

6.4 Appendix: Full analysis of SWIS locations

Table A summarises the general load and simulated PV characteristics of the four SWIS locations. This analysis includes the use of scatterplots where either the PV output and corresponding load for each half hour period were plotted against each other, or PV output or load for each half hour period was plotted against temperature. Such plots provide a picture of the general relationship between two factors ie. how one varies with respect to the other. Not all of this analysis is of direct relevance to placing a financial value on PV's ability to offset peak load periods but contributes to a more general understanding of the loads and their relationship to PV output.

Table A: General load and PV characteristics of SWIS locations

Characteristic	Description
Annual load profiles	All locations had (i) a fairly uniform minimum load and daily maxima about double the size of the minimum load, except for Osborne Park TX1 where the daily maxima were about triple the minimum load; (ii) a clear weekly cycle with weekend maxima generally well below weekdays, except for North Perth where the weekend maxima were almost as high as on weekdays; and (iii) a relatively small number of very high demand peaks, most commonly in summer but also in winter, many of which appear to be due to operational changes by Western Power such as switching from one transformer to another.
Seasonal match	Forrest Ave TX2 and Osborne Park TX1 peaked in summer and had a good match to simulated north-facing PV, Midland Jct TX1 peaked in summer but late in the day and so was a good match to simulated west-facing PV, North Perth TX2 peaked in winter at about 8pm and so did not have a good match to simulated PV.
General correlation between PV output and load	The scatterplots for Forest Ave TX2 and to a lesser degree Osborne Park TX1 loads were split into two distinct regions, corresponding to the baseload periods and the daytime peaks – where the latter displays some correlation to simulated north-facing PV. Midland Jct TX1 load had some correlation to simulated north-facing PV. North Perth TX2 had a very narrow load band and had little correlation to simulated north-facing PV.
General correlation with temperature	The scatterplots for Forrest Ave TX2 and Osborne Park TX1 had a fair correlation between load and temperature, although there were high loads at low temperatures and vice versa. Midland Jct TX1 had a much clearer correlation with load increasing with temperature, while North Perth TX2 had signs of a classic residential load correlation, with load increasing at low temperatures due to winter heating needs and at high temperatures due to summer cooling needs. PV output tended to increase at higher temperatures, which would normally occur during the middle of the day – although note there were instances of zero PV output at high temperatures, presumably on hot summer evenings.

FORREST AVE

Summary of characteristics

Forrest Avenue substation has two 66/11kV transformers and operates as a firm capacity substation. The load type is predominantly CBD Commercial with small amount of inner city residential. The substation capacity is 38.9MVA and is considered adequate until around 2013. Stage 1 works are expected in 2019 and Stage 2 works are expected in 2024. They will involve conversion from 66 kV supply to 132 kV (replacement of aged switchgear and infeeds) and distribution works as needed. Expected cost is approximately \$30 million.

Annual profile

The July 2003 to June 2004 load profile for Forrest Ave TX2 is shown in Figure 1. It is characterised by a constant baseload around 5MW, with daily maxima about double the size of the baseload and increasing during summer, especially February. It also has a clear weekly cycle, with reduced weekend loads, especially on Sundays – see Figure 2 (which also includes some of the peak load days assessed here’) and Figure 3. There are a number of days of extreme demand peaks, which are discussed in more detail below. Figure 4 shows the 2MW simulated north-facing PV output for ACDB site ‘Perth’, which increases in summer as expected, particularly late Feb and early March.

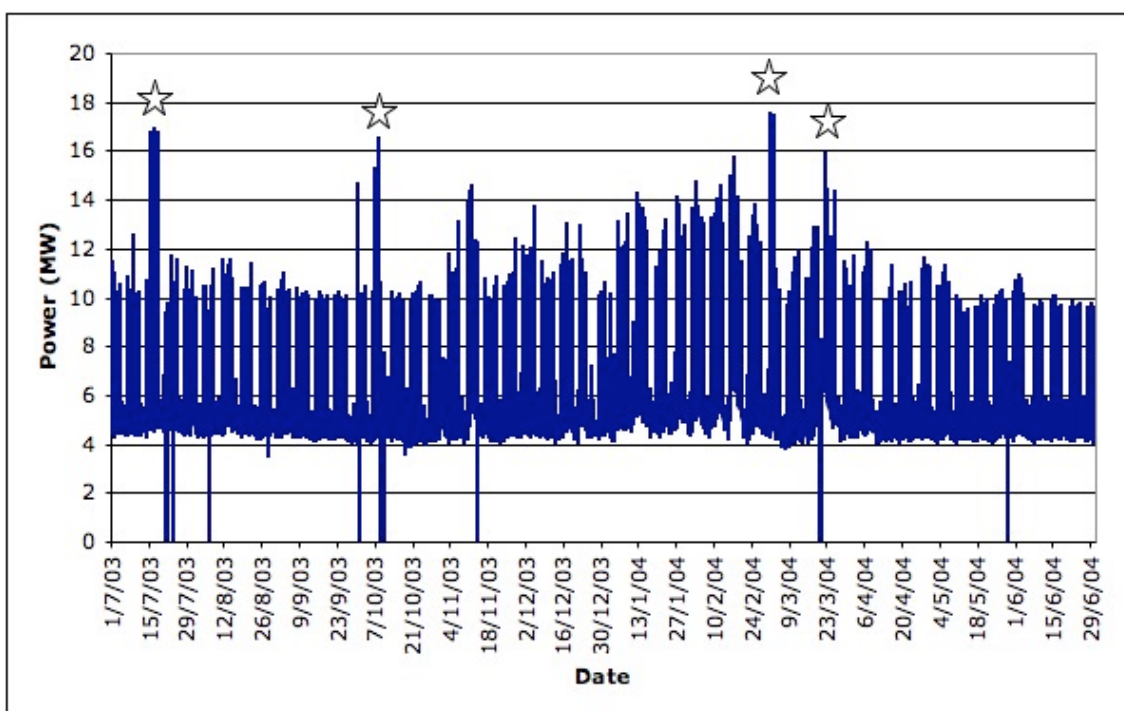


Figure 1: Forrest Ave TX2 Load
July 2003 to June 2004
(the stars indicate the peak days analysed in detail below)

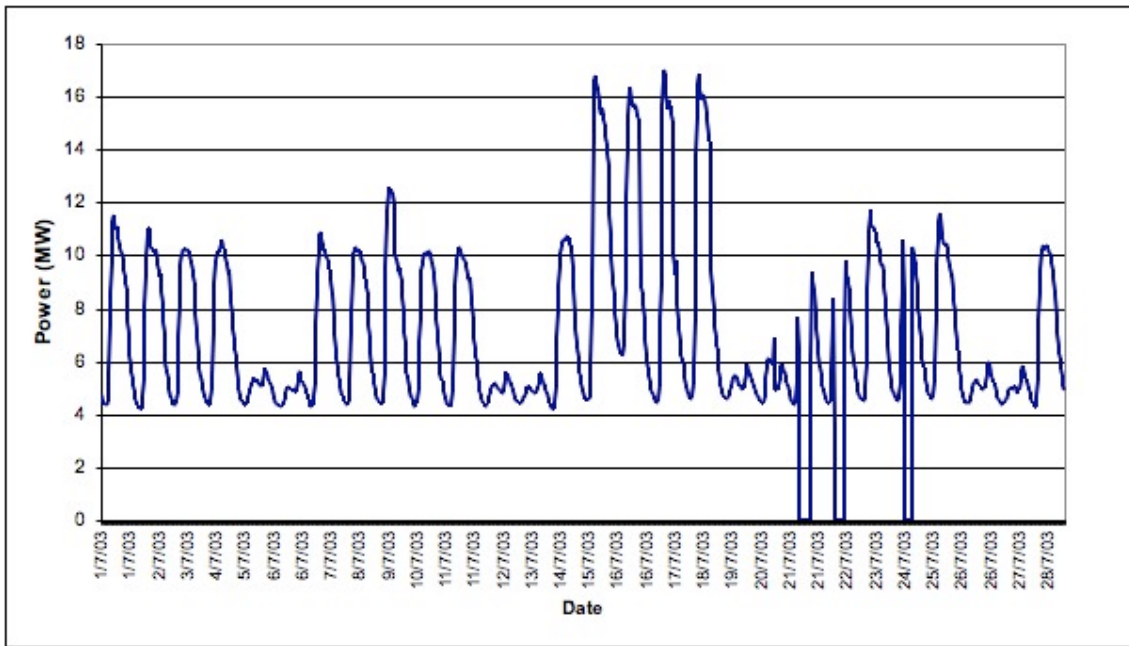


Figure 2: Forrest Ave TX2 Load - July
The first 28 days of July 2003

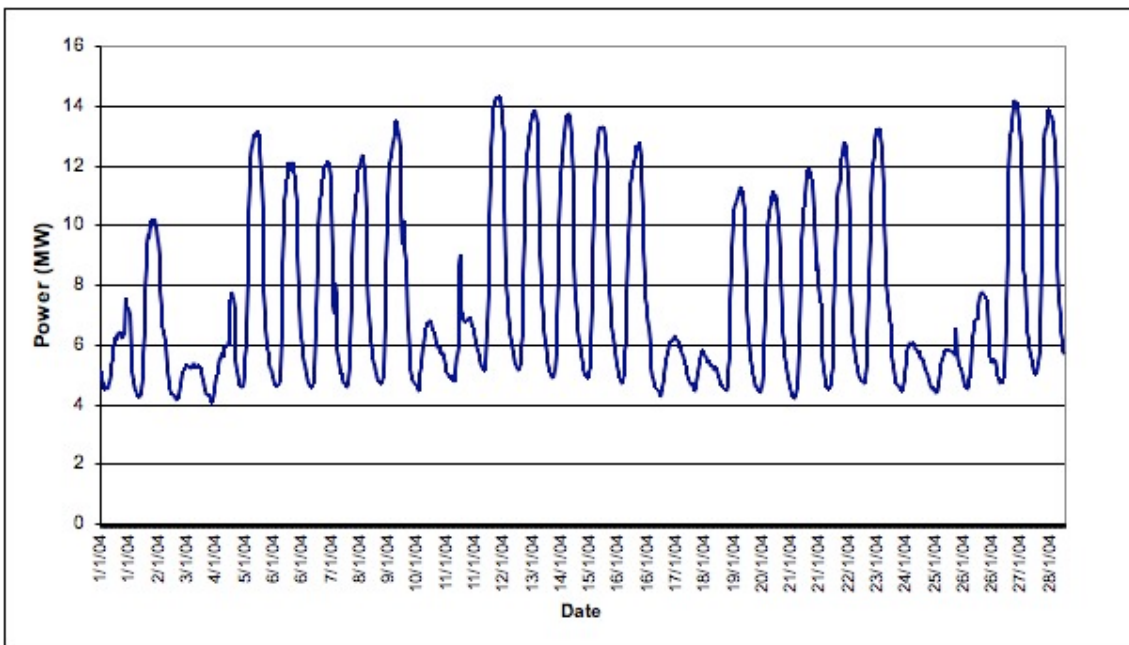
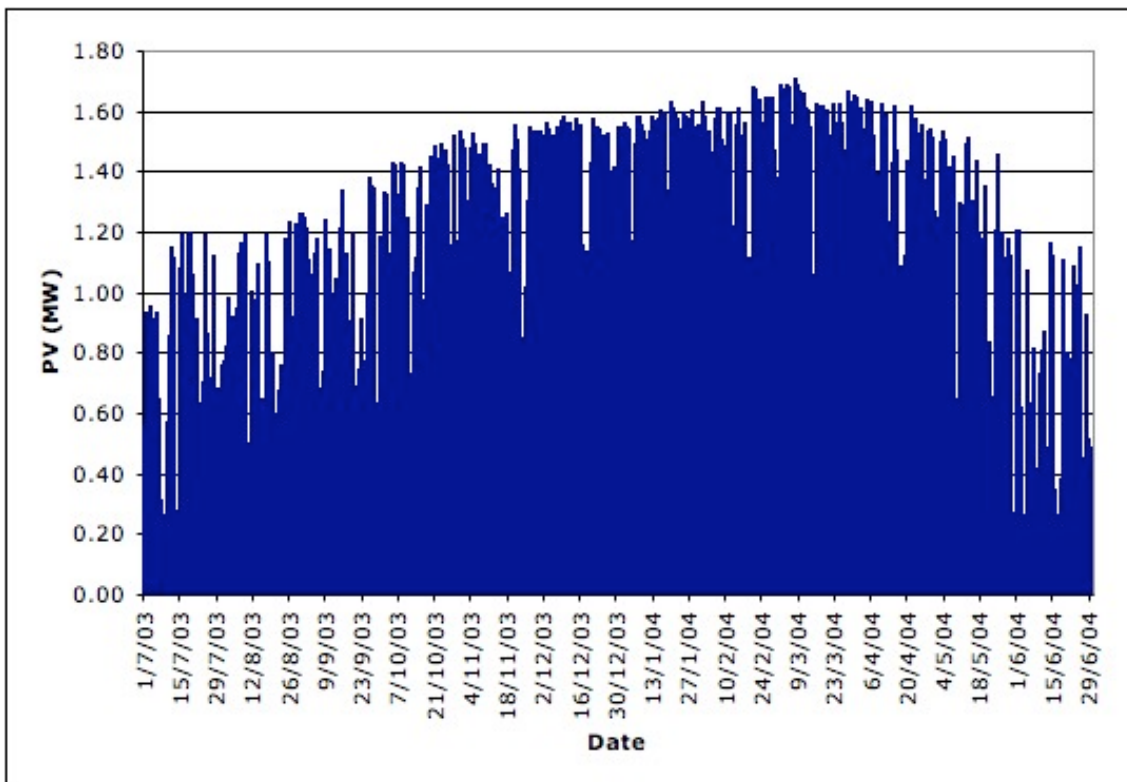


Figure 3: Forrest Ave TX2 Load - Jan
The first 28 days of Jan 2004



**Figure 4: Forrest Ave Simulated North-facing PV Output (2MW)
July 2003 to June 2004**

Daily profiles

Figure 5 shows the daily annual average load for Forrest Ave TX2, the simulated north-facing 2MW PV output, and the net load assuming it is reduced by PV. Both the annual average load and simulated north-facing PV peak at around 12:30pm. As can be seen from Figure 6 to Figure 9, although the spring and autumn loads also peak at this time, the summer peak occurs about an hour later and the winter peak occurs much earlier, at around 8:30am.

The highest seasonal peak occurs in summer and is reduced by the simulated north-facing PV and shifted to later in the day, to around 3pm. Both the spring and autumn peaks are also reduced, however because the winter peak occurs so early in the day, simulated north-facing PV has only a minor impact – although the reduced summer peak is still greater. The impact of simulated west-facing PV is discussed below.

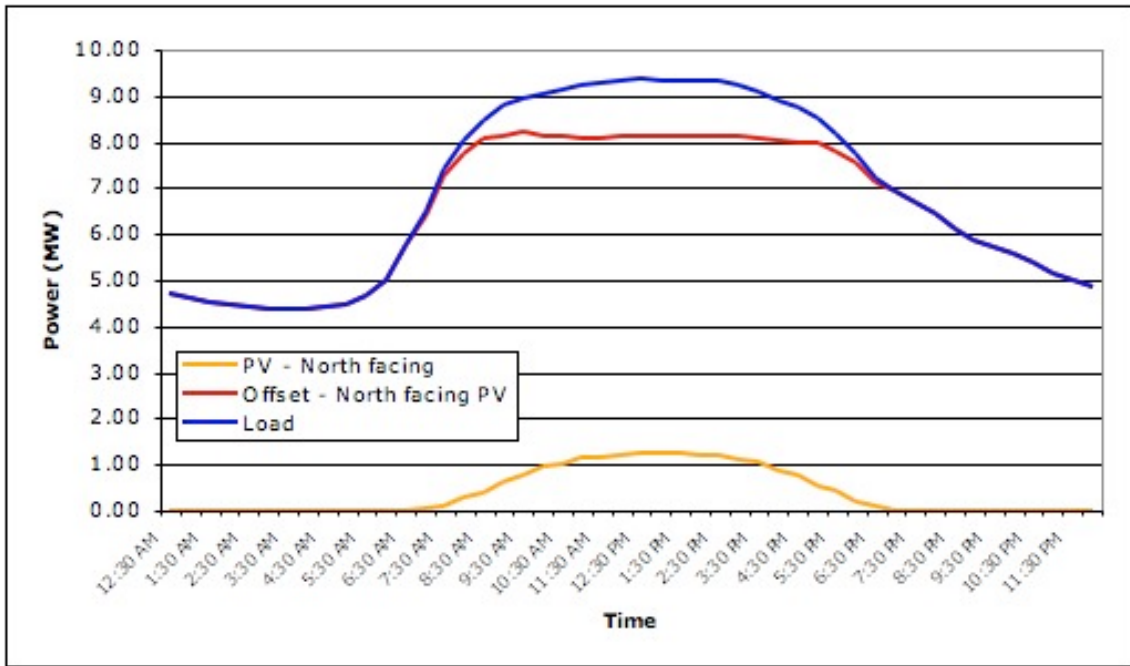


Figure 5: Daily Annual Average
 Forreast Ave TX2 Load, Forreast Ave Simulated North-facing PV (2MW) and Net Load
 after PV Offset
 July 2003 to June 2004

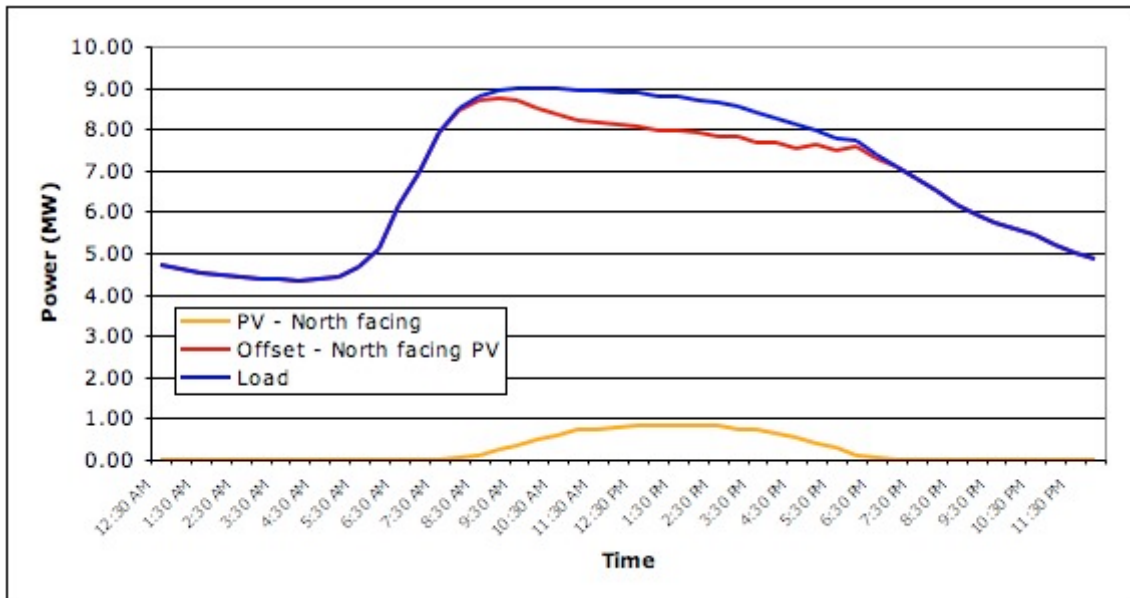


Figure 6: Daily Winter Average
 Forreast Ave TX2 Load, Forreast Ave Simulated North-facing PV (2MW) and Net Load
 after PV Offset
 June 2004 and July/Aug 2003

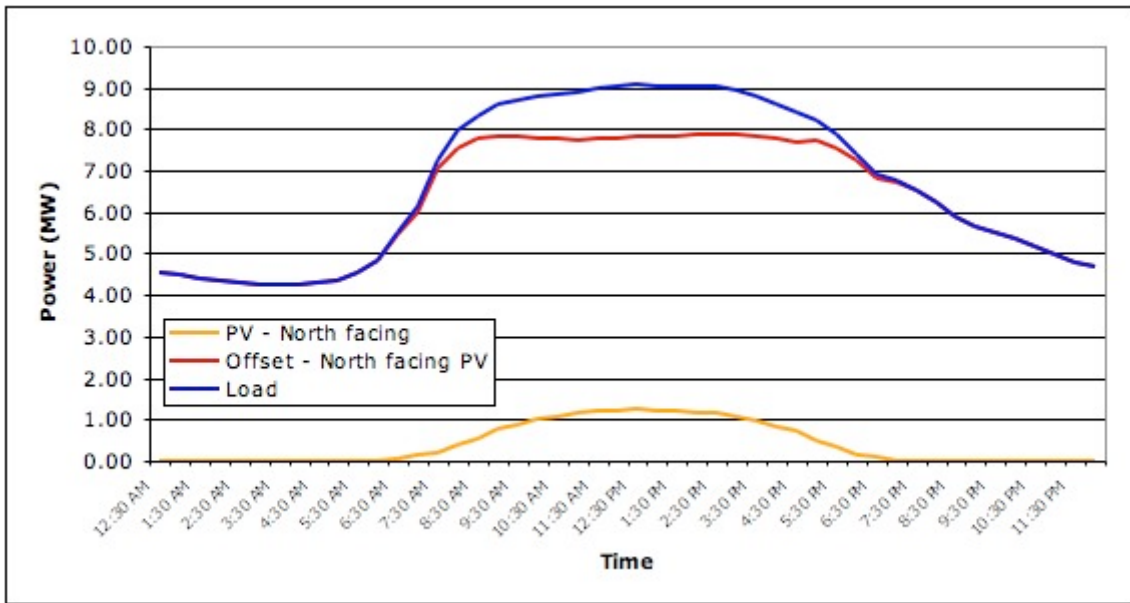


Figure 7: Daily Spring Average
 Forrester Ave TX2 Load, Forrester Ave Simulated North-facing PV (2MW) and Net Load after PV Offset
 Sept 2003 to Nov 2003

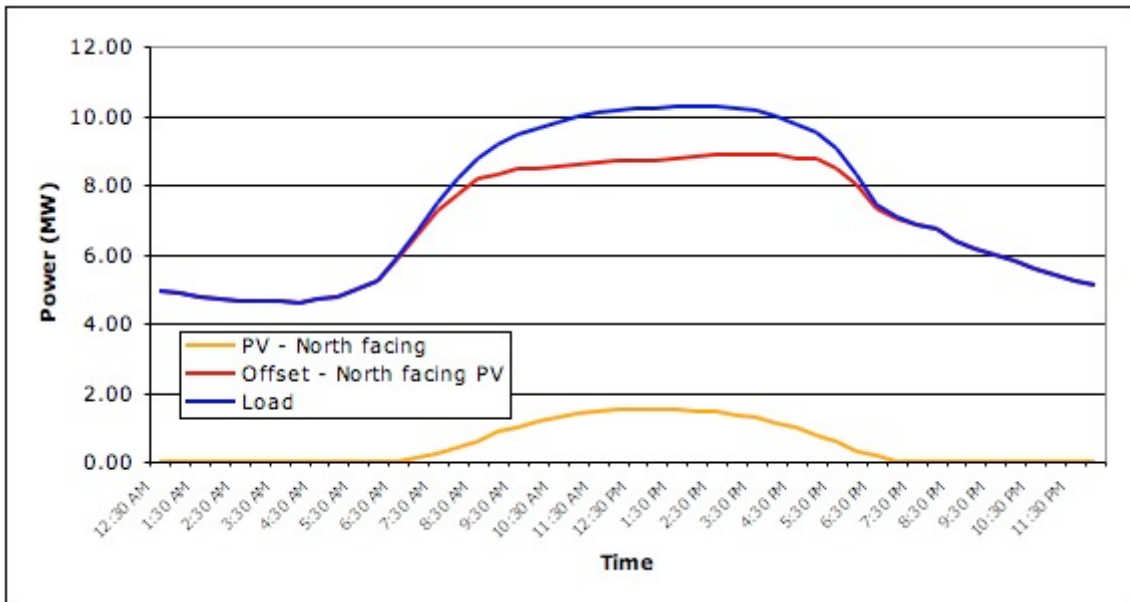


Figure 8: Daily Summer Average
 Forrester Ave TX2 Load, Forrester Ave Simulated North-facing PV (2MW) and Net Load after PV Offset
 Dec 2003 to Feb 2004

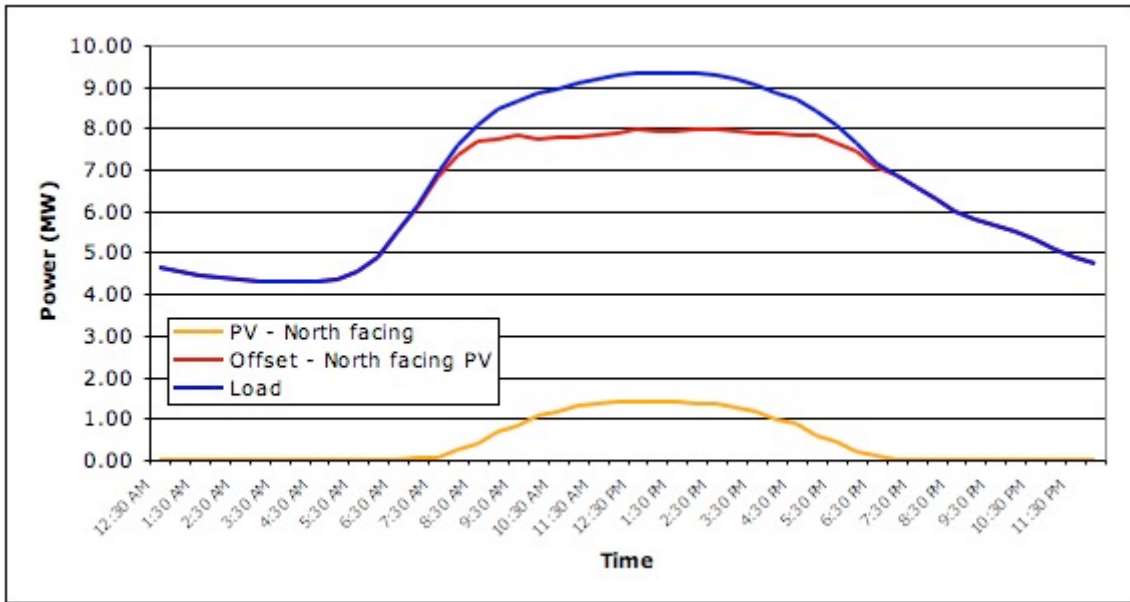


Figure 9: Daily Autumn Average
 Forrest Ave TX2 Load, Forrest Ave Simulated North-facing PV (2MW) and Net Load
 after PV Offset
 March 2004 to May 2004

The impact of simulated west-facing PV is illustrated in Figure 10 to Figure 14 and Table 1. Use of simulated west-facing PV with a tilt of 25 degrees shifts the peak PV output by about 1.5 hours later in the day, and a tilt of 45 degrees brings the shift to a total of about 3 hours. However, because the load and simulated north-facing PV output match so well, use of simulated west-facing PV has reduced ability to offset load.

Table 1: Annual Energy Output from Simulated 960W PV at Forrest Ave

Orientation	Tilt (degrees)	2003 (kWh/yr)	2004 (kWh/yr)
North	25	1,528	1,695
North west	25	1,585	1,757
West	25	1,476	1,614
West	45	1,409	1,546
West	90	1,015	1,116

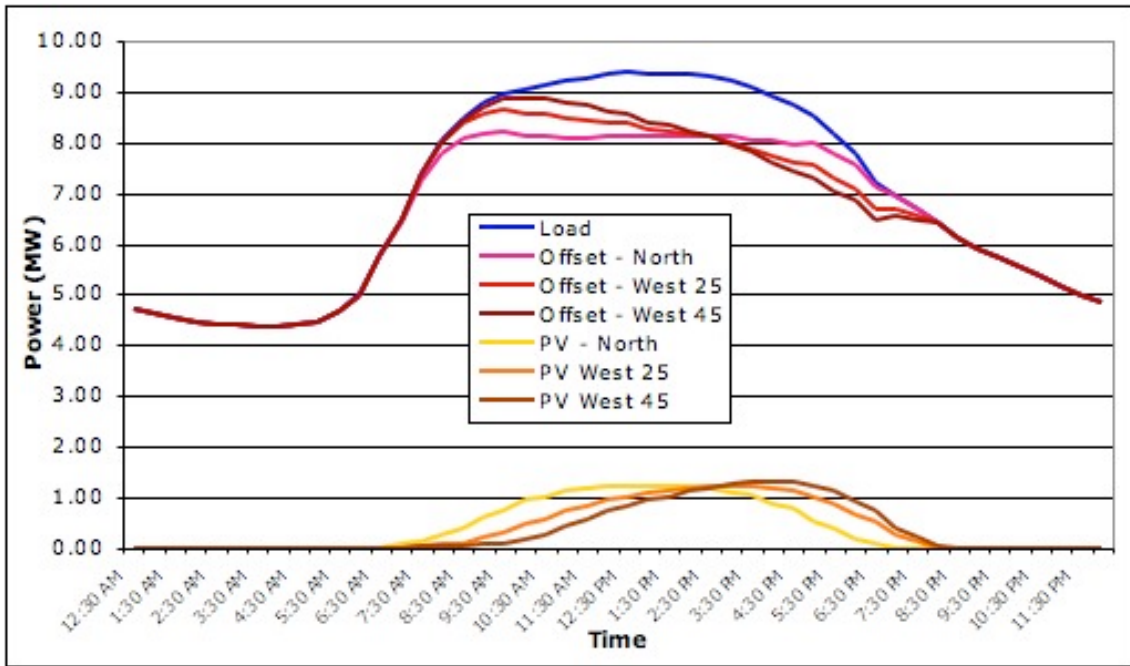


Figure 10: Daily Annual Average North, and West (25° and 45° inclinations) Forrest Ave TX2 Load, Forrest Ave PV (2MW) and Net Load after PV Offset July 2003 to June 2004

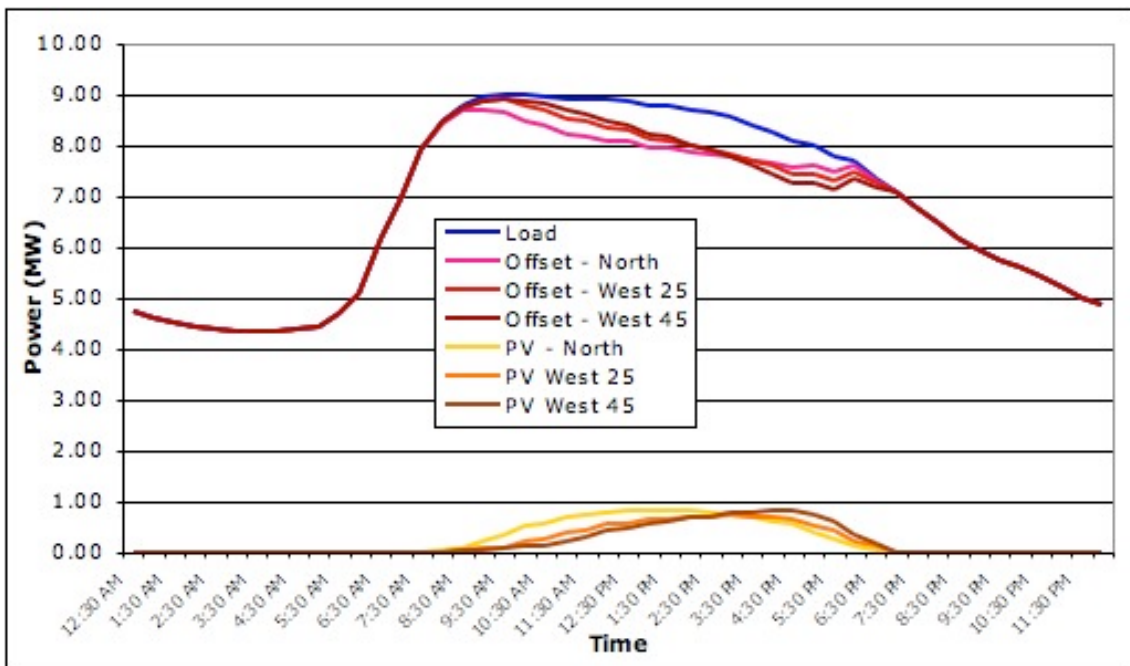
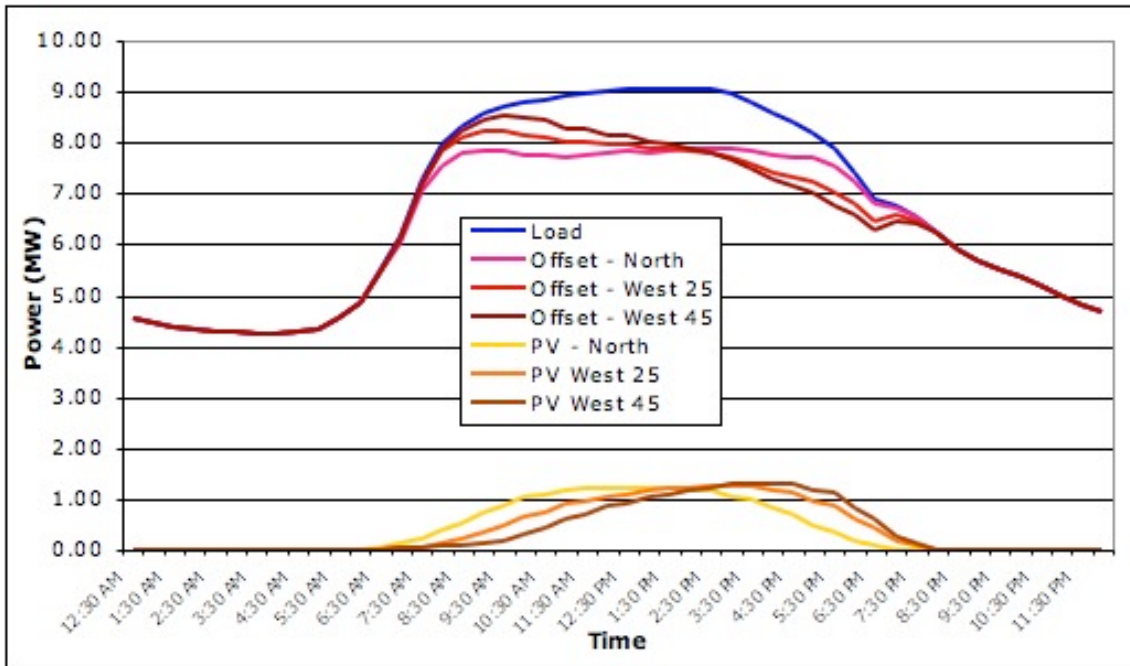
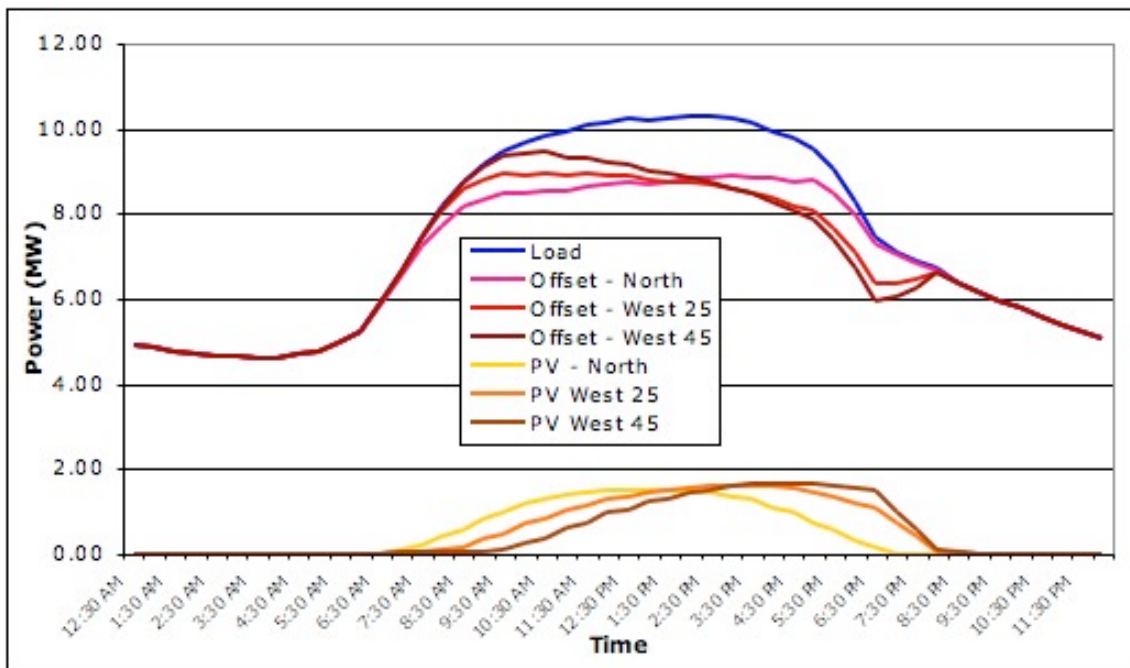


Figure 11: Daily Winter Average North, and West (25° and 45° inclinations) Forrest Ave TX2 Load, Forrest Ave PV (2MW) and Net Load after PV Offset June 2004 and July/Aug 2003



**Figure 12: Daily Spring Average
North, and West (25° and 45° inclinations)
Forrest Ave TX2 Load, Forrest Ave PV (2MW) and Net Load after PV Offset
Sept 2003 to Nov 2003**



**Figure 13: Daily Summer Average
North, and West (25° and 45° inclinations)
Forrest Ave TX2 Load, Forrest Ave PV (2MW) and Net Load after PV Offset
Dec 2003 to Feb 2004**

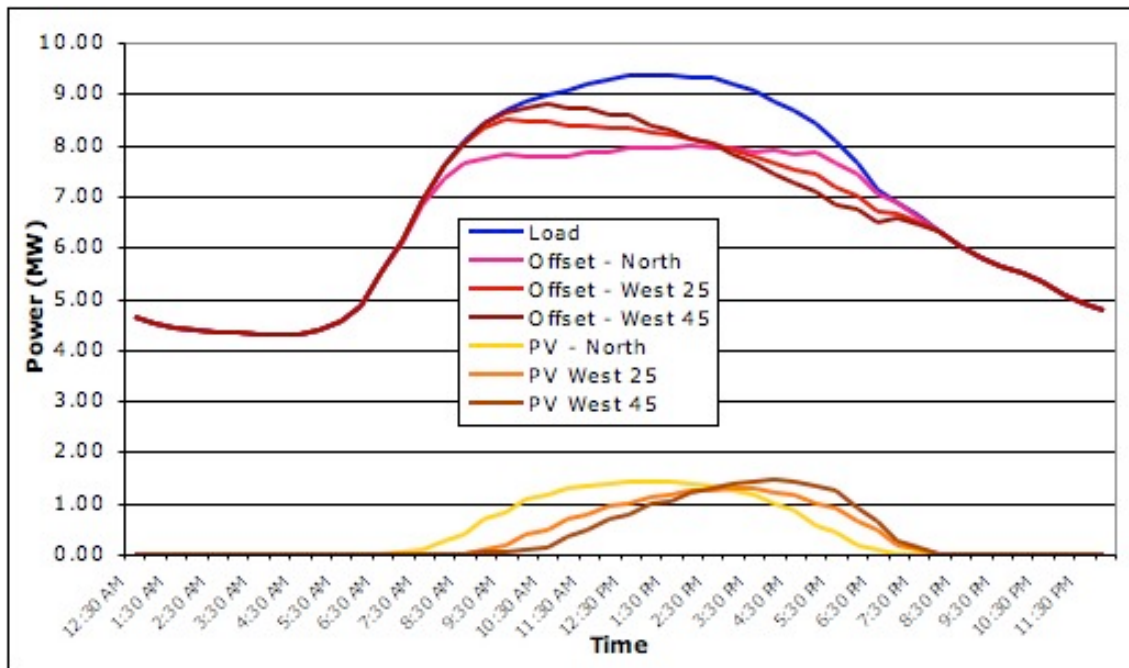


Figure 14: Daily Autumn Average North, and West (25° and 45° inclinations) Forrest Ave TX2 Load, Forrest Ave PV (2MW) and Net Load after PV Offset March 2004 to May 2004

Times of peak demand

The ten top half-hour demand periods at Forrest Ave TX2 are shown in Table 2. All occur on the 2nd and 3rd March 2004, which is illustrated in Figure 15, and are the ten highest points in the load duration curves in Figure 19 to Figure 21.

The highest peak load days for the study period (2nd and 3rd March 2004; Figure 15) were not particularly hot, reaching around 27°C, and involved rapid load increases in the early morning, around 8am and 6am respectively, probably due to operational changes by Western Power, such as switching from one transformer to another. On both days the simulated north-facing 2MW PV was a good match for the load, and, as can be seen from the load duration curves in Figure 20 and Figure 21, reduced the peak half hour periods for those days by between 1.5 and 1.7MW.

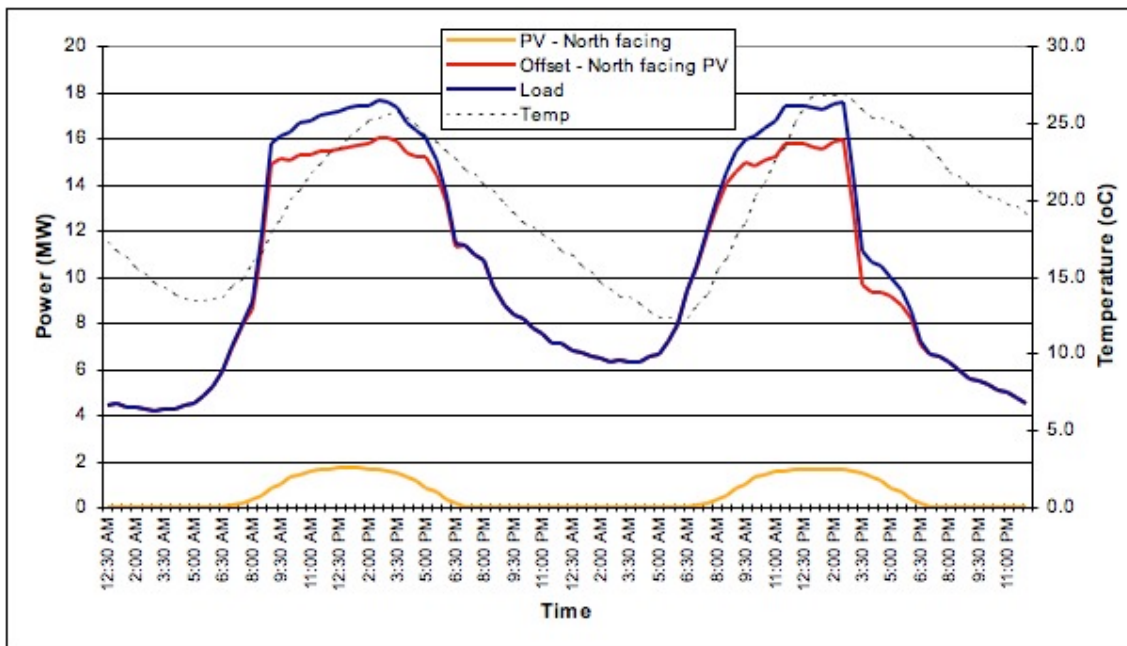
The second highest cluster of peak load days assessed here (16th -18th July 2003; Figure 16), were on a series of days where the load rapidly increases from around 6MW to around 17MW, peaking at around 9:30am, probably due to operational changes by Western Power. Because of this early peak the simulated north-facing PV is not a good match, resulting in only minimal load reduction.

The third highest cluster of peak load days assessed here occurred in spring (7th-8th Oct 2003; Figure 17) and peaked at around 3pm after a rapid rise at around 7am. Despite this relatively late peak, the simulated north-facing PV was able to make a significant contribution to load reduction.

The fourth highest cluster of peak load days assessed here includes a very hot day (over 40°C; 22nd-23rd March 2004; Figure 18), and again there was a very good match to simulated north-facing PV.

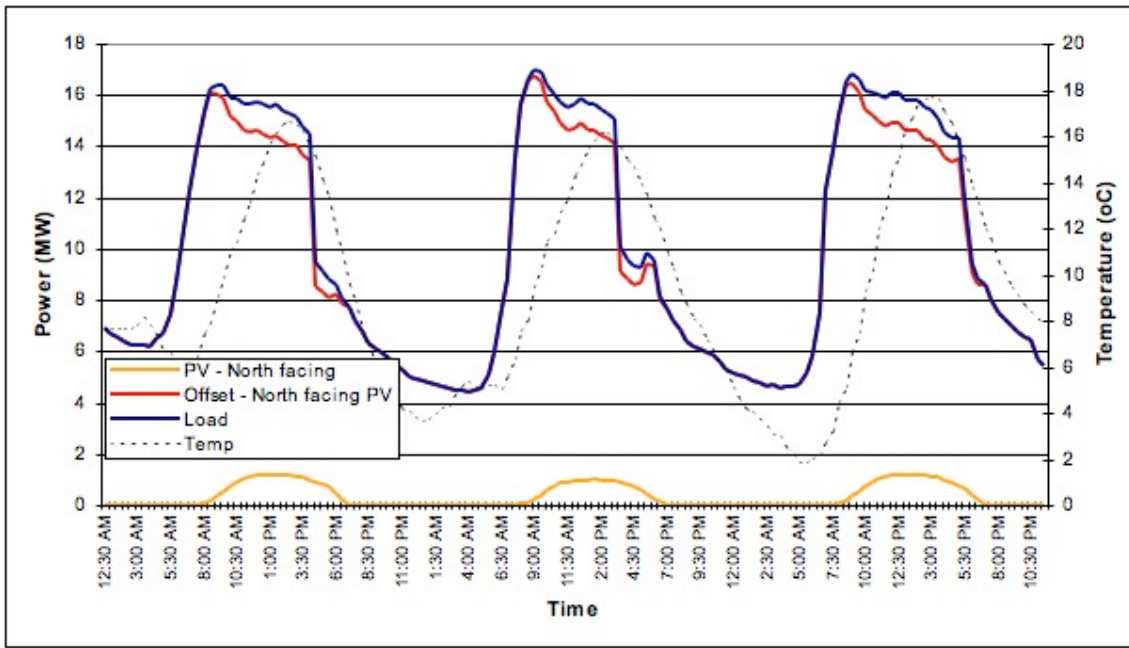
Table 2: Ten Top Half-hour Demand Peaks at Forrest Ave TX2

Demand (MW)	Date	Day	Time
17.62	2-Mar-04	Tues	14:30
17.57	2-Mar-04	Tues	15:00
17.52	3-Mar-04	Wed	14:30
17.48	3-Mar-04	Wed	14:00
17.42	3-Mar-04	Wed	12:00
17.40	2-Mar-04	Tues	14:00
17.40	3-Mar-04	Wed	12:30
17.37	2-Mar-04	Tues	13:30
17.35	3-Mar-04	Wed	11:30
17.28	3-Mar-04	Wed	13:00



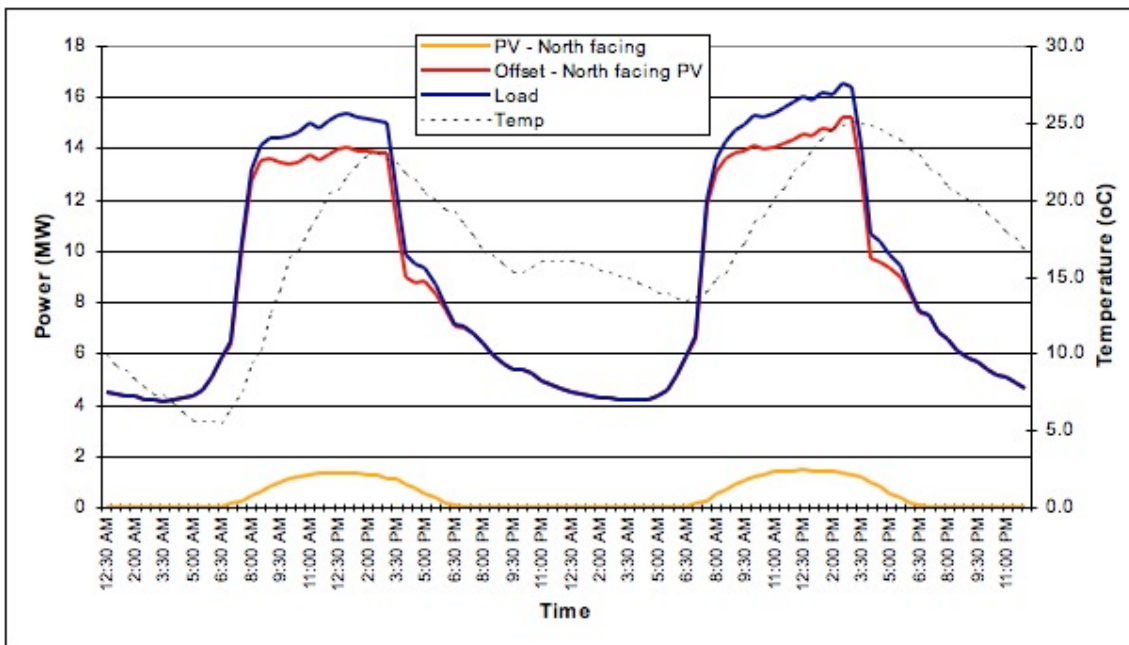
**Figure 15: Autumn peak days
2nd to 3rd March 2004**

Forrest Ave TX2 Load, Forrest Ave Simulated North-facing PV (2MW) and Net Load after PV Offset



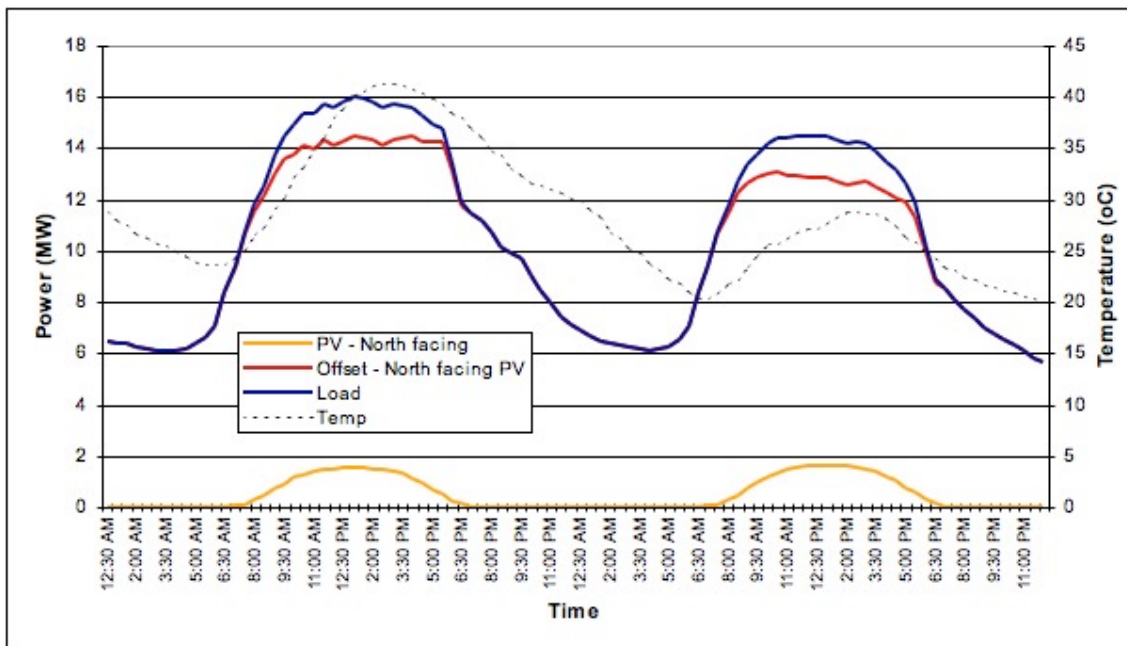
**Figure 16: Winter peak days
16th – 18th July 2003**

Forrest Ave TX2 Load, Forrest Ave Simulated North-facing PV (2MW) and Net Load after PV Offset



**Figure 17: Spring peak days
7th-8th Oct 2003**

Forrest Ave TX2 Load, Forrest Ave Simulated North-facing PV (2MW) and Net Load after PV Offset



**Figure 18: Autumn peak days
22nd-23rd March 2004**

Forrest Ave TX2 Load, Forrest Ave Simulated North-facing PV (2MW) and Net Load after PV Offset

Load duration curves

The load duration curve for Forrest Ave TX2 is in Figure 19 and displays the stepped pattern typical of a site with two main load periods – around 5MW and around 10MW. The top 50% of the load occurred for just under 30% of the study period, while the top 10% occurred for 0.4% of the time.

Figure 20 shows the top 50 half hour load periods, together with the offset load duration curve assuming reduction by simulated north-facing PV or simulated west-facing PV at either of two tilt angles (25° and 45°). It can be seen that the simulated north-facing PV resulted in the lowest offset load duration curve, followed by west-25 then west-45. 2MW of simulated north-facing PV resulted in the highest offset load period being 0.9MW lower than the highest original load period, and resulted in the top 10 offset load periods being lower by an average of 1.03MW.

Figure 21 shows the same load duration curves except that the offset periods now correspond to the load periods directly above them on the chart. This shows that during the highest load period, 81.5% of the simulated north-facing 2MW PV contributed to load reduction, reducing it from 17.62MW to 15.99MW (although note that what was originally a lower load period did not correlate as well to PV and so became the study period's highest offset load period at 16.72MW). On average during the 10 highest load periods, 81.5% the simulated north-facing 2MW PV was contributing to reducing peak load.

The large differences in the top load periods between Figure 20 and Figure 21 occur because the top periods in Figure 20 correspond to what appear to be operational changes by Western Power that result in high loads in the early mornings when there is

little contribution from PV. Changing the timing of these changes would significantly increase PV's contribution to reducing peak load.

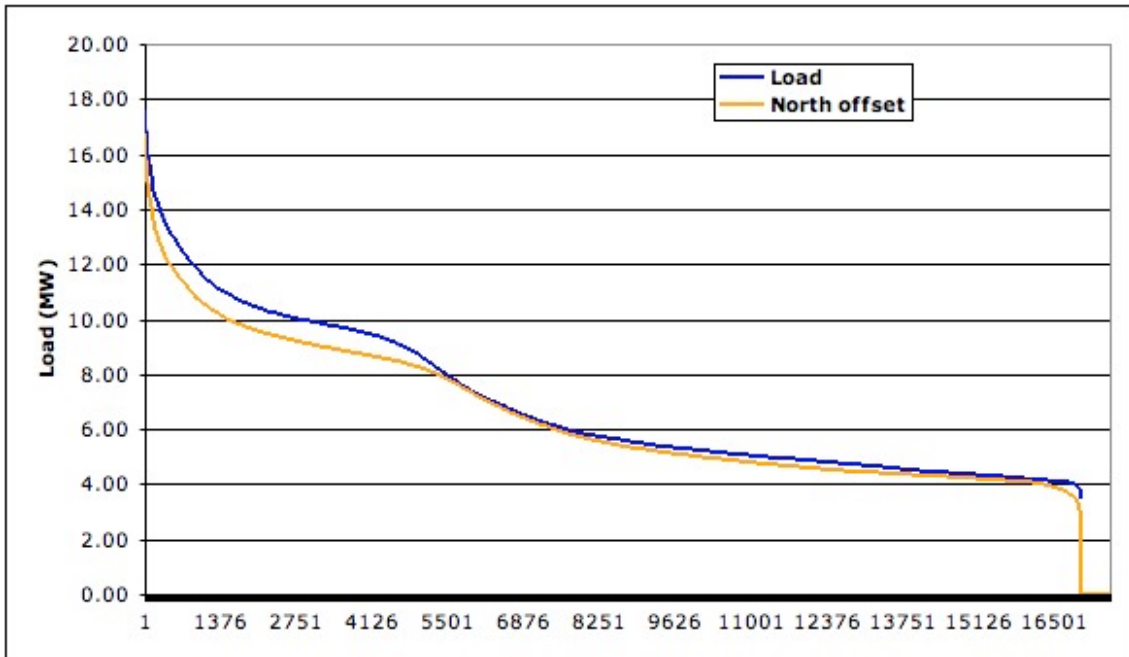


Figure 19: Load Duration Curve - July 2003 to June 2004
Forrest Ave TX2 Load and Forrest Ave TX2 Net Load after PV Offset (2MW)

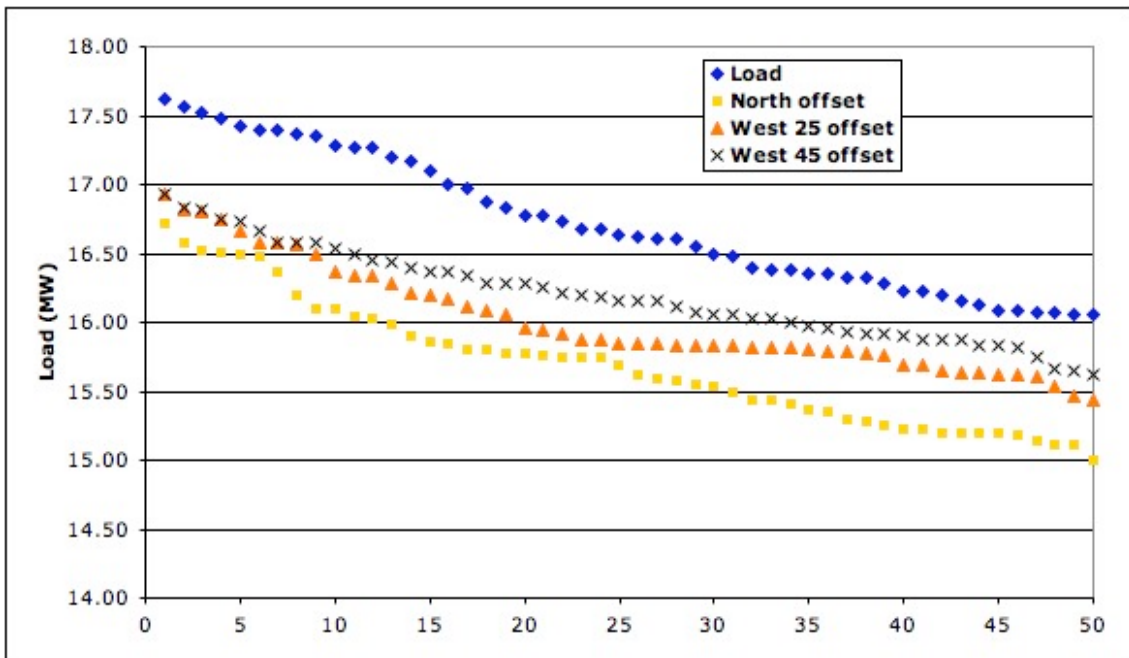


Figure 20: Load Duration Curve - top 50 load periods
North, and West (25° and 45° inclinations)
Forrest Ave TX2 Load and Forrest Ave TX2 Net Load after PV Offset (2MW)
July 2003 to June 2004

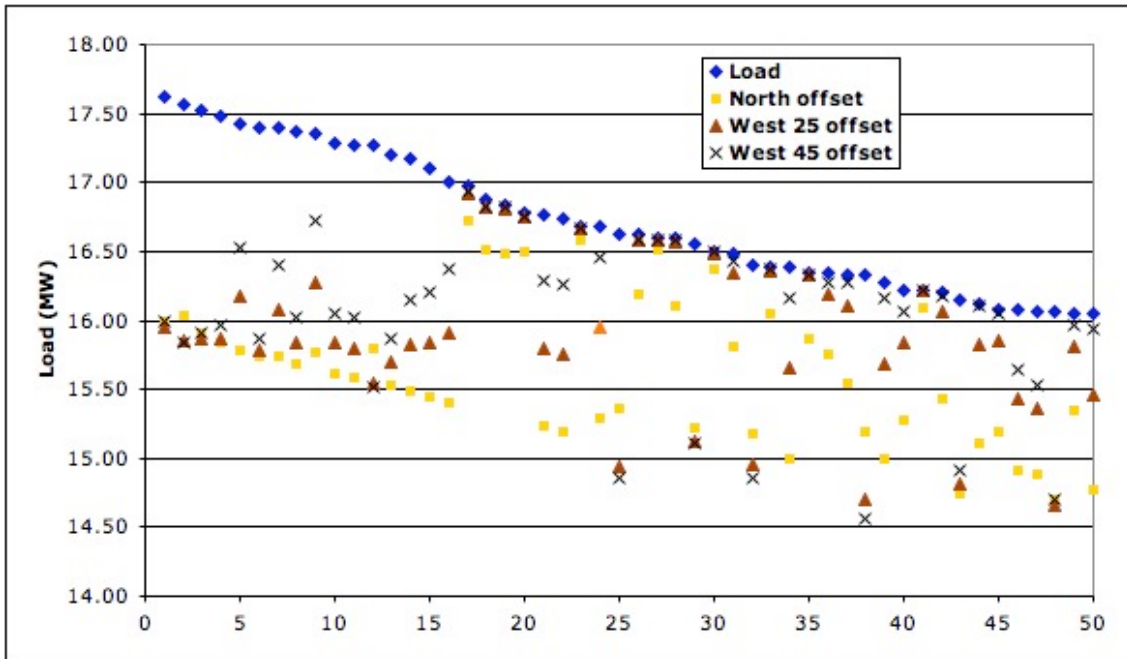
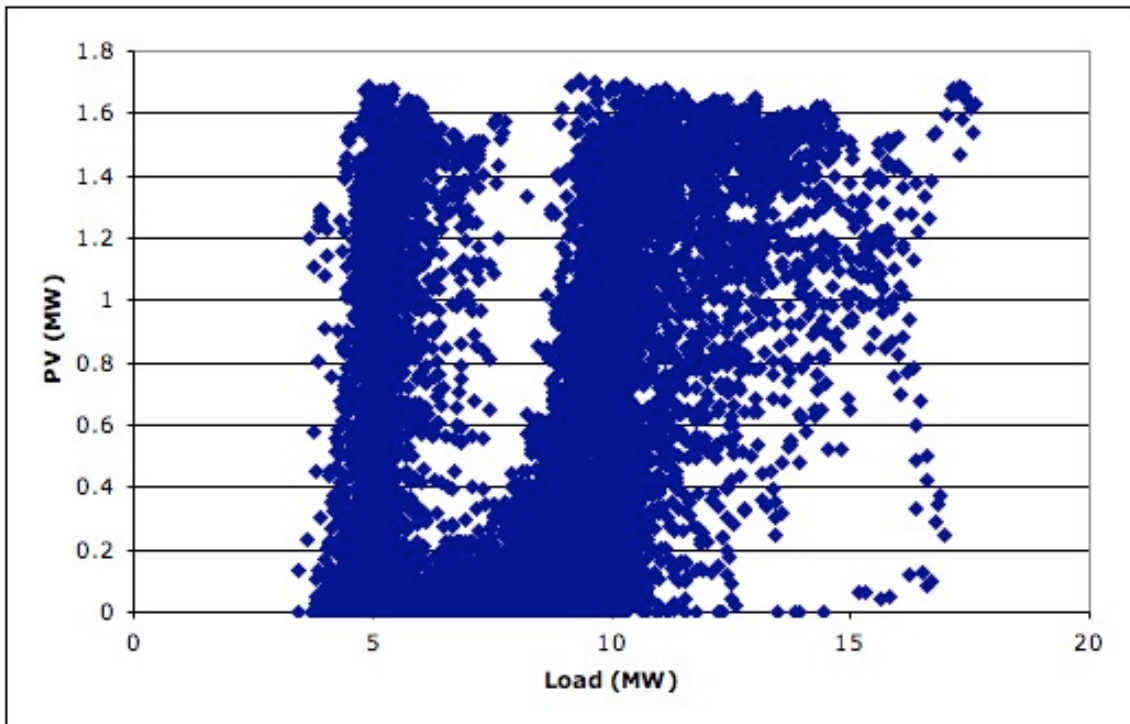


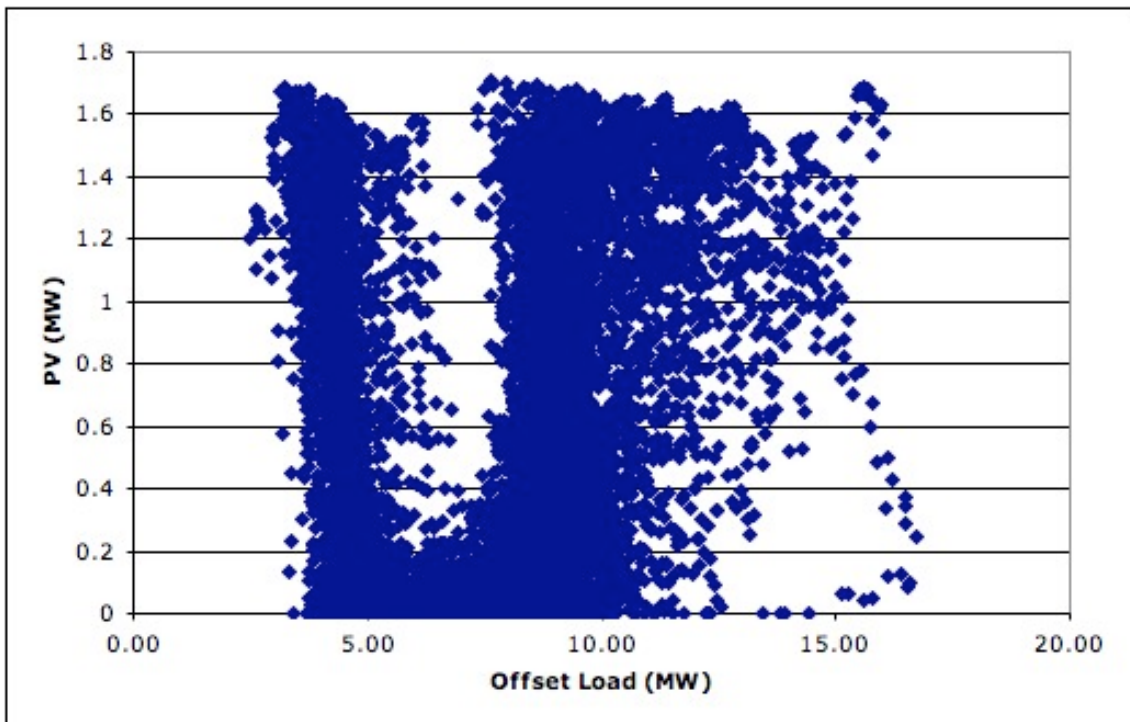
Figure 21: Load Duration Curve - top 50 load periods (linked)
 North, and West (25° and 45° inclinations)
 Forrest Ave TX2 Load and Forrest Ave TX2 Net Load after PV Offset (2MW)
 July 2003 to June 2004

General correlation between PV Output and Load

Figure 22 shows the relationship between north-facing simulated PV output and the Forrest Ave TX2 load at any one time, and shows some correlation. A high correlation would result in the data points being distributed from the bottom left to the top right of the chart. Instead, the load is split into two distinct regions, corresponding to the baseload periods and the daytime peaks – where the latter displays some correlation with PV output, extending up and to the right. When the PV output is plotted against the offset load (ie. reduced load because of PV), the PV shifts the load points at the top of the chart, which include the study period’s highest load points, to the left – see Figure 23. The highest load points at low PV output correspond to the early peaks on the 16th - 18th July 2003 (Figure 16) that are not significantly reduced by PV. Avoiding these peaks through other means such as demand side management or rerouting through a different transformer would significantly increase PV’s ability to reduce peak loads through TX2. The next highest load points (around 10MW) that occur at low PV output correspond to early morning and late afternoon loads on days of peak demand.



**Figure 22: Forreast Ave Simulated North-facing PV (2MW) vs Forreast Ave TX2 Load
July 2003 to June 2004**



**Figure 23: Forreast Ave Simulated North-facing PV (2MW) vs Forreast Ave TX2 Net Load
after PV Offset
July 2003 to June 2004**

Correlation with temperature

Figure 24 shows the relationship between the Forrest Ave TX2 load and temperature, and shows fair correlation, with load tending to increase with temperature. The cluster of detached load points around 15MW correspond to the load peaks identified in Figure 16 to Figure 15, none of which occurred on hot days.

Figure 25 shows the relationship between simulated north-facing PV output and temperature, and shows a similar correlation, where PV tends to increase at higher temperatures, which would normally occur during the middle of the day – although note there are instances of zero PV output at high temperatures, presumably on hot summer evenings. The sudden cut-off around 1.6 to 1.7MW is likely an artefact of the PV simulation.

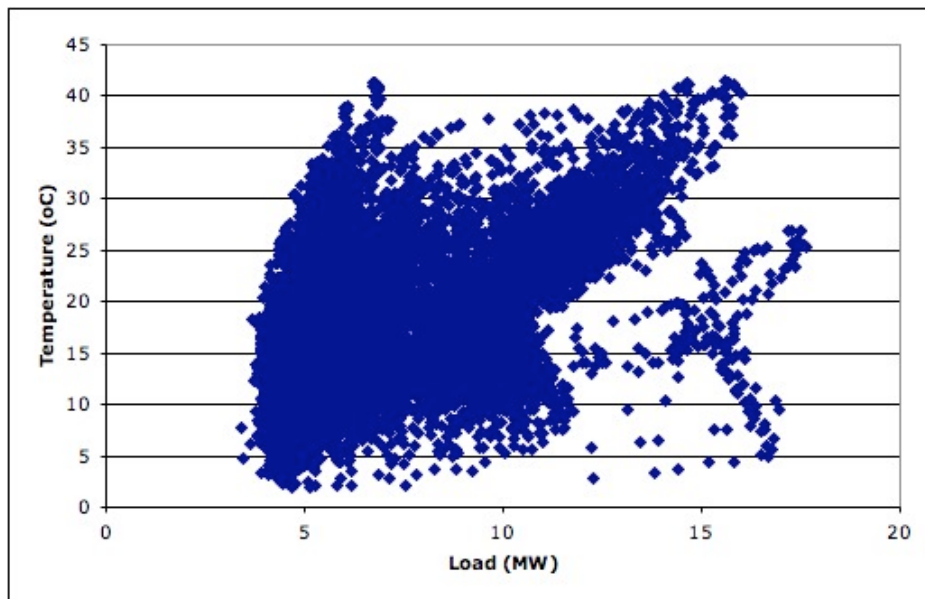


Figure 24: Forrest Ave TX2 Load vs Temperature
July 2003 to June 2004

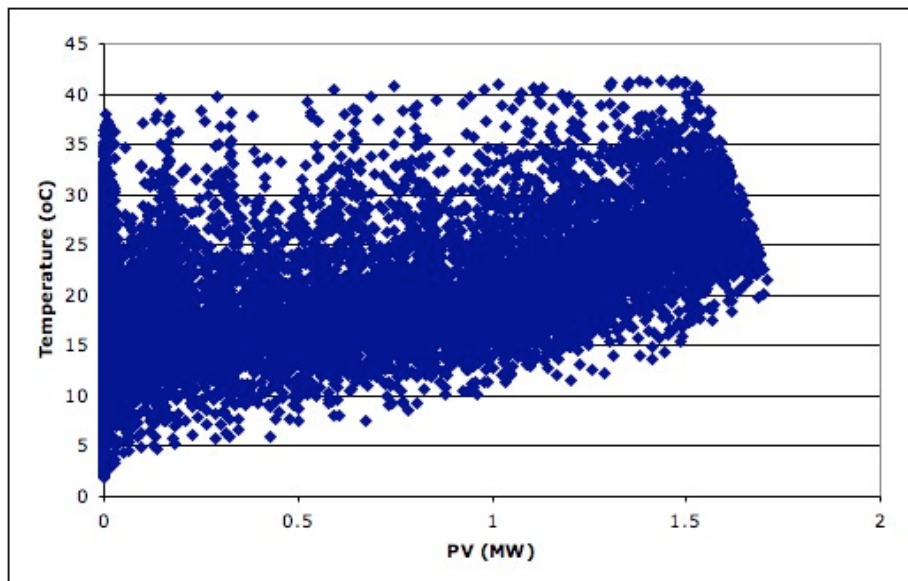


Figure 25: Forrest Ave Simulated North-facing PV (2MW) vs Temperature
July 2003 to June 2004