A Feasibility Study of Solar PV in Reducing Peak Electrical Demand and Consumption Costs in Commercial Buildings in Melbourne

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Declaration

This dissertation is an authentic account of original research conducted by me which has not been submitted towards another degree.

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Abstract

A significant part of the electricity cost of commercial buildings in Melbourne is due to high peak demand that usually occurs on hot summer afternoons. Installation of solar PV on commercial facilities to reduce this cost is not as wide spread as it is in the residential section, despite sharp increases in electricity prices and falling solar PV system costs. Existing literature has identified peak demand on transformers servicing commercial buildings in Melbourne as having a high coincidence in timing with high PV system output. This thesis investigates the feasibility of using solar PV to reduce electricity consumption and peak electricity demand in Melbourne commercial buildings to reduce electricity cost. It also investigates the technical issues involved, and whether such a system would be considered financially feasible by businesses in today's market.

A case study was conducted on a commercial facility (a Coles supermarket) in Melbourne to determine how well its peak demand profile matches PV output from a local array, the reliability of such a system in offsetting peak demand, and the potential savings based on the tariff in place.

The results show that only a maximum of 30% of PV system rated power output can be reliably counted upon to offset peak demand in summer. The timing of high PV output, whilst better than in residential applications, may still not coincide exactly with peak demand periods when using a north facing array to maximise annual energy output. In the case study and for other buildings with early afternoon demand peaks (typical of cooling related demand), an array rotated approximately 50 degrees to the west of True North, would provide an increase in demand offset, and a net increase in financial benefit. This maximum PV penetration could reduce a commercial building's annual grid electricity cost by $144 per kW installed depending on the tariff structure in place.

PV synched demand management is an alternative that could improve the effectiveness of such a system, by temporarily reducing building demand during periods of low PV output, so that peak demand event is avoided.

In conclusion, commercial buildings with summer peak demand that is substantially higher than winter, are better suited to PV offset due to tariff structures, and solar resource availability. These typically include buildings that have high cooling demands, such as office buildings, supermarkets, universities, and hospitals.

Acknowledgements

I would like to acknowledge the help of Dr Jonathan Whale and Dr Samuel Gyamfi for their support in guiding and shaping this work. In addition a big thank you goes to Paul Lang of Coles who generously supplied consumption and demand data, and answered questions throughout this piece of work, and the Melbourne City Council who kindly provided Solar PV data from their Queen Victoria Market site.

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Definitions

Consumption	Electricity used (measured in kWh)
Demand	Average value of electric load over a period of time (known as the demand interval)
Demand Management	The planning, implementation and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired change in the utilities load shape. i.e. changes in the time pattern and magnitude of a utility's load (Gellings, 1981)
Peak Demand	The maximum demand that has occurred over a specified period of time.
PV System	Solar Photovoltaic System
Tariff	Schedule of charges for supply, consumption and demand of electricity levied by electricity retailers and distributors.

Chapter 1 – Introduction

1.1 Motivation for the research

In 2009-10 Australia's energy consumption totalled 3703 petajoules, with commercial building energy consumption accounting for 8% of this (ABARE, 2011). Based on a breakdown of commercial sector end use (Centre for International Economics, 2007), an estimated 50-75% of energy is consumed in the form of electricity, equating to between 40 and 60 billion kWh annually out of a total national electricity consumption of 213 billion kWh (US Dept. Of Energy, 2012). Growth in Australian electricity consumption has averaged 2.5% per annum over last 10 years (Dept. Resources, Energy & Tourism, 2011). Data published by the Australian Energy Market Operator (AEMO, 2012b) reports that Victorian business electricity prices have undergone significant increases (15% in Financial Year 09/10, 13% in Financial Year 10/11, 17% in Financial Year 11/12). Although this rapid escalation in consumption is forecast to slow, with growth forecast to be 1.4% per annum to 2020-21, growth in peak demand forecast to be 1.6% per annum. (AEMO, 2012a).

Looking at each sector's contribution to demand, a study by the Sustainable Energy Authority of Victoria (SEAV) (2004) based on aggregated data from across NSW, showed the commercial sector accounted for approximately 26% of the peak demand during summer, ahead of the residential sector at 20% (See Figure 1).

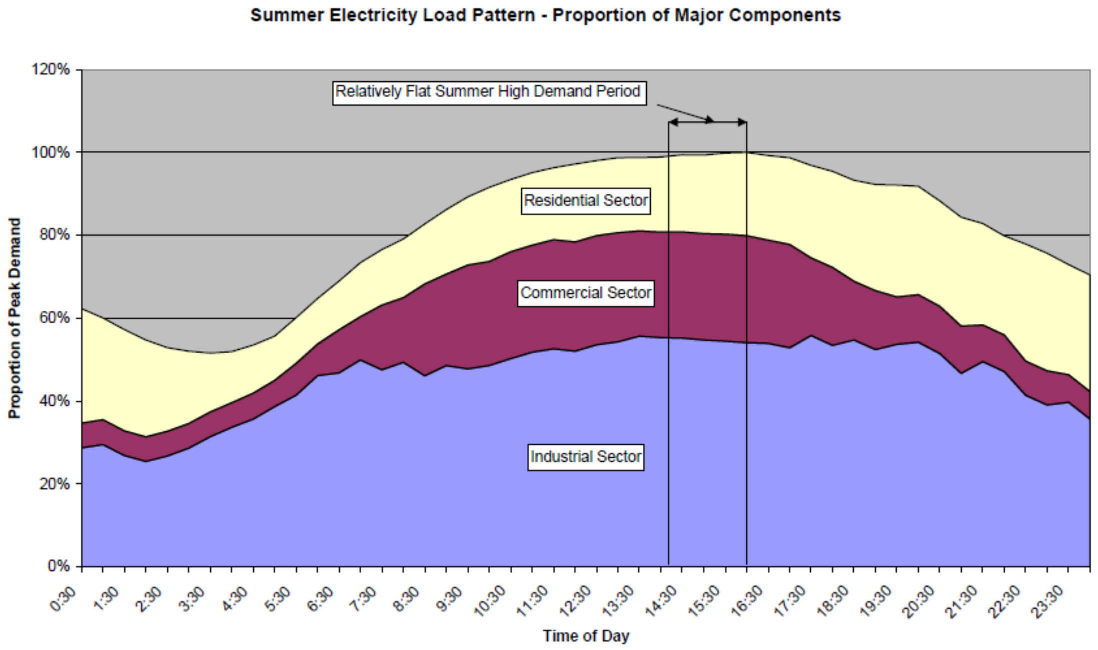


Figure 1. Summer Electricity Demand Makeup for NSW (SEAV, 2004)

Businesses are now paying significantly more in electricity costs than they were 5 years ago. These past increases coupled with some uncertainty about the impact of future potential Carbon Tax changes, mean that businesses are shifting their attention to ideas to minimise their energy costs.

To cover the costs involved in meeting peak demand by the utility, usually a part of larger commercial building energy costs is related to a maximum demand. United Energy (a Melbourne based distributor) has two charges that relate to demand. Firstly, a 12 month rolling demand charge that is based on maximum yearly demand and is levied throughout the year. Secondly, a summer demand charge which is active across only summer months (defined as November to March).

Alongside increases in electricity pricing, Solar Photovoltaic (PV) system prices have more than halved since 2009 with PV module prices now below the $1/W mark (GTM Research, 2013). This increases the potential that a such a system could be considered financially feasible by commercial building tenants in reducing both electricity consumption and peak demand costs.

This dissertation examines the potential of PV systems to offset peak demand events in commercial buildings in Melbourne, and consequently reduce the costs associated with both peak demand and consumption of electricity. A Coles Supermarket located near Melbourne is used as a case study building to investigate the feasibility of such a system.

1.2 Research Question

The research question around which this thesis is based can be formulated as follows:

“Is Solar PV likely to be considered feasible in reducing peak electrical demand and consumption costs in commercial buildings in Melbourne?”

This thesis aims to answer this research question using a set of specific objectives. These objectives are:

- To gauge the level of coincidence in timing of high PV system output and peak electrical demand for the case study building, and therefore for other similar commercial buildings in Melbourne.
- To assess the reliability of a typical PV system output in Melbourne and assess to what degree it is capable of reliably offsetting peak demand events.
- To examine whether solar PV could currently be considered technically and financially feasible in reducing electrical peak demand charges for the case study building, and for other similar commercial buildings.
- To investigate whether there are any enhancements that could improve the ability of PV systems to offset peak demand events.

- To identify some characteristics of commercial building peak demands that may increase their suitability for PV system offset.

1.3 Scope

This study looks at the electrical demand and consumption characteristics of a case study building, and assesses the feasibility of locally generated solar PV electricity in reducing demand and consumption charges. It considers the correlation in timing between peak demand events and peak PV output in Melbourne during summer periods, assesses the reliability of PV output, and consequently the ability to offset a peak demand event. It then offers some ideas to enhance a PV system output to improve the reliability.

The study focuses on commercial buildings as existing literature suggests higher coincidence of high PV output and peak demand. No consideration of issues affecting residential applications is given.

PV system data and tariff information used in the case study is from Melbourne and other tariff structures and PV output characteristic that may exist in other states are not considered.

Apart from some brief observations, it does not breakdown demand or consumption in detail (e.g. cooling, lighting etc.). The accuracy of consumption and demand data provided by Coles, and PV system data by the Melbourne City Council, has not been verified, although data with obvious errors or omissions has not been used.

Chapter 2 – Existing Literature

2.1 Peak Demand

To understand a little more about *peak demand* it is first necessary to define what is meant by this term. Demand can be defined as the average value of electric load over a specified period of time, and consequently peak demand is the maximum demand that occurs over a specified period. Why is peak demand of interest to both utility companies and consumers, in particular commercial consumers? To answer this question it is necessary to review the causes and costs associated with meeting peak electricity demands on utilities' networks.

Peak demand occurs as a result of coincidence in demand of many end-use appliances. A sample of Sydney commercial office buildings analysed showed that an average of 15% of demand capacity is required for just 1% of the time (Steinfeld et al.,2011). An earlier study found that 10% of Energy Australia's network capacity in New South Wales is used for <1% of the time (Dunstan et al, 2008). This requires utilities to provide and maintain generating equipment of up to 10-15% of total capacity that may only be used for 1% of the year. Because of the low use and urgency with which it can sometimes be required, this generating equipment typically needs to be of a type that can be brought online quickly. As a result peak power plants usually run on natural gas or diesel, which have high operating costs compared to base load supply equipment, and emit greenhouse gases.

Increasing demand for electricity during periods of peak consumption not only requires higher unit cost generation equipment to be brought online, but also significant investment in network infrastructure. In the Sydney Metro area the network augmentation to meet forecast peak demand for 2012/13 was in estimated to cost in excess of $200 million

(Energy Australia, 2007). These increased costs to electricity generators required to service periods of peak demand (Australian Energy Regulator, 2009) mean that it is not surprising that at least some of this cost is passed onto consumers. United Energy passes on peak demand charges to all larger consumers (> 400 MWh) (United Energy, 2011)) with some smaller consumers given the choice of having demand charges in exchange for lower consumption charges.

An alternative to the supply-side investments is to focus on managing the peak demand. Demand-side management is the planning, implementation and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired change in the utilities load shape, i.e. changes in the time pattern and magnitude of a utility's load (Gellings, 1981). Methods that can be used to manage peak demand include the use of onsite generation and storage of electricity for use during peak times (Shugar,1990) (Stadler, 2007) power system optimization algorithms that can prevent blackout during peak time (Hope, 2007), energy efficiency improvements (York, 2005), and demand response (Gyamfi,2012).

It has been estimated that reducing peak demand for the Sydney Metro area by around 75MVA by 2012/13, and 100MVA per year each year after would indefinitely defer the requirement for network augmentation to meet peak demand (Energy Australia, 2007)

The community also stands to benefit in many important ways from reducing the peakiness of demand on grid generated electricity in Victoria which at present is predominantly sourced from brown coal fired generators (Dept. Resources, Energy & Tourism, 2011). These include

- Less peaky demands on the network resulting in higher levels of reliability of supply i.e. reduced risk of black outs

- Less investment in infrastructure to service peak demands is required, the cost of which ultimately flows to most consumers either directly via utility charges or indirectly in the form or taxes etc.
- Potential for reduced greenhouse gas emissions associated with electricity generation as peaking generation equipment can be less energy efficient (compared to baseload)

Whilst the peak demand was greatest during the summer period, it was only 10% greater than for the winter period. The total was then broken into commercial sector applications, to show which applications contributed the most to summer or winter demand relative to their annual use. This was done by dividing the peak demand in Megawatts (MW) (for summer & winter) by the annual electricity consumption in PetaJoules (PJ). Figure 2 shows that cooling during the summer period is (as expected) the largest contributor to peak demand relative to average annual levels, whilst other applications (such as lighting, ventilation, and office equipment) contributed very little to peak demand beyond their average annual levels.

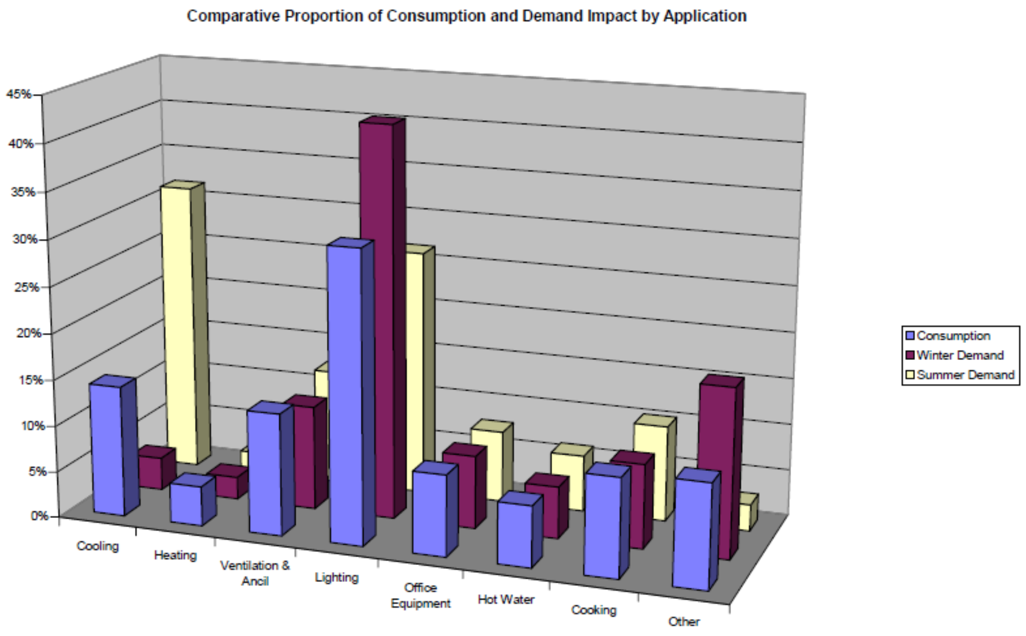


Figure 2. Comparative Proportion of Commercial Building Consumption and Demand Impact by Application (SEAV, 2004)

2.3 Reduction in cost PV

Alongside the recent sharp increases in electricity costs, there have been steady falls in the Levelised Cost of Electricity (LCOE) for electricity produced by PV systems (Melbourne Energy Institute, 2011). LCOE is a measure of the cost of electricity produced over the system's lifetime (and is discussed in more detail in section 6). Figure 3 shows that the fall in PV Module prices (a large proportion of PV system costs) are predicted to continue looking forward to 2015.

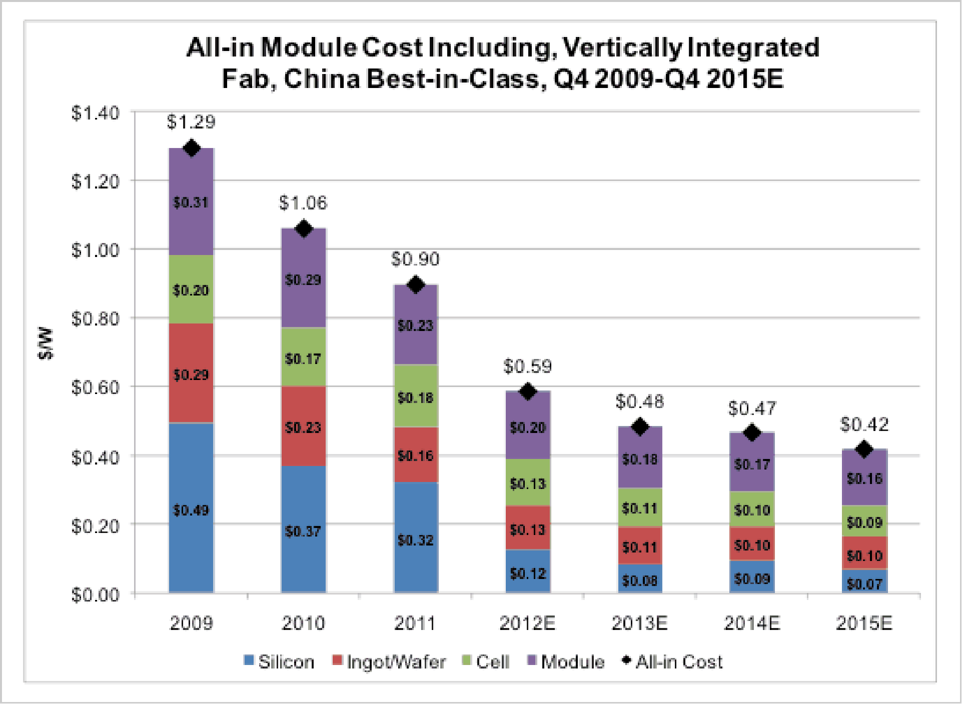


Figure 3. The Forecast Fall in PV Module Costs (GTM Research, 2013)

Rising electricity prices and falling PV costs suggests the use of PV to offset electricity costs will continue to become more attractive.

2.4 Coincidence of Building demand peak and PV output peaks

There are a number of studies that have indentified transformer load profiles (servicing predominantly commercial customers) as having demand peaks that coincide closely with the timing of peak PV output (Watt et al, 2005 & 2007, Rowlands, 2005). A Sydney case study shown in Figure 4 demonstrates this. The coincidence of aggregated commercial building demand and PV output peaks is usually much better by comparison to aggregated residential demand where the peak generally occurs a few hours after PV output peaking (Watt et al, 2005).

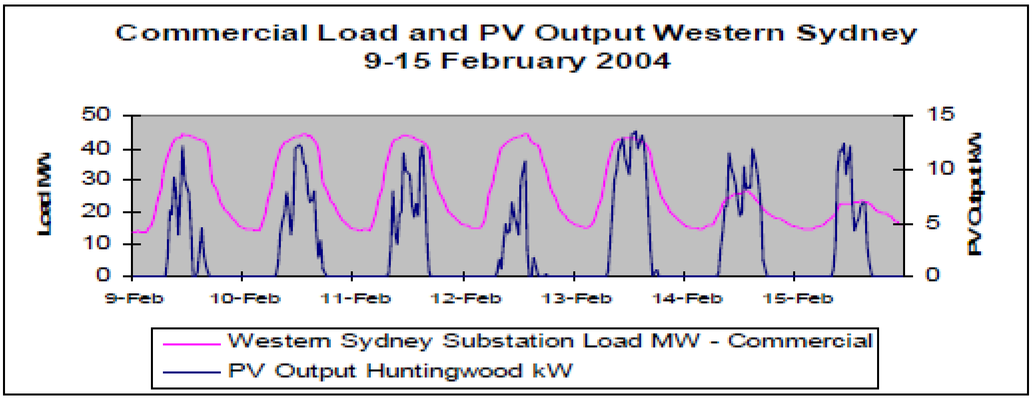


Figure 4 Coincidence of transformer commercial load and PV power output (Watt et al, 2005).

Peak demands for both residential and commercial buildings (and consequently the entire network) often occur during hot days in summer, and are primarily driven by building cooling (Steinfeld et al.,2011). Summer time is also period of peak output for PV systems indicating some suitability to offsetting peak demand.

Published research seems to have focussed more often on transformer load profiles, perhaps because there has been greater interest in identifying solutions to reduce expenditure on new infrastructure to meet increasing summer demand peaks. Aggregated commercial loads seen at the transformer level provide some information about what could be expected of an individual building load profile, but obscure finer details such as duration, timing, and variability of peak demand, and therefore how valuable PV systems could be to an individual customer. It is for this reason that research is being conducted into the technical and financial feasibility of PV at an individual building level.

Other studies on individual cases such as University of NSW (Watt et al, 2007) demonstrated that the coincidence of peak loads and peak PV output could be improved where necessary by changing the orientation of PV panels, but at the cost of lower total output over the year. In these cases tariff structure and pricing would determine whether trimming of peak demand is more valuable than maximising total energy production.

2.6 PV System output reliability

Steinfeld et al.(2011) observed that cloud cover, even on days of relatively high summer temperatures in Melbourne, had a significant negative impact on PV output (see 10th & 11th Feb in Figure 5). This is something that would need to be taken into consideration when aiming to offset peak demand events.

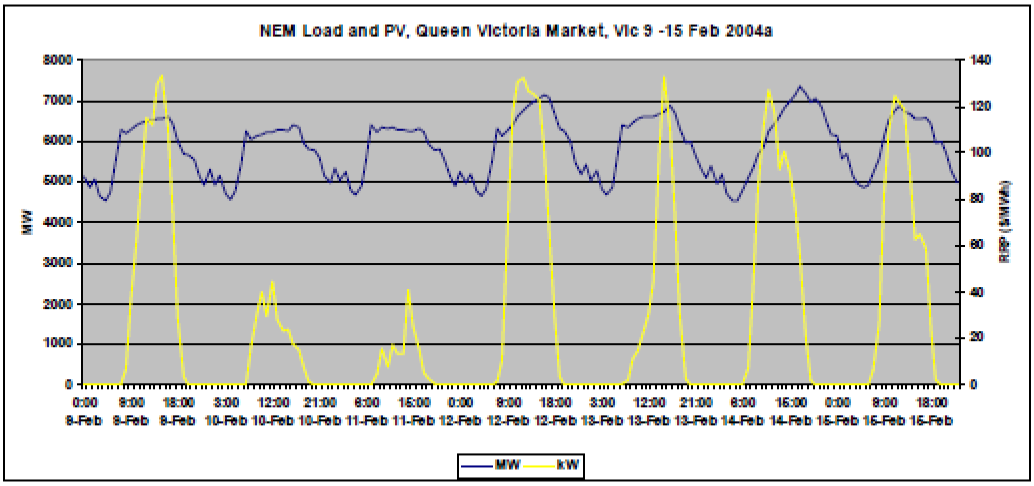


Figure 5 **Coincidence of NEM Load and PV output (Steinfeld et al.,2011).**

For a mixed residential and commercial substation Watt et al. (2006) & Passey et al.(2007) estimated that a single PV system is capable of providing between 30% and 75% of its rated capacity during peak periods for a load. Reasons given by Passey et al.(2007) for the reduced capacity included “inverter efficiency, temperature derating of panels and inverter, wiring losses, non-optimal orientation, shading, and dust build up”. Variability in insolation (solar radiation) levels due to cloud cover was the major cause of daily variability in PV output . Figure 6 gives PV average, maximum and minimum outputs for 30 PV sites (all located within one housing estate in Melbourne) during summer (December), and shows the minimum output at approximately 30% of average output.

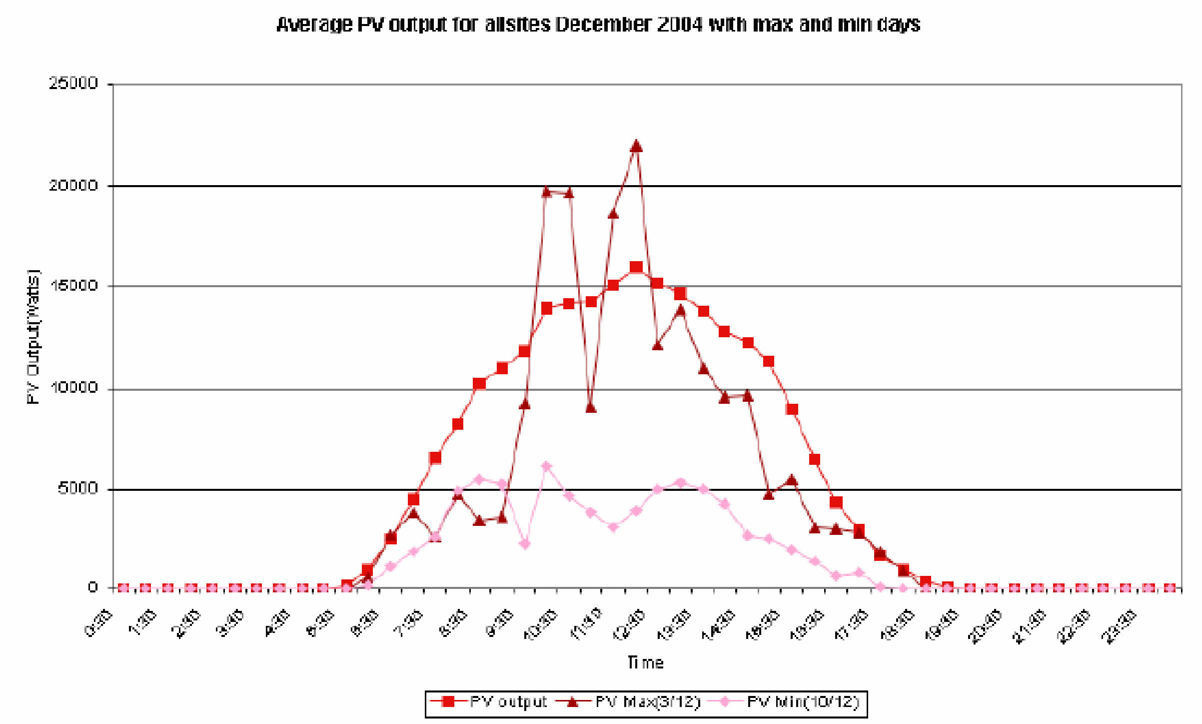


Figure 6 PV output from 30 localised sites (Passey et al., 2007)

Further research (Energy Australia, 2005, Watt et al, 2006, & 2005)) suggests that a more reliable PV output can be achieved by having a distributed group of PV systems, rather than in a single location system. Logically the distribution of PV systems has a greater potential to reduce the impact of geographic factors such as cloud cover on the overall PV network output. From an individual consumer perspective, current network structure and policy would make it very difficult (if not impossible) for individual customer's PV systems in dispersed locations to be utilised in offsetting peak demand at a single building location.

Chapter - 3 Methodology

3.1 Research Methodology.

The aim of the literature review was to understand where the best opportunities sat in terms of utilizing a PV system for peak demand offset, and where the potential issues may lie. This chapter focuses on the methodology that is applied to the case study, and to the application of findings to other similar buildings.

The basic methodology was as follows.

- Electricity demand and consumption data sourced for a case study commercial building (Coles Supermarket located near Melbourne). This was provided by Coles, who had sourced it from Origin Energy's data logging facilities.
- Solar PV system data sourced from Melbourne City Council's (MCC) solar array located on the roof of the Queen Victoria Market in Melbourne. This was recorded by MCC data logging equipment.
- 30 minute demand data was then overlayed with PV output to assess the coincidence in timing of peak demand events and high PV output.
- Reliability of PV output was assessed using PV array data to determine the likelihood of eliminating a peak demand event.
- Consideration was given to other technical issues to determine whether a PV system would be technically feasible in offsetting peak demand events
- PV system costs evaluated
- The potential avoided cost resulting from reduced peak demand and consumption charges as a result of using a PV system was determined
- Payback period calculated and compared to Coles investment criteria to determine financial feasibility. LCOE calculated to provide an alternative measure.

- Investigated technical alternatives that may enhance to capability of PV power to offset peak demand events
- Identified characteristics of the peak demand profile that improve the chance of feasibility in other commercial buildings.

Chapter 4 – Case Study Background

4.1 Building Details

The building that is the subject of a case study is a Coles Supermarket which is part of the Centro Shopping Centre located in Sommerville in Victoria, Australia. It is approximately 60km to the south east of Melbourne, in a small town largely characterised by residential buildings. Figure 7 shows the Centro centre with the Coles store located at the northern end (circled in pink) taking up approximately 1/3 of the centre's space.

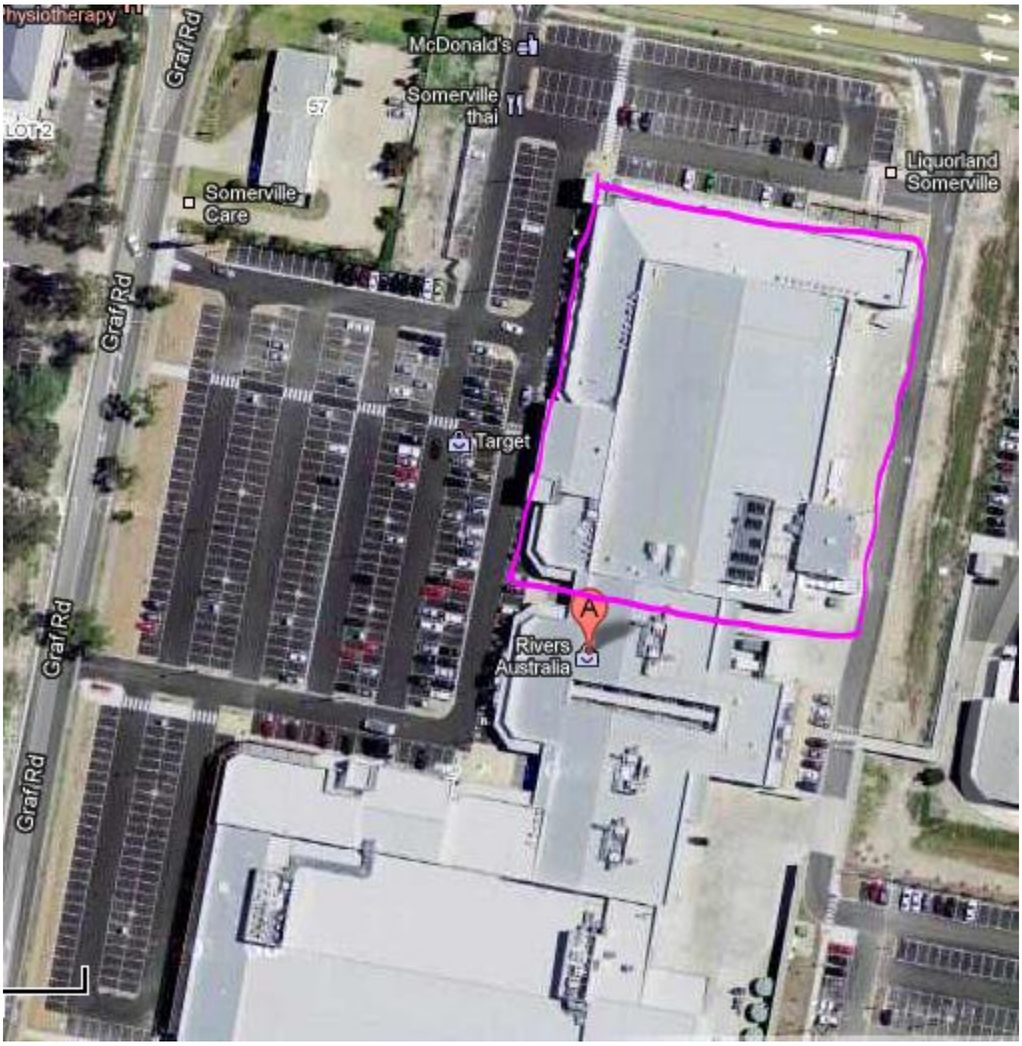


Figure 7 Aerial view of Sommerville Coles Store

The floor space occupied by the supermarket is in the order of 4000 m^2, and its summer time electrical demand arises from

- space cooling
- produce cooling (refrigeration and freezing)
- ventilation
- lighting
- office and register equipment
- food preparation equipment
- Misc. equipment

This building was selected because of its suitability for a PV system on the roof, the quantity and quality of electricity consumption data, and an interest by Coles in exploring ways to reduce electricity costs and CO2 emissions.

In Australia supermarkets consume more than 7,000 GJ of electricity each year costing around $200 million, and produce nearly three million tonnes of greenhouse gases. Refrigeration accounts for the largest proportion of annual energy use at 55 per cent, while air conditioning and lighting each account for 20 per cent. (Dept. of Industry, Tourism, and Resources, 2004)

4.2 PV System Details

The PV system that has been selected to represent the potential of an average Melbourne system is a large 200 kW array located on the roof of the Queen Victoria market in inner Melbourne. It was selected again because of the quantity and quality of data available, its good northerly orientation, and for being in relatively close proximity to case study building. It is also in very close proximity to the large quantity of Melbourne CBD buildings making it very representative of a system that could be applied to these buildings. PV data is logged onsite and is kept by the Melbourne City Council.

Whilst not all buildings will have capacity to installing a 200 kW system, systems can be easily scaled to appropriate size, and receive equally scaled benefits.

Chapter 5 – Technical Feasibility

5.1 Electricity Consumption and Demand

Looking at full years worth of electrical demand data from the case study building (see figure 8) it is clear that demand peaks start to appear around December and continue through until March. This was as expected due to the high proportion cooling and refrigeration demand which escalates during the hotter weather in summer periods. Thirty min peak demand in summer (defined as Nov 1 – March 31 by distributor United Energy) reaches 360 kVA, up to 30% higher than for the non summer period. A review of historical demand data for the previous 3 years showed that comparable summer peak demand has fallen from typical summertime peaks in the order of 400 KVA. Energy efficiency improvements made by the business are the most likely cause of this reduction as temperatures (measured as the number of days summer above 30 deg.C) have been relatively consistent with the exception of a cooler summer in 2011 (See Appendix E)

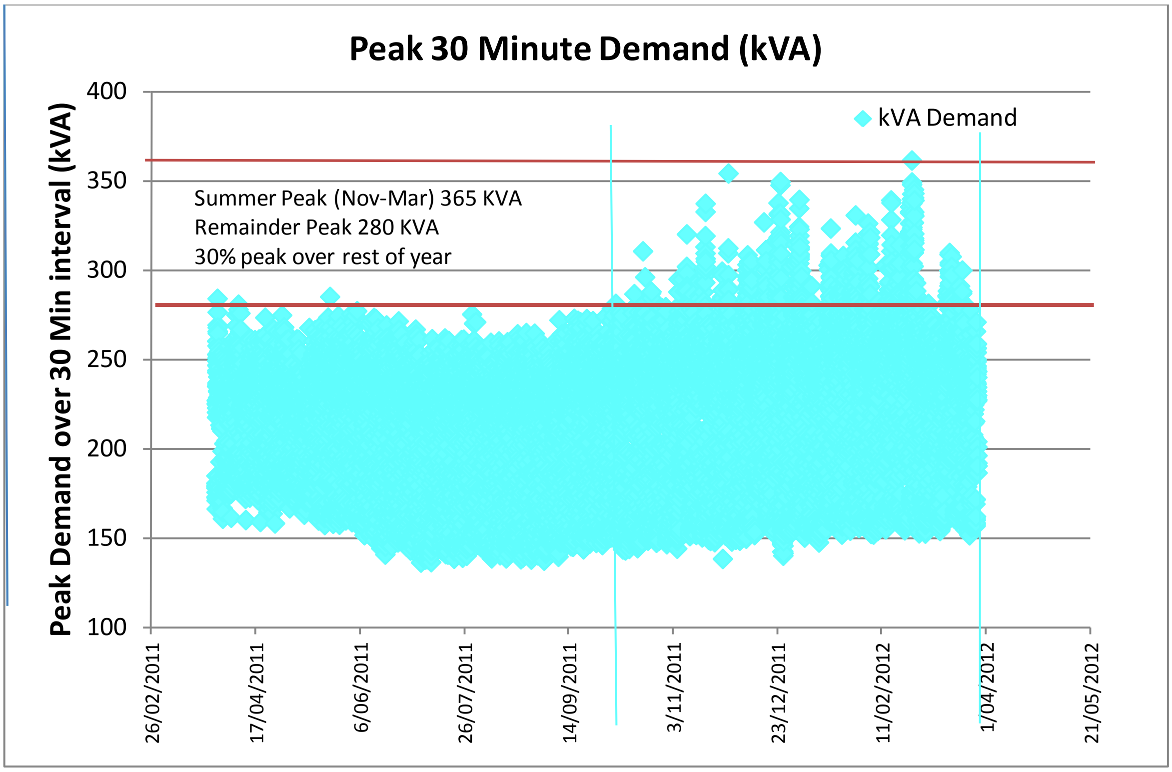


Figure 8. 30 Minute peak electrical demand for case study building

Figure 9 provides and idea of what the demand profile looks like for the month of Feb, which is relatively typical of the summer months. At 6am demand jumps from below 200 to above 250 kVA consistent with the business beginning trading at 6 am and operational equipment being utilized as opposed to a sudden spike in cooling loads. It remains above this 250 kVA level until an hour or so after store close at 10pm. The highest peak day for the month shown in Figure 9 is Saturday, whilst the lowest is a Wednesday, and so a small percentage of the increased demand could have come from additional equipment such as registers being operated to service additional customers. When the maximum outside temperature (24.6 v's 34.8 degrees C.) (Bureau of Meteorology, 2013) is taken in consideration however it is much more likely that this is the cause of increased cooling and therefore electrical demand.

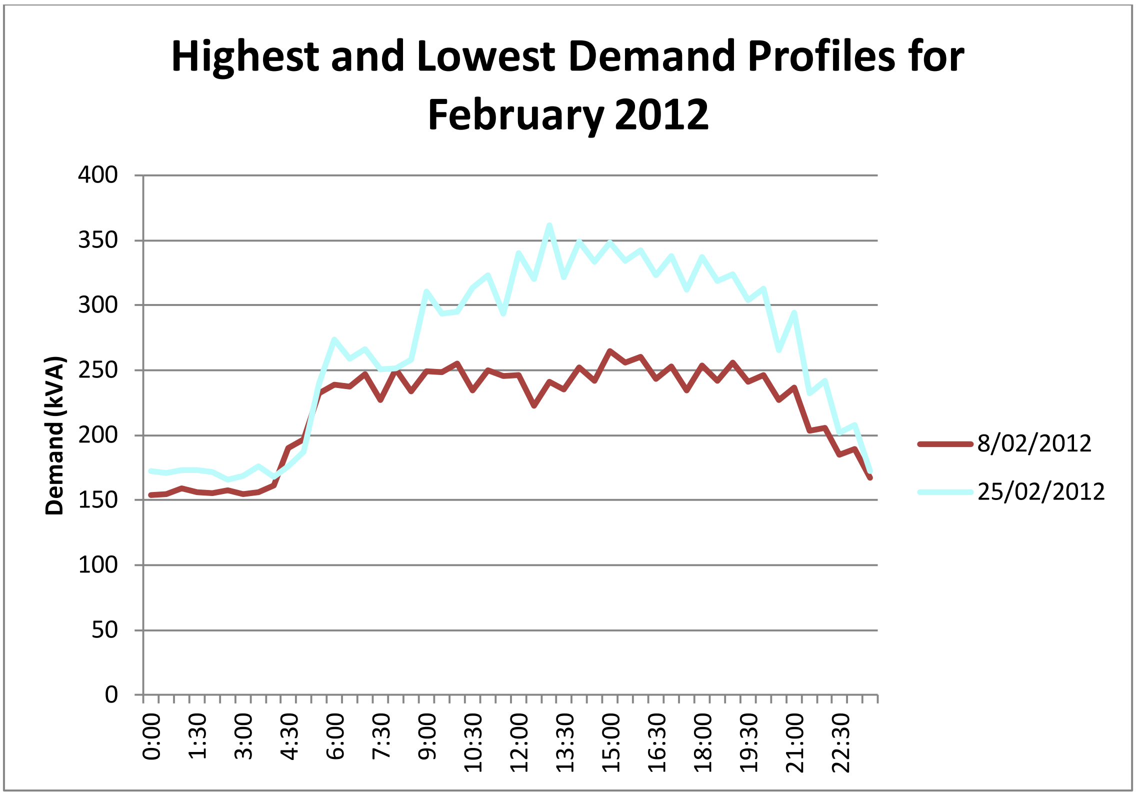


Figure 9. Peak demand profile curves for Feb 2012

The demand duration curve for the case study building shown in Figure 10 highlights that demand levels above 300 kVA exist for only 5% of the time. Short duration peak loads are a relatively common scenario for many building and transformer loads (Watt et al. 2003), hence the reason that utility companies impose demand charges for having to provide additional generation capacity for such short periods. Peaks over 300 kVA are almost exclusively between the hours of 10am and 6:30pm in summer, providing some hope of coincidence with high PV output. The remainder of the demand duration curve is relatively flat with some fall as the supermarket goes closes and drops below the non-trading 200 kVA level.

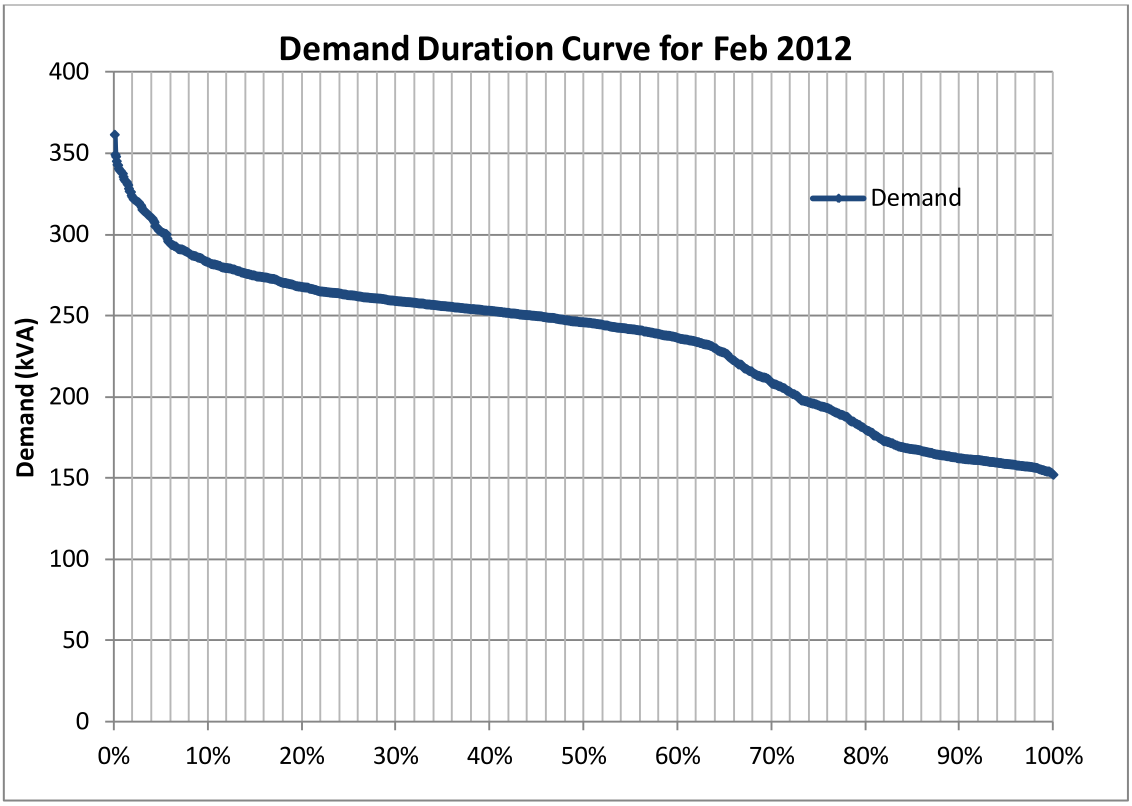


Figure 10. Demand duration curve for Feb 2012

5.2 Tariff Structure

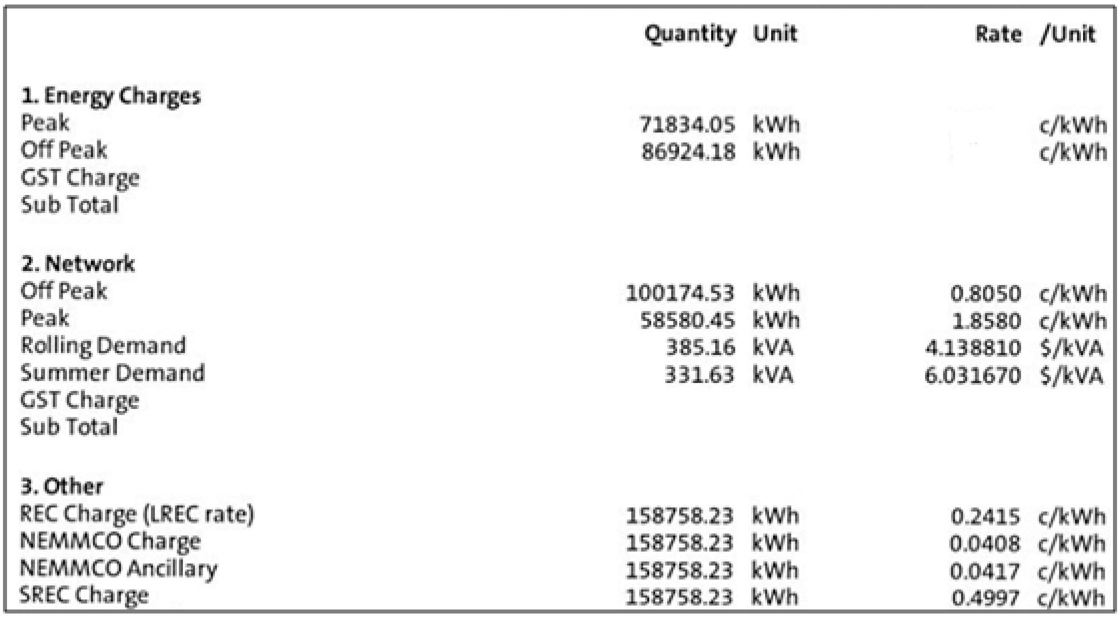
To understand how PV can best be used to minimise electricity costs it is necessary to understand the structure of the tariff. The electricity tariff is made up of retailer charges (shown in Figure 11 under "Energy Charges" – rates deleted for confidentiality), distributor charges (shown under "Network") and other miscellaneous charges relating to renewable energy programs and national electricity market management .

The Network tariff incorporates the demand charges applicable to the business and the tariff applied by the distributor is the LVkVATOU tariff. This is a low voltage, demand charged, time of use tariff. Access to a cheaper high voltage tariff HVkVATOU is possible but would require significant investment in infrastructure to accommodate a higher supply voltage.

The LVkVATOU Network tariff is made up of

- Summer peak energy consumption charge (Nov 1 – Mar 31, 7am – 7 pm)
- A non summer peak energy consumption charge (remainder of year, 7am – 7 pm)
- An off peak energy consumption charge (weekends, public holidays, 7pm – 7 am)
- A rolling peak demand charge (based on highest recorded demand event for last 12 months)
- A summer demand incentive charge (based on highest recorded demand event for current summer)

(United Energy, 2011)



	Quantity	Unit	Rate	/Unit
1. Energy Charges				
Peak	71834.05	kWh		c/kWh
Off Peak	86924.18	kWh		c/kWh
GST Charge				
Sub Total				
2. Network				
Off Peak	100174.53	kWh	0.8050	c/kWh
Peak	58580.45	kWh	1.8580	c/kWh
Rolling Demand	385.16	kVA	4.138810	$/kVA
Summer Demand	331.63	kVA	6.031670	$/kVA
GST Charge				
Sub Total				
3. Other				
REC Charge (LREC rate)	158758.23	kWh	0.2415	c/kWh
NEMMCO Charge	158758.23	kWh	0.0408	c/kWh
NEMMCO Ancillary	158758.23	kWh	0.0417	c/kWh
SREC Charge	158758.23	kWh	0.4997	c/kWh

Figure 11. Retailer, Distributor, and Misc. tariffs (Coles, 2011)

5.3 Solar PV data

The Queen Victoria Market PV system has a nominal size of 200 kW, although it is suspected (based on conversations with the Melbourne City Council when sourcing the data) that there are some faulty panels as there doesn't seem to be a regular check of system or individual panel output. Figure 12 below shows the energy output over 15 min periods during February 2011 which corresponds with periods of high peak demand in the case study building. Periods of zero output correspond with periods of darkness.

Fifteen minute energy output of approximately 30kWh corresponds to an average power output of 120 kW which is significantly less than the 200 kW rated capacity. There are a number of potential reasons for this loss, such as faulty panels, temperature effects, etc. and it is something that would be worth investigating by Melbourne City Council given the magnitude of the loss (estimates of losses for new systems are readily available from suppliers). It is the reliability and timing of output however that is of interest in determining the degree to which a PV system could offset peak demand. Figure 12 highlights some issues with the reliability of PV output (see 26th & 27th Feb) that are discussed in more depth in the next section.

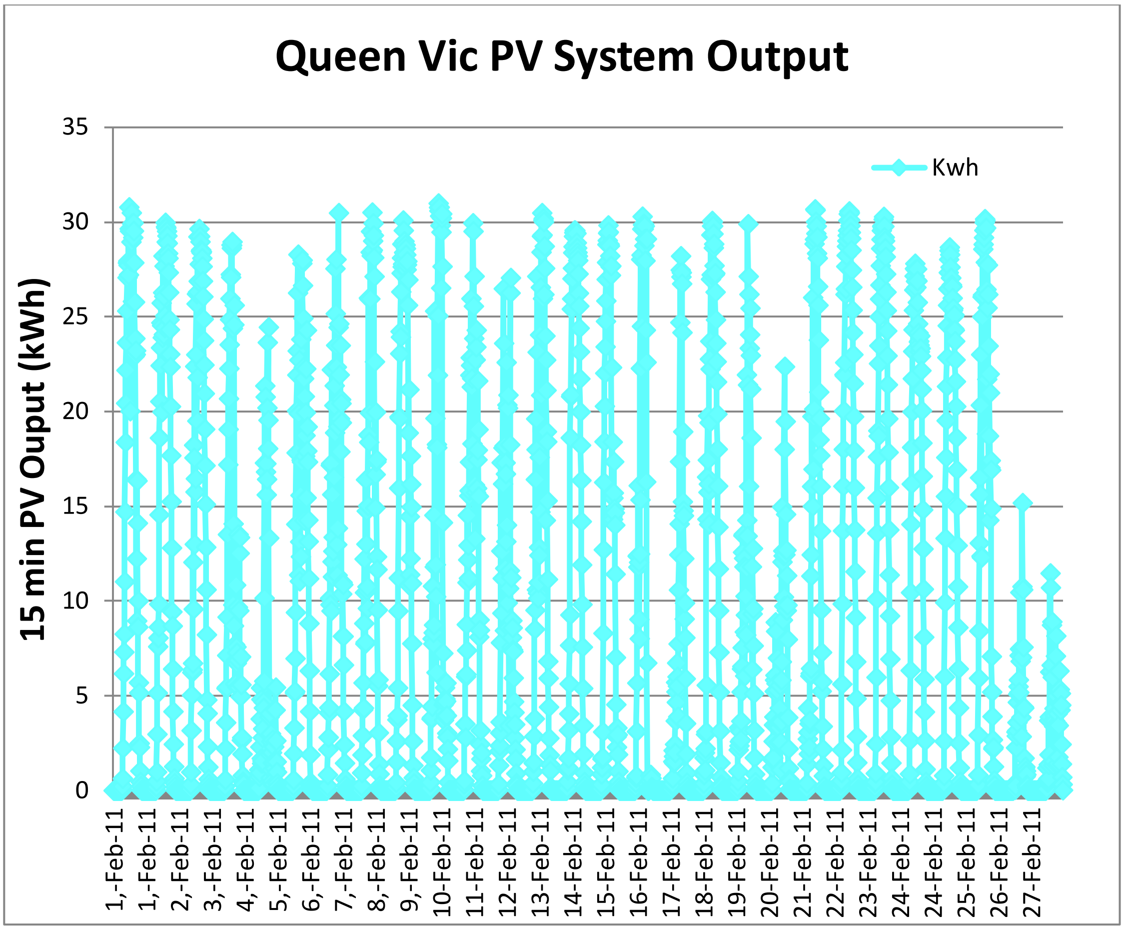


Figure 12. 15 min PV output Energy

5.4 Coincidence between PV output and Demand

For a PV system to be successful in offsetting peak demand it is important that there is a high degree coincidence in timing between the two events. Figure 13 shows that for the 24th & 25th of Feb, PV output peaks at approximately 11:00am (12 noon adjusting for daylight savings) compared to demand peak levels between 1:00 and 4:00pm. The PV peak could be delayed by rotating the array toward the west at the expense of annual energy output (Watt et al, 1998).

Figure 14 however shows that PV output can be dramatically different only a day later with the system failing to produce a peak of more than about 50kW throughout either days. Cloud cover is considered the most likely reason for this reduction but is difficult to verify. Figure 14 shows the 26th & 27th as the lowest PV output for the month, and if 30 kWh is taken as the maximum energy output for a 15 min period (based on the highest actual output recorded across and entire year), then the peak output on the 27th and 28th of Feb of 11kWh is in line with minimum 30% of nominal rating suggested by Passey et al.(2007). Output on the 28th is particular unreliable with two consecutive 15 min outputs of 5 and 6 kWh which correspond to averages of 20 and 24 kW's.

It is not uncommon to see substantial PV output variations when the frequency of sampling is less than 1 hour (Gansler et al., 1995, and Beckman et al., 2005) that are attributable to cloud cover. These periods of low output are frequent enough (see Figure 12) to allow a peak demand event to occur (a minimum 30 min period of high demand) and consequently eliminate the chance of rolling demand and summer demand incentive charge savings being made.

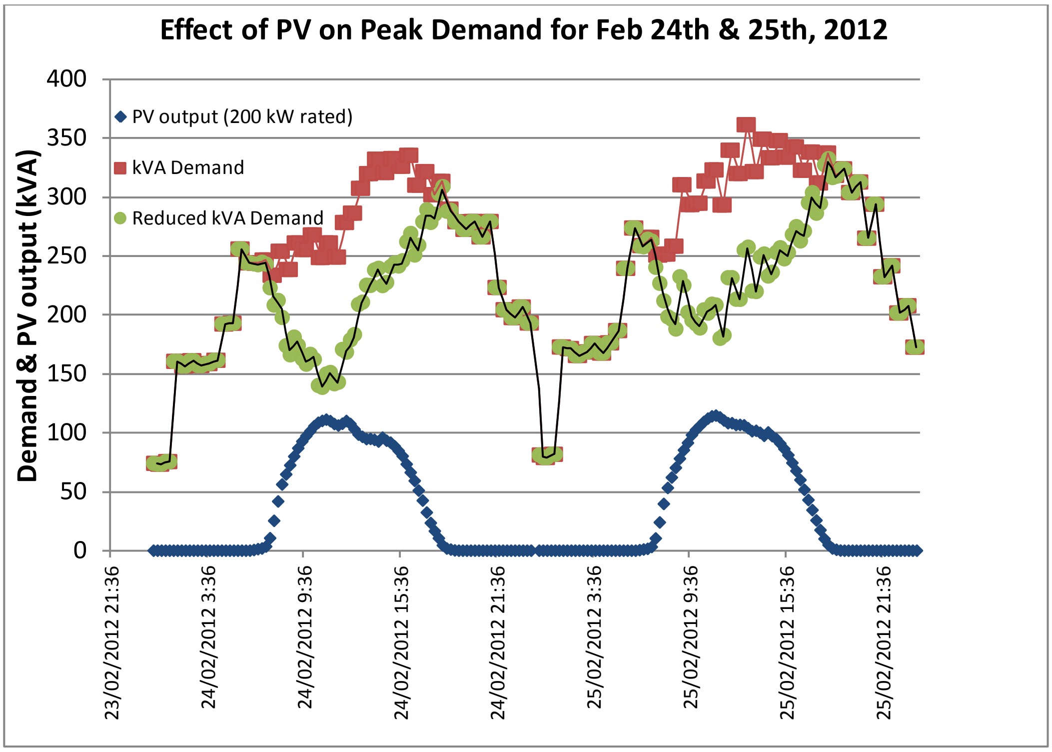


Figure 13. Effect of PV output on Peak demand curve during peak demand.

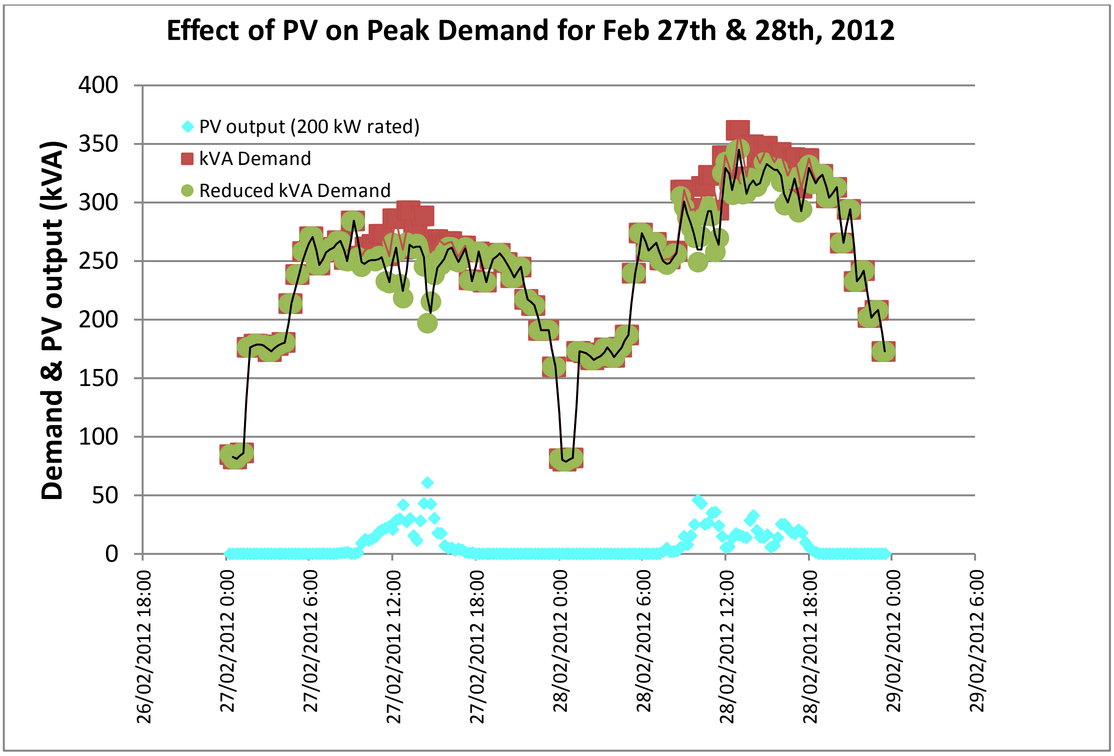


Figure 14. Effect of PV output on Peak demand curve during peak demand.

5.5 Sensitivity Analysis

To determine to sensitivity of using PV to offset peak demand under different conditions that could be exist in other Melbourne commercial buildings, an analysis was carried out where important variables were altered.

Demand profiles could vary in the following ways

- Differential between summer and winter peaks
- Daily timing of midpoint of summer peak demand
- Daily duration of summer peak demand

The differential between summer and winter peaks is a fairly straight forward analysis. If the summer demand peak is higher than the winter demand peaks by more than 30% of the rated PV system capacity then the full benefit of the 30% offset to peak demand can be achieved. This will be the case in most commercial buildings of medium to large size, as the capacity of the PV system that could be installed is usually limited by the physical space available. The large 200kW PV system applied to the Coles demand profile would still not reduce the summer demand to anywhere near the winter peak demand level. In few cases where 30% of the rated PV system size exceeds the summer - winter peak differential, the available savings resulting from demand offset would be limited to the difference between summer and winter peaks.

The other two variables, daily timing and duration of peak demand were investigated.

The peak magnitude of PV system output is not easily altered (apart from the unpredictable cloud cover reduction which has already been allowed for), however the timing of peak PV output can be altered as previously mentioned by changing the array orientation, and this is also investigated.

5.5.1 Sensitivity Analysis of Daily Demand Profile and PV Array Rotation

Several simple peak demand profiles were created to test the impact on demand offset.

These were

- A peak that is lasts for 2 hrs and is centred around 12 noon.
- A peak that is lasts for 4 hrs and is centred around 12 noon.
- A peak that is lasts for 2 hrs and is centred around 2 pm
- A peak that is lasts for 4 hrs and is centred around 2 pm
- A peak that is lasts for 6 hrs and is centred around 2 pm

Working on the basis that to prevent a peak demand event occurring, the entire peak must fit within the 30% PV output power curve the chart shown in Fig XX was produced.

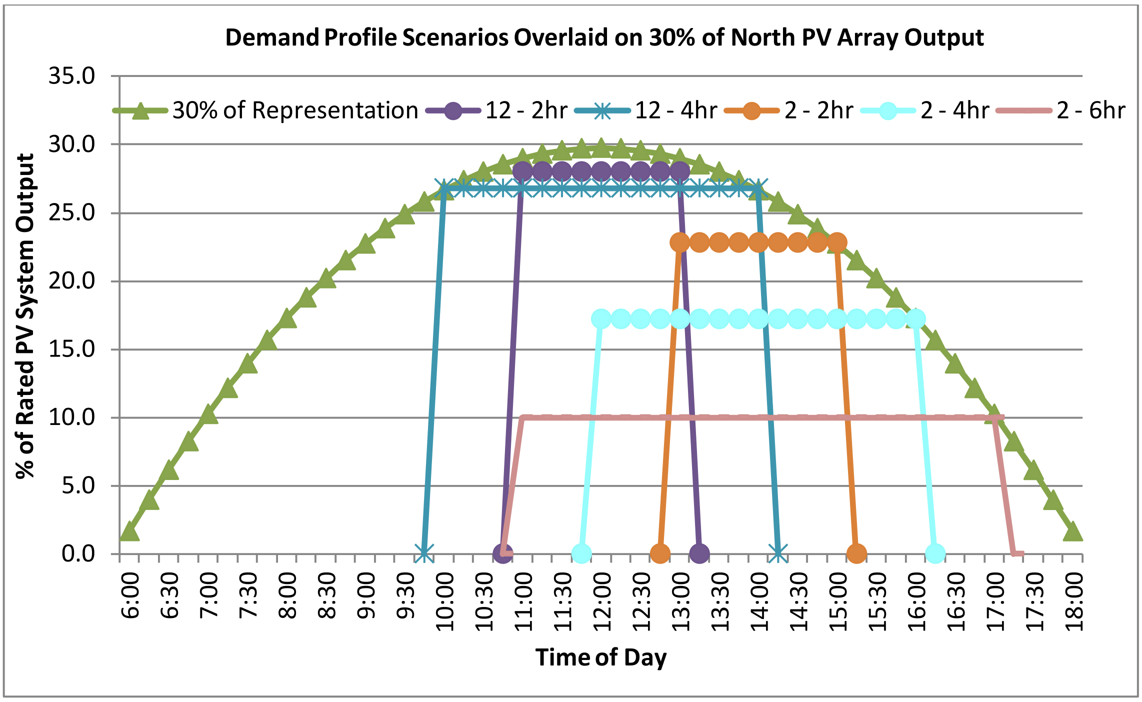


Figure 15. Demand profiles overlaid on north facing PV array

To observe the benefit of rotating the PV array for demand profile peaks that are centred around the early afternoon (typical of buildings with cooling dominated peak demand), a PV output curve was created using PVWatts software (NREL, 2013) for an array rotated 50% to the west of True North to produce a peak output occurred at approximately 2pm. The array was tilted an angle of 38% to the horizontal and was fixed. The changes in the percentage of rated output which can be applied are shown in Fig XX.

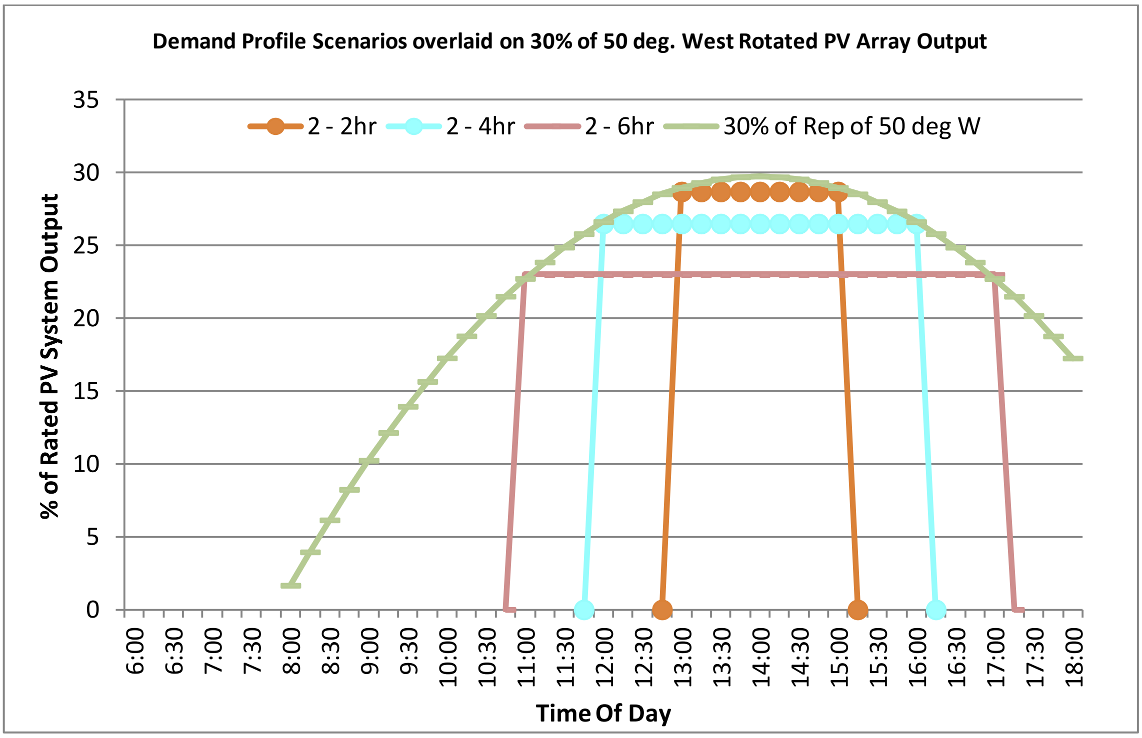


Figure 16. Demand profiles overlaid on 50 degree west rotated PV array

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As a result of rotating the PV array 50 degrees to the west, total annual energy output is reduced by 7%.

5.6 Alternative solutions

The following alternatives offer some potential solutions to the issue of unreliable PV output.

5.6.1 Energy Storage

One potential solution is the use of some type of energy storage so that PV generated energy can be stored for use when a peak demand event is about to occur. Onsite battery storage is an obvious solution, but comes with cost, energy loss, space, and maintenance considerations that will reduce the financial attractiveness of the total system. If we make a few simple assumptions, the capacity of batteries required to ensure that 10 kVA could be trimmed from peak demand for 3 consecutive days without any recharging is 4160 Ah (at a system voltage of 48V). At a cost of approximately $0.20 / Wh (Batterystuff.com, 2013) the cost of batteries would be approximately $40,000 (see Appendix B for calculations). Given the maximum achievable demand savings are $800 per annum (from section 5.1) for a 10kVA reduction in peak demand, it is clear that such as storage system is not going to be financially feasible in these circumstances.

Other forms of energy storage do exist (such as capacitors, flywheels, compressed air systems etc) but factors such as cost, space and maintenance requirements generally likely to make these alternatives less attractive than battery storage in most commercial building environments.

5.6.2 PV Synched Demand Management.

Another alternative to maximise the available demand reduction available from PV is to couple it with some demand management that is synchronised with PV output. In practice this would involve throttling back systems such as air-conditioning or switching off operating equipment for a period whilst PV output is reduced (e.g. due cloud cover). Perez et al. (2003) found in a study of 3 buildings in the US, that the use of solar load control (i.e. PV synched demand management) had the potential to be successfully applied in commercial buildings most effectively through the reduction in building cooling for a specified period of time. They found that a maximum allowance of 10 degree-hours (eg 5 hrs at 2 degrees C above the normal cooling set point) per day above the standard building temperature threshold, allowed combined synched cooling demand reduction and PV to provide more than double the peak demand reduction of PV alone.

Chapter 6 – Financial Feasibility

6.1 Ideal theoretical maximum potential savings

To gain an idea of the maximum potential savings that could be made by offsetting electricity consumption and demand charges a 12 month snapshot of data has been selected to properly incorporate the effect of the 12 month rolling demand charges.

Tariff rates applicable at Dec 2011 were applied to the entire period.

For the purposes of simplification in this thesis, an approximation has been made in equating the building electrical demand (measured in kVA) with real power (measured in kW). The case study building has a high power factor (typically 0.92 to 0.96) meaning the difference between the two quantities is relatively small, and allows for easier comparison with PV system output.

As a starting point an ideal 10kW PV system was assumed to provide a full 10KVA reduction to peak demand during the summer periods, and to provide a consumption reduction of 1680 kWh per annum (based on an average of 4.6 Peak Sun Hours for Melbourne).

This would provide total savings of approximately $2000 p.a. ($800 from demand charges, and $1200 from consumption charges).

See Appendix A for calculations.

6.2 Practical potential savings

Despite occasional periods of low daily PV output during summer, the annual energy output of a properly functioning PV system can be reasonably accurately predicted using available software. Some organisations may consider a PV system financially feasible based on energy savings alone. The intent of this research however is to determine whether significant energy and peak demand savings can be made simultaneously.

To determine a practical level of demand charge savings, 30% of a rated PV system output should be used in calculating an estimated demand charge saving. This would reduce the estimated demand savings for the case study 10kW rated system from $800 p.a. to $240 p.a.

6.3 Available Government Rebates

There have been a number of programs created to provide incentives to both commercial and residential customers to install PV and other renewable energy and energy saving appliances. At present PV systems are currently eligible for Small Scale Technology Certificates (STC's) under the federal government's Small Scale Renewable Energy Scheme, when installed in accordance with the guidelines. The number of certificates is dependent upon both the rated capacity of the system and the installed location (as this will affect the total energy production expected from the system).

For example a 10kW system installed in the Melbourne region would attract around 177 STC's (Clean Energy Regulator, 2013) which could be sold at the current price of approximately $30 (totalling $5300) to offset the purchase cost of the system. These schemes tend to undergo regular changes therefore current conditions should be verified.

6.4 PV System Costs

Outright purchase

The current cost of a mid range PV system (installed) is approximately $2/watt (after the benefit of STC's) (Solar Choice, 2012) making the cost of a 10kW system approximately $20,000 for outright purchase. An allowance of $5,000 has been made for cleaning and inspection of the system over its lifetime, bring the total system cost to $25,000.

Alternatives exist to outright purchase, such as PV system lease plans, and Power Purchase Agreements (PPA's).

Leasing

PV system lease plans are very similar to the car lease plans that have been around for many years. They involve an agreement to purchase PV generated electricity at set prices (sometimes with inflation adjustments to price). They have the following benefits

- Agreed purchase prices for electricity
- No maintenance costs, ownership risks such as weather damage or performance risk
- Usually the option to purchase the system at the conclusion of the lease period for a residual amount.

Power Purchase agreements

PPA's are an agreement by a customer to purchase some or all of the power generated by a PV system that is owned by a third party, for a specified period of time. They are often used in large scale renewable energy projects but are now also available for small scale PV systems. They have the following benefits:

- No upfront capital investment

- No maintenance costs, ownership risks such as weather damage or performance risk
- Allow businesses with insufficient space or inappropriate locations in which to install PV panels to access the benefits of such systems.
- Can lock in a fixed electricity purchase price for a number of years.

6.5 Financial Feasibility Indicators

There are a number of different measures for determining the financial feasibility of projects, ranging from a simple Payback Periods and Return On Investment (ROI) calculations, through to more detailed measures such as Levelised Cost. It has been assumed that the customer has chosen to purchase a PV system outright.

Simple Payback period = Total cost of system / Annual savings

= $25,000 / $1845*

= 13.5 years

* A slightly adapted Annual Savings is used which is equal to the average yearly amount saved across a 25 year lifespan with an assumed 2% increase in electricity costs per annum. Assuming a 4% increase p.a. would give a simple payback period = 10.4 years (See Appendix C). This method is used to provide some allowance for effect of increasing electricity prices over 25 years.

A very rough guide to the Coles investment criteria for investment in energy efficiency projects (provided in an email from Paul Lang of Coles on 23/08/12) is a payback period of less than 4 years.

This means that using the metric of simple payback period, the use of a standalone PV system to offset consumption and demand charges would not be considered feasible. It would require forecast increase in annual electricity prices in the order of 10%, which is well above current projections provided by AEMO (2012b) of 1-2% over the next 8 years.

A more sophisticated metric that takes into account factors such as the present value of future costs and savings is the Levelised Cost of Electricity (LCOE). It is described in *A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies*, by Short et al. (1995) as

"a metric used to understand the per unit cost of the electricity generated by that system. It is the cost that, if assigned to every unit of electricity produced by the system over its lifetime will equal the net present value of the total lifetime system cost at the point of implementation"

It is often used in renewable energy projects to determine whether over a certain duration (such as 25 years in our case), the cost of the renewable energy is likely to be lower than convention grid supplied electricity. It takes into account expenses such as capital, maintenance and operating costs of the system over the selected duration, as well as the discount rate (the amount by which future costs and income are adjusted to reflect their value in today's dollars) and the rate of increase of grid electricity prices. Whilst there is some judgement involved in setting parameters such as the discount rate and electricity price increases, it provides some guidance in comparing the cost of the different sources of electricity. Using a discount rate of 4%, and a rate of increase of grid electricity prices of 2% p.a. and a duration of 25 years (the remaining assumptions and calculator can be seen in Appendix D) the following results are obtained.

Levelised cost of PV electricity = 11.3 cents / kWh

Levelised cost of Grid electricity = 13.2 cents / kWh

Whilst a detailed discussion of the calculation and implications of levelised cost calculations are beyond the scope of this thesis, it suggests based on the provided assumptions that a PV system would in fact be a cheaper way to meet some of the consumption and demand requirements of the case study building over a 25 year period.

Chapter 7 – Discussion of results

7.1 Demand Observations

There is a high degree agreement between the reviewed literature and the results of analysis of the case study data. Summer demand peaks are greater than in winter. Not surprisingly however, supermarkets have a high proportion of cooling related demand (55% refrigeration and 20% space cooling) (Department of Industry, Tourism, and Resources, 2004) by comparison to the typical large office building average which is around 40% (Australian Greenhouse Office, 2005) but can vary a bit depending on climate. This helps explain the 30% differential in summer demand peaks compared to winter, and why this differential is greater than the commercial sector average.

The demand duration curve for the case study was fairly consistent with other commercial buildings (measured in literature via commercial transformer demand,) showing that for February 2012 demand only exceeded 300 kVA (peaking at 350 kVA) for 5% of the time (ie 14% of capacity is only required 5% of the time). What this curve doesn’t highlight is that the peaks in demand (> 300 kVA) are usually sustained for several hours over a limited number of summer days, as opposed to very short peaks experienced across a number of days. This becomes evident when looking at daily demand profiles and is consistent with demand being dominated by cooling loads in response to high temperatures that begin around midday and last in the order of 4-8 hrs.

7.2 PV output observations

The coincidence in timing of peak demand and high PV output was reasonably good as per previous commercial building case studies, with peak demand levels continuing for up to a 2 or 3 hours after PV output had peaked. The timing of high PV output can be altered to some degree by adjusting the orientation of the PV array toward the east or west , but at the expense of total annual energy output.

When the case study PV output data was examined over a sub-daily period, it was evident that the power output level which could be delivered with a high degree of reliability was only in the order of 30% of system rated power. This was also in agreeance with the literature, which attributed the low output primarily to cloud cover, compounded in summer by further losses due to high PV module temperatures.

PV systems located north of Melbourne are typically going to deliver greater energy and have less cloud cover annually, however unless there is a difference in the way peak demand events are assessed by utility companies, the 30% estimate of high reliability PV output would still be applicable as it only requires one cloudy day to potentially allow a peak demand event to be recorded.

7.3 Sensitivity of results to varying demand profiles and PV array orientations

Whilst there are many possible demand profiles that may occur in different types of buildings, some simple representations were made in Section 5.5 to test the effect these would have on the percentage of rated PV system capacity that could be used to offset peak demand. A summary of the results is given in Table 1 below.

	Peak Demand Period	True North	50 Deg West
12 -2hr	11:00 to 13:00	28%	N/A
12 - 4hr	10:00 to 14:00	27%	N/A
2pm - 2hr	13:00 to 15:00	23%	28%
2pm - 4hr	10:00 to 16:00	17%	27%
2pm - 6hr	9:00 to 17:00	10%	23%
Ann. Energy Output (kWh)		5049	4693

Table 1. Percentage of rated PV output that could be applied to offsetting peak demand for different demand profiles and array orientations.

One finding is that there is significant benefit in rotating the PV array so that peak output coincides approximately with the midpoint of peak demand. The benefit ranged from an additional 20 - 130% increase in offsetable power, with forecast output in annual energy output only falling by 7%. The biggest gain occurred where the demand peak was prolonged (6 hr), as PV output falls away relatively quickly from its peak.

From a financial perspective the 7% fall in annual energy output ($87) would be approximately equivalent to a 30% decrease in peak demand offset. This indicates that an array rotation of 50 degrees to the west is warranted for both the 2pm midpoint – 4hr duration and the 2pm midpoint – 6hr duration profile, for the tariff used in case study. An easterly rotation was not modelled as it was considered unlikely that there would be many buildings where the midpoint of summer demand occurred before midday, and consequently a negative impact would occur on both demand and annual energy offset. Further rotation to due west (90 degrees in total) shifts the peak PV output to closer to 3pm, with an annual energy output of 4017 kWh, a loss of approximately 20%. Given the relatively small shift of 1 hour in the timing of peak output, compared to the additional 13% decrease in annual energy output compared to the 50 degree rotation, it is considered unlikely that the small saving in demand charges for profiles that peak late in the day, would offset the rapidly declining annual energy loss.

7.4 Enhancements to PV system

Given 30% is a relatively low proportion of total PV rated power output, enhancement is warranted to try and increase the feasibility of the system. Energy storage via batteries was investigated and whilst it is well proven technically, it is a fair way from being financially viable in a peak demand offset scenario. Other energy storage devices exist but are generally likely to be less attractive due to one of more factors including cost, physical space requirement, maintenance, and technical complexity.

PV synched demand management was identified from existing literature as a possible solution with cooling related demand targeted as an area that could provide the required reduction at critical times. This could be trialled in many commercial buildings such as offices where the impact is a small change in the occupant comfort level, that is unlikely to cause financial loss (at least for the trial duration). In the case of a supermarkets, further investigation would be required to determine the impact of reduced cooling on product quality and life, as there is potential for significant financial loss through spoilt product, particularly in fruit and veg. sections where produce is often stored outside of refrigeration bays, relying on building space cooling for preservation. Another factor to be taken into consideration is that in an office building the occupants have no choice with regard to relocating to another cooler building (at least in the short term) whereas supermarket customers may display a preference to shop elsewhere in a cooler environment.

A feature that has already been identified as having the greatest potential for electricity consumption (and quite likely demand) reduction, are air locks at store entrances, to prevent the escape of cooled air (Department of Industry, Tourism, and Resources, 2004). This feature stands to produce greater savings where customers enter from the external environment versus from within a shopping complex. It could however be a valuable exercise to estimate to what degree supermarket cooling, (which in the author's experience is generally to a lower temperature than the shopping complex because of produce preservation requirements) supplements cooling in the remainder of the complex, where the store has a large open frontage.

Another enhancement that could assist is demand management in buildings with high cooling loads is thermal storage within the building's cooling systems. There have already been successful applications of chilled water and an ice storage unit within universities in Australia (Bahnfleth et al., 2003), that effectively store cooling capacity during off peak periods when the cost of energy is low, and there is no risk of creating a peak demand event. The stored cooling capacity is then discharged during periods of peak electricity demand, thereby reducing the peak demand, and minimising electricity consumption during higher cost peak periods. The economics of scaling this system up or down in size to suit individual building demand, maintenance, and physical space requirements would need to be considered in each application.

7.5 Technical Feasibility Result

From a technical perspective there aren't any show stopping issues that would prevent a standalone PV system from being used in the case study to offset peak demand and consumption charges. This can be extended generally to other commercial buildings provided the physical space for the PV array is available in location such that an unshaded northerly orientation can be achieved.

7.6 Financial Feasibility Result

One of the challenges immediately apparent when reviewing the case study tariff data is that the unit cost of electricity (cents / kWh) (factoring in both demand and consumption charges) is relatively low by comparison to the typical price that residential customers pay. For the month of December 2011, the average unit cost of electricity for the case study building, taking into account both consumption and demand charges, was around 10.5 cents / kWh, compared to a cost of 20-22 cents for residential customers(Ausgrid, 2012). Whilst January and February 2011 average electricity costs for the case study were likely a little higher than 10.5 cents due to higher cooling demand, the yearly average would not be expected to be any greater than this. Other commercial buildings with similar annual consumption levels may in fact have lower average electricity costs, as their demand across the year is usually a little more uniform than for supermarkets (SEAV, 2004), and hence demand charges will add less to the annual average unit cost.

Looking at the simple metric that Coles have supplied where the Simple Payback Period must be less than 4 years, it is obvious that the neither the standalone PV system or an enhanced version with battery storage, are going to be considered financially feasible. An assessment using the Levelised Cost of Electricity however gives a slightly different perspective, one that suggests over the life of the PV system, that it may in fact deliver cost savings. This metric is sensitive to the choice of discount rate (often a contentious issue) and to the forecast increase in electricity prices, and therefore the decision on financial feasibility may depend to a large degree on individual business preferences in determining these values.

Looking at the range of tariffs imposed by the distributor (United Energy, 2011) there is some evidence of an inverse relationship between the amount of consumption and the unit cost of demand charges. This may mean that some of the strategies investigated to reduced demand charges may perform better in buildings with lower annual energy consumption (<400 MWh p.a.) but which still have demand charges as part of their tariff. Further Information regarding consumption charges for smaller commercial consumers would be required before drawing any further conclusions.

7.7 Limitations of Results

The applicability of some aspects of these results to other commercial buildings will be dependent on the type of building and the nature of the business being carried out. Commercial buildings with relatively low cooling demand may find that their peak demand arises largely from other sources such as process equipment, and that this combined with increased lighting requirements in winter could result in peak demand events occurring at time when PV output is quite limited.

Different tariffs applied by other retailers and distributors in other locations will naturally influence financial feasibility and these should be allowed for, however the majority of findings are still applicable. Similarly geographic location will affect the annual energy output of a PV system to a degree, and this should be adjusted for when estimating savings.

Chapter 8 – Conclusion

An investigation into the feasibility of using solar PV to reduce demand and consumption charges in commercial buildings in Melbourne has produced some interesting conclusions that are generally in keeping with existing literature on the subject.

PV systems as a standalone option can only reliably provide a maximum of 30% of their rated capacity toward offsetting peak demand events due largely to the risk of cloud cover reducing their output during a peak demand period.

Whilst a higher coincidence exists between the timing of peak demand events and high PV output in commercial buildings compared to residential, the timing is still not optimal for a north facing array which would maximise annual energy consumption. If peak demand occurs in the early afternoon as would be expected when demand is driven by cooling and/or operating hours that extend past normal business hours, then an array rotation to the west (up to approx. 70 degrees) is likely to provide an increase in peak demand offset, and overall greater cost savings. The case study building demonstrated high demand peaks that were centred around 2pm, and would therefore benefit from an array rotation of approximately 50 degrees to the west.

Standalone PV systems whilst technically feasible in offsetting peak demand and consumption charges (providing space and orientation requirements can be met), struggle when it comes to financial feasibility. Relatively low demand and consumption charges (by comparison to residential rates), and the low level of usable rated PV capacity in offsetting peak demand events, mean PV systems at current prices have substantial payback periods that will often be beyond the threshold for investment set by many businesses. The Levelised Cost of Electricity provides a more sophisticated approach to determining financial feasibility and it is recommend that this should be carried out to provide an alternative perspective when assessing projects of this nature.

Enhancements to a standalone system in the form of energy storage via battery banks was also not viable due to the cost of significant storage capacity required to prevent a peak demand event occurring over a period of up to 3 days with cloud cover.

Where cooling represents a large proportion of summer peak demand, there is the opportunity to reduce demand by raising cooling system set points for a short period without significantly disrupting business activities in many types of buildings, to coincide with short periods of reduced PV system output. Exceptions to this would include buildings where internal temperature control has a material effect on business product, processes, or persons who are more sensitive to the effects of high temperatures such as those in hospitals or the elderly.

One area where further work could improve the value of a PV system in offsetting peak demand, is in investigating the response to a small short term rise in internal building temperatures as a result PV synched cooling demand reduction. Determining which types of commercial buildings and businesses are suited to this and the degree to which it can be implemented would be useful in assessing the benefits of this strategy.

In conclusion, commercial buildings that are best suited to PV demand offset are those where

- summer demand peaks that are greater than winter
- demand peaks have their midpoint between midday and 3pm (and a suitable array orientation is possible)
- demand peaks have durations of 4hrs of less
- the applicable tariff includes rolling (annual) and summer demand charges, and
- cooling related demand exists and a small degree of demand management will not significantly affect product or occupants

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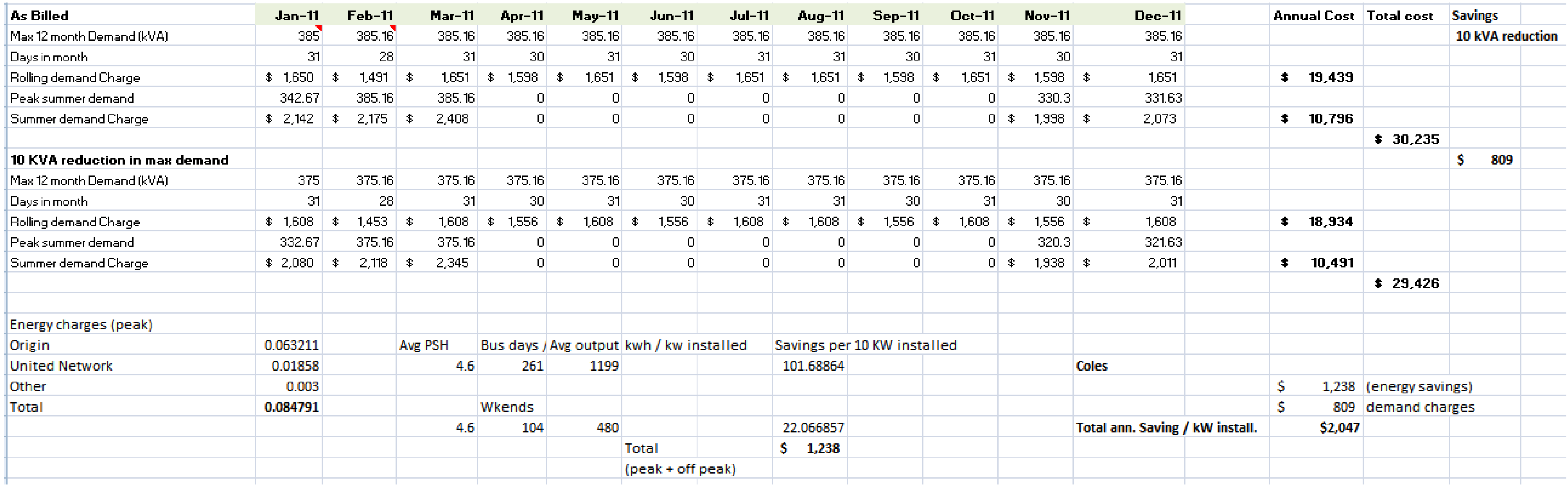
Appendix A



As Billed	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11		Annual Cost	Total cost	Savings	
Max 12 month Demand (kVA)	385	385.16	385.16	385.16	385.16	385.16	385.16	385.16	385.16	385.16	385.16	385.16				10 kVA reduction	
Days in month	31	28	31	30	31	30	31	31	30	31	30	31					
Rolling demand Charge	$ 1,650	$ 1,491	$ 1,651	$ 1,598	$ 1,651	$ 1,598	$ 1,651	$ 1,651	$ 1,598	$ 1,651	$ 1,598	$ 1,651		**$ 19,439**			
Peak summer demand	342.67	385.16	385.16	0	0	0	0	0	0	0	330.3	331.63					
Summer demand Charge	$ 2,142	$ 2,175	$ 2,408	0	0	0	0	0	0	0	$ 1,998	$ 2,073		**$ 10,796**			
															$ 30,235		
10 KVA reduction in max demand																$ 809	
Max 12 month Demand (kVA)	375	375.16	375.16	375.16	375.16	375.16	375.16	375.16	375.16	375.16	375.16	375.16					
Days in month	31	28	31	30	31	30	31	31	30	31	30	31					
Rolling demand Charge	$ 1,608	$ 1,453	$ 1,608	$ 1,556	$ 1,608	$ 1,556	$ 1,608	$ 1,608	$ 1,556	$ 1,608	$ 1,556	$ 1,608		**$ 18,934**			
Peak summer demand	332.67	375.16	375.16	0	0	0	0	0	0	0	320.3	321.63					
Summer demand Charge	$ 2,080	$ 2,118	$ 2,345	0	0	0	0	0	0	0	$ 1,938	$ 2,011		**$ 10,491**			
															$ 29,426		
Energy charges (peak)																	
Origin	0.063211		Avg PSH	Bus days /	Avg output	kwh / kw installed		Savings per 10 KW installed									
United Network	0.01858		4.6	261	1199			101.68864				**Coles**					
Other	0.003													$ 1,238	(energy savings)		
Total	**0.084791**			Wkends										$ 809	demand charges		
			4.6	104	480			22.066857				**Total ann. Saving / kW install.**		**$2,047**			
						Total		**$ 1,238**									
						(peak + off peak)											

Appendix B

The following parameters were used in roughly estimating the cost of storage

- Cost of battery storage is in the order of \$0.20 / Wh (Solar AGM Batteries) (Batterystuff.com, 2013)
- Overall efficiency of the battery, inverter, and other miscellaneous components is 80%
- Required storage capacity – assume sufficient energy is required to offset 3 days of 10 kVA of peak demand for 5 hours (12-5pm) without any charging occurring during this period.

AC Load = 50 kWh/Day x 240 VAC = 208 AH/Day @ 240 VAC

Convert to DC Battery Load. Inverter's Charger is 48 VDC and the efficiency is 80%.

DC Load = 208 AH/Day X 240/48 [voltage conversion] x 0.8 [efficiency] = 832 AH/Day battery load

For 3 days of peak demand offset without any charging, and allowing a drawdown of 60% of battery capacity,

Total battery capacity = 832 x 3 days /.6 = 4160 Ah @ 48V

Appendix C

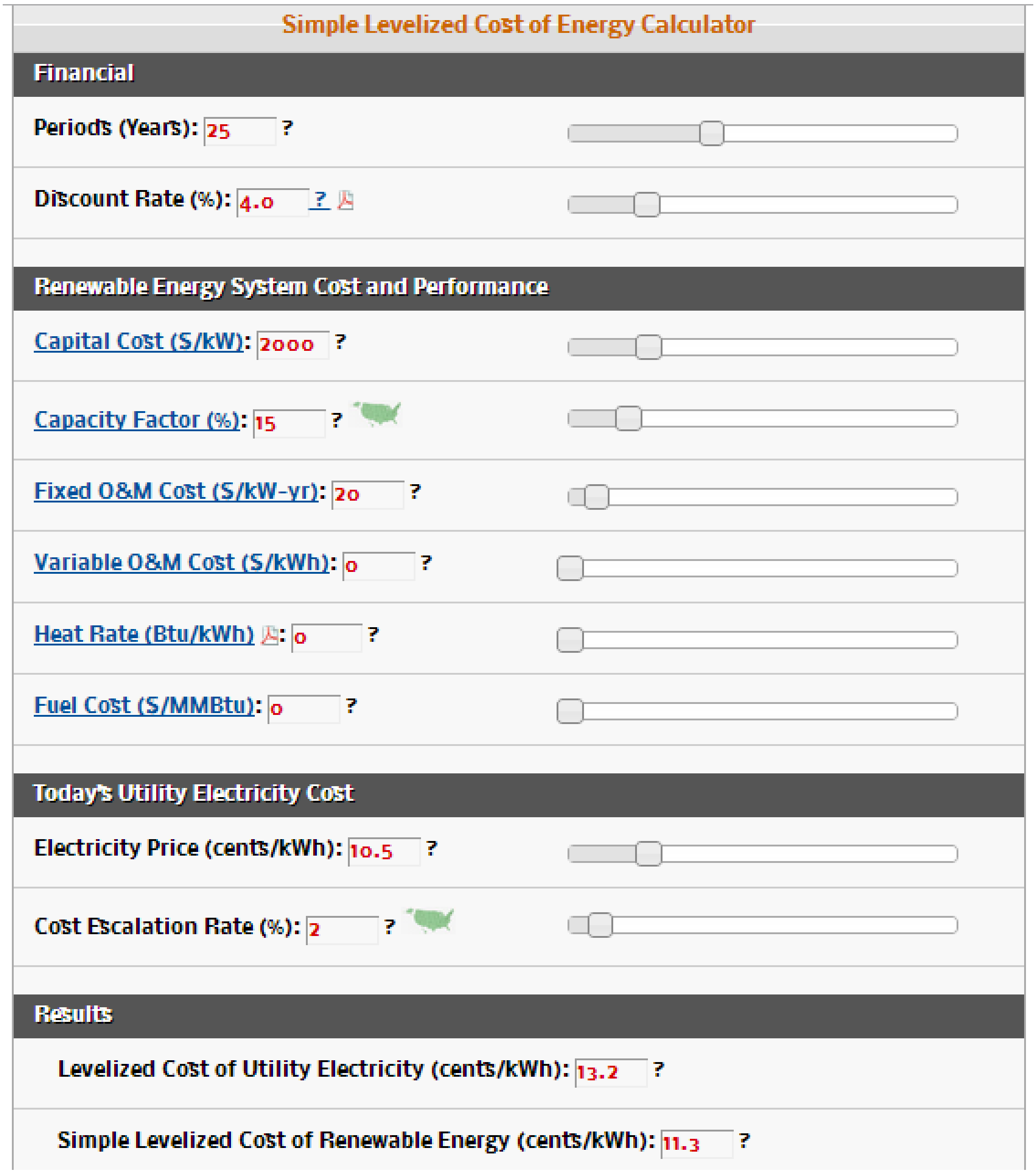
Annual Average Electricity Cost Savings Calculator

Year	2% increase	4% increase
1	$ 1,440	$ 1,440
2	$ 1,469	$ 1,498
3	$ 1,498	$ 1,558
4	$ 1,528	$ 1,620
5	$ 1,559	$ 1,685
6	$ 1,590	$ 1,752
7	$ 1,622	$ 1,822
8	$ 1,654	$ 1,895
9	$ 1,687	$ 1,971
10	$ 1,721	$ 2,050
11	$ 1,755	$ 2,132
12	$ 1,790	$ 2,217
13	$ 1,826	$ 2,305
14	$ 1,863	$ 2,398
15	$ 1,900	$ 2,494
16	$ 1,938	$ 2,593
17	$ 1,977	$ 2,697
18	$ 2,016	$ 2,805
19	$ 2,057	$ 2,917
20	$ 2,098	$ 3,034
21	$ 2,140	$ 3,155
22	$ 2,183	$ 3,281
23	$ 2,226	$ 3,413
24	$ 2,271	$ 3,549
25	$ 2,316	$ 3,691
Total savings	$ 46,124	$ 59,970
avg. ann. savings	$ 1,845	$ 2,399
Simple pay back period (years)	13.55	10.42

Appendix D

National Renewable Energy Laboratory (NREL) Calculator found at

http://www.nrel.gov/analysis/tech_lcoe.html



Simple Levelized Cost of Energy Calculator

Financial

Periods (Years): 25

Discount Rate (%): 4.0

Renewable Energy System Cost and Performance

Capital Cost ($/kW): 2000

Capacity Factor (%): 15

Fixed O&M Cost ($/kW-yr): 20

Variable O&M Cost ($/kWh): 0

Heat Rate (Btu/kWh): 0

Fuel Cost ($/MMBtu): 0

Today's Utility Electricity Cost

Electricity Price (cents/kWh): 10.5

Cost Escalation Rate (%): 2

Results

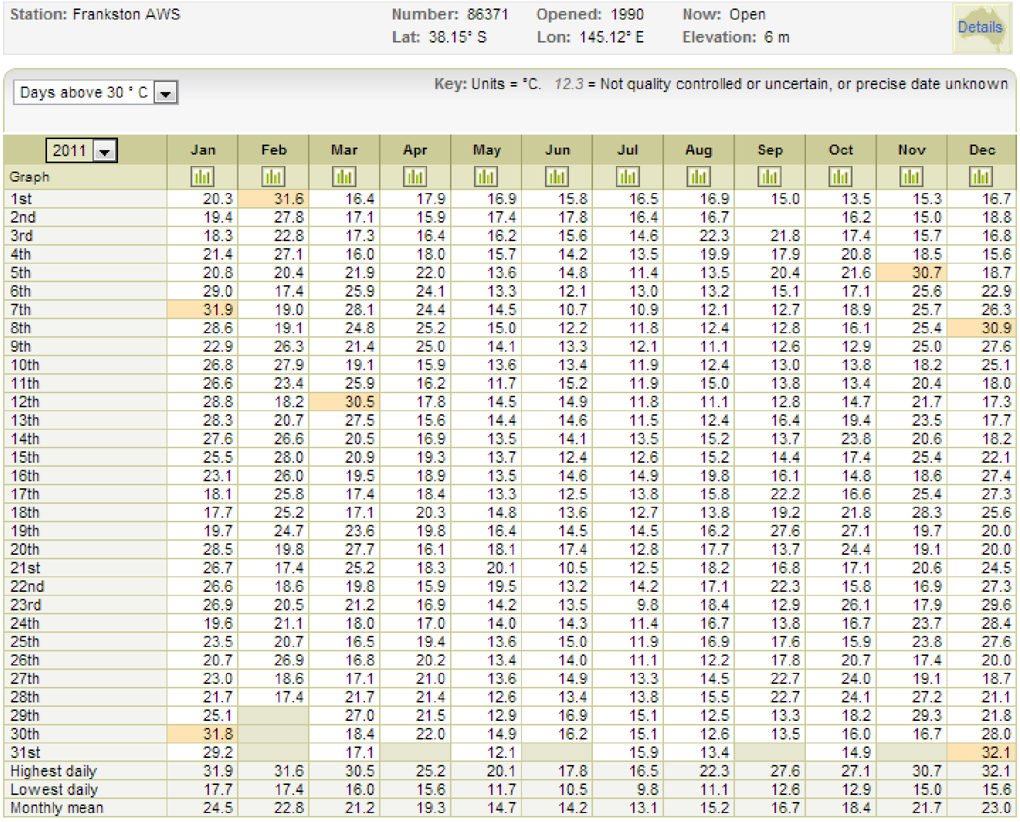
Levelized Cost of Utility Electricity (cents/kWh): 13.2

Simple Levelized Cost of Renewable Energy (cents/kWh): 11.3

Appendix E

Days with Max. Temps above 30 deg. C (shaded in pink)

Source = Bureau of Metrology (2013)



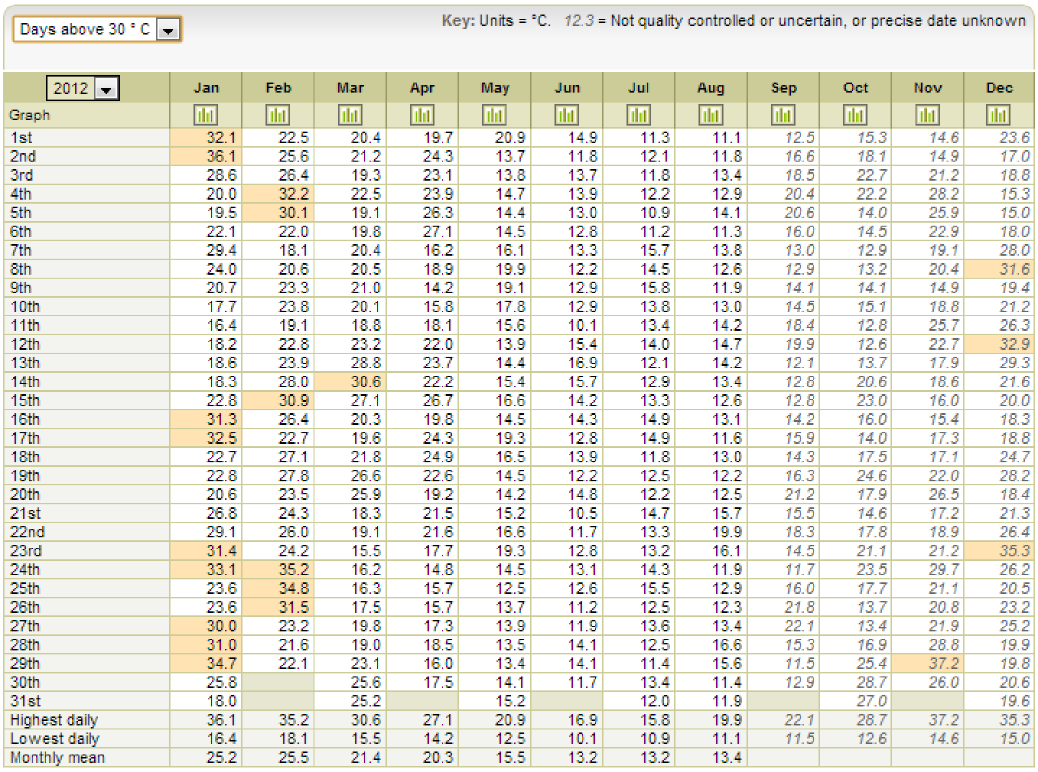
Station: Frankston AWS

Number: 86371 Opened: 1990 Now: Open

Lat: 38.15° S Lon: 145.12° E Elevation: 6 m

Key: Units = °C. *12.3* = Not quality controlled or uncertain, or precise date unknown

2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Graph	📊	📊	📊	📊	📊	📊	📊	📊	📊	📊	📊	📊
1st	20.3	31.6	16.4	17.9	16.9	15.8	16.5	16.9	15.0	13.5	15.3	16.7
2nd	19.4	27.8	17.1	15.9	17.4	17.8	16.4	16.7		16.2	15.0	18.8
3rd	18.3	22.8	17.3	16.4	16.2	15.6	14.6	22.3	21.8	17.4	15.7	16.8
4th	21.4	27.1	16.0	18.0	15.7	14.2	13.5	19.9	17.9	20.8	18.5	15.6
5th	20.8	20.4	21.9	22.0	13.6	14.8	11.4	13.5	20.4	21.6	30.7	18.7
6th	29.0	17.4	25.9	24.1	13.3	12.1	13.0	13.2	15.1	17.1	25.6	22.9
7th	31.9	19.0	28.1	24.4	14.5	10.7	10.9	12.1	12.7	18.9	25.7	26.3
8th	28.6	19.1	24.8	25.2	15.0	12.2	11.8	12.4	12.8	16.1	25.4	30.9
9th	22.9	26.3	21.4	25.0	14.1	13.3	12.1	11.1	12.6	12.9	25.0	27.6
10th	26.8	27.9	19.1	15.9	13.6	13.4	11.9	12.4	13.0	13.8	18.2	25.1
11th	26.6	23.4	25.9	16.2	11.7	15.2	11.9	15.0	13.8	13.4	20.4	18.0
12th	28.8	18.2	30.5	17.8	14.5	14.9	11.8	11.1	12.8	14.7	21.7	17.3
13th	28.3	20.7	27.5	15.6	14.4	14.6	11.5	12.4	16.4	19.4	23.5	17.7
14th	27.6	26.6	20.5	16.9	13.5	14.1	13.5	15.2	13.7	23.8	20.6	18.2
15th	25.5	28.0	20.9	19.3	13.7	12.4	12.6	15.2	14.4	17.4	25.4	22.1
16th	23.1	26.0	19.5	18.9	13.5	14.6	14.9	19.8	16.1	14.8	18.6	27.4
17th	18.1	25.8	17.4	18.4	13.3	12.5	13.8	15.8	22.2	16.6	25.4	27.3
18th	17.7	25.2	17.1	20.3	14.8	13.6	12.7	13.8	19.2	21.8	28.3	25.6
19th	19.7	24.7	23.6	19.8	16.4	14.5	14.5	16.2	27.6	27.1	19.7	20.0
20th	28.5	19.8	27.7	16.1	18.1	17.4	12.8	17.7	13.7	24.4	19.1	20.0
21st	26.7	17.4	25.2	18.3	20.1	10.5	12.5	18.2	16.8	17.1	20.6	24.5
22nd	26.6	18.6	19.8	15.9	19.5	13.2	14.2	17.1	22.3	15.8	16.9	27.3
23rd	26.9	20.5	21.2	16.9	14.2	13.5	9.8	18.4	12.9	26.1	17.9	29.6
24th	19.6	21.1	18.0	17.0	14.0	14.3	11.4	16.7	13.8	16.7	23.7	28.4
25th	23.5	20.7	16.5	19.4	13.6	15.0	11.9	16.9	17.6	15.9	23.8	27.6
26th	20.7	26.9	16.8	20.2	13.4	14.0	11.1	12.2	17.8	20.7	17.4	20.0
27th	23.0	18.6	17.1	21.0	13.6	14.9	13.3	14.5	22.7	24.0	19.1	18.7
28th	21.7	17.4	21.7	21.4	12.6	13.4	13.8	15.5	22.7	24.1	27.2	21.1
29th	25.1		27.0	21.5	12.9	16.9	15.1	12.5	13.3	18.2	29.3	21.8
30th	31.8		18.4	22.0	14.9	16.2	15.1	12.6	13.5	16.0	16.7	28.0
31st	29.2		17.1		12.1		15.9	13.4		14.9		32.1
Highest daily	31.9	31.6	30.5	25.2	20.1	17.8	16.5	22.3	27.6	27.1	30.7	32.1
Lowest daily	17.7	17.4	16.0	15.6	11.7	10.5	9.8	11.1	12.6	12.9	15.0	15.6
Monthly mean	24.5	22.8	21.2	19.3	14.7	14.2	13.1	15.2	16.7	18.4	21.7	23.0



Key: Units = °C. *12.3* = Not quality controlled or uncertain, or precise date unknown

2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Graph	📊	📊	📊	📊	📊	📊	📊	📊	📊	📊	📊	📊
1st	32.1	22.5	20.4	19.7	20.9	14.9	11.3	11.1	*12.5*	*15.3*	*14.6*	*23.6*
2nd	36.1	25.6	21.2	24.3	13.7	11.8	12.1	11.8	*16.6*	*18.1*	*14.9*	*17.0*
3rd	28.6	26.4	19.3	23.1	13.8	13.7	11.8	13.4	*18.5*	*22.7*	*21.2*	*18.8*
4th	20.0	32.2	22.5	23.9	14.7	13.9	12.2	12.9	*20.4*	*22.2*	*28.2*	*15.3*
5th	19.5	30.1	19.1	26.3	14.4	13.0	10.9	14.1	*20.6*	*14.0*	*25.9*	*15.0*
6th	22.1	22.0	19.8	27.1	14.5	12.8	11.2	11.3	*16.0*	*14.5*	*22.9*	*18.0*
7th	29.4	18.1	20.4	16.2	16.1	13.3	15.7	13.8	*13.0*	*12.9*	*19.1*	*28.0*
8th	24.0	20.6	20.5	18.9	19.9	12.2	14.5	12.6	*12.9*	*13.2*	*20.4*	*31.6*
9th	20.7	23.3	21.0	14.2	19.1	12.9	15.8	11.9	*14.1*	*14.1*	*14.9*	*19.4*
10th	17.7	23.8	20.1	15.8	17.8	12.9	13.8	13.0	*14.5*	*15.1*	*18.8*	*21.2*
11th	16.4	19.1	18.8	18.1	15.6	10.1	13.4	14.2	*18.4*	*12.8*	*25.7*	*26.3*
12th	18.2	22.8	23.2	22.0	13.9	15.4	14.0	14.7	*19.9*	*12.6*	*22.7*	*32.9*
13th	18.6	23.9	28.8	23.7	14.4	16.9	12.1	14.2	*12.1*	*13.7*	*17.9*	*29.3*
14th	18.3	28.0	30.6	22.2	15.4	15.7	12.9	13.4	*12.8*	*20.6*	*18.6*	*21.6*
15th	22.8	30.9	27.1	26.7	16.6	14.2	13.3	12.6	*12.8*	*23.0*	*16.0*	*20.0*
16th	31.3	26.4	20.3	19.8	14.5	14.3	14.9	13.1	*14.2*	*16.0*	*15.4*	*18.3*
17th	32.5	22.7	19.6	24.3	19.3	12.8	14.9	11.6	*15.9*	*14.0*	*17.3*	*18.8*
18th	22.7	27.1	21.8	24.9	16.5	13.9	11.8	13.0	*14.3*	*17.5*	*17.1*	*24.7*
19th	22.8	27.8	26.6	22.6	14.5	12.2	12.5	12.2	*16.3*	*24.6*	*22.0*	*28.2*
20th	20.6	23.5	25.9	19.2	14.2	14.8	12.2	12.5	*21.2*	*17.9*	*26.5*	*18.4*
21st	26.8	24.3	18.3	21.5	15.2	10.5	14.7	15.7	*15.5*	*14.6*	*17.2*	*21.3*
22nd	29.1	26.0	19.1	21.6	16.6	11.7	13.3	19.9	*18.3*	*17.8*	*18.9*	*26.4*
23rd	31.4	24.2	15.5	17.7	19.3	12.8	13.2	16.1	*14.5*	*21.1*	*21.2*	*35.3*
24th	33.1	35.2	16.2	14.8	14.5	13.1	14.3	11.9	*11.7*	*23.5*	*29.7*	*26.2*
25th	23.6	34.8	16.3	15.7	12.5	12.6	15.5	12.9	*16.0*	*17.7*	*21.1*	*20.5*
26th	23.6	31.5	17.5	15.7	13.7	11.2	12.5	12.3	*21.8*	*13.7*	*20.8*	*23.2*
27th	30.0	23.2	19.8	17.3	13.9	11.9	13.6	13.4	*22.1*	*13.4*	*21.9*	*25.2*
28th	31.0	21.6	19.0	18.5	13.5	14.1	12.5	16.6	*15.3*	*16.9*	*28.8*	*19.9*
29th	34.7	22.1	23.1	16.0	13.4	14.1	11.4	15.6	*11.5*	*25.4*	*37.2*	*19.8*
30th	25.8		25.6	17.5	14.1	11.7	13.4	11.4	*12.9*	*28.7*	*26.0*	*20.6*
31st	18.0		25.2		15.2		12.0	11.9		*27.0*		*19.6*
Highest daily	36.1	35.2	30.6	27.1	20.9	16.9	15.8	19.9	*22.1*	*28.7*	*37.2*	*35.3*
Lowest daily	16.4	18.1	15.5	14.2	12.5	10.1	10.9	11.1	*11.5*	*12.6*	*14.6*	*15.0*
Monthly mean	25.2	25.5	21.4	20.3	15.5	13.2	13.2	13.4				