ADOPTION OF SOLAR GRID-TIED PV SYSTEM ADOPTED IN A RESIDENTIAL BUILDING

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ABSTRACT

Emerging construction technologies can play a major role in solving a wide range of environmental and nature resource problem such as the greenhouse gas, which has focused particular attention on the role of energy-conserving technologies. Alternative energy is becoming a popular for property developers of its potential of becoming more economically viable option when compared to current energy source- electricity. The objective of this research report is to conduct a cost-benefit analysis of adopting a solar energy technology specifically the solar grid-tied system by comparing the cost of initial investment and usage in a typical three bedroom residential building to the conventional power supply. The research findings showed that the PV system is more cost-effective in the long term compared to the conversional electricity supply, although the pre-investment is relatively high, it is a reliable investment in the long-term. It is important to emphasised that the use energy efficient appliances, lighting, insulation and double glassing has enhanced the effectiveness of the system.

Keywords; Photovoltaic system (PV); Solar energy; cost-effectiveness;

INTRODUCTION

Alternative energy is becoming popular for property developers because of potential economic benefits when compared to the current energy source-electricity (Kats and Capital, 2003). Several renewable energy technologies such as bio-fuels, biomass, solar panels, geothermal and wind turbine are now available in the market place. These emerging renewable technologies such as solar panels, photovoltaic system, and wind turbines play major role in solving a wide range of environmental and nature resource problems such as the greenhouse gas and resource conservation (Panwar *et al.*, 2011), emphasising the importance of energy-conserving technologies. According to Dresselhaus and Thomas, (2001), renewable energy technologies for generating electricity may generally be more energy efficient than non-renewable equivalent source. Olz et al. (2007) added that use of renewable technologies would increases the diversity in the electricity supply sources.

In New Zealand, renewable energy plays an important role in New Zealand's energy supply system, with around 75% of electricity generated from renewable sources (Kelly, 2007). New Zealand has good solar radiation levels in many locations with an average of 2000 hours of bright sunshine each year in New Zealand (Ministry of Commerce and Eden Resources, 1993). Historically, the main renewable sources in New Zealand have been hydro and geothermal energy. However, concern about climate change and limits on fossil fuel reserves is driving the development and uptake of even better renewable energy technologies to generate electricity, provide heating and power machineries (Ghoniem, 2011). The invention and promotion of solar technology is making the power demand more close to energy self-sufficiency in New Zealand (Kelly, 2007). Several renewable technologies using solar energy is presently being used for generating electricity by means of photovoltaic panels for some residential building in New Zealand (Kelly, 2007). According to Boyle (2004) a solar house has proved to be more energy efficient than an equivalent conventional house built with the use of use “green” materials. However, a cost-benefit analysis has not yet been conducted on any of these emerging technologies for generating electricity in New Zealand. This study examined the cost analysis of adopting a solar energy technology such as the grid-tied photovoltaic solar system compared to conventional electricity supply in a typical three bedroom residential building in New Zealand.

SOLAR ENERGY – A RENEWABLE ENERGY SOURCE

Solar energy represents one of the environmental friendliest ways of generating electricity with no significant impacts to the environment. The benefits of solar energy as alternative source of power supply include providing a large proportion of a building's electricity supply, water heating requirements, operating at minimal cost, reducing the use of electricity or fossil fuels and reducing energy cost (Chakrabarti and Chakrabarti, 2002). Renewable energy systems such as the photovoltaic system would also reduce emissions of greenhouse gases (Vorobiev *et al.*, 2006). In addition, when electricity is generated and consumed within the same location, transmission and distribution losses are avoided and cost of wiring and maintenance is minimised, which reduces the utility's capital and maintenance costs (Vorobiev *et al.*, 2006). Overall, the use of solar energy not only reduces greenhouse gas, but also has the potential to save cost of energy expense. The next subsection provides a background on provides a background on the development and instalment of the photovoltaic solar system for residential buildings.

PHOTOVOLTAIC SOLAR SYSTEM

A photovoltaic system (PV) transmits solar energy from the sun into its solar cells and converts the energy into electricity that can be used either within the structure or can be fed back into the electricity grid (Vorobiev et al., 2006). This system can be used both electricity supply and heating purposes. A typical Grid-tied PV system includes solar panels; inverter/charge controller interconnection wring and battery bank. Figure 1 shows the components and connections in a typical grid-tied photovoltaic system. Photovoltaic panels in a typical residential building are mounted using a grid-system. The dc electricity from the photovoltaic array is converted into mains-compatible ac by the grid-tied inverter, and the ac electricity is fed into the building's main electricity supply. Any excess electricity generated not used within the building is exported to the electrical supply grid. Further, the gird-tied PV system has no moving parts, is noiseless, produces no emissions during use and is completely scalable from small to large scale in a completely modular for expansion (Vogel and Kalb, 2010). All processing involved in the grid-connected systems has no identifiable effect on the environment (Vorobiev et al., 2006).

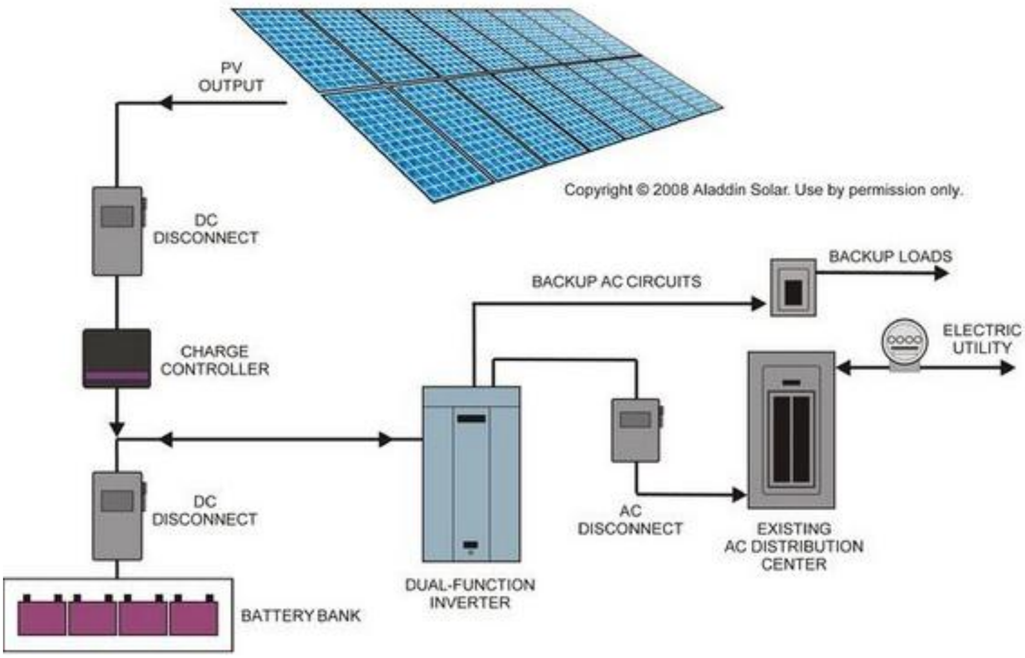

Figure 1- A typical PV Gried-Tied System with Battery Back-up (source: Vorobiev *et al.*, 2006)

The initial cost of installation has been a challenge for adopting alternative energy technologies with no exception to the PV system. The cost of installing the PV system can vary depending on the size of the system, type of PV cells used, and whether the system is grid connected or has a battery unit to store surplus energy for later use (Kelly, 2007). A 10KW system could cost about NZD100,000 to $300,000 (Kats and Capital, 2003). ARISE Technologies based in New Zealand supplies panels that have a 20 or 25 year warranty, depending on the type of cell. This warranty guarantees that the cells will produce at least 80% of original efficiency during the aforementioned 20 to 25 year period, while the cells have an expected life of 50 years (GB Report 2006). Also, a cooling system would need to be installed to prevent overheating of the panels. Energy costs can be saved in a building if approximately $100/year for a 10 KW system can be produced within the building itself with additional savings during the pay-back periods. The payback on solar heating systems ranges from 7 to 20 years depending on the cost of fuel displaced and the complexity of the system (Mills, 2004). Moreover, the cost of solar water heating systems has dropped over the past 20 years, with an initial installation cost of commercial systems is about $500/m^2 (Mills, 2004).

Periodic availability of solar energy is another challenge facing the adoption of alternative energy technologies. Most solar energy systems like the grid-tied PV system are limited by the amount of sunlight in a particular location and its orientation to the sunlight. A back-up and utility grid systems is required for storage and use of electricity during non-peak periods of sunlight (Vorobiev *et al.*, 2006). The use of these additional systems is important because the peak electricity demand occur from 6pm to 8pm, when solar energy is less available. Similarly, during winter solar energy used for water heating becomes less efficient due to lack of sunlight, thereby making it difficult to meet the peak-period demand. However, additional use of gas hot water heating and double glazing might help to resolve the peak-period energy demand (Mills, 2004). However, improving the storage capacity of the battery and the converting rate of solar panels technology may overcome the challenge of periodic availability of solar energy(Vorobiev *et al.*, 2006).

Despite this shortcoming, the design of a building and the use of certain equipment can in-directly improve the performance of a grid-tied PV system. Improving the efficiency of the PV system is possible through the use of energy efficient windows and lighting, heating and cooling systems, the use of insulation and appliances with built-in power management features, systems (Melaver and Mueller, 2009). Although, there is a growing perception within the construction industry the use of solar energy and that these additional energy efficient technologies increase construction costs (Yudelson, 2008). This study intends to demystify this perception by examining the adoption of a PV system and comparing costs of the PV system to that of a normal electricity supply in a typical three bedroom residential building.

RESEARCH METHOD

A case study method was adopted in this study to examine the adoption and cost-effectiveness of the grid-tied photovoltaic system in a residential building in New Zealand. A case study method was adopted because of its usefulness in examining contemporary real-life phenomenon through detailed contextual analysis (Yin, 2009). A single case study approach will be adopted in this study, using interviews and document analysis as data collection techniques. A residential house using grid-tied grid-tied photovoltaic solar system located in in Meadowbank, Auckland, New Zealand was used in this study. Five visits to the house and the analysis to the relevant documents detailing the installation, operational, and maintenance of the system were examined. Face-to-face interviews were conducted with key personnel's involved the design, supervision and on-going management of the house, which allow in-depth understanding of the topic and allow the use of intensive probing questions to gain more insight into the research problem. A total of 12 interviews were conducted using an interview protocol, enabling clarification on any possible ambiguities and ensuring that all research areas have been fully discussed during the interview. The interviews ranged between one to two hours with majority taking a little more than an hour and are audio-taped. The recorded interviews were transcribed, which facilitated the content analysis of the discussions. Content and thematic analyses were adopted as the data analysis technique (Yin, 2009). Care was taken so that the information provided by the participants was transcribed accurately and the information validated by the participants in order to ensure reliability and validity of the results presented in the following section.

FINDINGS

The building used has a case study in this research is located in Meadowbank, bank, Auckland, New Zealand. The building was redesigned and rehabilitated for solar energy supply while maintaining near zero external sources of conventional energy for electricity supply and heating purposes. It is a modern 609m2 property on prime north facing property which is necessary to maximum the solar energy supply to the property, with a 4.5 Kw photovoltaic panel and wetback powering energy efficient application. The discussion in this section provide empirical evidence of the cost effectiveness of the PV system combined with other energy efficient approach adopted in the design, construction and materials used in the building.

- **Solar Panels on Roof**

250m^2 of solar panel modules were installed on the building roof. The panels are fixed with a simple aluminium channel, wired together in a series configuration of 15 modules each. The building was designed facing North with a roof slope of 20 degrees to the horizontal to allow maximum harvest of solar energy at peak period. These panels generate a total of 4.5kW of electricity per peak sunshine hour. The cost of installing the PV panels is valued at over $60,000 dollars, though this was considered a significant initial installation cost when compared to a conventional building with very minimal installation cost of approximately $300 for wiring. Overall, the panels 90% of power used in the building.

- **Solar Energy Hot Water System**

The installation of solar hot-water panels on the roof provided an all year supply of hot water for under-floor and ambient air heating, cooking and washing purposes, while the installation of radiator system allows even distribution and control of the temperature in different rooms.

- **Use Energy Efficient lighting systems and Appliances**

Energy efficient appliances and lighting are used throughout the house. The study findings found that about 20% of the current electricity bill comes from lighting which can be reduced by $1/6^{th}$, if energy saving lighting bulbs are used. The illustration provided below by the property owners accounted for how the use of the LED light bulbs will save a massive $36000 dollar per annum in power bills.

For instance; using 50,000 Hours of 100 Watt light in a building:

- Cost of using 50 incandescent light bulbs - $1088.50 + $64.00 = $1,152.50 cost
- Cost of using 8 compact fluorescents $217.70 + $127.92 = $345.62 cost (+ cost from potential mercury poisoning and environmental damage)
- Cost of using 1 EarthLED bulb@ $141.51 + $110.49 = $252 cost (and did I mention no mercury, and 50,000 hours is 34 years.

The owners continued to demonstrated the cost effectiveness of using energy efficient lighting systems by using the use of energy efficient light bulbs/lamps from Philips Lighting

- *These lamps last for 8,000 - 12,000 hours of continuous use.*
- *A standard incandescent light bulb lasts for maximum of 1,000 hours.*

- *So immediately have extra 7,000 to 11,000 hours of use before having to replace one of them. Therefore, convenience and economic benefit achieved. Next, they use significantly less electricity to run. They generate light, rather than heat! A 9 watt one will consume around 10 watts of energy every* *hour it is on. Therefore in 100 hours one of them will use 1kW of power.*

- *In New Zealand this will cost you NZD$0.12 cents. The incandescent light bulb is rated at about 60 watts. It will only take 16 hours of running before it consumes 12 cents worth of electricity.*

- *The energy efficient compact fluoro bulb uses less than 1/6th of the power of the filament bulb! This is a huge saving. The initial cost of the energy efficient bulb is $5 dollars. The filament bulb cost about $0.50c.*

In addition energy saving appliances were sued throughout the building though these appliances were slightly more expensive than their counterparts. The property owner mentioned that;

- *All of the products last for about 5+ years, or in many cases 10-50+ years. This means they continue to save energy year after year after year, giving back to you the initial investment you made in them over and over again. Thus paying themselves off and putting money in your pocket over and over again.*

- **Electricity Supply Back-up System**

A back-up system for electricity supply was designed and put-in place in in case of emergency. The property owners adopted the first installation of NZ designed Whisper-Gen technology providing both an additional electricity source plus hot water for boosting during winter months when the supply of solar energy is relatively low. During winter months hot-water is boosted by wetback system in the fireplace including a boiler. A condensing boiler preserves energy by using heat exchangers designed to remove additional energy from the gases of combustion before leaving the stack. The flue gases produced from condensing boilers are at a much lower temperatures than those of non-condensing boilers to the extent that the water vapour in the flue gases condenses, thus releasing their latent heat and increasing efficiency of the boiler. Condensing boilers have efficiencies of 95% or greater as compared to the normal 70%-80% for non-condensing boilers. The property owner mentioned that:

> *Solar hot water system would have given us an absolute abundance of hot-water in the summer months. Moreover, in practice this has not been an issue at all, as the fireplace with the wetback integrated into it has been absolutely wonderful in winter.*

- **Insulation in the Walls, Floors and Ceiling**

All external and internal walls, floors and ceiling were insulated with a high grade insulation material to minimise heating requirements. All windows were double-glassed to reduce heat loss. The following assertions from the property owners emphasised the importance of using adequate insulation throughout the building.

  - *Installing insulation in the internal walls made perfect sense. The additional cost is minimal. If without insulation you are losing 100% of the heat you have generated within your home. A massive 35% via the roof, 25% via the walls, 15% through the floor, 10% out the single glazed windows and finally the last 15% out your doors.*

  - *Insulate the house-the best thing you could do for your health and general wellbeing. The best $3000 to $5000 you ever spent.*

  - *It is easier and cheaper to insulate your home when you are building/renovating it, however, putting insulation in your roof cavity and under the floor is usually a simple Saturday's job.*

- **Cost Analysis of the Power Bills**

The cost analysis data provided in Tables 1 and 2 demonstrated the cost-effectiveness of the PV system. On the average, the power bill amounts to$50 per month (see Table 1). The average power bill in Auckland is $133-200 dollars a month for similar amount types of house and using similar equipment and appliances. The technology and equipment adoption are following the principle of high efficiency. Photovoltaic solar electric modules, Inverter, batteries provide 90% power need and the cost is around 73000 NZD which including installation fee. Compare to conventional building, solar house has been adopted some equipment which may indirectly improve the performance of solar energy system. The 600 liters stainless steel hot water cylinder provides the hot water for occupants which 90% heating power are adopted from solar and 10% from gas backup. In addition, the hot water heating can provide another pipe through living room, which it provides a space heating for living area, then reduce power bill during the winter. Double glazing will avoid thermal loss and provides twice as effective as single glazing in terms of insulation. Heat recovery ventilation can save 75% or more of wasted energy, it pushes out stale air then pulls in fresh air. These technology and equipment adoption achieve a economic power bill which only 50 NZD per month for 609 square meter house. But the occupants have to face the extra construction and installation cost, it is more expensive that conventional house around 300 NZD per square meter.

Table 1 Energy Cost of the PV installed House in Meadow Bank, Auckland

Solar energy house in Meadowbank

Technology	Cost investment	Performances	Units	Service Units	Service period	Working life	Effect factor	Payback Period
photovoltaic solar electric modules	Over $60000	4.5kw modules provide 90% power need	2 sets of 15 modules	2 adults and 3 children; 7 computers, 4 staff	10-15 years	50 years	low effective during cloudy	6-7 years
Inverter	$3,000							
Batteries	Over 35000							
Installation	$6,000							
Solar water heating	Over $30000	600 litre stainless steel hot water cylinder; 90% power from solar, 10% from backup gas	4 Israel-made Chromagen solar heating collector; Total 11.2 square metres	4 badroon shower; Space heating system	15-20years	50-60years	low effective during cloudy'; but has backup system	6-7 years
Insulation	$3000-$5000	blocking every single hole; also dampen noise transmitting from one room to another	Autex's greenstuf product	Walls, Floor & Ceiling	N/A	over 50years	Fire; damp	N/A
Under floor heating	$3000-$4000	Save $50 pre month but winter only	3/8" diameter copper pipe on the floor; 18mm thick fibrolite on top	3 of the 4 bathrooms	N/A	over 50years	N/A	5-6 years
Space Heating	$3000-$4000	Solar hot-water flow pipe to warm room; Booster backup	through radiators to provide us with space heating	Main room; lounge	15-20 years	50-60years	Cloudy but backup system can get over it just add extra bill	3-5years
Double Glazing	Over $15000	Avoid thromal loss	twice as effective as single glazing, in terms of heat insulation	Windows and Doors	N/A	Over 50years	N/A	5-10years
Heat Recovery Ventilation	$4000-$5000	An HRV can save 75% or more of wasted energy; As it pushes out stale air, it pulls in fresh air	HRV products	Bedrooms; mainrooms; lounges	Clean core and check fans; During Check condensate drain Check grilles and ducts in house Reset dehumidistat (40 – 80 per cent) During Sep or Oct	15-20 years	Require maintain on time	N/A
BAN the incandescent light Bulb	around $1800	reliability and natural warm colour effect	Use compact Fluoro or New LED light Bulb; Philips products	All the light	N/A	50000 hours	N/A	N/A
Total	$200,000							

Note: Original house value $380000 in 2005， Simon has value his power bills of solar energy house which it is avarge only $50.

Table 2 Energy Cost in a Conventional Building in Meadow Bank, Auckland

Conventional building in Auckland							
Techonlogy	Achieve equipment	Power Supply	Performances	Electricty/Gas Bills	Service Units	Service period	Working life
Single Glazing	Simgle glazing	N/A	Thromal loss; indirectly increasing power supply	N/A	Windows & Doors	N/A	Over 50years
Heating system	Heater	Electricity	Individual heater; flexiable	$250-$300	Individual room	N/A	5-10years
	Gas Central Heating	Gas	using ventilation systems within the ceiling; and temperature is controlled by the switch board;The boiler heat rooms, Room air is absorbed through pipes to tank of hot water, and warm air is supplied to each room.	$150-$200 pre mounth	Worm house	1-2year	10years
Cooling System	Air condistion	Electricity	Add electricity bills	$50-$100	lounge, office room	2-3years	10-15years
Hot water heating	Gas hot water	Gas	Fire heat cold water; hot water through pipes to supply	$50-$100 per mounth	baths, showers, laundry and so on	5years	10-20years
	Electricity hot water	Electricity	Same as solar hotwater system, but power is from electricity	$150-$200	baths, showers, laundry and so on	2-5years	10-20years
Insulation	lots NZ home have no insulation	N/A	Thromal loss; indirectly increasing power supply	N/A	Walls, Floor & Ceiling	N/A	Over 50years
Under floor heating	Cooper Pipes	Electricity	Worm badrooms floor	$50 pre month	Badrooms	N/A	Over 50years
BAN the incandescent light Bulb	100W Bulbs	Electricity	Save install cost, but more bills in long term	$50-$100 per mounth	House	N/A	8000-12000hours
Others applications	TV, Computers, Fridger etc	Electricity	Daily life requirement	$100 pre-month	House applications	N/A	N/A
Total bills of power	$500-$550						
Note: Heat Recovery Ventilation may installing in Conventional house as well, it does not account Bill of power list							

DISCUSSION OF RESULTS

The property used a case study could be seen as an enthusiast's dream of gadgets and wires, over-capitalised with expensive rooftop solar electric modules. However, the property owners viewed their investment in and renewable energy as a giant for home-based businesses. The owners run tours through the house, and the energy features are tax-deductible because they're an essential element of their business marketing. The property is also used a foundation for a low-maintenance retirement home with minimal running and maintenance costs. The property has not only achieved low energy bills, but also have provided for extensive water collection.

The solar photovoltaic (PV) modules generate electricity from the sun's energy. So far, they had 2 kilowatts and then they added another 2 kilowatts in 2009 to power the office as it expands with more employees. They were going to also install an additional 640 watt array connected to a small battery pack to act as uninterruptible power supply for the office and essential systems when the grid fails. Fortunately new technology from the inverter manufacturer SMA has been invented to solve this common challenge the Cope's also experienced in NZ; 99% of the time the power grid is fine. This solar energy house is over twice the size as their previous, yet only uses an average of three units a day – all achieved through cost effective energy efficient appliances and materials. A typical house of this size in Auckland would use over 30+ units a day. The solar photovoltaic electricity has on a house to achieve a sub $30 dollar electricity bill every month.

CONCLUSION

Solar radiation is an abundant energy source which is free, non-polluting, and renewable. New Zealand has good solar radiation levels in many locations, yet this energy source is vastly under-utilised. A case study method was adopted to examine the implementation and cost analysis of adopting a grid-tied photovoltaic (PV) solar system compared to conventional electricity supply in a typical three bedroom residential building in New Zealand. The research findings showed that the PV system is more cost-effective in the long term compared to the conversional electricity supply, although the pre-investment is relatively high, it is a reliable investment in the long-term. It is important to emphasised that the use energy efficient appliances, lighting, insulation and double glassing has enhanced the effectiveness of the system. Overall, New Zealand's electricity bills are generally higher than other countries such as China. The adoption of the PV systems is a good opportunity for the development of renewable energy in New Zealand if adequately supported by the government.

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