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# Solar panels: Real efficiencies, potential productions and payback periods for major Australian cities

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ABSTRACT

In spite of continuous campaign and efforts large scale adoptions of solar panels are yet to be materialised, mainly due to lack of confidence on potential energy savings. This paper presents real efficiencies achieved from four houses in two Australian cities; Melbourne and Adelaide. Based on actual solar energy productions and actual incoming solar radiations during a monitoring period, efficiencies of solar panels installed in the selected houses were calculated. It was found that among the four monitored houses, a maximum efficiency of 7% was achieved. Considering this maximum achievable efficiency and annual average incoming solar radiations, potentials of energy savings for eight major cities of Australia are presented considering two different solar panel systems; 2 kW and 5 kW. It was found that for a typical 4-members household winter-demand, a 2 kW system and 5 kW system is expected to generate 19–29% and 49–73% of total energy. In addition, considering the current costs and expected savings, payback periods of different sized solar systems are presented for the eight cities.

## Introduction

To achieve global sustainability, several government and private authorities have been promoting different sustainable energy options, among which solar panels are most widely used. In Australia, the government has been offering incentives/subsidies to the residents installing solar panels to augment their energy demands. However, large scale adoption is still not happening. One of the main reasons for this is uncertainty on claimed efficiencies and lack of confidence on payback period. According to Bamberg and Schmidt [2], social norms emerge as having a strong effect on one's intention to invest. What seems to matter to consumers is the belief that global warming is a global problem that everybody must deal with and take action. Social influences can be very significant in this regard depending on one's environment [17]. In a study conducted by Ozaki [11] the decision-making process consumers adopt when deciding to invest in renewable energy was analysed in-depth. The results of this study showed that possessing "pro-green" attitudes towards pro-environmental behaviours was not enough reason for adoption of a solar energy system. Ozaki [11] further demonstrated a sense of uncertainty about the relatively new energy source emerged as being the primary deterrent for people adopting renewable energy sources. There is a consensus of uncertainty about the quality, efficiency and reliability of alternate energy sources. Switching to a renewable energy source was also considered a hassle, which further affected the adoption of renewable energy.

As Australia receives the highest amount of solar radiation of any continent in the world, it has become a focal point of research for the solar panel industry [3]. The solar radiation that Australia absorbs each year is over ten thousand times the amount it uses each year. As such there is much potential for more advanced solar energy developments. In Australia, solar photovoltaic cell is the fastest growing of all related solar panel technologies [7]. However, in general real efficiencies of installed solar panels are lower than expected/claimed. As the panels get heated during operation/sunlight, its energy producing efficiency goes down. Different studies were done to overcome this issue of heated solar panel. Thakur et al. [16] investigated the improvements of efficiency using solar panels immersed in a liquid to keep those cool. Parmar et al. [12] investigated effectiveness of using roller-style dust remover to keep the panels clean from dust, which obstruct absorption of sunlight on the panel surface. Balamuralikrishnan et al. [1] investigated using optical filters on solar panel surface to reduce reflections of sunlight from solar panel surface, due to which some portion of sunlight is reflected back (i.e. lost). However, all these additional features attract additional costs to the solar panel, which are quite expensive in some countries.

Although, solar energy is emerging as one of the most cost-effective and affordable sources of electricity in Australia, a majority of the people still do not have a positive perception on expected payback

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**Table 1**
Details of solar measurement stations selected for spatial variation study.

| City | Station location | Station number | Latitude | Longitude |
|---|---|---|---|---|
| Melbourne | Laverton | 87031 | 37.86S | 144.76E |
| | Ringwood | 86379 | 37.79S | 145.24E |
| | Dandenong | 86224 | 37.98S | 145.22E |
| | Olympic Park | 86338 | 37.83S | 144.98E |
| Adelaide | Gawler | 23107 | 34.60S | 138.74E |
| | Unley | 23119 | 34.94S | 138.60E |
| | McLaren Vale | 23876 | 35.23S | 138.54E |
| | Lobethal | 23726 | 34.90S | 138.87E |
| Brisbane | Caboolture | 40975 | 27.08S | 152.95E |
| | Ipswich | 40101 | 27.61S | 152.76E |
| | Brisbane City | 40690 | 27.47S | 153.03E |
| | Romani | 40894 | 27.85S | 152.91E |
| Sydney | Observatory Hill | 066062 | 33.86S | 151.21E |
| | Airport | 066037 | 33.95S | 151.17E |
| | Parramatta | 067041 | 33.82S | 151.01E |
| | Terrey Hills | 066059 | 33.69S | 151.22E |

period. According to Flannery and Sahajwalla [7] in Australia, on average a solar panel system with a minimum life expectancy of 20 years has the total cost of setting it up can be reimbursed through savings within seven years. However, this payback period can differ based on numerous factors such as; the actual type of solar panel system, the cost of installation, how the panels are arranged, the amount of unobstructed sunlight hitting the panels, the amount of energy used compared to the amount generated and the actual physical location [7].

In Australia, when solar panel owners generate more electricity than what they actually use, the excess energy is rerouted back into the electrical grid allowing the owners to be paid for the total amount they produce. These payments occur in one of two ways; gross feed-in tariff schemes or net feed-in tariff schemes. Net feed-in tariff scheme offer payments for the excess amount of energy returned to the electricity grid, while gross feed-in tariff scheme offer payments for the total amount of energy generated regardless of whether it is returned to the grid or not [7]. Due to these tariff schemes, in some areas electricity generated by solar panels has reached cost competitiveness with other traditional and popular methods [5]. With all these positive features and government incentives, adoptions of solar panels in Australia is not occurring at expected rate as most of the end-users are not convinced with the claimed expected savings and payback periods. In general, solar panel producers/sellers tend to claim a high level of savings and shorter payback periods. Anecdotal evidence in support of their claims are often missing. To overcome this issue, this study independently investigated real efficiencies of solar panels achieved from four individual houses (in two different cities) in Australia. Based on maximum achievable efficiency and total annual incoming solar radiations, potentials of energy savings through household solar panels for eight major cities of Australia are presented in this study. Also, based on all the associated costs of solar panel installation, government incentive and expected energy savings, payback periods of different sized solar panel systems (1 kW–5 kW) for the eight major cities are presented.

**Table 3**
Incoming solar radiations and climatic conditions of the selected cities.

| City | Mean Annual Solar Radiation ($MJ/m^2$) | Mean Maximum Temperature (°C) | Mean Minimum Temperature (°C) | Mean Annual Rainfall (mm) |
|---|---|---|---|---|
| Melbourne | 5511 | 19.7 | 9.3 | 686.5 |
| Adelaide | 6387 | 21.6 | 11.5 | 442.7 |
| Sydney | 5986 | 21.7 | 13.8 | 1215.7 |
| Brisbane | 6789 | 26.5 | 16.3 | 1021.6 |
| Cairns | 7190 | 29.0 | 20.8 | 2271.5 |
| Perth | 7044 | 24.7 | 12.8 | 727.5 |
| Canberra | 6278 | 21.0 | 6.7 | 643.1 |
| Darwin | 7738 | 32.1 | 23.2 | 1733 |

## Methodology and data

First of all, to test the representativeness of solar radiation data from a particular station for the whole city (especially for a large city), measured solar radiation data was collected from four remote parts of four largest cities in Australia; Sydney, Melbourne, Brisbane and Adelaide. Earlier, Imteaz et al. [10,9,8] presented significant spatial variations of one of the climatic variables, rainfall for some of these cities. Spatial variations of annual average incoming solar radiations of the selected stations in each city were compared. Details of the locations of each selected station in all the selected cities are presented in Table 1.

For the evaluations of existing solar panels' efficiencies, four houses (two from each city of Melbourne and Adelaide) were selected where solar panels were installed and have been in operation for several years. Houses were selected based on accessibility of data on household electricity uses/bill and solar panels' properties. In Australia, houses having solar panels receive electricity bills having information on solar energy produced, used and/or supplied to the main grid. For the selected houses for particular monitoring periods (depending on the data availability), the above information was collected from the individual households' electricity bills. Incoming solar radiation data from the nearby station of each selected house was collected from the Bureau of Meteorology website [4]. Details of the locations of the selected houses, solar panels' properties, monitoring periods and selected solar measurement stations are presented in Table 2. Multiplying solar panel area with the incoming solar exposure of that particular location during the individual monitoring period, total incoming solar radiation on the solar panel of each house was calculated. Then dividing the solar energy savings of a particular house (obtained from electricity bills) with the total incoming solar radiation on the same house's solar panels, real efficiencies of the installed solar panels in all the four houses were calculated. Also, to evaluate seasonal variations, average daily solar energy produced were compared with average daily household electricity demands (obtained from electricity bills) in different seasons for the selected houses.

To assess maximum achievable solar energies in the eight major Australian cities (Sydney, Melbourne, Brisbane, Canberra, Perth, Darwin, Adelaide and Cairns), the mean annual incoming solar radiation data for each of these cities were collected from the Bureau of

**Table 2**
Details of selected houses used for solar energy measurements.

| Location | Blackburn, Victoria | Niddrie, Victoria | Mypolonga, South Australia | Torrensville, South Australia |
|---|---|---|---|---|
| System size (kW) | 2 | 5 | 1.5 | 0.75 |
| Number of solar panels | 12 | 25 | 8 | 4 |
| Area of panels ($m^2$) | 15.88 | 32 | 10.24 | 5.12 |
| Bureau of Meteorology station number | 086338 | 087015 | 024584 | 023119 |
| Installation year | 2009 | 2013 | 2000 | 2010 |
| Monitoring periods | 17/12/2009–18/5/2015 | 15/11/2013–17/2/2014 | 8/4/2014–7/7/2014 | 25/3/2014–24/8/2015 |


**Fig. 1.** Spatial variations of solar exposures in different cities; (a) Melbourne (b) Sydney (c) Brisbane and (d) Adelaide.

Meteorology website. Considering the maximum achievable efficiency from the studied houses and two different sizes of solar panels (2 kW and 5 kW), the annual expected solar energy savings were presented. Table 3 shows the general climate characteristics of all the eight selected cities.

Finally, to evaluate expected payback periods for different sized solar panels for the eight mentioned cities, a comprehensive spreadsheet based calculation system was developed considering all the associated costs related to solar panel installation, government levy and expected savings. In the payback period analysis, cost of replacement, system's degradation, expected rate of increase of electricity cost and expected inflation rate were considered.

**Table 4**
Details of solar energy produced and efficiencies achieved.

| Location | Blackburn, Victoria | Niddrie, Victoria | Mypolonga, South Australia | Torrensville, South Australia |
|---|---|---|---|---|
| Actual solar energy produced (kW h) | 8947 | 943 | 109 | 749.6 |
| Solar exposure for same time period (kW h/m$^2$) | 7962.3 | 582.9 | 217.8 | 2144.4 |
| Incoming solar radiation on the panels (kW h) | 126497 | 18653 | 2230 | 10979 |
| Solar panel efficiency | 7.07% | 5.05% | 4.88% | 6.83% |

**Table 5**
Claims of different companies on different solar systems' efficiencies (SroeCo Solar).

| Manufacturer | ID | Efficiency (%) | Tier |
|---|---|---|---|
| Sanyo Electric of Panasonic Group | HIP-200BA20 | 17.24 | 1 |
| SunPower | SPR-200-BLK-U | 16.08 | 1 |
| Trina Solar | TSM-200DA01A.08 | 15.85 | 2 |
| Canadian Solar | CS6A-200MM | 15.82 | 2 |
| Suntech Power | PLUTO200-Ade | 15.66 | 2 |
| Jinko Solar | JKM200M-72B | 15.66 | 2 |
| Renesola Jiangsu | JC200S-24/Db | 15.66 | 2 |
| Kyocera Solar | KC200GT | 14.74 | 3 |
| Schuco USA | SPV 200 SMAU-1 | 14.21 | 3 |
| BP Solar | SX3200B | 14.17 | 3 |
| Yingli Energy (China) | YL200P-26b | 13.65 | 4 |
| Sharp | ND-200UC1 | 12.27 | 5 |

## Results

### *Spatial variations of solar radiations*

For the investigations of spatial variations, four solar radiation measurement stations were selected from each studied city. Fig. 1(a, b, c & d) shows average annual incoming solar radiation for each selected station grouped with the selected cities. From the figure it is clear that spatial variations of incoming solar radiations for a particular city is quite insignificant; with a maximum deviation from the mean value of 2.3% for Melbourne, 2.0% for Adelaide, 0.9% for Brisbane and 1.0% for Sydney. As such, in regards to solar radiation, any measuring station within a city can be considered representative for the whole city even if it is a large city.

### *Evaluations of actual solar efficiencies*

Basically from the total incoming solar radiation data during the monitoring period, incoming solar radiations on the individual house solar panels were calculated by multiplying incoming solar radiation (per square metre) with the individual household's solar panel area. Then solar energy savings were explored from the individual household's electricity bill. It is to be noted here that the monitoring periods were not same for all the houses, due to the availability of the data from individual household. As mentioned in the earlier section, actual efficiencies were calculated by simply comparing the actual incoming solar radiations on the panels and actual solar energy savings. Table 4 shows the data on actual solar energy savings, actual incoming solar energy and efficiency for each of the selected house. From the table it is evident that actual efficiencies vary from around 5%–7%, which are significantly lower than the claims made by solar panel companies. Table 5 shows the claims made by different solar panel companies in regards to their efficiencies [15], which claims efficiencies from around 13%–18%. These values are more than double the actual efficiencies achieved in the studied houses. This discrepancy is one of the major reasons for residents who are not convinced to install solar panels. It is worthy to note that solar panel companies might have obtained these data in perfect laboratory conditions with newly produced panels. It is likely that these panels' efficiency deteriorates in real conditions and with the passage of time. Also, it is to be noted that lots of researches are going on to increase the efficiency of solar panels, therefore it is very likely to achieve higher efficiencies (even more) claimed by the companies in future.

To visualise the seasonal pattern of average solar energy savings in compared to actual demands (daily average), seasonal variations are shown in Fig. 2 (a, b) for two houses (one from each city of Melbourne and Adelaide). Both the total energy demands and solar energy produced in different seasons were taken from the actual electricity bills of the houses. In general, as expected winter demands are high, while solar energy production is comparatively low, which reveals that a sole solar supply to satisfy a typical household demand is really impossible at this stage until an extremely high efficiency on solar energy conversion could be achieved.

### *Potential solar productions*

Based on maximum achievable efficiency from the current monitoring and mean annual solar radiations for eight major cities in Australia, potentials of solar energy productions for the selected cities were calculated. The cities are: Sydney, Melbourne, Adelaide, Brisbane, Canberra, Cairns, Perth and Darwin. For the calculation of solar energy production potential for a particular city with a particular size solar panel, solar panel's average standard area (for a particular size) was multiplied the with the mean daily incoming solar radiation for the selected city (available from the Australian Bureau of Meteorology website, http://reg.bom.gov.au/climate/data/). Then multiplying this available daily solar energy (in kW h) for a particular city with the maximum achievable efficiency (i.e. 7% for this study), potential energy production was calculated. Also, calculated solar energy potentials were compared with a typical 4-people Australian household winter energy demand (19.5 kW h/day) available from a local energy retailer, Origin Australia (www.originenergy.com.au). For the solar panel system, two different types were considered; 2 kW and 5 kW. It is to be noted that only two systems (2 kW and 5 kW) were presented, just to avoid repetitions of the same thing. For all other systems' savings, the values will be just proportional. Fig. 3 shows the potentials of the average daily solar energy productions in comparison to a typical 4-people household demands in those cities for both the 2 kW and 5 kW systems. From Fig. 3, it is found that among these cities on average 3.8–5.6 kW h of daily solar energy can be saved from a 2 kW system; Melbourne being the lowest and Darwin the highest. Darwin, being located in the tropical region and blessed with extreme sunlight is likely to have that much solar energy savings. These energy savings equate to approximately 19–29% of average energy demand of a typical 4-popole household. With a 5 kW system, it is expected to produce 9.5–14 kW h/day depending on the city, which equates to 49–73% of the typical household electricity demand of 4 people. Even with the current lower achievable efficiency, it may look very promising to be able to fulfil 49–73% of the household energy demand. However, it should be noted here that this scenario is in the case of a 5 kW system, which requires a very large roof area and very few houses are having that large effective roof area. Nonetheless, as day by day more efficient technologies are being developed; more efficient solar panels will be developed and on the other hand household energy demand will be reduced with the adoptions of more energy efficient devices. As such, it is not far that depending on the city location, total energy demand of a typical household can be fulfilled solely through solar energy.

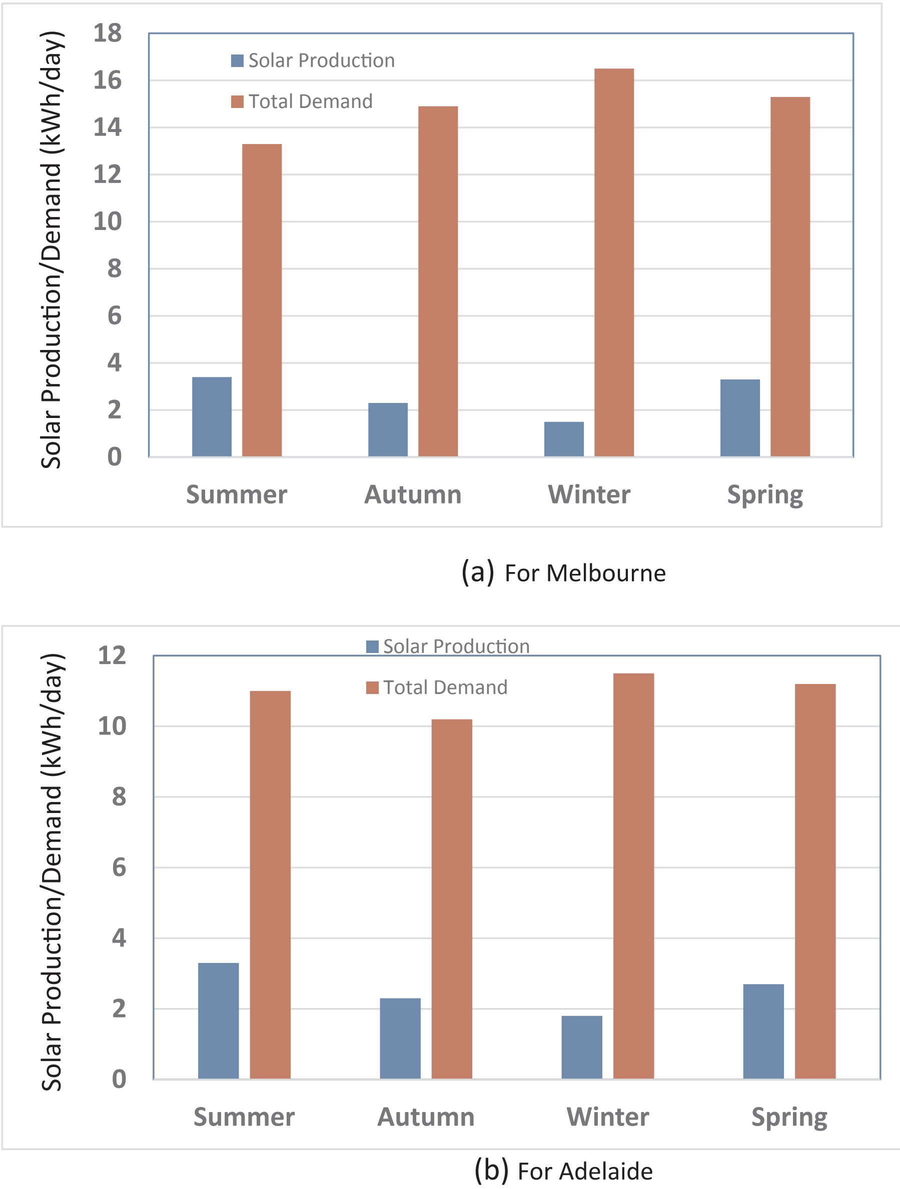


**Fig. 2.** Actual average daily solar energy productions and demands.

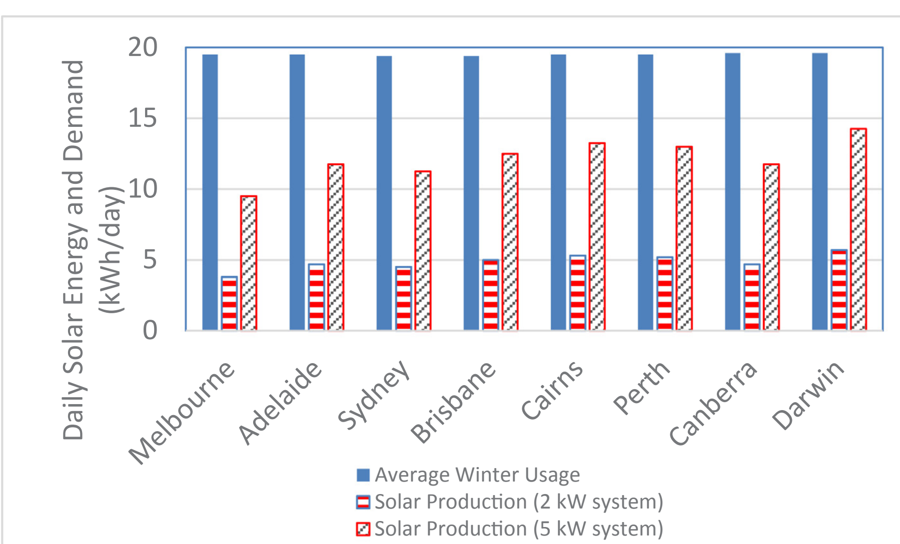


**Fig. 3.** Potentials of average daily solar energy productions and typical demands.

**Table 6**
Costs of solar panels and government rebates for different sized panels.#

| System Size (kW) | Cost (A$) | Government rebate (A$) |
|---|---|---|
| 1 | 4156 | 700 |
| 1.5 | 4774 | 1050 |
| 2 | 5712 | 1400 |
| 3 | 7503 | 2100 |
| 4 | 9529 | 2800 |
| 5 | 11487 | 3500 |

# These values are based on 2015 condition/rule.

### *Payback period analysis*

The most basic cost, i.e. installation costs for different sized systems were taken from a local supplier [13]. Current (2015) government incentives vary with supply and demand, however usually valued approximately $700/kW. For this study, the exact values were calculated from an online source calculator [14]. Table 6 shows net cost of solar panels and associated government rebate (as per year 2015) for different sized solar systems. The System's degradation rate (i.e. reductions in efficiency over the years) was considered as 1% based on information provided at Energy Informative [6]. Base year solar panel efficiency was considered as the maximum achieved efficiency from the studied four houses. Expected annual solar exposures for the eight cities were taken from the BoM website as used for the calculations of potential solar energy productions in the previous section. In general, 'solar inverter' needs to be replaced in 15 years' time period. As such, for any specific case if the payback period becomes longer than 15 years, additional replacement cost was incorporated once in every 15 years. Eventually payback periods for 6 different system capacities (1, 1.5, 2, 3, 4 & 5 kW) were calculated for each of the eight selected cities. For the payback period calculations, current electricity price supplied from the national grid was considered. In Australia, this price varies from state to state and during the time of this study (i.e. 2015) the price varied from A$0.234 to A$0.367 (collected from major electricity supply retailer, Origin Australia). Expected energy savings were converted to expected monetary savings as per the unit electricity price for each city. In addition, for the payback period calculations, the future costs/savings were brought down to a net present value using an inflation rate of 2.5%. Payback period is the length of years, after which accumulated monetary savings over the years becomes equal or more than the initial net installation cost (and inverter replacement cost, if it becomes more than 15 years). Fig. 4 shows all the calculated payback periods for all the eight cities. From the figure, it is clear that for Darwin, Cairns, Brisbane and Perth the expected payback periods are quite low; less than 15 years. This is due to high incoming annual solar radiations in these cities being located around the tropical region. Even for the cities far from tropical region (i.e. Sydney, Melbourne and Adelaide), expected payback periods are less than 15 years, except for the case of a system with 1 kW capacity. Payback periods are less than 10 years for Adelaide with a 2 kW system, for Melbourne with a 3 kW system and for Sydney with a 4 kW system. In regards to payback period, Adelaide is better than Melbourne mainly because of higher annual incoming solar radiation in Adelaide (1752 kW h/m$^2$) compared to Melbourne (1450 kW h/m$^2$). In spite of having higher solar exposure, Sydney's payback periods are worse than Melbourne mainly due to lower electricity price in Sydney compared to Melbourne. Among all the studied cities, Canberra has the highest payback periods predominantly due to its lowest electricity price ($0.234/kW h). For Canberra, the payback periods for 1 kW, 1.5 kW, 2 kW and 3 kW systems are 36 years, 25 years, 21 years and 17 years respectively. Among the tropical cities (Darwin and Cairns), although Darwin receives higher solar radiations (2153 kW h/m$^2$) compared to Cairns (2044 kW h/m$^2$), payback periods for Cairns are lower, due to cheaper electricity price in Darwin ($0.296/kW h) compared to Cairns ($0.328/kW h).

## Conclusion

Solar energy provides a clean emission free energy alternative; however, it is often disregarded due to the uncertainty surrounding it. Majority of the people are not convinced with the expected return/savings through installing solar panels. Usually solar panel industries/installers/sellers greatly exaggerate expected returns from a particular solar panel. This paper presents an independent study on actual energy savings efficiencies through solar panels in two Australian cities. First of all, spatial variations of solar radiations within large cities were investigated with the hypothesis that it might significantly vary. However, solar radiations data from four major Australian cities found that spatial variations of incoming solar radiations within a city is negligible. Therefore, any measured data from any location of the city can be considered as representative for the whole city. Nonetheless, there are significant seasonal variations within a year. However, this seasonal variation should not affect solar panel decision until residents are solely depending on solar energy without any other energy supply. Moreover, any excess solar energy produced is feed to the electricity grid.

Efficiencies of solar panels installed in four houses in two cities were evaluated by comparing measured incoming solar energy on the roofs/panels with the actual solar energy produced during the same monitoring periods. It was found that among the four studied houses, a maximum efficiency of 7% can be achieved, which is very low

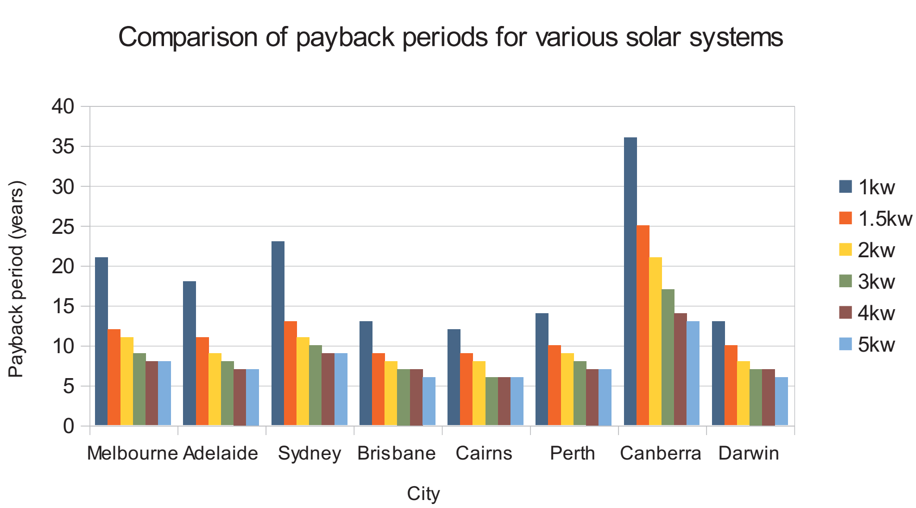


**Fig. 4.** Payback periods of different sized solar systems for major Australian cities.

compared to the claims by the local solar panel industries, which is up to 18%. It is to be noted that the industry claimed efficiencies might have been achieved in ideal laboratory conditions, which in reality do not exist in real rooftop conditions. Also, as researches are continuing towards achieving higher efficiencies, in future it is likely to achieve the claimed high efficiency even under real conditions.

Based on maximum achievable efficiency (i.e. 7%), solar energy savings potentials of eight major cities of Australia were evaluated considering two different systems of solar panels. It was found with the current achievable efficiency condition, that the use of solar energy as a solitary energy source is not realistic for urban residential dwellings. It is found that expected solar energy productions vary significantly. For a typical 4-member household's winter-demand, a 2 kW system and 5 kW system is expected to generate 19–29% and 49–73% of total energy depending on the city; Darwin having highest potential and Melbourne having lowest potential. Darwin being a tropical city has got the maximum potential of solar energy production as expected.

In regards to payback periods, it is found that for high solar radiation receiving cities (Darwin, Cairns, Perth and Brisbane) payback periods even with a smallest size system (1 kW) are lucrative being less than 15 years. For Sydney, Melbourne and Adelaide payback periods are less than 15 years for a system size of 1.5 kW or higher. It is found that not only total annual receiving solar radiation is the main parameter contributing to payback period, but electricity price has also got a significant contribution as shown in the case of Darwin and Canberra. Darwin, although blessed with the highest solar exposure (among the studied cities) does not provide the lowest payback periods for the solar panel users. Whilst, Canberra despite being the third-lowest (among the studied cities) in regards to incoming solar radiation, turn out to be the worst lucrative to the users in regards to payback periods.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.seta.2017.12.007.

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