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TOWARDS 2020: AN ENERGY-NEUTRAL COUNCIL WORKS DEPOT

A dissertation submitted by

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Towards 2020: An Energy-Neutral Council Works Depot

ABSTRACT

Energy efficiency is gaining momentum in local government authorities as cost benefits are realised and leadership within local communities is being exercised. New construction projects are prime candidates to incorporate well-engineered site-specific energy efficient solutions based on physical location and local climatic conditions. This research project proposes and substantiates solutions for energy and water efficiency at a new council works depot that consolidates three existing sites into one, due for construction by 2020.

Works depots support a large proportion of Council staff and operations, and consume a significant amount of energy. Energy neutrality will contribute towards local carbon reduction targets to minimise the impact on climate change, particularly the effects of sea level rise and more extreme weather events, which will socially and financially impact on local communities. The rapid progress of renewable energy and storage technologies allows evaluation and selection of site-specific technologies that will eliminate dependence on grid electricity.

An audit of historical energy consumption at the three existing sites provides half-hourly baseline data. Hourly, daily and annual variations are modelled and compared to historic climatic conditions. Modelling enables the evaluation of the availability of solar irradiation on surfaces of any tilt and azimuth, and is applied to all solar-dependent technologies. Concept site planning was undertaken to balance infrastructure requirements for depot operations, physical site constraints and energy generation and storage capacity.

Site and location constraints limit technologies suitable for implementation. However, the implementation of more efficient practices combined with a combination of solar PV panels, evacuated tube solar collectors, shallow geothermal HVAC loops and chemical storage provide sufficient resources for reliable energy sustainability. Only during extended periods of cloud cover would grid electricity be required. Variability in site

demands largely follows the availability of renewable energy resources, making the energy neutral depot a financially feasible reality.

The rapid development of energy generation and storage technologies – efficiency improvements, new technologies and cost reductions – compel the engineer to review the proposal during design phases of the construction project, and incorporate technologies that will supersede those recommended in this report.

Energy neutrality at a multi-faceted council works depot is a financially feasible reality in 2016. By construction in 2020, enhancements in technology will provide greater reliability and further cost savings that will likely result in a more financially feasible result than that presented herein.

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Signature

6 October 2016

Date

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ABBREVIATIONS

AC   -   Alternating Current

BIPV   -   Building Integrated Photovoltaic

BMS   -   Building Management System

CSP   -   Concentrating Solar Power

CSP   -   Concentrating Solar Power

DC   -   Direct Current

ETSC   -   Evacuated Tube Solar Collector

GHG   -   Green House Gas

GSHP   -   Ground Source Heat Pump

HVAC   -   Heating, ventilation and cooling

kWh   -   Kilowatt-hour

MWh   -   Megawatt-hour

PV   -   Photovoltaic

CHAPTER 1 – INTRODUCTION

1.1.Introduction

Climate change presents a significant challenge to today's global community. With far reaching effects including longer and more severe droughts, higher intensity extreme weather events, sea level rise and reductions in viable agricultural land, climate change is predicted to have major health, social and economic impacts on the world. The significance of the issue is highlighted by 195 of the world's leaders gathering in December 2015 and committing to a global climate deal, now known as *The Paris Agreement*, which is due to be forced in 2020. The deal aims to limit global temperature rise to $2^{\circ}C$ above pre-industrial levels, acknowledging scientific modelling that indicates any further temperature rises will lead to irreparable environmental damage and catastrophic events throughout the world.

Climate change is widely accepted to be largely caused by human activity, predominantly by activities that add greenhouse gases (GHG) to the atmosphere. These gases absorb heat energy from the sun and prevent heat dissipation from the atmosphere into space. Higher concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) increase the amount of heat retained within the atmosphere which results in higher temperatures at land and sea level. The burning of fossil fuels, reductions in vegetation and deforestation, and increasing agricultural practices are the main contributors to greenhouse gas levels. As such, mechanisms to avoid, offset or limit emissions from such practices are required if the world is to achieve the targets set in The Paris Agreement.

A collaborative approach is required across all levels of government, the business community and individuals if Australia is to meet its obligations. This includes the acceptance of climate change as a reality, acceptance that activities at the micro-level will make a difference to the global environment, development of policies to support proactive measures to reduce climate change, and implementation of new practices and infrastructure that support sustainability. A shift in the mindset of many individuals and leaders is required to effect real change. Installing a solar panel may seem insignificant compared to the billowing smoke stack; however, action is required in all industries so that new climate-sustainable practices become standard practice.

1.2.Background

1.2.1. Strategic Context

The development of new initiatives is often identified in strategies and plans that provide a vision for the future. Sustainable building practices are not a new concept, however, governmental policy and emphasis on the reduction of GHG emissions is providing a surge in the development of technologies and the number of organisations implementing such initiatives. Government funding is also made available to eligible entities to install energy saving devices. As such, understanding the strategic context of constructing a completely energy and water sustainable council works depot is important, to determine the feasibility of the project and identify the financial and non-financial value of the project which assists in garnering support for the venture.

Climate change is a topic of global significance and therefore strategies for action have been developed from international through to the local level. This does not incorporate every strategy on the topic, however, a brief overview of the overarching strategies at each level is provided below to establish sufficient context for this project.

International

The Paris Agreement was reached at the 21st annual Conference of Parties in December 2015, in which 195 countries adopted a climate change deal to limit global temperature increase to $2^{o}C$ and have climate-neutrality by 2100. The Agreement provides flexibility for each country to determine its own mechanisms to achieve that outcome, to best respond to the industries and economies of that country. The Agreement also requires each country to publicly report its progress towards achieving the target. The Australian Government is bound by the agreement and is required to take action to meet international expectations.

Federal

The specific mechanism/s by which the Australian Government addresses climate change is subject to the policy of the government in power. There has been much debate between political parties in recent years as to what actions will be most effective at reducing Australia's emissions. The current *Direct Action Plan* targets a reduction of 5% in GHG emissions below those of year 2000 by 2020 and the *Clean Energy Act 2011* (Cth)

mandates an 80% reduction of 2000 levels by 2050 (Climate Change Authority 2012). This is largely to be achieved through an Emissions Reduction Fund, which offers incentives for local governments and industries to implement any number of actions that are proven to reduce GHG emissions. A Clean Energy Innovation Fund is also currently available to assist in the commercialisation of emerging technologies that are in the research and development stage. These two strategies are particularly important to this project, as offset funding or credits would be available to assist in the development of a sustainable works depot, and the emergence of new technologies is likely to occur between the current planning and future construction. More efficient outcomes are likely to be available and should be considered at that time.

State

The Queensland Government establishes the development framework for local governments to accommodate anticipated population growth across the state by the State Infrastructure Plan 2016 (Department of Industry, Local Government and Planning 2016). Two priority areas support the development of energy and water sustainable infrastructure:

1. Improving sustainability and resilience – infrastructure is resilient and adaptive to climate change and contributes to reductions in GHG; and

2. Adapt to new technologies in the energy sector – the electricity sector will be transformed over the next 20 years in response to a range of renewable energy generation and storage capabilities (Queensland Government, 2016).

The current project aims to adopt both priority areas and may be used by the Queensland Government as a demonstration case study for state-wide modelling.

Local

Several documents have been endorsed by Moreton Bay Regional Council to support the project identified in this project. The Moreton Bay Regional Council Planning Scheme was adopted in 2015, which incorporates the effects of climate change into development codes, including the IPCC's expected sea level rise of 0.8m by year 2100. Council's Climate Change Roadmap (Moreton Bay Regional Council 2013) stipulates that infrastructure projects with a lifespan greater than 20 years must integrate sustainability measures, be resilient to extreme weather events and minimise operational costs. A Climate Change Policy (2010) requires working in partnership with stakeholders to

reduce infrastructure vulnerability to weather-related risk, manage the carbon footprint including GHG production management and to capitalise on opportunities to improve climate change mitigation and adaptation. In 2016/17, Council will strengthen its policy position on climate change through the development of a specific energy and water efficiency strategy. These documents support the investigation into the development of fully energy and water sustainable works depot. Council's financial investment into the future development will be significant and therefore requires life cycle feasibility analysis to assist in budgetary decision making.

1.2.2. Local Effects of Climate Change

Moreton Bay Regional Council is the third largest local government authority by population in Australia, being located immediately north of Brisbane City and to the immediate south of the Sunshine Coast. An estimated 442,565 people reside in the region in 2016, which is modelled to expand to 622,276 by 2036 or 1.9% growth per annum (Queensland Government Statistician's Office 2016). The Queensland Government's State Infrastructure Plan identifies the region as a key growth corridor in accommodating the State's population influx, indicating sustained growth and additional impacts on resources over the next 20 years.

The region encompasses 2,037 square kilometres of diverse environments, including island and bayside communities, low and medium density urban environments, rural and farming communities, and mountainous forest parks. A report commissioned by Moreton Bay Regional Council in 2009 identified primary, secondary and tertiary risks to the region as a result of anticipated climate change. Whilst the region is expected to feel the effects of climate change that are common globally - such as more frequent extreme weather events, higher temperatures and drier conditions - the location and natural features of the region particularly predispose it to be most affected by a rising sea level, increased frequency and severity of flood events, an increased chance of cyclones and increased bushfire risk.

Current mapping identifies that 321.3 square kilometres or 15.8% of the region is affected by flooding in a 1 in 100 year (Q100) flood event. A further 97.5km^2 is affected by storm tide, totally 338.0km^2 during a combined severe weather event. Taking into account the effects of the currently-accepted 0.8m sea level rise associated with climate change by the

year 2100, modelling predicts a total of 378.6km^2, or 12.0% increase in area, will be inundated during a combined 1 in 100 year flood and storm tide event. Much of today's flooding is limited to open space; however, future events are anticipated to affect residential areas where previous planning permitted construction. Some coastal communities with medium density housing will be flooded in their entirety. The scale of devastation and cost of infrastructure recovery will be significantly greater than any events experienced to date. Similarly, the exposure to cyclones will have far-reaching implications, with existing buildings not constructed at a rating to withstand such events and therefore exposed to significant loss, insurance premiums expected to rise to accommodate the additional risk, and changes required for planning policies and building codes to ensure future buildings are located appropriately and constructed to higher standards and are more cost-effective for quick repair (Climate Risk Pty Ltd 2009).

The social cohesion, sense of community and support of local economies are important considerations for all local governments. The effects of climate-related events will have ripple effects throughout all aspects of life. Moreton Bay Regional Council has, through its new Planning Scheme, Climate Change Policy and continuing climate-related studies, committed to limiting the local effects of climate change and providing frameworks that will promote swift recovery to business and community life should an extreme weather event occur.

1.3. Project Aim

This project aims to develop a fully energy and water sustainable council works depot. As a visible leader to local commercial enterprises and the broader community, local governments have the opportunity to showcase best practice and influence change across many sectors. Moreton Bay Regional Council, as the third largest council by population in Australia, has various operations that can improve towards greater sustainability and a large number of constituents to which the activities can be promoted and encouraged. One of the council's largest energy-consuming areas is the Works Depot, which accommodates a high proportion of the operational workforce in the parks, roads, building and fleet maintenance departments. To streamline efficiencies, there is an opportunity to consolidate three existing works depots into a single depot at a new location within three to five years. As a major new facility, Council has determined its desire to lead local industry by developing a completely energy and water sustainable

facility, and publicly demonstrate mechanisms to reduce greenhouse gas emissions, which has both cost-saving and environmental implications.

1.4. Project Objectives

The purpose of this dissertation is to conceptually plan the new consolidated works depot by providing the facility layout, and nominating a range of site-suitable energy and water saving initiatives that require incorporation into future designs. Recommendations are to be produced on the basis of sound engineering and financial feasibility assessment utilising recorded local climate conditions and expected site usage patterns.

Specifically, the objectives are to:

a) Prepare a concept plan for the layout of a new consolidated Works Depot, with placement of buildings to support energy and water efficiency practices and outcomes;

b) Provide justification for the implementation of a suite of energy producing, energy efficient and water efficient technologies as part of the construction of the new facility; and

c) Implement sufficient technologies to provide a completely energy-efficient and water-sustainable site when in operation.

1.5. Implications of Project

Climate change action begins at an individual site level. The targets for emissions reductions, as set by governments and the international community, are achievable through synergistic action of individuals, corporations and governments. As a local government authority responsible for approximately 400,000 residents or approximately 1.7% of the Australian population, Moreton Bay Regional Council recognises its role in implementing measures that prevent further climate change. The future capital works program provides a sound opportunity to incorporate new measures as standard practice.

A project to consolidate three existing works depots into a single operation at a new site is currently under investigation within a three-year horizon. Due to the functions undertaken at depots and the high staffing levels, depots are amongst the highest water and energy consumers across all council facilities, alongside administration centres and aquatic centres. Council can achieve significant emissions reductions and water savings by focussing action within these facility classes. Starting with one site - the focus of this paper - is in line with this "tackling the big fish first" approach. This project is based on a greenfield development, whereby the facilities can be planned and constructed as required to achieve the outcomes of this report. The limitations of retrofitting existing facilities do not exist; therefore, this project has the capacity to set the scene for future developments.

The successful implementation of energy and water saving initiatives at an individual prominent site can achieve results well beyond its physical footprint. The project can:
   a) Provide immediate emissions reductions;
   b) Reduce the ongoing operational financial costs to water and power suppliers;
   c) Install equipment and infrastructure that have reduced maintenance and cost requirements compared to traditional counterparts;
   d) Provide impetus for the new practices to filter through other capital works projects;
   e) Enhance the knowledge and experience of local suppliers and tradespeople, which can result in the filtration of ideas and suggestions to other customers throughout the community; and
   f) Provide an opportunity to showcase energy and water efficiency technologies to the business and residential community, acknowledgement of council's leadership towards sustainability, and encourage others to implement similar practices.

Action starts at one site. A positive experience, demonstrated functionality and success of the installed technologies, and sound financial outcomes will reinforce the decision to implement the measures for a sustainable site, and encourage further investment in water and energy efficient technologies in future council projects.

Furthermore, the outcomes of this dissertation may be replicated or used as a foundation by any of the other 571 local governments in Australia, or other entity looking to establish similar facilities.

CHAPTER 2 – LITERATURE REVIEW

2.1. Introduction

Developing engineered solutions to problem requires an appreciation and understanding of the existing conditions and scientific research which has been undertaken in the field of concern. This section reviews a range of research studies, industry standards and other publications that provide the current state of affairs in relation to water and energy sustainability. Three aspects of energy sustainability are considered – generation, storage and energy use minimisation. Three aspects relating to water sustainability are also reviewed – water capture and storage, use minimisation and re-use or recycling water.

2.2. Energy Generation Technologies

Renewable means of power have been used as far back as the first century when the wind wheel was used to undertake work. These early mechanisms however, used natural resources to directly undertake work rather than generate electricity. Opportunities for direct usage of work at point of generation are limited in an urban council works depot. The majority of energy demand is from electrical appliances and equipment that require 240V 50Hz electricity as either a 1-phase or 3-phase supply.

Multiple and varied technologies exist - and continue to be advanced – that generate electricity from renewable resources. This section details the most common options available at this point in time, including the most suitable applications for use, to assist in future feasibility assessment for the subject site of this report. Section 2.3 will detail options for the storage of the generated electricity.

Renewable energy technologies can be broadly classified by the primary fuel resource, as described in Table 1. Each of the technologies is described further herein.

Table 1. Categorisation of Renewable Energy Technologies

Category	Sub-Category	Technology
Solar	Thermal Radiation	Solar Photovoltaic (PV) Cells
		Building-Integrated Photovoltaics
		Concentrating Solar Power
		Evacuated Tube Solar Collectors
		Solar Air Conditioning
		Ocean Thermal Energy Conversion
	Wind	Wind Turbines
	Wave	Wave Power
	Hydro	Hydro Power
	Biofuels	Biomass and biofuels
Gravitational	Tidal	Tidal Turbines
Geothermal	-	Geothermal

2.3.1. Solar Photovoltaic (PV) Cells

Solar photovoltaic (PV) cells (collectively arranged on a 'solar panel') are the most common renewable energy technology being implemented at the individual site level, with 1.42 million small-scale systems having been installed across Australia by the end of 2014 (Clean Energy Council 2016). The accumulation of installations accounts for 15.3% of the total renewable energy production within Australia but only 2.1% of the country's total energy production (Clean Energy Council 2016).

Photovoltaic cells are comprised of semi-conducting materials, most commonly silicon with boron or phosphorus, which converts sunlight into direct current (DC) electricity. The PV cell material absorbs energy from the photons in sunlight to excite electrons in the valence band of the material's atoms and, due to the manufactured arrangement of the material; the free electrons are only able to move in a single direction, thus creating the direct current. As the intensity of sunlight (i.e. irradiation) increases, more photons are striking the PV cell to excite a higher number of atoms within the material. Consequently, solar panels generate much higher electrical outputs during summer months when solar irradiance is high compared to winter months.

Australian locations, particularly in the north, have significant solar energy potential. The Australian Bureau of Meteorology (2016) report Brisbane's average solar global insolation to vary between a low of 3.3kWh/m^2/day in June to a peak of 6.8kWh/m^2/day in January. Annual mean sunshine duration in Brisbane is between 8-10h/day, 126 days/year feature full sunshine and a further 135 days/year have no more than 75% cloud cover between 9am and 3pm. Actual data collected account for these variations in cloud cover. The annual mean daily solar global insolation falling on a horizontal surface in Brisbane is recorded as 5.3kWh/m^2/day. Every square metre receives 1935kWh (or 6972MJ) of solar radiation per annum (Bureau of Meteorology 2016).

Temperature also affects the output performance of PV cells, as a result of the material properties of the semi-conductor. The band gap of the material's atoms reduces with an increase in temperature, effectively reducing the voltage of the cell. The reduction in voltage associated with higher temperatures is generally larger than the increase in current and, since power is a linear function of current and voltage, the output power decreases with an increase in temperature above the recommended product's rated operating temperature. Silicone-based PV cells have a reduced performance of approximately -0.4 to -0.5% per degree Celsius (PV Education 2014).

The large majority of solar panels are currently manufactured using silicone in either monocrystalline or polycrystalline form. Whilst monocrystalline panels generally convert solar irradiance to electricity at a higher efficiency compared to polycrystalline panels, they are more susceptible to temperature-affected performance reductions. Efficiencies with today's commercial products commonly range from 15-18% at the nominal operating temperature, however, a strong global focus on research and development to gain competitive edge has produced prototype silicone-based panels with efficiencies of up to 21.5% (NREL 2016). A range of second-generation panels called thin-film solar cells are emerging, being produced from alternative semi-conductors such as cadmium telluride or copper indium gallium deselenide. Conversion efficiencies are reported up to 21% however are generally much lower than traditional PV cells. The advancement on the traditional PV panels comes in the form of large reductions in thickness, weight and greenhouse gas emissions during production, with a low payback period of up to only 1.4 years (Solterra Renewable Technologies 2016).

A complete solar system, comprising of solar panels, installation brackets, DC-to-AC inverter and wiring, is required for full system functionality. The rated output capacity of the system requires detailed investigation to match the electricity offset expectations of

the owner and the electricity consumption pattern. Commercial suppliers of small-scale solar panel installations offer computerised but generic methodologies to determine the sizing of systems for buyers. Thorough evaluation by a suitably qualified engineer provides a more accurate and site-specific outcome, particularly for larger systems and where facilities are yet to be constructed, and can therefore be appropriately located and oriented with the system performance taken into account.

Traditional installations of small-scale solar panels are fixed to the roof of the applicable building/s which restricts its full generating capacity. Installations of this nature are inexpensive, however, may be unable to achieve ideal orientation and tilt of the panels for year-round maximum performance. The variation of the sun's path throughout the year challenges the installer for the ideal positioning. Total output for one year is maximised when a fixed-tilt solar panel is installed at an angle equal to the location's latitude, as this matches the sun's angle on the equinox and therefore greatest average exposure across the year. On a clear sunny day, approximately 90% of the total solar energy falling on a fixed-tilt panel installed at this angle is from direct irradiation, with the remaining approximate 10% from diffuse or scattered light (Kelly and Gibson, 2009). One- or two-axis tracking systems maximise the direct solar irradiance on the panels from sunrise to sunset by actively rotating the panels according to the location of the sun, and being spaced sufficiently to minimise shading on successive panels. An increase in solar energy capture of 30% to 50% is commonly recorded for two-axis tracking systems compared to fixed tilt panel of identical size during clear conditions (Roth et al 2004 and Kacira et al 2004) but electronic hardware and brackets associated with the tracking significantly increase the initial capital cost, particularly for small-scale installations. Abdallah and Nijmeh (2004) demonstrated the gains in solar radiation falling on a panel achievable by utilising an actively controlled two-axis tracking system, as demonstrated in Figure 1. The highest gains are achieved early morning and late afternoon, which enables greater renewable energy contribution towards energy demands on the extremities of daylight hours.
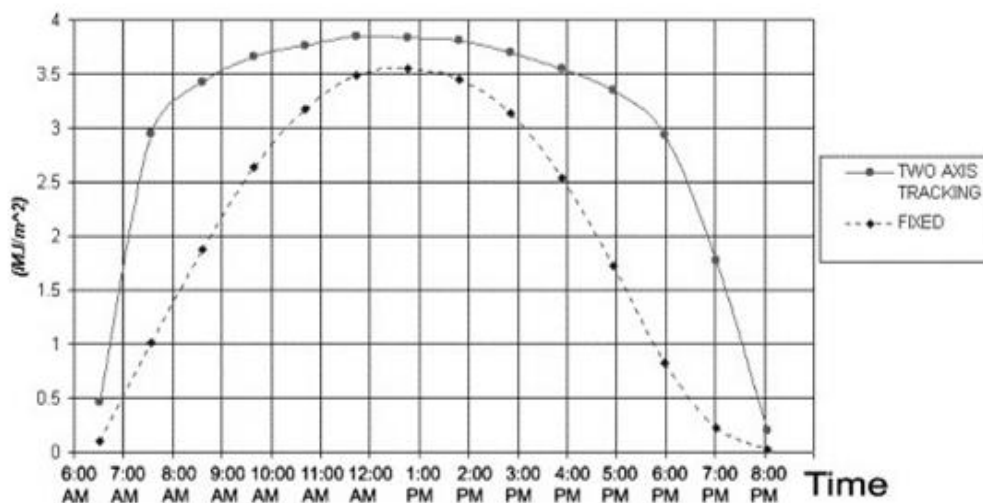
Figure 1. Solar radiation for fixed and two-axis tracking PV panels (Abdallah and Nijmeh 2004).

In contrast, Kelly and Gibson (2009) show that fixed panels in a horizontal position provides up to 50% greater output compared to tilted or tracking panels during overcast conditions due to the greater exposure to diffuse irradiation. During overcast conditions, direct solar irradiation is negligible and almost all irradiation is diffuse. An evaluation of site specific conditions and the frequency of long periods of overcast conditions can be accommodated in the determination of the preferred system and orientation.

An alternative mechanism to utilise photovoltaics gained prominence and peaked early in the second decade of this century, labelled as concentrating photovoltaics (CPV). The technology captures direct irradiation only - i.e. no diffuse or reflective irradiation - on a parabolic, dish or reflector system and concentrates the radiation by a factor of 100 to 1000 times onto a small but highly efficient photovoltaic cell. Four-junction solar cells are recording efficiencies in the order of 39-43%, with the Fraunhofer Institute of Solar Energy Systems (2016) demonstrating a 0.9% absolute improvement each year since 2002. This method reduces the area of PV material required to achieve the same output, hence, reducing the cost of the installation. However, the same authors report challenges in the industry and its inability to match the manufacturing cost reductions being achieved in the traditional PV market. Subsequently, the former benefits of reduced PV material quantities and comparative cost have been eroded and CPV technology is now largely limited to a few large-scale industrial developments. Research and development

investment in this technology is likely to advance the efficiencies achieved by the more prevalent PV installations but at present are cost prohibitive for a small-scale installation.

Individualised investigation of site-specific weather patterns and electricity demands is warranted to determine the ideal arrangement for each installation. A feasibility assessment of comparative payback periods shall determine the size of the system, the specific type of panels selected and if any tracking systems are to be implemented.

A summary of the benefits and drawbacks of solar photovoltaic cells for consideration in product selection are presented in Table 2.

Table 2. Selection considerations for solar PV

Pros	Cons
Point-of-demand electricity generation – reduced electricity network costs and loss factors	Low reliability of stand-alone systems during periods of cloud cover
Peak electricity generation generally coincides with the site's peak energy demand (summer air conditioning loads)	Comparatively low conversion efficiency of available energy solar irradiation to useful electricity
Modular installations provide for site-specific sizing and future upgradeability to match demand	Larger systems are expensive and not currently eligible for government rebates
The greenhouse gas emissions from the manufacture of a solar panel are estimated to be paid back by approximately 2 years of use of the panel, dependent on selected product	Maximum efficiency is obtained from tracking systems, which require installation at ground level and therefore more land area
Fixed panels can be fitted to building structures without detriment to land availability or aesthetic implications	

2.3.2. Building-Integrated Photovoltaics

Building-integrated photovoltaics (BIPV) utilise photovoltaic modules to replace conventional building materials. BIPVs may be installed as a functional element of the

building, such as an awning, roof, facade or window shade (Pillai, Aadiya, Mani and Ramamurthy, 2013) and produce energy in direct response to the energy demands of the building. The conversion of solar energy to electricity occurs in the same manner as standard photovoltaic cells as presented previously (refer Section 2.3.1), however, their efficiency can be significantly reduced due to reduced direct irradiance depending on the installed fixed location and orientation. Proponents for BIPVs argue that the replacement of building elements, and thus no requirement for the purchase of those materials, makes the installation of BIPVs more financially viable, does not increase the building envelope and that any electricity generation is an improvement on existing building materials (Pillai et al 2013 and Strong 2011).

The increase in temperature of PV panels has received the greatest attention in research and is arguably the largest inhibitor of a rapid uptake of BIPVs, particularly as the flexibility of PV cells increases and becomes more cost effective. The absorption of solar energy by PV panels creates a heat bank which, combined with their low thermal mass (i.e. ability to store and buffer heat loads), transfers the additional heat directly through the BIPV and into the internal building space (Pillai et al 2013). In a sub-tropical environment, this creates user discomfort and increases the cooling load of the building – a counter-productive outcome to energy efficiency. Many studies have given their attention to the ideal arrangement and uses of PV cells as BIPVs, particularly investigating passive and active cooling mechanisms to offset the heat bank factor. At this stage research is continuing to maximise convective heat loss from the panels through ideal air gaps and angling of BIPVs, and active cooling mechanisms that avoid excessive energy consumption or thermal stresses induced from sudden temperature changes. In cooler environments where heat gain is beneficial, BIPVs may be presented as a more viable option in the short-term.

A summary of the benefits and drawbacks of building-integrated photovoltaic cells, for consideration during product evaluation and selection, are presented in Table 3.

Table 3. Selection considerations for BIPVs

Pros	Cons
Electricity generation capacity surface area increased	Accumulation of heat banks in tropical and sub-tropical environments, which are transferred internally to the building if installed as part of the building fabric

Provides heat load to buildings in cold environments, to offset heating demands	Very low conversion efficiency to useable electricity
Can be installed as part of building construction or retrofitted to existing buildings	High cost compared to traditional building materials
	PV cells cannot be oriented for maximum output and may be seen as 'wasteful' if not providing high output

2.3.3. Concentrating Solar Power

Concentrating solar power (CSP) utilises reflectors or lenses to concentrate direct normal irradiation - i.e. no diffuse or reflected irradiation - onto a working fluid, which is heated and passed through a heat exchanger to produce steam. The derived steam drives a turbine-generator set to convert the heat energy into mechanical and subsequently electrical energy. Several commercially-available arrangements exist, however, 90% of the operational CSP plants across the globe utilise parabolic trough collectors (Sawin and Martinot 2011). Figure 2 demonstrates the basic principle parabolic trough collectors. The collectors concentrate the solar radiation onto a horizontal tube positioned within the collector, to maximise heat gain in the working fluid, which is pumped at a specified rate to an adjacent power plant. The efficiency of the CSP installation is largely dependent on the heat of the fluid - the higher the temperature that can be achieved, the more heat energy that will be available for conversion to electricity. On this basis, other less common CSP installations involve the construction of a central receiving tower surrounded by concentric rings of heliostats that reflect the sunlight onto the single structure. The concentration of energy from a large number of heliostats results in much higher working temperatures and therefore higher plant efficiencies. The infrastructure costs and ancillary requirements such as cooling towers and high water consumption in the steam cooling process make these installations less feasible than the parabolic trough collectors at this time (NREL 2016).

CSP technologies are based on thermally-driven electricity generation which require significant infrastructure, land area and capital expenditure. For this reason, they are suited to large-scale centralised electricity generation rather than as a site-specific power

source. Systems around the world are currently operating with capacities in the order of 10 to 100MW (NREL 2016). As such, CSP is not suitable for the current project.
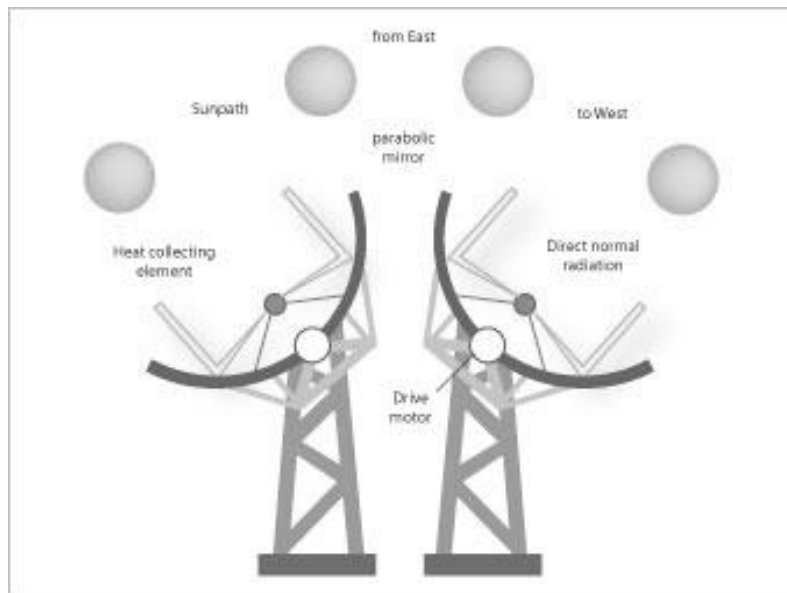
Figure 2. Solar trough reflectors and concentration of heat (Puddicombe 2008)

A summary of the benefits and drawbacks of concentrating solar power, for consideration during product evaluation and selection, are presented in Table 4.

Table 4. Selection considerations for CSP

Pros	Cons
Higher conversion efficiency of available solar irradiation to useful electricity compared to PV panels	Not suitable for small-scale installations
Peak electricity generation generally coincides with peak daytime demand on the power network	Centralised power generation which results in transmission losses to location-of-use
Some systems are modular and could be increased in the future if demand exists	Susceptible to variable output as a result of cloud cover; generally requires an associated heat storage unit

Easily integrated with heat storage units for continuous power supply	Requires cooling tower and significant ancillary infrastructure; large capital investment
Cost per kWh produced is less than PV panels when installed capacity of plant in MW range	Maximum efficiency is obtained from tracking systems, which require installation at ground level and therefore more land area
	Land suitability limitations, including size, gradient; limited locations suitable in urban fringes
	Reflectivity may impact on neighbours and aircraft

2.3.4. Evacuated Tube Solar Collectors

Evacuated tube solar collectors (ETSC) are utilised in thermal applications, by converting solar energy to heat. They consist of a two layers of glass tubes which contain an internal heat pipe that is connected to a manifold at the top of the assembly, through which a separate water supply is passed and gains heat from the internal heat pipe through heat exchange (refer to Figure 3). Generally the heated water is stored in an insulated holding tank and used for direct application rather than to generate electricity through a steam turbine.

ETSC technology specifically functions by the inner tube being surrounded by a black absorber coating to capture solar radiation and a vacuum between the outer glass tube which prevents heat loss to the atmosphere. The inner tube contains an internal heat pipe which contains a small amount of working fluid, usually water or an alcohol-based solution. A vacuum is created within the heat pipe to lower the boiling point of the working fluid. According to the phase diagram of water, the boiling point of water is reduced to $30^{o}C$ at approximately 4kPa (Zhang et al 2015). Solar radiation is absorbed and transferred to the water, raising the temperature above the low-pressure boiling point to create steam. The steam rises to the top of the heat pipe in the manifold whereby heat exchange occurs directly to usable water, which is pumped through a separate water network. The now-cooled steam in the heat pipe condenses and returns to the bottom of the heat tube for reheating.

Evacuated tube solar collectors offer an alternative to traditional solar hot water systems which rely on fixed flat plate collectors, both of which are largely used in domestic and small commercial situations. ETSCs reportedly achieve higher thermal conversion efficiency than the traditional counterparts, with Haw et al (2009) reporting an overall solar radiation-to-water heating peak efficiency in the order of 70%. However, efficiency calculations are based on the aperture area of the ETSC rather than the total area of the assembly. Apricus (2016) report that, when the spacing between adjacent ESTCs is taken into account, the peak efficiencies are comparable to flat plate collectors. The benefit of ETSCs is derived from their passive tracking of the sun, with the full aperture of the tubes being exposed to solar radiation for a longer period throughout the day compared to a flat plate collector. Therefore, the peak efficiencies between the two options may be similar but the output from ETSCs remains high for a longer period each day.
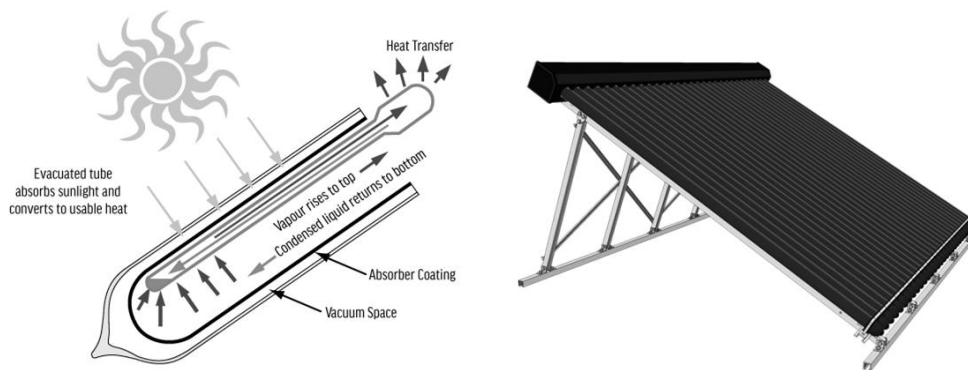
Figure 3. Evacuated tube solar collectors a) cross-section; and b) assembly Source: Apricus

A summary of the benefits and drawbacks of evacuated tube collectors, for consideration during product evaluation and selection, are presented in Table 5.

Table 5. Selection considerations for evacuated tube collectors

Pros	Cons
Modular and scalable in size to match demands of site	Not suitable for direct electricity generation
Individual collectors can be maintained and replaced if damaged without affecting overall installation	Not suitable for instantaneous hot water applications; requires time to heat water
Passive solar tracking maximises solar irradiation without additional infrastructure	Fixed positioning may be dependent on orientation of existing roof; not ideal for maximum heat generation
Directly offsets energy demands of site, previously attributed to water heating	
Suitable for direct application hot water in various applications, including space heating	
Mature technology with few moving parts; long product lifespan	
Easily retrofitted onto existing buildings and plumbing systems	

2.3.5. Solar Air Conditioning

Heating, ventilation and cooling (HVAC) processes globally consume approximately 50% of the energy demand in all commercial sector buildings, with Perez-Lombard et al (2008) identifying 48-55% of energy being consumed by HVAC services specifically in office buildings. They (Perez-Lombard et al 2008) also attribute a large portion of the 0.5%-4.2% annual growth in commercial building energy consumption to the expansion of HVAC services as humans seek greater comfort in temperature-controlled environments. In a sub-tropical environment such as Brisbane, air conditioning for cooling and dehumidification is used for the majority of the year for the comfort of facility patrons.

Renewable energy technologies that offset the high demands of HVAC systems have received much attention in recent years but many commercially-available products are in their infancy and likely to experience significant improvements as a result of ongoing

research and development. HVAC systems remain largely reliant on grid-supplied electricity to ensure reliability and high peak demand but the congruence between peak solar radiation and the cooling demands in buildings enhances the feasibility of such systems. Many variations have been developed in search of a solar-based air conditioning system that largely offsets the demands on fossil fuels. Solar heating and cooling systems utilise solar thermal heating, electricity generated from solar PV panels, or a hybrid of both (Henning 2009). In their recent review of the solar air conditioning industry, Nkwetta et al (2016) conclude that the current solar thermal heating technologies that achieve medium temperatures (75-120°C) are the most suitable option for achieving stand-alone solar cooling and space heating. On the contrary, PV-based systems that generate electricity to directly power the vapour compression cycle of the air conditioning unit have proven most popular in terms of market penetration. The authors indicate that this is likely to be due to the simplicity of the system and ability to retrofit into existing systems. PV-based systems, however, are limited in their use to daylight hours until battery storage becomes feasible, and have the lowest conversion efficiencies of available solar irradiation (Nkwetta et al 2016). As such, PV-based systems only offset electricity demands and reduce peak loads rather than operating from 100% renewable energy resources.

Thermal-driven cooling systems operate by utilising the heated working fluid as either a direct heat source for the generator of a sorption cooling cycle or to produce mechanical power for use in the conventional vapour compression cycle (Nkwetta et al 2016). Research is continuing in the development of the most efficient arrangement with highest coefficient of performance for the sorption cooling cycle, including comparisons of single and double-effect absorption chillers, air versus water cooling, and the preferred working fluid. Nkwetta et al (2016) note six different authors who report the single-effect water-cooled absorption chiller using lithium-bromide as the working fluid and evacuated tube solar collectors as the most commercially developed option, and one that achieves full self-sufficiency during full sunlight. Self-sufficiency has not yet been achieved during overcast conditions; however, the implementation of other energy efficient practices and building materials may lessen the demand on the air conditioning system and therefore assist in bringing the current systems closer to full sustainability.

A summary of the benefits and drawbacks of solar air conditioning, for consideration during product evaluation and selection, are presented in Table 6.

Table 6. Selection considerations for solar air conditioning

Pros	Cons
Suitable to all building types and can be retrofitted to some existing systems	Not completely energy-sustainable during cloudy conditions or at night
Stand-alone systems that can be implemented at any location; use of energy at point-of-generation	Limitations on roof or land availability will require prioritisation between this technology and other technologies that require same area – i.e. may not have sufficient space to accommodate all desired installations
Systems are scalable to meet usage demands; larger buildings with higher demands may have larger roof area (except medium/high rise buildings)	High initial cost of solar heating or PV element compared to electricity grid connection
Options available to meet budget and system complexity	

2.3.6. Ocean Thermal Energy Conversion

A temperature differential between the surface water of the ocean and deep ocean water creates the ability to harness thermal energy for electricity generation, with the efficiency of the technology increasing as the size of the differential temperature increases. Ocean Thermal Energy Conversion (OTEC) is a large-scale electricity producing technology, with infrastructure generally established onshore but Jung-Yeul et al (2016) identify that it may also be constructed to provide electricity to floating platforms and other infrastructure constructed remotely at sea. The technology harnesses the thermal energy of the surface water to vaporise a working fluid with a low boiling point in an evaporator, which then expands to drive a turbine-generator set to generate electricity. The vapour is condensed by the cool deep sea water which is pumped to the condenser. The working fluid is continually pumped through the closed loop cycle. Figure 4 provides a representation of the process.
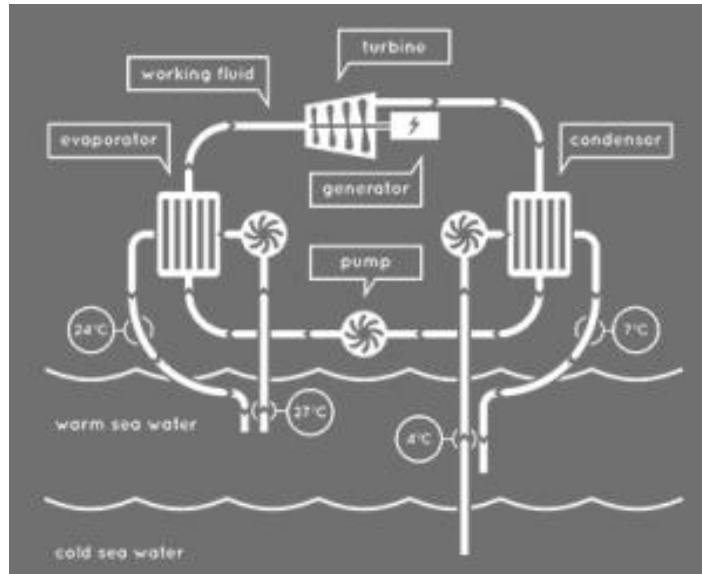
Figure 4. Graphical representation of the Ocean Thermal Energy Conversion process (OTEC Foundation 2016)

On the basis of the Organic Rankine Cycle, the maximum efficiency of the process with a temperature differential of no more than 25°C is in the order of 7% (Jung-Yeul et al 2016). However, Faizal et al (2013) and Jung-Yeul et al (2016) both identify that actual results are much lower, with the working fluids of ammonia and the refrigerant R-134a achieving efficiencies of 0.5-0.75% and 1.5%, respectively for a temperature differential of 22°C. The greatest temperature differentials are achieved where surface water is warmest, which leads the OTEC Foundation (2016) to determine that the most feasible locations for the installation of OTEC plants is in the equatorial region, particularly on islands that have poorly developed existing electricity networks that experience frequent outages due to fluctuating demand.

A summary of the benefits and drawbacks of ocean thermal energy, for consideration during product evaluation and selection, are presented in Table 7.

Table 7. Selection considerations for ocean thermal energy

Pros	Cons
Suitable for remote locations with limited electricity infrastructure	Centralised large-scale energy generation with low efficiency; further losses applicable through the distribution network

Large availability of ocean water; unaffected by relative miniscule heat exchange	Working fluids that have best efficiency are worse for the environment; environmentally-neutral working fluids suitable for in-ocean applications have lower efficiencies
Cold water capture and OTEC by-products can be used for additional purposes such as direct cooling, food production via mariculture harvesting and generation of fresh water, which are valuable in island and developing countries	Long payback period for large capital investment

2.3.7. Wind Turbines

The largest renewable energy source in Australia at present is from wind turbines, accounting for 30% of the country's renewable energy generated in 2014 and supplying 4.2% of the total electricity demand (Clean Energy Council, 2014). Wind turbines are most frequently installed in multiples (i.e. a 'wind farm') by commercial or government-owned electricity companies, as a means to supplement an existing power network. Small-scale installations for stand-alone electricity supply are uncommon in urban areas, however, are gaining prevalence in remote areas where network electricity is limited, unreliable or non-existent. Wind turbines for other direct-work industrial purposes such as water pumping are more common than electricity-generating turbines, particularly for applications that are not time-critical and are not hindered by variability in wind resources.

Wind turbines convert the kinetic power of the wind into torque of the turbine blades which, through a drive train and generator, is converted to electricity. Conversion efficiencies of 30-45% of wind power into electricity have been reported on commercial two- and three-blade turbines in Australia (Department of Environment, Climate Change and Water 2010). The power generated by a wind turbine is in direct proportion to the blade swept area, tip-speed ratio and cubic wind speed. As such, power output is maximised under the conditions of:

a) Increased turbine blade length – Australia's largest wind turbines are installed at 85m height with 55m blade length (Parkinson 2013);

b) Optimised tip-speed ratio with the number of blades to maximise air disturbance passing through the swept area – optimise tip-speed ratio increases the power coefficient of the turbine; and

c) High wind speeds – doubling the wind speed (m/s) produces eight times the power; wind speed is generally higher in offshore locations or at higher elevations.

The wind characteristics at a given location are the most important determinant of the feasibility of a wind turbine. For commercial applications, Barnes et al (2015) identify that an average wind speed of 10m/s or above at turbine installation height is classified as a Class 1 site, and locations in Australia with such classification have largely been consumed by wind farms. The authors investigated variations in the design of turbine blades to suit lower site classes, as these represent the new frontier in wind turbine locations in Australia. Locations with high average wind speeds, minimal interruption from natural or built structures and the ability to place the turbine high above ground level are ideal candidates for future installations. The variability of wind at a given location is particularly important in reducing the intermittency of electricity production from wind turbines. A wind speed in the order of 4-5m/s is commonly required for the larger turbines to start, below which useful electricity is not generated. Domestic-scale wind turbines, however, are able to produce power at lower wind speeds but are limited by small blade length (one to five metre length). Speigel et al (2016) indicate that commercially-available micro wind turbines range from 100W to 1300W rated power, with power curves indicating outputs at 5m/s wind speed for the same turbines being 30W to 212W, respectively. Use in an urban environment is further challenged by large variability in wind distribution created from built obstacles, with Sehar et al (2016) reporting this as the main reasoning for lower-than-predicted energy generation from building-mounted micro wind turbines. As such, a wind turbine in an urban context can be expected to produce less than its rated power output.

Wind turbines also require braking mechanisms to withstand extreme weather events. Depending on the design characteristics of the turbine, wind gusts above 50m/s may cause damage to the rotor and drive train, and require high structural capacity (Barnes et al 2015). Turbine designs accommodate wind characteristics by incorporating yaw to face the direction of the wind, incorporate braking mechanisms above defined speeds, and are sufficiently elevated and spaced to receive uninterrupted wind through each swept blade.

Australia's electricity-generating wind turbines are almost exclusively located in the southern states of Victoria, South Australia and Tasmania, and offshore, where the wind characteristics are suitable for feasible application. A stand-alone small-scale installation in Queensland would require detailed individual assessment based on the above characteristics at the site and the anticipated electricity demand.

A summary of the benefits and drawbacks of building wind turbines, for consideration during product evaluation and selection, are presented in Table 8.

Table 8. Selection considerations for wind turbines

Pros	Cons
Relatively high conversion efficiency of available-to-useable power	Multiple turbines are required to generate commercially-feasible electricity supply
Small gains in wind speed result in large power gains	Large uninterrupted land area required to maximise available wind energy
Land use for activities requiring no built form, such as farming, unaffected by installations	Reported health (noise-initiated) and aesthetic concerns for nearby residents
Offshore installations possible with high reliability	Centralised power generation which results in transmission losses to location-of-use
	Large capital investment
	Stand-alone system in urban environment has lower generating capacity compared to open environment
	Requires a minimum 5m/s wind to commence power output

2.3.8. Wave Power

Waves are formed by wind blowing over the surface of large water bodies, with the shear stress from the wind adding energy to the slower moving water body. Several devices have been developed in an attempt to harness the estimated 3.7TW of power available from waves (Mork et al 2010), however, the technologies rarely withstand the cyclic loads of large forces and torques associated with waves, have difficulty achieving

compliance with the environmental standards of authorities, and are not receiving the level of research and development investment of other renewable technologies (Henriques et al 2016).

Devices may be categorised according to the mechanism by which power is derived. The most common devices involve the attachment of a floating element such as a buoy to a fixed point in the seabed. The rise and fall or oscillatory movement of components with waves drives a hydraulic pump to generate electricity. Direct electricity generation may occur from devices such as oscillating water columns. These comprise of vertical cylinders with a volume of internal air at the top which, when wave motion occurs and fills the column, compresses the air and forces it through an air turbine on the top of the structure.

A summary of the benefits and drawbacks of wave power, for consideration during product evaluation and selection, are presented in Table 9.

Table 9. Selection considerations for wave turbines

Pros	Cons
Harnesses energy from a significant and reliable source	No proven design to withstand the large cyclical forces associated with wave energy
	Few long-term successful installations
	High capital investment for unproven long-term results
	Not suitable for point-of-use electricity generation
	Harsh operating conditions for materials
	Concerns over environmental impacts on marine life

2.3.9. Hydro Power

Hydro power or hydroelectricity is produced by the uni-directional flow of water through turbines that are integrated into a dam wall, converting potential energy into mechanical shaft power which subsequently drives an electricity generator. The power available is

directly proportional to the head of water (H) and the discharge volume flow rate (Q), according to the equation:

$$P = Q \times H \times \rho \times g \times \eta_t$$

where η_t is the efficiency of the turbine and ρ is the density of the water.

Hydro power can be generated at all scales, from local rivers (referred to as mini hydro schemes) to large-scale developments usually in mountainous regions. Water availability is the largest factor in determining the feasibility of a hydro power installation. The Australian Renewable Energy Agency (2016) recognise hydro power as the most advanced and mature technology relating to renewable energy, with over 120 operational hydroelectric power stations across Australia, which contribute almost 20GWh per year or 8% of the country's total electricity generation (AREA 2016). The opportunities for large-scale hydro power stations within Australia have largely been realised, with future developments likely to focus on small dams used for local water supplies, flood mitigation or irrigation purposes. These schemes will be subject to far greater variability in water supply, with undetermined periods where no use will be possible as predicted climatic conditions lead to lower rainfall and longer droughts.

A summary of the benefits and drawbacks of hydro power, for consideration during product evaluation and selection, are presented in Table 10.

Table 10. Selection considerations for hydro power

Pros	Cons
Reliable source of power in river systems within mountainous regions that experience snow fall or other areas of high annual rainfall, such as the tropics	Small-scale developments will have lower reliability of water resources than existing installations
Mature technology with proven success and high power output	Centralised power generation which results in transmission losses to location-of-use
	Must be located in areas subject to water flow, which restricts location

2.3.10. Biomass and Biofuels

Biomass is organic carbon-based material, including plant, animal and animal waste products. These products obtain energy from solar radiation which, through photosynthesis, is converted to chemical energy in plant products. Animals consume the plant products to obtain the stored energy. Biomass may be purposely produced for biomass energy, such as forest plantations, or be redeemed from by-products of other agricultural activities as an approach to minimise energy wastage.

Biomass can provide functional use through various mechanisms. Direct burning of biomass, particularly wooden plant materials, provides direct heating. Ghafoor et al (2016), states that 2.6 billion people or 38% of the global population rely on biomass for cooking and heating applications, particularly in developing countries. Biomass may also be directly combusted to generate heat to drive electricity generation from a gas turbine (Bin et al 2016). Alternatively, biomass may be converted to solid, liquid or gas biofuels via chemical or biological processes, depending on the biomass characteristics.

Biogas (usually CH_4 and CO_2) is produced from organisms that digest and breakdown biomass under anaerobic conditions. Energy use from biogas can occur either through direct use of the gas in compressed form for heating or as fuel for vehicles, or combusted in a combined heat and power plant for electricity generation (University of Florida 2015). Closed landfill sites produce significant biogas in quantities that make small-scale electricity generation feasible (EPA 2015), with generators installed onsite. Bioliquids are similarly produced and refined to produce alternative fuels such as ethanol via alcoholic fermentation, which is mixed with oil-based fuels to power vehicles throughout the world.

In general, the energy value of biomass is in the order of one-quarter to one-third of coal on a per-volume basis (Bhatt 2016). As such, large quantities of biomass are required to provide sustainable energy supplies. In remote areas of developing countries where access to fossil fuel-based energy is limited and agricultural products are prevalent, biomass energy production is proving a viable option (Bhatt et al 2016). The sustainability of biomass is causing some concern to authors (Ghafoor et al 2016, Bhatt et al 2016 and Bin et al 2016), highlighting that dedicated farming for biomass feedstock is at the detriment to other agricultural purposes. Ongoing research is occurring to identify fast growing vegetation, such as eucalypts, that contain high levels of stored energy and can be contained within a defined area to provide the required energy input. Other

authors suggest that true sustainability is only achieved when utilising the waste products of existing resources, such as farm animal waste, sewage or offcuts from sawmills, or where natural processes achieve quick regeneration, such as aquatic algae production.

Bin et al (2016) argue that whilst biomass energy can functionally contribute to global renewable energy supplies, the use in commercial buildings and households in developed countries is not yet suitable due to inadequate supply chains of feedstock, lack of feedstock standards and immature technologies compared to other forms of building-related renewable energies. Huang et al (2011) investigated a biomass fuelled tri-generation system to deliver heating, cooling and electricity supply to a commercial building. They discovered that a standalone system, whilst recovering heat and exhaust, was unable to singularly supply the demands of the building and, moreso, was found to emit CO_2 equivalent to fossil-fuel derived electricity due to its low conversion efficiency.

A summary of the benefits and drawbacks of biomass and biofuels, for consideration during product evaluation and selection, are presented in Table 11.

Table 11. Selection considerations for biomass and biofuels

Pros	Cons
Resource availability generally high in locations where fossil fuel access is low	Ethical consideration of feedstock production specifically for biofuel at the detriment of land for food-producing agriculture
Bioliquids can subsidise traditional vehicular fuel without detriment to motors	Supply chains into urban environments can be difficult and costly
Direct energy supply at point of use	Requires dedicated area for appropriate material storage
	Further research required to determine most suitable feedstock sources for particular applications

2.3.11. Tidal Turbines

Tidal turbines utilise the natural movement of large bodies of water due to gravitational forces to generate electricity. Several variations of tidal turbines exist – tidal barrage,

tidal lagoon, tidal reef and tidal fence – with the tidal barrage being by far the most common and most successful installations to date (Waters et al, 2016). The predictability and reliability of tidal times, heights and energy outputs provides a distinct advantage of this form of renewable energy over other sources. EY (2013) indicate a global potential of 337GW of tidal and wave turbines.

Tidal power is created by separating two bodies of water with a constructed solid wall or similar, depending on the variation, with turbines placed within holes in the divider. This is usually constructed near the mouth of an estuary or similar water body where the upstream basin is physically separated and quantifiable. The dividing wall stops the flow of the natural ocean tide to create a head difference between the two bodies of water. Once the minimum hydrostatic head difference of the turbines is reached, the sluice gates are opened for water to flow through the turbines to generate electricity. Refer to Figure 5 for graphical representation. Turbines may be uni- or bi-directional, resulting in two or four electricity-generation time periods per day, respectively. Yang et al (2013) report that, whilst bi-directional turbines provide double the movement of water, the operational efficiency of the turbine favours a single direction (90.49% versus 71.55%) and are much more expensive to purchase and maintain.
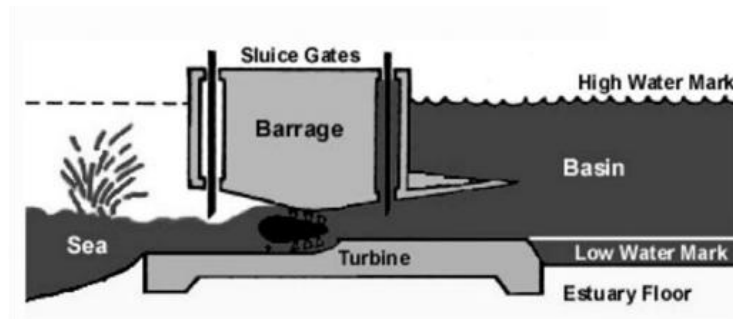
Figure 5. Schematic of tidal turbine (Australian Institute of Energy, 1999).

Energy production is based on the square of the head difference between the basin and the ocean, according to:

$$E = \frac{1}{2} A \rho g h^2$$

where A is the basin area, ρ is the water density and h is the head difference. The feasibility of a tidal turbine increases substantially where a large natural head is available.

Alternatively, turbines may also be reversed to pump additional water following the natural tidal transfer, to create an additional favourable head. Whilst this mechanical process consumes power, there is a positive energy payback through the head-squared relationship.

The first operational tidal range project, La Rance tidal barrage in France, remains in full operation today, having been commissioned in 1967 (Andre 1976). The 720m barrage contains 24 no. 10MW turbines for a combined rated output of 240MW, producing 480GWh of electricity per year (Aggidis 2010 and O'Rourke et al 2010).

Water et al (2016), report that the impact of underwater turbines on sea life is the largest inhibitor of wide-scale uptake of the technology. Direct trauma to sea life from turbine blade movement and the blocking of species movement between ocean and habitat are the largest cause of concern. Modifications of turbine designs are continuing in an effort to lessen the impact of turbine blades on marine life, whilst turbine fences and other mechanisms are being advanced as alternatives to the solid barrage infrastructure.

Tidal turbines are a large-scale technology that generates power at a single location for distribution via the existing electricity network. They are not suitable for small-scale point-of-place electricity generation.

A summary of the benefits and drawbacks of tidal turbines, for consideration during product evaluation and selection, are presented in Table 12.

Table 12. Selection considerations for tidal turbines

| Pros	Cons
High energy output, being feasible to replace a significant proportion of fossil-fuel electricity at ideal locations	Very high capital investment
High reliability and predictability of energy generation	Environmental impacts can be large, and of sufficient impact to prevent development
High number of estuaries along coastlines with high tidal range	Centralised power generation which results in transmission losses to location-of-use

2.3.12. Geothermal

Geothermal energy is a reliable renewable energy resource obtained from heat below the earth's surface, which has been caused by the decay of radiogenic elements such as uranium and thorium over millions of years (Australian Renewable Energy Agency 2016). The earth's core is estimated to be above 5000°C, which cools as it reaches the surface. The sub-surface temperature is not globally consistent, with areas of hot rocks and hot aquifers interspersed across the planet. Whilst rich geothermal resources were historically believed to be restricted to volcanic areas, recent discoveries have determined that non-volcanic countries such as Australia have access to valuable geothermal resources (AREA 2016).

Bin et al (2016) identifies two primary forms of geothermal energy utilisation, being direct geothermal heating and geothermal electricity generation. The former provides direct heat for either space heating, particularly in cooler climates such as Iceland (Gunnarson 2002) or to heat exchangers for other applications. Power generation occurs via the use of the geothermal heat to generate steam, to drive turbines for electricity generation. Bin et al (2016) identify rapid developments in the latter in recent years and expect the technology to contribute a significant proportion of renewable energy in future.

The use of geothermal energy in Australia has lagged behind other countries due to previous belief of unsuitable resources. Research and development on large-scale electricity generation is now focussing on enhanced geothermal systems from hot rocks and from hot sedimentary aquifers (AREA 2016). However, caution is still being displayed due to the geographic variability in geothermal supplies (Bertani 2012).

A variation on geothermal energy applications is emerging for use on a small-scale individual site level, which utilises the constant shallow ground temperature as a reliable low-temperature heat source or heat dump. Bertani (2012) identified the main utilisation of this resource at an individual site level is to offset the energy consumption of heating and air conditioning in buildings. An earth loop of thermally-conductive pipes is installed underground either vertically to the desired depth, or horizontally at a shallow depth. Water or refrigerant is pumped through the pipes and heat transfer occurs across the pipe wall to bring water and ground temperatures to equilibrium. If an aquifer is available below the site, the loop is opened to retrieve and return water to the aquifer. Refer to Figure 6 for a depiction. The constant ground temperature varies depending on latitude and in Brisbane is recorded to be in the order of 22°C. During summer, the earth

loop deposits heat from the water that has been warmed by the room ambient air. During winter, the earth loop obtains heat from the ground. The constant temperature water supply significantly reduces the power required to operate the compressor, fan and pump unit, with coefficients of performance recorded between 3.0 and 5.0 (Regenauer-Lieb et al 2008). Whilst this infrastructure is a form of geothermal energy use, they are also referred to as Ground Source Heat Pumps.
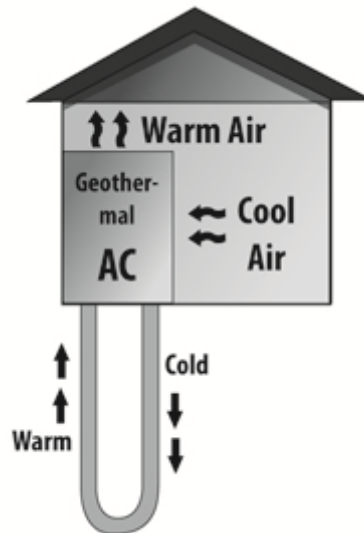
Figure 6. Schematic of geothermal HVAC system (National Geographic 2013).

A ground temperature that matches the comfort level of humans (19°C to 26°C) can provide direct temperature control. Florides and Kalogirou (2004) found that, at their subject site in Cyprus, little daily or annual variation in temperature occurred at a ground depth below 15m, being a consistent 22°C. The authors acknowledge that underground temperatures and the depth of constant temperature will be affected by soil type, average ambient temperatures and the presence of underground water bodies. Site specific analysis would be required to determine the optimal depth for a temperature-constant shallow underground heat supply.

A summary of the benefits and drawbacks of geothermal power and geothermal HVAC, for consideration during product evaluation and selection, are presented in Table 13.

Table 13. Selection considerations for geothermal power and HVAC

Pros	Cons
Power	
No reported environmental effects on health of underground aquifers	Restricted to use in areas with suitable geothermal activity and hot aquifers
Well developed technology with global recognition, use and demonstrated outcomes	Centralised power generation which results in transmission losses to location-of-use
Reliable and predictable source of energy	
HVAC	
Low ongoing maintenance since few moving parts. Easy access to mechanical plant above ground.	Does not eliminate all electricity demand, with power required to drive compressor, fan and pump
High reliability and consistency of ground temperature, providing ease of site-specific engineered solution	Retrofitting of existing buildings is difficult if land-locked, such as in dense urban environment
Point-of-use energy generation to offset fossil-fuel derived electricity	Proven inefficient in hot, humid locations; favour cooler climates
Requires only small land area, or no area if installed underneath new buildings as part of construction	
Systems can operate with water as working fluid, reducing environmentally-harmful refrigerants	

2.3.13. Suitability of Generation Technologies for Current Context

Twelve of the most common renewable energy technologies and their variants have been presented above, along with considerations for use in a proposed development. The suitability of each in the context of a greenfield development of a council works depot located without direct access to ocean or river resources - the subject of this report - is presented and rationalised in Table 14. The indication of "possible" suitability refers to the need for a site-specific assessment of the particular proposed system utilising the stated technology.

Table 14. Suitability of renewable energy generation technologies for a commercial development

Energy Generation Technology	Suitability			Rationale
	Yes	Possible	No	
Solar PV Cells	✓			Sub-tropical location of site, subject to frequent and high level of incident solar radiation
Building-Integrated Photovoltaics		✓		Suitable only for applications that are largely horizontal to maximise output and have open air flow underneath, such as carports or open structures
Concentrating Solar Power			✓	Technology favours large-scale electricity generation; requires large area of land at the expense of other facilities
Evacuated Tube Solar Collectors	✓			Sub-tropical location of site, subject to frequent and high level of incident solar radiation. Hot water demands and/or integration with solar air conditioning system may be suitable
Solar Air Conditioning	✓			Ability to offset up to approx. 50% of site energy consumption if self-sufficient system is viable
Ocean Thermal			✓	Site not located sufficiently close to ocean; technology favours large-scale electricity generation
Wind Turbines		✓		Technology favours large-scale electricity generation but opportunity for small-scale development for onsite usage if climatic conditions are suitable
Wave Power			✓	Site not located sufficiently close to ocean; technology favours large-scale electricity generation

Hydro Power			✓	Site not located sufficiently close to dam or river system; technology favours large-scale electricity generation
Biomass and biofuels			✓	Site not located sufficiently close to landfill site; lower access to energy source compared alternative renewable energies; suitability for vehicular fuels only, which are not subject to this study.
Tidal Turbines			✓	Site not located sufficiently close to ocean; technology favours large-scale electricity generation
Geothermal	✓			The greenfield development provides opportunity to install piping for geothermal HVAC prior to building construction for space minimisation. Reliable energy source with increasing popularity and demonstrated outcomes.

On the basis of this initial evaluation, the following technologies meet the preliminary requirements of a small commercial development in an urban context:

- Solar PV modules
- Building-integrated PV
- Evacuated tube collectors
- Solar air conditioning
- Wind turbines
- Geothermal (small-scale only).

Further site-specific assessment shall occur in the proceeding sections of this report for these technologies.

2.3. Energy Storage Technologies

The large majority of renewable energy resources are variable in nature, providing intermittent power depending on meteorological conditions (wind and solar-based technologies) or natural climatic cycles (wave, tidal and hydro technologies). This challenges the reliability, quality and amount of power available for consumption. Some authors (Yang et al 2016, Speidel et al 2016, Motalleb et al 2016) argue that, to some extent, this uncertainty of supply has been a roadblock to wide scale uptake of renewables as a primary energy source and has forced grid electricity network providers to limit the allowable size of renewable energy installations at residences to prevent major voltage and frequency fluctuations. The second drawback of renewable energy reliance is the difference in timing and quantity of demand and supply, whereby the immediate energy demands of the consumer are not aligned with the generation of power from the renewable energy source.

These factors have driven research and development into energy storage technologies in recent years, as governments and commercial entities focus on overcoming barriers of the use of renewable in an effort to achieve global emissions reductions targets. The storage of energy provides the ability to retain energy generated in excess of demand for periods when demand excess generation. For sites consuming network-supplied electricity, energy storage also accommodates a flattening and shift of the load curve, whereby stored energy can be used at times that network-supplied power is in higher demand by all users and more expensive and the network power may be used to supplement the stored energy in low demand, low cost periods (Motalleb et al 2016).

A multitude of energy storage technologies exist at all stages of development, some being mature technologies subject to ongoing refinement whilst others are in the product conception and testing phase. The technologies can be broadly classified according to the form in which energy is stored (Menconi et al 2016). Each classification is generally associated with the energy generation technology, which maximise efficiencies by storing the energy in a similar form to which it was created. Table 15 identifies the classifications, storage technologies and the associated energy generation technologies.

Table 15. Overview of Energy Storage Technologies

Storage Classification	Storage Technology/s	Generation Technology/s
Electrical	Super-capacitor Superconductive magnetic coil	Solar PV Wind Wave Tidal
Chemical	Batteries - Lithium-ion - Lead-acid - Nickel-cadmium - Nickel-metal hydride - Flow batteries Fuel cells - Hydrogen storage - Natural gas storage	Solar PV Wind Wave Tidal
Thermal	Sensible heat in fluids - Water - Oils - Molten salts Latent heat Thermo-chemical	CSP Evacuated tube collectors Ocean thermal Geothermal
Mechanical	Flywheel Compressed air	Solar PV Wind Wave Tidal

2.4.1. Electrical Energy Storage

Electrical storage technologies are primarily reserved for large-scale electricity generation and supply purposes, such as solar and wind farms, as a means of controlling frequency and voltage fluctuations, dispatch and control to the electricity network (Motalleb et al 2016 and Yang et al 2016). They have a combination of high power densities and low energy density which suits large-scale applications; however Speidel et al (2016) indicate

that they are unsuitable at the small scale due to significantly higher costs per kWh compared to other storage technologies. As a result of markets demands, electrical energy storage infrastructure is manufactured almost entirely for industrial level application. Given the lack of availability and high cost, electrical energy storage will not be further considered for the current proposal.

A summary of the benefits and drawbacks of electrical energy storage, for consideration during product evaluation and selection, are presented in Table 16.

Table 16. Selection considerations for electrical energy storage

Pros	Cons
High power density; able to provide immediate electrical output in response to demand	Suitable only for large-scale electricity distribution network
Variable electrical output to match fluctuations in demand, from small to very large output	High cost of manufacture; requires large capacity and high use for viable payback

2.4.2. Chemical Energy Storage

Chemical storage in the form of batteries is the most feasible option for storing energy for direct electricity use in residential and individual small-scale commercial developments (Speidel et al 2016). Significant differences exist in the storage capacities, lifetimes, flexibility and costs of the various forms of batteries, which are largely determined by the underlying chemistry of the battery.

Table 15 identifies five types of batteries that are prevalent in a variety of applications. A summary of each is provided below, including an explanation of the possible suitability in small-scale developments.

    a. Lithium-ion – exchange lithium ions between electrodes of the battery to store electricity as chemical energy, or discharge by a reverse flow of ions to create electricity. Lithium-ion batteries are the most popular of the rechargeable batteries due to their high power and energy densities, low self-discharge rate and long cycle life. Sky (2012) indicates that one commercially-available lithium-ion

battery model reaches 3,000 cycles at 80% of initial capacity, which is more than double the standard of other types of batteries. For a daily loading cycle, this accounts for over eight years of reliable use. This is reflected in the higher initial cost; however, the popularity of the technology and competitive market forces has significantly reduced the financial impact. Given the high life cycle of the technology, an emerging market of second-hand lithium-ion batteries from electrical vehicles that have reached the end of their life are proving a source of lower cost batteries with remaining reliability (Tong et al 2013). The main disadvantage of Li-ion batteries is the requirement for protective circuitry to prevent overcharging and subsequent shortening of expected life (Speidel et al 2016). The current battery market associated with small-scale renewable energy from wind turbine and solar PV installations are largely lithium-ion, with ongoing research and development resulting in larger capacities at smaller sizes. The Tesla Powerwall, arguably the highest profile battery commercially available, is based on lithium-ion technology.

b. Lead-acid – may be either a deep cycle (low power output, high number of cycles) or starting (high power output, low number of cycles) battery. They have a low energy density, a long recharging duration, require regular maintenance and contain hazardous waste at the end of their useful life. Speidel et al (2016) assess that the normal duty cycles of batteries connected to a solar PV or wind energy source (daily and intra-daily discharge and recharge) would degrade the lead-acid battery quickly and therefore, would be unsuitable for such purpose.

c. Nickel-cadmium – various forms of NiCd batteries are available with differing performance characteristics, which suit a range of functions. All varieties provide high peak power, maintain internal resistance over its life, require minimal maintenance, have short recharge duration and have long life cycles. They are, however, significantly more expensive than lead-acid batteries, have low energy density, contain the harmful cadmium and are generally reserved for what Speidel et al (2016) refer to as "mission critical" applications such as emergency braking systems in trains. The high cost of the technology is prohibitive for widespread application at small-scale site level.

d. Nickel-metal hydride (NiMH) – an environmentally-safe alternative to the nickel-cadmium battery with higher energy density, however, they exhibit a drop in energy capacity in early cycles. The life cycle of the NiMH battery is less suited to regular (daily) electricity cycling that will occur in a small-scale building development, in comparison to other battery types.

e. Flow batteries – contain two externally-housed reservoirs of liquid electrolytes which are pumped into a membrane-separated unit and exchange ions to create an electric charge. This reversible process provides for the electrolytes to be charged by converting electrical energy from the renewable energy source into chemical energy, or discharged when the power is needed by acting in reverse. Flow batteries are efficient, charge almost instantly if supply is available, have good power density, can be cycled without loss of efficiency and are relatively low cost. They are, however, generally quite large compared to other battery types on a capacity comparison, and require external pumps, with associated maintenance and cost, to function. The Energy Storage Association (2016) indicate that flow batteries may challenge the popularity of lithium ion batteries for powering small-scale sites into the future, however, are limited in use at this point in time as a result of their size.

The other primary non-battery chemical energy storage option is a fuel cell. Fuel cells provide electricity through an oxidation reduction process of oxygen and stored hydrogen. The hydrogen is produced through electrolysis and stored in a tank as either a liquid or gas. Fuel cells are largely being further developed and refined for automotive purposes as alternatives to fossil-fuel based diesel and petroleum, however, Wang and Nehrir (2008) have demonstrated theoretical feasibility of integrating fuel cells with wind and solar PV systems. At this stage it remains a fledgling and expensive technology and is not commercially available for small-scale purposes in Australia, but is receiving strong governmental support for further development in the United States (Fuel Cell Technologies Office 2016 and Speidel et al 2016).

A summary of the benefits and drawbacks of chemical energy storage, for consideration during product evaluation and selection, are presented in Table 17.

Table 17. Selection considerations for chemical energy storage

Pros	Cons
Various options available; products largely able to match intended application	Large size for applications requiring high peak output and large storage capacity
May be fixed or moveable, depending on application	Some products use environmentally-damaging materials
Scalable in size to match requirements	High initial cost; price per kWh over life of product exceeds grid-supplied electricity

Immediate availability of electricity upon demand	
Rapidly advancing technology for commercial applications and integration with renewable energy sources	

2.4.3. Thermal Energy Storage

Thermal energy storage retains energy by heating or cooling a particular medium and storing in a well-insulated vessel or environment for later use - refer to Figure 7 for an example in use to support air conditioning. The technology utilises the chemical properties of the storage medium in one of three ways – sensible heat storage, latent heat storage or thermo-chemical storage. Stored thermal energy may be applied either directly, for example, for space heating through an air source heat pump, or to provide energy to create steam to drive a turbine for electricity generation.
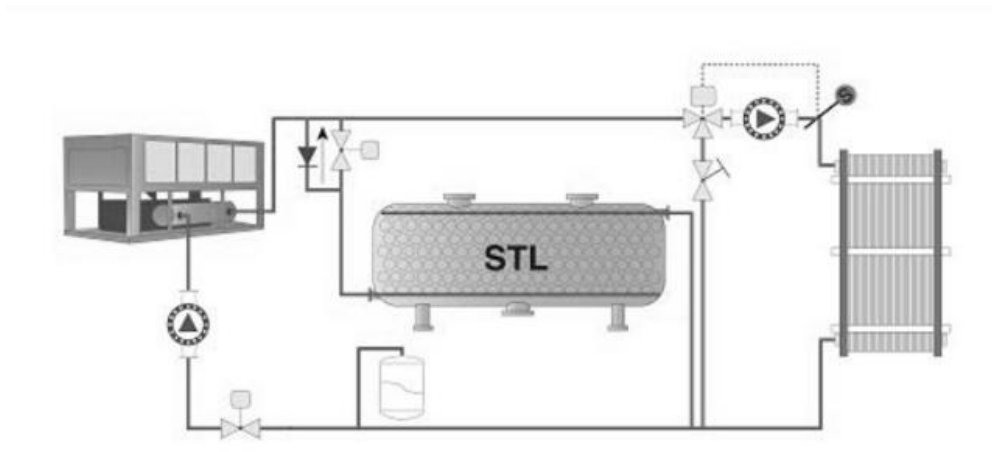
Figure 7. Common thermal energy storage arrangement (Cristopia n.d.)

Thermal energy storage has received much attention as there is great potential to combine with the many industrial practices, including the conversion of renewable energies to electricity, that already lose heat to the environment. The ability to capture and re-use this heat energy can significantly enhance the efficiency and viability of the process, and reduce CO_2 emissions. The use of thermal energy storage in conjunction with compressed air energy storage (described in Section 2.4.4) is reported to increase the

efficiency of the process from approximately 50% to over 70% (IRENA 2013, Energy Storage Association 2016).

Sensible heat storage involves the heating or cooling of fluids or solids that retain the same physical state. Common storage media include water, oil and molten salts. The specific heat of the media, the melting and boiling temperatures, and the available storage volume determines the amount of energy able to be stored. Water is the most popular medium due to its prevalence and minimal cost, and suitability for direct use applications in residential and commercial situations. However, the stored energy density is the lowest of the three thermal energy storage technologies and therefore requires large storage highly-insulated tanks for use in industrial, commercial or network purposes (IRENA 2013). Use in small-scale applications is suitable, as insulated tank sizes are reasonable and cost effective. Current research is focussing on the storage of media in the building fabric, particularly in walls for point-of-place use.

Latent heat storage involves phase-change materials that store the energy required to change physical states, for example, from a solid to a liquid. The latent heat varies between materials but the storage of the medium in another state significantly enhances the energy density of the material. For example, IRENA (2013) identify that the storage of water can provide in the order of $25kWh/m^3$ whereas the phase-change to ice increases the capacity to $100kWh/m^3$. Latent heat storage, however, is much more expensive due to insulation requirements and the equipment that is required to capture the change in enthalpy upon discharge.

Thermo-chemical heat storage provides high energy density storage (up to $300kWh/m^3$) through liquid adsorption to another solid or liquid, such as water vapour to silica gel. The heat energy is retained in the bond between the elements. Thermo-chemical heat storage has potential for a wide variety of applications due to the transportability of reactants. Pilot projects are researching the capture of waste heat energy from industrial applications via thermo-chemical storage, transporting the products via trucks to distances up to 7km away, and using the retained heat for other purposes. IRENA (2013) indicate that this mobile storage project is achieving success with a storage capacity of 3MWh and discharge power of 500kW. To date, however, economic feasibility remains low, particularly in consideration of the reliance of fossil fuels for transportation and the cost of specialised storage units.

A summary of the benefits and drawbacks of thermal energy storage, for consideration during product evaluation and selection, are presented in Table 18.

Table 18. Selection considerations for thermal energy storage

Pros	Cons
Scalable technology, with potential for very large energy storage capacities	Efficiency losses in the reversible conversions between electricity and thermal storage
High energy density in the stored medium; stores high energy per unit volume	Does not provide immediate electricity upon demand; requires conversion
Ability to store at point-of-use	High infrastructure requirements for conversion and storage processes
	High capital cost; economic feasibility limited to high use applications

2.4.4. Mechanical Energy Storage

Two primary mechanisms to store energy in mechanical form are the flywheel and compressed air energy storage. The flywheel consists of a rotor which spins in a virtually frictionless enclosure to store rotational kinetic energy. The rotor is driven by an integrated motor-generator which may be powered from a renewable energy source and, when energy is required, the same motor-generator draws down the power to produce electricity. The work performed by the flywheel reduces the rotational inertia until it can be re-energised by the motor-generator. The amount of energy that can be stored is dependent on the size of the flywheel and a function of the square of its rotational speed, therefore much development is focussing on the material qualities and design to achieve high speeds. Current market-leading products are achieving up to 100,000rpm. Flywheels are particularly prevalent to regulate and improve electricity supply quality and frequency, and to provide short-term back-up power during power outages (Energy Storage Association 2016). Flywheels require little maintenance, have negligible environmental impact and have a long life, with new products achieving 175,000 complete (i.e. 'full depth') charge-discharge cycles (Energy Storage Association 2016). This mechanism of energy storage lends itself to high power, low energy applications that require a high number or frequent cycles, such as telecommunications systems, vehicle

power regulation and network power regulation. The energy demand of buildings makes this type of energy storage less favourable than other mechanisms.

Compressed air energy storage is used in a variety of situations, from small-scale applications such as pneumatic motors and powering mine locomotives to large-scale utility use to meet the electricity network demand. The Energy Storage Association (2016) indicates that the technology has been used since the 1870's, however, limited large-scale storage developments have occurred due to the high cost and inherent inefficiencies of the technology. Compressed air energy storage utilises an energy source, which may be a renewable energy supply, to drive a turbo-compressor to pressurise atmospheric air to a level dependent on the proposed use and storage mechanism. Various storage options exist, however, the pressurised air is commonly stored in a pressure vessel or an underground cavern. At the time of energy demand, the pressurised air is expanded with a turbo expander or an air engine in a turbine, which drives a generator to produce electricity. In accordance with the Ideal Gas Law, the pressurisation process causes heating of air, with this heat requiring removal prior to storage. In reverse, the stored pressurised air must be heated prior to expansion to extract useful work, usually by a natural gas burner or heated metal. As such, this technology has largely been inefficient and required fossil-fuel intervention. New generation methods are currently under development, with large-scale storage units with 70% or greater efficiencies currently under construction in Germany (200MW) and England (40MW) (Storelectric 2015). Compressed air has low environmental impact, high energy density and immediate power but the power lowers as the air depletes and the completely-renewable technology is yet to be refined for wide application. There is limited capacity for compressed air to serve as a reliable energy storage mechanism for a standalone commercial development at this stage.

A summary of the benefits and drawbacks of mechanical energy storage, for consideration during product evaluation and selection, are presented in Table 19.

Table 19. Selection considerations for mechanical energy storage

Pros	Cons
High efficiency for particular applications and at full storage	Mature mechanical storage technologies suitable for electricity network regulation (smooth peaks and troughs) rather than wholesale storage

Small storage units transportable, if required	Compressed air storage a fledgling technology with few demonstrated successes in commercial applications
Very low environmental impact	Compressed air limited to locations with underground caves or requires large pressurised units for commercial application
	Efficiency reduces quickly as stored energy depletes

2.4.5. Suitability of Storage Technologies for Current Context

Four classifications of energy storage technologies and their sub-sets have been specified above, along with considerations for use in a proposed development. The suitability of each in the context of a council works depot is presented and rationalised in Table 20, with those classified as "possible" requiring further site-specific assessment.

Table 20. Suitability of energy storage technologies for a commercial development

Energy Generation Technology	Suitability			Rationale
	Yes	Possible	No	
Electrical – Super Capacitor			✓	High cost; technology favours large-scale electricity generation plants
Electrical – Superconductive Magnetic Coil			✓	High cost; technology favours large-scale electricity generation plants
Chemical – Batteries	✓			High cost but decreasing rapidly in line with technological advances; storage capacity can be matched to site requirements; batteries suitable for intended use are commercially available; energy on demand
Chemical – Fuel Cells			✓	Sizeable installation but has high storage capacity; fledgling technology with minimal proven success in situ

Thermal – Sensible Heat	✓			Sound application in HVAC processes which will be significant at the site; reasonable efficiency and cost
Thermal – Latent Heat		✓		High efficiency technology suitable for HVAC processes in particular; requires high-cost infrastructure; economic feasibility for site-specific purpose required
Thermal – Thermo-Chemical			✓	Fledgling technology not yet commercially proven for intended purpose
Mechanical – Fly Wheel			✓	Technology favours large-scale electricity regulation rather than wholesale storage
Mechanical – Compressed Air			✓	Compressed air used for other purposes on the site; storage of large energy quantities favoured by underground storage which is expensive in built form and not available in natural form at this location.

On the basis of above, the following energy storage technologies meet the preliminary requirements of a small commercial development in an urban context:

- Chemical – batteries
- Chemical – fuel cells
- Thermal – sensible heat
- Thermal – latent heat

Further site-specific assessment shall occur in the proceeding sections of this report for these technologies.

2.5. Energy Efficiency Technologies and Strategies

A holistic approach to energy sustainability is required, whereby all activities and factors that contribute towards energy consumption are reviewed. A reduction in consumption requires less energy generation and therefore smaller, lower cost and more economically feasible systems can be implemented. Opportunities to offset the total energy demand must be evaluated. In the context of a commercial development, these may include, but not be limited to, the building fabric, the selection and performance of electricity-consuming equipment for peak and average consumption, the automated control and review of building HVAC and other electricity consumption in coordination with ambient conditions, internal configurations of buildings, the availability and use of natural lighting, air flow and passive heating/cooling, and building orientations (Krem et al 2013). Furthermore, whilst not reducing total energy demand, mechanisms can be implemented to lower the cost of network-supplied electricity to effectively time shift consumption to off-peak periods, when the supply cost is reduced. An overview of energy efficiency technologies, applicable to the proposed commercial development, is described herein. For perspective, the commercial development of a Council Works Depot includes an administration building, vehicle workshops, equipment storage sheds, parts, products and safety materials storage shed, shaded lunch areas, amenities and secure uncovered machinery parking bays.

2.5.1. Building Materials

The building envelope, including roof materials, window and door thermal insulation and opaque walls, plays a significant role in the energy consumption of a building. As reported earlier, approximately 50% of energy consumed in an office building can be attributed to HVAC processes. The thermal performance of building materials can significantly influence the entry of outside heat or loss of internal conditions, which places addition strain on the HVAC system to maintain the conditions at a comfortable level. Minimum energy efficiency standards are being introduced through Australia's regulatory National Construction Code (formerly Building Code of Australia) for various building types. The selection of building materials is therefore not only an important aspect of achieving energy efficiency, but a mandated practice.

Schiavone et al (2016) argue that insulation materials are the most important factor of all building materials in achieving energy efficiency targets. With common external building materials generally varying in thermal conductivity between 0.10W/m.K for softwood weatherboards to 1.44W/m.K for solid concrete, and up to 210W/m.K for aluminium roof sheeting (Australian Government 2007), insulation plays a major role in enhancing the overall R-value (inverse of thermal conductivity) of the wall and roof of the building. In Schiavone et al's (2016) significant review of insulation materials, the thermal conductivity (W/m.K) and thermal transmittance (U-value) (W/m^2.K) of 26 commercially-available products and 19 unconventional products were evaluated, along with their acoustic transmission, water vapour diffusion, fire resistance and life cycle environmental impacts. Aerogels recorded the lowest thermal conductivity at 0.013W/m.K and therefore can meet minimum standards with thinner, more lightweight walls compared to other products, however, exhibit limitations in their cost and are severely compromised if pierced. More common products such as glass wool have a thermal conductivity of 0.031W/m.K which, when combined with conventional building products, is able to achieve an overall high R-value for the wall or roof/ceiling. The installation of insulation to the roof and walls of open work sheds, where no HVAC exists, can significantly improve the internal conditions of the building.

2.5.2. Electrical Equipment Performance

Overall and peak energy demand can be reduced by the selection of electrical items that are more energy efficient and operate on lower wattages compared to their counterparts. The reduced energy demand of particular items may also have flow-on effects, such as lower heat emissions which reduce the demand on the HVAC system for space cooling. Perez-Lombard et al (2007) indicate that lighting and appliances account for 15% and 10% of energy consumption across all commercial sectors, respectively. In office administration centres, the same authors report the proportion to increase to approximately 20% and 10%, respectively. Therefore, the selection of electrical equipment and installations can provide significant overall energy savings. Options may include:

a) The use of LED lighting in lieu of traditional incandescent and fluorescent light bulbs. An equivalent output is achieved by LED lighting with 20-30% of the energy consumption of its traditional counterparts, which is largely attributable to reduction in heat required to function (Digilight 2014). Significant quantities of

light fixtures must be installed throughout administration, storage and workshop facilities to achieve minimum Australian Standards, and external security lighting operates for at least 10 hours each night. A large quantity of energy and heat can be saved by the installation of LED lighting. Whilst they have a higher initial cost compared to traditional counterparts, the average lifespan is in the order five times (for fluorescent) to fifty times (for incandescent bulbs) longer and do not suffer the same reduction in output over the useful life (Digilight 2014 and Design Recycle Inc 2016).

b) Personal computers are selected with an evaluation criterion being energy efficiency. Heat dissipation from PCs should also be considered, as it adds to the space cooling requirements.

c) Kitchen appliances can be selected to match the number of users and the functionality of the site. An evaluation can be undertaken to determine the lowest-energy approach for fewer but centralised larger refrigerators and freezers, or a higher number of smaller dispersed appliances. The use of instantaneous hot and cold water units can be similarly evaluated. Appliances that are not required outside of hours can be remotely or timed to shut down, and started again prior to use. This is particularly useful in facilities that are used during set working hours and periods of non-use such as weekends occur.

d) Vending machines operate continuously, irrespective of the operating hours of the facility. They are commonly on a lease arrangement with the supplier and negotiation may occur to replace older machines with newer, more efficient machines. Additionally, machines with sensor or timing controls will allow the machines to power down and consume minimal energy to maintain baseline internal conditions. The machines can be programmed to power up to full load in advance of the facility being used by patrons.

e) Use of legislated appliance "Star Ratings" that provide for easy energy efficiency comparison between products. Where products have equivalent functionality, the item with the higher star rating should be selected.

f) In workshops where high-power equipment is required, an evaluation should occur to determine the genuine functional requirements of the product. Items that are significantly over specified for the intended purpose should not be selected, as they will consume additional energy to achieve the same outcome as a lower specified product.

All electrical items selected for use should be considered for its functionality, time in use and energy consumption. Matching the operation of electrical items to their usage assists in ensuring that the overall site electricity demand is as small as possible.

2.5.3. Building Management System

Monitoring and control of the electrical and mechanical components of a building can be undertaken via a building management system (BMS), which provides real-time and historical data from installed instrumentation such as temperature sensors, flow meters and electricity sub-meters. A single user interface via an applicable software package allows the building manager to review data, program the scheduling of plant and undertake trend analysis. The BMS provides energy efficiency functionality through two primary mechanisms, being energy loss rectification and energy waste minimisation:

a) Swift rectification of issues – user-driven alarms can be established to notify of problems with any element of the electrical and mechanical plant, such as the constant operation of an air conditioning chiller unit or heating occurring when outside ambient temperatures are within the comfortable range. The building manager can be notified with a priority matching the importance of the issue, enabling rectification to occur to reduce unnecessary energy expenditure.

b) Programmability to match user requirements – various functionality exists to program the electrical and mechanical plant associated with the building to operate within given parameters, rather than requiring human action on a daily (or more frequent) basis. Meeting rooms may only receive air conditioning 15 minutes before a scheduled meeting and turn off at the conclusion of the meeting. Air conditioning may be programmed to run at particular times of the day to match business operations and only if ambient temperatures are outside of a set range of programmed conditions. Electrical outlets can be shut down outside of business hours to minimise energy consumption. These measures and more can be established to prevent the consumption of energy unnecessarily.

A building management system requires a combination of hardware, instrumentation, network ports and software for integration. Organisations with an existing BMS on another building could expand the system more economically than establishing a new system, to accommodate a new development.

The amount of energy that could be saved by the use of a BMS is difficult to predict, as the benefits are derived from a change in operational procedures and controls for an existing building. For a greenfield development, the BMS will rather provide greater confidence in the predicted total energy consumption of the site, as there will be higher controls in place to limit unexpected use. This allows more accurate calculations for the appropriate sizing of renewable energy generation installations.

2.5.4. Natural Lighting and Air Flow

Artificial lighting and ventilation are required to achieve minimum standards prescribed by Australian Standards applicable to the particular function of the space, however, these energy-consuming practices can be offset by designing buildings and incorporating elements that maximise natural lighting and encourage natural ventilation. Designs that enhance natural lighting must consider the heat implications, to ensure that extra cooling load is not placed on the HVAC system. Similarly, natural ventilation systems must be congruent with any HVAC system to allow for the control of air intake, minimise air loss and maintain effective climate control. Depending on the function of the building or the area within the building, various mechanisms may be suitable. The following items are suitable in the context of a Works Depot:

a) Windows in administration spaces and all rooms, to minimise demand on artificial lighting. The windows may be inoperable to maintain HVAC control and efficiency and, depending on location on the building, may be tinted to reduce heat gain during summer.

b) Translucent roof sheeting installed at regular intervals in storage sheds and mechanical workshops. Artificial lighting installed within the facilities could be fitted with photo-electric cell sensors to only switch on when light provided through the translucent sheeting does not reach the minimum set level.

c) Doors (roller doors and personal doors) and windows appropriately located within storage sheds to facilitate natural ventilation, usually at opposite ends of the building and in respect of wind directions experienced at the location during different seasons of the year.

d) Roof ventilation in sheds, which may be wind-driven or solar-powered. Lien and Ahmed (2011) report several authors that prove the effectiveness of wind-driven roof ventilators in reducing internal temperatures, condensation, excessive humidity and the build-up of smoke, pollutants and odours from industrial

buildings. These can be facilitated further by the installation of low-energy consuming ceiling fans.

e) The use of covered but open structures for other areas such as lunch/gathering spaces, external amenities blocks and external areas that may support PV panels (e.g. carports) to facilitate natural convection of any built up heat.

Opportunities for natural lighting and ventilation should be considered where appropriate in all aspects of the construction of a new facility, particularly given that a large proportion of operations at a Works Depot utilise sheds and open structures that cannot be climate controlled through HVAC systems.

2.5.5. Building Orientation

Architects have long espoused the importance of building orientation in maximising natural elements and minimising heating and cooling costs (Mazria 1979). An orientation that provides the length of the building along an east-west axis has been argued to maximise sun exposure along the northern wall, and therefore heating, from a lower sun during winter months. Similarly, the narrower walls on the eastern and western ends minimise heating during summer months. Wind direction affects natural convection, heat loss from the building, and the natural cooling capacity during summer. A building orientation that aligns with the predominant prevailing wind direction reduces natural convection and ventilation, and therefore, increases artificial climate control and energy consumption through air conditioning. The Australian Bureau of Meteorology (2016) indicates that the predominant prevailing winds for the subject site are east/north-easterly during summer months and west/south-westerly during winter months. These contrast the ideal building orientation for solar maximisation. The impacts of the sun are likely to have greater impact on the energy consumption within the building compared to natural convection, particularly at the subject site where mean wind speed is low, being in the order of 4m/s (BOM, 2016).

Krem et al (2013) modelled various building shapes and orientations in four different climates. They found that an elongated shape with an east-west orientation can provide up to a 16% energy reduction compared to other building orientations and shapes in a sub-tropical climate, which the subject site in Brisbane experiences. Site limitations will

dictate the available footprint for building construction and vehicular flow throughout the site, but preferred orientations should be considered and applied where possible.

2.5.6. Internal Building Configuration

The positioning of spaces within a building, and the subsequent placement of walls, can have an effect on energy efficiency of a building. The usage characteristics of each of the spaces can be used to tailor the lighting and HVAC systems for operational efficiency. Large open administration spaces can be climate-controlled through a series of temperature and CO_2 sensors that integrate with a branch of the air conditioning ducting. This provides consistency across the space, however, if the area is not fully utilised as working space, additional energy is wasted in controlling the conditions of an unnecessary volume of air. Meeting rooms and individual office spaces, which may be used less frequently, can be individually controlled to restrict air conditioning to those spaces when not in use. If there is a reduced usage of the building during any period, such as weekends, smaller areas can be dedicated for this purpose, with climate control restricted to the area of use. The detailed design of mechanical services to a building is specific to the floor plan and intended usage, and can achieve operational energy efficiencies. Future alteration of the floor plan may significantly impact on the suitability of the original installation, potentially leading to user complaints.

The internal configuration should also maximise the use of natural light, placing large open plan areas alongside windows and minimising the use of high partitions or wall which prevent natural light filtration across the space.

2.6. Integration of Energy Generation, Efficient Use and Storage

A completely energy sustainable building development requires a combination and integration of sustainable energy practices, use of energy efficient products, the generation of renewable energy and the storage of energy if supply cannot meet demand at all times. It is commonly understood that the current renewable energy generation technologies for small sites are challenged in their ability to provide 100% of energy demands at all times throughout the year, largely due to the natural and seasonal

variations in climatic conditions (i.e. solar radiation, wind, cloud cover and rainfall). Speidel et al (2016) report that the University of Western Australia's "Future Farm", an off-grid farm with residential and farming electricity demands, experienced occasional power outages throughout the year, despite the use of a solar PV system sized 2.5 times the site's average daily demand and a battery storage unit. The outage periods followed three or more days of cloud cover and low solar radiation, and required the use of back-up energy supply through a diesel generator. Therefore, a completely off-grid Works Depot is unlikely to be achievable unless all generation and storage technologies were severely overspecified which would be both costly and wasteful for the large majority of the year. Further analysis is required to determine the most feasible option and system sizing for a specific site.

Many options exist for the integration of energy generation and storage technologies, with demand responsive building operation. Speidel et al (2016) point to various authors that demonstrate the viability in residential and small-commercial buildings of installing solar PV or wind energy generation with battery storage, thermal energy production with HVAC systems and thermal storage technologies, and solar PV generation with ice (i.e. latent heat) storage. They indicate, however, that the most common commercially available combination is a solar PV-lithium ion battery combination. In these arrangements, batteries may be installed either in parallel with energy consuming devices, whereby the battery is charged only if production exceeds usage demand, or in series whereby the battery is charged directly from the DC supply and once full, the DC is converted to AC for use. Conversion efficiencies to and from the battery are lower in the first option, but it is a more cost-effective solution and prioritises immediate site demand over storage. Specific viable options for the subject site will be investigated further in Section 4.6 of this report.

Demand management, incorporated with energy storage technologies, plays a significant role in reducing both the cost of energy obtained from grid-supplied electricity and the peak demands at a site. Demand management, also known as load levelling, aims to shift energy demands away from peak periods to utility provider-specified off-peak hours, and to obtain energy from storage units during peak usage periods during the day (Hemmati 2016 and Sehar et al 2016). This can reduce the size and cost of the renewable energy generation source, as the system does not need to be designed to meet loads that occur intermittently across the year. Sehar et al (2016) point to several studies that indicate successful integration of demand management practices, renewable energy generation and energy storage in residential and commercial applications. The same authors

acknowledge that the use of ice or low chilled water temperature storage reduces HVAC chiller loads, downsizes the chiller plant, reduces fan and duct sizes, improves humidity control and reduces overall demand on the renewable energy source.

New intelligent control systems are emerging to assist in the demand management of a facility. They integrate trend data from a building management system with ambient climatic conditions and predicted climatic conditions to control the source of energy at any given time. As such, a period of predicted clear warm weather can be compared to expected building demand to determine if the renewable energy source will be sufficient to provide full supply and to top up the energy storage mechanism. Alternatively, a known period of overcast conditions will dictate that the energy storage system be refilled by grid-supplied electricity during off-peak hours.

2.7. Water Efficiency Technologies

Rainfall variability is expected to increase as a result of climate change, with areas likely to experience higher intensity rainfall events and longer periods of dry weather. This unpredictability requires site developers to consider options that will both store water for use as required, and to mitigate the immediate impact of high water flow from intense events.

South-east Queensland was subject to varying levels of water restrictions from May 2005 to January 2011, peaking in 2007-08 with Stage 6 (of 7) restrictions enforced as the dams supplying water to the region reached near-critical levels (Bureau of Meteorology 2011). Continued rapid population growth of the region, without further dam developments, will place additional strain on the resource in the future. The implementation of water sustainability measures in all future developments will assist in reducing the load on reticulated (i.e. supplier-provided mains) water networks. Water sustainability is largely achieved through three mechanisms, by which the demand on the potable water network is reduced:

a) Rainwater harvesting;
b) Use of recycled water; and
c) Implement water efficient practices, including the use of water efficient devices.

Each is described further herein, in the context of a Works Depot.

2.7.1. Rainwater Harvesting

The most common method of water sustainability is rainwater harvesting, where rainfall run-off is captured in tanks and stored for later use. The source of water capture determines the suitability for re-use and the infrastructure required to harvest the water. Rainwater from roof areas can directly enter tanks; however, some tanks may include a first-flush mechanism to divert the initial water to the stormwater system as it is likely to carry dirt and other contaminants from the roof. These are particularly common in off-network locations where the water will be used for human consumption (enHealth 2011).

Run-off from hardstand areas such as concrete pathways and asphalt roadways/car parks is likely to contain additional contaminants such as grease, oil, tyre rubber particles, wood chips, plastic packaging and other general rubbish from everyday use. Treatment of run-off water from these locations is required prior to being suitable for use. Furthermore, capture and treatment is legislated under the Queensland Government's *Environmental Protection Act 1994,* which stipulates that all reasonable and practical measures are taken on a site to prevent pollution of the environment. This includes both the management of higher flows that occur as run-off from hardstand areas, and the quality of the water that exits the site and flows to natural waterways.

The treatment of run-off prior to entering the storage tank is required to occur as part of the water sensitive urban design (WSUD) of the property. This may include a one or a combination of methods including a gross pollutant trap, biofiltration swale drains, raingardens and bioretention basins (Melbourne Water 2016). Specific treatment of water captured from areas exposed to high fuel and oil content, such as workshops and re-fuelling stations, may also incorporate dedicated oil-water separators (Department of Planning and Local Government 2010).

The captured and, if required, treated water can be used for a variety of purposes at a Works Depot, offsetting the demand on the potable water network. Uses include, but not limited to:
- Water in amenities for flushing
- Vehicle washing
- Cooling of renewable energy generation devices
- Cleaning/washing of building exteriors and pathways
- Filling of water trucks for off-site use, including vegetation/landscaping management, construction dust suppression, road works and other purposes

- Irrigation of plants in the nursery.

Water outlets that may be used for drinking, dishwashing sinks and eye wash stations must be separately plumbed to the reticulated potable water network to ensure Class 1A water is available.

Rainwater storage tanks may be installed above ground at the location of capture and re-use, or underground, which is connected to the stormwater treatment devices. High volumetric demands require large infrastructure, which may only be accommodated underground due to site area constraints. Further analysis of site demands and the required size of water storage tanks shall be presented further in Section 1.

2.7.2. Use of Recycled Water

A reticulated recycled water network is available to limited locations in the Moreton Bay region, providing access to approved customers for specific-purpose applications (Unitywater 2016). Sites that are not serviced directly may, following approval, gain access to recycled water via stand pipes located at dedicated waste treatment plants for filling recycled water trucks.

Recycled water differs from water captured from rainwater harvesting and is subject to more stringent usage limitations. Recycled water is treated effluent that has been previously used in a residential or commercial setting, and returned to the treatment plant via the sewer network. Five treatment standards are imposed by the Queensland Government, with each treatment plant generally producing only one classification of recycled water. The recycled water class stipulates the allowable use of the product and the precautions that must be applied, such as time of use restrictions, distance limitations from human activity and personal protective equipment requirements.

The use of recycled water can save a significant volume of potable, drinkable water particularly in high use applications that do not require the highest water quality such as for irrigation and construction activities. Whilst recycled water saves overall water resources and the cost associated with first class water supply, it still requires significant infrastructure and energy consumption to produce the lower grade water. As such, rainwater harvesting is a preferable option as a primary water source compared to recycled water.

2.7.3. Water Efficient Practices and Devices

The overall demand of water, and subsequent reliability of any installed storage capacity, can be preserved by efficient use practices and the installation of water efficient devices. Water efficient practices, such as switching taps off when water is not required, often rely on the actions of individuals and may be encouraged through organisational culture or the enforcement of specific rules. A review of existing water usage habits enables site-specific practices to be established. In the context of a Works Depot, these may include:

- Cleaning and wash-down schedules – the areas/items cleaned and the frequency of cleaning impacts total water consumption. An evaluation of the impact of a reduced level of service may result in water and cost saving;

- Watering of gardens – hand watering saves more water than a running hose; consider the selection of plants that require minimal water; and

- Flushing of urinals – user operated systems result in the consumption of large quantities of water. Timed or sensor-controlled flushing or waterless urinals are water saving initiatives.

Human intervention is difficult to control across a large organisation with each individual's commitment towards water efficient practices varying. Engineered solutions lessen the impact of the human factor. The installation of water efficient devices automatically limit water consumption to reduce overall demand and flow-on effects such as lower costs and reduced heating requirements. A range of water efficient devices can be installed at a Works Depot as part of its overall water efficiency strategy. The Australian Government's WELS Regulator (2016) identifies a range of water efficient products, provides an endorsed star rating for water efficiency for each item and summarises the potential savings that can be achieved through their use. Devices may include:

- Automatic water shut-off devices – installed in series with the internal plumbing, either at the water meter or on an internal branch of the water reticulation network, to monitor down-stream water consumption. The device is user-controlled to set allowable limits for water consumption per period of time. If usage exceeds the limit, the device automatically shuts off water from the installed location. This device is predominantly used to detect large water leaks and prevent unnecessary water loss and cost, however, may prevent losses from user error such as taps being left running overnight.

- Flow restrictors – devices installed in series with the plumbing to limit the flow rate of water beyond that point of installation. These devices are particularly

useful in the retrofit of facilities where existing plumbing may be over specified for current demands and therefore delivering excess water through taps. Flow restrictors may also be used as part of a single device (e.g. tap) to limit flow to that item without affecting the pressure to other elements on the same branch. For example, the plumbing in a kitchen may provide full water flow to a dishwasher but have a flow restrictor installed with the tap in the sink.

- Shower heads, toilets, urinals and taps – the Water Efficiency Labelling and Standards (WELS) scheme provides star ratings to these devices in accordance with their water consumption. Products with a minimum rating of 3 stars (of a possible 5) save 30-40% of water compared to traditional non-rated products (WELS 2016). The same organisation identifies that the installation of taps with in-built aeration can cut consumption by up to 85%.

- Spring-loaded or timed taps – installed in amenities, drink fountains or other locations where a limited volume of water is required. The mechanism automatically shuts down water flow after use to prevent wastage.

- Trigger spray guns – connected to the end of a hose to operate similar to the spring-loaded tap, whereby the user must depress and hold the trigger for water flow. Hoses used for cleaning vehicles or watering gardens can be switched at the tap but water is controlled at the point of use, thereby preventing water from running when not required.

Additionally, water transported in trucks for offsite purposes constitutes a large component of water consumption at a Works Depot. The efficiency of water delivery systems connected to the trucks can be enhanced by the installation of adjustable flow control within the truck cabin and metered supplies to given locations. Water sprayed roadside garden beds can be directed accurately and in a different configuration and flow rate to that used on a road construction site.

There are various and interrelated options towards achieving water sustainability at a Works Depot, as specified above. These options shall be further evaluated for site specificity in Section 4.7.

CHAPTER 3 – RESEARCH DESIGN AND METHODOLOGY

3.1. Introduction

An evaluation of the suitability and feasibility of an energy and water sustainable Works Depot has been undertaken by determining the existing energy and water demands, quantifying and applying savings generated by the implementation of efficient devices and practices, calculating the size of each technology required to meet both peak and average needs of the site, and determining suitable combinations of technologies that will provide full sustainability. Further details on each process, as applicable to the relevant technology, are provided below.

3.2. Energy Demand Assessment

The future Works Depot will consolidate three existing sites, each with historical energy consumption data available. An evaluation of existing data provides a rational basis for determining anticipated future energy demands on an annual, monthly, daily and/or hourly basis. In the simplest form, consumption data from the five electricity meters that supply the three existing sites can be summed for estimated future demand. Four of the electricity meters are classified as 'small' meters, where total annual consumption is below 100MWh. Consumption data from these meters are reported on a three-monthly basis by the electricity retailer. The fifth electricity meter is classified as an 'interval' meter, which supplies over 100MWh of three-phase power to the largest of the existing sites. Interval meters record electricity consumption and feed-in to the grid (where applicable) on a regular small interval basis. For the existing site, the meter records data for every 30-minute interval of every day of every year. This data provides for more detailed analysis, including hourly, daily and monthly variations, and peak demands.

The assessment of the energy demands of the future Works Depot has been undertaken as follows:

a) Combine electricity consumption data from all existing meters to determine total annual consumption.

b) Evaluate data from the large site interval meter on the single site for the most recent 12-month period to determine:

   i) Total annual consumption as a percentage of combined sites;

   ii) Peak daily and hourly demand (kWh) for the year; and

   iii) Daily consumption on work days and non-work days.

c) Determine hourly and daily baseline consumption for existing sites when unoccupied (i.e. weekends). This represents the core or fixed component of consumption, to support the likes of network operations, hot water systems, security and emergency systems. The remaining consumption represents the usage-dependent or variable energy consumption, including the likes of internal lights, IT equipment, power tools and pumps.

d) Record installed capacity of existing HVAC units at the large site, and calculate proportion of peak demand for four evenly spaced months of the year. From knowledge of site operations, it is assumed that peak energy consumption occurred when all HVAC units are in operation less those that service intermittently and infrequently used meeting rooms.

e) Quantify the impacts of changes in staff numbers at the new site, consolidation of building footprints, HVAC demand variations, and energy savings from the implementation of identified efficient devices and practices.

f) Calculate the total heat transfer into buildings (heat block) during peak conditions from solar radiation, convection, conduction, solar gain through windows, equipment heat dissipation and human activity.

g) Undertake linear regression to determine an equation that will describe the mean energy consumption for work days throughout the year.

Item (f) above establishes the ultimate energy demand of the new site. HVAC demands are the single largest contributor to energy consumption in commercial buildings, and therefore heat transfer principles are applied to validate the application of Australian Standard AS 1668.2-2012 in calculating peak air conditioning loads at maximum ambient temperature. AS 1668.2-2012 *The use of ventilation and air conditioning in buildings – Mechanical ventilation is buildings*, as it applies to this project, is described further in Section 3.3.1.4. The heat load to the building consists of internal heat sources, such as electrical equipment and human activity, and external sources from convective, conductive and irradiative solar heat through the building materials. Known solar irradiance at the location ($q_{r,in}$) enables the calculation of surface temperatures (T_{surf}) via the application of:

$$q_{r,in} + q_{b,int} = \sigma\left(T_{surf}{}^4 - T_{sky}{}^4\right) - \overline{h_c}\left(T_{surf} - T_{air}\right) \tag{1}$$

where $q_{b,int}$ is the heat generated from activities internal to the building, σ is the Stefan-Boltzmann constant, $\overline{h_c}$ is the convective heat transfer coefficient, T_{sky} is the temperature of the sky being 0K and T_{air} is the ambient air temperature.

The calculated T_{surf} provides outer surface temperature for the calculation of heat transfer per area (m^2) to the internal space by equation:

$$\frac{q_{in}}{A} = U\left(T_{surf} - T_{in}\right) \tag{2}$$

where U is the overall heat transfer coefficient incorporating radiative and convective heat transfer on the outer surface (R_s), conduction through the building material (R_c), and convective heat transfer inside the office space (R_{in}). That is,

$$U = \frac{1}{R_s + R_c + R_{in}} \tag{3}$$

where

$$R_s = \frac{1}{\left({(T_{surf} - T_{air})}\Big/{\sigma\left(T_{surf}{}^4 - T_{air}{}^4\right)} + {1}\Big/{\overline{h_c}} \right)} \tag{4}$$

For the subject site, wind speeds are estimated at an average of 2.5m/s, which corresponds to free convection $\overline{h_c}$ of 20Wm^{-2}K^{-1}. $\overline{h_c}$ in forced convection internal to the office space, in very low speed environment is estimated at 10Wm^{-2}K^{-1}.

3.3. Energy Generation and Storage

Six energy generation technologies have been proposed for further evaluation, following the initial assessment of the suitability for the type and location of use. Four technologies – solar PV modules, building-integrated photovoltaics, evacuated tube collectors and solar air conditioning – are dependent on the solar irradiance available at the site. A fifth

technology, wind turbines, is dependent on the available wind energy and distribution. The remaining technology – small-scale geothermal – is dependent on the stable ground conditions of the site.

Three energy storage options are also considered, with sub-categories investigated for chemical storage (batteries). Thermal options of sensible heat and latent heat storage are evaluated. The research methodology for each category varies and is therefore presented separately below.

3.3.1. Solar Irradiance

The solar irradiance available at the site is required to calculate the expected output of photovoltaic cells (in any form) and evacuated tube collectors. Modelling of hourly solar irradiance for each month of the year at the subject site provides initial data for the evaluation and optimisation of each technology, based on their respective efficiencies. Solar irradiance-dependent technologies have been determined via the following process:

a) Preparation of a Microsoft Excel-based model that calculates the instantaneous irradiance (kW/m), daily, monthly and annual solar insolation (kWh/m^2) on a surface of any tilt and azimuth (i.e. orientation) at any given longitude and latitude. Since the model calculations are based on the day of the year (starting at n=1 for January 1), the average daily insolation is calculated for the middle day of each month as the average daily amount for that month, and multiplied by the number of days of the month to determine monthly values. Each month is summed to obtain annual insolation availability.

b) Develop and incorporate technology-specific inputs in the model prepared above, including efficiencies, temperature-dependent losses, other losses and equipment sizing.

c) Iterate the inputs for the subject site to determine the optimum tilt and orientation for:
   a. maximum energy generation at the site; and
   b. energy generation that matches site demands.

d) Calculate average daily and peak energy generation difference from energy demand (over- or under-supply) across the year and specifically for four months that represent the seasonal fluctuations for each tilt and azimuth of the generating technology.

e) Refine tilt and orientation parameters following site concept planning to determine the impact on energy generation from sub-optimal installation based on final building orientations and dimensions.

f) Confirm average daily generation matches or exceeds average daily demand, in conjunction with energy storage capacities, incorporating extended periods of inclement weather.

Solar Irradiance and Insolation Calculations

A Microsoft Excel model has been developed to calculate instantaneous global solar irradiance (G_β) for each hour of sunlight for the middle day of each month, and total daily, monthly and annual insolation values. Site specific inputs are used, including longitude, latitude, surface tilt above the horizontal and orientation of the surface from due north. The instantaneous global solar irradiance on any surface of tilt angle (β) consists of the beam component of direct irradiation (B_β), diffuse irradiation hitting and entering the surface (D_β) and a component of reflected irradiation from the ground and other nearby structures hitting and entering the surface (R_β):

$$G_\beta = B_\beta + D_\beta + R_\beta \qquad (5)$$

Each component has been calculated in accordance with models evaluated and formulae presented by Demain et al (2013).

Direct Component

$$B_\beta = G_H \left(\frac{\cos \theta_i}{\cos \theta_z} \right) \qquad (6)$$

where G_H is the instantaneous direct solar irradiance on a horizontal surface (recorded at site), calculated by converting the average daily solar irradiance for the month as measured from historical meteorological data at the subject site (H_H) for the day number of the year (N) representing the central day of the month of interest (e.g. 16 March is N=75) using the following formula:

$$G_H = \frac{\pi H_H}{2N} \sin \left(\frac{\pi T_s}{N} \right) \qquad (7)$$

T_s indicates the time after sunrise, which accounts for changing lengths of days throughout the year. Hourly measurements are calculated using this formula, to determine the variation of solar irradiance from sunrise to sunset on the given day.

The incidence angle (θ_i) indicates the angle between direct beam sunlight onto the surface and the perpendicular of the surface, calculated by:

$$\cos \theta_i = \sin \delta \sin \varphi \cos \beta - \sin \delta \cos \varphi \sin \beta \cos \alpha \qquad (8)$$
$$+ \cos \delta \cos \varphi \cos \beta \cos \omega$$
$$+ \cos \delta \sin \varphi \cos \beta \cos \alpha \cos \omega$$
$$+ \cos \delta \sin \beta \sin \alpha \sin \omega$$

where δ is the solar declination angle, φ is the latitude of the subject site location, β is the tilt angle of the surface from the horizontal plane, α is the surface azimuth angle or rotation (measured clockwise from due north in the southern hemisphere), and ω is the hour angle.

The solar zenital angle (θ_z) is calculated as:

$$\cos \theta_z = \sin \delta \sin \varphi + \cos \delta \cos \varphi \cos \omega \qquad (9)$$

Diffuse Component

Diffuse component, calculated using Willmot's anisotropic model which accounts for variation in diffuse radiation across the sky dome:

$$D_\beta = R_d D_i \qquad (10)$$

where

$$R_d = \frac{G_H r_b}{S_o} + C_\beta \left(1 - \frac{G_H}{S_o}\right) \qquad (11)$$

where S_o is the solar constant 1367W/m², and

$$C_\beta = 1.0115 - 0.20293\beta - 0.080823\beta^2 \qquad (12)$$

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and

$$D_i = G_H(1 - 1.13K_t)$$ (13)

where K_t is the clearness index, which varies throughout the day:

$$K_t = \frac{G_H}{H_H}$$ (14)

Reflected component

$$R_\beta = \rho G R_r$$ (15)

where ρ is the reflectivity index of the surroundings, G is the global horizontal irradiance and R_r is the transposition factor for ground reflection. Demain et al's (2013) approach using the ideal isotropic assumption is replicated here:

$$R_r = \frac{(1 - \cos \beta)}{2}$$ (16)

The calculation of instantaneous global solar irradiance on a surface of any tilt and orientation (i.e. azimuth) is undertaken using the above process. Average monthly irradiance data is calculated for the middle day of each month using data provided by the Bureau of Meteorology at the nearest weather station to the subject site. The variation of irradiance throughout the day can be calculated at any preferred interval, depending on the study needs. In this report, hourly irradiation is calculated from sunrise to sunset, for each month of the year. The operation of a council Works Depot occurs generally from 6am to 6pm throughout the year, with existing electricity demands recorded in 30-minute intervals. The use of 1-hour intervals will provide sufficient accuracy for comparison between hourly generation capacity, peak generation capacity and site energy demands.

The developed model in Microsoft Excel represents the above, with results provided in Section 4.5. The outputs provide the theoretical environmental conditions on any given day, for application in the evaluation of the four solar radiation-dependent technologies. The applicable methodologies for each are provided herein.

3.3.1.1. Solar Photovoltaics

The availability of solar irradiance is converted to functional power through solar photovoltaic panels and associated wiring and inverters. Several factors influence the overall efficiency of solar PV systems (η_{total}), including:

- the nominal solar panel or module efficiency (η_{nom}) with a manufacturing tolerance (tol) usually in the order of $\pm 3\%$;

- pre-conversion losses (η_{pre}), i.e. dirt build-up, shading and reflection which are recognised by the industry as reducing efficiency by up to 4%;

- module losses (η_{mod}), i.e. thermal losses, with performance decrease dependent on ambient air temperature and instantaneous irradiation from standard test conditions according to:

$$\eta_{mod} = 1 - \left(\frac{CP_{cell}(T_{cell} - 25)}{100} \right) \qquad (17)$$

where CP_{cell} is the solar panel's temperature coefficient of power, according to manufacturer specification; and

$$T_{cell} = T_{air} + \left(\frac{G_{\beta}(NOCT - 25)}{800} \right) \qquad (18)$$

where T_{cell} is the instantaneous temperature of the solar panel cell and $NOCT$ is the nominal operating temperature of the solar panel according to the manufacturer specification; and system losses (η_{sys}), i.e. inverter and wiring losses, which are commonly in the order of 5%.

Equations (17) and (18) indicate the dependence of PV cell efficiency on ambient temperature. Whilst peak irradiance provides resources for high PV cell output, the coincident heightened ambient temperature reduces the efficiency of the cell's conversion of irradiance to useable power. Modelling hourly temperature variations based on recorded maximum and minimum temperatures is complex; however, the 'Wave' method proposed by De Wit et al (1978) has been demonstrated to provide sound modelling. Hourly temperatures are calculated:

Before sunrise

$$T_{air} = T_{ave} + AMP\left(\cos\left(\frac{\pi(H + 10)}{10 + RISE}\right)\right) \quad (19)$$

Between sunrise and 2pm (inclusive)

$$T_{air} = T_{ave} - AMP\left(\cos\left(\frac{\pi(H - RISE)}{14 - RISE}\right)\right) \quad (20)$$

After 2pm

$$T_{air} = T_{ave} + AMP\left(\cos\left(\frac{\pi(H - 14)}{10 + RISE}\right)\right) \quad (21)$$

where $T_{ave} = (T_{max} + T_{min})/2$, $AMP = (T_{max} - T_{min})/2$, H is the hour of the day in 24-hour format and $RISE$ is the time of sunrise in hours.

Modelled temperatures are incorporated into hour-specific calculations of PV output in the developed Excel model.

The total efficiency of a solar PV system can therefore be calculated as:

$$\eta_{total} = (1 - tol)\eta_{nom}\eta_{pre}\eta_{mod}\eta_{sys} \quad (22)$$

with each item previously described. When accounting for industry standard losses, generally equates to:

$$\eta_{total} = 0.885\,\eta_{nom}\eta_{mod} \quad (23)$$

The useable power output (P) per square metre of a selected solar panel at a given instant of temperature and irradiation is normalised by accounting for the solar panel area (A_{panel}):

$$P = \frac{G_\beta \eta_{total}}{A_{panel}} \quad (24)$$

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Summation of values of P for each hour of daylight for the average day of each month provides the average daily useable energy output (kWh m^{-2}) for that month. Multiplying by the number of days in the respective month and summed for each month of the year provides the total annual useable energy output from the solar panels.

The area of PV cells receiving solar irradiation is also affected by the positioning of panels. Panels placed on the horizontal can be abutted to avoid shading effects, however, have reduced output compared to panels at ideal tilt angles. Panels are most easily fitted to a roof on brackets parallel to the roof pitch, but brackets may be installed at any angle. Panels may also be installed at ground level on any preferred angle or orientation with fewer challenges from roof pitch and orientation. The distance between successive rows of panels, if desired to have no shading, is determined by the winter solstice whereby the sun is lowest in the sky.

$$Sun\ angle\ above\ horizontal\ (\alpha) \tag{25}$$
$$= 90° - latitude - declination\ angle$$

For the winter solstice, the declination angle is 23.5°, therefore:

$$\alpha = 66.5° - latitude \tag{26}$$

For a flat roof or a ground-based installation, the distance between the bases of successive rows of panels (d) is calculated using the sine rule:

$$d = L\ \frac{\sin(180 - \beta - \alpha)}{\sin \alpha} \tag{27}$$

where L is the side length of the panel which will be determined by the placement orientation and may not be the longest side of the panel.

For panels oriented in the same direction as a roof of pitch τ, d will be less than that for a flat roof, calculated as:

$$d = L\ \frac{\sin(180 - \beta - \alpha)}{\sin(\alpha + \tau)} \tag{28}$$

The installation of panels on a pitched roof at an orientation different to the roof is uncommon, expensive and would cause variable shading. Complex modelling would be required to determine the effects of such an arrangement and is not considered further here.

Tracking infrastructure may be integrated with photon-sensitive technology to rotate PV panels on either a single or dual axis system, to maximise exposure of the PV cells to direct irradiation, which constitutes the largest component of solar radiation, during all daylight hours. Tracking systems add significant cost to the installation and a feasibility evaluation needs to be done to determine its suitability. The developed model provides hourly evaluation of solar irradiance for surfaces of all orientations and tilts. The one-way tracking system is evaluated by retaining a constant orientation of 90° to reflect a row of panels installed on a north-south aligned rotating bracket, which variably tilts the panels in an east-west direction (refer to Figure 8 for a model image). Available irradiance is recorded for the months of January, April, July and October to represent the four seasons. A similar process is conducted to model maximum irradiation at each hour for the same months, adjusting both orientation and tilt. The model does not account for shading and therefore successive parallel rows of tracking panels will result in reduced output at different times throughout the day if not sufficiently spaced apart. It is beyond the scope of this report to model these distances and arrangement.
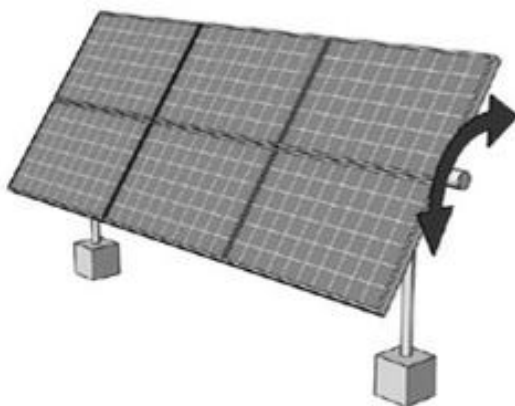
Figure 8. Single-axis solar tracking system (PV magazine 2010).

3.3.1.2. Building-Integrated Photovoltaics

Photovoltaic cells integrated into the building fabric generate energy on the same basis as regular photovoltaic panels, as detailed in the previous section (3.3.1.1). The developed model calculates available irradiance for surfaces of any orientation and tilt. Walls, windows and similar coverings are modelled at a 90-degree tilt and the applicable orientation of the structure on the building (e.g. facing north, south, east or west). Roof and shade surfaces are modelled at any pitch and orientation.

Replication of equations (23) and (24) for the specified product will calculate the estimated total annual energy generated per square metre on the structure. Total energy available from the BIPV is calculated by the energy generated from each ith wall of surface area (SA):

$$\sum P_i \times SA_i \qquad\qquad (29)$$

Instantaneous, hourly, data and annual data are calculated as presented previously, incorporating the effects of temperature on PV cell efficiency.

3.3.1.3. Evacuated Tube Solar Collectors

Similar to photovoltaic cells, the energy derived from evacuated tube solar collectors (P_c) is dependent on the available solar irradiance at any tilt angle (G_β), the total collector conversion efficiency of solar irradiation to heat energy (η_c) and the total area of tube apertures (A_c) exposed to solar irradiation:

$$P_c = G_\beta \eta_c A_c \qquad\qquad (30)$$

In this scenario:

$$\eta_c = \eta_{sp}\eta_{pf} \qquad\qquad (31)$$

where η_{sp} is the conversion efficiency of solar irradiance to heat energy inside the collector tube and η_{pf} is the subsequent efficiency of the conversion of heat energy inside the head manifold from the fluid in the collector tube to the working fluid in the external

loop. Haw et al (2013) indicate the total efficiency of today's solar collector tubes (η_c) is in the order of 0.70, which correlates with the specification sheets of several ESTC manufacturers; and

$$A_c = n_t \times A_t \tag{32}$$

where n_t is the total number of evacuated tubes in the assembly and A_t is the aperture area of an individual tube.

The working fluid in the external closed loop system with specific heat c_p transfers power (P_c) by a combination of raising the temperature of the working fluid within the manifold ($T_{f,out} - T_{f,in}$) and its mass flow rate ($\dot{m}$), according to:

$$P_c = \dot{m}c_p(T_{f,out} - T_{f,in}) \tag{33}$$

The reciprocal relationship between mass flow rate and rise in temperature at constant power allows the user to specify and design a system based on the higher need for the intended purpose. Higher water temperatures require slower mass flow rates and vice versa. Site specific needs determine the applicable parameters, and the subsequent selection of equipment such as circulation pump size.

3.3.1.4. Solar Air Conditioning

The two prominent options for solar air conditioning systems involve:
a) direct PV electricity generation specifically for the operation of the vapour-compression cycle and fan unit, which will rely on the conversion of solar irradiance as described in Section 3.3.1.1, with the PV cells being dedicated wholly to the air conditioning unit or the unit consuming energy generated from a larger non-specific PV system; or
b) thermally driven vapour-compression cycle utilising heat generated from evacuated tube solar collectors, as described in Section 3.3.1.3, with sorption chillers.

Both options require no additional methodology to be provided for energy generation calculations, as the air conditioning demand will be provided through energy generated through one of the previously described means. HVAC system outputs, however, must

adhere to or exceed Australian Standard AS 1668.2-2012 (Standards Australia 2012), which requires an office-based building to have 6-10 complete air flushes per hour or 10L/s air flow per person, whichever is the greater. Minimum air flow (A_{min}) is therefore:

$$A_{min} = 10 \times n_{occupants} \times \rho_{air} \tag{34}$$

or where the middle value of eight (8) flushes per hour is taken:

$$A_{min} = \frac{8 \times V_{building} \times \rho_{air}}{3600} \tag{35}$$

The power required for a backward curved airfoil centrifugal fan ($\eta_{fan} \approx 0.75$) to deliver the required air flow is defined by:

$$P_{input} = \frac{\Delta p \times A_{min}}{\eta_{fan}} \tag{36}$$

where Δp is estimated at 500Pa.

The total air volume can be a mix of fresh air intake and recycled filtered internal air, which reduces the demand on heating or cooling. According to AS 1668.2-2012, the minimum fresh air intake in office buildings is 10L per second per person. The cooling demand (Q) on the condenser coils for treating outside air is therefore:

$$Q = \dot{m}_{OA} \Delta H_{OI} \tag{37}$$

where $\dot{m}_{OA}$ is the mass flow rate of fresh outside air based on number of persons in the building and ΔH_{OI} is the change in enthalpy required between outside and inside air. The use of enthalpy is required to incorporate both temperature and humidity changes in the air (i.e. sensible and latent heat changes), as office worker comfort is determined by the two factors. An internal environment of 24°C and 50% relative humidity is deemed ideal.

Demand assessment of site-specific air conditioning use will be further evaluated in Section 4 to determine the most efficient and feasible option in consideration of the available area for solar energy collectors.

3.3.2. Wind Energy

Wind speed data is available from the Australian Bureau of Meteorology for applicable weather stations, with recordings taken only at 9am and 3pm. Average data from observations over multiple years is used as the basis for further calculations. It is assumed that the overall monthly wind speed can be calculated from the mean of the average 9am and average 3pm wind speeds. It is also assumed that data recorded by the Bureau are from anemometers installed 10.0m above ground level.

Wind energy calculations are undertaken for the representative months of January and July, which correlate with the highest and lowest energy demands of the site.

Wind speeds are generally well-described by a Weibull distribution (Azad et al 2014). The probabilities of particular wind speed bands can be calculated at any proposed height above the ground by determining the Weibull parameters of k, c, m and n from real observations. The probability equation for Weibull distribution can be expressed as:

$$\phi = \exp\left[-\left(\frac{u'}{c}\right)^k\right]$$

(38)

where k is the shape factor and c is the scale factor that defines the Weibull distribution.

Parameters k_{ref} and c_{ref} at the reference height of h_{ref} are found by substituting observation data for two selected wind speeds, whereby ϕ is the proportion of time that wind speed equals or exceeds the selected value.

The parameter c remains constant regardless of speed, so equation (38) is rearranged and two sets of observation data inserted to determine k:

$$\frac{u_1}{\sqrt[k_{ref}]{-\ln(\phi_1)}} = \frac{u_2}{\sqrt[k_{ref}]{-\ln(\phi_2)}}$$

(39)

The calculated k_{ref} value is reinserted into equation (38) to determine c. The mean wind speed, shape and scale factors are related according to the formula:

$$\overline{u^n} = c^n gamma(1 + {}^n/_k)$$

(40)

The reference Weibull parameters above are re-calculated for any installation height (h) of a wind turbine to accommodate a varied wind pattern, according to the equation:

$$k = k_{ref} \frac{\left(1 - 0.088 \ln\left(\frac{h_{ref}}{3.048}\right)\right)}{\left(1 - 0.088 \ln\left(\frac{h}{3.048}\right)\right)} \tag{41}$$

$$m = \frac{\left(0.37 - 0.088 \ln\left(c_{ref}\right)\right)}{\left(1 - 0.088 \ln\left(\frac{h_{ref}}{3.048}\right)\right)} \tag{42}$$

$$c = c_{ref} \left(\frac{h}{h_{ref}}\right)^m \tag{43}$$

The new probabilities of wind speed bands ($\Delta u'$) are calculated and plotted from the formula:

$$\phi_{u'+0.5\Delta u' > u > u' - 0.5\Delta u'} = \frac{k}{c}\left(\frac{u'}{c}\right)^{k-1} \exp\left[-\left(\frac{u'}{c}\right)^k\right] \Delta u' \tag{44}$$

The potential generation or output power of the wind turbine (P_o) is directly proportional to the cubic wind speed according to:

$$P_o = \frac{1}{2}\rho A u^3 \eta C_p \tag{45}$$

where ρ is air density, A is swept area of blades of the turbine, η is the overall rotor and drive train efficiency and C_p is the power coefficient. P_o is calculated in an ideal free stream and excludes minimum and maximum or cut-out speed of the wind turbine, whereby no power is generated. Product specifications will define the unit efficiency on a case-by-case basis but are considered here to be suitably approximated at 31% whilst operational.

3.3.3. Small-Scale Geothermal

Also referred to as ground source heat pumps, this energy efficient technology pertains to heating, ventilation and air conditioning, and is an alternative to solar air conditioning, as described in Section 3.3.1.4. The amount of heat that can be dissipated (in cooling) or gained (in heating) from the ground is dependent on the building heating or cooling load (i.e. total energy requiring dissipation or gain in a given time period), the thermal conductivity of the soil, the thermal conductivity of the tubes and grout surrounding the tubes, the temperature of the soil at depth (T_g), the incoming (T_{wi}) and outgoing (T_{wo}) working fluid temperatures, the proximity of boreholes to each other and the length of tubes within the ground (L). For vertical loops, the length of tubes required to accommodate the cooling building load is calculated from (Lund 2003):

$$L = \frac{q_a R_{ga} + (C_f q_l)\left(R_b + {q_m}/{q_l} \cdot R_{gm} + R_{gd} F_{sc}\right)}{\left({T_{wi}}/{T_{wo}}\right) - T_g - T_p} \tag{46}$$

where,

q_l, q_m and q_a are the peak cooling load, average cooling load for the peak month and the average annual cooling load (W), respectively

R_{gd}, R_{gm} and R_{ga} are the effective thermal resistances of the ground when subjected to the daily, monthly and annual loads, respectively (W/m.°C) which vary due to time exposure and changes within the soil as a result of the exposure to load

R_b is the total thermal resistance of the bore, including the tube wall and grout (W/m.°C)

C_f is the heat pump correction factor for a given coefficient of performance

F_{sc} is the short-circuit heat loss factor

T_p is the temperature penalty for interference from adjacent bores (°C).

The above calculation is dependent on turbulent flow of the working fluid, which is confirmed by the Reynold's number under the operating conditions given by the fluid speed (V), diameter of the tube carrying the working fluid (D_H) and the working fluid density (ρ) and absolute viscosity (μ) at its bulk fluid temperature:

$$Re_{D_H} = \frac{\rho V D_H}{\mu} \tag{47}$$

The total length of tube required, as calculated above, represents a single direction of flow. The depth of each borehole and the number of boreholes determine the total length. Spacing of the boreholes is important due to interference of heat dissipation, with the selected distance being incorporated into the equation (46). Use of this distance between each of the boreholes determines the total area required to achieve the cooling load.

3.3.4. Chemical Storage

Two options for chemical storage – lithium-ion batteries and vanadium-water flow batteries – are evaluated on four parameters in comparison to predicted site energy demands:

a) Peak draw available – the maximum energy that the battery can supply instantaneously to meet intermittent high demands from the site. This is determined from the largest instantaneous difference between site energy demand and the supply of energy from renewable energy generation sources;

b) Total draw available – the total cumulative capacity of an extended period over which there is a deficiency in the supply of renewable energy; that is, from afternoon through to following morning when supply overtakes demand;

c) Peak or maximum instantaneous draw during a prolonged cloudy period – supply from solar energy sources is reduced; however, the site energy consumption is also less due to lower ambient temperatures and reduced demand for air conditioning/HVAC; and

d) Total draw during prolonged cloudy period – the difference between total energy generation and site demand over the set period.

A three-day period is typically considered a prolonged cloudy period and is therefore used in modelling. Historical data from the representative months is used to determine the minimum daily insolation and three-day minimum insolation. HVAC demands are proportioned on the basis of average solar insolation for the three-day period to the average solar insolation for the month.

All of the above parameters are evaluated for the four representative months of the year to determine the operating limits of the battery system. The battery system is sized appropriately on the basis of battery draw capacity and DC-AC conversion efficiency for both normal conditions and prolonged cloudy period.

$$Size_{total,PD} = \frac{(Demand - Supply)_{max,hourly}}{\eta_{DC-AC}} \times$$
$$\frac{Battery\ size_{unit}}{Battery\ rated\ peak\ draw}$$

<div align="right">(48)</div>

$$Size_{total,TD} = \frac{Demand_{total,night}}{\eta_{DC-AC}}$$

<div align="right">(49)</div>

The maximum calculated figure dictates the required battery size, from which a suitable option may be selected. For systems that involve co-generation from multiple renewable resources, the same methodology is applied with the incorporation of applicable offset of energy demand according to full-sun or cloudy conditions.

3.3.5. Thermal Storage

<u>Sensible Heat</u>

The heating or cooling of a fluid of density (ρ), volume (V) and specific heat (C_p) results in energy gain or loss according to the equation:

$$Q_{total} = \rho V C_p (T_2 - T_1)$$

<div align="right">(50)</div>

The requirement for a heated or cooled fluid is dependent on the application and the infrastructure that the storage supports, primarily for HVAC purposes. The fluid can be applied directly for space heating or cooling; low temperature water through an air conditioning system to offset the electrical demand for the vapour-compression cycle; or as high temperature water through a thermal-driven air conditioning system supported by evacuated tube solar collectors. Each option requires a different approach. If the heat is used directly, equation (50) can be rearranged and values for the thermal conductivity of pipe work and flooring/walls applied to determine the final room temperature. This option is not considered suitable as part of this project, as it largely favours heating spaces in cold climates. The remaining two options are considered by the following process:

a) Calculate peak deficiency between HVAC demand and supply (early morning, late afternoon);

b) Calculate daily excess of energy produced through renewable resources for the four representative months of the year;

c) Determine volume of fluid that can be cooled or heated to desired temperatures;

d) Apply fraction loss during storage; and

e) Calculate total annual offset available.

Energy loss during storage is dependent on the shape of the storage unit, particularly the ratio of volume to surface area, and the thermal transmittance (U-value) of the tank. For a cylindrical vessel of radius (r):

$$Q_{fraction\,loss} = \frac{r\rho C_p}{3U} \qquad (51)$$

For use of the stored fluid, standard evaluation processes and equations apply for the applicable technology, as per methodologies already stated in this report.

Latent Heat

Excess electricity produced from renewable energy sources (during daylight hours of PV panels or anytime for wind energy) may be used as input power to convert a phase change material between phases, most commonly from a liquid to solid to avoid instability and risk factors with gases.

The heat to and from a material is a combination of sensible heat reduction and heat of fusion:

$$Q_{total} = mC_{p1}\left(T_{pc} - T_1\right) + mh_{pc} + mC_{p2}\left(T_2 - T_{pc}\right) \qquad (52)$$

where C_{p1} is the specific heat of the media in solid state, C_{p2} is the specific heat in liquid state, h_{pc} is the latent heat of fusion, T_{pc} is the temperature at which fusion occurs, T_1 is the final temperature in solid state and T_2 is the original temperature of the liquid.

The use of electrical vapour-compression-driven equipment as input to reduce the temperature and remove the latent heat from the fluid to form solid state requires inclusion of equipment efficiency:

$$Q_{demand} = \eta_e Q_{total} \qquad (53)$$

Energy loss during storage is applicable as per equation (51).

The rate of energy retrieval is dependent on the surface area of solid contact with the heat exchanger, which varies from unit to unit. In situ applications commonly report low thermal conductivity and slow rate of heat release due to challenges with this interface. Offset of peak demand is therefore not a suitable option but rather suited to long-term energy release.

3.3.6. Water Consumption and Capture

Water usage patterns vary between the three existing sites given the type of work performed and proximity to external infrastructure. The largest site which also incorporates administration staff is located directly adjacent to a recycled water plant, from which water is directly sourced. It is estimated that the potable water consumption at this site is 50% for genuine potable water needs to meet legislative standards, and the remaining 50% is used for outside purposes such as washing equipment.

Consumption at the two remaining sites is almost completely related to activities that are suited to the use of recycled water, such as watering establishing roadside plants and dust suppression during road construction. It is estimated that these two sites combined account for 30% of actual total water use, and the remaining 70% is not currently captured in existing data due to direct sourcing from the recycled water plant.

Predicted future consumption data is calculated by:
a) Collating quarterly (3-monthly) water consumption data for one year for the three sites;
b) Calculate half of annual consumption for largest existing site, as future potable water consumption and therefore a required cost to the service provider;
c) Quarterly consumption of remaining two sites ÷ 0.3 for predicted total quarterly recycled water demand;
d) Quarterly data split evenly over the applicable three months, for a monthly consumption; and
e) Monthly data is summed for total annual demand.

In line with the effects of climate change, past rainfall data may not be a suitable predictor of future rainfall. To account for extreme conditions, median and 5th percentile

(very low) data from 37 years of observations from the nearby Mango Hill weather station are used to calculate the trend in replenishment of a storage tank of selected size. The area of water capture is determined from car parks and building roof space and rationalised based on natural ground contours (natural catchment areas) for the size of pre-tank filtration devices. The following equation is iterated for each month. At tank capacity, excess water is distributed overland in an approved manner.

$$Tank\ water\ level\ (kL) \qquad\qquad\qquad\qquad (54)$$
$$= \frac{Rainfall(mm)}{1000} \times runoff\ area(m^2)$$
$$\times Infiltration\ rate - Consumption$$
$$+ Previous\ month\ water\ level$$

where infiltration rate is assumed to be 90% from hardstand bitumen and roof areas.

3.4. Site Concept Planning

The site for the proposed new Works Depot has been selected previously along with the building footprints required to meet the future needs of the workforce. Concept planning is undertaken following an opportunities and constraints analysis of the existing land parcels, including contours, road accessibility, natural landscape/environment characteristics, and town planning limitations. Developable areas are selected and buildings placed and oriented to accommodate proposed site usage, internal vehicular flow, separation of pedestrian from large vehicular movements, separate parking for machinery and employee vehicles. Consideration is given to renewable energy generation capacities at given orientations, with adjustments made if the benefit from additional generation capacity justifies any cost or site usage impositions as a result of the change. However, as energy generation is a supportive element of site functionality, it is the generally intention that the energy generation and storage technologies are adjusted or re-sized to meet site needs.

CHAPTER 4 – RESULTS

4.1.Overview

The methodologies presented in the previous section have been applied for each component of the project. Site planning, energy demand assessment, energy generation capacity, energy storage requirements, and water demand and storage requirements are evaluated separately below.

4.2.Site Concept Layout

The proposed site consists of two adjacent parcels of land totalling $14,150m^2$, with a creek defining the northern boundary at an orientation of approximately 35° east of north, and a road defining the southern boundary, curving from approximately 28° east of north to 30° north of east - refer to Figure 9. Existing clearing and contours of the site are largely oriented with the road at 28° east of north. Town planning for the site allows for light industry, with maximum development of three storeys or 10m. Access between the two parcels is uninhibited but the northern parcel is generally 5m higher above sea level due to previous activities (i.e. gravel extraction) on the southern parcel.

An estimated 350 staff will utilise the depot as their base, incorporating 120 office-based staff and 230 field staff. Car parking and buildings can be separated between the two work forces without detriment to operations. The separation particularly enhances pedestrian safety around machinery. Large vehicles and machinery must be able to traverse the site and be stored overnight. Supportive infrastructure including a machinery workshop, fuel tanks, storage sheds and goods store are required in the field operations section of the site. Maximisation of the site occurs by aligning all functional and ancillary facilities along or close to parallel with the axis of the site, i.e. 28° east of north.

Figure 9. Site aerial and characteristics

The proposed site layout was prepared by a consultancy firm through an engagement by Moreton Bay Regional Council, and is provided in Appendix B. A two-storey main administration centre is located at the southern aspect of the site, oriented at 25° east of north, providing a reduced size building footprint for the large number of staff. The smaller roof area reduces direct heat exposure and therefore lessens cooling energy demand. A 1000m^2 workshop, 1000m^2 stores, 500m^2 storage sheds and 300m^2 lockers are provided on the northern half of the site, with large circulation and parking spaces for fleet vehicles and machinery. Staff car parking is separated as shown and end-of-trip facilities provided for cyclists.

The building configurations do not align perfectly with the ideal orientation for solar energy generation maximisation, as will be presented in Section 4.5 below, but builds upon the natural site attributes, incorporates town planning limitations, provides

functional site usage requirements and provides opportunities for renewable energy generation with minimal compromise. These factors combine to form the lowest development cost with maximum return on investment.

4.3. Existing Sites Energy Demands

In a like-for-like consolidation, whereby the total energy demands from the three sites transfer to the new site, i.e. no efficiencies gained, annual electricity demand would be 285.1MWh. Half-hourly energy consumption is only available through one meter, which records 196MWh per annum or 69% of the total consolidated demand. Extrapolation of the pattern of energy consumption to the consolidated site (i.e. 1/0.69) without any implementation of energy generation or efficiency measures results in the data shown in Table 21. Three classifications of energy demand are reported – fixed, variable and HVAC. Fixed occur every hour of every day consisting of base loads such as refrigerators, ice machine, IT network equipment and emergency evacuation lights. Variable demands only occur on work days, incorporating lighting, computers and workshop equipment. HVAC incorporates the heating, ventilation and air conditioning systems, which are also variable in nature but require separation from other variable demands due to renewable energy options that directly support HVAC systems.

Table 21. Consolidated Site Energy Demands

	Existing Main Site	Extrapolated Consolidated Site (Excluding Efficiencies)
Actual Annual Demand	196.7MWh	285.1MWh
Actual Average Work Day Demand	675.8kWh	983.1kWh
Actual Average Non-Work Day Demand	229.1kWh	333.3kWh
Actual Hourly Peak Demand	79.4kWh (recorded 2/2/2016)	115.5kWh
Actual Daily Peak Demand	930.5kWhp (recorded 1/2/2016)	1353.6kWhp

Actual HVAC Installed Capacity and Estimated Demand at Peak	58.3kW (cooling, installed) 40.1kW (cooling, peak)	84.5kW (installed) 58.1kW (peak)
Daily		
Daily Fixed Demand (all days)	216.0kWh	313.0kWh
Average Daily Variable Demand	263.4kWh	381.7kWh
Average Daily HVAC Demand	196.4kWh	284.6kWh
Hourly		
Hourly Fixed Demand (all days)	9.0kWh	13.0kWh
Average Hourly Variable Demand (work days 6am-5pm)	20.4kWh	29.6kWh
Average Hourly Variable Demand (work days 5pm-6am)	3.0kWh	4.3kWh
Average Hourly HVAC Demand	17.9kWh	25.9kWh

The average hourly and daily HVAC demands specified above are calculated from annual data. Average figures are not suitable to determine future system sizing, as large seasonal variability in HVAC energy demands. The estimated HVAC demand during a representative month of each quarter of the year yields the results in Table 22 below. Actual data is obtained from the interval electricity meter. The estimated daily energy demand for HVAC purposes of the new consolidated site is also indicated.

Table 22. Estimated HVAC at primary existing site and total demand (without efficiencies)

	January	April	July	October
Actual Average Total Daily Consumption (kWh)	826	670	564	660
Average Daily Fixed and Variable Load (kWh)	479	479	479	479
Average Daily HVAC Load (kWh)	347	191	85	181
HVAC Proportion of Daily Consumption	42.0%	28.5%	15.1%	27.4%
Extrapolated Existing HVAC Average Daily Demand at All Sites (kWh)	503	277	123	262

Actual daily demand on work days, as measured through the large interval meter, follows a single sinusoidal period across the year as shown in Figure 10. Energy demands on non-work days remains relatively consistent throughout the year (229.1kWh per day) with random variations from intermittent events that require the site to be in operation, such as emergency weather events. Using regression, work day demand through the single meter is determined to be most suitably modelled by:

$$Demand = 139 \ \cos\frac{2\pi}{365}(n - 23) + 670 \ \text{(R}^2\text{=0.727)}$$

where n is day of the year. R-squared value is reduced by lower energy demands during the school holiday period in December and January, when the sites are functional (i.e. classified as work days) but have reduced staff and work volumes.

Figure 10. Actual energy consumption through largest site meter

4.4. Future Site Energy Demands

A total of 258 staff operate from the three existing depots, including 68 office-based staff. The proposed development aims to accommodate 120 office-based staff and 230 field staff, in line with projected requirements due to significant population growth in the council region. Office staff currently operate from a series of individual relocatable

office modules which have been added over time as need emerges. Consolidation of the existing sites into a purpose-built facility will provide energy efficiency opportunities, as saving in current energy usage are realised.

4.4.1. Heating Ventilation and Cooling (HVAC)

Heating, ventilation and cooling represents the single largest component of energy consumption and therefore requires specific interrogation and offset, where possible. The existing office modules and shed spaces are fitted with HVAC units that are over specified to incorporate a factor of safety and therefore exceed necessary demand. Consolidation of all administration staff into a purpose-built, double-storey block work building with a specifically-engineered HVAC solution enables efficiencies to be gained. However, the building is forecast to accommodate a 76% increase on existing numbers, which will increase demand. A total floor area 2364m^2 or 1182m^2 per level is proposed, to fit with land constraints. At 2.7m ceiling heights, total internal air volume is 6383m^3.

Peak demand determines the required size of a HVAC unit, with mechanical components operating below peak capacities at all other times. Building demand assessment has been undertaken in three categories to determine overall system requirements on the basis of ideal internal conditions of 24°C and 50% RH and external conditions of 34°C, 40% RH or 28°C, 80% RH (January climate):

Fresh Air Intake into Buildings

AS1668.2-2012 stipulates a minimum fresh air intake of 1.47kg/s for 120 persons. Of the two climatic conditions during January, the enthalpy of air is higher for the 28°C 80% RH condition, at 77kJ/kg-dry air. The enthalpy at ideal internal conditions is 48kJ/kg-dry air. According to equation (37), sensible and latent heat removal totals 42.6kW. The addition of an industry-standard 15% factor for unforeseen extreme conditions results in a total peak cooling demand of outside air of 49.0kW. The fan/s within the HVAC system are required to deliver 14.2m^3/sec of air to comply with equation (35), with a power input to drive the fans at 9.5kW.

Building Fabric

The peak heat transfer into the building is estimated to be 91.5kW. Taking approximate exposure at 2pm during January, the building fabric heat transfer is summed from first principles, consisting of:

- 17.1kW due to conductive, convective and radiative heat transfer through the 1182m^2 roof (R-value 3.0 to meet Code) at 70°C and 1000W/m^2 solar radiation;

- 3.5kW due to conductive and convective heat transfer though 70% of 280m^2 western wall (R-value 1.8 to meet Code) receiving 800W/m^2 solar radiation at 63°C;

- 13.8kW due to conductive heat transfer through double-glazed western windows, being 30% of 280m^2 of western wall area (R-value 0.24);

- 2.0kW due to conductive and convective heat transfer through 70% of 280m^2 northern wall receiving 300W/m^2 solar radiation at 45°C;

- 7.4kW of conductive heat transfer through northern windows;

- 2.2kW conductive and convective heat transfer through southern and eastern shaded walls but exposed to ambient temperature of 34°C;

- 7.1kW conductive heat transfer through windows on southern and eastern walls;

- 23.2kW solar gain through western windows (sun at 30° from vertical, 50% of 800W/m^2, double-glazed windows SHGC 0.69);

- 8.7kW solar gain through northern windows;

- 6.5kW infiltration losses from door openings and the like.

Internal Activities

Heat generated from internal activities is calculated as 57.9kW, consisting of:
- Human body heat - 120 staff x 0.15kW
- Electrical equipment (excluding server room) - 12W/m^2 x 2364m^2
- Server room electrical equipment – 5kW constantly
- Lighting - 400 x 0.018kW x 90% heat output

Total

The minimum cooling capacity of the HVAC system to achieve compliance to all criteria and to remove heat generated from all areas to the new administration building is therefore 212.9kW. Applying the same process determines that the office located in the Stores building requires 6.2kW cooling at peak demand. The coefficient of performance

(COP) of the selected HVAC units will define the power input required to operate each system. COPs vary in operation from 0.7 for thermally-driven absorption chillers to approximately 2.5 for electrical-driven vapour-compression chillers during peak conditions (up to 3.0 in ideal conditions) and 4.0 for ground-source heat pump (GSHP) units.

The renewable energy generation technology selected will determine the size of system required to accommodate demand at peak operation and climatic conditions. Accounting for the above coefficients of performance, the required sizes to meet sites demands are:

1) 306kW of thermal heat, utilising evacuated tube solar collectors;
2a) 86kW of electricity from solar PV panels for vapour-compression systems; or
2b) 54kW of electricity from solar PV panels to drive the GSHP plus applicable number of boreholes to dissipate the building load (calculated in Section 4.5.3).

4.4.2. Energy Efficiency Opportunities

The calculation of future site energy demands must incorporate, as much as known, changes to current operating conditions. Technologies and systems will change over time and may either increase or decrease energy demand at the site. However, the energy efficiency opportunities in Table 23 have been identified, quantified where possible, and included in the results of successive sections of this report.

Table 23. Energy saving measures for future site

Mechanism	Detail	Est'd Current Daily Demand (kWh)	Est'd Future Daily Demand (kWh)	Daily Change (kWh)	Est'd Current Average Demand (kW)	Est'd Average Demand Change (kW)
Replace fluorescent and incandescent lights with LED and rationalise quantity (10% fixed, 90% variable)	Fluorescent 60W tubes replaced with 18W LED tubes. High bay 400W lights replaced with 120W LED. Halogen security lights replaced with LED fittings. [1]	215.9	190.6	-25.3	18.4	-2.9
Natural lighting (Variable)	Translucent sheeting in sheds and sky lights in admin building to reduce qty of lights by 5%	3.7	0	-3.7	0.3	-0.3
Hot water storage system (Fixed)	Primer for zip boilers and to supply amenities (install of solar hot water system)	14.0	5.6	-8.4	1.2	-0.7
Energy efficient devices (Fixed)	Minimum star ratings for appliances, power tools and IT equipment	-	-	-7.2 (1.5% saving)	24.1	-0.4
Building Management System (Fixed, Variable & HVAC)	Sensor-controlled lighting and other mechanisms, intuitive controls, automated shut downs outside work hours, variable speed drives, and alarm management for reduced energy wastage	47.3 (5% saving after other items)	0	-47.3	3.2 (5% of demand)	-3.2
	TOTAL		Daily (kWh)	-91.9	Average Hourly (kW)	-7.5

[1] Future tubes quantity: 500 - 400 admin building (1 light per $6.2m^2$) + 50 storage shed (1 light per $9m^2$) + 30 locker storage (1 light per $9m^2$) + nominal 20 in workshop and stores sheds; High bay lights quantity: 1 light per $35m^2$

4.4.3. Total Future Site Energy Demand

The predicted peak hourly and daily energy demand of the consolidated site, including the implementation of energy efficiency technologies, is shown in Table 24. The peak demands indicate the output required from renewable energy generating technologies if sustainability is to be achieved. A core fixed daily demand of 278.6kWh will be required for site operation on every day of the year. A further 193.3kWh is required to operate equipment on work days, or 471.9kWh in total excluding HVAC demand. HVAC varies throughout the year due to changes in ambient conditions, which can be modelled based on the day of the year. Similar to the existing sites, variability in energy consumption across the year at the future site is expected to follow a sinusoidal pattern as shown in Figure 11.

Table 24. Estimated future site peak energy demands

	Existing Sites (kWh)	Proposed Site (kWh)	Change (kWh)
Peak Hourly			
Fixed demand	13.0	12.0	-1.0
Variable demand	29.6	24.4	-5.2
HVAC demand	58.1	53.8 (GSHP)	-4.3
		85.9 (electricity)	+27.8
		305.7 (thermal)	+247.6
Total Peak Hourly	**100.7**	**89.4 (GSHP)**	**-11.3**
		121.5 (electricity)	**+20.8**
		341.3 (thermal)	**+240.6**
Peak Daily			
Fixed demand	313.0	288.2	-24.8
Variable demand	381.7	321.2	-60.5
HVAC demand	658.9	556.7 (GSHP)	-102.2
		886.6 (electricity)	+227.7
		3154.7 (thermal)	+2495.8
Total Peak Daily	**1353.6**	**1166.1 (GSHP)**	**-187.5**
		1496.0 (elect.)	**+142.4**
		3764.1 (thermal)	**+3630.5**

Whilst peak hourly HVAC demand through thermal application is 5.3 times the existing sites, the floor area of the administration space triples from approximately 800m^2 to the 2364m^2 and the number of staff to be accommodated almost doubles. The electrical load for the vapour-compression (electricity) and to run the GSHP HVAC systems are not dissimilar from the existing sites due to the incorporation of energy efficiency strategies. Peak demand occurs rarely but establishes the minimum system size.

The average daily load for the site is defined by equation:

$$\overline{D}_{total} = 715.7 \cos\left(\frac{2\pi(n - 23)}{365}\right) + 2152.6 \tag{55}$$

and depicted in Figure 11. By integration across the year and incorporating the lower weekend demand, the total annual load is 613.3MWh. This actual energy demand required from renewable energy sources will vary depending on the efficiency of each technology employed.
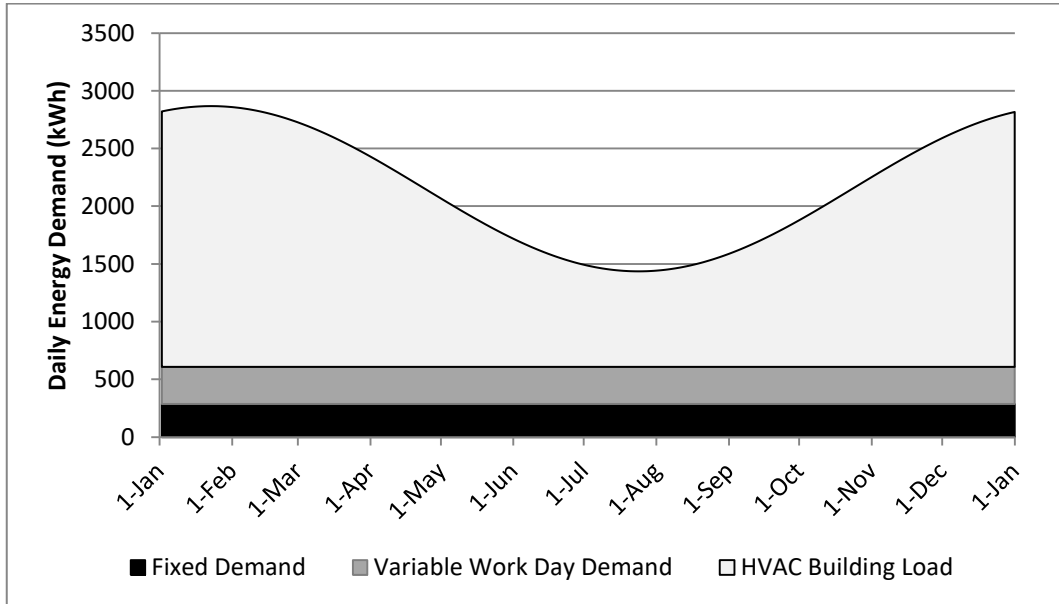
Figure 11. Predicted total site average work day daily energy load (stacked)

Considering HVAC services only, the average daily HVAC load is defined by the equation:

$$\bar{D}_{HVAC,load} = 715.7 \cos\left(\frac{2\pi(n-23)}{365}\right) + 1543.2 \tag{56}$$

whereby integration across the year and removing weekends indicates an annual load of 394.0MWh. The HVAC load for the peak month (January-February) is 49.8MWh.
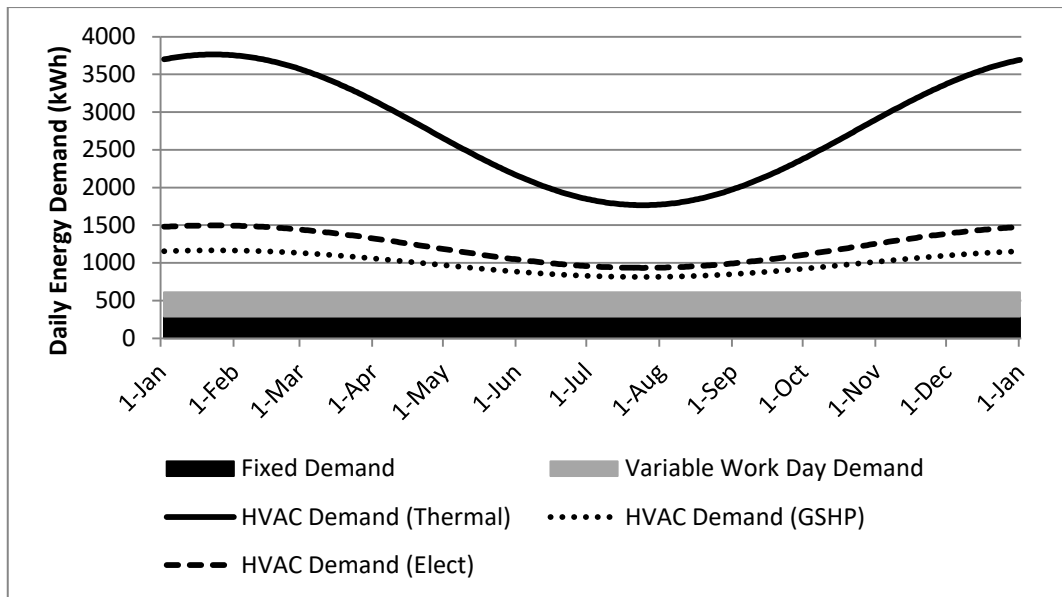
Figure 12. Predicted total site average work day daily energy demand utilising different technologies

The annual variation in energy demand is depicted in Figure 12, where the stacked graph compares the total energy demand for the three HVAC options. The separation of HVAC demand from the other energy usages provides for a specific interrogation and a tailored solution to the generation of renewable energy to meet the needs of the site. The graph indicates the predicted average daily consumption but for full sustainability peak values as per Table 24 are to be accommodated in the sizing of renewable energy systems.

4.5. Energy Generation Capacity

Various technologies were preliminarily identified as suitable, for further site-specific evaluation. This section presents the results and sizing requirements of each energy generation technology, and its final suitability for the specific needs of the site.

The subject site is located at -27.204°S and 153.000°E, with climate data obtained from the nearby Mango Hill weather station (identifier 040986), which is located at -27.230°S and 153.027°E, or 3950m to the south-east of the site. This is considered sufficient in proximity to render valid results.

4.5.1. Solar Technologies

Modelling of solar exposure has been undertaken by an Excel-based model that was developed as part of this project based on Equations 5 through 28 as presented in Section 3.3.1 of this report. The available annual horizontal solar exposure at the site was calculated at $2578kWh/m^2$. Maximum annual exposure on a surface of any tilt and azimuth is $2889kWh/m^2$, which occurs at 32° tilt and a rotation of 10° east of north.

The building orientation of 25° east of north and whilst not essential, placement of solar-based technologies on roof space generally occurs in alignment with building orientation for space maximisation, ease of installation, and aligned separation for ongoing maintenance. At this azimuth, maximum annual exposure is $2874kWh/m^2$ at 32° tilt, a 0.5% reduction from the ideal maximum. A 20° tilt results in a reduced annual solar exposure of $2832kWh/m^2$ (2.0% reduction from peak) but more closely correlates with the total site energy demand variations throughout the year. Both options are indicated in Figure 13, along with a comparison to the horizontal solar exposure and the modelled site energy demands whereby HVAC is serviced by electricity.
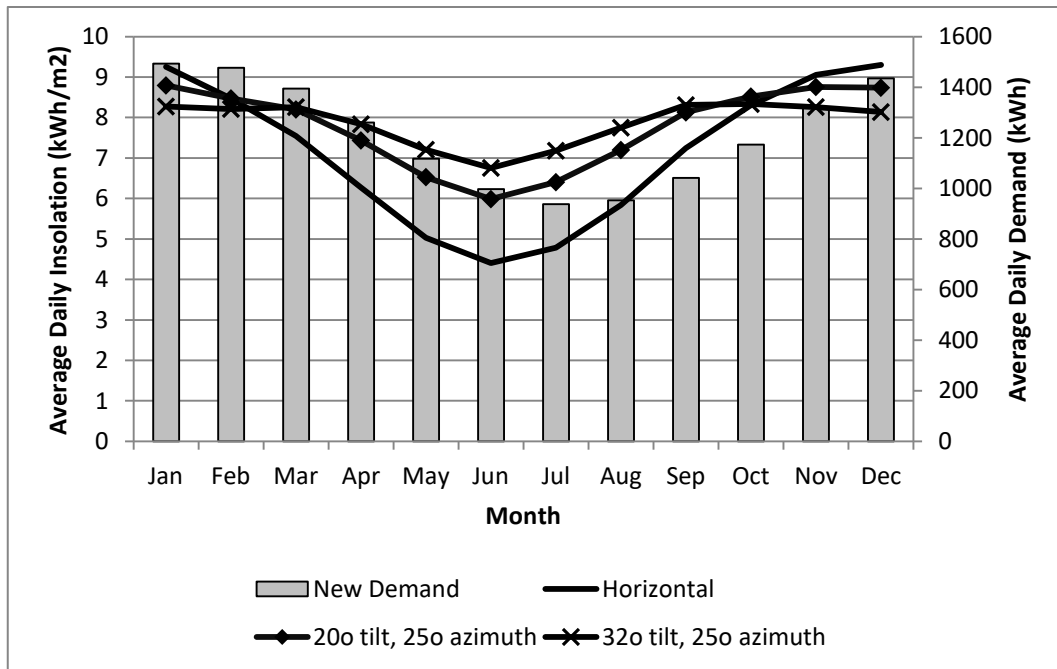
Figure 13. Comparison of annual surface solar exposure and site energy demand

Solar dependent technologies may also be installed on the roof of the sheds to be constructed at site. A similar alignment to the administration building at 25° east of north provides 15° pitch roof at azimuth 65° west of north 65° east of south. At installation parallel to the roof for cost efficiency, the north-west and south-east facing roofs are exposed to an annual insolation of 2713kWh/m^2 and 2516kWh/m^2, respectively.

Solar PV Panels

A commercially-available high efficiency solar PV panel has been selected for evaluation. Specifications under standard test conditions include a rated efficiency of 18%, NOCT 45°C and temperature coefficient of performance -0.45%/^{o}C. Solar PV panels are required to accommodate peak (1-hourly), daily, monthly and electricity demand of the total site. The average daily site electrical demand is modelled by:

$$\bar{D}_{daily,elect} = 280.9 \cos\left(\frac{2\pi(n-23)}{365}\right) + 1215.1 \tag{57}$$

Integration of the formula provides total demand for the year and the selected months. Considering monthly and annual demand first, the four options of PV panel tilt and orientation to match those described above are presented in Table 25. Option 1 requires the least area of solar panels to achieve the annual demand (1052m^2) but January demand requires 1259m^2. Additionally, the angle of tilt requires 0.8m spacing between successive rows of PV panels to prevent shading or an effective length of 2.33m for each panel. By comparison, Option 2 requires 1188m^2 of panels to meet annual and January monthly demand at an effective length of 2.19m. No shading is applicable to Options 3 and 4.

Table 25. Monthly solar PV electricity production

	Monthly Demand (kWh)	Option 1: 32° Tilt 25° Azimuth (kWh/m^2)	Option 2: 20° Tilt 25° Azimuth (kWh/m^2)	Option 3: 15° Tilt -65° Azimuth (kWh/m^2)	Option 4: 15° Tilt 115° Azimuth (kWh/m^2)
January	46,201	36.7	38.9	40.3	41.5
April	37,774	34.4	32.7	29.9	26.5
July	29,166	33.7	30.3	25.7	20.5
October	36,450	37.7	38.5	38.2	37.4
Annual Total	443,511	421.7	415.3	396.9	371.7

Daily and peak demands are considered. The peak demand specified in Table 24 requires the PV panels to supply 121.5kW at its maximum during January, for a peak daily total of 1496kWh. The base load (fixed and variable components only) requires a peak supply of 35.6kW and daily total of 609.4kWh, with the remaining being attributable to HVAC load. The hourly distribution of site electricity demands are compared to the four panel configuration options for a representative day in January in Figure 14. This figure assumes that all energy demands of the site, including HVAC, are supplied by electricity.
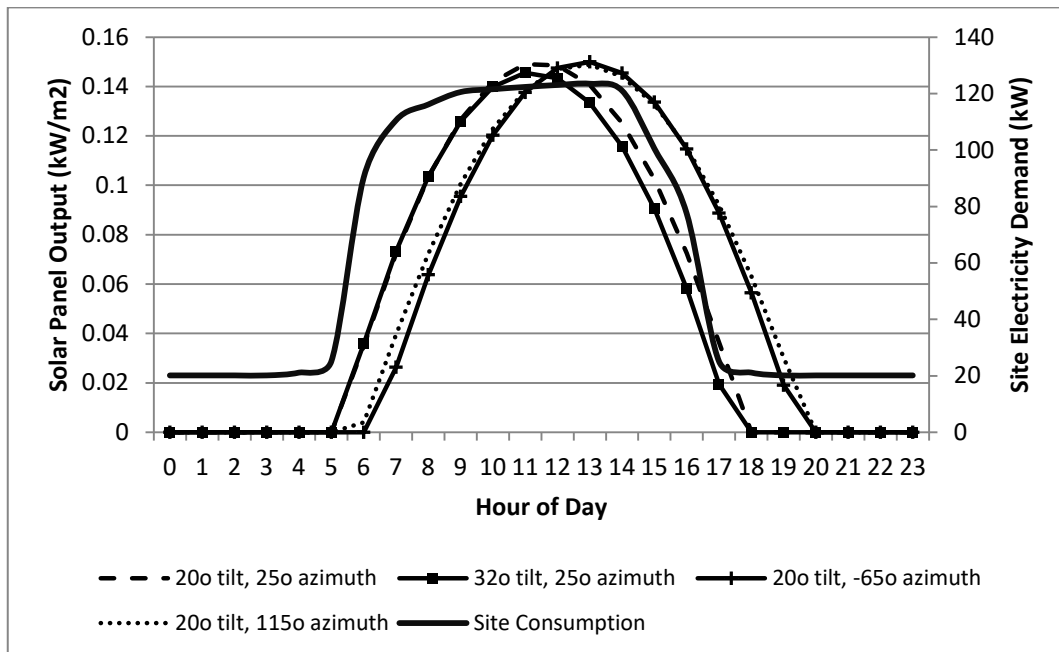
Figure 14. Hourly PV panel output in various configurations in January compared to consumption

Option 2 provides a more favourable distribution compared to Option 1, with Options 3 and 4 providing a delayed output that would assist in accommodating the afternoon demands. Option 2 is able to meet the peak demand with 816m^2 of solar panels and daily total demand with 1197m^2 of solar panels. Therefore, 1197m^2 of solar panels in Option 2 configuration is required to meet hourly, daily, monthly and annual demands. At the rated efficiency, this equates to 497.1kW system, or rounded up to 500kW. Incorporating spacings to prevent shading, the total roof area required for the installation is 1,550m^2, which exceeds the footprint of the administration building.

Single or dual-axis tracking systems increase the total daily output from installed PV panels, particularly in early morning and late afternoon, if additional infrastructure is installed. Modelling predicts that a single-axis tracker provides an additional 22% total daily output and a dual-axis tracker provides an additional 27% total daily output. Peak output remains unaffected. Use of a single-axis tracker would require 982m^2 of panels and dual-axis tracker 943m^2 of panels.

The exclusion of electricity-driven HVAC demand is achieved most efficiently by the 32° tilt, 10° azimuth configuration. Total monthly fixed and variable demand remains relatively constant across all months of the year, with this configuration providing the most consistent monthly output (refer to Figure 13). The system size of 580.0m^2 of panels is dictated by the daily demand of 608.4kWh during the winter months when system output is lowest. Peak daily (34.5kW) and annual demand (222.4MWh) are met by a system of this size. Incorporating spacings to prevent shading, the total roof area required for such an installation is 706m^2.

Building-Integrated Photovoltaics

The use of BIPVs on the roof of the administration centre, at a rated conversion efficiency of 11.2%, generates 237.8kWh/m^2 per annum. As this is lower than the traditional solar PV panels, BIPVs would only require consideration if insufficient energy can be generated from other means at the site. If required, BIPVs could be installed as other elements of the buildings, particularly walls or shade structures, which would be subject to lower solar irradiation but be suitable to supplement total site generation.

As demonstrated with the alternative technologies, sufficient energy can be generated for the site demands and therefore BIPVs are excluded from further consideration at this site.

Evacuated Tube Solar Collectors

ETSCs service only the HVAC demands of the site utilising a chiller with COP of 0.7. The modelled peak hourly HVAC demand requires 313kW of heat to be removed from internal building spaces. Average daily HVAC demand throughout the year using ETSCs is modelled as:

$$\bar{D}_{HVAC,ETSC} = 999.5 \cos\left(\frac{2\pi(n-23)}{365}\right) + 2155.3 \qquad (58)$$

To accommodate peak demand and assuming water is used as the working fluid, equation (33) is used to determine that the ETSCs must heat 1.50L/s of water to 75°C from an inlet temperature of 25°C through the manifold.

The tube collectors themselves have a standard operating efficiency of 70% between the temperatures of 25°C and 75°C, requiring a nominal capacity of 447.2kW to meet peak demand. According to equation (30), the output of the tubes is dependent on their orientation and tilt to absorb available global irradiance. At 20° tilt and 25° rotation east of north, G_{β} (January peak) is 1079W/m^{2}, requiring 414.6m^{2} of collectors. An evaluation of the size of an ESTC installation to meet monthly and annual demands is provided in Table 26. A modified system is also evaluated, as sizing to peak demand results in wastage at all other times of the year. The modified system is sized to the total annual demand but would require additional electricity input from alternative energy sources during summer months to meet total demand.

Table 26. ESTC production

	Monthly Demand (kWh)	Monthly Insolation (kW/m^{2})	Minimum Size Required (m^{2})	Modified Size (566.9m^{2}) Monthly Production (kWh)
January	97,177	272.6	727.5	75,723
April	69,360	223.0	634.8	61,945
July	36,562	198.5	375.9	55,140
October	62,481	264.1	482.8	73,362
Annual Total	**786,684**	**2832.0**	**566.9**	**786,684**

At approximately 0.1m^{2} per tube, 7275 tubes are required at the specified tilt and azimuth to meet full demand, or 5670 tubes in the modified system. Incorporating surrounding space and manifold, each tube requires an area of 0.15m^{2}. At row spacing to avoid shading, total roof area required is 1425m^{2} for the full system or 1110m^{2} for the modified system. The latter could be accommodated completely on the roof of the administration building.

4.5.2. Wind Energy

Average wind data from 1950-2000 sourced from the Bureau of Meteorology weather station at Brisbane Airport (identifier 040842), located 19km to the south, is provided in Table 27.

Table 27. Percentage of day at given wind speeds for selected months

Month		Proportional Wind Speed				
		0-10km/h <2.78m/s	10-20km/h <5.56m/s	20-30km/h <8.33m/s	30-40km/h <11.11m/s	40+km/h >11.11m/s
January	9am	45.3%	36.9%	15.9%	1.7%	0.2%
	3pm	6.1%	38.4%	46.8%	7.9%	0.8%
	Average	25.7%	37.65%	31.35%	4.80%	0.5%
	Cumulative %	*25.7%*	*63.4%*	*94.7%*	*99.5%*	*100%*
	Mean Wind Speed ($\bar{u}$)	16.7km/h (4.63m/s)				
April	9am	47.5%	45.4%	6.3%	0.7%	0.1%
	3pm	18.4%	49.1%	29.4%	2.9%	0.1%
	Average	33.0%	47.2%	17.9%	1.8%	0.1%
	Cumulative %	*33.0%*	*80.2%*	*98.1%*	*99.9%*	*100%*
	Mean Wind Speed ($\bar{u}$)	13.88km/h (3.86m/s)				
July	9am	46.6%	41.8%	9.7%	1.5%	0.3%
	3pm	29.5%	44.5%	20.8%	3.9%	1.2%
	Average	38.1%	43.2%	15.2%	2.7%	0.8%
	Cumulative %	*38.1%*	*81.3%*	*96.5%*	*99.2%*	*100%*
	Mean Wind Speed ($\bar{u}$)	13.47km/h (3.75m/s)				
October	9am	47.2%	38.5%	12.8%	1.4%	0.1%
	3pm	7.0%	35.1%	45.6%	10.4%	1.9%
	Average	27.1%	36.8%	29.2%	5.9%	1.0%
	Cumulative %	*27.1%*	*63.9%*	*93.1%*	*99.0%*	*100%*
	Mean Wind Speed ($\bar{u}$)	16.69km/h (4.64m/s)				

The Weibull parameters k, c, m and n for the selected months are determined from equations (40) through (43) and are provided in Table 28, applicable at the reference height of h_{ref}=10m.

Table 28. Weibull parameters for wind speed at Brisbane airport

Month	k_{ref}	c_{ref}	m_{ref}	n
January	2.645	5.549	0.245	0.01
April	2.207	4.469	0.266	0.01
July	1.709	4.109	0.274	0.01
October	2.379	5.516	0.245	0.01

The power output available from one of the largest commercially available wind turbines – Proven 15, 15kW turbine at installed height of 25m, rotor diameter 9.0m – is evaluated for suitability. The specifications indicate a cut-in wind speed of 2.5m/s and cut-out wind speed of 70m/s. The height-adjusted Weibull parameters and average wind speed are provided in Table 29.

Table 29. Weibull parameters at 25m above ground at Brisbane airport

Month	K	c	m	N	$\bar{u}_{25}$ (m/s)
January	2.907	6.946	0.245	0.01	6.94
April	2.425	5.702	0.266	0.01	5.70
July	1.878	5.282	0.274	0.01	5.28
October	2.614	6.904	0.245	0.01	6.90

The probability of wind speeds between 0 to 18m/s are presented graphically in Figure 15 below. All wind speeds below 2m/s provide insufficient energy for the turbine to produce power.
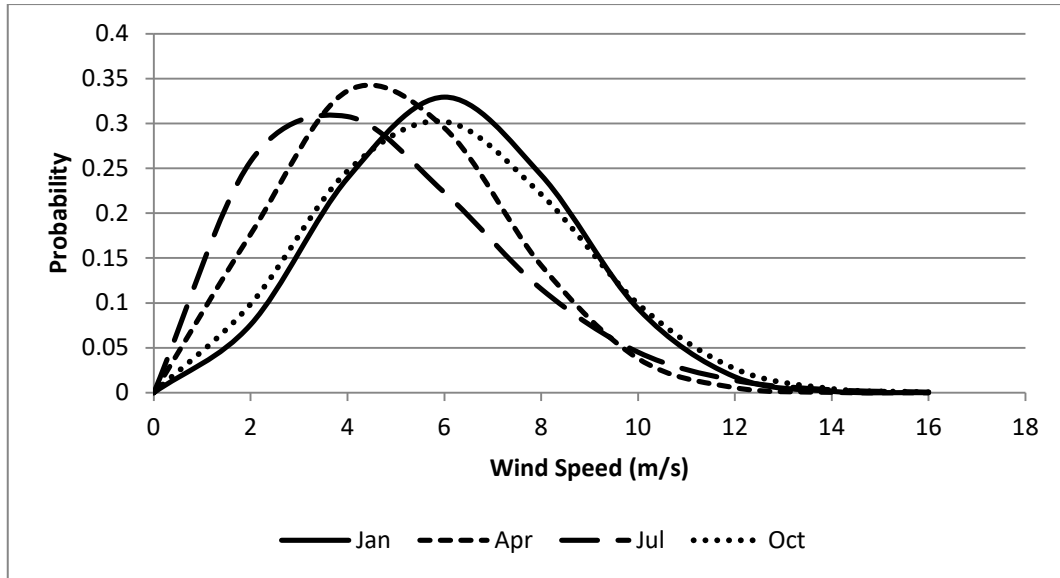
Figure 15. Probability distribution of wind speed for the representative months

The generation of power in a free stream is determined by equation (45). An overall combined average system efficiency and power coefficient of 31.6% is applied to calculate the monthly power output values shown in Table 30. The theoretical power output at each wind speed is incorporated with the probability of the given wind speed.

Table 30. System power output.

$\bar{u}$ (m/s)	P_{out} (kW)	Jan $\phi\, P_{out}$ (kWh)	Apr $\phi\, P_{out}$ (kWh)	Jul $\phi\, P_{out}$ (kWh)	Oct $\phi\, P_{out}$ (kWh)
0	0	0.00	0.00	0.00	0.00
2	0.096	5.45	12.29	18.54	7.09
4	0.773	137.46	187.08	177.04	141.96
6	2.609	639.44	554.20	433.36	586.14
8	6.184	1116.29	631.99	532.18	1016.39
10	12.079	842.22	331.73	406.35	888.54
12	20.873	274.39	84.76	212.80	412.68
14	33.146	36.61	10.67	80.66	102.40
16	49.477	0.00	0.00	22.88	13.38
18	70.447	0	0	0	0
	Total	**3051.86**	**1812.72**	**1883.83**	**3168.58**

The required monthly output from the wind turbine/s varies depending on the source of HVAC services. Taking electricity-driven vapour-compression HVAC, monthly electricity demand for January (peak) and July (minimum) equate to 27,310kWh and 10,276kWh, respectively. A total of nine (9) wind turbines would be required to achieve year-round sustainability. The use of geothermal GSHP for HVAC services would similarly require 6 wind turbines for sustainability. An operational noise level of 65dB per turbine is specified for the selected model and, combined with possible interference with telecommunication signals, these factors require further consideration given the proximity to a residential area.

4.5.3. Geothermal Energy (Ground Source Heat Pump)

The annual, monthly and peak HVAC demands calculated in Section 4.4 need to be used in equation (46), along with estimated ground conditions to determine the length of boreholes required for HVAC requirements. Detailed geotechnical testing at the site would be required to confirm soil type and thermal conductivity. It is assumed that the majority of the depth of soil at the site would be wet shale, R_{ga}, R_{gm} and R_{gd} being 0.23m.K/W, 0.19m.K/W and 0.10m.K/W, respectively. A standard installation of 150mm diameter borehole with 25mm U-shaped DR-9 high density polyethylene pipe and thermally-enhanced grout provides an R_b of 0.10 and at 8m spacings between boreholes, the impact of adjacent boreholes (T_p) is estimated at 5°C and F_{sc} is 1.04. At COP of 4.5 for heat exchanger component only, C_f is 1.225. The average ground temperature at depth for Brisbane remains constant at 22°C and the working fluid achieves a maximum temperature of 50°C from space cooling and returns from the ground at 22°C.

The length of tubes required to dissipate the full building HVAC load is 8,965m (single direction). At a nominal maximum depth of 100m, 90 boreholes would be required, covering an area of 64m x 72m.

As the calculation is sensitive to ground conditions (thermal conductivity and adjacent borehole penalty), the results of geotechnical testing may significantly alter the required length and coverage area.

Consideration may be given to utilising GSHP for smaller stand-alone HVAC units. The HVAC load for the office in the Stores building would require a tube length of 254m, or 3 boreholes at 90m depth. The perennial HVAC needs of the IT server room could be serviced separately by GSHP, requiring a tube length of 205m, or 3 boreholes at 75m depth.

The use of geothermal or GHSP renewable energy still requires electricity to operate the chiller and working fluid circulation pumps, therefore is reliant on another renewable energy generation source such as solar PV panels. The demand, however, is reduced as a result of the underground heat exchange. The modelled average daily electricity required to power the GSHP with an overall COP of 4.0, which incorporates the chiller and fluid pumps, is described by the equation:

$$\bar{D}_{HVAC,GSHP} = 176.4 \cos\left(\frac{2\pi(n-23)}{365}\right) + 380.3 \qquad (59)$$

Annual electricity consumption required from another renewable energy source to specifically operate a complete GSHP HVAC system on work days is modelled to be 96.5MWh. For the Stores office and IT server room stand-alone applications, the alternative energy source would need to supply 2.73MWh and 2.2MWh, respectively.

4.6. Energy Storage

Three categories of energy storage were identified in Section 2.4.5 for evaluation – Chemical (lithium-ion batteries and flow batteries), Sensible Heat Storage and Latent Heat Storage. The previous section showed that energy generation does not perfectly match site energy consumption. Excess energy may be stored to provide supply as it is required. Stored energy may be used at times when generation does not meet demand – such as non-sunlight hours, refer to Figure 16 – or modelled levels, such as during prolonged periods of cloud cover. Modelled capacities in this section assume a maximum of three consecutive cloudy days and coincide with a reduction in demand due to lower HVAC requirements.
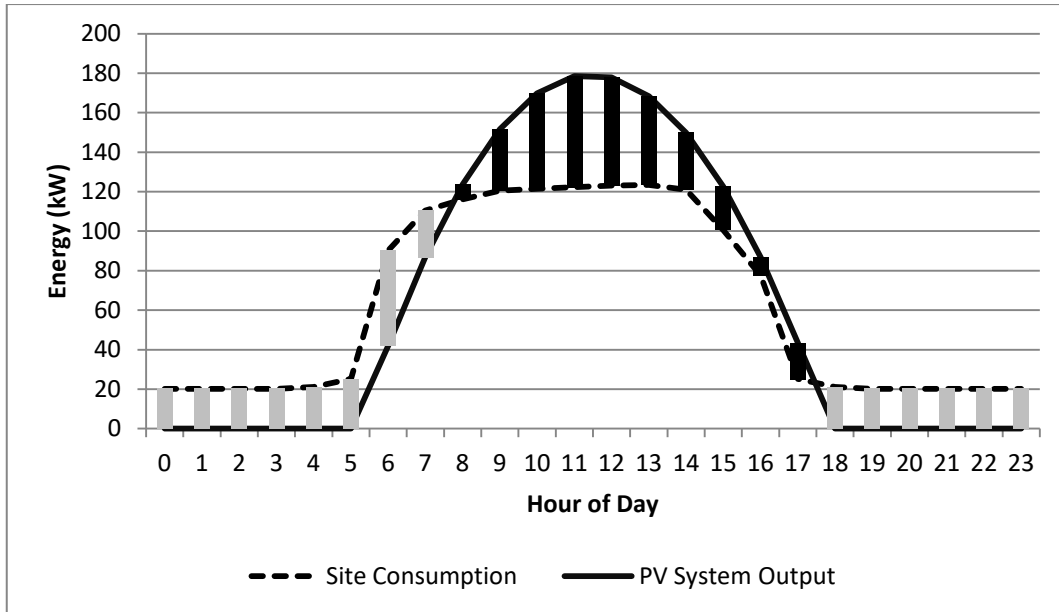
Figure 16. Difference between site energy generation and consumption

This representative January day with proposed 1197m^2 solar PV panels providing electricity for HVAC demand shows excess energy generation between 8am and 5pm, and depletion at other times. An excess of 40.85kWh is produced for this 24 hour period. Table 31 indicates that an excess of energy is generated each month throughout the year from the sole-PV system.

Table 31. Site energy availability

	Daily Excess(kWh)	Monthly Excess (kWh)
January	+40.9	1267.9
April	+63.7	1911.0
July	+229.2	7105.2
October	+280.2	8686.2
Annual Total	**+53,603**	**+53,603**

The size and type of energy storage dictates the rated instantaneous (peak) output and capacity to support diminished supply of energy overnight and during adverse weather conditions. Table 32 provides detail on the requirements of the energy storage system to meet site demands. Peak draw indicates the largest difference between renewable energy

generation and site demand for any given hour, and nightly draw indicates the total energy required from the time demand exceeds generation until the following demand when generation exceeds demand. During cloudy conditions, modelling has incorporated a reduction in insolation based on real data for the selected months and incorporated an associated reduction in HVAC demand. The impact of cloud cover is greatest in the summer months which experience the largest reduction in available insolation due to thick persistent cloud cover. Cloud cover in winter months is thinner, moves quicker and daily insolation are therefore not affected to the same extent.

Table 32. Energy storage requirements - chemical

	Mean Day		Cloudy Conditions	
	Peak Draw Required (kW)	Nightly Draw (kWh)	Three-Day Peak Draw (kW)	Three-Day Total Draw (kWh)
January	48.3 (6-7am)	320.7	42.9 (7-8am)	320.4
April	57.5 (6-7am)	345.1	47.3 (6-7am)	96.9
July	51.5 (6-7am)	325.2	50.6 (6-7am)	141.5
October	24.2 (6-7am)	282.9	46.1 (6-7am)	719.4
Annual Peak	**57.5**	**345.1**	**50.6**	**719.4**

4.6.1. Chemical Storage

Lithium-ion batteries are commercially available as 14kWh units, connected in series up to 200kWh at total DC-charge, AC-discharge efficiency of 81.0%. Peak draw of the 14kW battery is 6kW, continuous draw is 4kW. Vanadium-water flow batteries are available as 11kWh units, connected in series up to 5,000kWh at total DC-charge, AC-discharge efficiency of 76.0%. Peak draw of the 11kWh unit is 7.5kW, continuous draw is 5kW.

To meet the worst-case scenario specified in Table 32 at rated efficiencies, the sizes of each type of battery are shown in Table 33. A reliability of 96% equates to 5 instances of three-day periods within one year during which the system would fail to meet full energy demands.

Table 33. Battery storage – PV only

	Efficiency (DC-AC)	Size to Provide Peak Draw (kWh)	Size to Provide Nightly Draw (kWh)	Size to Provide Three-Day Draw (kWh)	Annual Reliability at 500kWh size
Li-ion Battery	81.0%	166	426	888	96%
Vanadium-Water Flow Battery	76.0%	111	454	947	96%

Applying the same process for ETSC-driven HVAC (modified size) and GSHP HVAC systems provides the outcome presented in Table 34. At times when the ETSCs and GSHPs are insufficient to meet site HVAC demands, it is assumed that backup electricity is provided from the battery storage. The co-generating PV system is sized at 580m^2 or 86.4kW for ETSC and 5.8m^2 or 1kW for GHSP to supply the IT server room only (24-hour operation) when installed at preferred tilt and azimuth. Due to ETSCs consuming the full roof space of the administration building, the installation of solar PV panels on storage shed and workshop facing north-west requires a larger size system at 90kW to produce the same output. Peak draw occurs at 6am, before all renewable technologies generate electricity but the site is in operation.

Table 34. Battery storage – ETSC-PV combination and GSHP-PV combination

		Size for Peak Draw (kWh)	Size for Nightly Draw (kWh)	Size for Three-Day Draw (kWh)	Recom-mended Size	Annual Reliability at Recom-mended Size
Evacuated Tube Solar Collectors-PV System	**Li-ion Battery**	162	426	927	500kWh	96%
	Vanadium-Water Flow Battery	109	454	988	500kWh	96%
Ground Source Heat Pump-PV System	**Li-ion Battery**	166	377	839	500kWh	96%
	Vanadium-Water Flow Battery	111	402	894	500kWh	96%

A 500kWh battery of either nature provides the same overall reliability for the variety of scenarios presented. The recommended size borders the upper limit of Li-ion battery capacity but fits well within the capacity of vanadium-water batteries. The feasibility of each, including life expectancy, is included in section 5.2.

4.6.2. Sensible Heat Storage

The use of water for sensible heat storage is considered due to its availability, low cost and suitability for long-term storage. Two options are considered: a) heated water from excess energy generated from ESTCs; and b) cooled water through by vapour-compression cycle utilising excess electricity generated from PV panels.

The excess energy produced by the stand-alone PV system was specified in Table 31 and the energy demands in Table 32. Peak shortfall in energy supply occurs between 6am and 7am throughout the year. It is assumed that all PV generation supports fixed and variable demands, with the shortfall being attributable to unsupplied variable demand and largely HVAC requirements. With latent heat storage servicing HVAC only, fixed and variable demands are removed, with modelling predicting the HVAC demands in Table 35. Sub-generation demand refers to the total energy required during the period when demand exceeds energy generation from renewable sources – that is, generally between 4pm and 7am. Incorporating heat generation from equation (50), energy loss through the vessel wall (assuming 1m radius, U=0.2) from equation (51), and the operating efficiency of the unit when hot or cold water is used, the required water volumes are calculated for both options.

Table 35. Energy storage requirements – sensible heat

	Mean Day		Heating	Cooling
	Peak HVAC Demand Required (kW)	Total HVAC Sub-Generation Demand (kWh)	Required Water Volume at 75°C	Required Water Volume at 4°C
January	48.3 (6-7am)	72.1	2.91m^3	1.94m^3
April	56.2 (6-7am)	72.5	2.93m^3	1.95m^3
July	34.2 (6-7am)	60.2	2.42m^3	1.61m^3
October	55.7 (6-7am)	61.6	2.48m^3	1.65m^3
Annual Peak	**56.2**	**72.5**	**2.96m^3**	**1.95m^3**

A volume of 2m^3 for cooling or 3m^2 for heating would meet HVAC demands during fringe hours of the day, however, cannot meet the overnight electricity demands of other electrical equipment at the site.

4.6.3. Latent Heat Storage

Cold storage of ice is evaluated as the most applicable latent heat storage option for the small-scale needs of the site and the maturity, simplicity and relative low cost of the technology. As for sensible heat storage, excess daily energy is used to lower the temperature of water and then convert to ice. Assuming starting water temperature of 25°C and storage temperature of -4°C, 1kg of water requires extraction of 447.2kJ. At a conversion efficiency of 60% through a commercial ice generator and fraction of heat loss through the storage unit, the vessel volume required to meet demand for the peak month of April is 0.348m^3 or 0.4m^3 to accommodate expansion. As with sensible heat storage, overnight energy demand is not met by latent heat storage and would require a further storage mechanism.

4.7. Water Efficiency Opportunities

The three existing sites used a combined 843kL of water during 2015/16 at a cost of $5,900. Accounting for the proposed change in recycled water acquisition directly from site storage, it is estimated that the new site will require:

- 60kL of potable water through a standard 25mm water meter; and
- 2.25ML of recycled water with suitable on-site storage capacity.

The supply of the potable water for human consumption and kitchen purposes is a legislative requirement and has little opportunity for further saving due to tight regulations on minimum product flow rates, for example tap flows. The installation of an AquaTrip© device or similar that includes smart controls to automatically shut off potable water supply to the site if consumption exceeds a set volume per time interval would prevent unexpected or undetectable leaks and saving on clean water resources. With these measures in place and those mentioned in section 2.7.3, the potable water volume is minimal compared to total site demand and therefore excluded from further calculations.

Figure 17 demonstrates the annual variation in predicted recycled water consumption against historical median (50th percentile) and low (5th percentile) rainfall for the nearby Mango Hill weather station. Winter rainfall is significantly lower than summer rainfall; however, consumption remains relatively constant throughout the year.
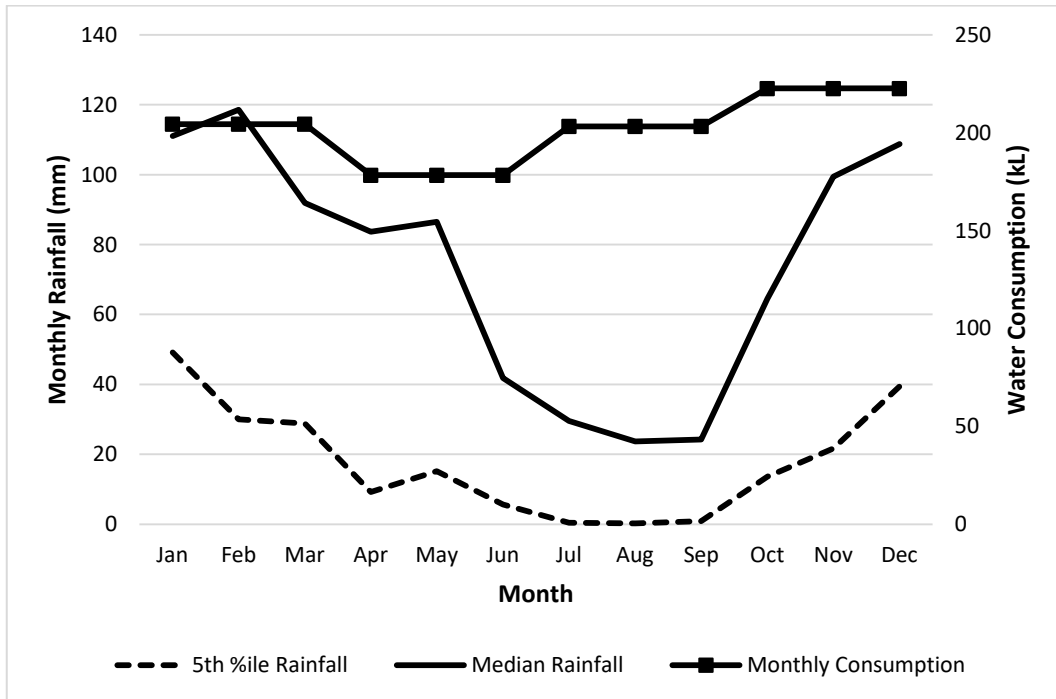
Figure 17. Median and low (5th percentile) rainfall versus site consumption

The size of a system to capture excess rainfall and run-off during summer and autumn months to supply winter demand is evaluated. A 200kL underground tank serviced by 10,000m^2 of treated car park and building roof run-off at estimated 90% efficiency is modelled for the two rainfall scenarios in Figure 18.
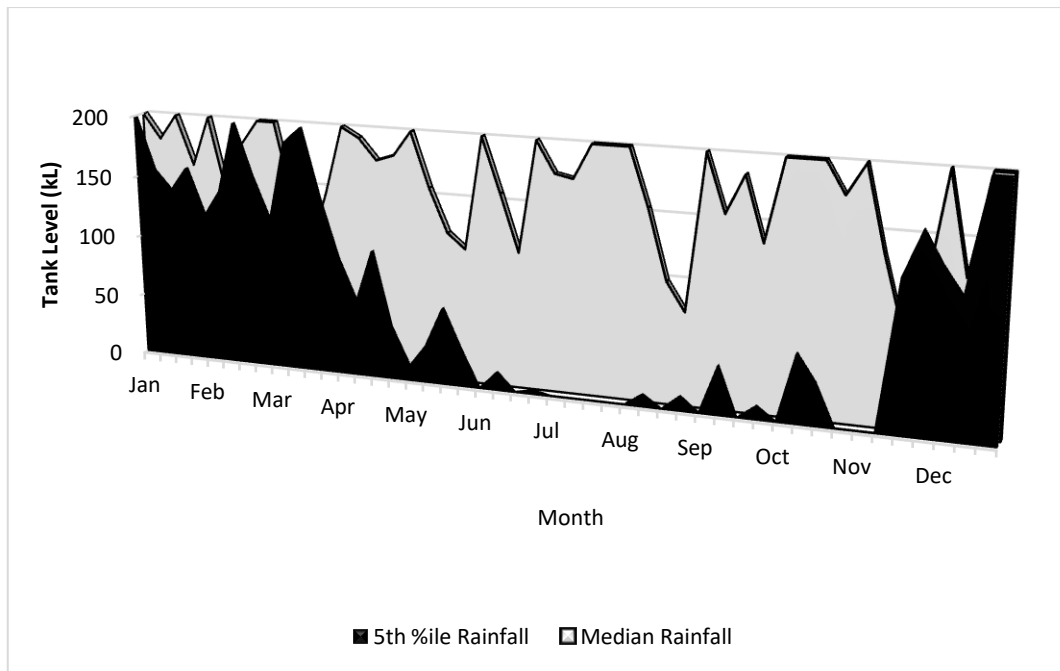
Figure 18. Recycled water availability in 200kL tank for different rain scenarios

The selected tank size of 200kL provides 100% sustainability throughout the year for median rainfall. Partial depletion of the tanks occurs each calendar month but rainfall is sufficient and frequent enough to replenish the tank without running dry. The low rainfall scenario results in only 67.5% of the annual recycled water demand being serviced by the tank, a shortfall of 788kL which would require purchasing. The pattern of rainfall indicates that a larger tank size would prolong the initial time to depletion during the month of June. To provide complete sustainability for the 5th percentile scenario, a total tank capacity of 975kL is required. At a cost of approximately $1,000 per kL capacity and a purchase price of recycled water at $2.05/kL, the additional 775kL is not justifiable with a payback period of 480 years.

A reduction in the potable water demand at the site also reduces the size of water meter required compared to the existing sites, with reduced water access charges applicable from the service provider. The current billing methodology also charges sewerage fees as a proportion of the water access meter size and water consumption volume. At median rainfall, and therefore no external charging for any shortfall in recycled water, the total annual cost saving from the site consolidation and water rationalisation equates to $6,330 per annum.

4.8. Summary of Site Options

No single technology has the ability or capacity to supply the complete energy demands of the new site with 100% reliability. To achieve the objective of sustainability, a combination of generation and storage technologies is required. Table 36 presents each of the options and provides commentary of suitability following detailed investigation. It is assumed that the identified energy and water efficiency technologies and practices are implemented in all scenarios. Note that the battery size remains unchanged throughout all options as it has been sized according to the three-day cloud cover scenario to give 96% reliability. The battery size could be reduced for each applicable option should the lower reliability be acceptable at the time of construction. However, for the purposes of this report, the aim is sustainability to the greatest feasible extent. To achieve this end, and account for unforeseen circumstances, it is recommended that the site be supported by back-up power sources including connection to grid electricity for very minimal use and an emergency site backup diesel generator with automatic operation during power outages. Connection of the generator to the site building management system will enable automatic shut down of all non-essential equipment to minimise draw on the generator and reduce consumption of fossil fuels.

Table 36. Overview of energy generation and storage options

Technologies	Size	Location	Level of Suitability
Solar PV + Li-ion battery storage	500kW 500kWh	Admin & shed Ground	High reliability throughout the year; simplicity in technologies and configuration; batteries subject to deep discharge at upper limit of capacity which reduces lifespan
Solar PV + Va-H_2O battery storage	500kW 500kWh	Admin & shed Ground	High reliability throughout year; simplicity in technologies and configuration; suitable battery capacity and ability to generate high peak power on demand
Solar PV + ETSC + Battery storage	90kW 5670 tubes 500kWh	Stores/workshop Admin Ground	High reliability; some complexity in configuration; some wasted heat energy; reduced solar panels but replaced with ETSCs
Solar PV + Geothermal + Battery storage	500kW 210m 500kW	Admin & shed Adjacent admin Ground	High reliability; geothermal provides little benefit for site climate compared to simpler PV panels
Solar PV + Geothermal + ETSC + Battery storage	90kW 210m 5670 tubes 500kW	Stores/workshop Adjacent admin Admin Ground	Unnecessary configuration unless site being used for test case / demonstration purposes; simpler arrangements achieve same outcome
Solar PV only	Not recommended		Only meets site demand generally between 7am and 4pm. Site requires energy 24 hours per day.
Wind Turbine	Not recommended		Insufficient wind at site to meet demand; requires 4 turbines that would exceed allowable noise levels for the location.

Geothermal (comprehensive)	Not recommended	Significant effort to achieve same outcome of more basic solar PV or ETSCs and still requires electricity source; not as suited to sub-tropical climate compared to cool climates
Sensible Heat Storage	Not recommended	May be suitable to offset HVAC energy demands during shoulder periods but other storage options are sufficient size to accommodate demand. Requires additional storage technology to supply overnight energy demand.
Latent Heat Storage	Not recommended	As per Sensible Heat Storage but more expensive option.

CHAPTER 5 – DISCUSSION

5.1. Overview

Various stand-alone and combinations of energy generation and energy storage technologies have been evaluated throughout this report. Opportunities for energy saving by installing efficient equipment and practices have also been identified to reduce peak and overall energy demand, effectively reducing the size and cost of HVAC equipment. Furthermore, the potable and recycled water demands of the site have been calculated and evaluated against rainfall to determine the preferred tank size.

Several configuration options of generation and storage technologies exist to viably support the full energy demands of the site. The final selection of the preferred configuration is based on financial feasibility, payback period, comparison to grid-supplied electricity and life-cycle cost difference between renewable options and fossil-fuel based electricity.

5.2. Financial Feasibility Assessment

The comparison of costs associated with each generation-storage configuration option over a 25 year period is presented in Table 37. For simplicity, it is assumed that the cost of maintenance and electricity will rise in accordance with inflation and the cost associated with replacing Li-ion batteries remains constant, effectively reducing by the inverse of inflation rate. Under this mechanism, the presented model provides results consistent with net present value.

The cost of grid-supplied electricity currently varies with monthly peak demand but is rounded to $0.25/kWh. The predicted annual consumption is 613.3MWh. Annual maintenance service costs are assumed to be 2.5% of the installation cost. All other costs associated with the HVAC system, including chillers, compressors, ductwork and the like are expected to remain consistent with existing costs and similar across all options, and are therefore excluded from the options. Latent and sensible heat storage would require additional infrastructure but are not evaluated as suitable options due to their deficiencies.

The combination of a 90kW solar PV system, 5,670 evacuated tube solar collectors and a 500kWh vanadium-water flow battery presents the best option with a payback period of 7.4 years. Over the 25 year period, this equates to an overall saving of $2,703,750.

Table 37. Feasibility comparison of energy options

Option Configuration	Size	Element Cost	Lifespan (years)	25-year System Cost	Payback Period
Solar PV + Li-ion battery storage	500kW 500kWh	$500,000 $625,000	25 5	$4,328,125	28.2 years
Solar PV + Va-H$_2$0 battery storage	500kW 500kWh	$500,000 $350,000	25 40	$1,381,250	9.0 years
Solar PV + ETSC + Battery storage	90kW 5670 tubes 500kWh	$115,000 $230,000 $350,000	25 25 40	$1,129,375	7.4 years
Solar PV + Geothermal + Battery storage	500kW 210m 500kW	$500,000 $300,000 $350,000	25 100 40	$1,868,750	12.2 years
Solar PV + Geothermal + ETSC + Battery storage	90kW 210m 5670 tubes 500kW	$115,000 $300,000 $230,000 $350,000	25 100 25 40	$1,616,875	10.5 years

The preferred option justifies the upfront capital expenditure; however, opportunities may exist to offset these costs through Federal Government funding programs that have been established specifically to reduce greenhouse gas emissions and councils' carbon footprints. The detailed justification provided within this report can be used to further substantiate any such application. Any external funding will minimise initial expenditure and provide the equivalent additional benefit over the 25 year life of the assets. Furthermore, the value of the project in demonstrating council's commitment towards achieving global targets, providing industry leadership for local organisations to take similar action and the savings that may be realised from future climate-induced severe weather events are not priced but should be incorporated into final decision-making regarding this project.

At median rainfall, water savings from the proposed system amount to 2.25ML per year. Connection with potable water supply is required for legislative purposes but the meter size would be a minimal 25mm connection for the supply of estimated 60kL per annum. Maintenance is estimated at 0.5% per annum, including the replacement of pumps every 5 years. Recycled water costs are modelled at $2.05 per kL and potable water at $3.65 per kL. After the 40 year life expectancy of the tank, total cost saved from water costs is $179,580, or $60,240 short of continued potable water supply. This calculation assumes water costs rising with inflation rate. Variable supplies and the impact of future uncertainly of water availability as a result of climate change is likely to result in higher price rises with water in the future, making the storage option a more financially feasible outcome.

Table 38. Feasibility of water storage

Outcome	Size	Element Cost	Lifespan (years)	40-year System Cost	Payback Period
Potable water supply + Underground tank	25mm meter + 200kL tank	$ - $200,000	Perpetual 40 years	$240,000	Not achieved

5.3. Technology Advances

The content, calculations and cost estimates provided in this report as current in 2016. Rapid advances have been made in technology efficiencies over the past 10 years, and industry research, development and competitiveness are driving higher energy outcomes at lower prices. This trend is expected to continue as governments support industry to achieve agreed global carbon emission reduction targets. Current predictions indicate that by the year of this proposed development – in 2020 – solar photovoltaic cells will be achieving efficiencies towards 25% and panels will be replaced with clear PVC solar cells rolled out on any roof or surface. Energy storage solutions will improve in capacity and price as stand-alone or off-grid commercial developments gain momentum.

In line with the technological advances, it is recommended that the details of this report are reviewed, updated and expanded to include new technologies that emerge in the ensuing three years.

CHAPTER 6 – CONCLUSIONS

This report has demonstrated that Moreton Bay Regional Council has a prime opportunity to demonstrate its commitment towards achieving responsible carbon reductions in line with global and national targets in a manner that is financially beneficial to ratepayers over the expected life of the renewable energy and recycled water system. Various options and configurations are possible that will achieve that end, however, estimated 25-year lifecycle costs vary from $1.13 million to $4.3 million for energy purposes and $240,000 over 40 years for water recycling.

A total of 613.3MWh of grid-supplied electricity are predicted to be saved per annum, equivalent to 576.3 tonnes equivalent-CO_2. 2.25ML of water can be recycled for on- and off-site purposes. These outcomes provide cost savings to the rate payer, promote council's leadership in the field of energy and water sustainability for other organisations to follow, and contribute to the social and ethical responsibility of limiting the effects of future climate change.

The construction of the new Works Depot described in this report is currently scheduled for 2020. The technologies described within this report are current in 2016 but are likely to be swiftly superseded by more efficient, less visually-intrusive and longer-lasting equipment at a lower price. A reassessment of available options should occur during the detailed design stage of the project to ascertain applicable changes and detail the specific locations, installation methods and structural design requirements to withstand the new technologies.

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APPENDIX A – PROJECT SPECIFICATION

ENG4111/4112 Research Project

Project Specification

For: Brent Armstrong

Title: Towards 2020: An Energy-Neutral Council Works Depot

Major: Mechanical Engineering

Supervisors: Dr Ruth Mossad, BEng, MEng, PhD

              Mr Matt Kosar, Moreton Bay Regional Council

Sponsorship: Moreton Bay Regional Council

Enrolment: ENG4111 – EXT S1, 2016

              ENG4112 – EXT S2, 2016

Project Aim: To investigate and recommend a suite of innovative technologies to achieve energy-neutrality for inclusion in the future construction of a consolidated Council Works Depot, including concept layout and feasibility assessment based on local climatic conditions.

1. Obtain electricity consumption data for a 12-month period, including interval data where it exists (for which the Energex meter at the site records electricity consumption in either 15-min or 30-min periods), for the existing three sites that are to be consolidated into a single site.

2. Obtain water consumption data from the existing three sites, including potable and recycled water.

3. Research options for water capture and any legislation or standards applicable to the re-use of harvested stormwater. Investigate the type, size and power needs of infrastructure associated with stormwater harvesting. Determine the processes that will require water usage at the Depot and applicable volumes. Undertake a desktop analysis to determine the proximity of the nearest reticulated recycled water network and its size.

4. Research energy generation and storage technologies for consideration and evaluate for site/climate suitability.

5. Research energy-efficient technologies that could be suitably stipulated as specifications of future buildings, including insulation minimum standards, skylights, building orientation, building management systems and smart technologies that reduce energy wastage.

6. Calculate future total site energy demand and energy generation/storage capacity.

7. Prepare site concept plan, locating all office spaces, workshops, vehicle storage, equipment stores, vehicular movement paths, and energy generating/storing and water saving initiatives.

8. Prepare cost feasibility analysis, including life cycle evaluation.

If time and resources permit:

9. Evaluate vehicular movements, including frequency and destination, to determine if site consolidation results in reduced travel distance and therefore overall lower fuel consumption.

10. If energy generation capacity exceeds demand requirements, consider options for co-location of other industry or council services at same location.

11. Determine options and feasibility for retro-fitting a separate existing Depot (brown-field site) with energy-efficient technologies to achieve complete sustainability.

APPENDIX B – SITE CONCEPT PLAN

LOCATION PLAN
SCALE : 1:5000@A1

SITE 2

SITE 1

BOUNDARY ROAD

LEGEND:
G GENERATOR
F FIRE HYDRANT BOOSTER
T TRANSFORMER

SITE 2

CAR PARK
(200 CARS)

SITE BOUNDARY

TRUCK PARKING

TRUCK PARKING

WORK
SHOP

WASH
BAY

STORAGE

LOCKERS

STORE

SITE 1

OFFICE
(2 STOREY)

G

F

CAR PARK
(68 SPACES)

SITE BOUNDARY

BOUNDARY ROAD

PROPOSED WORKS DEPOT

CONCEPT DESIGN

1:1000 @ A1   0 10 20 30 40 50   100

N

Project No: 15570BNE
Date: 04.12.15
Scale: 1:1000@A1
                 1:2000@A3
Drawn / Check: TB

SK - 01   1