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Design of solar energy system in food manufacturing environment

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Abstract: Global climate change has driven many manufacturing organizations to consider renewable energy as an alternative source of power for their operations. However, the instability and unpredictability of renewable energy has made it difficult to design an optimal solution. This is particularly critical for food manufacturing which is constrained by timing and seasonable fluctuations. This paper describes a feasibility study of offsetting grid supplied power by local generation using a roof top photovoltaic system. The study shows that the company can significantly reduce their carbon emitting energy usage by a 100 kW photovoltaic solar system that helps to reduce the annual electricity consumption by 39%. The system sizing methodology has taken into account the load profile of the food manufacturing plant and seasonal solar energy availability with the constrain to consume all solar power immediately.

Subjects: Clean Tech; Production Engineering; Systems & Control Engineering

Keywords: solar energy; food manufacturing; load profiling; power management; system sizing

1. Introduction

In recent years, many studies indicated that global climate is changing due to significant level of greenhouse gas emission. Jemala (2013) studied the effect of technology and economic development on regional environmental sustainability. The analysis discovered 40 regional hotspots around

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PUBLIC INTEREST STATEMENT

Global climate change has driven many manufacturing organizations to consider renewable energy as an alternative source of power for their operations. However, the instability and unpredictability of renewable energy has made it difficult to design an optimal solution. This is particularly critical for food manufacturing which is constrained by timing and seasonable fluctuations. Unfortunately, investment for renewable equipment is high and takes years to pay back. Therefore, it is important to develop a methodology to properly design the solar system to maximize the return on investment. This paper uses a pasta manufacturer case study to illustrate the systematic methodology involving collection of data from many different sources, analyses on the fluctuating solar and factory energy consumption, and recommended actions for the manufacturer to achieve the desirable system outcomes.

the world and highlighted the sustainability problems by a range of criteria including as biodiversity, standard of living, CO_2 emissions and GDP per capita. Liu, Shi, and Jiang (2009) used an energy technology model to analyse the trend of new energy sources in China. The key factor in the transition from traditional power generation to renewable energy sources is the increased research, demonstration and application of new power generation technologies. Mo and Chen (2008) investigated the possibility of sourcing different forms of renewable energy on Australian landscape. They concluded that full installation of renewable energy sources on every square metre of the land was still not sufficient to replace traditional coal fired power. Hence, the solution should be on both energy source development and energy consumption reduction.

Food manufacturing consumes a lot of energy during the cooking and chilling stages of food processing. However, the scope for energy reduction in these processes is rather limited due to time criticality and hygiene requirements. Instead, a more intelligent methodology should be adopted to specify and design the energy system. Schaede, Ahsen, Rinderknecht, and Schiereck (2013) proposed a specification, design and assessment method to analyse the applications load profile of renewable energy systems. The method considered the energetic behaviour, future prospects, life cycle costs as well as environmental impacts of energy harvesting and storages. Many different harvesting techniques have been developed in the last decade (Harb, 2011). These techniques should be integrated with power management systems to maximize their performance. For example, many standalone installations would include a mix devices such as photovoltaic, wind, diesel and battery systems. Merei, Berger, and Sauer (2013) showed that using batteries in combination with the renewable energy sources was economical and ecological. However, the complexity of integrating a variety of electrical devices should not be underestimated. Farid, Khudhair, Razack, and Al-Hallaj (2004) investigated the use of phase change energy storage materials. Unger and Myrzik (2013) used agent based management approach and achieved higher efficiency with the implementation of different agents in the system. Gupta, Shukla, and Srivastava (2013) analysed a solar drying unit with phase change material storage systems. Their application was interesting because it demonstrated that the solar dryer was effective to dry fruits and vegetable and other food products for preservations.

It was on this basis that a pasta manufacturer, Melbourne Chef requested a feasibility study of the possibility to offset grid supplied power consumption by local generation using a roof top photovoltaic system. Figure 1 shows some of the products manufactured by Melbourne Chef. This paper outlines an assessment of the amount of energy that can be collected, usage analysis for before and after the proposed solar system installation. The rigorous analysis also includes an estimate of the savings and reduction in consumption and carbon emissions.

2. Literature review

There are many ways to capture and store renewable energy. Olaofe and Folly (2012) studied the economic viability of a 3 kW wind conversion system for residential use. The study concluded that the system was sufficient for meeting the daily energy needs of each household requiring 84 kWh/month with an annual average wind speed of approximately 18.7 km/hr. Prabhakar and Ragavan (2013) proposed a new power management based current control strategy for an integrated wind–solar–hydro system equipped with battery storage. The system was modelled and simulated MATLAB/Simulink and showed advantages of simpler control algorithms and use of fewer power electronic converters. Saravanan and Thangavel (2013) simulated the performance of a neural network and fuzzy logic controller for maintaining a constant voltage at point of common coupling and efficient power flow control for multiple renewable energy sources such as solar energy, wind energy, and fuel cell energy with battery backup. Qi, Liu, and Christofides (2013) designed a distributed supervisory model predictive control system for optimal management and operation of distributed wind and solar energy generation systems integrated into the electrical grid. The system was simulated on a 24-h operation cycle. The result showed that operational support such as battery maintenance could be minimized.

Figure 1. Some products of Melbourne Chef.

(a) Filos

(b) Bolognese Lasagne

(c) Vegetable Frittata

(d) Quiche Lorraine

(e) Ravioli Bolognese

(f) Antipasto Frittat

The concept of combining hydrogen with photovoltaic system is quite popular. Contreras, Guirado, and Veziroglu (2007) analysed a 250 kW photovoltaic–hydrogen system and determined the parameters for high energy yield. Takubo, Takahashi, Imai, and Funabiki (2013) studied the performance of a hybrid renewable power generator comprising a photovoltaic system, a fuel cell and an electrolyser and proposed a hydrogen management algorithm to minimize bad influences on electric power quality such as frequency and voltage fluctuations. Dou and Andrews (2012) employed a photovoltaic array while any surplus energy was stored in the form of hydrogen. The objective was to replace diesel and photovoltaic battery systems with hydrogen fuel cell for remote area applications. Their work was still preliminary and was limited to establishing design principle of a control unit for a solar-hydrogen system with hydrogen generation via a proton exchange membrane electrolyser. Caisheng Wang and Nehrir (2008) proposed a hybrid renewable energy system consisting of wind, photovoltaic and hydrogen fuel cell. The system was managed on an AC link. The system was analysed by a simulation model using MATLAB/Simulink. Torreglosa, García, Fernández, and Jurado (2014) presented an energy management system for stand-alone hybrid photovoltaic-hydrogen-wind-battery system. The validity of the system was proven by simulating the control responses for both long term (up to the service life of the system) and short term slave configuration.

Energy management is a key factor in multi-renewable energy source environment. Duryea, Islam, and Lawrance (2001) estimated that about 80% of all photovoltaic were used in stand-alone applications where continuous power was maintained by batteries. Hence, managing charging and discharge of lead acid batteries would determine the life of these batteries and subsequently the life cycle costs. Miland and Ulleberg (2012) tested an experimental power system based on hydrogen and solar energy. Some practical problems were identified including limited control, minimal ability to regulate power and voltage levels, potential failure of the air-cooled metal hydrides. Natsheh, Natsheh, and Albarbar (2013) introduced an on-line energy management system for a three layer hybrid system consisting of photovoltaic, battery and fuel cell. The current flow between layers and the optimum set points were studied. The research offered a potential tool for optimising the hybrid power system for smart-house applications. In a more realistic trial, García, Fernández, Torreglosa, and Jurado (2013) developed a hybrid power system based on fuel cell, battery, ultra-capacitor for an electric tramway. Integrating with the energy storage and regenerative energy sources during brakings and decelerations, the simulation model showed that the energy management system could be applied effectively to the tramway under investigation.

These researches were interesting but they were still at low technology readiness levels and would not be practically feasible for immediate application. It was therefore considered more appropriate to focus on photovoltaic only or photovoltaic plus battery renewable energy system in this research.

With good energy management system and operating conditions similar to standard test conditions, most commercial polycrystalline photovoltaic modules could achieve efficiencies between 11 and 15% (Pure Energies, 2015). Some advanced control algorithms such as maximum power point tracking (MPPT) could further improve the maximum output power at 1 kW/m^2 and 25°C using DC/DC converters as compared to traditional method (Koutroulis, Kalaitzakis, & Voulgaris, 2001). Xiao and Dunford (2004) extended the MPPT method with a modified adaptive hill climbing0020method to avoid tracking deviation. Better performance in both transient and steady states was observed. Shmilovitz (2005) used the MPPT output voltage and current to control the photovoltaic power output, rather than using its input voltage and current. The approach was more practical because it could use a single output control parameter and could be applied to nearly all load types. Zhang and Chau (2011) tested an experimental thermoelectric-photovoltaic hybrid energy system for use on automotive. They found that MPPT control was a key requirement for such system.

To design a renewable energy system for practical use, a detail energy system analysis is required. Lund (2014) illustrated a methodology for comparing different energy systems' abilities to integrate fluctuating and intermittent renewable energy sources. The comparative analysis could be used for understanding the impact of changes in energy systems on national and international levels. Alam, Muttaqi, and Sutanto (2013) studied the impact of high penetration of roof top solar photovoltaic resources into low-voltage distribution networks and proposed a migration strategy by a distributed energy storage system. The strategy included a charging/discharging control method which dynamically adjusted the charging rate to ensure the desired level of current state of charge. Dalton, Lockington, and Baldock (2008) evaluated the feasibility of powering a hotel with over 100 beds with total renewable energy sources. The assessment criteria were based on financial parameters, i.e. net present cost, renewable factor and payback period but were also constrained by the specific operational characteristics of the tourism accommodation sector, such as 24-h operation, comfort provision and low tolerance for failure.

These researches highlight the fact that the design of solar system using photovoltaic modules would require careful evaluation and data analysis of the actual requirements. This paper takes into account the stringent food manufacturing environment and outlines an analysis methodology to guide future projects in this industry sector.

3. System design methodology

When considering the methodology to tackle this problem, several factors should be taken in consideration:

- Solar energy is fluctuating daily and annually.
- Consumption is governed by a base load and relatively minor variations.
- A weekly pattern exists due to working week cycle.
- Freshness requirement in food processing.

The system diagram can be represented in Figure 2.

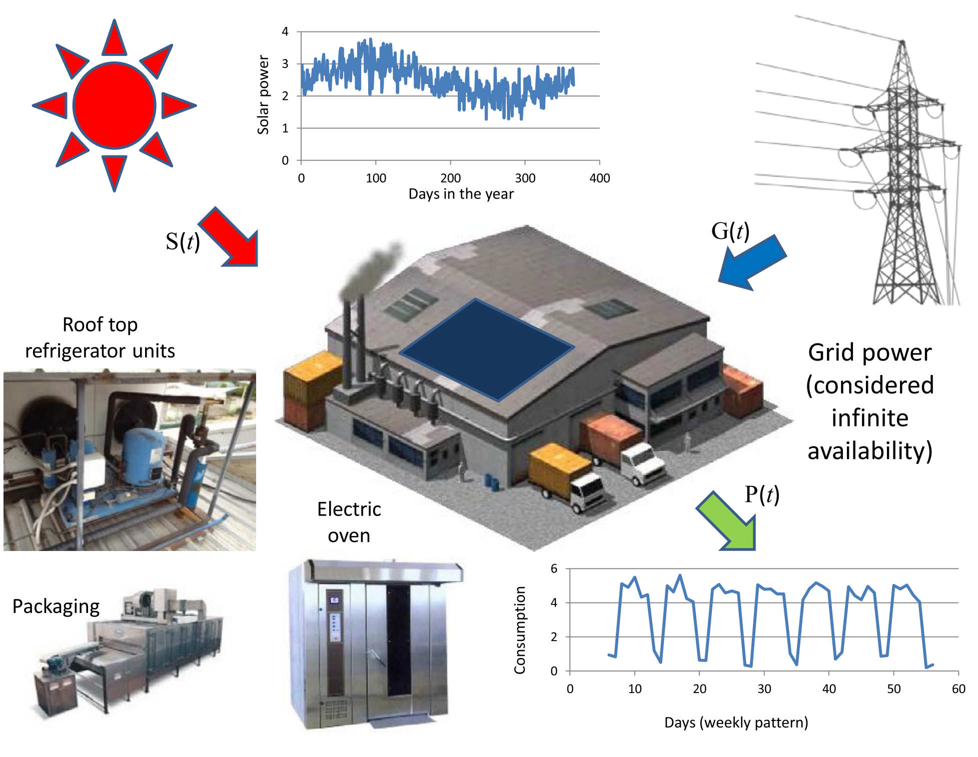
The energy balance in Figure 2 can be expressed as:

$$P(t) = G(t) + S(t) \tag{1}$$

where P(t) = power consumed, G(t) = power drawn from grid, S(t) = solar power depends on time of day and seasonable variations.

Theoretically, it is possible to sell solar power back to the grid but the price for this type of renewable energy feed is less than 30% of the grid power price. It is therefore not advisable to generate more energy than necessary in the factory. Hence, the methodology for system design will have the objective to minimize the use of grid power with the constraint that the grid power feed is always positive, i.e:

Figure 2. System diagram.



$$G(t) > 0 \tag{2}$$

To determine size of the system, it is necessary to collect operating information from the factory. A series of site surveys were conducted including:

- Capture the power rating of all equipment on site.
- Obtain power bills from the factory for the last 12 months.
- Search for solar information from the Weather Bureau.

The result of these investigations are analysed and presented in the following section.

4. Analysis of existing load profile

Currently the energy used by Melbourne Chef for various functions splits in Table 1.

Table 1 shows the proportion of energy consumed in Melbourne Chef. It is easily seen that the two major energy intensive processes are cooking and refrigeration. Cooking of pasta is a daily activity that must occur in certain pattern between 9 am and 2 pm on working days. The cooking process consists of washing, preparation, vegetable process, pasta production and boiling, packing and chilling. Therefore, the peak power requirement occurs in the morning hours.

The second most important area of energy consumption is the refrigeration load. This is a base load and is fairly constant day and night but it can be reduced significantly by installation of more efficient refrigeration equipment. The study of a new intelligent refrigeration system is outside the scope of this paper. However, the base load characteristics of refrigeration imposes constraints to the often unpredictable and fluctuating solar energy supply.

Like many small to medium enterprises, Melbourne Chef does not have a good recording system of energy consumption over the years. The company does not even have a database of the machines that are used on site and how they are used. Instead of searching the company's records, the current base line consumption of electricity from the grid based on bills spanning 18th February 2012 to 17th February 2013 was 570,179 kWh per year which splitted into 392,124 kW used in peak tariff periods and 178,055 kWh used during off peak periods. Substantial reductions in this consumption could be made by supplementing with solar power source with direct and indirect monetary savings.

The premises were acquired at different times and hence two separate electricity meters were in use on site. Figure 3 shows 15 min interval metering data for one year from 1st March 2012 for one of the Melbourne Chef premises. This data has been obtained from the power supplier, AGL. The 52 weekends are clearly visible as are the Christmas/New Year breaks just before record 30,000. The summer clearly shows higher demand than the winter.

Figure 4 shows the 15 min interval data for a week in the middle of August, Monday 13th to Sunday 19th for the same premises.

The demand has clearly been reduced through the week and the two days of the weekend show lower consumption. The peak demand in this week was 31.57 kWh in a 15 min period which equates to 126.28 kW which the bill indicated the highest actual metered demand for August.

Outside office hours, when the load is mainly just refrigeration compressors keeping (closed) cool rooms cold. The base load was about 4–7 kWh over 15 min, i.e. 16–28 kW. From this data, it is estimated that there was a fixed (24 h/day) controllable load of 22 kW. Unfortunately, the billing periods for the accounts at No. 29 and No. 33 Barrett St did not match up and the meter type at No. 33 was set up as an accumulation meter so no interval data was available. For this reason the ratio of the electricity used in No. 33 Barrett St to that used in No. 29 Barrett St has been assumed to be fixed.

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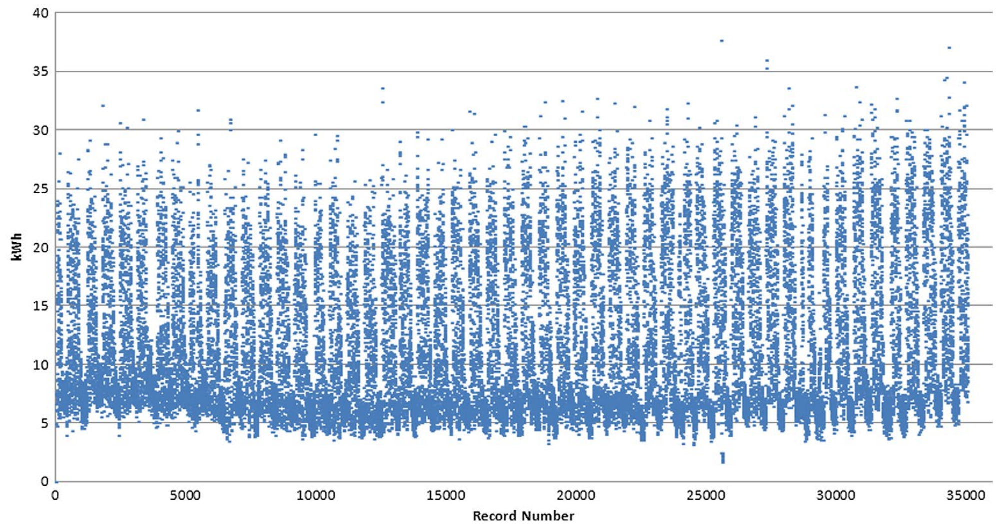


Figure 3. Interval meter data for 29 Barret Street.

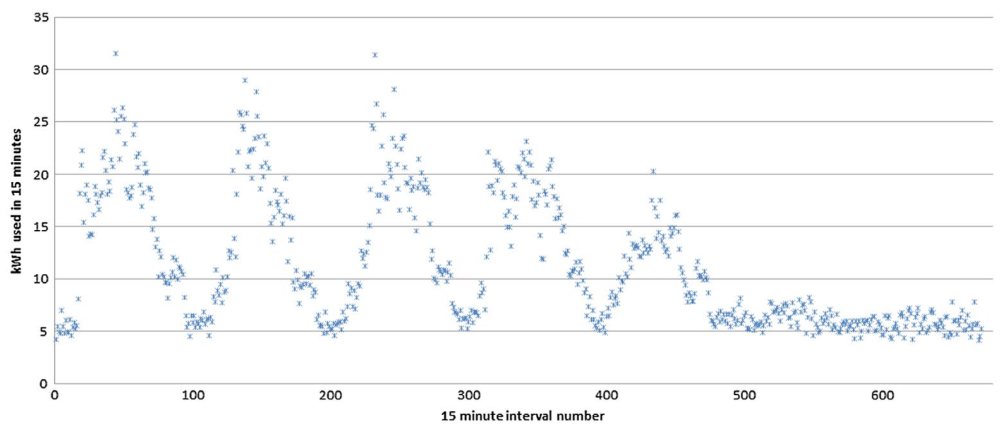


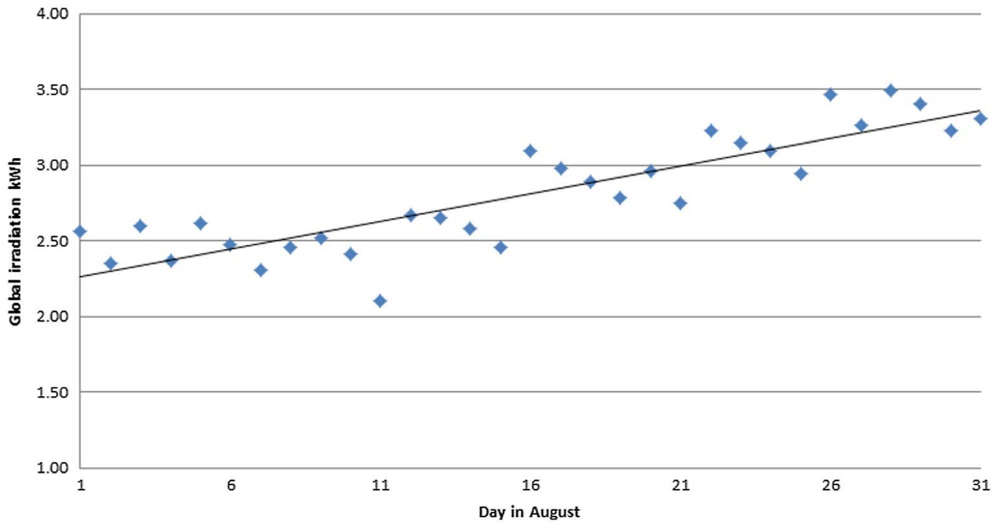
Figure 4. Interval meter data for week beginning Monday 13th August.

The 12 electricity bills provided by Melbourne Chef for each account shows the totals used in each billing period had reasonably constant ratio between the two accounts in peak and off-peak periods. Subsequently, the average of these ratios which show that, in peak time, No. 33 Barrett Street uses about half the electricity that No. 33 uses and during off peak times No. 33 uses about 0.3 times the electricity used at No. 29.

5. Assessment of solar energy availability

August data relating to daily global irradiance from the Australian Bureau of Meteorology (ABM) was used (Bureau of Meteorology (BOM), 2015). The observations were taken at ABM station nearest to Melbourne Chef in Kensington. This 23 year data-set included 47 days on which measurements were missing. For these days the missing data was replaced by the average of the data which was captured in the August days of the year in question. The average for all August days was 2.8 kWh/m^2 and the standard deviation was about 1 kWh/m^2. The sunniest August occurred in 2011 with an average of 3.1 kWh/m^2/day and the least sunny was 1992 with 2.4 kWh/m^2/day. The sunniest August day over the whole 23 year period (the last day in August 1996) gave 5 kWh and the least sun was 0.06 kWh (a range of almost two orders of magnitude). To give these August figures a little more perspective, it was noted that Melbourne has just passed the Autumn equinox (March 21st 2013) when the length of the day (light) was its exact average (about 12 h). It was also noted that on 26th March, Melbourne had an almost cloudless day with a solar energy record of 5.2 kWh/m^2 of global irradiance falling on a horizontal surface.

Figure 5. Average sun in each day in August (1990–2012).



On average, the energy from the sun in Melbourne increases through August as shown in the plot in Figure 5.

If we take the average for the week of 13–19th August over the last 23 years we get 2.78 kWh/m^2/day (very close to the average for all August days).

Radiant energy reaches the collector, in this case photovoltaic modules, in two ways: by direct rays from the sun and by indirect (reflected, refracted and re-emitted) rays coming from other directions (from clouds, dust and air in the atmosphere). How the collector is orientated affects how much energy impinges on it. From the measurement records described in the last paragraph, the energy falling on a horizontal module can be estimated to be 4.4 kWh/m^2/day.

In Melbourne substantially more energy is collected over a year from a module facing North tilted to the Latitude (37.8°). Compared with a horizontal module, a North facing orientation adjusted according to the Latitude could be close to a configuration that will collect most energy. Whether or not the cost of a tilt system is less than simply installing more modules is becoming debatable but, for now, it seems to be a better option. Whether or not facing the modules due North is the optimal for this application depends on several factors including the time of peak consumption for the business and the demand charges levied by the supplier of grid power. If the North facing inclination is considered an optimal, the average amount of energy over the year falling on modules orientated this way in Melbourne is 5.1 kWh/m^2/day.

Hence, the ratio of the average daily global irradiance compared to that which falls on North facing modules inclined at Melbourne's latitude is 5.1/4.4 for average days averaged over the whole year. For simplicity of computation, this ratio is assumed to be correct when only August days are considered. This gives the expected energy falling on modules oriented in such a manner as 3.22 kWh/m^2/day. In August the modules should not get as hot as in summer because the average intensity of the energy falling on them will be less and the ambient temperature will also be lower.

6. System sizing

Currently the typical size for a single module used in commercial sized projects is 2 × 1 m. These modules are rated at 300 W under standard test conditions. A system rated at 100 kW would include 333 modules over a total area of 666 m^2. The energy collected by the modules per day would therefore apparently average 509 kWh/day. There will be losses in the system due mainly to heat dissipation in the wiring and inverter inefficiency. Peak efficiencies for large transformer-less inverters are typically 98% but we must assume a lower figure for average efficiency under actual operating conditions. We will be reasonably conservative and assume the losses total 10% of the energy collected which gives an average of 458 kWh produced each day.

A 100 kW system produces 100 kW under Standard Test Conditions. Under Standard Conditions the modules are irradiated with a simulation of sunlight which has been modified in spectrum by passing through by 1.5 atmospheres. This is to account for the fact that the sun's rays are not usually reaching the ground having passed exactly vertically through the atmosphere but at most times of the day pass at an angle which increases absorption. The intensity of the light energy under Standard Conditions is 1 kW/m^2 which is about that of sunlight reaching the ground on a clear day with the sun directly overhead. The temperature of the modules under Standard Conditions is 25° Centigrade. All this means that in practice it is rare to get a 100 kW rated system actually producing 100 kW. The main factor reducing the modules' output is their reduction in efficiency with temperature. This amounts to about 0.5%/°C (National Renewable Energy Laboratory, 2015). If we assume an operating temperature of 50°C we should expect a reduction in the power collected of 12.5%. The potential 458 kWh then becomes 401 kWh/day averaged over the year. To reduce complexity of the system, it was decided to use a fixed panel configuration.

The energy obviously varies according to the time day, time of year and the atmospheric conditions and this can be averaged over the same period from multiple years to give a reasonable predictive figure for a particular time period in a particular day in a particular month.

The peak rate tariff for Melbourne chef is 9.61 ¢/kWh (although the basic rate seems to have reduced in the February 2013 bill) but there are also consumption related network charges, carbon tax, AEMO fees, renewable energy levies and metering charges. All of these add another 16.09 ¢/kWh. This means the value of 401 kWh/day at the current rates applicable to Melbourne Chef is $3194/month which would cover about a third of the average bill however, when more electricity is being produced than is being used the excess will be exported. This exported electricity is not as valuable to Melbourne Chef as that which is used on site. The reason for this is it is unlikely the feed-in tariff, which is to be negotiated with the supplier, will exceed 10 ¢/kWh. This is much less than the total per kW charged for grid supplied electricity. In other words, demand should be tailored to match the amount being generated as closely as possible in order for the system to be most financially advantageous.

The actual metered maximum demand for the Melbourne Chef bill to 31st August 2012 was 126 kW. The supplier, AGL, report that the maximum demand has reached 150 kW in the recent past. This indicates that, even with the very best sunlight and cool wind conditions, a 100 kW rated system will never be able to eliminate all electricity consumed by the premises under their current demand profile. However, a 100 kW system may be close to the most economical size, especially if the demand profile is controlled more tightly by integration with upgraded refrigeration equipment to try to match it to the energy produced on site. 100 kW will be used as a base size for an initial analysis. To start with we will take the available August consumption data and compare it with the predicted average energy production which would have occurred for a 100 kW system in operation in Melbourne over the last 23 Augusts. Then we will repeat the analysis for Summer time conditions.

Currently the average demand profile in August week days looks like the pattern as shown in Figure 6.

Clearly the overall shape of the current load profile in August and the collected energy for North facing modules in August is similar with reasonably symmetrical shapes around the peaks which occur at the same time at about 13:00. Currently the demand outside the main sunlight hours (about 9:00–17:00) is significant with a total of 47% of the day's consumption being at a time when there is insignificant input from the sun. Fortunately, from the standpoint of running costs, almost half of this totally grid based consumption is during off peak tariff times. Over the weekend the demand

Figure 6. Average percent of daily energy used each hour of the weekday in August.

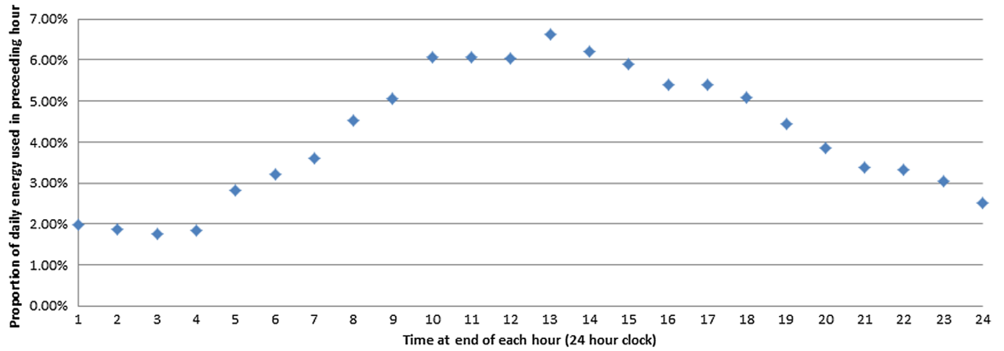


Table 1. Energy use in Melbourne Chef

Process	(%)
Cooking (ovens)	38
Refrigeration	32
Air conditioning	6
Lighting	2
Other (packing machinery etc.)	21

profile is quite flat. This means much of the energy collected when the sun is strong will be exported to the grid.

This electricity production will have a profile through the day. The profile will depend on the orientation of the modules. It will also depend on average atmospheric conditions. The best way of obtaining the profile would be through analysis of long term measurements observations from equipment using this orientation but insufficient data is currently available to us. Therefore, we use calculated data obtained from the Renewable Resource Data Center (RReDC) which is a service provided by the US Department of Energy's National Renewable Energy Laboratory. This service is called "PVWatts" and a description of it is given in National Renewable Energy Laboratory (2015).

The calculations include de-rating for typical system inefficiency as well as for module temperature effects and the figures which have been used apply the corrections based on previously detailed assumptions concerning module temperature and system losses. In fact PV Watts also gives predicted total energy outputs for each of the the days in August but these predictions are based on observational data for only a single year (1996). Also, the DC power rating for the modules is based on a 4 kW system taking 35 m^2 which implies module efficiency of around 11%; in recent years module efficiencies have improved significantly. This means using the figures outlined above in this document for the daily energy production rather than those given by PVWatts should result in a more accurate prediction; only the profile shape from the PVWatts predictions will be used.

The profile, averaged over all days in August for the single year used, is shown in Figure 7.

The equation for the best fitting curve is a second order polynomial. Obviously most of the energy is collected in the middle of the day and the best advantage in terms of smoothing demand would be gained from the system if the load profile for August days matches this curve.

Next, the average reduction in electricity consumption for this typical week in August will be considered. A plot of the hourly consumption for the week is overlaid with the average hourly energy produced as shown in Figure 8.

Figure 7. Average percent of daily energy incident on tilted module per hour in August.

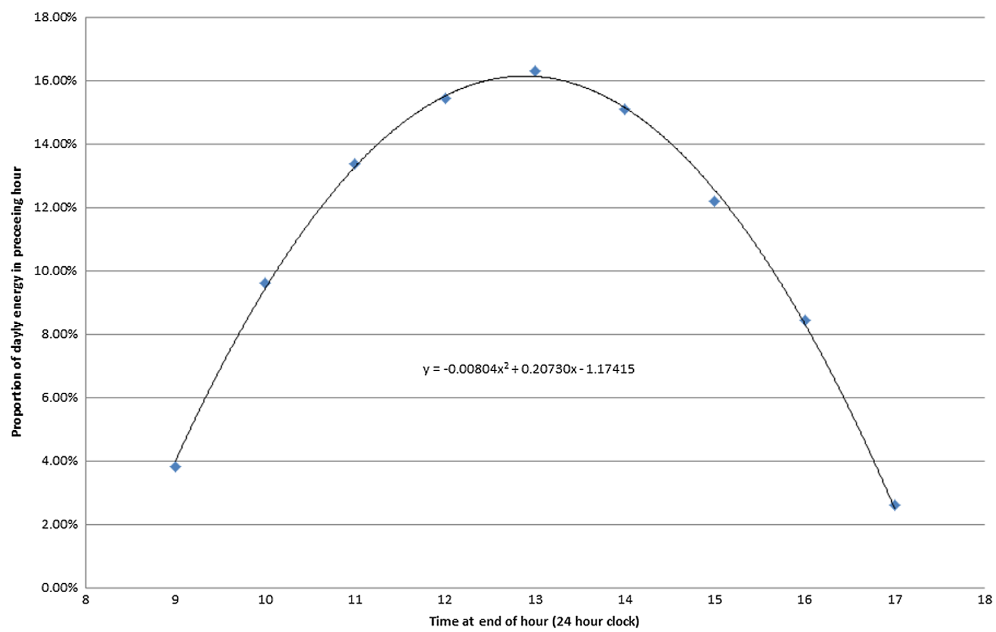
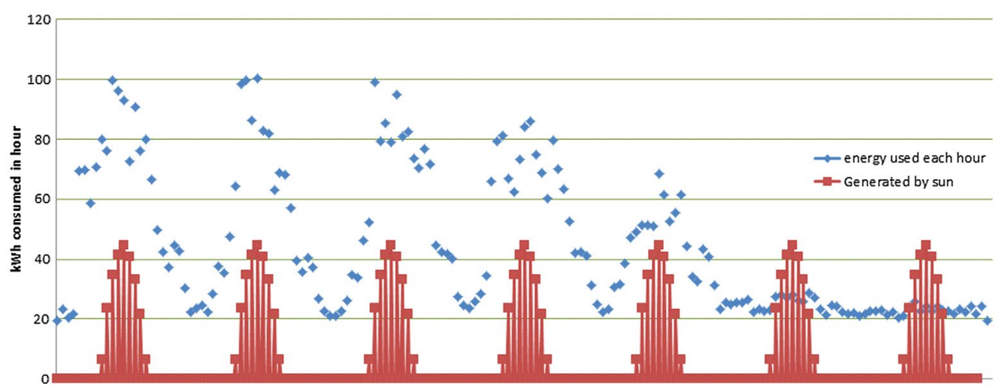


Figure 8. Comparison of hourly consumption and energy generated by proposed solar system in August.



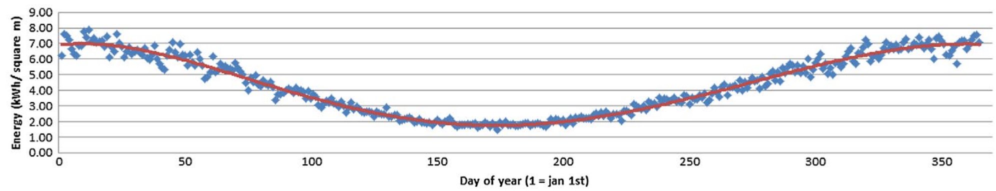
The overall consumption for this week, for the 29 Barrett St property only, would have been reduced from 7,573–5,929 kWh, a reduction of 22%. Assuming the peak and off peak consumption ratios specified earlier for the 33 Barrett St site (0.5 peak and 0.3 off peak), the overall consumption in this week would have reduced from 10,880–9,236 kWh, a reduction of about 15%.

If only the 29 Barrett St site was connected to the solar system then the peak demand would have been reduced from 126.28 to about 110 kWh which would allow a slight reduction in the demand charge on this account. The demand charge is currently $7.79/kW so a reduction of the order of $125 over the 31 day billing period could be expected. The value of the electricity generated and used on-site in this week would be $363 (equivalent to $1,608 for the usual 31 day billing period). The exported energy which was produced at the weekend due to there being insufficient load totalled 129 kWh with value $12 giving a total saving for the week of $375 ($1,661 for the billing period) assuming a feed-in tariff of 9 ¢/kWh.

7. Extended analysis to annual operation

A similar exercise can be done for each month of the year to hone the prediction of yearly savings and reduction in consumption and as a part of the optimisation exercise. For now we will just consider a single summer month. One might expect the most sun to be around the time of the summer

Figure 9. Sun energy falling on a horizontal surface in Melbourne through the year.



solstice (21st December). In fact average atmospheric conditions in Melbourne are such that the early days in January probably have a little more sun (see Figure 9 for daily averages for 23 years over the year). The likely reduction in early January consumption due to the tradition of Melbourne residents taking January off for a holiday might make calculations for that period over optimistic. We will therefore take the last week before Christmas to represent the summer time pattern.

The average global irradiance for the days of this week over the last 23 years is 6.52 kW/m^2/day. The ratio of the average daily global irradiance compared to that which falls on North facing tilted modules is 4.4:5.1 over the whole year but with the sun much higher in the sky the ratio will be lower in the summer months, so using this ratio gives an optimistic answer for expected energy falling on modules oriented in such a manner as 7.56 kWh/m^2/day.

Using the same assumptions relating to efficiency as before, which again is probably optimistic because the modules will get much hotter in the summer, the total average daily electricity produced for this week in December will be, on average, 594.8 kWh. As we did for August, using data from PV Watts we get the average profile for the days in December as shown in Figure 10.

Notice that the shape of the curve is broader and slightly flatter than for August but, as before, the peak is for the hour ending at 13:00.

The load profile is a little different in December to its shape for August, see graph in the next section: The average load profile for days in December looks like the pattern in Figure 11.

This indicates a mismatch in the summer between when electricity is needed and when it would be produced by a North facing system. The solution is either to re-organise when consumption occurs in the day or, simpler to implement, face the modules slightly east.

Figure 10. Average percent daily energy incident on tilted module per hour in December.

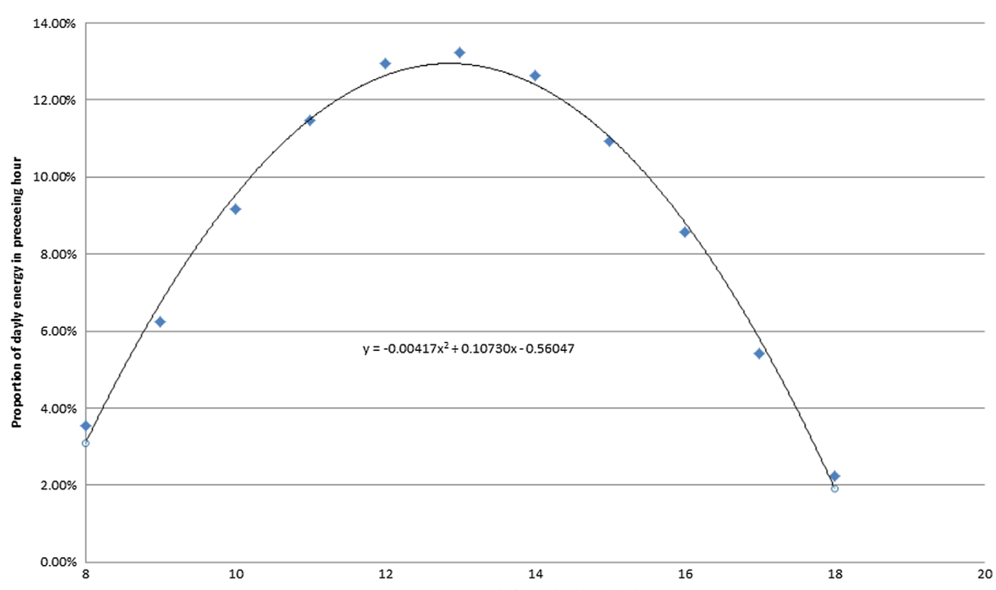
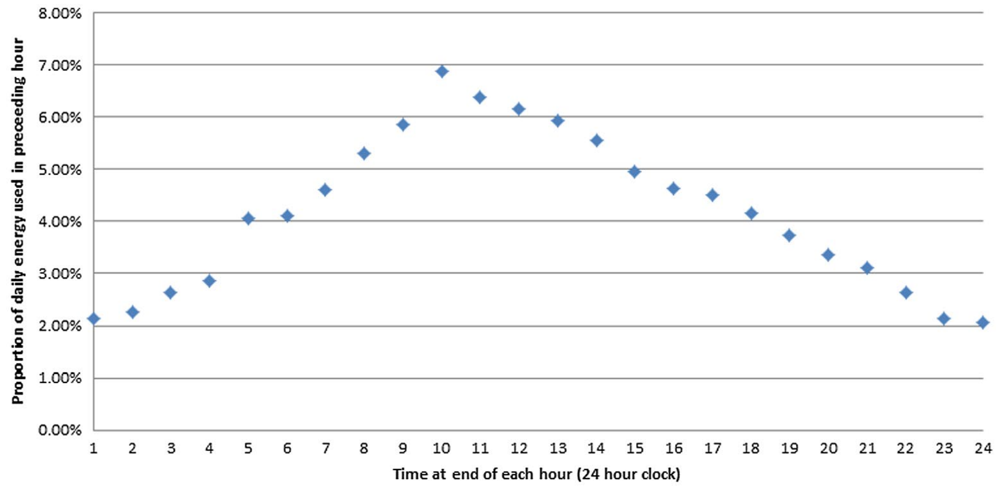


Figure 11. Average percent daily energy used each hour of the weekday in December.



8. Savings from current electricity usage

A comparison of the likely energy generated and the consumption is shown in Figure 12.

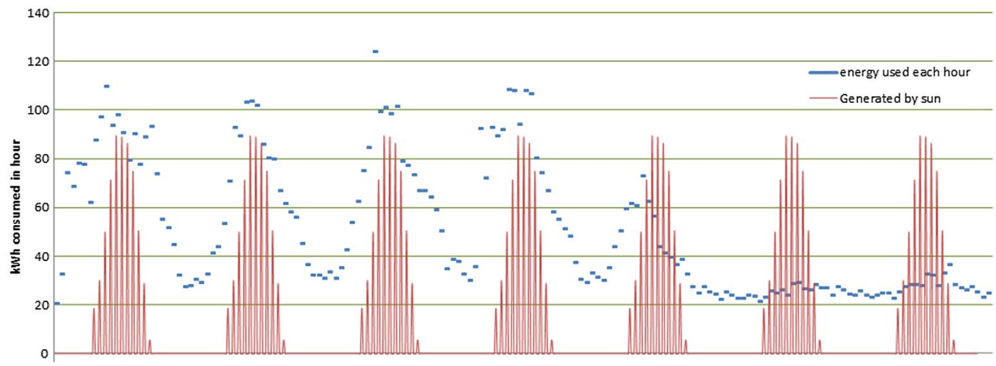
It shows that a 100 kW system is well matched to the typical weekday demand in the summer. For most days the system is not over sized but over the weekend there is inevitably more energy generated in the sunny hours than is consumed with the current consumption pattern.

The overall consumption for this week, for the 29 Barrett St property only, would have been reduced from 8,612–5,271 kWh, a reduction of 39%. Assuming the peak and off peak consumption ratios specified earlier for the 33 Barrett St site (0.5 peak and 0.3 off peak), the overall consumption in this week would have reduced from 12,308–8,967 kWh, a reduction of about 27%.

If only the 29 Barrett St site was connected to the solar system then the peak demand would have been reduced from 134.4 to about 90 kWh which would allow a reduction in the demand charge on this account. The demand charge is currently $7.79/kW so a reduction of the order of $350 over the 31 day billing period could be expected. The value of the electricity generated and consumed on-site in this week (and therefore the saving) would be $771 (equivalent to $3,414 for the usual 31 day billing period). The exported energy, mostly generated at the weekend, totalled 823 kWh with value $74 assuming a feed-in tariff of 9 ¢/kWh which gives a total saving of $845 for the week ($3,742 saved over the billing period).

The monetary saving of the proposal can be computed from the electricity prices. Having done a reasonably detailed analysis of the way the collected solar energy gets distributed between usage

Figure 12. Comparison of hourly consumption and energy generated by proposed solar system in December.



on site during peak and off peak times and excess exported energy for the two week long periods in August and December we must now consider what is likely to happen over a complete year.

With a typical August billing period saving of $1,661 and a typical December billing period saving of $3,742 from the PV system we will assume a yearly saving of the average of these two months multiplied by 11.8 (to compensate for these months having more days than the average) which is about $31,877. Added to this is the demand charge saving of about $2,800 calculated in the same way. This gives a total expected saving in electricity supply cost of $34,677 each year. Added to this is the additional saving due to the improved efficiency of the refrigeration. This amounts to about 16% of the entire pre-PV installation load which gives a saving of $10,900 assuming a 12 ¢/kWh average electricity cost making the total overall savings generated by the project $45,577/year.

Likewise, the carbon saving of the proposal can be computed. Using the same approximation technique to arrive at the expectation for the whole year based on August's and December's expected generation which was consumed on-site, i.e. 130,250 kWh/year. Melbourne chef used 570,179 kWh in these 365 days but the energy efficiency savings due to the new refrigeration plant is expected to reduce this by 16%. This gives a total expected overall saving of 39% for the site-wide emissions (with a small additional state wide emission reduction due to the renewable derived exported energy).

9. Conclusion

This research has demonstrated a vigorous analysis of the potential annual power savings for a food manufacturer applying photovoltaic technology for harvesting solar energy into the energy supply of the factory. The system design methodology has taken into account the objective of reducing grid power while maintaining at a level that does not require back-feeding of solar energy to the grid. The detail load profile analysis shows that the optimum system size is determined at a level that will not exceed the normal power demand level, and the changes in load requirements over years. The feasibility study has considered different scenarios under a number of reasonable assumptions that assist in speedy resolution of the system size. Two advantages are realized from this design: (1) Saving on the installation of the solar system which does not include power back-feeding control devices; (2) Minor changes to the manufacturing process to adjust the consumption pattern on the day maximizes the use of solar energy when it is available.

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