FEASIBILITY STUDY OF LOW VOLTAGE DIRECT CURRENT POWER DISTRIBUTION

PROGRESS REPORT SEMESTER 1

by
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Submitted for the degree of
Bachelor of Engineering &
Bachelor of Finance (IX28)

in the division of . . .

November & 2016.

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November 4, 2016

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 and footnotes, 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.

Past Queensland University of Technology engineering student **Steven Donohue** for his valuable prior thesis on 48 V direct current home power systems.

Geoffrey Woods and **Norman Higgins** from Queensland University of Technology's Building Management Services for providing technical drawings and electricity data.

Abhishek Bhasin and **Isaac Linett** from Q Electrical for their technical assistance and frequent questions.

Abstract

This design project aims to solve the issue of incorporating 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.

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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 an 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 VAC 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 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?

2.1 Initial Design Consideration

The research completed and discussions with Geoff 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 intial plan is to utilise analyse this application [9]. The cables being run would follow Australian building standards at 2 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 m^2 and 100 m^2 although further calculations are required to confirm this. An office space is approximately 9 m^2 requiring only 4 LEDs to provide necessary lux levels meaning the load for lighting should not exceed 40 watts and at 48 V DC that's only 0.83 A. With multiple rooms such as this, the design should be feasible with further simulations.

3 Background & Literature Review

3.1 Literature Review

3.1.1 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 [10]. Alternating current is run to outlets at 240 V AC, 50 Hz 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 [11].

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 [12]. 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 frequency of DC energy sources [12]. Utilising DC generation systems could also fulfil the power industry's obligation to increase the sustainability of their systems and be more environmentally conscious [13]. The required converters to change the AC supply into DC for electronics reduces the efficiency (increasing voltage drop) of the overall system [12].

3.1.2 Low Voltage Direct Current

DC power is currently restricted to special applications such as telecommunications, electric vehciles and high-voltage direct current (HVDC) transmission [14]. 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 [14]. 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 [14]. 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 [13].

3.1.3 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 [15]. This could be services such as telephony and internet access without the necessity of additional cabling [15]. Firstly, this voltage level is chosen due to it being marginally 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 [16]. Photovoltaic arrays, due to their DC source nature, could be used with a DC to DC boost converter and regulator to power these systems.

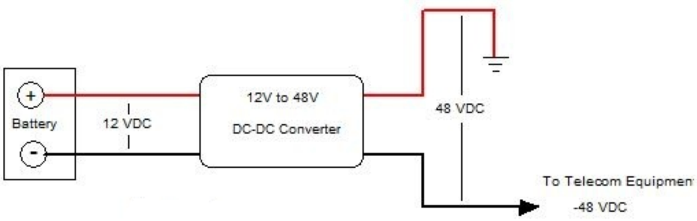

Figure 1: Single Battery Communications Room [1]

3.1.4 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 [17]. In order to transport electricity over large distances (excess of 2km) without severe losses, very high voltage and low current is used [17]. 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 [18]. These devices are placed through the circuit to protect the more expensive equipment closer to the transformer and grid.

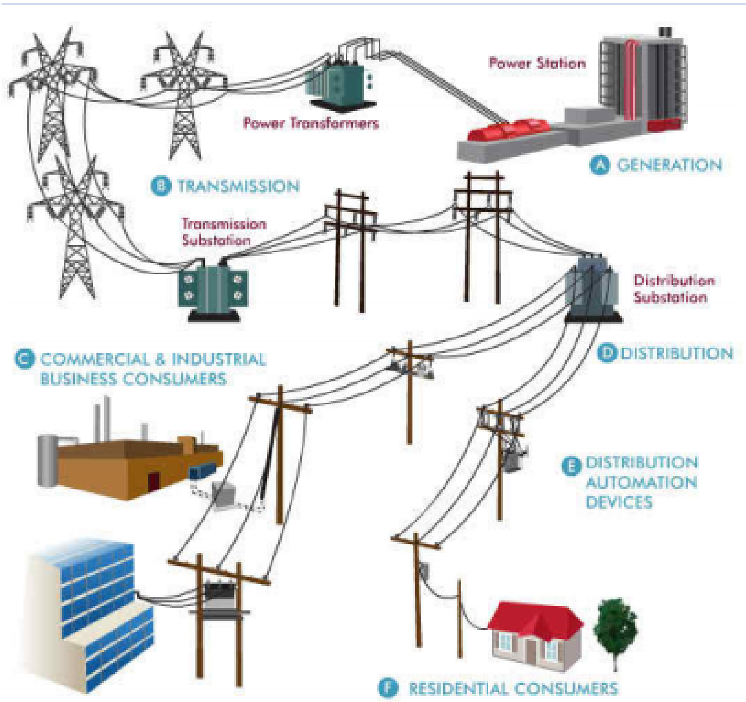

Figure 2: Existing Power Distribution Methods [2]

3.1.5 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 [19]. 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.

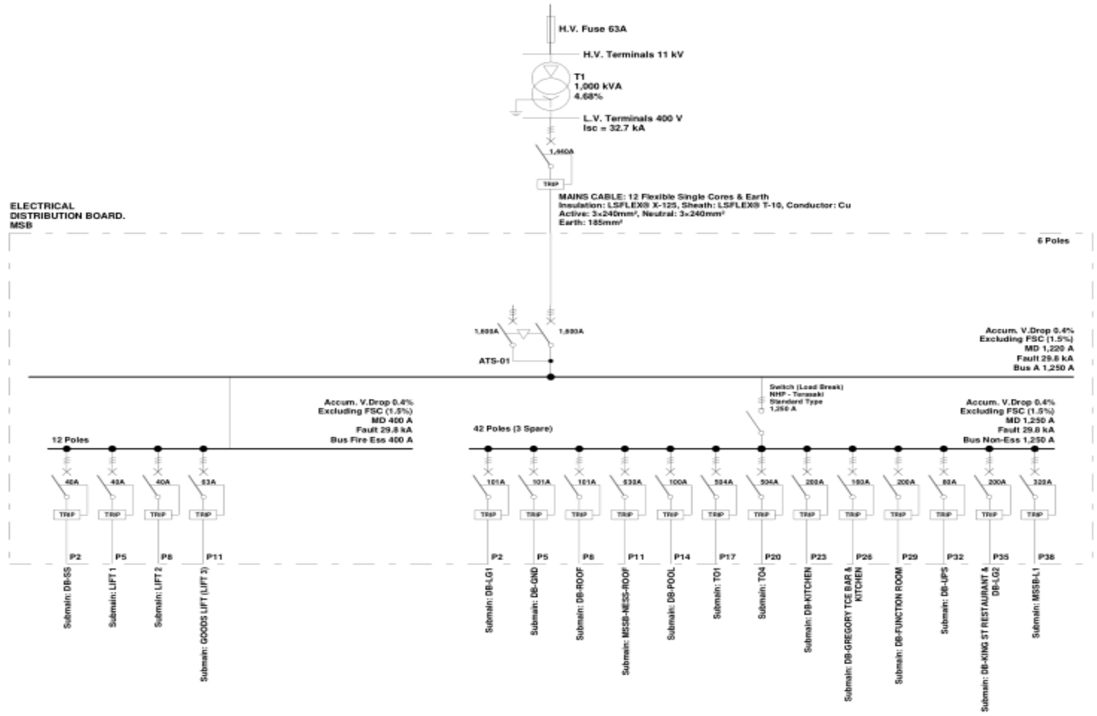

Figure 3: Hotel Single Line Diagram

3.1.6 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 [20]. 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.

3.1.7 Photo-Voltaic Arrays and DC Arcing

With the popularity of PV systems increasing, the risk of DC arc faults are being analysed further [21]. 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 [21]. 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 [22].

Photovoltaic generators are non-linear sources that vary with intensity of sunlight and behave mainly as a DC current source [16]. There is an additional negative of PV systems than AC due to the occurence of DC arc faults. The DC circuits that combine to form the PV power system distribution are able to generate and syustain arcs of considerable intensitives. DC arcs have their uses in applications such as welding, but for a power system they are only a risk [16]. The risks of DC arcs can be reduced by incorporating proper safety equipment and reducing DC voltage levels [16].

3.1.8 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 [18]. 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 [18]. A circuit breaker is a smarter and re-useable version of a fuse that is triggered by overcurrent, overloads or shirt circuits to fulfil the same purpose [18]. 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 [18].

3.1.9 Electrical Safety in Low Voltage DC

Fuses, mechanial 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 equpment [23]. Plugs, sockets and safety equipment with nominal currents of 20 A are commercially available for pre-existing DC data centres [23].

3.1.10 Converters

Converters are electrical devices designed and constructed to convert current between AC and DC [24]. Rectifiers are used to convert the voltage from AC to DC and inverters converter from DC to AC [24]. 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 [24].

3.1.11 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 [25]. 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 [25]. The panels generate electricity that is fed through a boost converter then into an inverter to change to AC in order to be distributed throughout the load for standard use [25].

3.1.12 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 [26]. 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 [27]. 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 [7]. 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 [28].

3.1.13 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 [29]. 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 [30]. 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 [31]. The consideration will be whether the cost reduction in electricity bill will be worth the investment in the equipment and future cost reduction.

3.1.14 LED Lighting

Table 1 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 LVDC grid powered LED lighitng system with additional automation aspects and energy storage [6]. Typical lighting systems are flurescent bulbs or tubes that are powered directly from standard 230 V AC due to the devices' high efficacy [6]. When comparing an AC flurescent system and a LVDC LED system, the LVDC gid system requires sigificantly less power conversion which increases the overall effiency [6]. The table below represents these factors. For applications, this means less physical lights are necessary for equivalent light reducing project costs [32].

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 1: Comparing Efficiencies of Lighting Types (Bulbs) [6]

3.2 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 papers.

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

Steven Donohue completed his undergraduate thesis under Geoffery Walker in 2014 [9]. 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 [9]. He proposed that an installation model for low voltage distribution was uneconomical with current solar feed-in tariffs [9]. 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.

3.2.2 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 [33]. 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 1.5 mm^2 and 2.5 mm^2 are impossible due to severe losses.

3.2.3 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 [34]. They can be created in a variety of ways with gas and diesel generators being popular but expensive [34]. 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 acccess 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

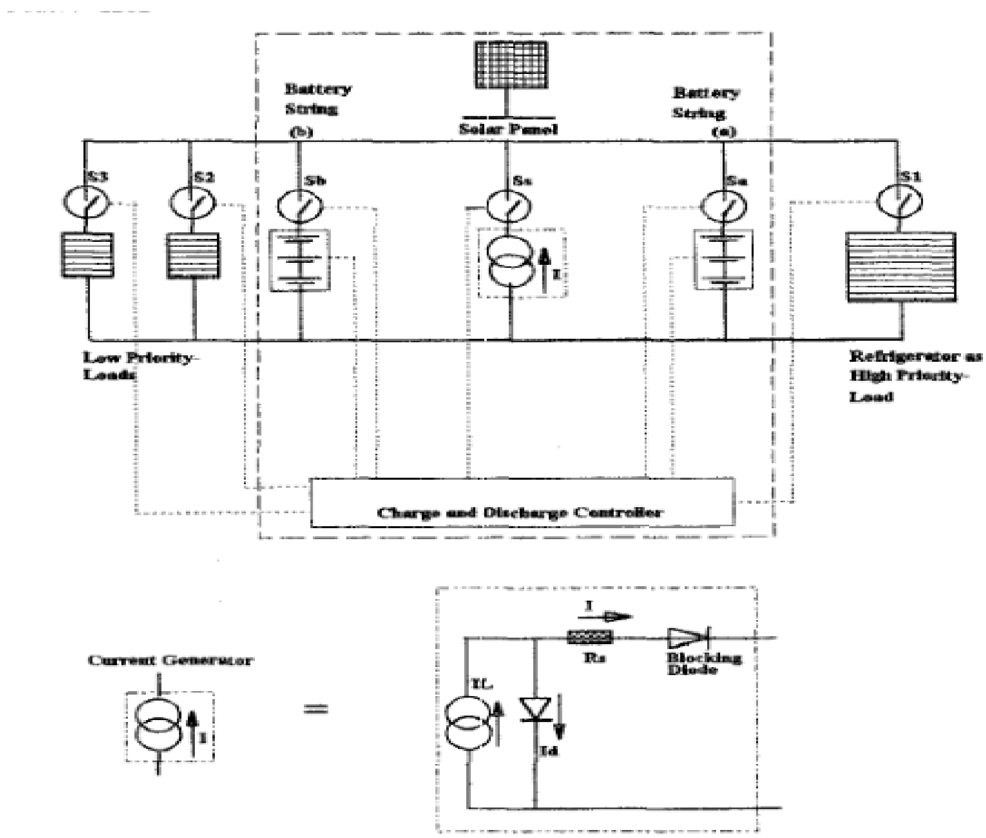

Figure 4: Block Diagram for Photovoltaic RAPS System [3]

3.2.4 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 400V DC distribution [4]. This application has 400 V DC cabinates 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.

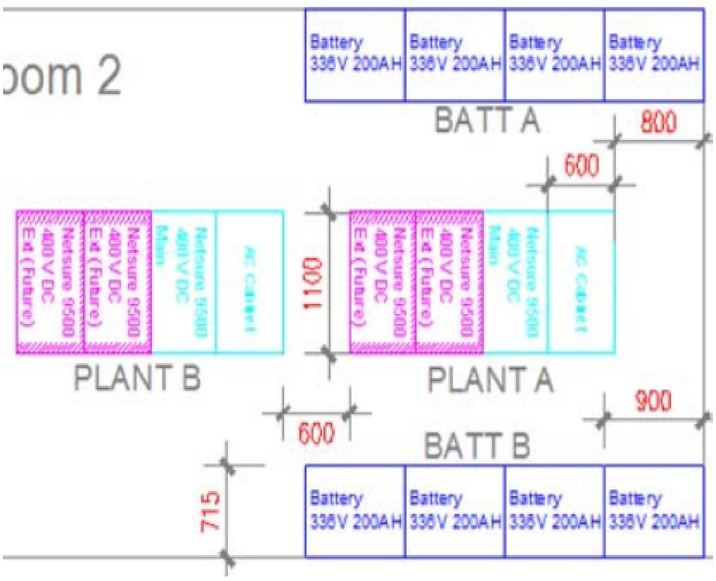

Figure 5: Floorplan of DC Backup Data Centre [4]

3.2.5 Emphase Micro-Inverters

A competitor to the system that will be designed throughout this thesis will be recent developments in micro-inverter technologies by Enphase [35]. 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 240V 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% [35].

4 Program and Design

4.1 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.

4.2 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 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 [17]. Although research of 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.

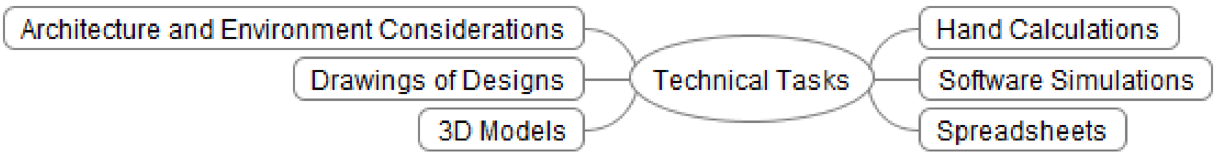

Figure 6: Considerations for a Technical Design Task

4.3 Research Plan

A majority of the project will completed through simulations and calculations utilising Matlab, PowerCad5, Dialux4.12, Microsoft Excel and Homer. 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.

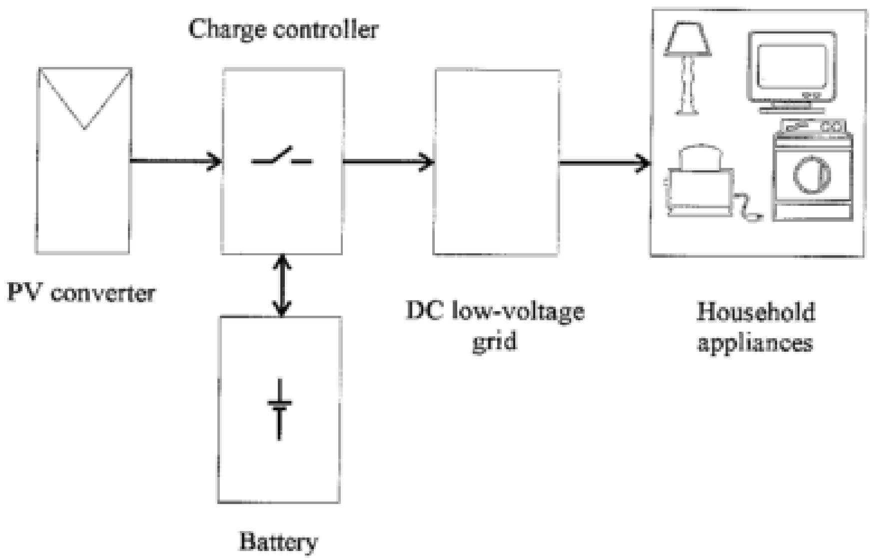

Figure 7: Initial Design Consideration for DC Home Power System [5]

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.

4.4 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.

4.5 Project Team

As previously stated, this project is being solely undertaken, however there are three students undertaking topics that are interrelated. In addition to my task focusing on low voltage DC systems in larger applications, the other two students are analysing sub issues in the same broad category. There will be discussions between the three students on relevant articles, journals and standards that each person finds.

5 Project Time line

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 myself already having installed free ones. Personal time will be the major difficulty as it will be balanced between other University classes, part-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 2 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.

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

5.1 Stage 1 Analysis of Timeline

This section outlines the initial analysis of the originally projected time line. Table 3 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.

Initial Project Timeline Analysis		
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 3: Initial Project Timeline Analysis

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 4: Revised Timeline for Milestones

6 Results 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.

6.1 QUT Electricity Consumption and Generation Data

To design a feasible commercial building incorporating low voltage DC electricity an approximate building size and layout was required. 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. Additionally, a computer login to the Electricity Management System (EMS) at QUT was created. This interface tracks all the electricity consumed from every meter on campus. 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.

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. It was not until Week 11 of Semester 1 that this data was made available leaving very little time before the presentation and final progress report.

6.2 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 5 m^2 represented in Figure 8. The purpose of this simulation was to analyse approximate lighting loads for the environment. Once the QUT data is analysed further, a more accurate floor plan will be created during the summer break as per the revised time line.

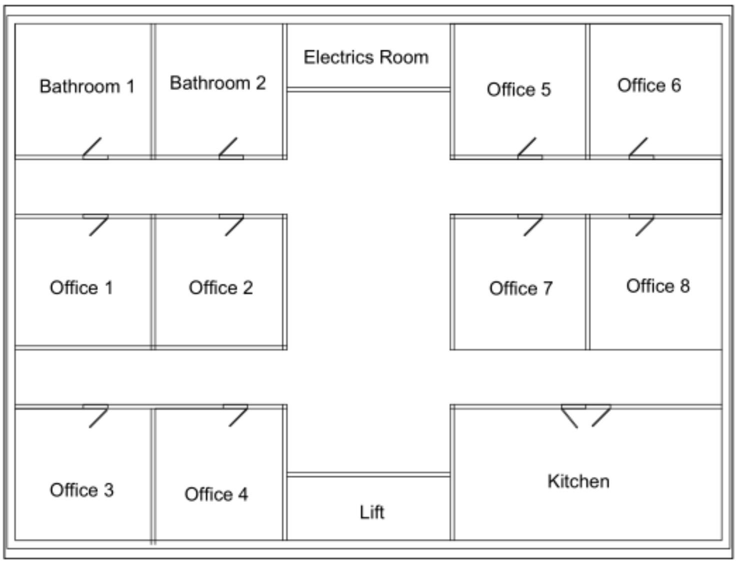

Figure 8: Temporary Office Floor Plan Design

6.2.1 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 5.

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

Table 5: Lighting Requirements as per AS/NZS Standards [7]

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 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 6 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 10.1 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 6: Dialux Outputs of Draft Floor Plan

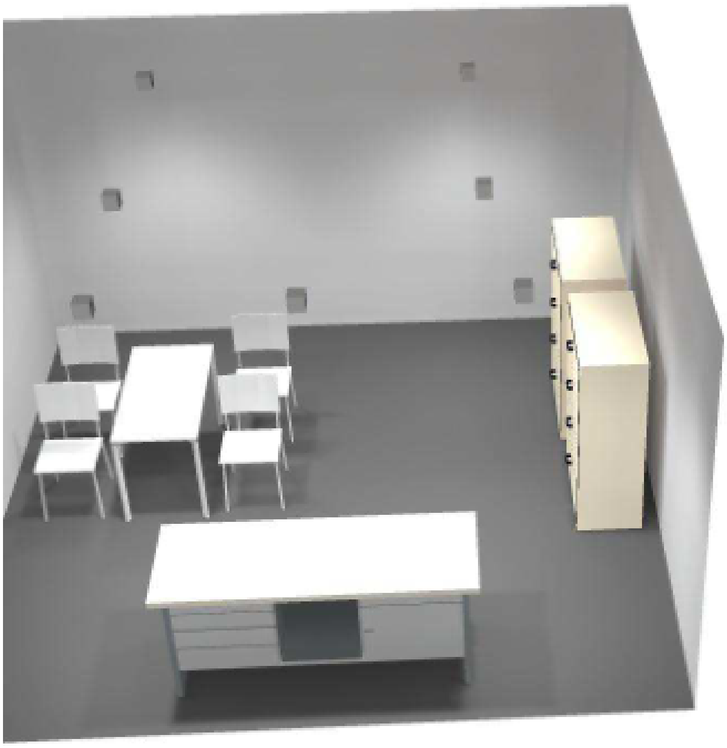

Figure 9: Draft Lighting Test 3D Render

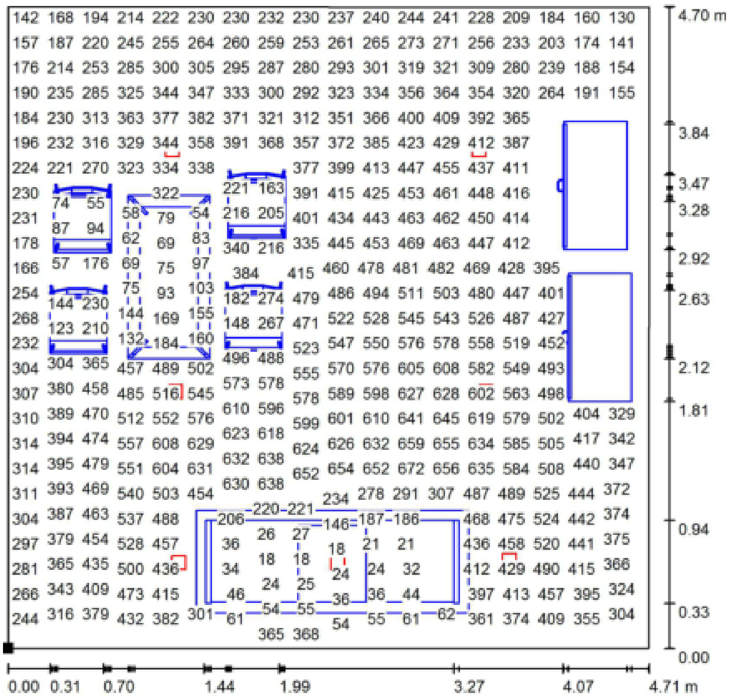

Figure 10: Draft Lighting Test Lux Output

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 Project Questions

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

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

To determine what voltage level would be optimal for the suggested distribution systems, research was enlisted over technical tests. The previous QUT student, 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 [9].

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 7 below shows the DC resistances from TriCAB cable suppliers [8] and Table 8 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 7: TriCAB Catalogue DC Resistance Cable [8]

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 8: 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 Future Work

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.

9 Conclusion

The project being undertaken plans to design and confirm the feasibility of a DC power distribution for commercial buildings to power low load electronics such as lighting and simple devices with 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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10 Appendices

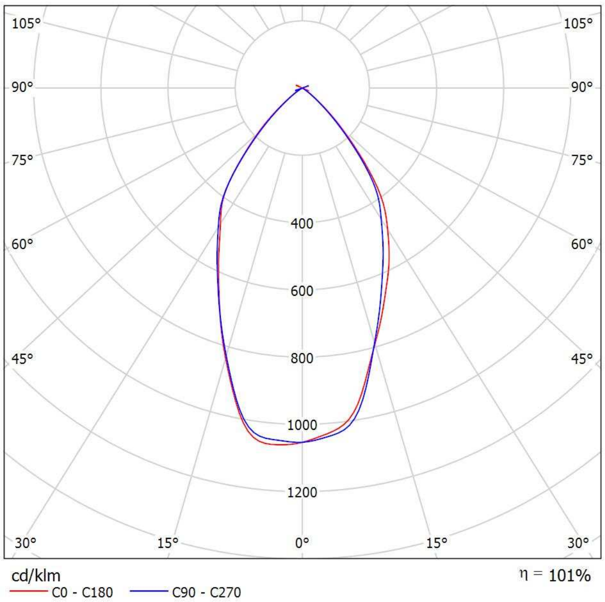
10.1 Draft Floor Plan Lighting Analysis Report

Operator
Telephone
Fax
e-Mail

onok 530 LED / Luminaire Data Sheet

Luminous emittance 1:

See our luminaire catalog for an image of the luminaire.

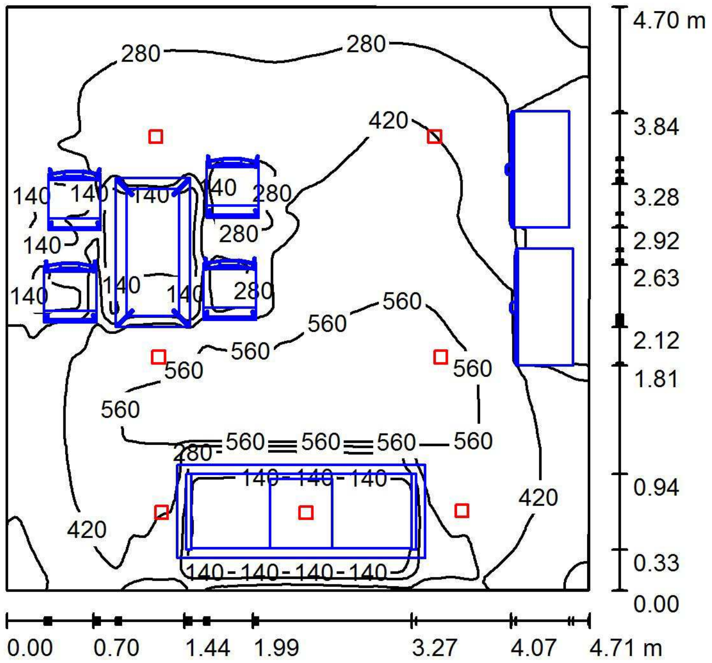


Luminaire classification according to CIE: 100
CIE flux code: 87 100 100 100 101

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.

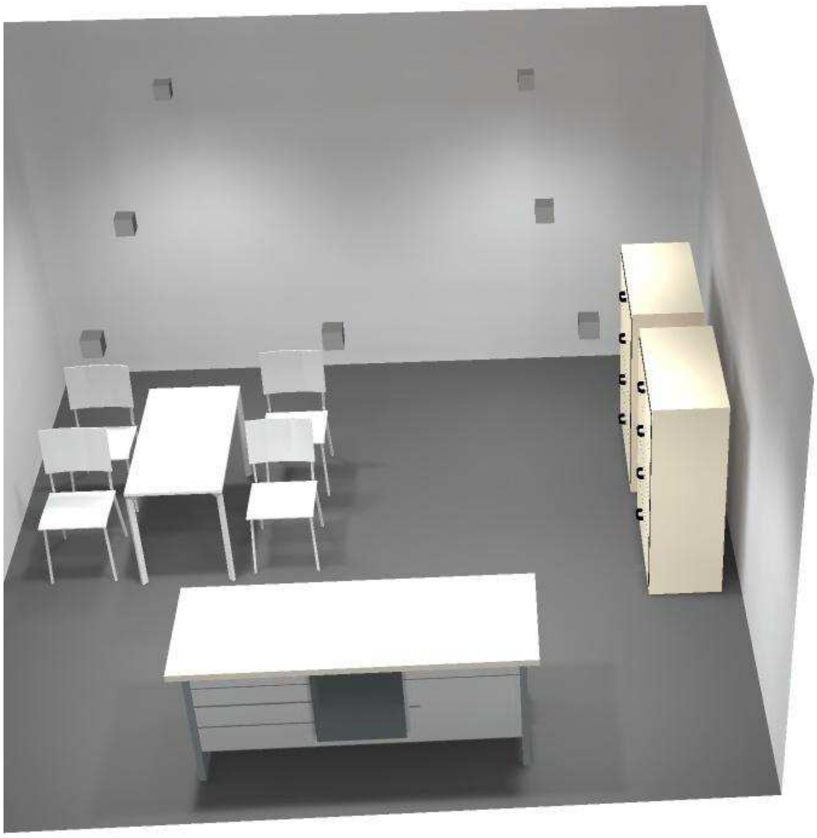
Luminaire Parts List

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)

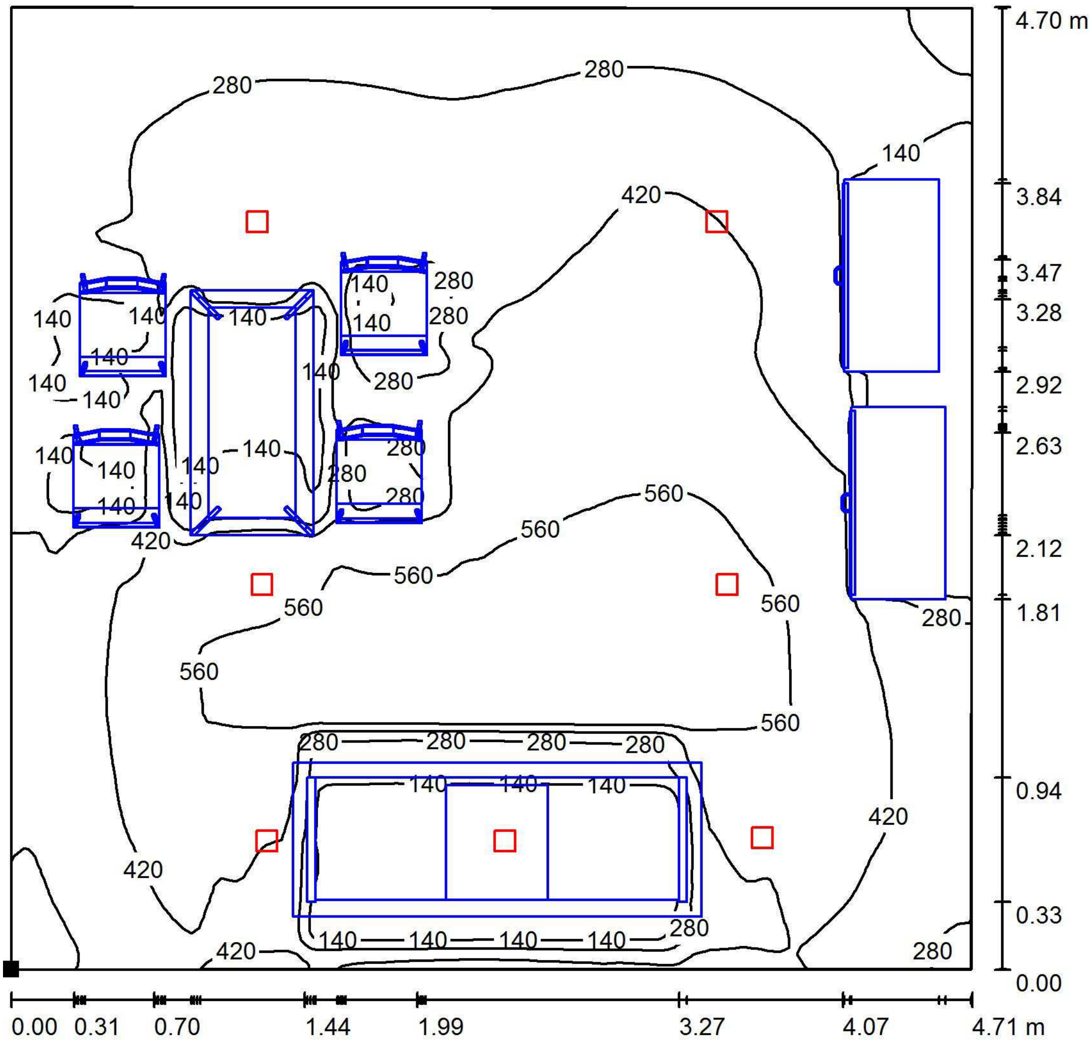
Operator
Telephone
Fax
e-Mail

Typical Office / 3D Rendering



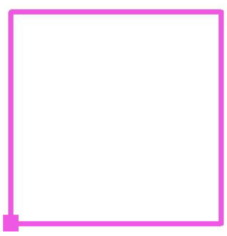
Operator
Telephone
Fax
e-Mail

Typical Office / Workplane / Isolines (E)



Values in Lux, Scale 1 : 37

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

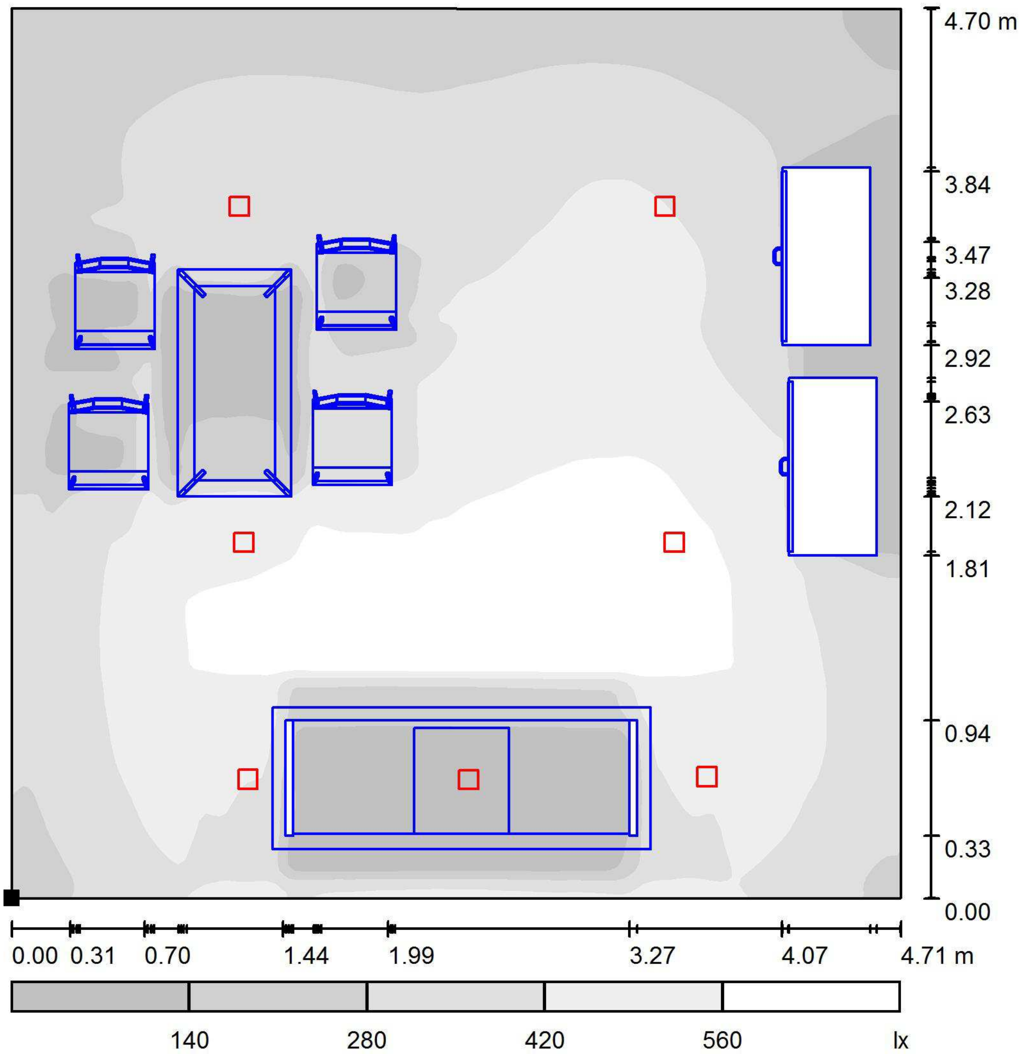


Grid: 128 x 128 Points

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

Operator
Telephone
Fax
e-Mail

Typical Office / Workplane / Greyscale (E)



Scale 1 : 40

Position of surface in room:
Marked point:
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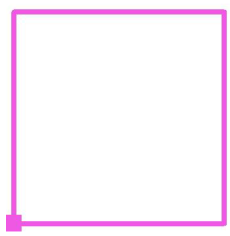
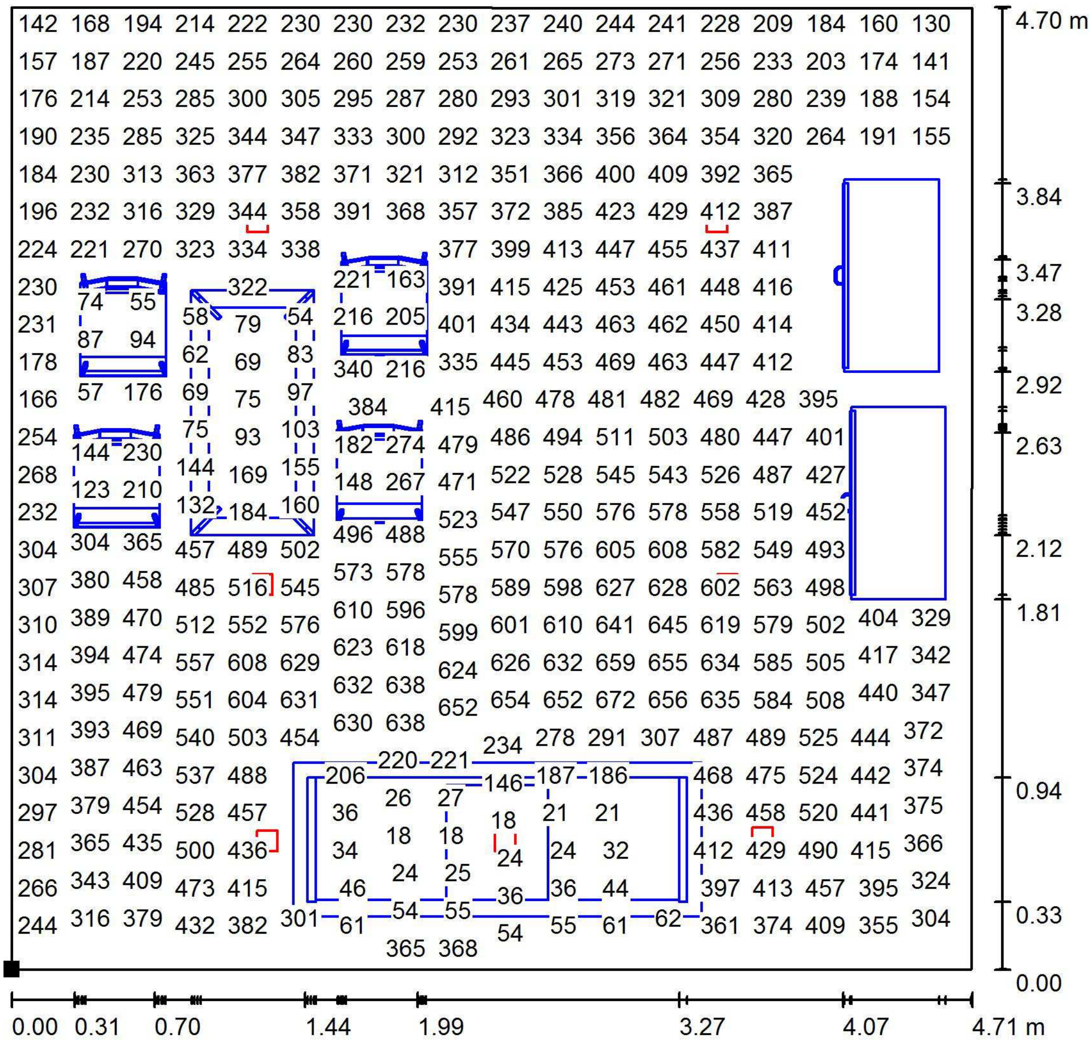


Grid: 128 x 128 Points

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

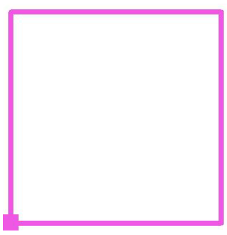
Typical Office / Workplane / Value Chart (E)



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)

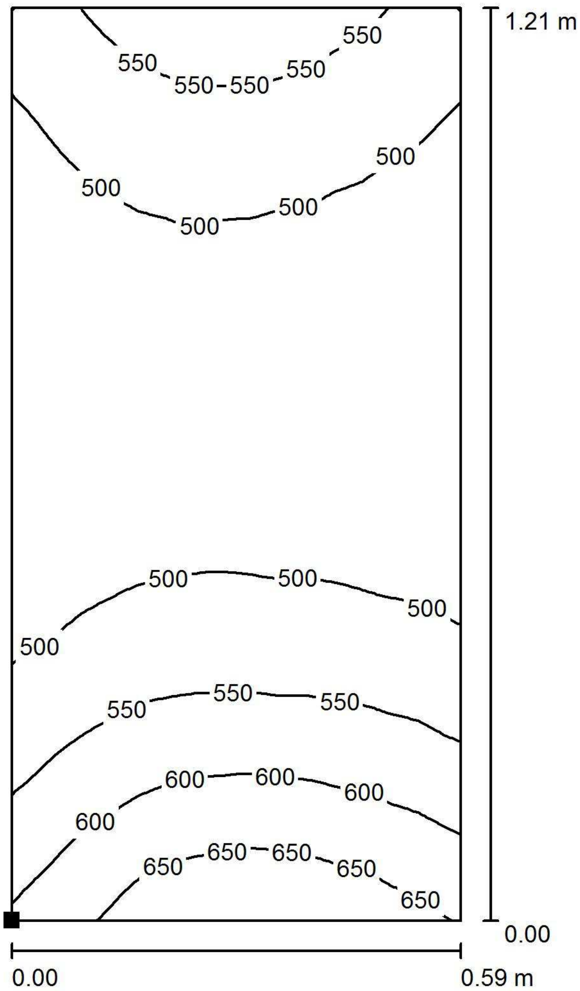


Grid: 128 x 128 Points

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:
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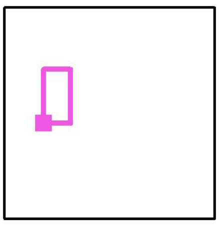
(6.338 m, 9.569 m, 0.760 m)

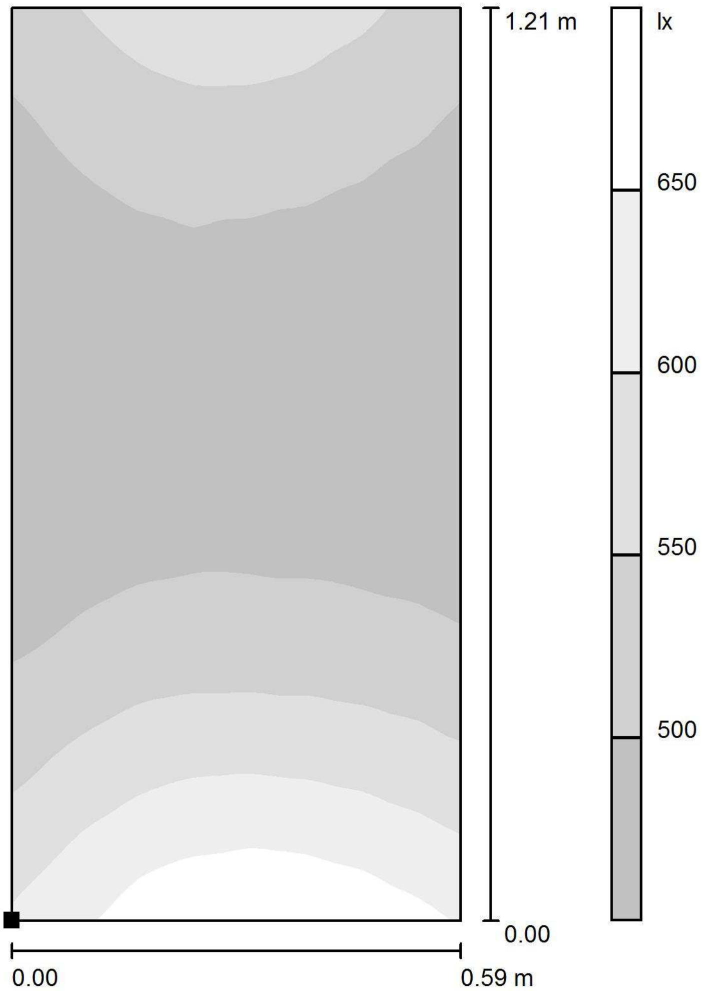


Grid: 32 x 64 Points

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

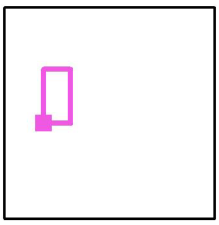
Operator
Telephone
Fax
e-Mail

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)

1.21 m

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

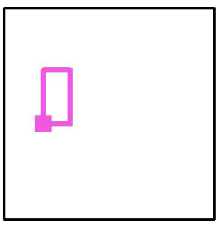
0.00

0.00 0.59 m

Values in Lux, Scale 1 : 10

Not all calculated values could be displayed.

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

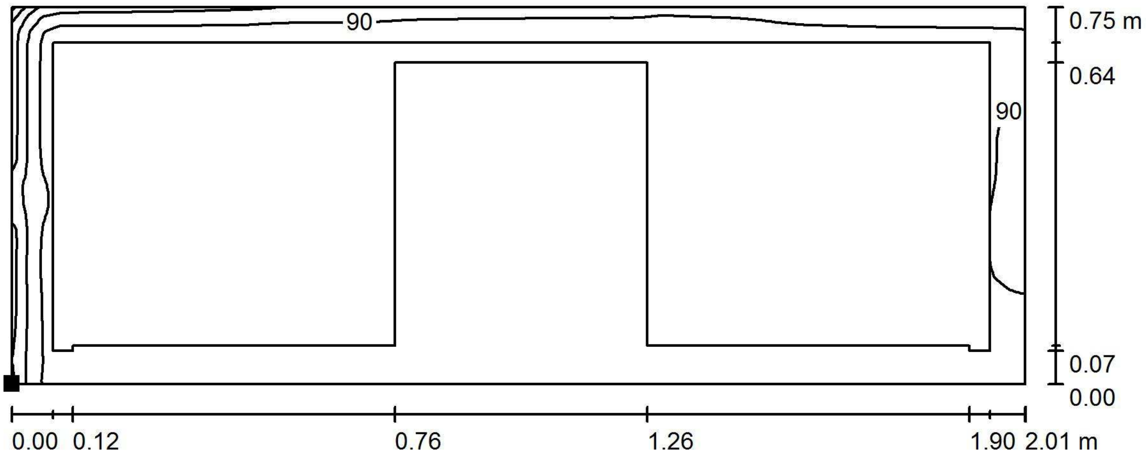


Grid: 32 x 64 Points

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

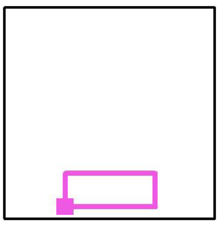
Operator
Telephone
Fax
e-Mail

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



Values in Lux, Scale 1 : 15

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

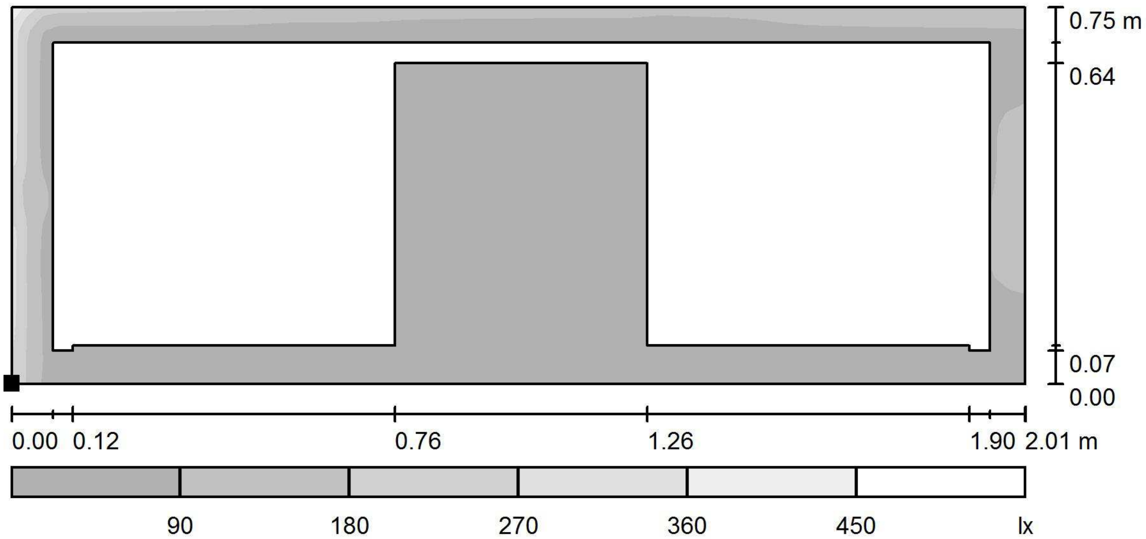


Grid: 64 x 32 Points

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

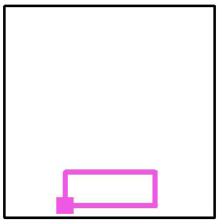
Operator
Telephone
Fax
e-Mail

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



Scale 1 : 15

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

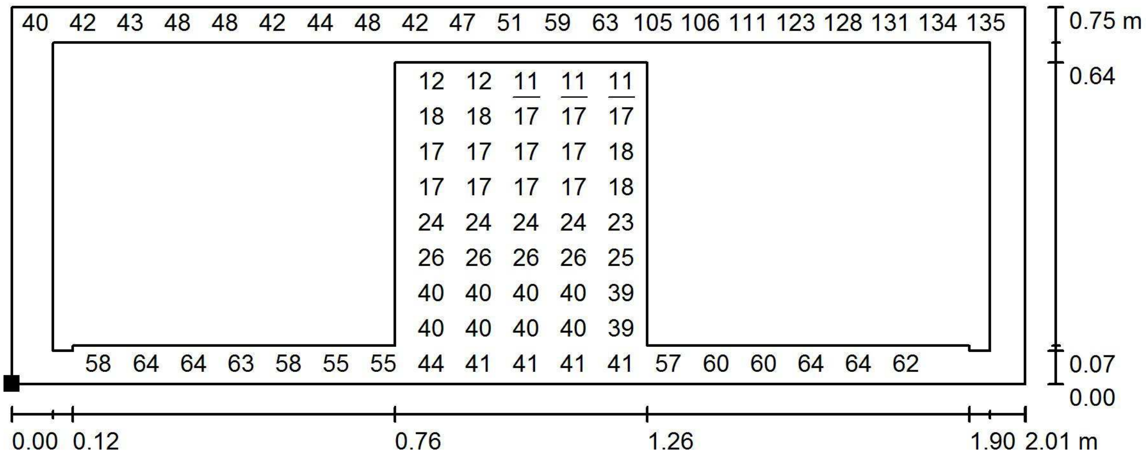


Grid: 64 x 32 Points

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

Operator
Telephone
Fax
e-Mail

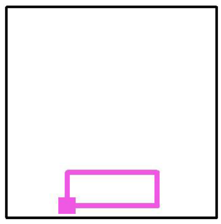
Typical Office / Work Desk / Value Chart (E, Perpendicular)



Values in Lux, Scale 1 : 15

Not all calculated values could be displayed.

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



Grid: 64 x 32 Points

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