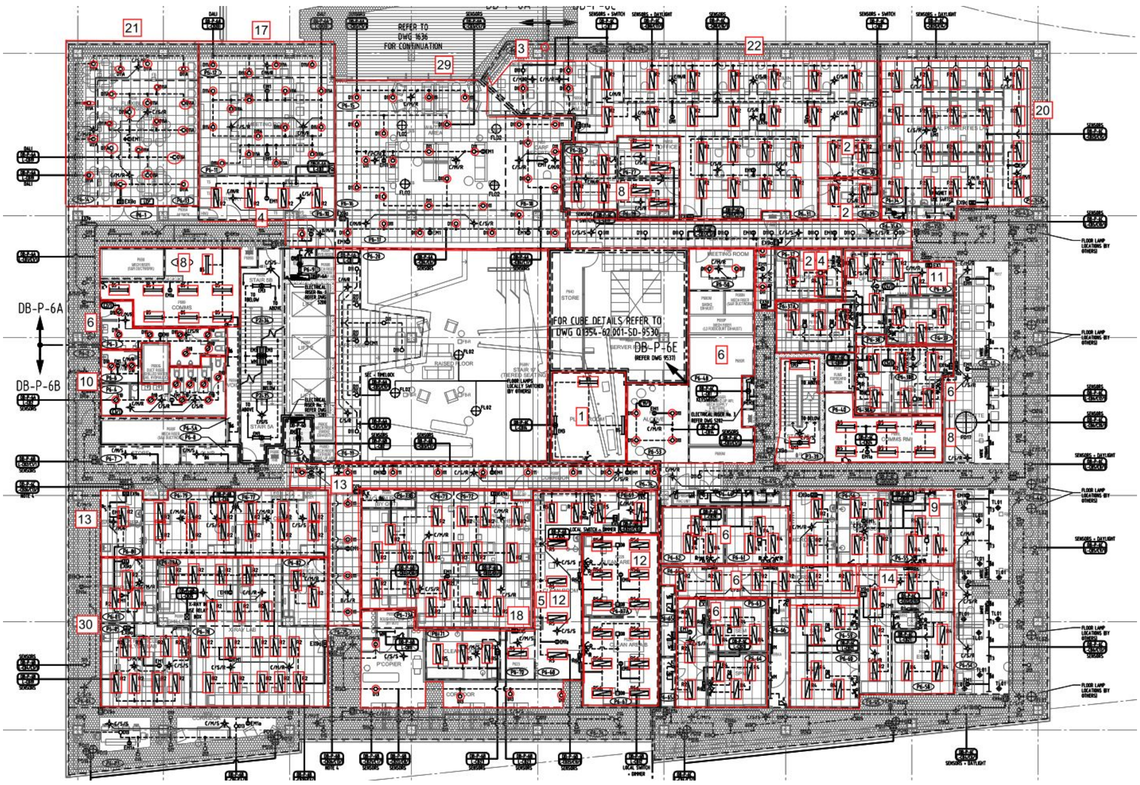

Figure 20: QUT: P Block Level 6 Lighting Markup

Table 10 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 8 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)**
LED Downlight	36.0	24.0	110.0	165.0
LED Barlight	56.0	24.0	224.0	522.7

Table 10: QUT: P Block Level 6 Lighting Count and Calculations

7.3.2 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.

7.3.3 Photovoltaic Modules

This information is elaborated on further in Section 8.2.1 however to briefly preface, the test model will be based on utilising the average photovoltaic module of 250 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.

7.3.4 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.

8 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.

8.1 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, Steven Donohue did extensive research on this aspect of the solution in 2014 for his 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 [10].

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 11 below shows the DC resistances from

TriCAB cable suppliers [9] and Table 12 shows approximate cable areas required for different DC voltages and loads.

Conductor DC Resistance		
Cable Size (mmˆ2)	**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 11: TriCAB Catalogue DC Resistance Cable [9]

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 12: 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.

8.2 Can Photovoltaic Systems Be Used Effectively for this Application?

Photovoltaic systems are being considered for this project due to their nature to produce electricity in DC form naturally. 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.

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

8.2.1 PV Panel Overview

There are two main types of Photovoltaic cells; monocrystalline and polycrystalline [39]. They are both based on crystalline silicon. Crystalline silicon is silicon that has solidified into atoms that are arranged in a crystal lattice [39]. 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 [39].

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 [39].The additional factors to consider are mounting systems, control system incorporation, direction of tilt and azimuth [39].

8.2.2 Brisbane Solar Data

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 21.

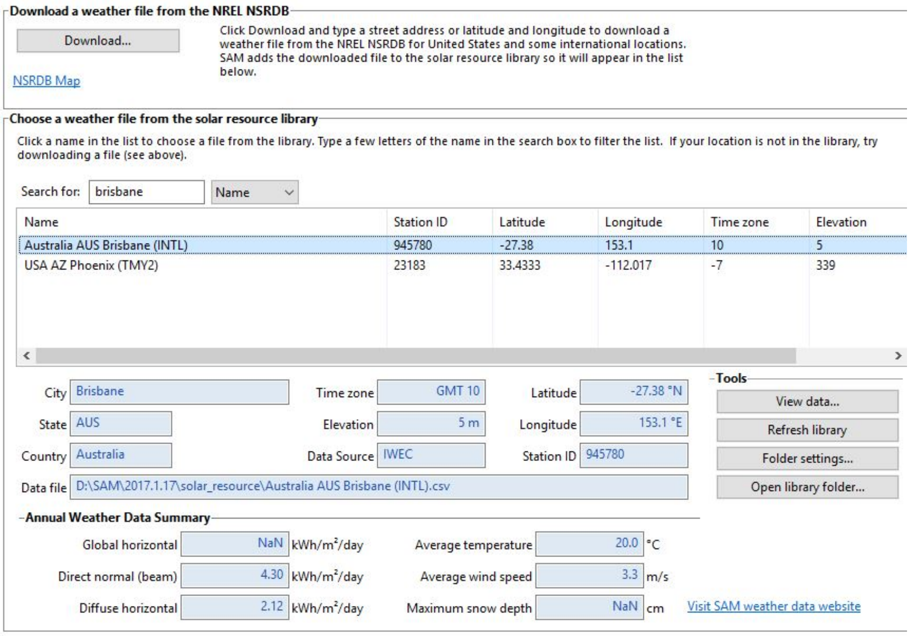

Figure 21: SAM System Design: Weather Settings

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 [39]. 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 22 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 23. 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.

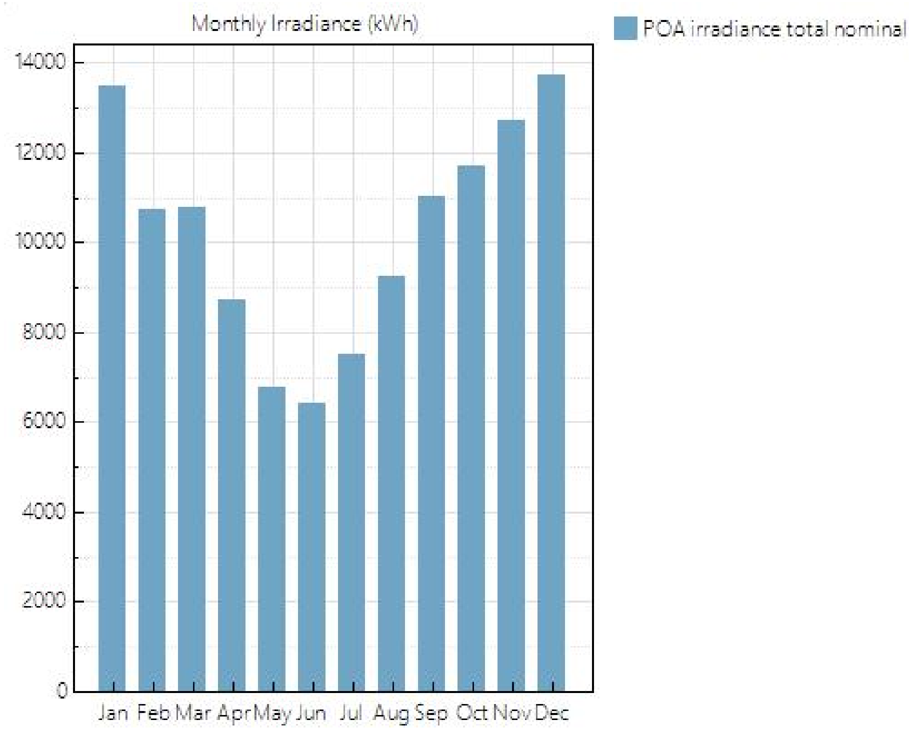

Figure 22: SAM System Design: Brisbane Monthly Irradiance

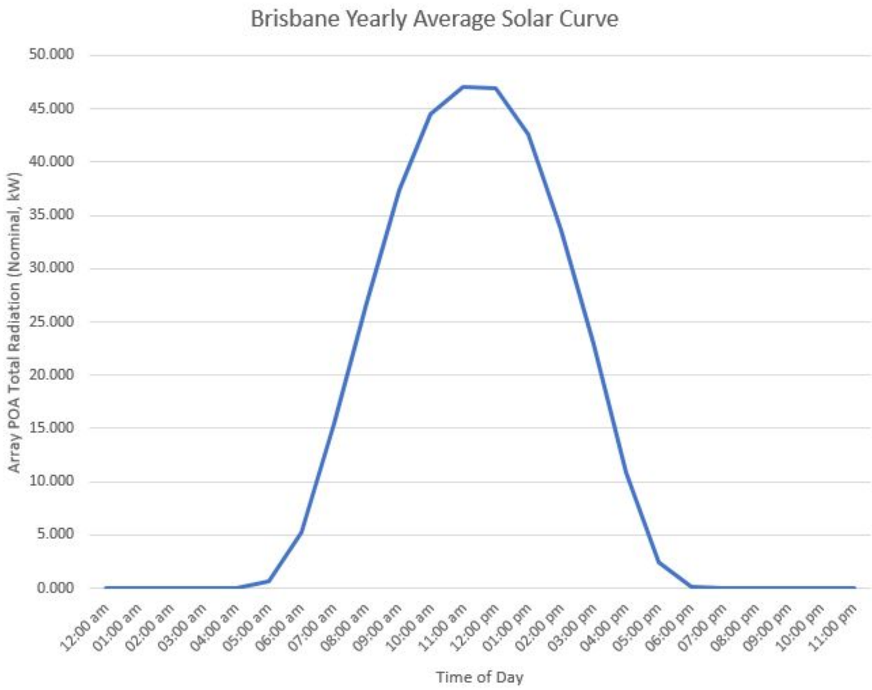

Figure 23: SAM System Design: Brisbane Monthly Irradiance

8.2.3 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 [40]. 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 30 panels with 8 strings in parallel 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 Figure24.

- Location of Brisbane, Australia with automatically imported weather data
- Tilt of 5 degrees
- Azimuth of 0 degrees (North facing)
- Ground Coverage Ratio (GCR) of 0.1 therefore assuming minimal shading
- Flat mounted onto roof

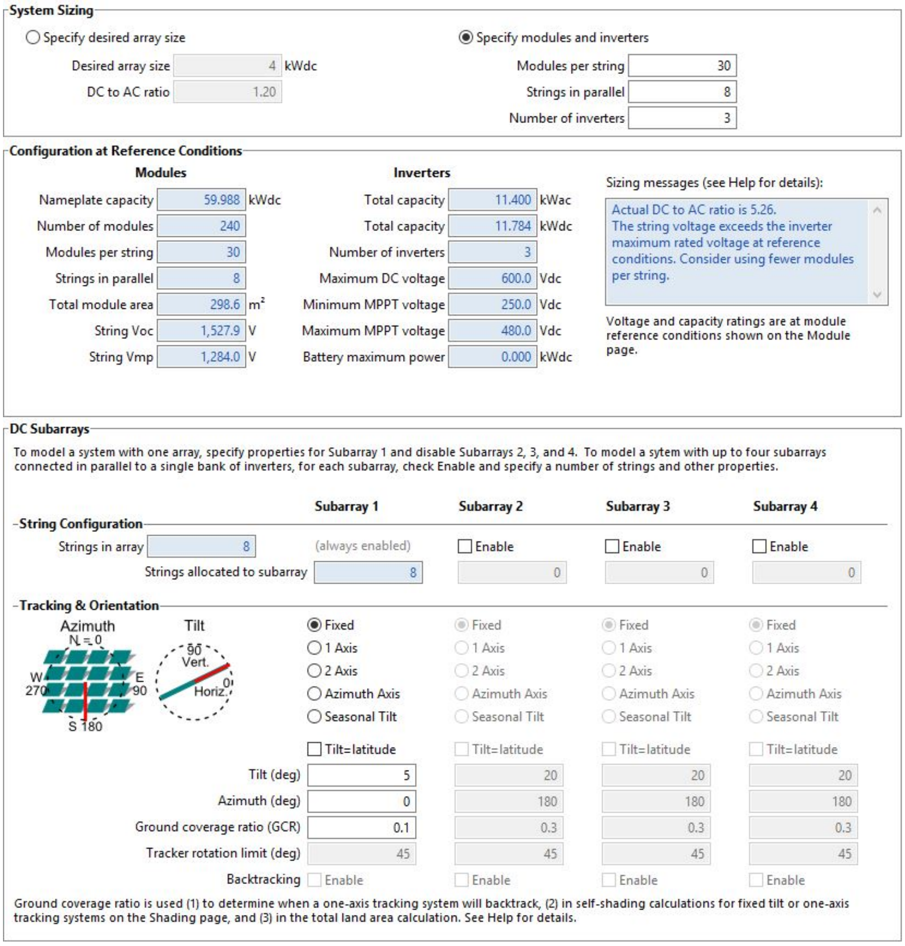

Figure 24: SAM System Design: Test Model 1

SAM results indicate the losses approximated over one year of data and simulations. As can be seen from Figure 25, the major losses are from soiling, the module, inverter clipping and DC wiring. Of those, the proposed DC system could remove the 54.134% loss from the inverters and incorporate a more efficient DC to DC converter.

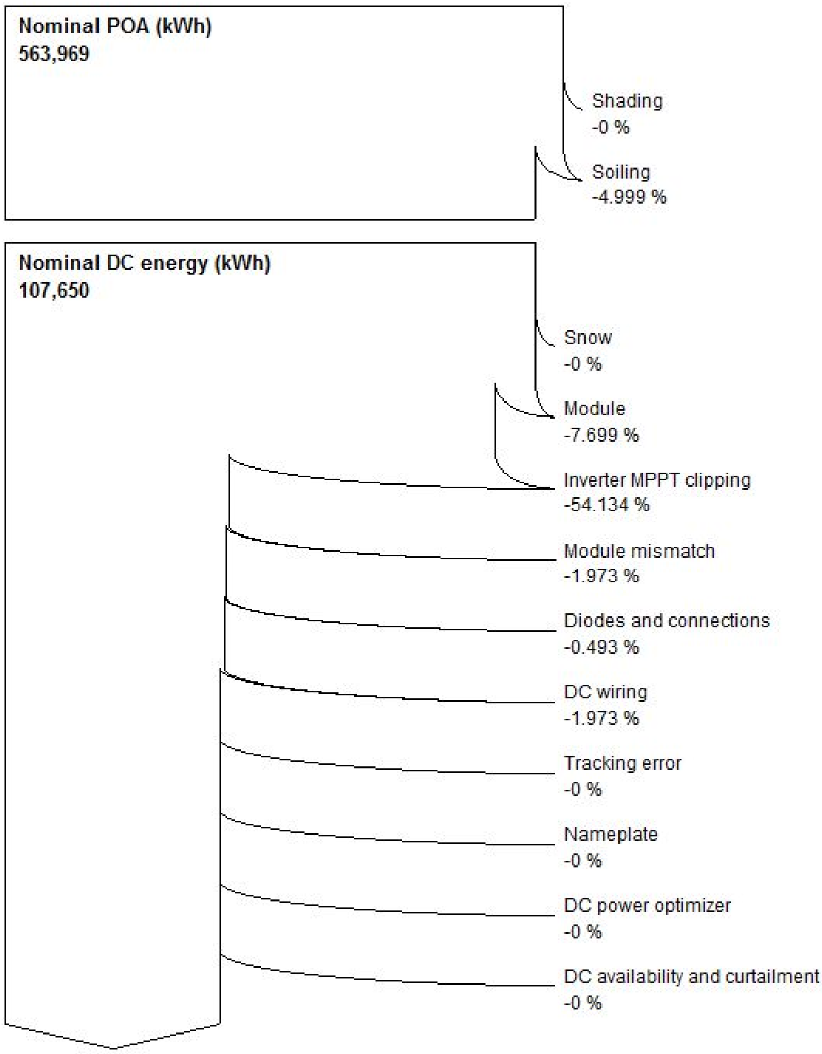

Figure 25: SAM System Design: Test Model 1 Losses

8.2.4 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 26 [6].

Figure 26 displays the curve representing voltage, current and power.

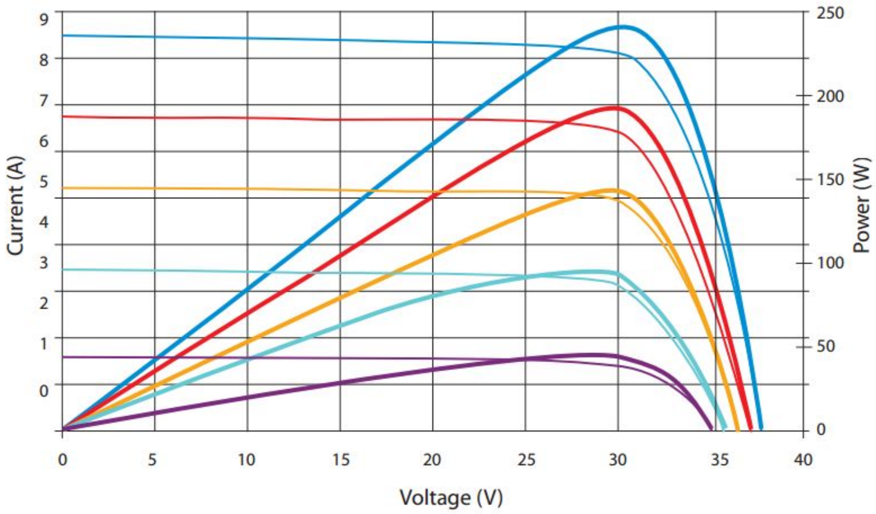

Figure 26: SAM System Design: PV Module Current Voltage Power Graph [6]

8.2.5 Mounting of Modules

TO BE COMPLETED

8.2.6 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.

8.3 Can Lighting Requirements Be Met Through the Proposed System?

For lighting requirements, as previously discussion in Section 7.1 there are Australian standards that impact the quantity and types of luminaires. Table 6 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) [8].

To begin the analysis, the project test model standard office was modelled in the lighting simulation software package Dialux. As discussed in Section 7.3 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.

8.3.1 Office Room Lighting Model

The large floor plan shown in Section 7.1 was loaded into Dialux and an office separated out for modelling. The room was approximation shows that offices on this are $22\,\mathrm{m}^2$ 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 27.5W fitting from Pierlite [41]. The DWG file additionally outlined some architectural objects including a table which was included in the modelling.

When modelling in Dialux, assumptions are required for things like roof heights, luminaires mounting heights and surface reflectances. Following building standards Table 13 below outlines the assumptions made in the completed lighting analysis.

This calculation was completed as a test basis to ensure that the information received from the schematics were correctly understood. Appendix 11.2 shows the complete report however the important aspects are of course the lux values throughout the workplace shown in Figure 27 and the 3D render for visual appeal shown in Figure 28.

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

Table 13: QUT: P Block Level 6 Office Lighting Simulation Assumptions

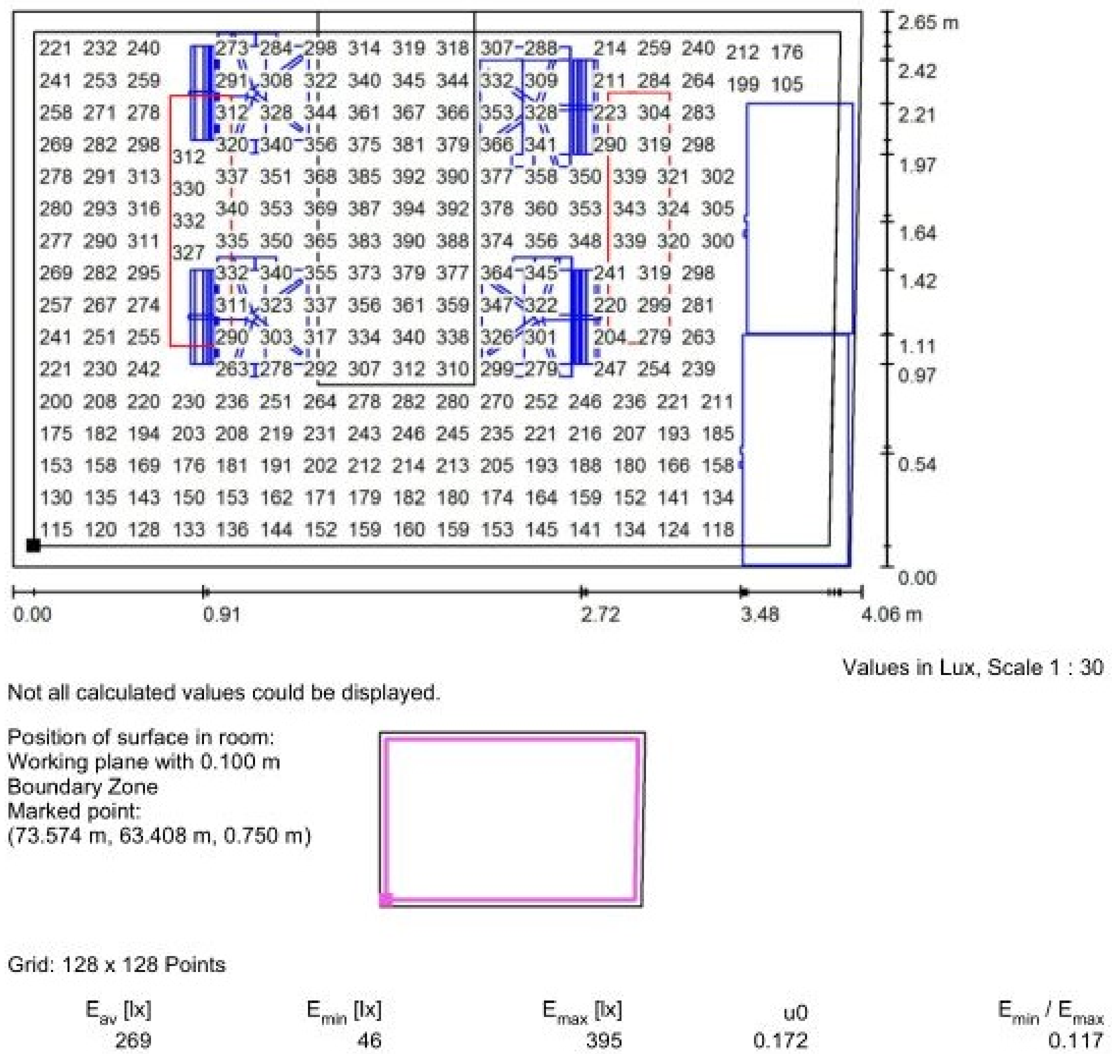

Figure 27: QUT: P Block Level 6 Office Lux Analysis

Figure 28: QUT: P Block Level 6 Office 3D Render

8.3.2 Lighting Model Discussion

TO BE COMPLETED

8.3.3 DC Light Devices

TO BE COMPLETED

8.4 Structural Design and Safety Mechanisms to Minimise Cable Losses

Include:
Mounting of panels ELV devices Cable Length breakdown with maximum lengths for losses

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

8.5.1 Assumptions

This is the overall question of the project. In conjunction with the previous questions a final solution can be found based off of the following assumptions:

- Assumption 1
- Assumption 2

8.5.2 Efficiency Comparison

Losses in AC Systems
TO BE COMPLETED

Losses in DC Systems
TO BE COMPLETED

8.5.3 Financials

Capital Expenditure

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

Luminaire Cost Comparison
TO BE COMPLETED

New Infrastructure Costs
TO BE COMPLETED

Capital Expenditure
TO BE COMPLETED

Energy Savings
TO BE COMPLETED

Monthly Costs or Savings
TO BE COMPLETED

Return on Investment
TO BE COMPLETED

Payback Period
TO BE COMPLETED

9 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.

OLD
There is still work to be completed on this project before future suggestions on other topics or expansions can be made. The tasks that remain to be completed are outlined in the time line in Section 5. The next major task, as previously discussed, is to use the data provided by QUT as well as floor plans and lighting schematics to model a more feasible design for a commercial building. Once this is completed a more accurate representation of load demand can be analysed. From here specifics of the design can be calculated including current values, voltage drops, cable lengths and locations of devices. Specific devices can be researched and chosen including switchboards, circuit breakers, photovoltaic panels and LED lights. Following calculations and device selection, the financial analysis will be completed as well as an efficiency comparison between a comparable AC system. This is the existing overall plan for completing this project. If hurdles or additional ideas arise throughout, it will be adjusted to allow for the highest quality research possible.

10 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.

As of the submission of this progress report (April 2017) calculations have been completed and some conclusions made. The remaining tasks are ***TO BE COMPLETED***

Thus far, 48 V DC has been deemed the most appropriate voltage level for the system and remaining calculations based off that value. ***TO BE COMPLETED***
OLD

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 a group 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. The initial research phase has been completed and designs have begun initial stages.

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.

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. January 2017 will have a complete preliminary design along with justification for the feasibility so that a presentation can be made and successful progress shown. By ensuring that this stage is reached, valuable feedback will be provided via the project supervisor and academic team behind the course.

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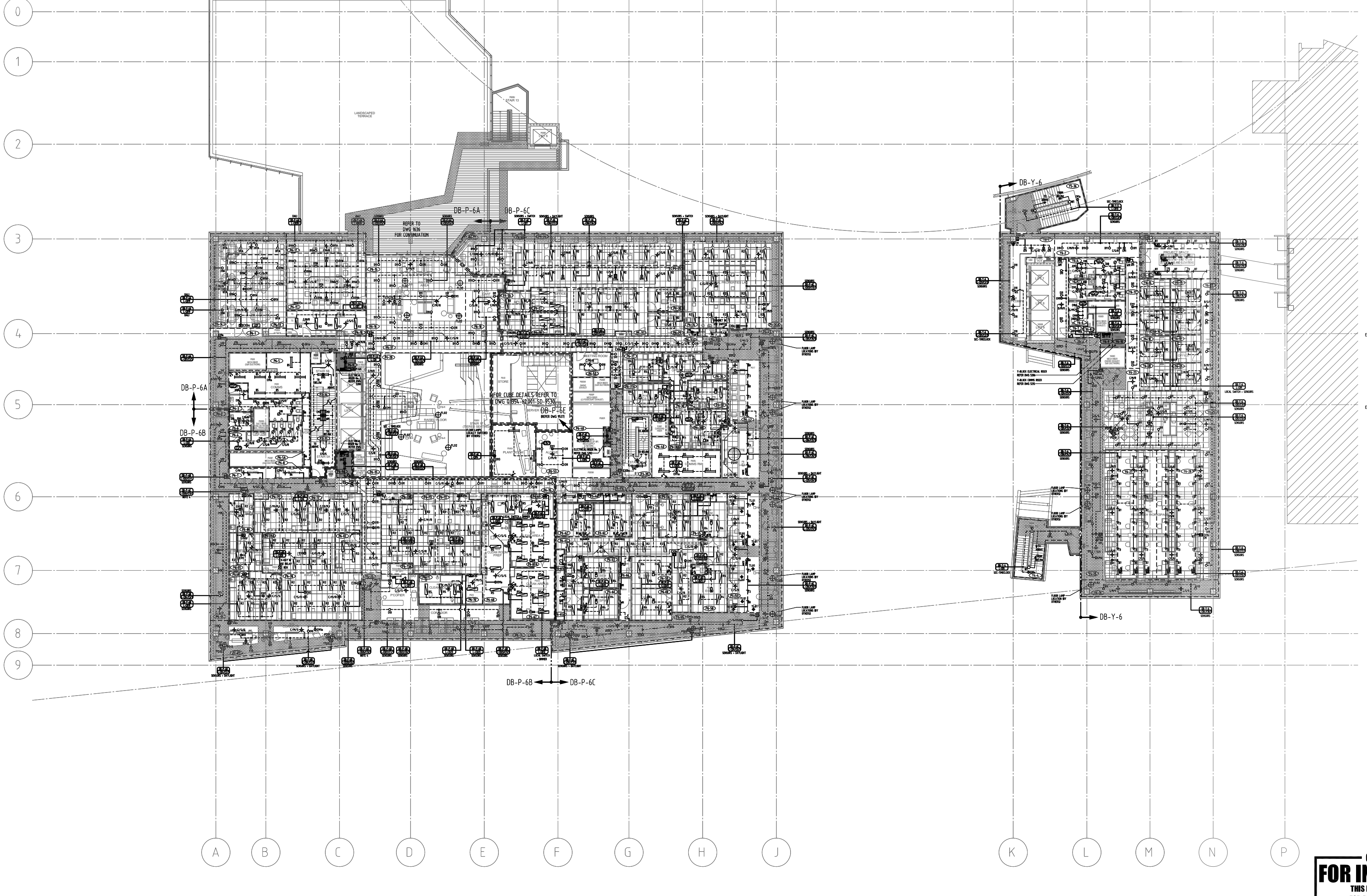
11 Appendices

11.1 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 (m^2)	LIGHT SWITCHING METHODOLOGY
Y6-1	LIFT LOBBY	$46m^2$	• MASTER/SLAVE SENSORS, 30min • SEC-TIMECLOCK
Y6-2	PERIMETER WALKWAY CORRIDOR	$26m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-3	CORRIDOR	$31m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-4	FEMALE AMENITIES	$14m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-5	MALE AMENITIES	$16m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-6	PWD	$6m^2$	• MOTION SENSOR
Y6-7	CLEANERS	$2m^2$	• MOTION SENSOR
Y6-8	PLANT ROOM	$3m^2$	• KEY SWITCH
Y6-9	ELECTRICAL DB ROOM	$2m^2$	• KEY SWITCH
Y6-10	COMMS ROOM	$2m^2$	• KEY SWITCH
Y6-11	CORRIDOR	$20m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-12	PERIMETER LIGHTING	$16m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-13	PROJECT SPACE	$31m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-14	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-15	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-16	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-17	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-18	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-19	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-20	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-21	SMALL OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
Y6-22	PERIMETER WALKWAY	$26m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-23	KITCHEN AREA	$90m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-24	PERIMETER WALKWAY	$37m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-25	PERIMETER WALKWAY	$59m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-26	PERIMETER WALKWAY	$30m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-27	WORK AREA	$90m^2$	• MASTER/SLAVE SENSORS, 30min
Y6-28	WORK AREA	$77m^2$	• 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 (m^2)	LIGHT SWITCHING METHODOLOGY
P6-1	CORRIDOR	$53m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-2	CORRIDOR	$41m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-3	MALE AMENITIES	$19m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-4	FEMALE AMENITIES	$23m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-5	COMMS ROOM	$36m^2$	• KEY SWITCH
P6-6	PWD	$6m^2$	• SENSOR, 30min
P6-7	STORE	$6m^2$	• SENSOR, 30min
P6-8	CLEANERS	$5m^2$	• SENSOR, 30min
P4-9	ELECTRICAL DISTRIBUTION CUPBOARD	$4m^2$	• KEY SWITCH
P4-9A	ELECTRICAL DISTRIBUTION CUPBOARD	$5m^2$	• KEY SWITCH
P6-10	SERVERY	$26m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-11	MEETING ROOM	$59m^2$	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-12	MEETING ROOM PERIMETER	$20m^2$	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-13	FLEXIBLE MODELLING SPACE	$56m^2$	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-14	FLEXIBLE MODELLING SPACE PERIMETER	$36m^2$	• SENSORS ACTIVATE BASE LIGHTING, 30MINS WITHIN ZONES AS SHOWN. OTHER LIGHT SCENES VIA LIGHTING CONTROL PANEL
P6-15	PERIMETER AREA	$22m^2$	• MOTION SENSOR, (30min)
P6-16	CARF LOUNGE	$79m^2$	• MOTION SENSOR, (30min)
P6-17	WALKWAY	$39m^2$	• MOTION SENSOR, (30min)
P6-18	MEETING ROOM	$23m^2$	• MOTION SENSOR, (30min)
P6-19	LIFT LOBBY	$36m^2$	• MASTER/SLAVE SENSORS, 30MINS SECURITY FITTINGS ON BMS TIMECLOCK
P6-20		$165m^2$	
P6-21	DIRECTIONS OFFICE	$29m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-22	OFFICE	$9m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-23	OFFICE	$15m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-24	CARF ADMIN	$62m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-25	CARF ADMIN	$51m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-26	MEETING ROOM	$16m^2$	• MOTION SENSOR, (30min)
P6-27	OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-28	OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-29	OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-30	OFFICE	$11m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-31	OPEN PLAN OFFICE	$50m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-32	(ZONE DELETED)		
P6-33	(ZONE DELETED)		
P6-34	PHYSICAL PROP LAB	$65m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-34A	PHYSICAL PROP LAB PERIMETER	$55m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-35	WALKWAY	$30m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-35A	ELECTRICAL DB	$2m^2$	• KEY SWITCH
P6-35B	EQUIPMENT ROOM	$2m^2$	• KEY SWITCH
P6-36	OPTICS PREP 1	$26m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-37	OPTICS LAB 3	$16m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-37A	OPTICS LAB 2	$18m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-38	OPTICS PREP 2	$30m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-39	OPTICS LAB 1	$15m^2$	• MOTION SENSOR, (30min)
P6-40	COMMS ROOM	$28m^2$	• KEY SWITCH
P6-41		m^2	
P6-42	OPEN AREA	$53m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-43	PERIMETER WALKWAY	$48m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-44	PERIMETER WALKWAY	$40m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-45	PERIMETER WALKWAY	$62m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-46	CORRIDOR/WALKWAY	$48m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-47	CORRIDOR/WALKWAY	$14m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-48	ELECTRICAL CUPBOARD	$2m^2$	• KEY SWITCH
P6-49	CORRIDOR/WALKWAY	$54m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-50	MEETING ROOM	$12m^2$	• MOTION SENSOR, (30min)
P6-51	RESEARCH CAVE	$18m^2$	• MOTION SENSOR, (30min)
P6-52	SERVER ROOM	$24m^2$	• KEY SWITCH
P6-53	RESEARCH CAVE	$22m^2$	• MOTION SENSOR, (30min)
P6-54	OPEN AREA	$29m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-55	ESEM LAB	$18m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-56	FUME CUPBOARD	$18m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-58	ESEM LAB	$23m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-59	SEM LAB	$17m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-60	SEM LAB	$17m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-61	TEM LAB	$17m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-62	TEM LAB	$17m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-63	SEM LAB	$15m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-64	SEM LAB	$15m^2$	• ROTARY DIMMER + OFF SWITCH • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-65	MICROSCOPY LAB WALKWAY	$31m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-65A	EQUIPMENT ROOM	$3m^2$	• KEY SWITCH
P6-65B	EQUIPMENT ROOM	$4m^2$	• KEY SWITCH
P6-65C	EQUIPMENT ROOM	$5m^2$	• KEY SWITCH
P6-66	EQUIPMENT ROOM	$10m^2$	• KEY SWITCH
P6-67	CLEAN ROOM B	$31m^2$	• MASTER/CLAVE SENSOR, 30min AND SWITCH (AUTO/OFF) • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-67A	CLEAN ROOM A	$28m^2$	• MASTER/SLAVE SENSOR, 30min AND SWITCH (AUTO/OFF) • LOCAL SWITCH FOR ROOM IN USE LIGHT
P6-68	CLEAN ROOM PREP	$47m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-69	AIRLOCK	$7m^2$	• MOTION SENSOR, (30min)
P6-70	AIRLOCK	$8m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-71	CLEAN ROOM	$16m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-72	ANALYTICAL CHEM LAB	$44m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-73	ANALYTICAL CHEM LAB	$61m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-73A	EQUIPMENT ROOM	$4m^2$	• KEY SWITCH
P6-73B	EQUIPMENT ROOM	$4m^2$	• KEY SWITCH
P6-74	PERIMETER WALKWAY	$47m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-75	CIRCULATION AREA	$54m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-76	CORRIDOR/WALKWAY	$66m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-77	OFFICE	$27m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-78	X-RAY LAB	$50m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-78A	X-RAY LAB	$38m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-79	OFFICE	$26m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-80	SAMPLE PREP C	$12m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-81	SAMPLE PREP B	$17m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-82	OFFICE	$14m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P6-83	PERIMETER WALKWAY	$60m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-84	PERIMETER WALKWAY	$30m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-85	BULK ANALYSIS LAB	$33m^2$	• MASTER/SLAVE SENSORS, 30MINS
P6-86	STORE	$10m^2$	• MASTER/SLAVE SENSORS, 30MINS
P2-34	STAIR 5B	$19m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P2-35	STAIR 5A	$19m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)
P3-39	STAIR 10	$24m^2$	• MOTION SENSOR (30min) AND SWITCH (AUTO/OFF)

ELECTRICAL SERVICES

Qelectrical
commercial and industrial solutions

Q electrical Pty Ltd 540 Logan Road, Greenslopes QLD 4120 PO Box 6143 Buranda QLD 4102
P 61-7 3391 0688 F 61-7 3391 0833 E qelectrical@qelectrical.com.au www.qelectrical.com.au
ABN 70 068 364 617 QLD ELECTRICAL CONTRACTORS LICENCE 9475

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

2009 BCA IS USED FOR ASSESSMENT OF THIS BUILDING

NOTES:
1. Figured dimensions take preference over scaled.
2. Figured dimensions are in millimetres unless noted otherwise.
3. Check all dimensions on site prior to commencement of work, fabrication or setout.
4. Confirm scale of hardcopy drawings using attached scale bar.
5. Refer schedule of selections and cover sheet (dwg. PR0000) for description of codes for finishes and materials.
6. Refer any discrepancies to the architect.

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, Bixley 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

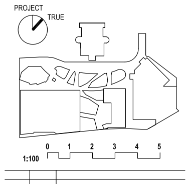
ARCHITECTURAL DRAWING REFERENCE
DWG: Q1354-OV-DWAR-1470
REV: WDL DATE: 05.06.12
DWG: Q1354-OV-DWAR-1670
REV: WDF DATE: 16.12.11

QUT

LEIGHTON

PROJECT
SCITECH

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



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

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

Q1354-62.001-SD-1070 ABF

11.2 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

Operator David Petrie
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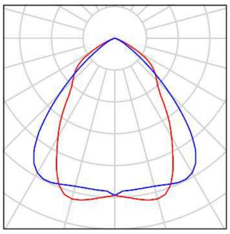
e-Mail david.petrie@connect.qut.edu.au

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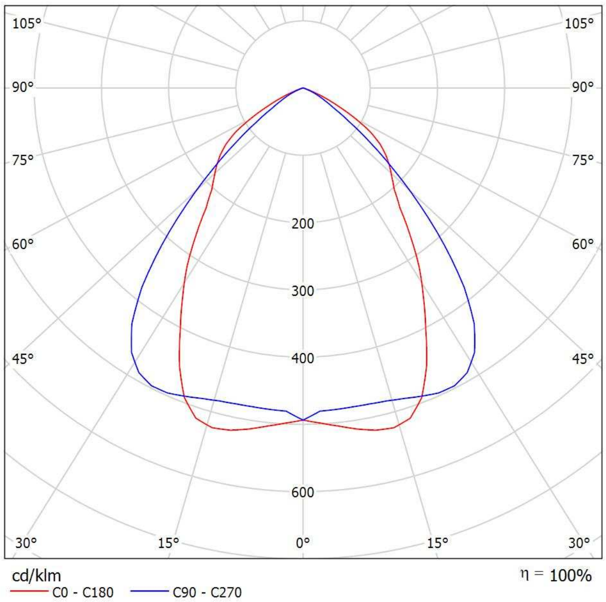
Gerard Lighting F-LED_1234U1 Pierlite Futcha LED 300x1200 4000K 27W DALI / Luminaire Data Sheet

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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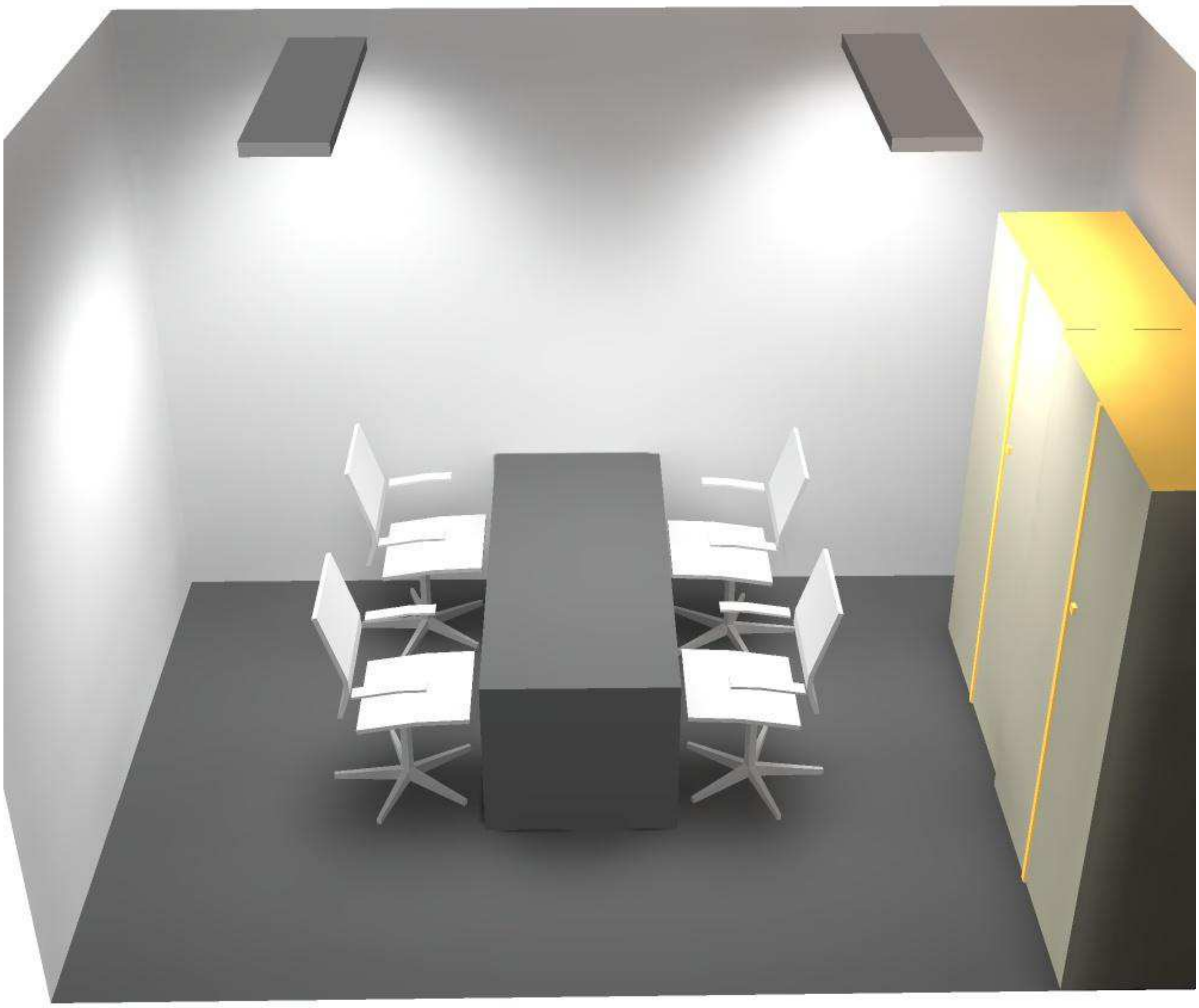
Standard Office / 3D Rendering



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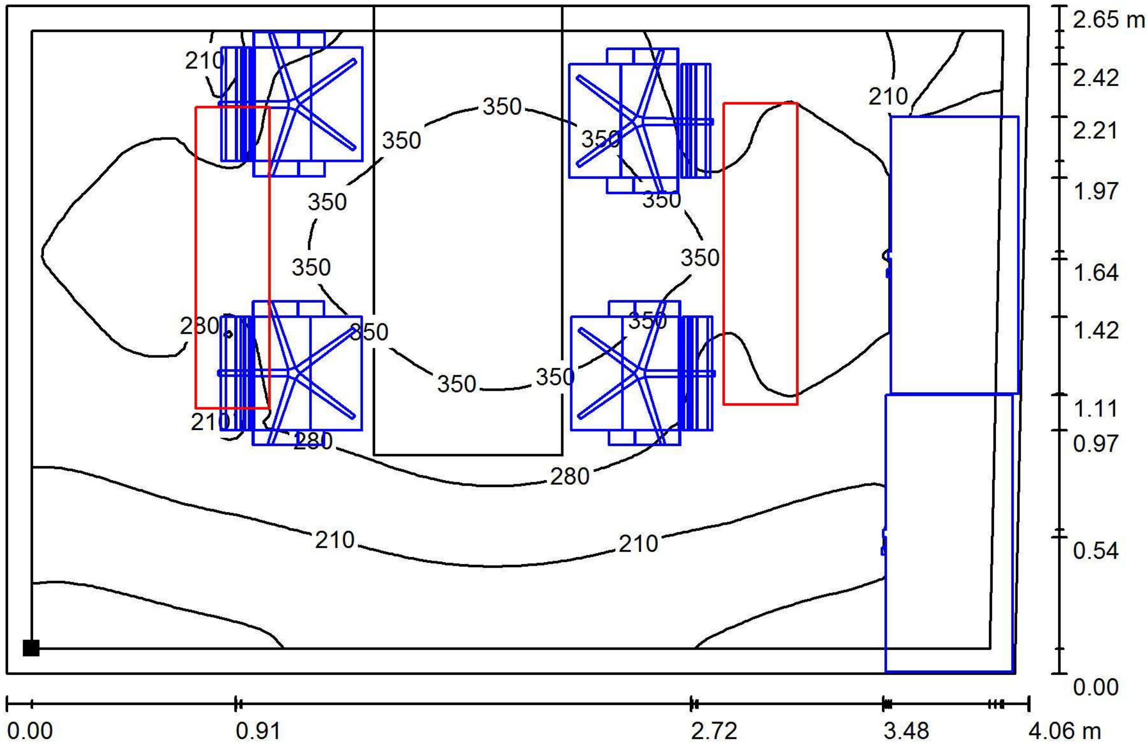
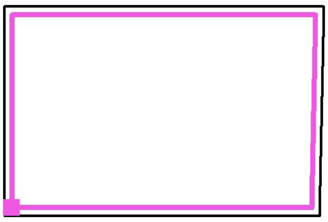
e-Mail david.petrie@connect.qut.edu.au

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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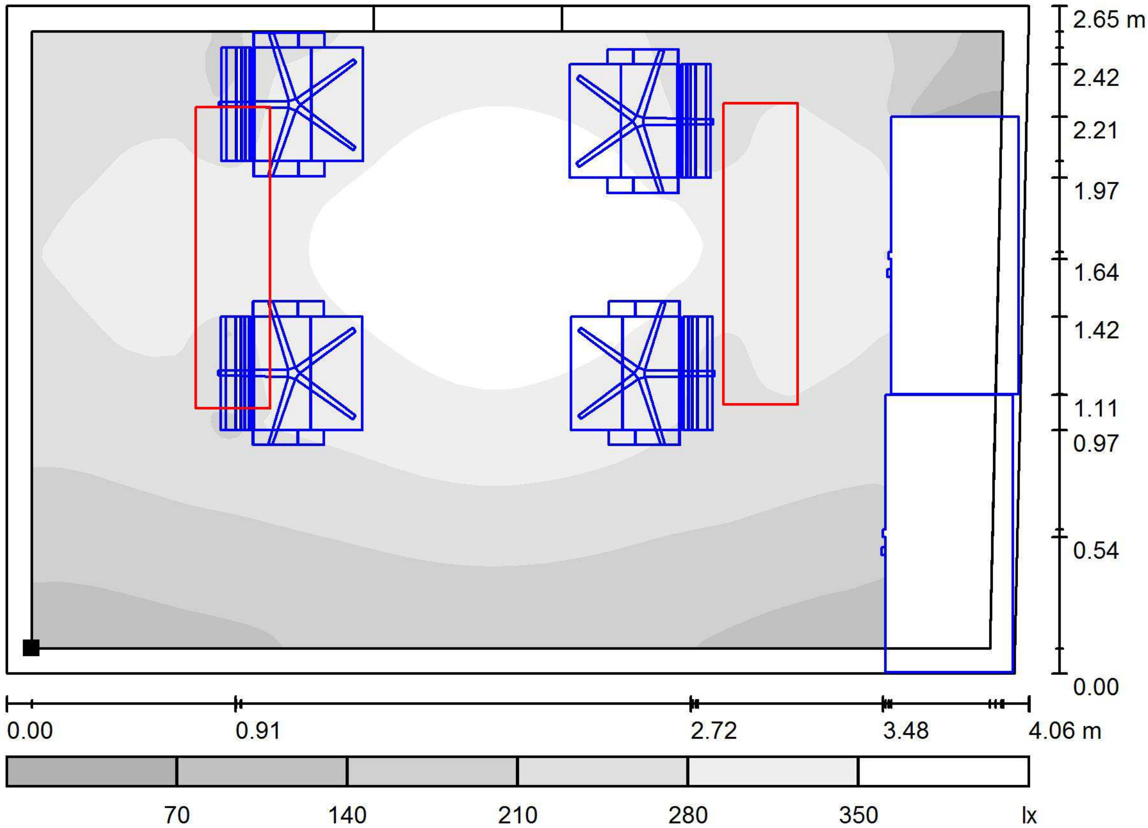
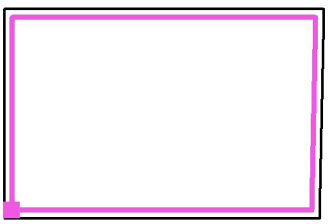
Standard Office / Workplane / Greyscale (E)



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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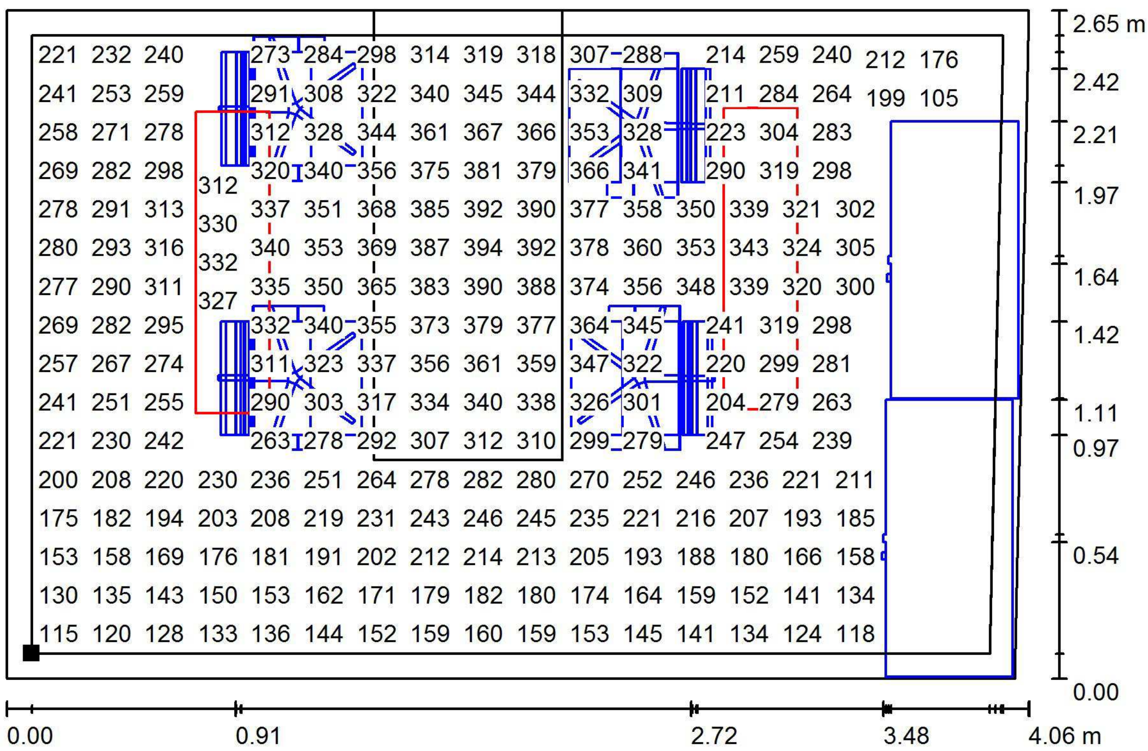
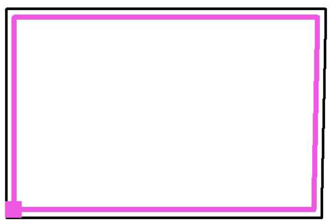
Standard Office / Workplane / Value Chart (E)



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

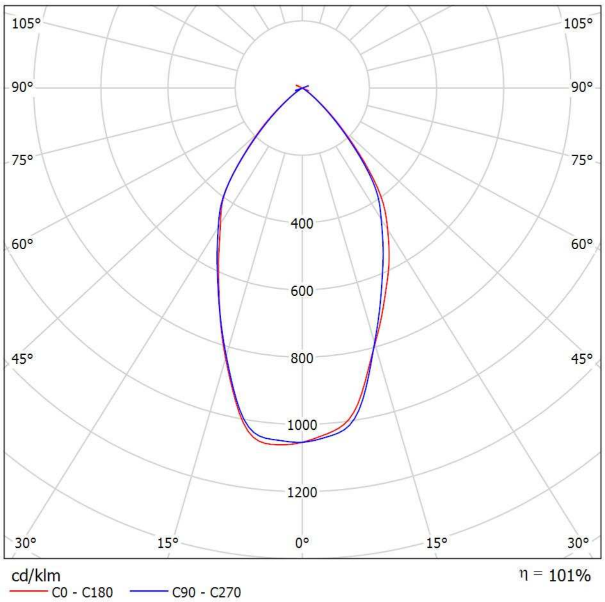
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
269	46	395	0.172	0.117

11.3 Draft Floor Plan Lighting Analysis Report

Operator
Telephone
Fax
e-Mail

onok 530 LED / Luminaire Data Sheet

Luminous emittance 1:



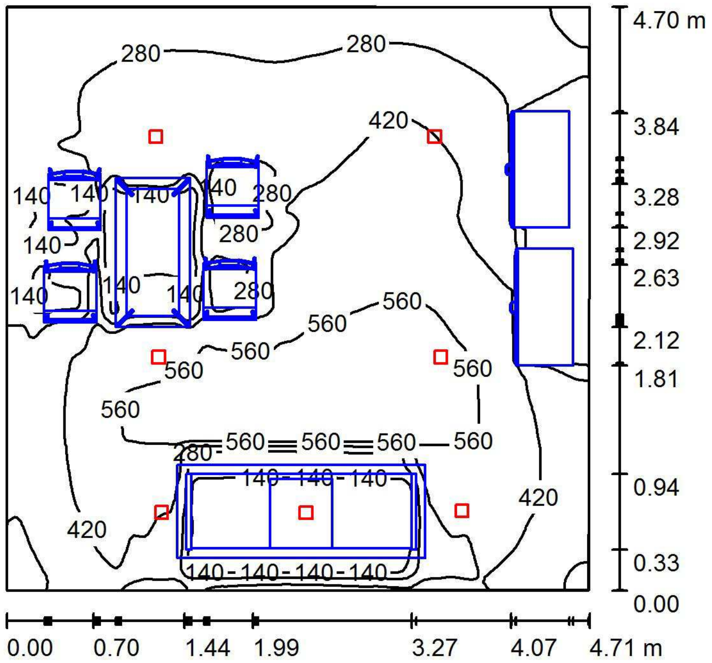
See our luminaire catalog for an image of the luminaire.

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.

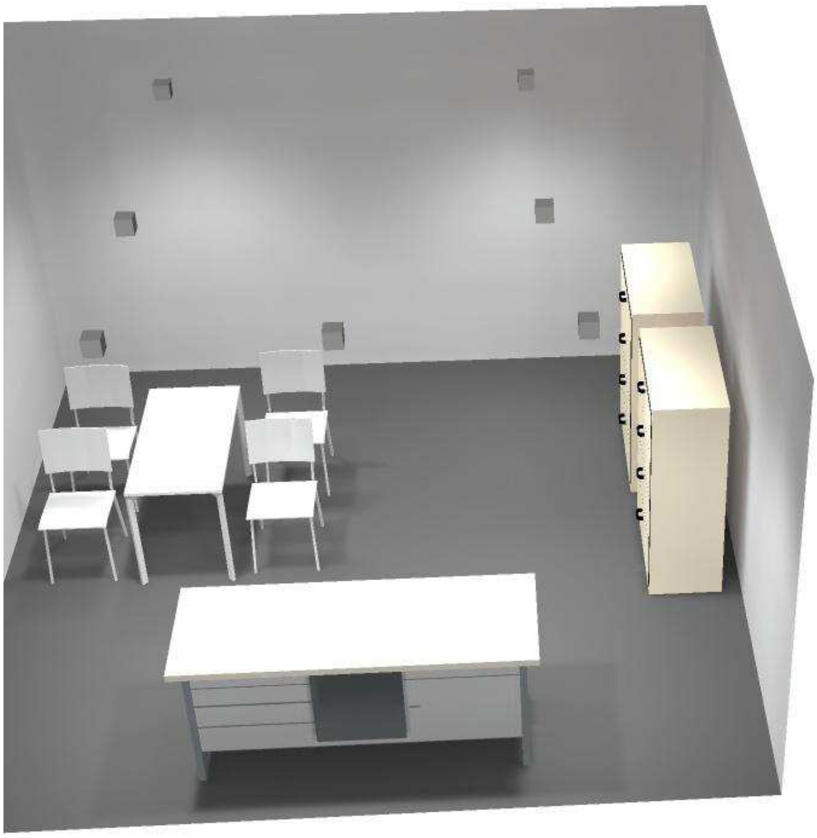
Luminaire Parts List

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

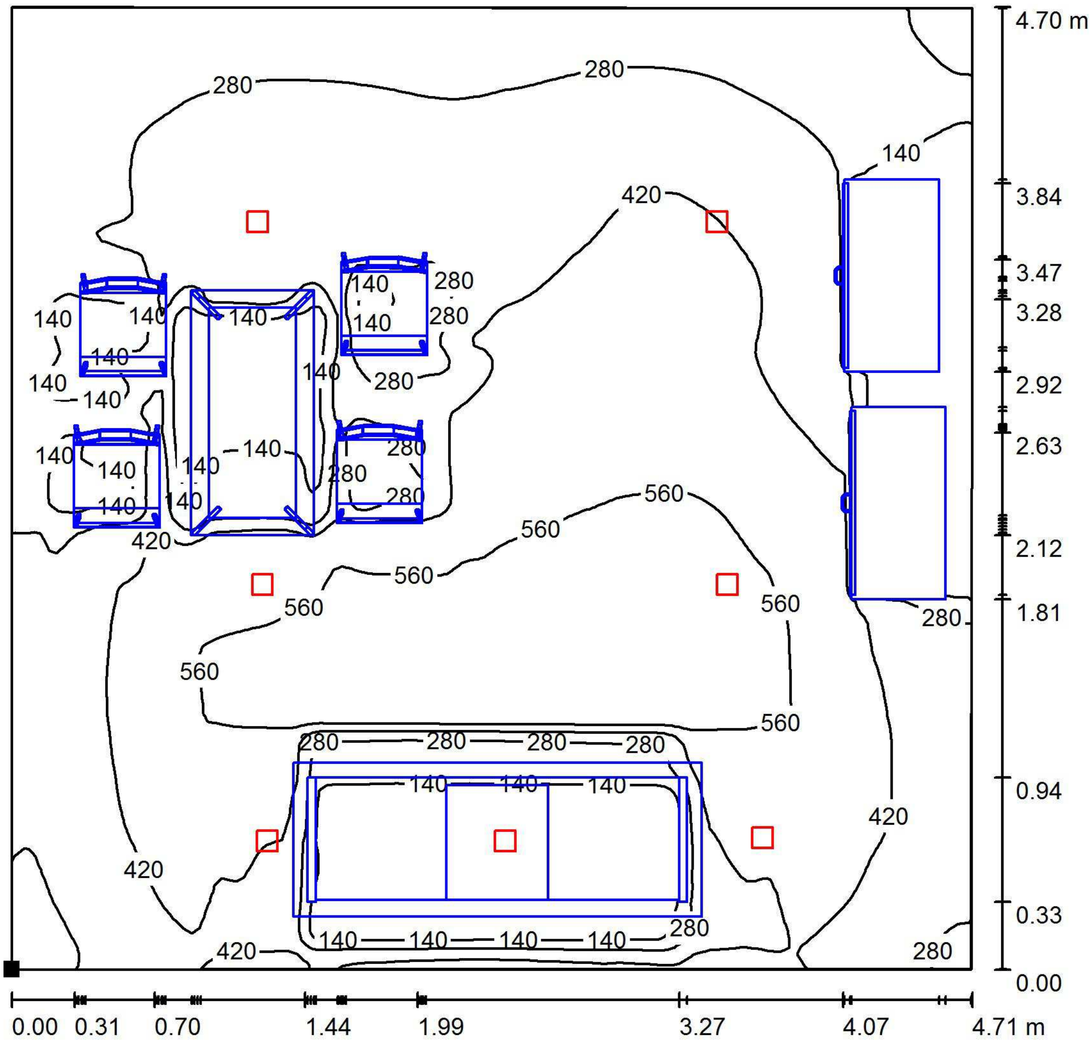
Specific connected load: 0.00 W/m² = 0.00 W/m²/ lx (Ground area: 22.10 m²)

Operator
Telephone
Fax
e-Mail

Typical Office / 3D Rendering

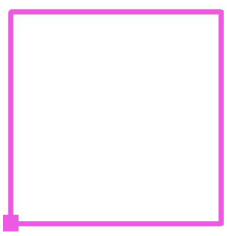


Typical Office / Workplane / Isolines (E)



Values in Lux, Scale 1 : 37

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

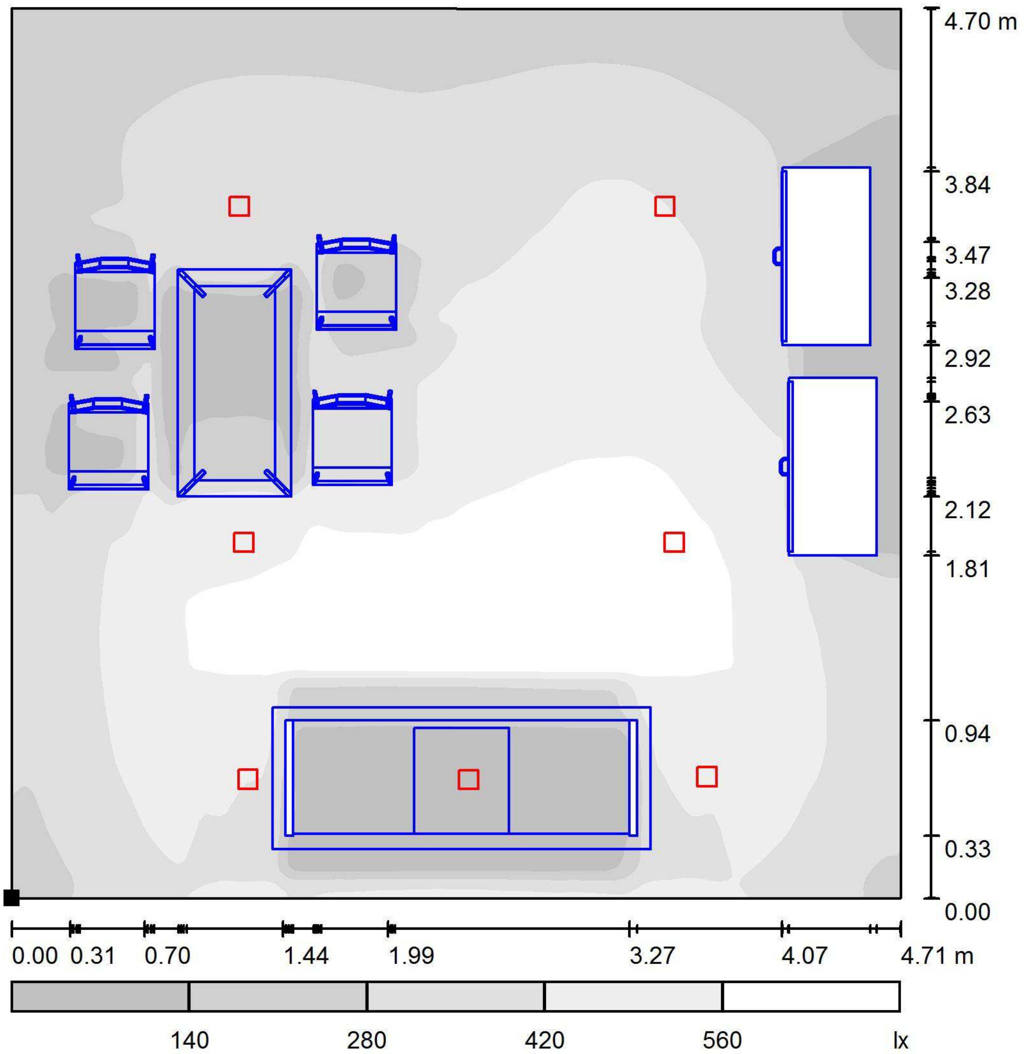


Grid: 128 x 128 Points

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

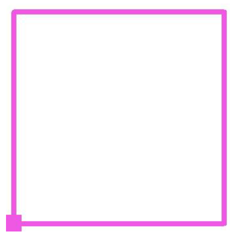
Operator
Telephone
Fax
e-Mail

Typical Office / Workplane / Greyscale (E)



Scale 1 : 40

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

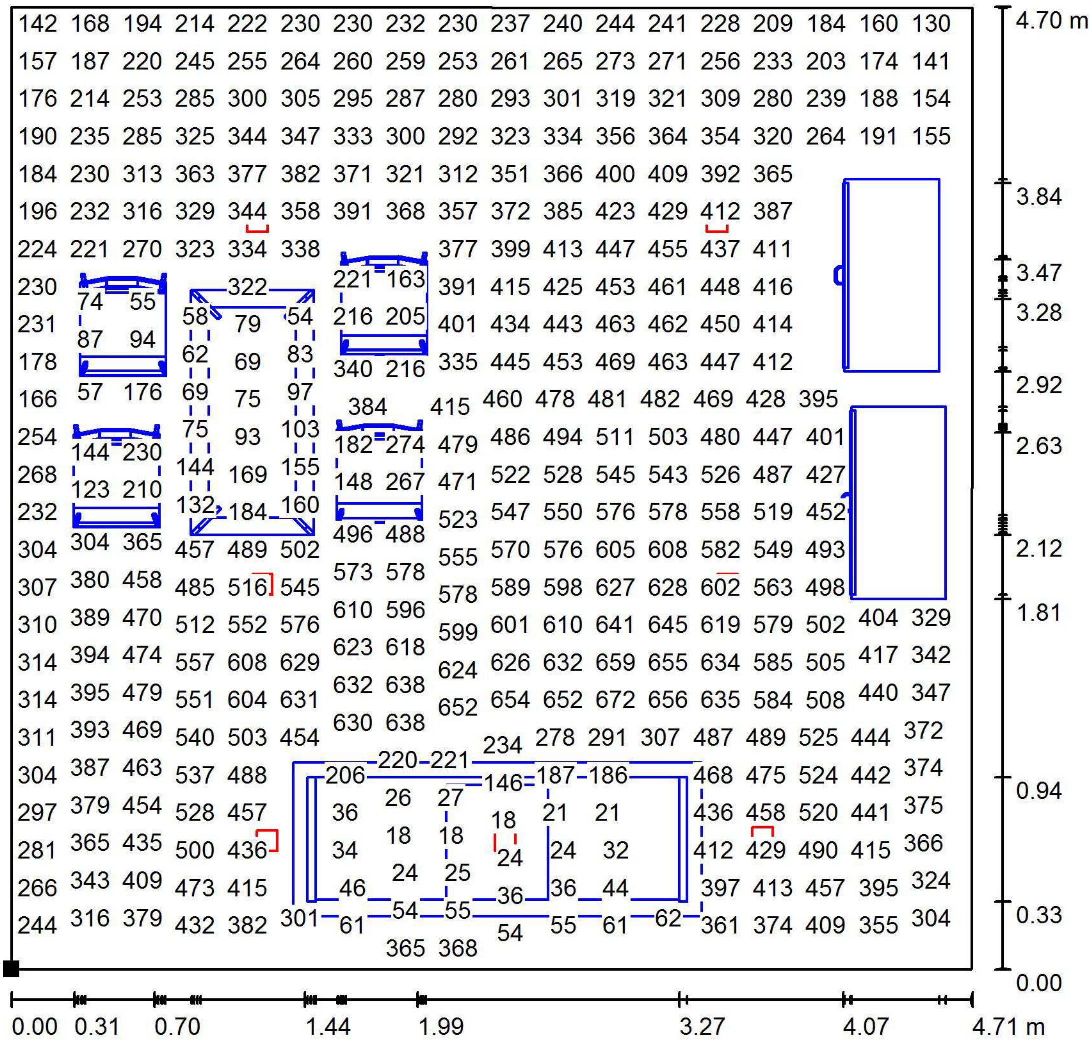


Grid: 128 x 128 Points

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

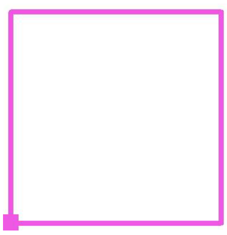
Typical Office / Workplane / Value Chart (E)



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)

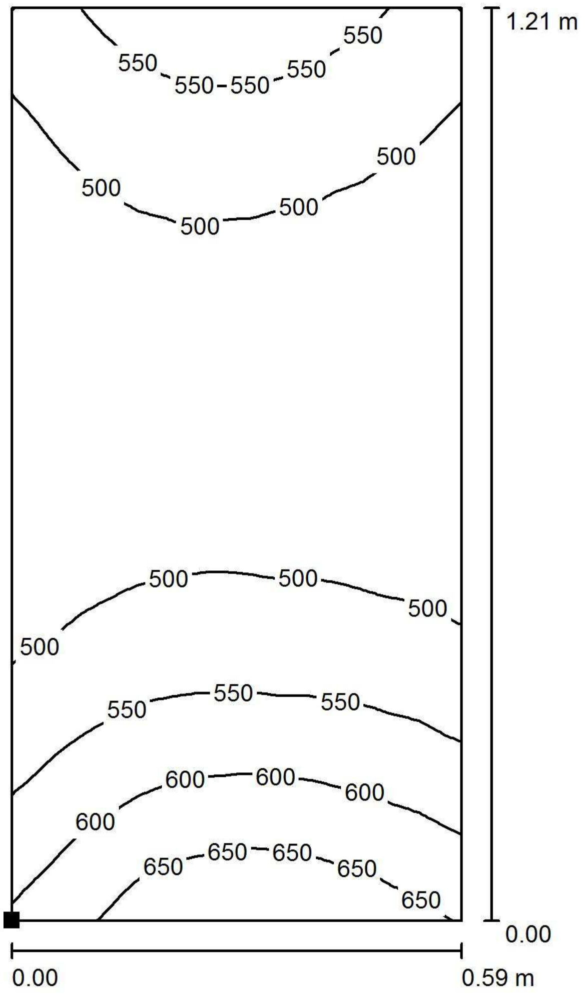


Grid: 128 x 128 Points

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

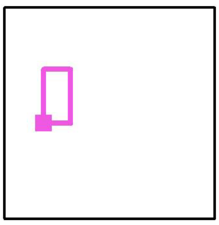
Operator
Telephone
Fax
e-Mail

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)

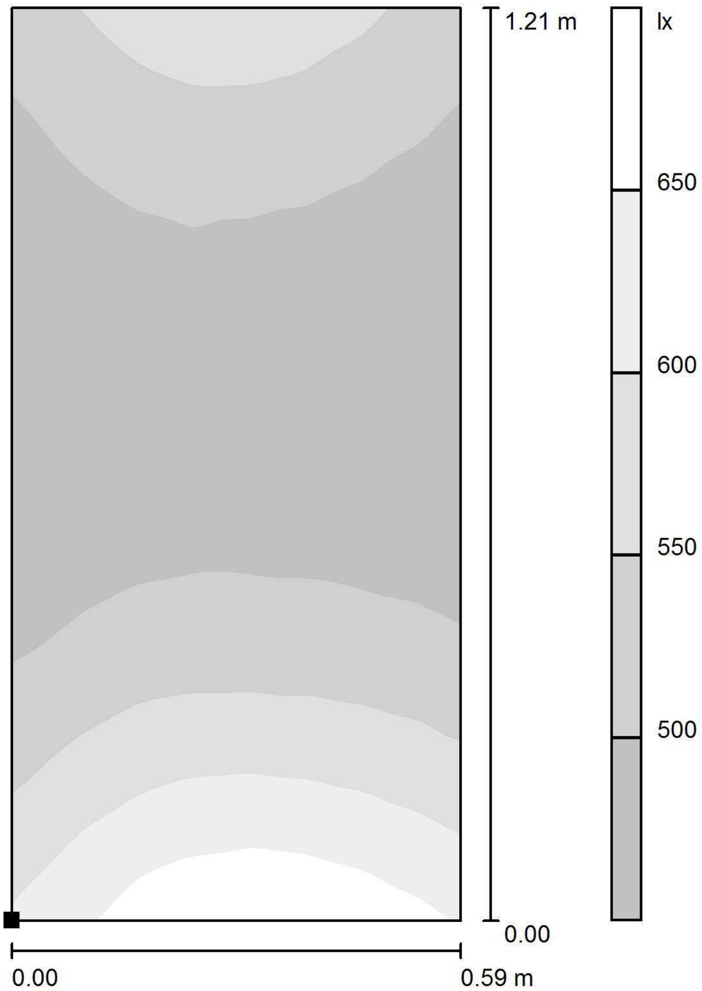


Grid: 32 x 64 Points

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

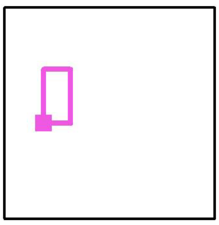
Operator
Telephone
Fax
e-Mail

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

Operator
Telephone
Fax
e-Mail

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

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

1.21 m

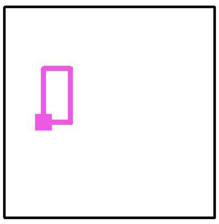
0.00

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)

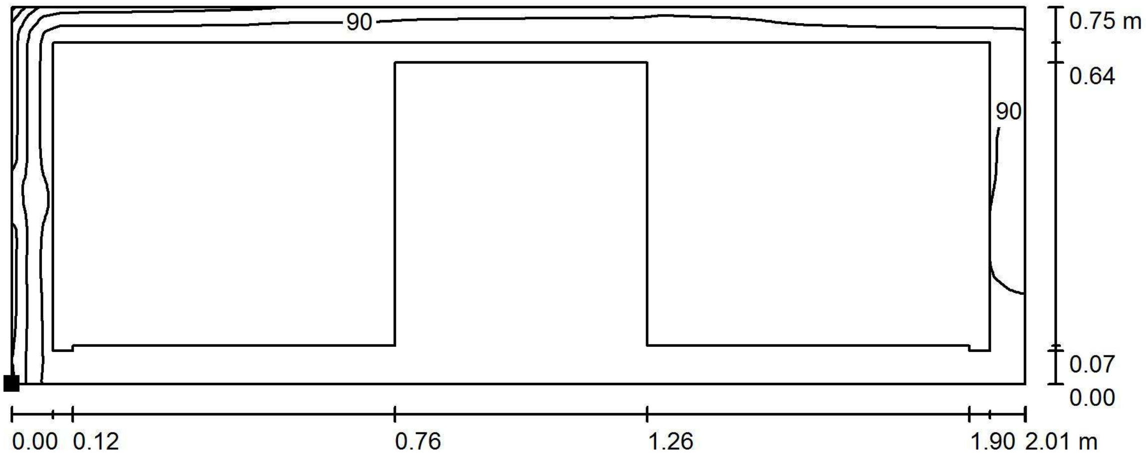


Grid: 32 x 64 Points

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

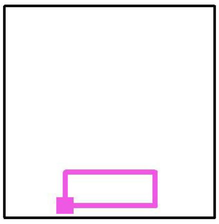
Operator
Telephone
Fax
e-Mail

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)

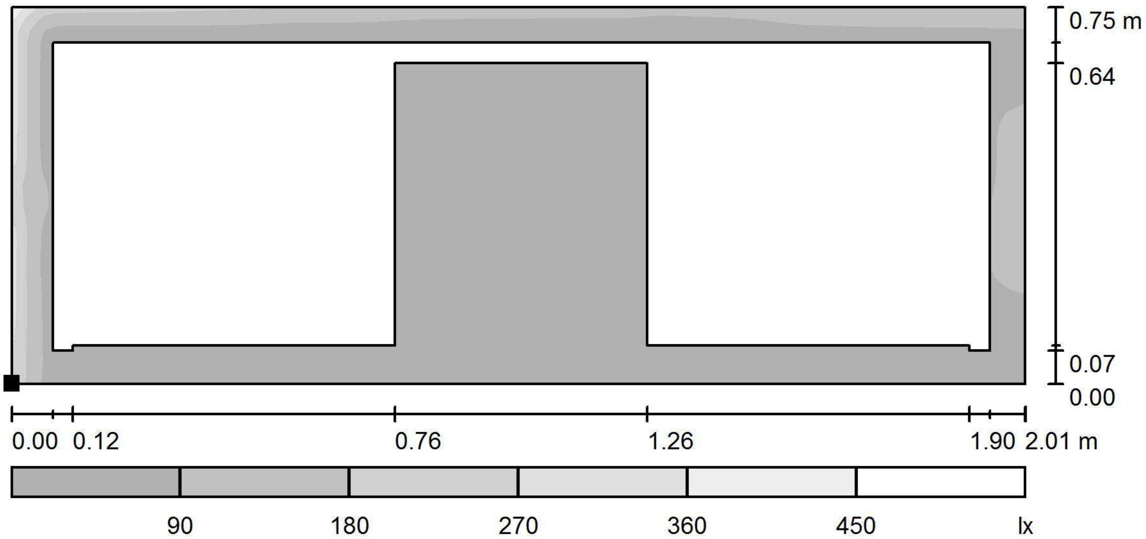


Grid: 64 x 32 Points

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

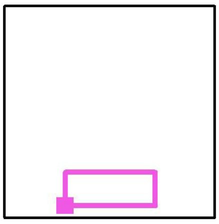
Operator
Telephone
Fax
e-Mail

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)

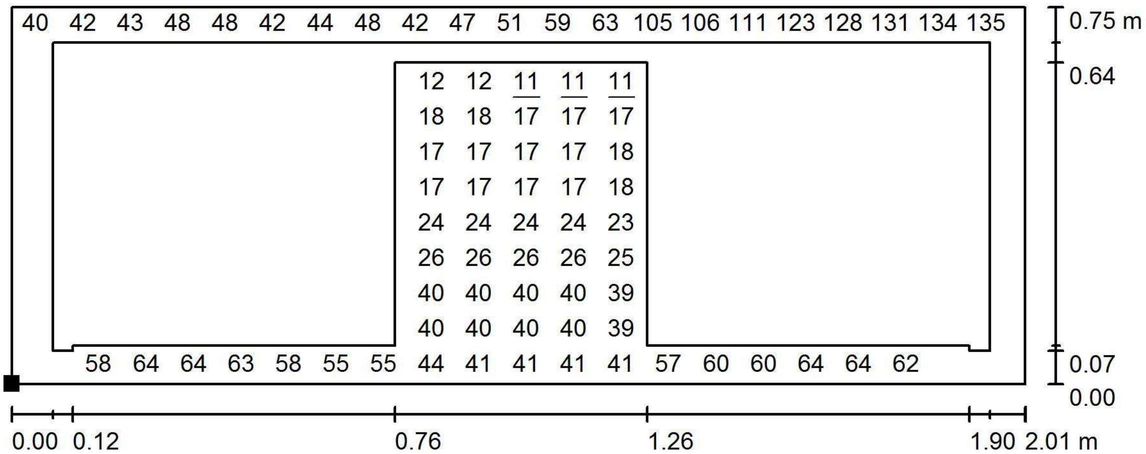


Grid: 64 x 32 Points

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

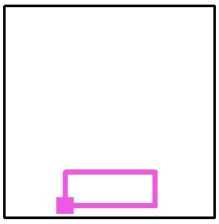
Typical Office / Work Desk / Value Chart (E, Perpendicular)



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