Centre for Energy and Environmental Markets

Newington Village

An analysis of photovoltaic output, residential load and PV's ability to reduce peak demand

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About CEEM and this report:

The Centre for Energy & Environmental Markets was founded in 2004 to allow the University of New South Wales to provide interdisciplinary research and advice on the design, implementation and operation of energy and environmental markets.

The Centre formally brings together researchers from within the Faculty of Engineering, the Faculty of Commerce & Economics and the Australian Graduate School of Management. CEEM also has active collaborations occurring across other faculties at the UNSW and with a number of Australian and international universities and other organisations.

This paper presents an analysis of PV output and household load data for 30 homes in Newington, and of data from the Homebush Bay substation, for the period July 2004 to June 2005. These data are also analysed with respect to corresponding temperature and National Electricity Market load and price data, in order to help assess the value of the PV output to the householder and to the electricity network more generally.

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Executive Summary

Background to the Newington Solar Village

As part of the planning process for the 2000 Sydney Olympics, the organisers agreed to create a "green" village and environmentally sustainable facilities. The Athletes Village was purpose-built as an energy and water efficient medium density development with a mix of free-standing homes, apartments and community facilities. It was part of the new suburb of Newington and some of the houses were used to accommodate Olympic athletes during the Games and then sold. All free-standing homes are equipped with solar power (photovoltaic or PV) systems and solar water heaters. By 2004, 780 homes had been built with 1000 Wp of PV each and 199 houses with 500 Wp each. Passive solar design features, energy efficient appliances and grey water systems are also used in all homes. These were expected to reduce net energy and water requirements significantly compared to standard Sydney households.

When first built, Newington was the largest solar powered suburb in the world. Around 5000 people now live in Newington, and are serviced by schools, shops and community facilities. The suburb adjoins both Bi-Centennial Park, with its extensive parklands, and Sydney Olympic Park, with its range of sporting facilities and several large PV systems, including the iconic stadium lights.

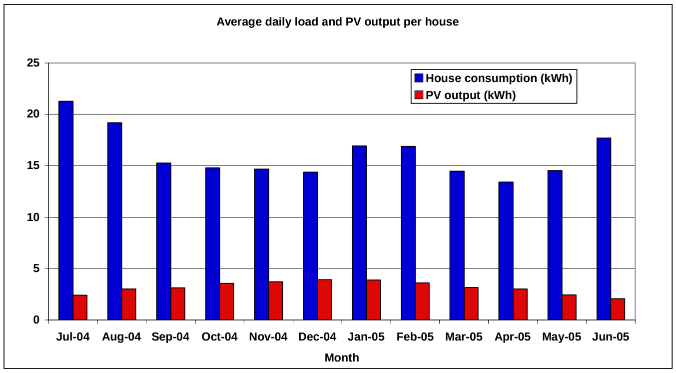
Although it was generally promoted as a Solar Village, the design and marketing of the Newington homes was more circumspect with regard to their energy efficiency and solar features. The solar arrays, although not totally hidden, were generally roof integrated and placed discretely so as not to be too visible from the street. The homes were purposely marketed to the general home buyer, not to the 'energy aware' or 'green' customer market. The energy features were part of a total home package and purchasers may not necessarily have been especially interested in them. This has ramifications for the energy usage patterns and PV performance emerging through this study.

With the suburb now well established, the NSW Department of Planning monitored a selection of the homes as part of its electricity demand management activities, in order to assess the overall impact of the sustainable energy measures used, as well as the effectiveness of the PV systems in minimising peak loads on the grid. A complementary study is currently being undertaken to assess the wider implications of customer knowledge and interest in their sustainable homes.

For this project, data on electricity use and PV output were collected from 30 homes over 12 months from the beginning of July 2004 through to the end of June 2005. The data consists of half hourly PV output, with import and export of electricity from the grid measured separately. This allows assessment of the overall impacts of urban-scale use of PV on the network, examination of the variability between different houses, together with any correlation between PV output and load. The household load and PV profiles were examined against half hourly loads at the local Homebush Bay zone substation and on the National Electricity Market (NEM), as well as compared to NEM spot prices and ambient temperatures in the Sydney Olympic Park area.

PV Output

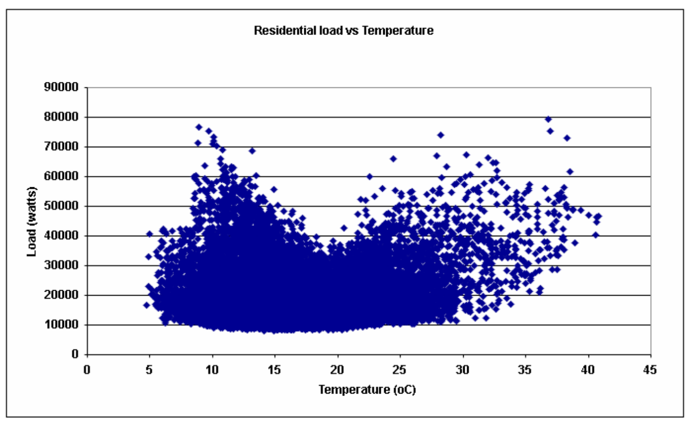
The average daily PV output per house was 3.16 kWh, or 19.6% of consumption. Total PV output from the 30 sites over the year was 34,560 kWh. Two of the PV systems were found to be faulty, one not operating at all, the other showing very low output. The householders are either unaware that the systems are not operating, or do not have easy access to maintenance contacts.



The highest total PV output in any half hour period from all 30 sites over the whole year was just over 13 kW, and occurred between 12:30 pm and 1:00 pm. In the summer months the average for this time was 15 kW, dropping to 12 kW in winter. The annual average solar radiation available in Sydney at a tilt angle of 25 degrees is 5.2 kWh/m^2 per day. The Newington systems rated at 1 kWp, if optimally oriented, could produce a maximum of 5.2 kWh per day on average over the year. The 30 Newington systems therefore have a Performance Ratio (PR) of 0.61. If the two non-functional systems are removed from the data, the remaining 28 systems have a PR of 0.65. This compares with international averages of 0.70 for systems installed after 1996. Hence the Newington systems are performing below the normal range. The reasons for the lower output of the total system, compared with the nominal rating of the PV panels, include, inverter efficiency, temperature derating of both the panels and the inverter, wiring losses, non-optimal orientation, shading (although no obvious shading was apparent), dust build-up, data and time inaccuracies and system malfunction. Insolation levels for the monitored year were not compared to the long term average for the area to see whether or not they were typical. Hence long term average performance may vary from the figures reported here.

Residential Load

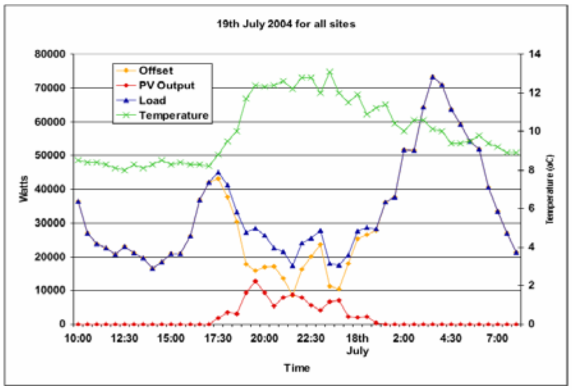
Over the period July 2004 to June 2005 the 30 houses studied had an average daily electricity consumption of 16.12 kWh per house – much higher than 7.5 kWh anticipated. The maximum loads occur on winter evenings, although summer loads can also be high. The peak load occurs between 6pm and 10pm. Half the maximum load days occurred on weekends. Household load was strongly influenced by temperature, indicating an apparent high take-up of electrical heating, despite the availability of gas, and also of cooling.

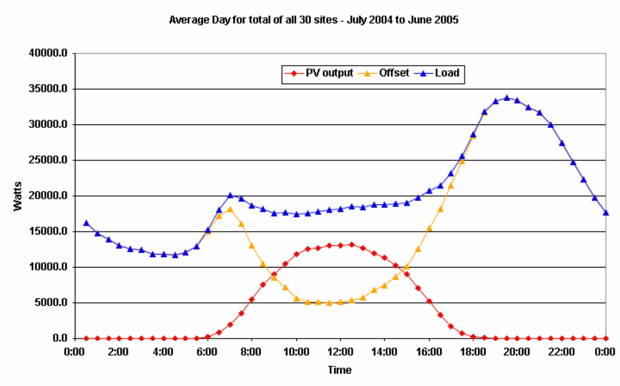


Correlations of Load and PV Output

Residential Load

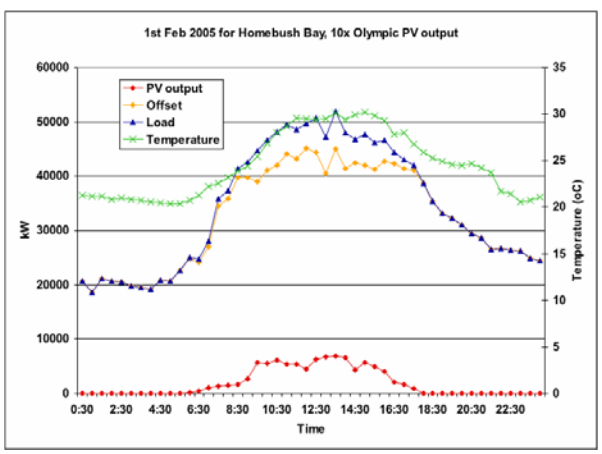
The PV average maximum contribution occurs between 10:00am and 2:00pm, whereas the average Newington residential load peaks between 6:00pm and 10:00pm. Thus PV makes the Newington residential peaks, as seen by the network, even more distinct. Load from the 30 Newington homes is also very peaky, with about half the load occurring for only 5% of the time. PV changes this very little, the main impact is to offset the load when it is very low which results in export to the grid at these times. Note that at all times when it is operating, PV at Homebush Bay would be expected to reduce energy losses. Interestingly, only two of the highest load points occurred in the summer months. All the top 10 readings occurred on three days in November and July. Ten of the top 20 peaks occurred on Sundays. The peak loads on all these days were late in the afternoon, when PV could not contribute. The graphs below show the load and the PV contribution on a peak load day and on average over the whole year.

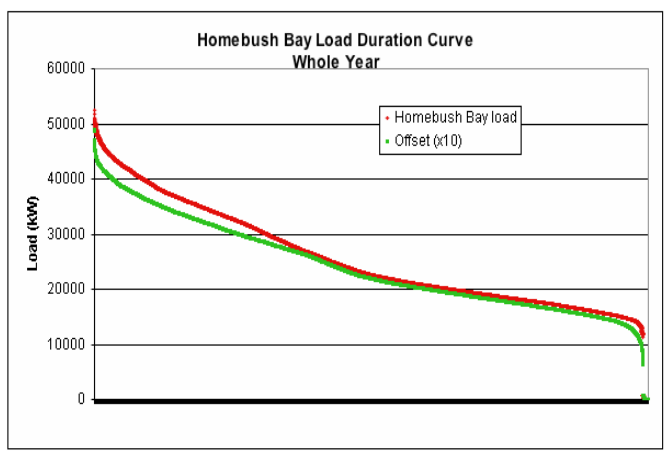


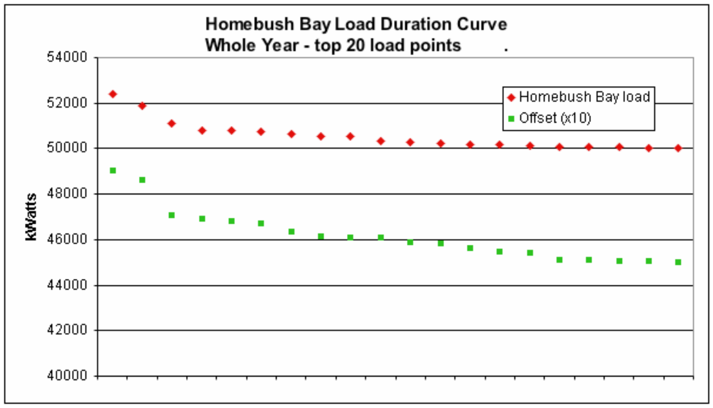


Homebush Bay Substation Load

Newington is serviced by the Homebush Bay substation, which has a large industrial and commercial load and a corresponding peak load between 11am and 2pm, which allows PV to align well to overall network load. The 30 monitored sites were assumed to be representative of the total installed PV at Olympic Park which feeds into the Homebush Bay substation. The graphs below show PV output, load, net load and temperature on 1st February, a typical high load day at the substation, as well as the annual load duration curve, with the resultant load as reduced by PV output. The top 20 load points are also shown, both before and after being offset by PV. To make the contribution by PV to offsetting the total Homebush Bay load more obvious, the estimated Olympic site PV output was multiplied by 10. It is clear that in addition to reducing energy losses, the PV reduces peak load right up to the very highest load points. The 3.4 MW reduction in the highest load point means that 29.5% of the assumed 11.54 MW (10x current PV) was contributing directly to offsetting the peak load. Any assessment of PV's usefulness in meeting peaks should take into account the fact that it is acceptable for loads to exceed the network's capacity a small percentage of the time.

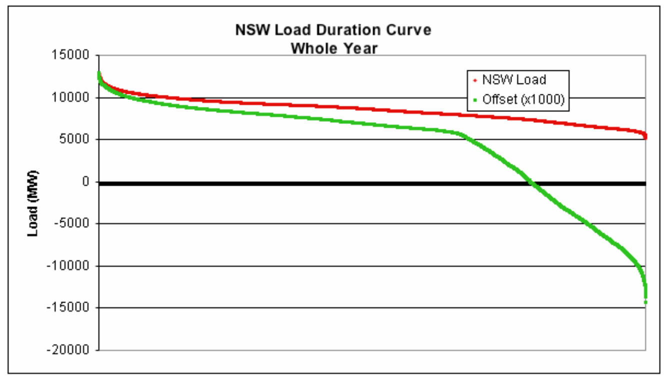






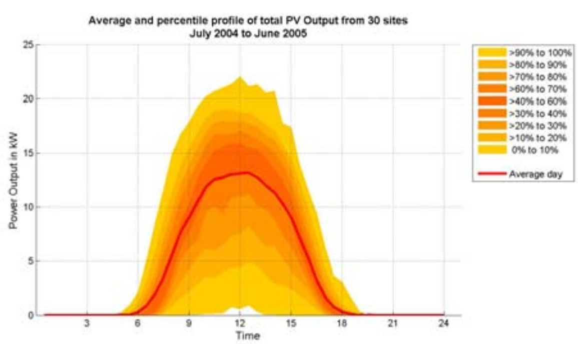
NSW Load

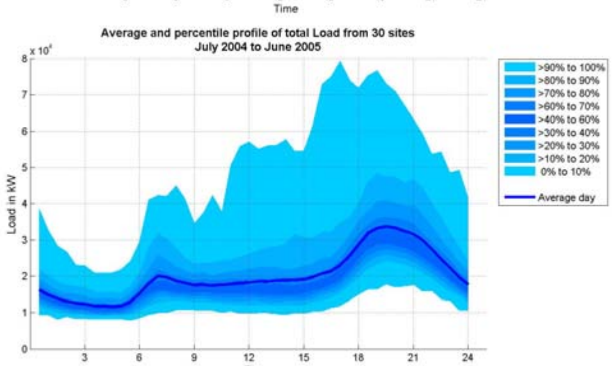
The relationship between PV output and the NSW load is better than for the 30 site load, however the points of highest demand are still unchanged by PV. The estimated Olympic site PV output was multiplied by a factor of 1000 so it would have a noticeable impact on the NSW load.

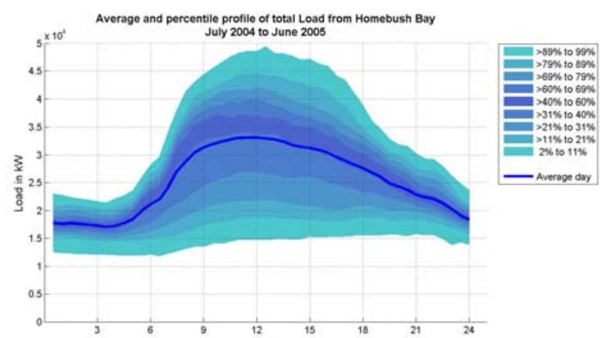


Variability in Load and in PV Output

Both PV output and load vary significantly around the average. Very high residential loads occur only for only a small percentage of time, while PV output and Homebush Bay load variability are more uniformly spread between high and low levels.

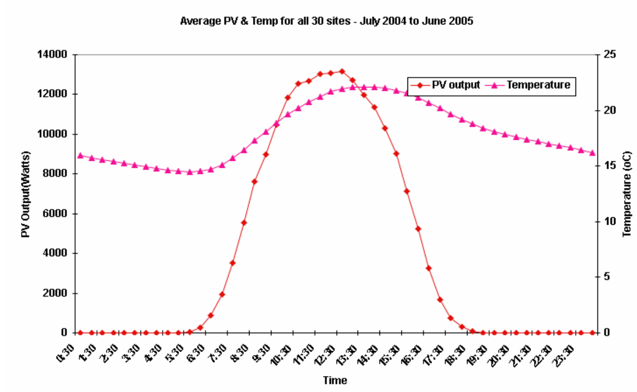






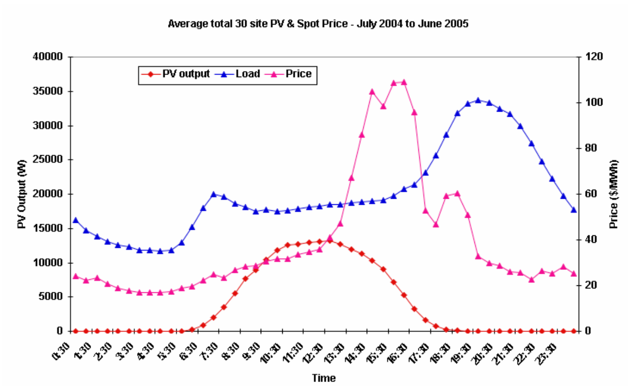
Correlations of Temperature and PV Output

As would be expected, there is a general increase in PV output with increasing temperature because of increased insolation. In general temperature peaks lag PV output peaks by a few hours. Temperature derating of PV output, caused by both PV panel and inverter deratings as temperatures rise above 25°C, is likely to be one of the main loss factors occurring in the Newington PV systems. Although efforts have been made to allow air flow behind the PV panels to reduce temperatures, roof temperatures in Sydney are often 20°C or more above ambient while some of the inverters are installed on west facing walls, which would receive the worst of the summer afternoon sun.



Correlations of Load and NEM Prices

There is little general correlation between either PV output or residential load and NEM spot prices, although there is an occasional coincidence of high load and high spot price.



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Introduction

As part of the planning process for the 2000 Sydney Olympics, the organisers agreed to create a “green” village and environmentally sustainable facilities. The Athletes Village was purpose-built as an energy and water efficient medium density development with a mix of free-standing homes, apartments and community facilities. It was part of the new suburb of Newington and some of the houses were used to accommodate Olympic athletes during the Games and then sold. All free-standing homes are equipped with solar power (photovoltaic or PV) systems and solar water heaters. By 2004, 780 homes had been built with 1000 Wp of PV each and 199 houses with 500Wp each. Passive solar design features, energy efficient appliances and grey water systems are also used in all homes. These were expected to reduce net energy and water requirements significantly compared to standard Sydney households. When first built, Newington was the largest solar powered suburb in the world. Around 5000 people now live in Newington, and are serviced by schools, shops and community facilities. The suburb adjoins both Bi-Centennial Park, with its extensive parklands, and Sydney Olympic Park, with its range of sporting facilities and several large PV systems, including the iconic stadium lights.

With the suburb now well established, the NSW Department of Planning monitored a selection of the homes as part of its electricity demand management activities, in order to assess the overall impact of the sustainable energy measures used, as well as the effectiveness of the PV systems in minimising peak loads on the grid. A complementary study is currently being undertaken to assess the wider implications of customer knowledge and interest in their sustainable homes.

For this study, data on electricity use and PV output were collected from 30 homes over 12 months from the beginning of July 2004 through to the end of June 2005. The data consists of half hourly PV output, with import and export of electricity from the grid measured separately. This allows assessment of the overall impacts of urban-scale use of PV on the network, detailed examination of the variability between different houses, together with any correlation between PV output and load.

For this analysis, the household load and PV profiles were examined against half hourly loads at the local Homebush Bay zone substation and on the National Electricity Market (NEM), as well as compared to NEM prices and ambient temperatures in the Sydney Olympic Park (Homebush Bay) area.

Figure 1 The Newington Roofline
Photo courtesy BP Solar

Photovoltaic System Operation and Performance

Photovoltaic (PV) panels convert solar radiation into dc electricity. PV panels are rated at insolation levels of 1000 W/m^2 at 25 degrees Centigrade. Hence a 1 kWp PV panel would expect to generate 1 kW of dc electricity under these reference conditions. Output is below this level if insolation levels are lower or temperatures are higher. For maximum exposure to incoming solar radiation over the year, fixed PV panels in Australia are faced North, at an angle equal to the latitude angle. Sydney's latitude is 34°S, so the optimal orientation is 34°N. However, roof angles are typically 20-25°, so that panels placed flush with the roof would have slightly higher summer output and lower winter output than they would at 34°N.

Commercial PV panels range in efficiency from 5 to 20%, depending on the PV technology used. The PV panels at Newington which were monitored for this project are made from crystalline Silicon and have efficiencies of around 15%. This efficiency drops by about 0.5% for each degree above 25°. Since roof temperatures are often 20 to 30 degrees above ambient temperature, the efficiency of PV systems at Newington on a 35° summer day could be reduced by 15-20%, that is, the panel efficiency would be 12%. For this reason, it is important to allow as much ventilation behind the panels as possible.

There are other losses in the system which must also be taken into account. PV panels are connected together to form arrays. For grid connected systems, such as those in Newington, the arrays are connected to an inverter that converts the dc solar electricity into 240 V ac, so that it is compatible with grid electricity. Inverter efficiencies are 85-95%. Losses will also occur through the wiring, if any dust accumulates on the panels or if any part of the array is shaded.

A useful measure of PV system performance is the Performance Ratio (PR). The PR is calculated by dividing the actual PV system output over a year by the expected output of the PV panel under those same insolation conditions. The PR therefore reflects the total system losses from all the factors described above. An International Energy Agency study of 339 grid connected PV systems around the world over 1200 operational years found the average PR to be 0.684 (IEA-PVPS Task 2, 2004). The same report found that for systems built after 1996, the PR was 0.70, reflecting slight improvements in system design and component efficiencies.

It should be noted that monitored data itself can add another layer of data uncertainty and error. The monitoring equipment may have errors or have incorrect settings. There may be time lags in data sets, for instance, PV systems which were installed in summer may have their clocks set at daylight saving time, which would cause data lags against the electricity meter and other variables.

As for any appliance or energy supply system, PV systems benefit from routine inspection and maintenance. PV panels have very low failure rates and low maintenance requirements and in grid-connected systems failures are typically associated with the inverter or with wiring. Owners are usually provided with a simple set of system checks to perform from time to time. These involve visual inspection of the panels for damage, corrosion or dust build-up and checks against the quarterly electricity bill, or the inverter meter, to ensure the system is operating. As indicated below, awareness of energy use and an interest in the PV system assist in ensuring optimal system performance.

Energy Efficient House Design and Operation

The Newington homes were all designed for maximum energy efficiency, using passive solar design features and energy efficient appliances. Passive solar houses aim to work with the local environment so as to reduce external energy needs. They are oriented and shaded so as to maximise solar gain in winter and minimise it in summer. They have high levels of insulation and use internal mass in floors or walls to store winter heat. Nevertheless, minimising energy usage in energy efficient homes requires the active participation of the occupants. For instance, energy aware householders who purchase solar water heaters, may turn their boosters on only when required and turn them off over Summer. Similarly, taking maximum advantage of passive solar design features requires appropriate opening and closing of blinds and curtains, and of doors and windows for ventilation. Householders who make a conscious decision to purchase PV systems, which typically involves an investment of $5000 or more, may be expected to keep a keen eye on their energy bills and on the system output. A Danish study of households which purchased PV systems found that their energy use decreased, based on an increased energy awareness resulting from their purchase decision (IEA-PVPS, 2004).

The Olympic Village was designed and marketed from another perspective. Although it was generally promoted as a Solar Village, the design and marketing of the Newington homes was more circumspect with regard to their energy efficiency and solar features. The solar arrays, although not totally hidden, were generally roof integrated and placed discretely so as not to be too visible from the street. The homes were purposely marketed to the general home buyer, not to the 'energy aware' or 'green' customer market. It is not possible at this stage to assess what level of information or guidance was provided to home purchasers regarding the optimal use of the homes' energy features. The social survey being undertaken in parallel with this study may provide some relevant information in that regard. Nevertheless, it should be noted that the energy features were part of a total home package and purchasers may not necessarily have been especially interested in them. This has ramifications for the energy usage patterns and PV performance emerging through this study.

Methodology

The Newington Solar Systems

All 979 free-standing houses in Newington include PV systems. The majority of these (780 homes) have a $9m^2$, nominal 1 kWp PV array comprising 12 BP Solar 80-85 Wp laminates (unframed PV panels). The remainder have either $4.5m^2$, 0.5 kWp arrays comprising 6 BP Solar 75-80 Wp laminates or a $4.3m^2$, 0.5 kWp PVSolar Tile system comprising 3 x 160 Wp monocrystalline Suntech panels. In the BP Solar systems, the laminates are fitted into a weather-proof metal tray which in turn is recessed into the roof so that the PV array lies flush with the roof surface. For the 76 homes with a PVSolar Tile system, the PV laminate tiles are placed onto a frame with inbuilt ventilation using PV AIRFLOW metal roof battens and openings at the top of the sarking into the ventilated roof space. Thus the architectural aesthetics and the integrity of the roof are maintained, while providing a secure PV fixture and also allowing air circulation around the laminates to facilitate cooling.

Each 1 kW PV array is connected to the household power supply via a 0.85 kW grid-interactive inverter. This inverter size was selected because some temperature derating of the PV panels was expected. Here it is assumed the inverters for smaller systems were similarly undersized, although this may not be the case. The inverter size limit may contribute to some output restriction during periods of peak solar radiation. Household load is supplied via the inverter, with any PV electricity excess of the load being exported to the grid and any shortfall imported as needed. The PV arrays face generally between North East to North West. The 30 systems examined in this report are all nominally 1 kWp and faced predominantly North – North - West.

Newington was designed to ensure all homes had approximately north facing solar access and could thus take advantage of passive solar design features which maximise the use of natural light, solar gain in winter and shading in summer. In addition, high levels of insulation were used, along with energy efficient appliances and gas for space heating, cooking and solar water heater boosting. The intent was to create homes which would require minimum use of heaters and no air conditioners. With these features, it was anticipated that the homes would use around 7.5 kWh per day of electricity, up to half of which would be supplied by the (larger) PV system. The monitored data, however, indicates that electricity usage has been significantly higher than this. This may reflect the significant uptake of computers, entertainment systems and other electrical appliances over the past decade across the community generally, as well as a low level of understanding of the energy efficient features of the homes and how best to take advantage of them. Despite gas being available, reverse cycle air conditioners appear to have been retrofitted in some homes, leading to high electricity use during periods of temperature extremes in both summer and winter, as shown in Figure 3 and Figure 46.

Monitoring

On the electricity network, Newington is supplied via the Homebush Bay Zone substation. This substation also supplies the Olympic Park site and a number of industrial customers. 30 homes, each with a 1kW PV system, located on two separate electricity feeders were monitored for this study. A total of over 1 MW of PV is installed at the Homebush Bay site, including the home systems, the stadium lights, the Superdome roof and several water pumps.

Figure 2 is a schematic of the electrical connection and monitoring points for the 30 monitored homes. AC electricity supplied from the inverter and grid electricity used by the household were monitored at half hourly intervals for 12 months from July 2004 to June 2005. Household load was calculated as 'Grid electricity imports – PV export + PV output' for any given half hour period. This allowed analysis of PV contribution to the load of each house.

In order to assess the contribution of PV to the wider network, load data for selected days was obtained from Energy Australia for the Homebush Bay substation. In addition, half hourly load data from the NSW node of the NEM was used to assess PV contribution on a State-wide level.

Half hourly temperature data was obtained from the Bureau of Meteorology for Sydney Olympic Park in order to assess temperature impacts on load.

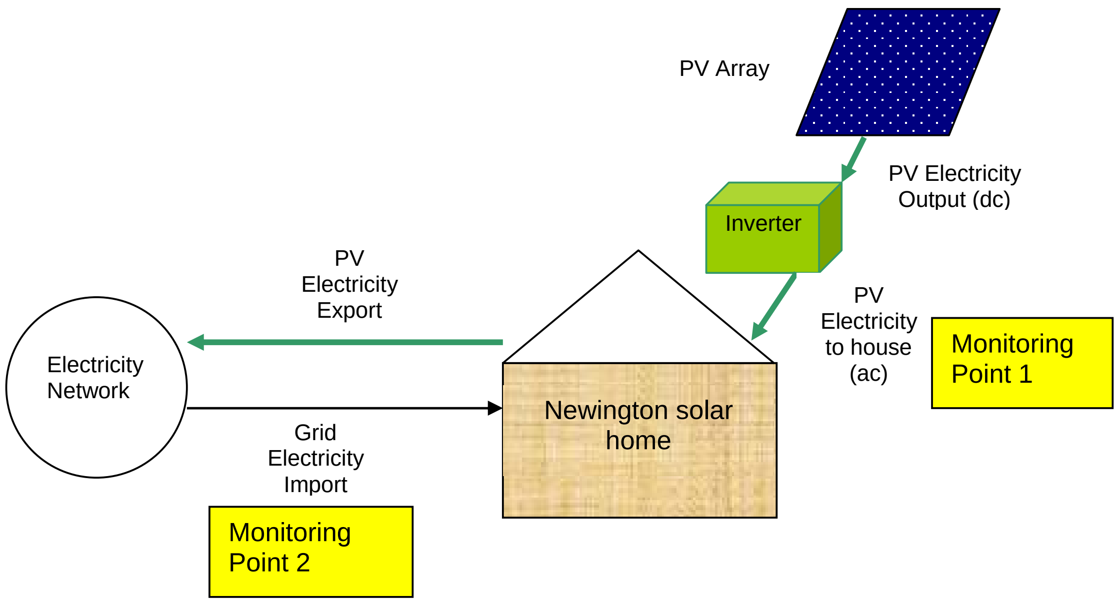

Figure 2 **Layout and monitoring points for the Newington solar home systems**

Results

Average Residential Load and PV Output

Over the period July 2004 to June 2005 the 30 houses studied had an average daily electricity consumption of 16.12 kWh per house, which is significantly higher than the anticipated 7.5 kWh. The average daily PV output per house was 3.16 kWh, or 19.6% of consumption. Total PV output from the 30 sites over the year was 34,560 kWh. Two of the PV systems were found to be malfunctioning. One system was not operational and the other had an output maximum of only 30 W.

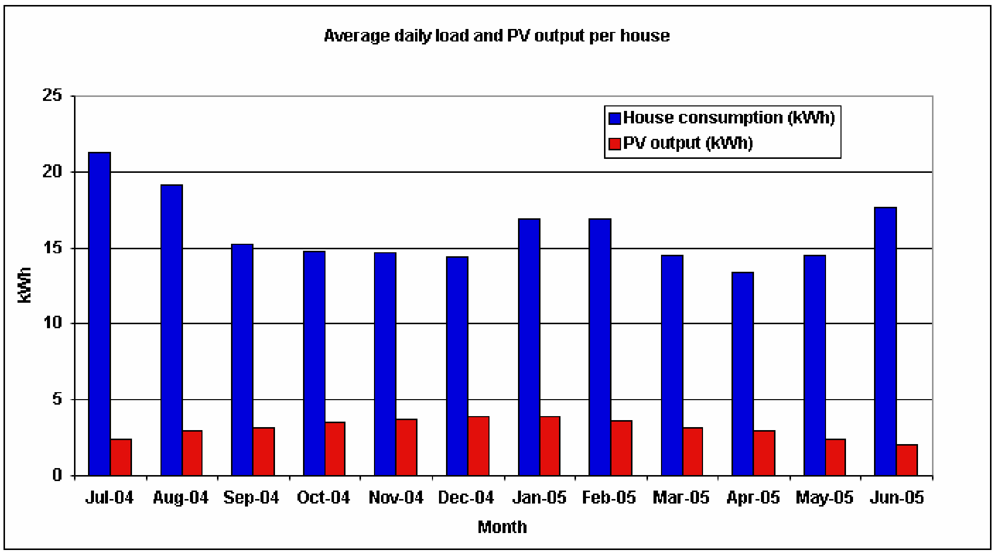

Figure 3 Average daily load and PV output per house – July 2004 to June 2005

Figure 3 shows the average daily load and PV output per house. The load is highest in the winter months, presumably due to heating needs, and possibly also because people tend to stay indoors more in winter and so appliance and lighting use increase. Electricity use also increases in January and February, presumably due to air conditioner use. PV output follows a smooth curve, being highest in the summer months and lowest in the winter months, as expected.

The highest average PV output in any half hour period from all 30 sites over the whole year was just over 13 kW, and occurred between 12:30 pm and 1:00 pm. In the summer months the average for this time was 15 kW, dropping to 12 kW in winter. The annual average solar radiation in Sydney at a tilt angle of 25 degrees is 5.2 kWh/m^2 per day (Lee et al, 1995). The average daily output of 3.16 kWh thus means the 30 Newington systems have a Performance Ratio (PR) of 0.61. If the two non-functional systems (see below) are removed from the data, the remaining 28 systems have a PR of 0.65. Hence the Newington systems are performing slightly under the normal range. The reasons for the lower output of the total system, compared with the nominal rating of the PV panels, include, inverter efficiency, temperature derating of both the PV and the inverter, wiring losses, non-optimal orientation, shading (although no obvious shading was apparent), dust build-up and system malfunction (see below). In the Newington systems, the inverters are rated at 0.85 kW max, which may limit some peak production, although only one system exceeded 0.85 kW over the monitored year. Insolation levels for the monitored year were not compared to the long term average for the area to see whether or not they were typical. Hence long term average performance may vary from the figures reported here.

One site (number 11) had no PV output data, although it did register a load. Site 13 had a normal PV profile but with a maximum output limited to 30W. Site 7 very occasionally registered a small (up to 200W) brief negative load. All three of these errors may have been due to metering problems, and the first two may have been due to a malfunction of the PV system or inverter. Here we have assumed the first two are due to problems with the PV system or inverter, and that the 30 sites are indicative of the full 980 PV homes in Newington since faults of various kinds can always be expected to occur. The site 7 fault is unlikely to have any material effect and so has been ignored.

It is not known how long these PV systems have been malfunctioning, nor whether or not the homeowner is aware of the problems, or has sought repairs. The social survey currently underway may provide some feedback as to customer understanding and awareness of their PV system and its performance, as well as of the level, if any, of routine PV system checks undertaken either by the customer, the electricity utility or the system supplier. It may also ascertain what level of initial advice was provided to home purchasers with regard to PV system inspection and maintenance procedures or what contacts are available to them for repairs. It is also not known what level of information is provided to customers on their electricity bills regarding PV exports. The faults in the two non-operational PV systems may be very simple to fix.

Daily Profile of PV Output and Residential & Commercial Loads

Annual Profile for all 30 Sites, the Homebush Bay substation and NSW

The annual average profile of total PV output, load and PV offset for all 30 sites from July 2004 to June 2005 is shown in Figure 4. The PV average maximum contribution occurs between 10:00am and 2:00pm, whereas the average load peaks between 6:00pm and 10:00pm. Thus PV makes the Newington residential peaks, as seen by the network, even more distinct.

Information regarding how many of the 30 houses had air conditioners during the time data were collected is not available. However, since the Newington homes are all well insulated and include passive design features, the overall air conditioning load for the suburb is likely to be lower than the Sydney average for new suburbs – both because fewer air conditioning units are in place and because they would be used less.

Newington is serviced by the Homebush Bay substation, which has a large industrial and commercial load and a corresponding peak load between 11am and 2pm, which allows PV to align well to overall network load. Figure 5 shows the average load at the Homebush Bay substation and the average estimated PV output for July 2004 to June 2005. The 30 sites were assumed to be representative of the total Olympic site PV.[1] To make the contribution by PV to offsetting the total Homebush Bay load more obvious on the graph, the estimated Olympic site PV output was multiplied by 10 in Figure 6.

Figure 7 shows the correlation between PV output and the NSW load – where the estimated Olympic site PV output has been multiplied by 1000 to make it 'noticeable' by the load. Although again the load peak occurs later in the day (around 6pm), demand during times of PV output is greater than for residential loads alone, with the result that PV can reduce the secondary system peak, which is around 10am.

Figure 8 compares the weekend and weekday 30 site load and PV output. Figure 9 shows the weekend and weekday 30 site load after it is offset due to PV output ie. the net load supplied by the grid. Compared to the weekend load, the weekday load peaks around breakfast time, is slightly lower during the day, then has a slightly higher peak in the evening.

[1] This may not be strictly true since the Olympic Park site PV systems may have more optimal orientation and ventilation and, being larger, may also have more efficient inverters. Note also that the total PV output across the Homebush Bay area would be more diverse than that from the 30 monitored sites and so would be smoother.

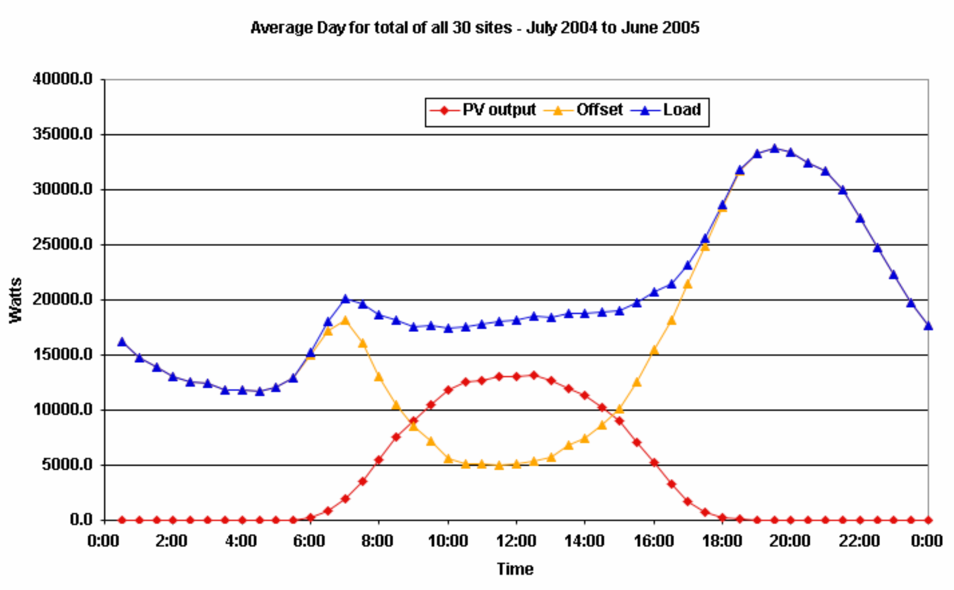

Figure 4 Annual average daily load, PV output and residual load (offset) for the total 30 monitored Newington home sites – July 2004 to June 2005

The PV (red line) average maximum contribution occurs between 10:00am and 2:00pm, whereas the average load (blue line) peaks between 6:00pm and 10:00pm. Thus PV makes the Newington residential peaks, as seen by the network (orange line), even more distinct.

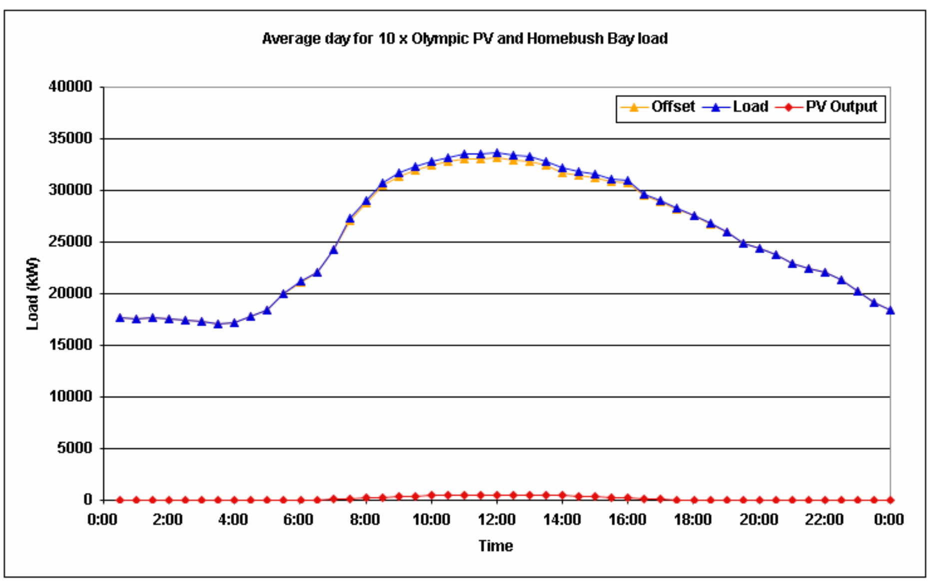

Figure 5 Annual average daily load, estimated PV output and residual load (offset) for Homebush Bay – July 2004 to June 2005

Figure 5 shows the annual average daily load at the Homebush Bay substation and the estimated annual average PV output. The 30 monitored home sites were assumed to be representative of the total Olympic site PV (1.154 MW) and so their output was multiplied by 1154/30 to estimate the total Olympic site PV output. The Homebush Bay load was then obtained by adding the PV output to the measured substation load. The substation has large industrial and commercial loads and a corresponding peak load between 11am and 2pm, which allows PV output to align well to overall substation load.

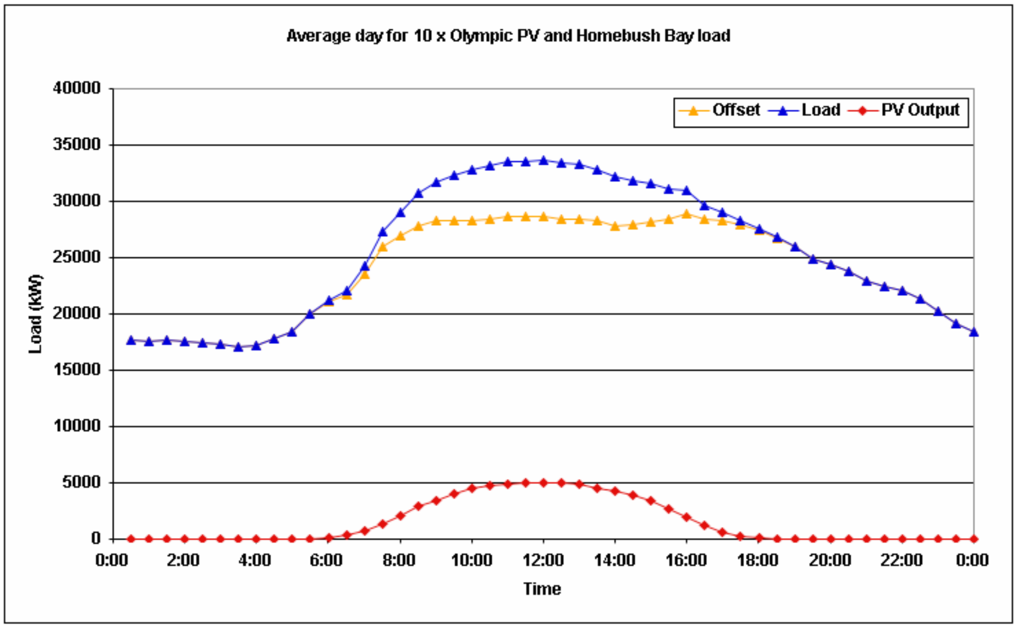

Figure 6 **Annual average daily Homebush Bay load and estimated PV contribution if 10x current PV were installed – July 2004 to June 2005**

Note the significant peak load reduction potential of PV at the Homebush Bay substation.

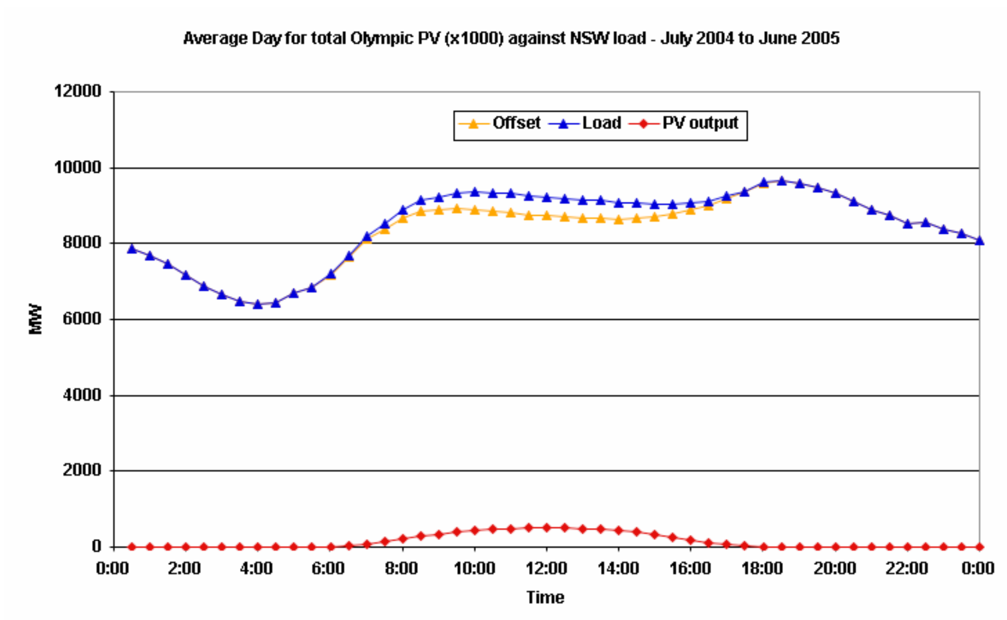

Figure 7 **Annual average daily PV output at Homebush Bay (x1000) against NSW load – July 2004 to June 2005**

Figure 7 shows the correlation between PV output and the NSW load – where the estimated PV output from all of Olympic Park and Newington has been multiplied by 1000 to make it 'noticeable' by the load. Although again the load peak occurs later in the day (around 6pm), the State load is a mix of residential, commercial and industrial loads and so demand during times of PV output is greater than for residential loads alone, with the result that PV can reduce the secondary system peak, which is around 10am.

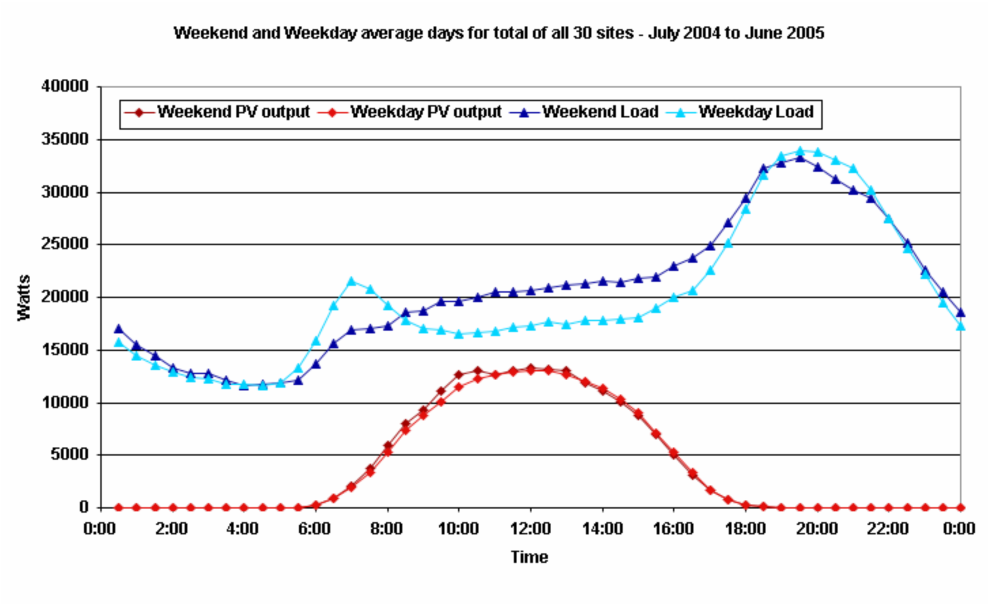

Figure 8 **Weekend and weekday average annual daily PV output and load for the total 30 monitored sites - July 2004 to June 2005**

Compared to the weekend load (dark blue), the weekday load (light blue) peaks around breakfast time, is slightly lower during the day, then has a slightly higher peak in the evening. Weekend PV output (maroon) is slightly higher than weekday output (red) around 9:00am to 11:00am. This could be a statistical aberration, because of the relatively few data points, or an indication of lower levels of air pollution on weekends due to lower levels of traffic and industrial air pollution.

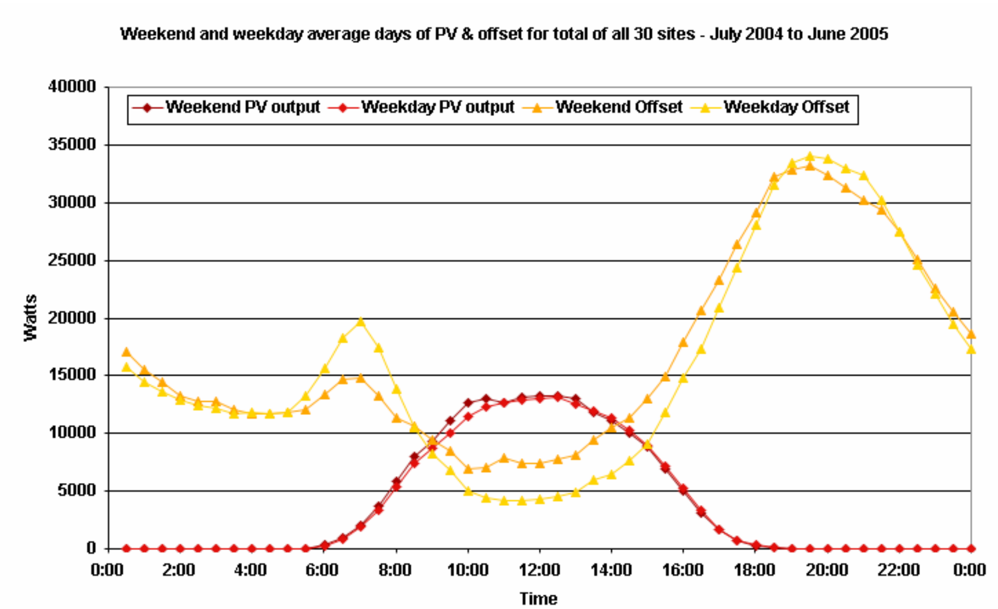

Figure 9 **Net annual average daily weekend and weekday household load and PV output for the total 30 sites - July 2004 to June 2005**

The net load is that seen by the feeder and substation after the households have used whatever PV output is available to meet their loads at the time.

Seasonal Profiles for all 30 Sites

The graphs of load, PV output and offset for the total of all 30 sites averaged for each season are given in Figure 10 to Figure 13. The average monthly profiles of the total for all 30 sites, including weekday and weekend averages, are shown in Appendix A. The equivalent average seasonal graphs are in Appendix B.

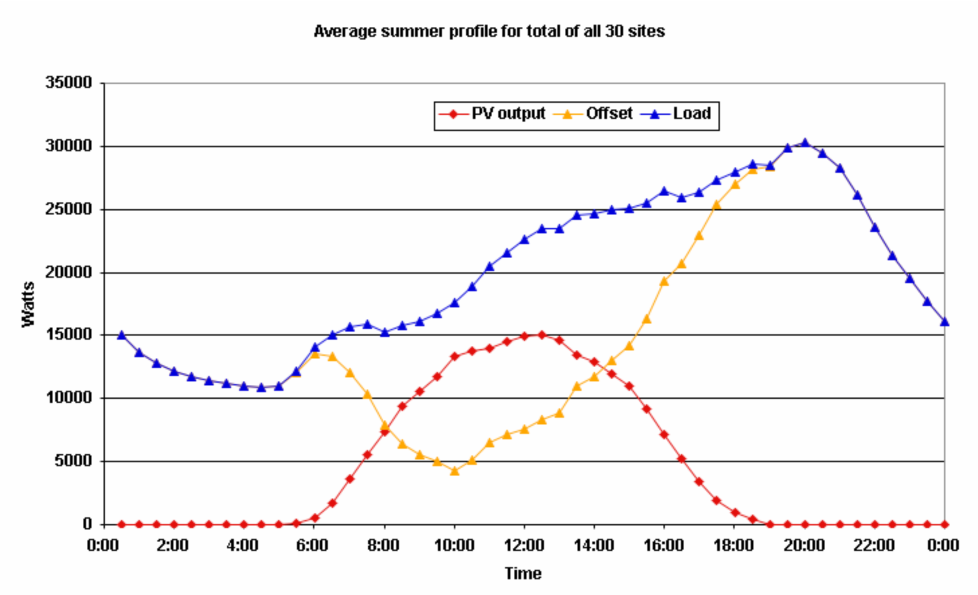

Figure 10 Average daily Summer load and PV output for total of all 30 Sites

Note that the daytime load is significantly reduced by PV, but the afternoon peak, which is around 8pm, is too late in the day for PV to contribute.

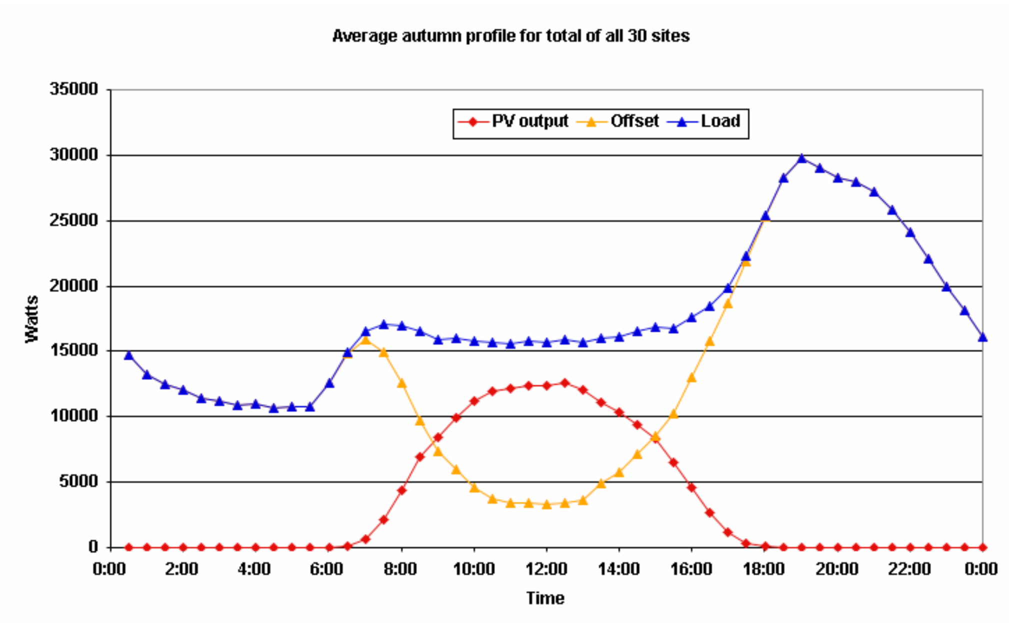

Figure 11 Average daily Autumn load and PV output for total of all 30 Sites

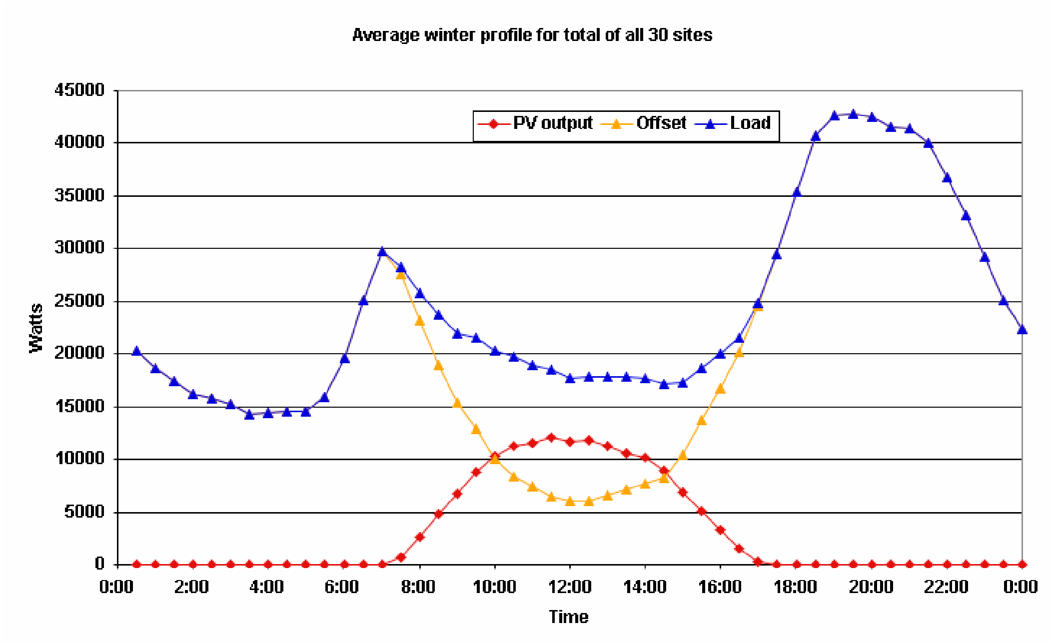

Figure 12 Average Winter Profile for total of all 30 Sites

Note that the annual peak load for these Newington homes is in Winter, with both the morning and the evening peaks outside the range of solar availability.

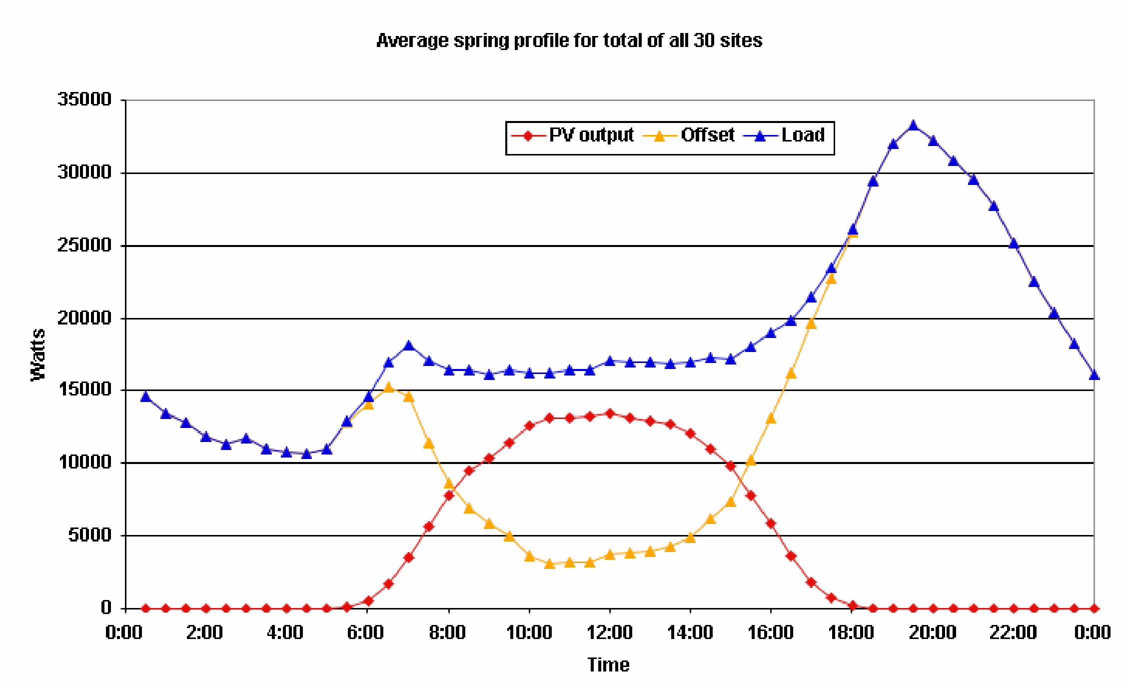

Figure 13 Average daily Spring load and PV output for total of all 30 Sites

The main differences between the monthly profiles are described below. Note that all time is in Eastern Standard time and times are not changed to account for daylight saving.

i) **Morning demand peak** (6:00am to 8:00am): The morning demand is highest in the winter months (~35kW) as people turn on their heaters and appliances when they get up. Although the weekday peak is higher (in all months except May), the weekend winter peak is still significant at ~25kW. The morning peak is lowest from Oct through to Jan and in April, all at ~15kW. In both Feb and March it is slightly higher than average, possibly because of early cooling needs, plus higher cycling of refrigerators and freezers.

ii) **Midday demand peak**: In no month is there a midday demand peak as such. In the summer months the 12:00 midday average demand is 20 to 25kW, however demand continues increasing from that time until the evening peak. The 12:00 midday demand is lowest in spring and autumn, dropping to an average around 15 to 17kW. PV output is also greatest at around 12:00 midday, reaching an annual average peak of around 15kW during Nov through to Feb, and a winter peak of around 10kW in June/July. Although in all months the midday demand is lowest during weekdays, in some months this is much more pronounced: July, Aug, Sept were presumably because of higher weekend heating needs; and Nov, Feb and April may have been because of weekend cooling needs – Nov and April were unusually hot and people were more likely to be at home during Dec and Jan. The resultant midday demand seen by the grid (after being offset by PV) is lowest in April at an average less than 1kW, much lower than the demand at 4:00am which in that month was an average ~10kW. The August weekday offset also resulted in very low resultant midday demand at ~ 1kW. The resultant average midday demand seen by the grid was highest in Feb at just under 10kW, due to a combination of both high demand and possible temperature derating of the PV.

iii) **Evening demand peak** (6:00pm to 10:00pm): The evening demand is greatest in the winter months reaching ~50 kW in July, presumably due to space heating. The summer peak is in February at ~35 kW, presumably due to residual air conditioning load. This evening peak is by far the greatest load across all months and is only marginally offset by PV in the summer months. The PV contribution to the winter evening peak would be zero, even if the PV were oriented directly to the west, which would delay the PV peak output to around 3:00pm. For the summer peak, westerly orientation could have a small impact on reducing the early peak demand, since it would be possible to capture more of the late afternoon sunlight (see Figure 14). The overall evening peak is similar for weekends and weekdays, although it has a slight tendency to be higher on weekdays – possibly because of cooling, heating or other needs that weren't performed during the day eg. Feb (note Sept is an exception to this).

iv) **Baseload demand** (4:00am to 5:00am): Baseload demand was constant through most months at around 10kW, although much higher at around 15kW in July and Aug (presumably because of overnight heating), and slightly higher at 11kW in the summer months (possibly because of higher overnight cooling loads - refrigerators, freezers and air conditioners, where installed). An average baseload of 12 kW would result in about 9.6kWh per house per day, which is very high and represents about 60% of the total daily consumption of 16.12 kWh per house.

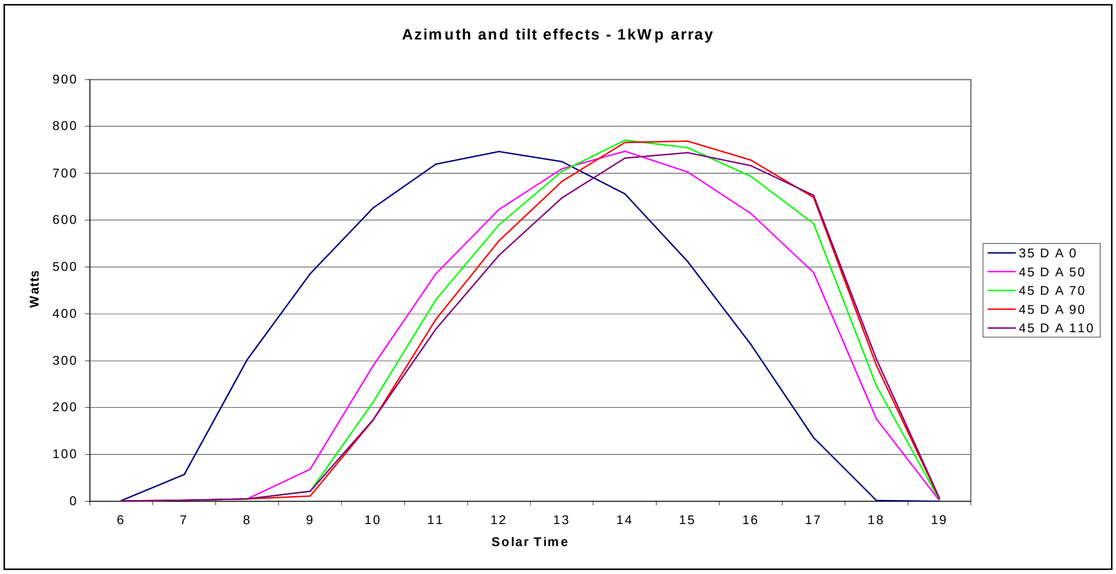

Figure 14 January Output from a 1 kW array in Sydney, with different Azimuth and tilt angles (from Watt et al, 2003)

Note that a West facing array (red line) would produce its peak output at around 3pm, compared to 12 midday for a North facing array (black line). PV output can therefore be extended further into the afternoon by about 3 hours with a West facing array, but drops off more sharply than for a North facing array.

Seasonal profiles for total Olympic Site's PV output and Homebush Bay load

The graphs of total Olympic site PV (x10), Homebush Bay load and net residual (offset) load averaged for summer and winter are given in Figure 15 and Figure 16. The summer, autumn and spring profiles have very similar shapes, while the winter profile's peak occurs earlier. Summer has the highest load peak, closely followed by autumn, then winter then spring. Although PV output is greatest in summer, the offset load would be lowest in spring and winter assuming a 10x Olympic site PV output.

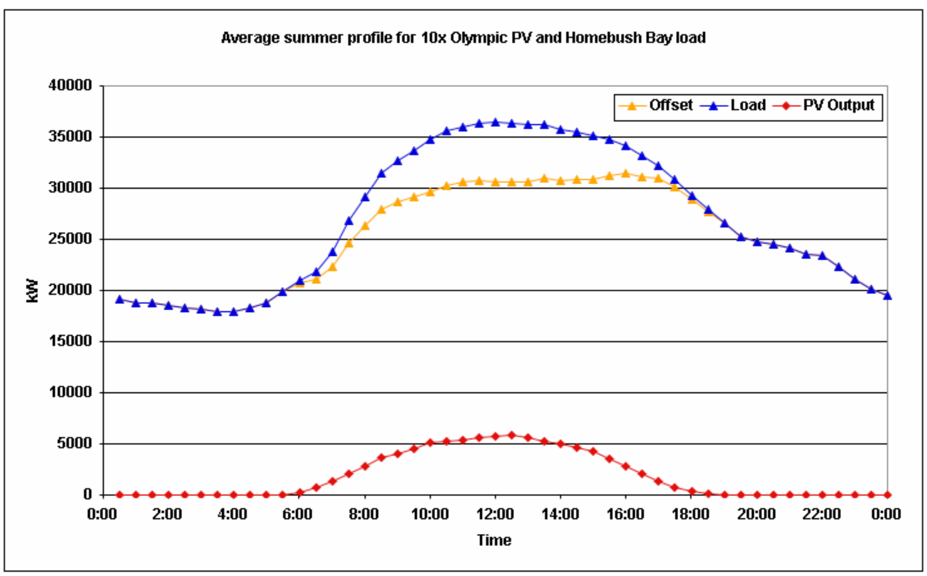

Figure 15 Average Summer Load Profile for the Homebush Bay substation with 10x the current Olympic Park installed PV capacity

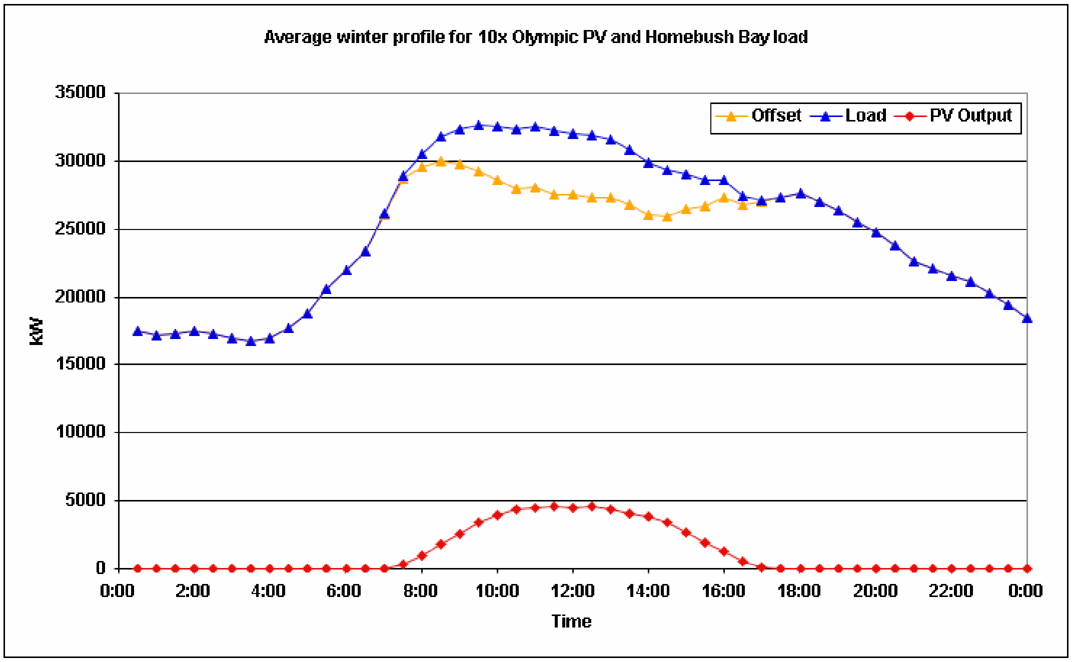

Figure 16 Average Winter Profile for the Homebush Bay substation with 10x the current Olympic Park installed PV capacity

Characteristics of times of peak demand

Newington 30 site load

The times and dates of the 20 highest demand peaks for the total load over the 30 sites are shown in Table 1. These also correspond to the 20 highest points in the load duration curve eg Figure 38 on page 39. Interestingly, only two of these highest load points occurred in the summer months – the 14th and 16th highest readings at 8:30pm on the 8th Feb and at 4:00pm on the 14th Jan respectively. All the top 10 readings occurred on three days in November and July. These three days are graphed in Figure 17, Figure 18 and Figure 19. It is interesting to note that ten of the top 20 peaks occurred on Sundays.

The 28th November peak occurred after an unusually hot day (about 38^{o}C) and so probably resulted from high cooling loads combined with the standard evening peak. The 18th and 19th of August peaks were on a Sunday and a Monday respectively, and were both cool to cold days with maxima at around 13^{o}C. The main difference between the two days is the higher morning peak and lower midday load on a weekday, as expected.

Table 1 The times of twenty highest total demand peaks for all 30 sites

Demand (watts)	Date	Day	Time
79301.2	28-Nov-04	Sun	17:00
76734.5	18-July-04	Sun	19:00
75385.4	18-July-04	Sun	17:30
75196.9	28-Nov-04	Sun	16:30
74002.2	28-Nov-04	Sun	17:30
73203.7	19-July-04	Mon	19:30
72885.2	28-Nov-04	Sun	16:00
71857.1	18-July-04	Sun	18:00
71487.1	18-July-04	Sun	19:30
70999.5	19-July-04	Mon	20:00
70304.4	20-July-04	Tues	20:00
68986.6	20-July-04	Tues	19:30
68793.3	26-July-04	Mon	19:00
67258.5	8-Feb-05	Tues	20:30
67123.0	30-Nov-04	Tues	20:00
66428.0	14-Jan-05	Fri	16:00
66078.5	18-July-04	Sun	17:30
66010.1	28-Nov-04	Sun	18:00
64587.8	13-Oct-04	Wed	19:00
64510.1	13-Oct-04	Wed	19:30

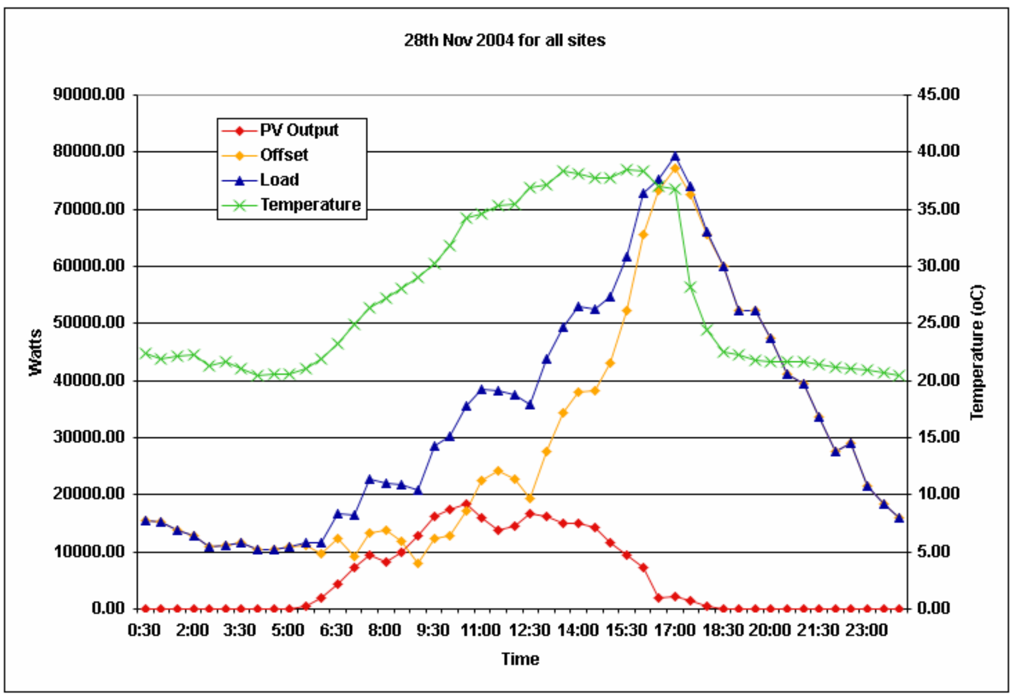

Figure 17 Total Load, PV Output, Offset and Temperature for 28th November 2004 - a peak high temperature day - for all 30 sites

Five of the top 20 peak load points occurred on Sunday 28th November 2004. There is evidence of temperature derating of the PV output. The load drops off reasonably sharply as the temperature falls.

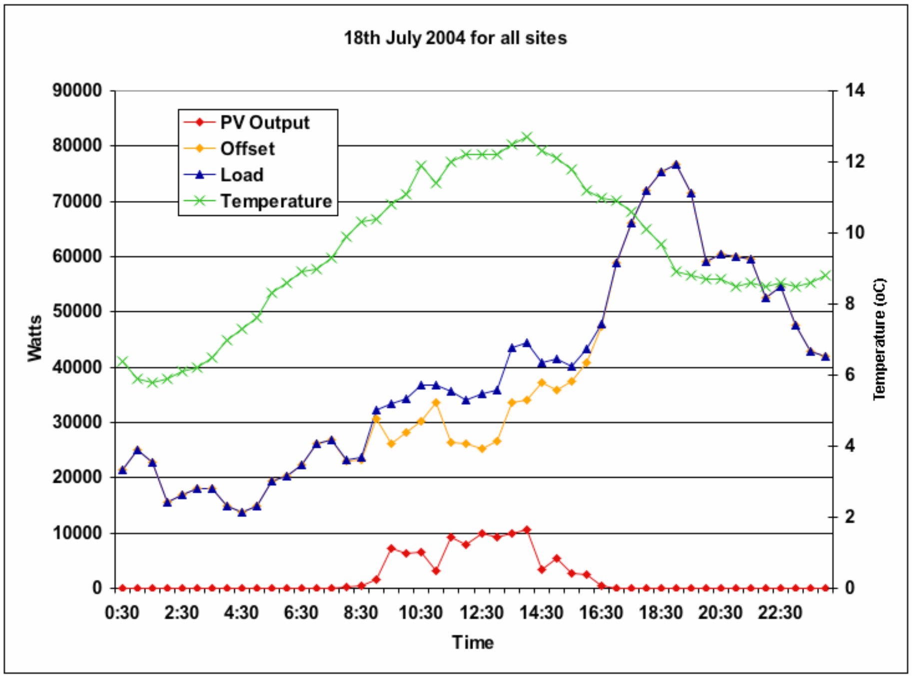

Figure 18 **Total Load, PV Output, Offset and Temperature for 18th July 2004 - a peak low temperature day - for all 30 sites**

Five of the top 20 load points occurred on Sunday 18 July 2004. The PV contribution is reasonably low and appears to be affected by cloud cover. The evening peak drops off in stages but remains high through the night.

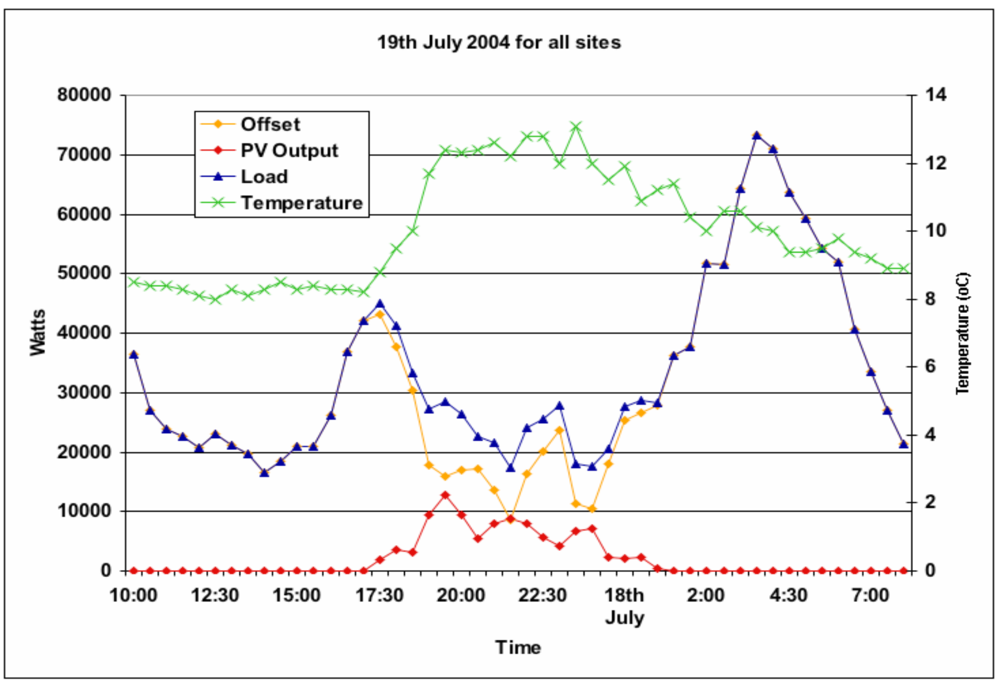

Figure 19 **Total Load, PV Output, Offset and Temperature for 19th July 2004 for all 30 sites**

Despite continued cold weather, the daytime load drops on Monday 19th July. However it rises again sharply from 3pm on.

Homebush Bay load

The times and dates of the 20 highest demand peaks for the Homebush bay substation are shown in Table 2. These also correspond to the 20 highest points in the load duration curve eg Figure 41 on page 40. All the peaks occurred during the summer months, and as expected, 19 of the 20 occurred on weekdays (one on a Sunday). Interestingly, 11 of the peaks occurred on Wednesdays and 6 were on Tuesdays (presumably due to a particular industrial process), only 1 was on a Thursday and 1 on a Friday. The daily profile of the two highest loads (10:30 on the 1st Dec and 13:30 on the 1st Feb) are graphed in Figure 20 and Figure 21.

The 1st Dec peak occurred early on an unusually hot day (on which 7 of the top 20 load peaks occurred), while the 1st Feb peak occurred in the middle of a day where the temperature reached only about 30^{o}C. Thus it is possible these peaks are associated with load unrelated to temperature – although note the 1st Dec load is maintained longer than normal, possibly due to cooling requirements.

Table 2 The times of twenty highest demand peaks at Homebush Bay substation

Demand (kilowatts)	Date	Day	Time
52,398	1-Dec-04	Wed	10:30
51,858	1-Feb-05	Tues	13:30
51,098	25-Feb-05	Fri	11:00
50,801	1-Dec-04	Wed	11:00
50,796	15-Mar-05	Tues	13:00
50,758	8-Dec-04	Wed	13:00
50,636	1-Feb-05	Tues	12:30
50,545	15-Mar-05	Tues	11:30
50,516	8-Dec-04	Wed	12:00
50,307	21-Nov-04	Sun	8:30
50,286	15-Mar-05	Tues	12:30
50,206	2-Mar-05	Wed	12:30
50,195	8-Feb-05	Tues	13:30
50,174	2-Feb-05	Wed	12:30
50,123	1-Dec-04	Wed	11:30
50,084	1-Dec-04	Wed	13:30
50,079	1-Dec-04	Wed	13:00
50,052	1-Dec-04	Wed	14:30
50,036	1-Dec-04	Wed	12:00
50,026	9-Dec-04	Thurs	13:00

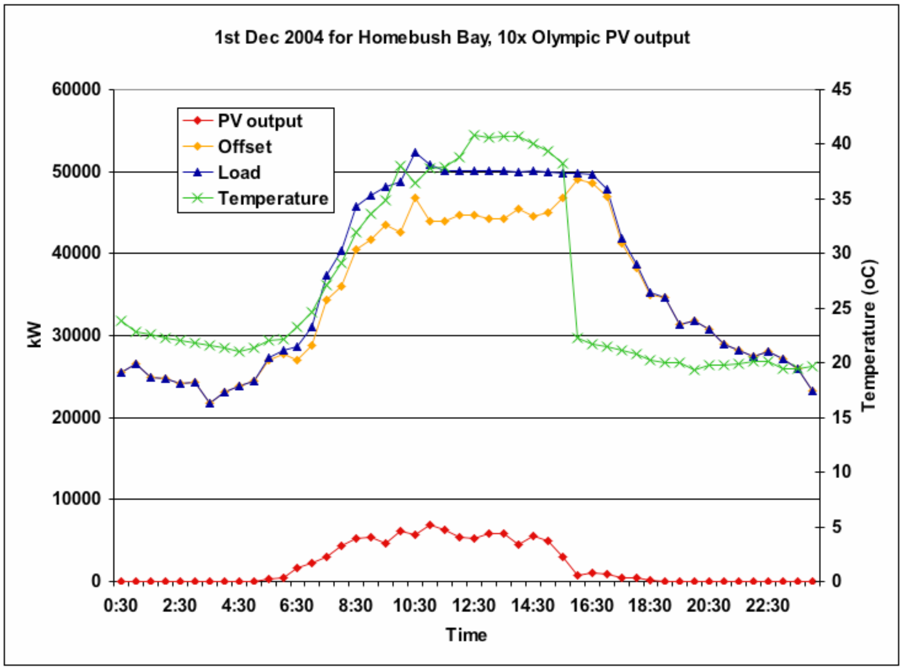

Figure 20 **Total Olympic site PV Output (x10, for visual impact), Homebush bay load, Offset and Temperature for 1st Dec 2004**

The 1st Dec peak occurred early on an unusually hot day (on which 7 of the top 20 load peaks occurred). It is possible these peaks are associated with load unrelated to temperature – although the load is maintained longer than normal, possibly due to cooling requirements. PV output is a reasonably good match to the peak load, although its contribution falls off towards the late afternoon.

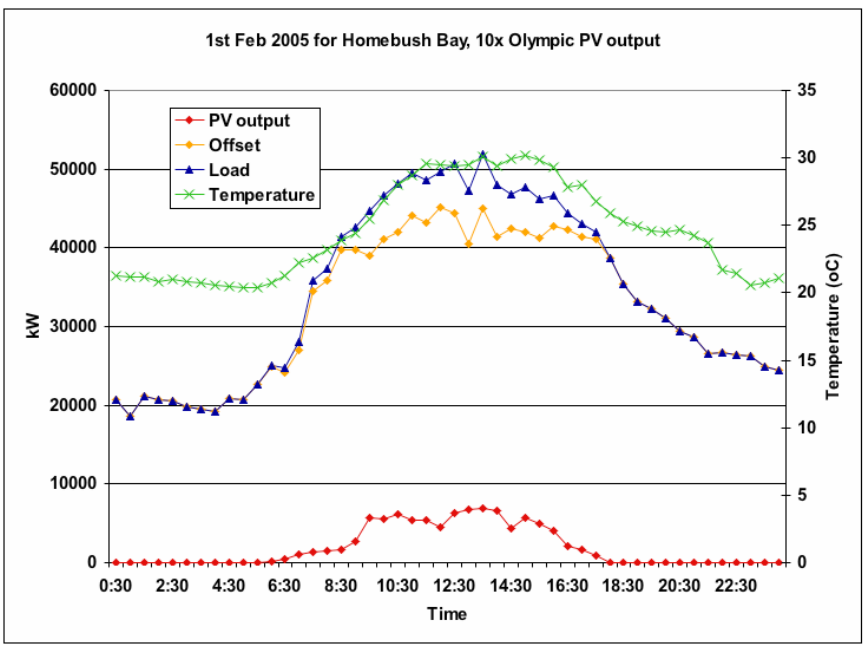

Figure 21 **Total Olympic site PV Output (x10 for visual impact), Homebush bay load, Offset and Temperature for 1st Feb 2005**

1st Feb was not especially hot, indicating that the high load is probably caused by industrial processes or other activity. PV output is a good match to the peak load.

Variability: Daily average, maximum and minimum profiles

PV Output Variability for all 30 Sites

Figure 22 shows the average daily profile for total PV output from the 30 sites for July 2004 to June 2005, together with the percentiles for likelihood of PV output (eg. '>60 to 70' means 60% of the data was lower than the lower boundary and 70% was less than the upper boundary). The equivalent seasonal profiles are in Appendix C. It is clear that over the year there was great variation in PV output, and that this variation occurred in all seasons.

In addition, for each month the maximum and minimum PV profiles that occurred on particular days have been compared to the average for that month. Because the PV maxima occur around midday, this time was used as the point of comparison. Figure 23 to Figure 25 are illustrative examples of both variable and smooth output curves. The complete set of monthly profiles is in Appendix D. PV output at midday varied considerably within all months – with for example, lows around 2-4 kW to high's around 16-20 kW, and with peaks in output next to troughs well below the average.

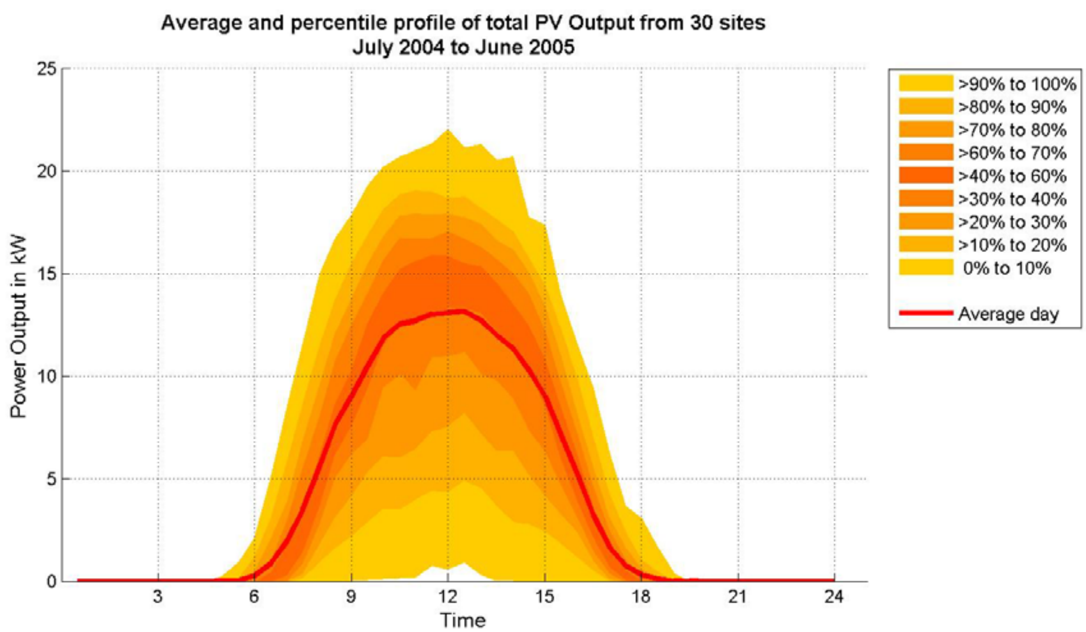

Figure 22 Average and percentile profile of total PV output from 30 sites – July 2004 to June 2005

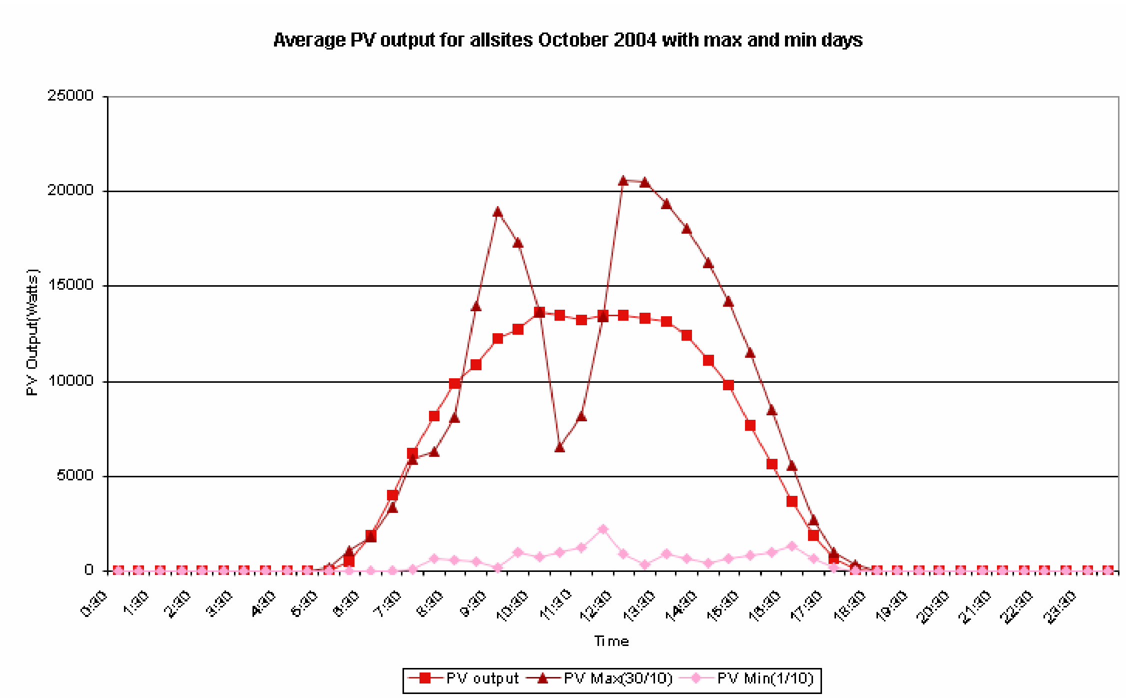

Figure 23 Profile of total PV output in October for 30 sites and also showing the maximum and minimum days

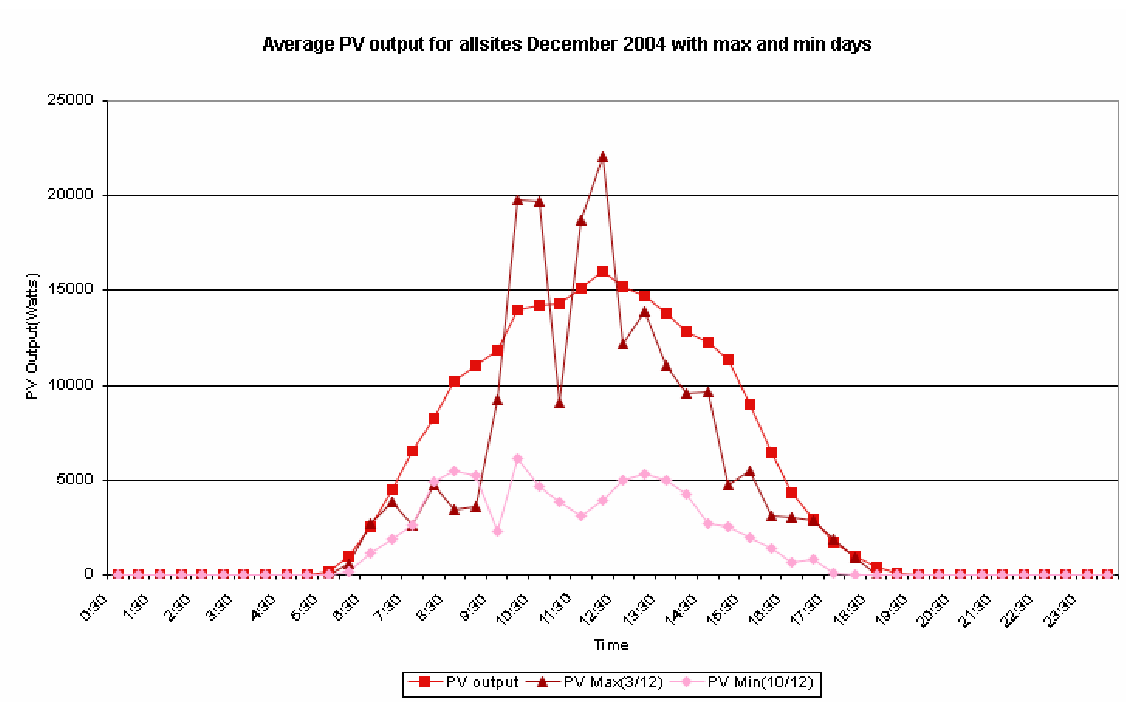

Figure 24 Profile of total PV output in December for 30 sites and also showing the maximum and minimum days

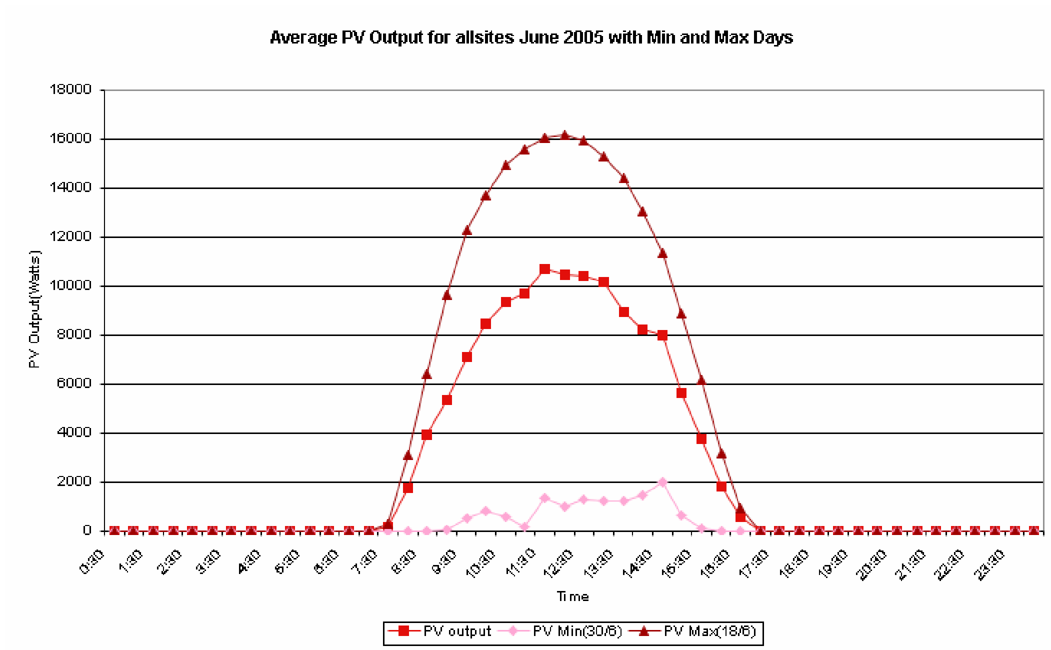

Figure 25 **Profile of total PV output in June for 30 sites and also showing the maximum and minimum days**

Load Variability for all 30 Sites

Although PV output is variable, so too is the load. Percentile charts equivalent to those for PV output were also made for the 30 site load, where the evening peak was used as the time of comparison – see Figure 26, and see Appendix E for the seasonal profiles. The most distinguishing feature of these percentile load profiles is the fact that the very high loads occur only a small percentage of the time – this is especially true for spring, which includes November and its unusually hot days.

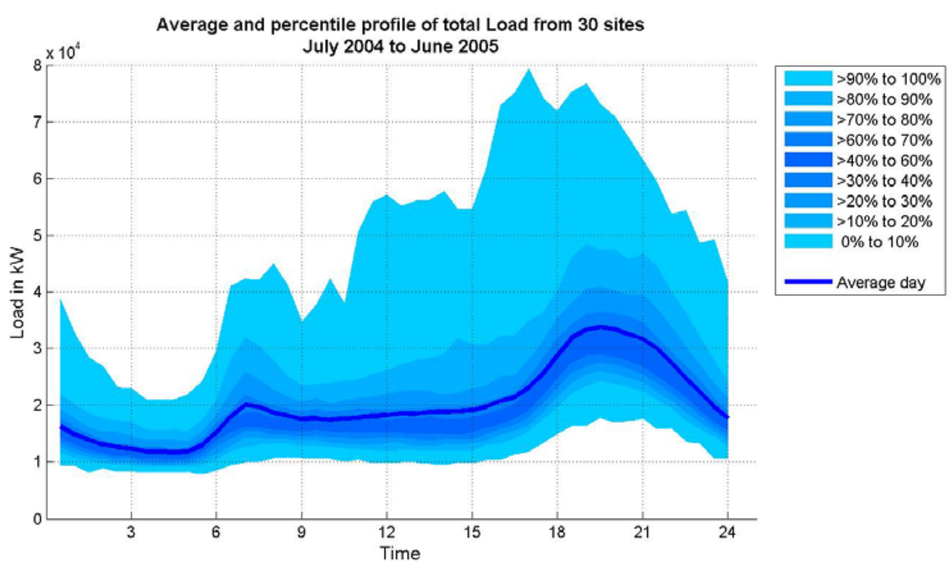

Figure 26 **Average and percentile profile of total 30 site load – July 2004 to June 2005**

Again, for each month the maximum and minimum that occurred on particular days have been compared to the average for that month. August, November and December all had very high degrees of variability during the time of peak load – see Figure 27 to Figure 29. The complete set of monthly profiles is in Appendix F. The greatest variation from the average was always an increase, which indicates the impact of discretionary loads above the base load. The August load profile shows distinct morning and evening peaks, with the maximum load around 20 MW higher than the average load during the afternoon peak and around 40 MW higher than the minimum load. In November and December the load grows steadily during the day, with an evening peak. In November, this peak is approximately 50 MW higher than the average evening peak and in December approximately 30 MW. These summer peaks are far more prolonged than the winter peaks. In contrast, the maximum loads in March and May are less than 20 MW higher than the average.

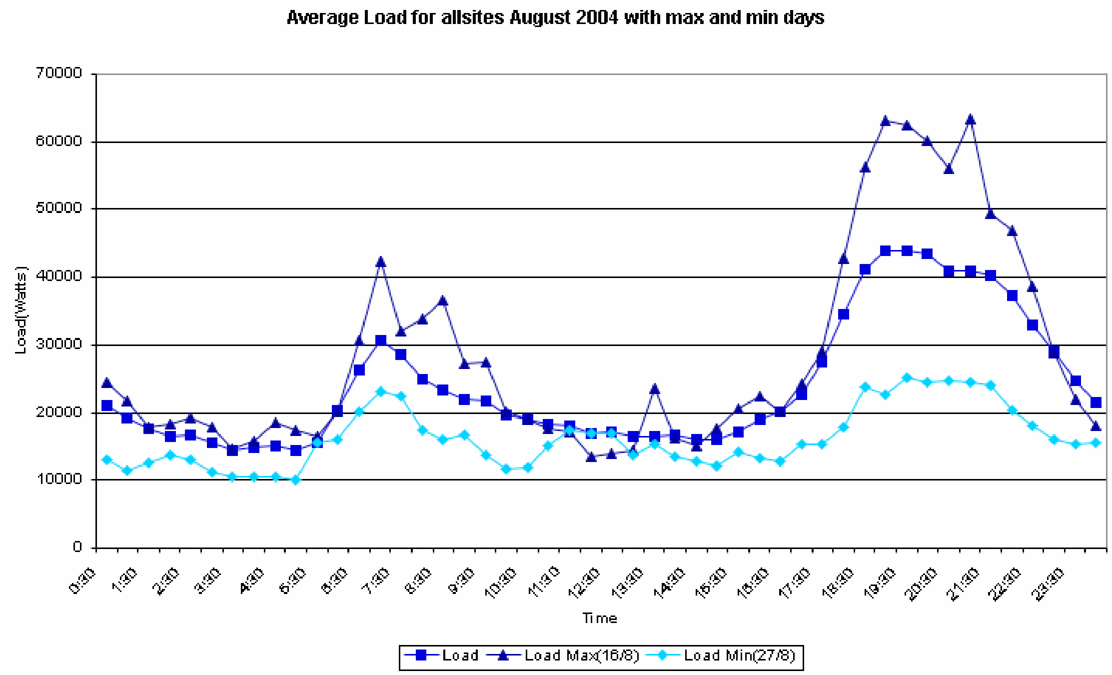

Figure 27 Average, maximum and minimum 30 site load profile – August 2004

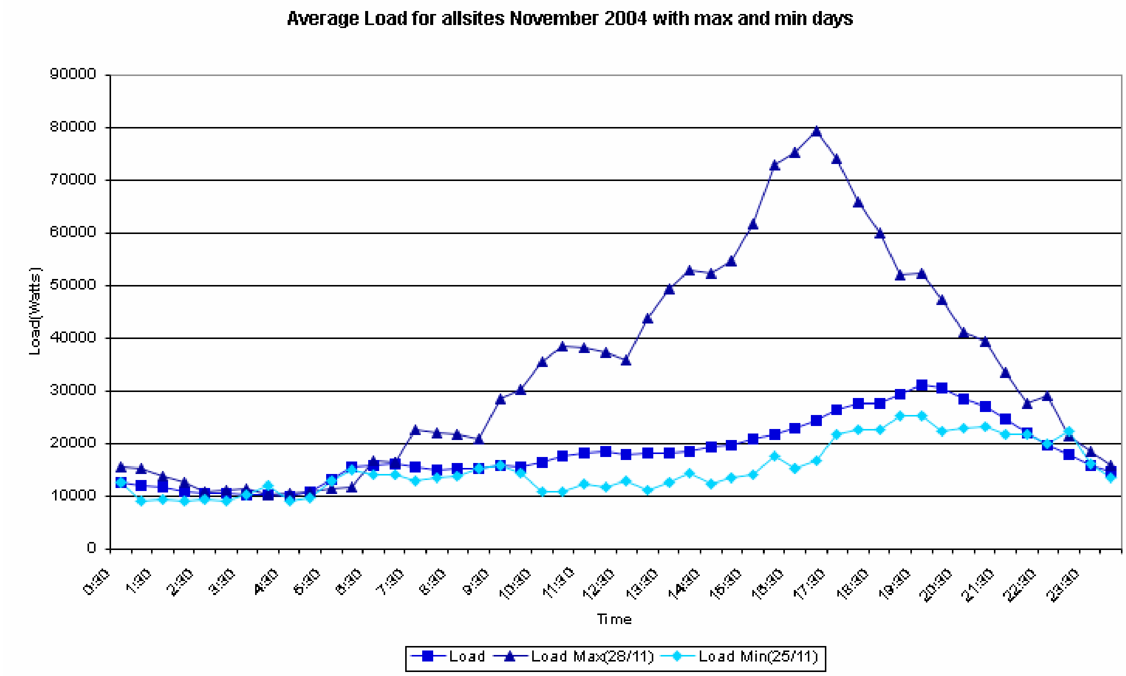

Figure 28 Average, maximum and minimum 30 site load profile – November 2004

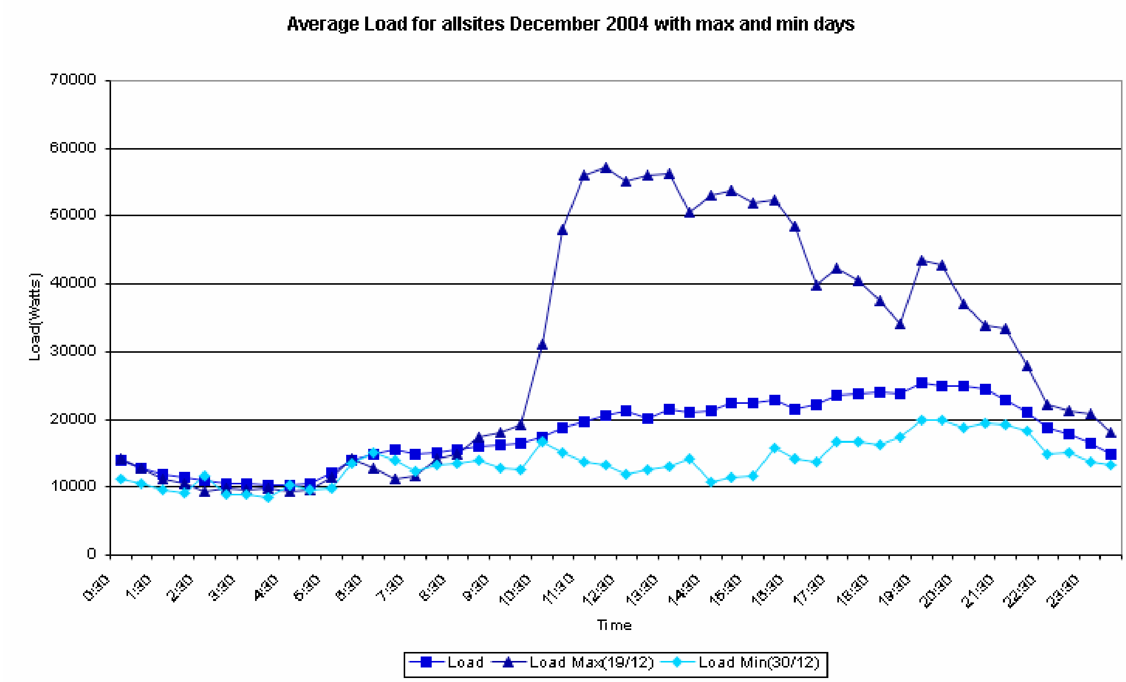

Figure 29 Average, maximum and minimum 30 site load profile – December 2004

Load Variability for Homebush Bay

Equivalent percentile charts were also made for the Homebush Bay substation load – see Figure 30 and Appendix G for the seasonal profiles. The main difference between the Homebush Bay load and the 30 site load (apart from the profile of the average), is that the Homebush Bay loads seem to be even more variable, with the percentile bands spread more evenly – this is especially true for summer.

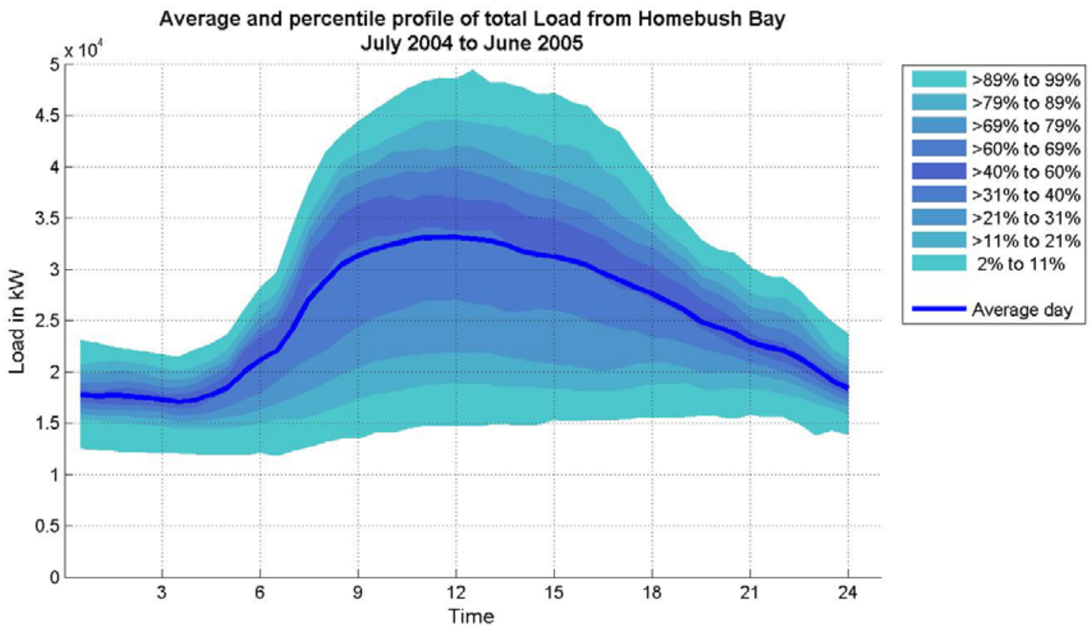

Figure 30 Average and percentile profile of Homebush Bay load – July 2004 to June 2005

Probabilistic Analysis

Figure 31 shows the relationship between PV output and the 30 site load at any one time, and shows a very low level of correlation. A high correlation would result in the data points being distributed from the bottom left to the top right of the chart. Instead, there are many times of high demand with zero PV output (reflecting the evening peaks when there is little sun), and times of high PV output and very low load (in the middle of the day when residential load is low). As a result, when the PV output is plotted against the offset load (ie. load seen by the grid), the main impact of the PV is to shift the low load points at the top of the chart to the left ie. into export to the grid – see Figure 32.

As expected from its commercial and industrial load profile, the relationship between Olympic site PV output and the Homebush Bay substation load is much more favourable (Figure 33). The data points are grouped into two distinct clusters, most probably because the Homebush Bay baseload is around 20 MW, the daytime load is around 30 to 40 MW, while in the intervening periods the load is changing relatively rapidly from one to the other. With 1.154 MWp of PV in the Homebush Bay network, a very useful contribution is being made at the substation level, even if the PV output is not ideally matched to the load of the Newington home occupants.

When the PV output for the entire Olympic site is multiplied by 10 to make its contribution more obvious, and plotted against the Homebush Bay offset load, the PV shifts the high load points at the top of the chart to the left – see Figure 34. This is consistent with the load duration curves (Figure 39 to Figure 42 on pages 39 to 41) which show a significant drop due to the Olympic site PV. The points at the bottom right of the chart (high load, lower PV), which are the highest load points in the offset chart in Figure 34, correspond to 16:00 and 16:30 on Wed 1st Dec 2004, and 14:30 on Wed 2nd Feb 2005, and are the 26th, 32nd and 50th highest load points respectively. Refer to Figure 20 for the daily load profile of Wed 1st Dec 2004 where it can be seen that two of these load points occur where the load is maintained longer than usual, combined with a sudden drop in PV output – probably due to a thick cloud judging by the sudden temperature drop.

The relationship between PV output and the NSW load is slightly better than the 30 site load but not as good as the Homebush Bay load (Figure 35).

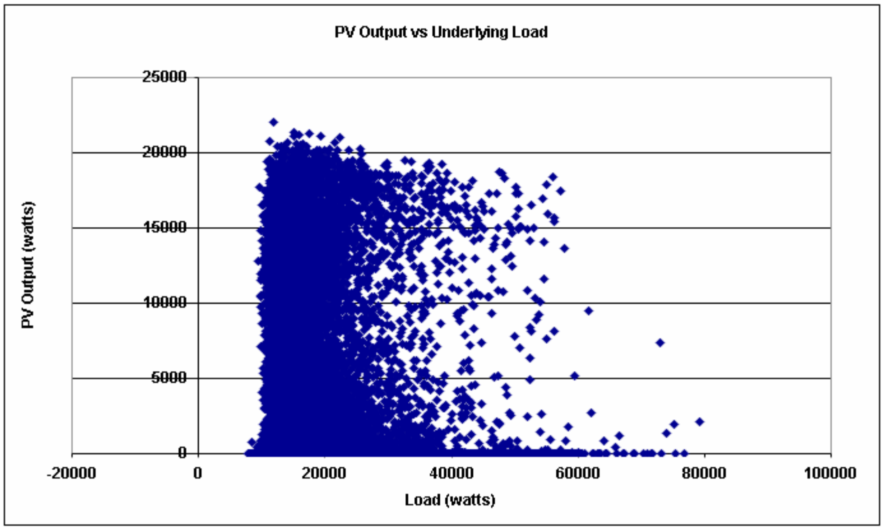

Figure 31 Relationship between PV output and 30 site load

This graph illustrates the relatively low correlation between PV output and household load at Newington, with PV output clustered towards the low load periods.

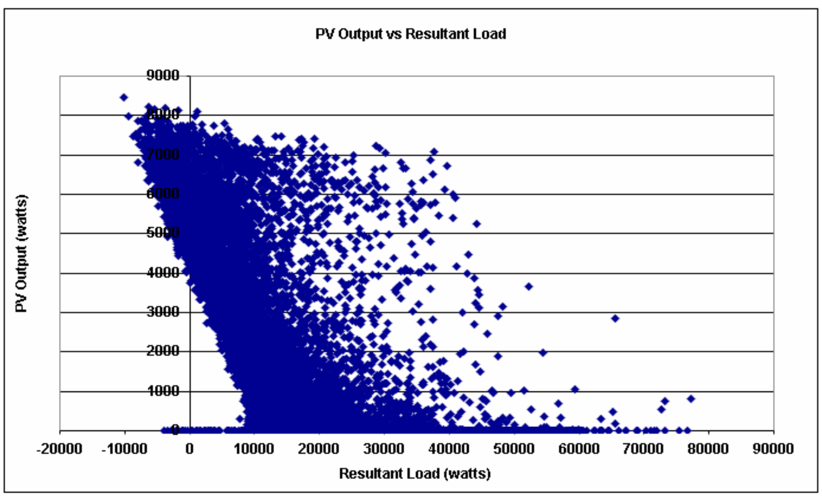

Figure 32 Relationship between PV output and offset 30 site load

Because PV output often during periods of low load, a significant portion of excess electricity generated can be exported to the grid. This registers as a negative load on the feeder.

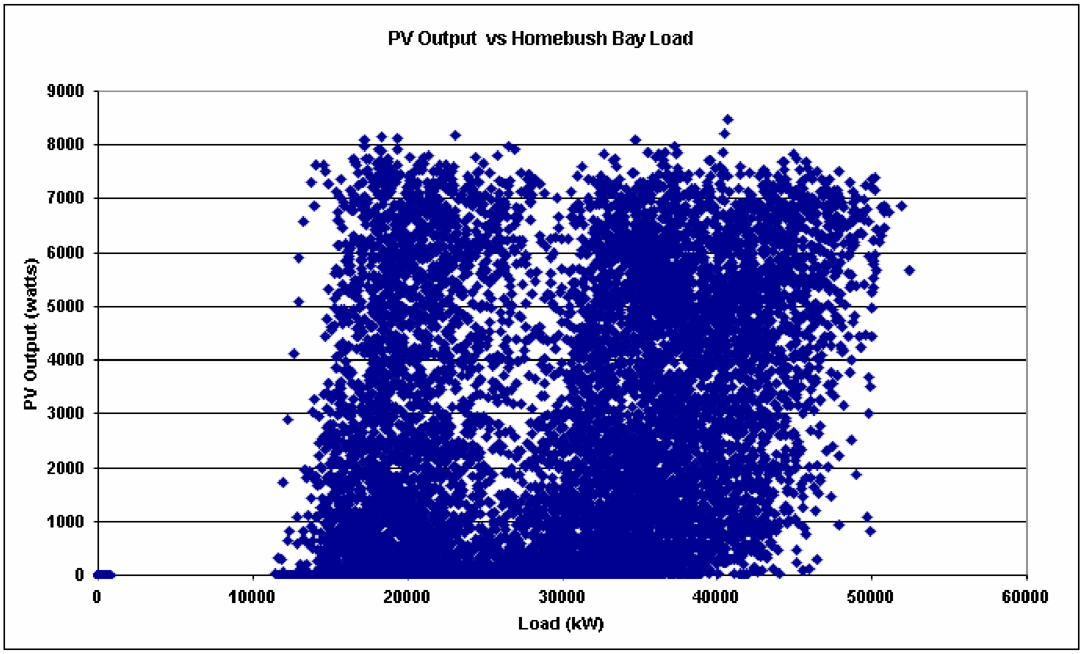

Figure 33 Relationship between PV output (10 X current installed capacity) and Homebush Bay substation load

The PV contribution is spread more evenly across load points and is reasonably significant during high load periods.

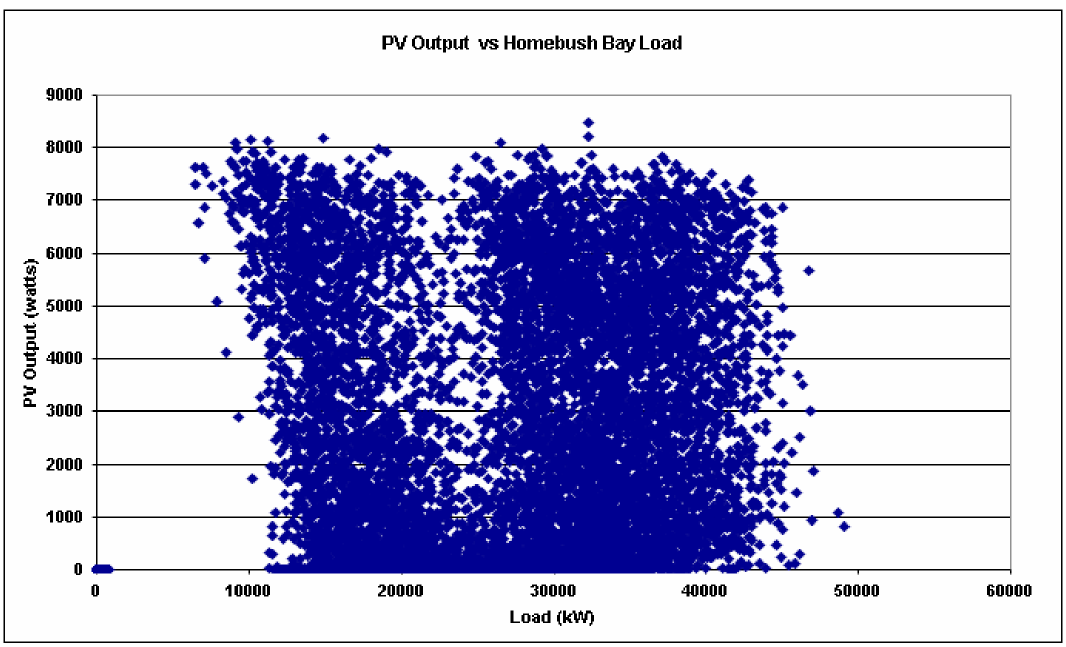

Figure 34 Relationship between PV output (10 X current installed capacity) and the offset Homebush Bay substation load

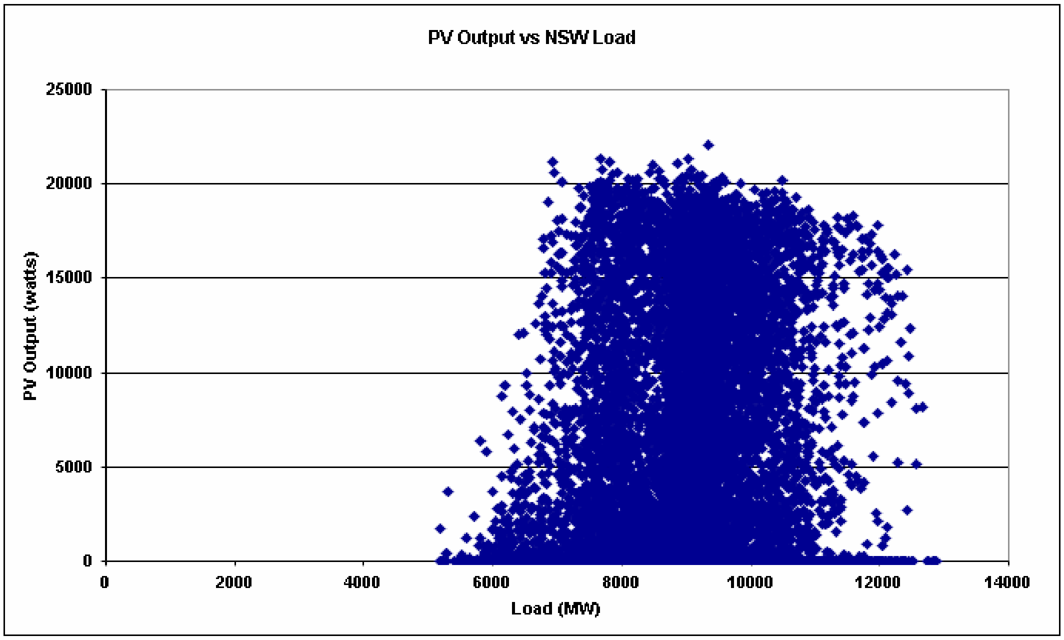

Figure 35 Relationship between PV output and NSW load

PV output also shows moderate correlation with overall NSW electricity load, with a number of high loads at zero PV output.

Load Duration Curves

The load duration curve for the 30 site total in Figure 36 shows the proportion of time the load is above a particular level. Also shown is the offset load seen by the grid after accounting for PV output. Load from the 30 Newington homes is very peaky, with about half the load occurring for only 5% of the time. PV has changed this very little – see Figure 37 and Figure 38 which show the same chart but for the top 500 and top 20 load points respectively. The main impact of the PV is in fact to offset the load when it is very low which results in export to the grid at these times. This is consistent with the loads occurring in the evenings, well after the PV output peaks.

As expected, the impact of PV on the load duration curve for the Homebush Bay substation is much more favourable (Figure 39). Note that as for Figure 6, the Olympic site PV output was multiplied by a factor of 10 so that it would have a noticeable impact on the Homebush Bay load. Figure 40 and Figure 41 show the Homebush Bay load duration curve with the top 500 and 30 load points respectively. It is clear the curve, including the very highest load points, is shifted downwards – the highest load point after allowing for PV (multiplied by 10) being 49MW, 3.4MW lower than the highest load point without PV. This means that 29.5% of the 11.54 MW of 10x PV was contributing directly to offsetting the peak load. Figure 42 shows the same load duration curve except that the offset points now correspond to the load points directly above them. This shows that on the day of the highest load point (on Wed the 1st Dec), a 10x Olympic site PV would have reduced the load by 5.7MW from 52.4MW to 46.7MW.

The highest offset load point in Figure 41 and Figure 42 corresponds to 16:00 on Wed 1st Dec 2004, which is the 26th highest load point before PV is taken into consideration – again refer to Figure 20 for the daily load profile of Wed 1st Dec 2004.

The relationship between PV output and the NSW load is better than for the 30 site load, however the points of highest demand are still unchanged by PV (Figure 43). It is also clear the NSW load is much less peaky than the Newington load. Again, as for Figure 7, the PV output was multiplied by a factor of 1000 so it would have a noticeable impact on the NSW load.

An assessment of PV's usefulness in meeting peaks should take into account the fact that it is acceptable for loads to exceed the network's capacity a small percentage of the time. According to the *2000/01 NSW Electricity Network Performance Report*, EnergyAustralia allowed for substation firm capacity to be exceeded up to 1% of the time, or that the annual probability of a failure, which requires load shedding, should not exceed 1% (whichever comes first). NorthPower (now part of Country Energy) allowed between 125% and 150% overload of transformers for up to 2 hours depending on location and season, and between 110% and 120% overload of transformers for up to 8 hours again depending on location and season (MEU, 2002).

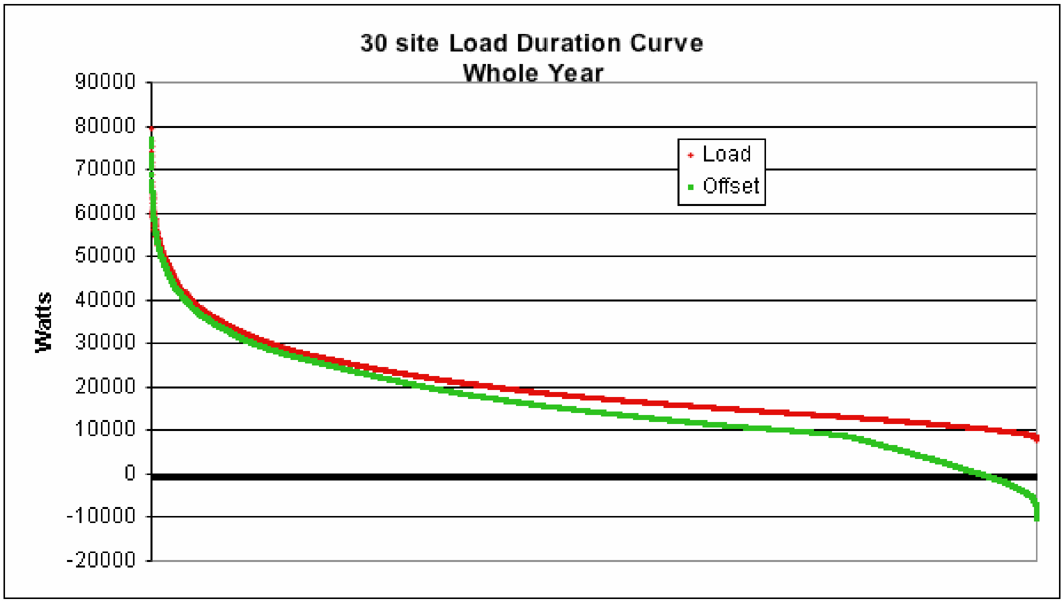

Figure 36 Load Duration curve for 30 sites - July 2004 to June 2005

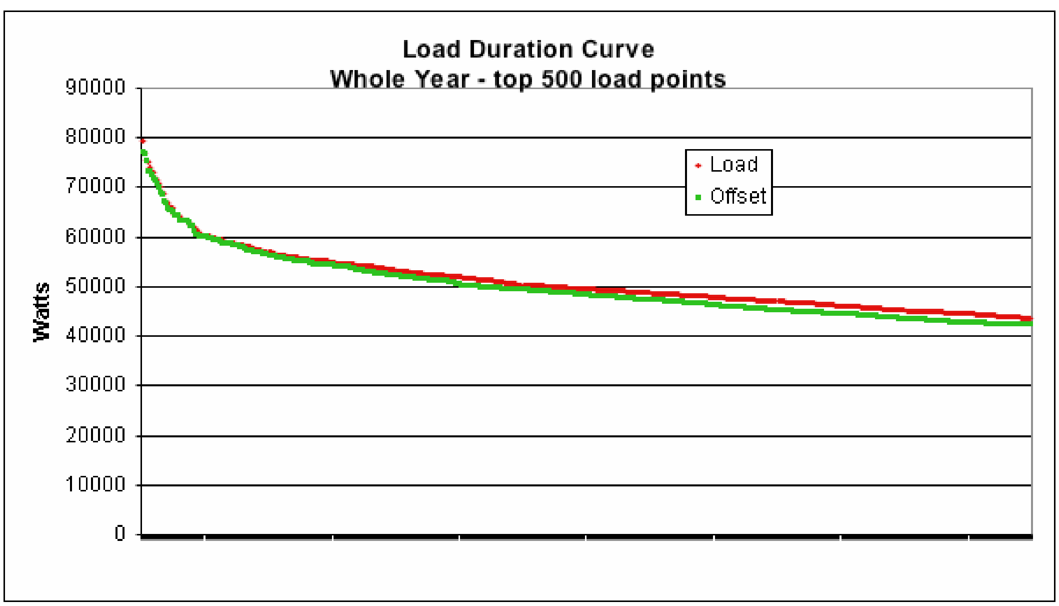

Figure 37 Load Duration curve for 30 sites July 2004 to June 2005 – top 500 load points

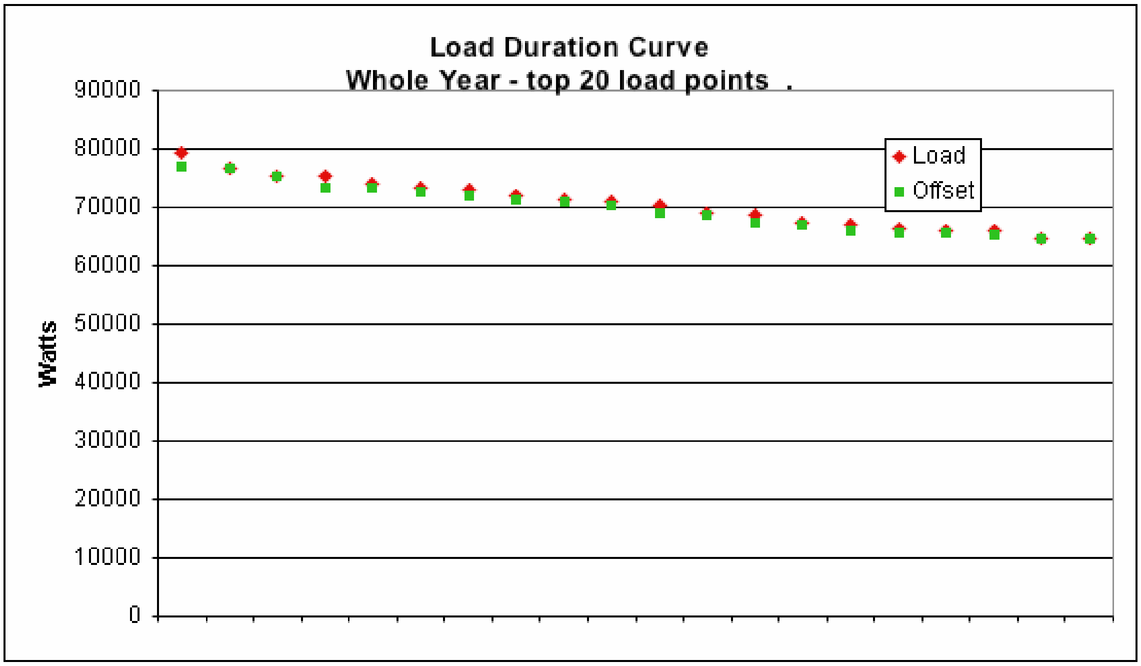

Figure 38 Load Duration curve for 30 sites July 2004 to June 2005 – top 20 load points

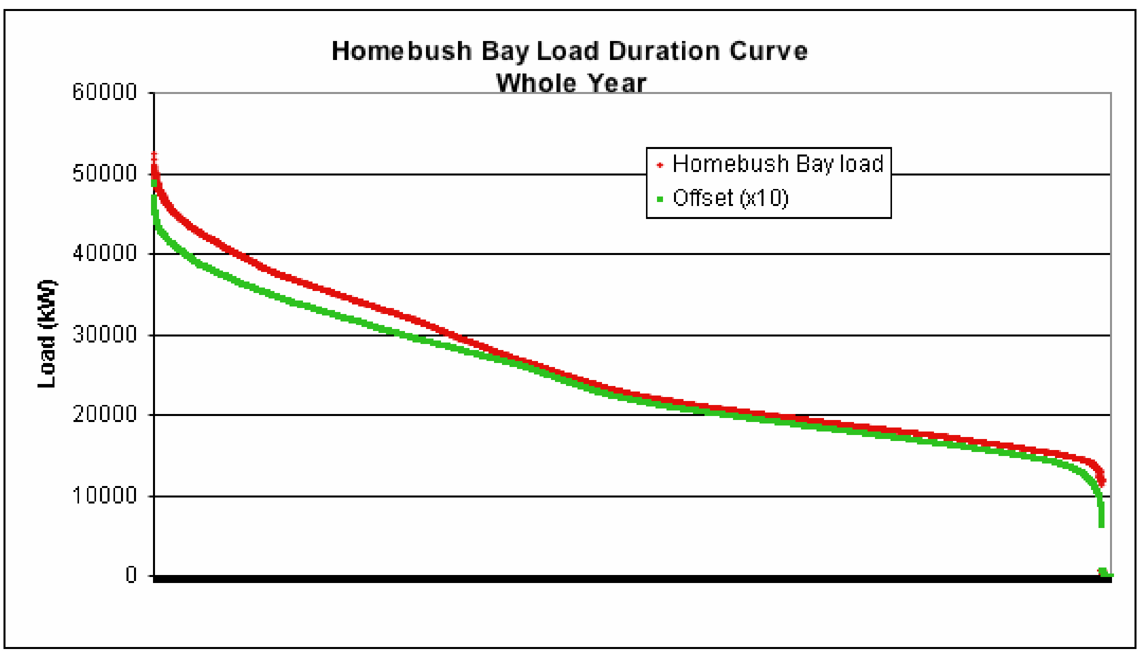

Figure 39 Load Duration curve for Homebush Bay substation with 10x current PV - July 2004 to June 2005

PV is able to reduce peak loads significantly at substation level.

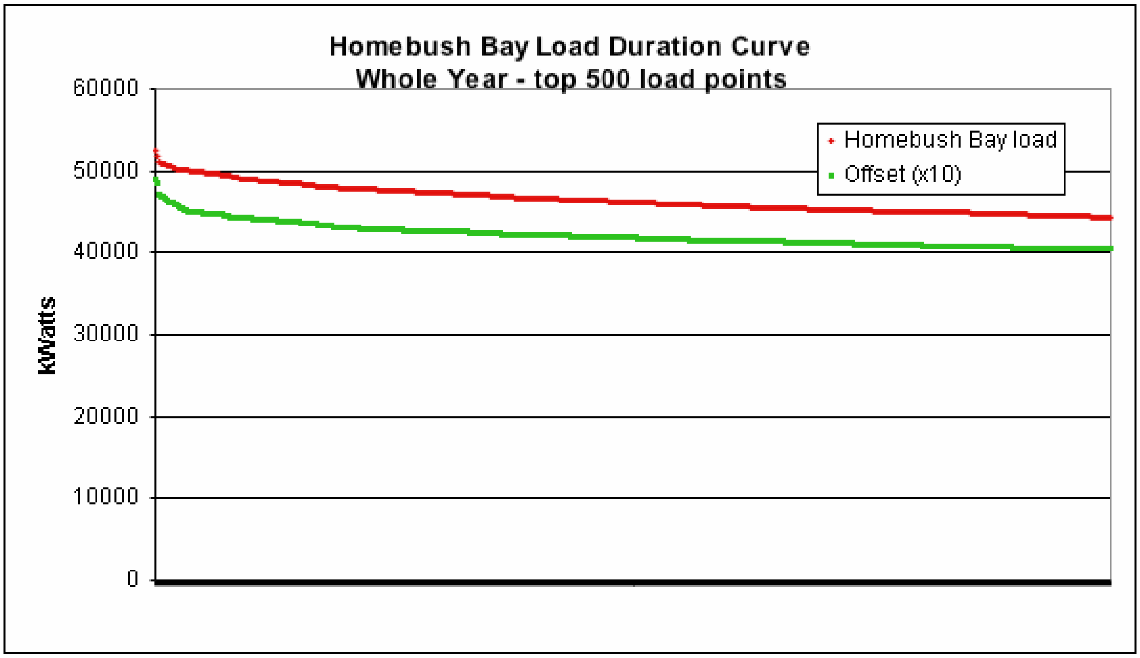

Figure 40 Load Duration curve for Homebush Bay substation with 10x current PV – top 500 load points

PV contributes well in the high load periods

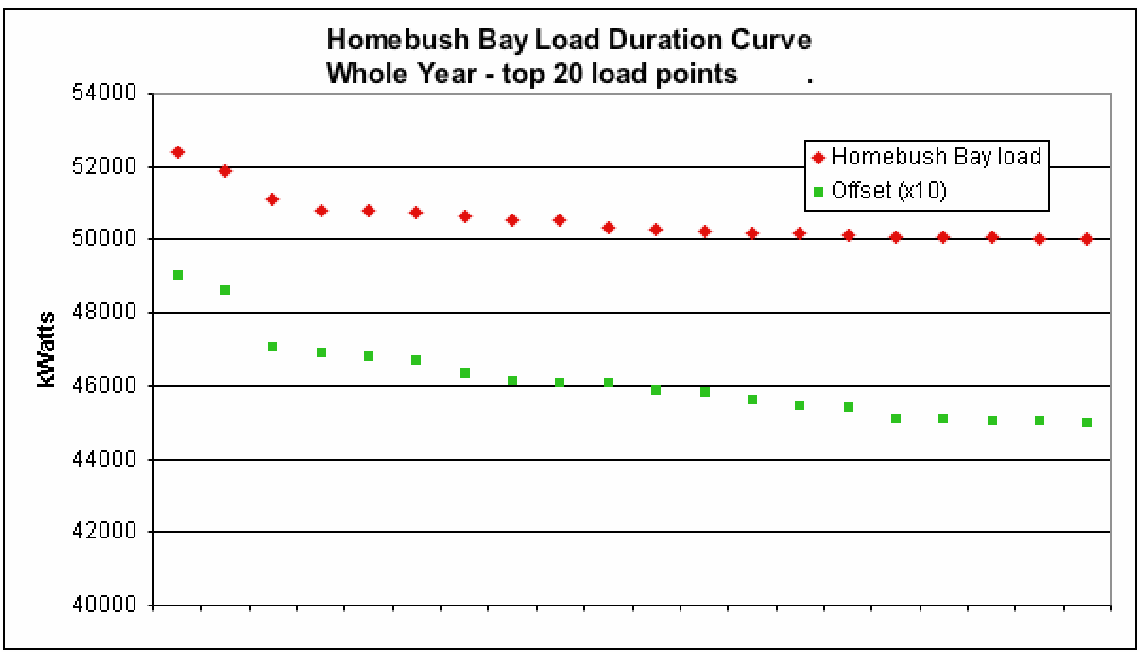

Figure 41 Load Duration curve for Homebush Bay substation with 10x current PV – top 20 load points

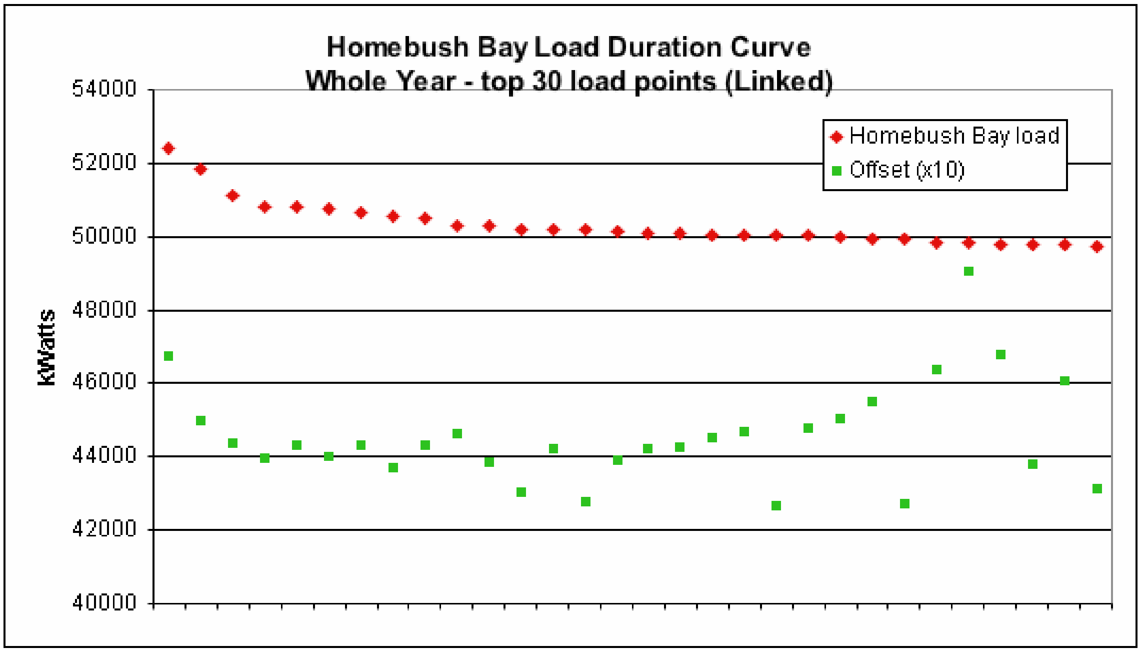

Figure 42 Load Duration curve for Homebush Bay substation with 10x current PV – top 30 load points (Linked)

This figure shows the impact of 10x the current PV at Homebush Bay on the top 30 load points. Such PV would have significantly decreased these loads. The highest 10x offset load point (green) is the same as the highest 10x offset load point in the previous figure.

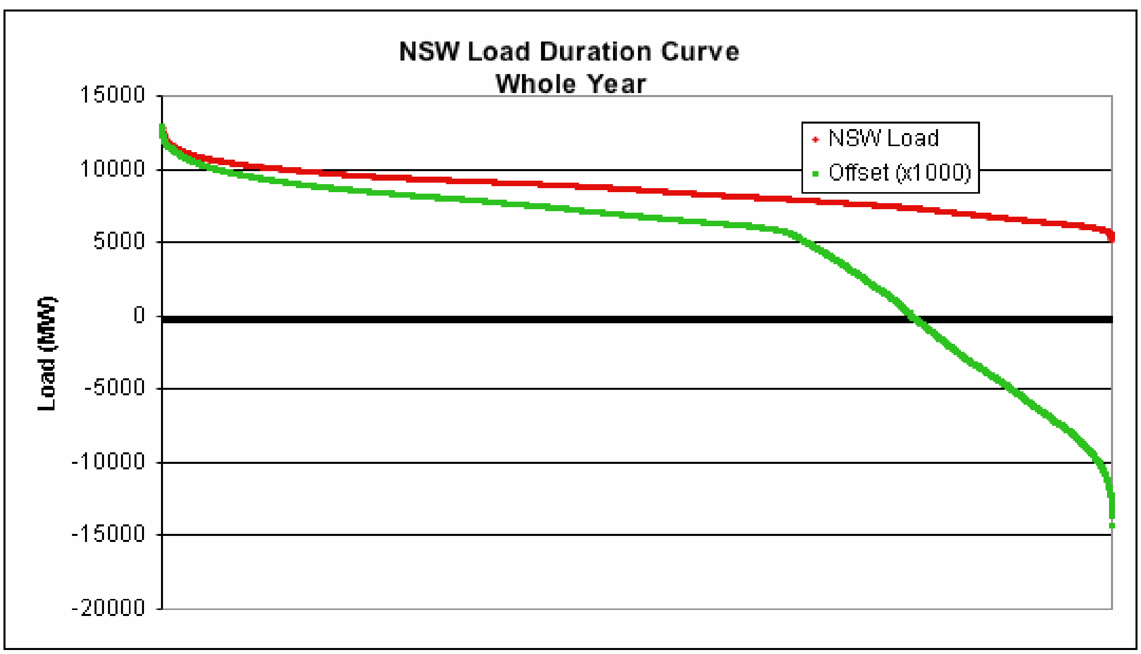

Figure 43 Load Duration curve for NSW - July 2004 to June 2005

PV contributes well across most load points, but not significantly during the highest loads.

Correlation of PV Output with Ambient Temperature

Figure 44 shows the relationship between PV output and temperature at any one time, and shows a moderate level of correlation, with PV output showing a tendency to increase at higher temperatures, which would normally occur during the middle of the day. However, there are many instances of zero PV output at high temperatures – presumably on hot summer evenings. Figure 45 compares the annual average PV output with the annual average temperature profile. For both the annual average and seasonal profiles, maximum temperature lags maximum PV output by a couple of hours.

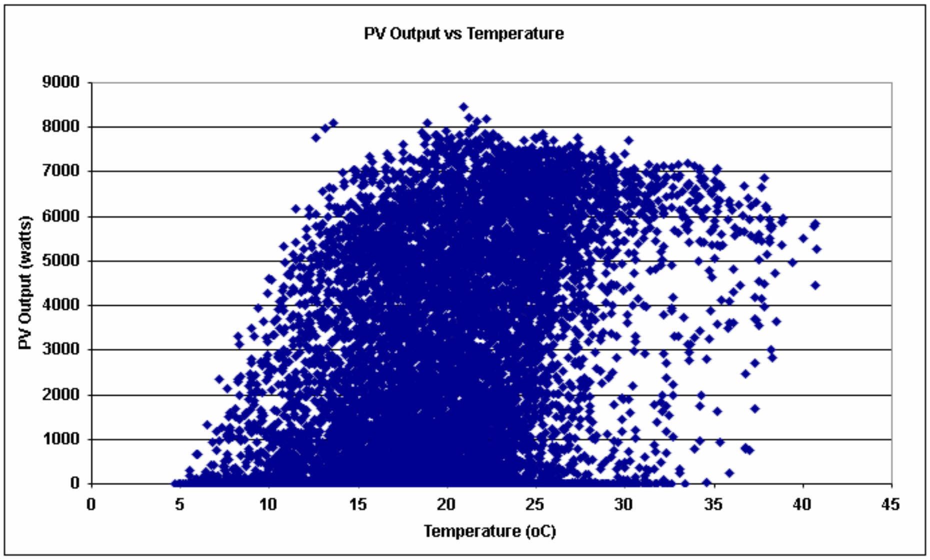

Figure 44 Relationship between PV output and ambient temperature

PV output showing a tendency to increase at higher temperatures, which would normally occur during the middle of the day. However, there are many instances of zero PV output at high temperatures.

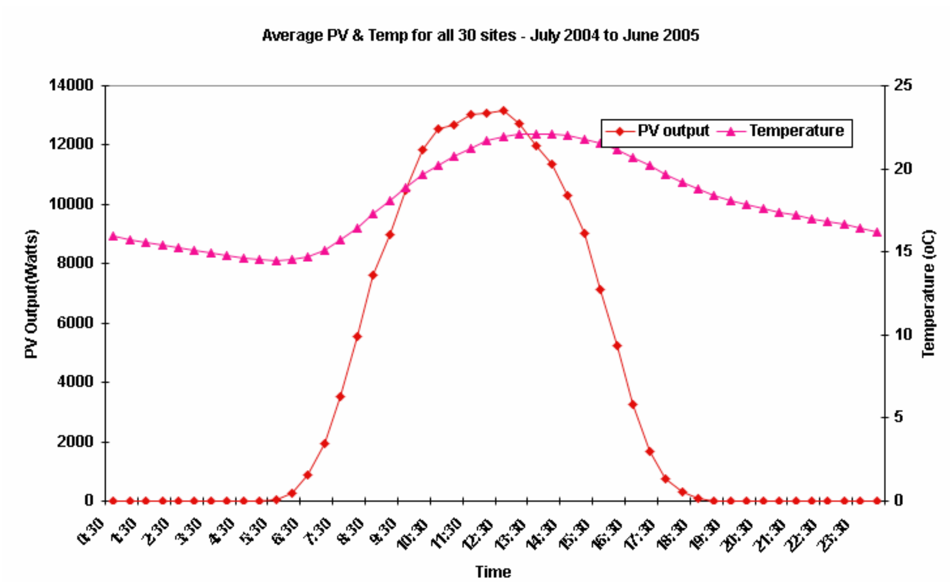

Figure 45 Average total PV output & temp for all 30 sites – July 2004 to June 2005

On average, temperature lags PV peak output by a few hours.

Correlation of Load with Ambient Temperature

Residential load

Figure 46 shows the relationship between the total 30 site residential load and temperature at any one time, and shows an interesting type of correlation, with load showing a tendency to increase at both lower and higher temperatures, centering around about 20^{o}C. Ideally, 5 star houses like those at Newington would show less sensitivity of the load to temperature – although it is likely they are still better than the Sydney average.

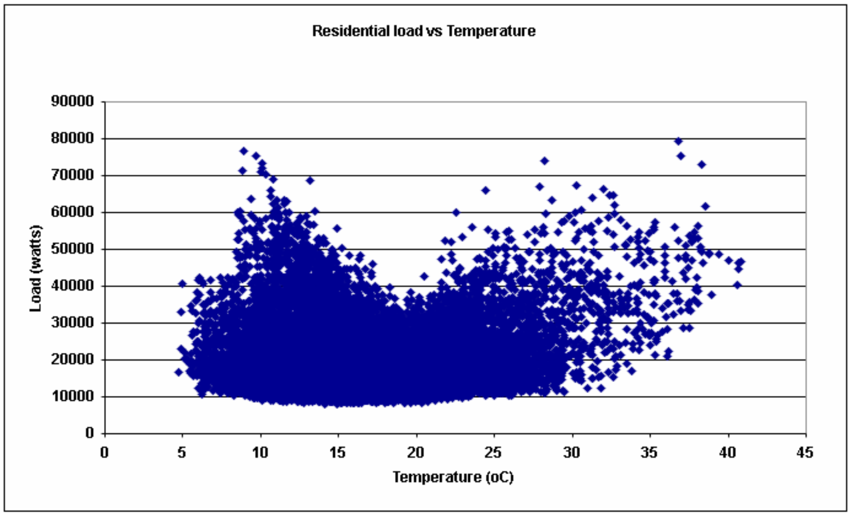

Figure 46 Relationship between residential load and ambient temperature

This graph shows a strong relationship between temperatures higher and lower than 20 degrees and electricity usage in the Newington homes.

Homebush Bay load

Figure 47 shows the relationship between Homebush Bay load and temperature at any one time, and shows that as temperature increases, in general, so does the load. The zero load points were where load data were missing.

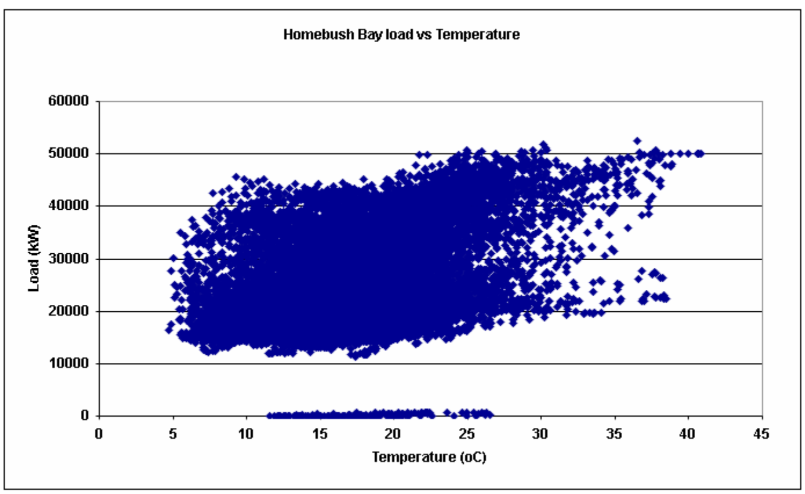

Figure 47 Relationship between Homebush Bay load and ambient temperature

There is tendency for load to increase with temperature. The zero load points are where data was missing.

Correlation of '30 site' Load and PV Output with NEM Spot Price

Figure 48 shows the relationship between total PV output and NEM spot price at any one time. Because the spot price can on occasion be far greater than the average, most of the prices are clustered at the lower end of the range – hence the logarithmic scale. However, it is still clear there is little if any correlation between output and price. Figure 49 shows the relationship between 30 site load and NEM spot price at any one time – again using a logarithmic scale. Here there is a slightly greater correlation, although still high process at relatively low loads.

Figure 50 compares the annual average PV output profile with the NEM spot price, showing there is only partial overlap between the annual average PV output with the NEM spot price. Only the autumn and winter graphs show any real correlation – Figure 51 and Figure 52.

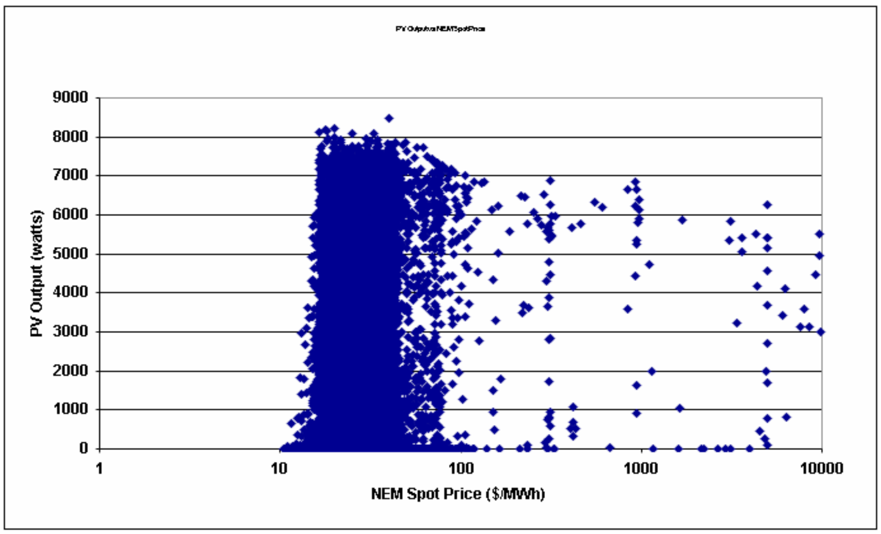

Figure 48 Relationship between total PV output and NEM spot price showing low correlation

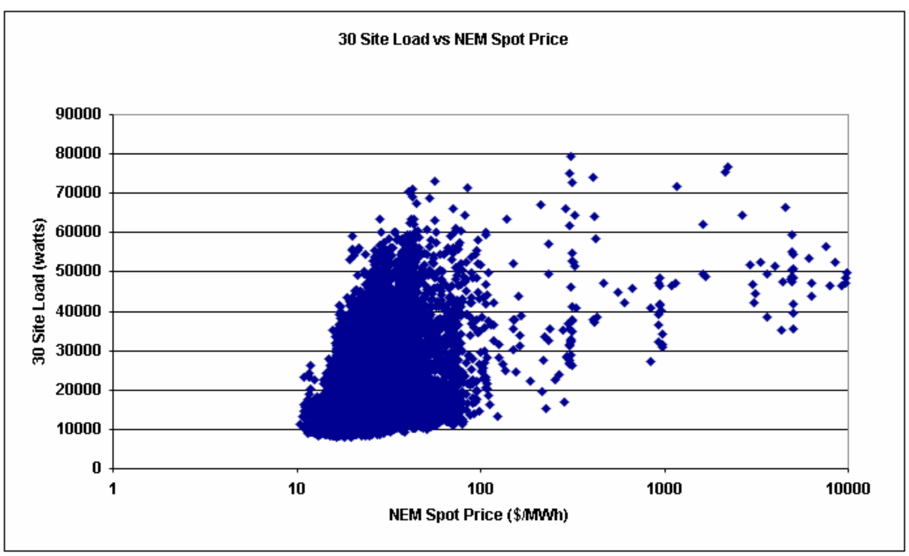

Figure 49 Relationship between 30 site load and NEM spot price

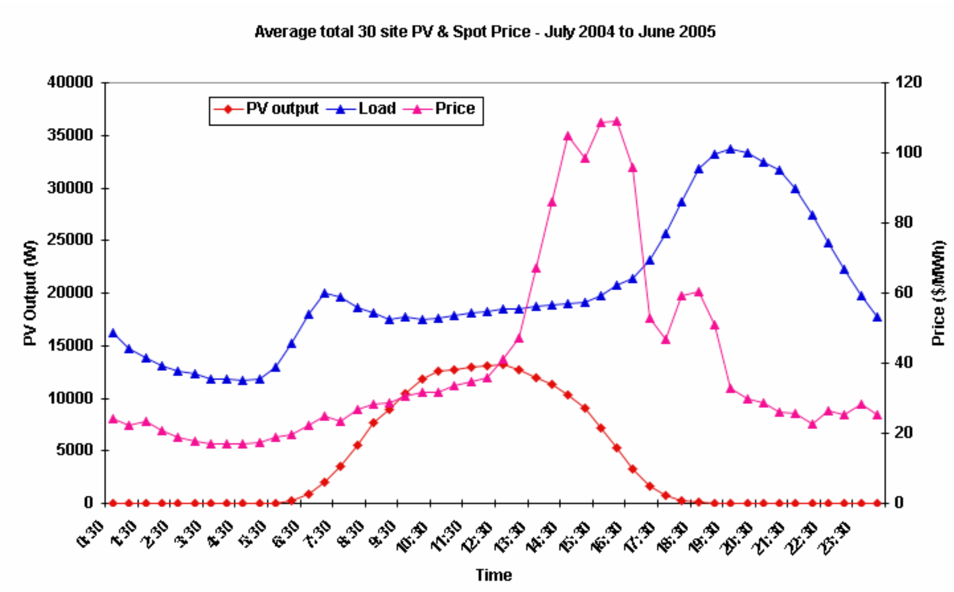

Figure 50 Average total 30 site PV output & spot price – July 2004 to June 2005

There is little relationship between load and NEM price and between PV output and NEM price.

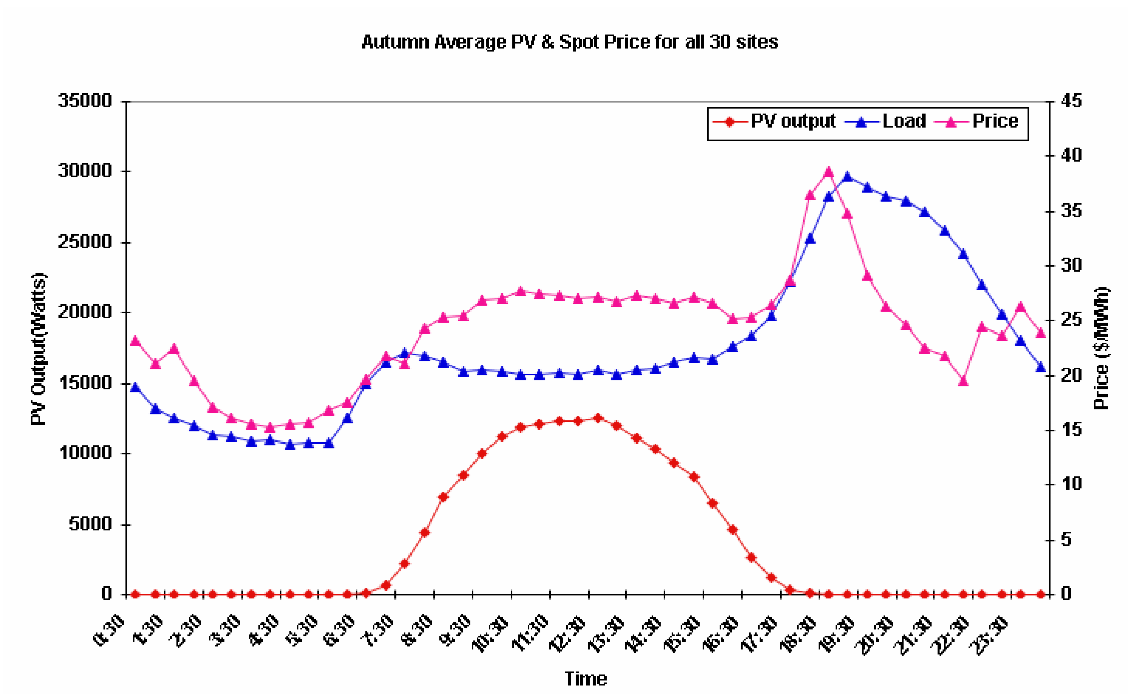

Figure 51 Autumn average total 30 site PV output & spot price – July 2004 to June 2005

The Autumn NEM price shows strong correlation with load. This could reflect the one high peak day on 28 November 2004.

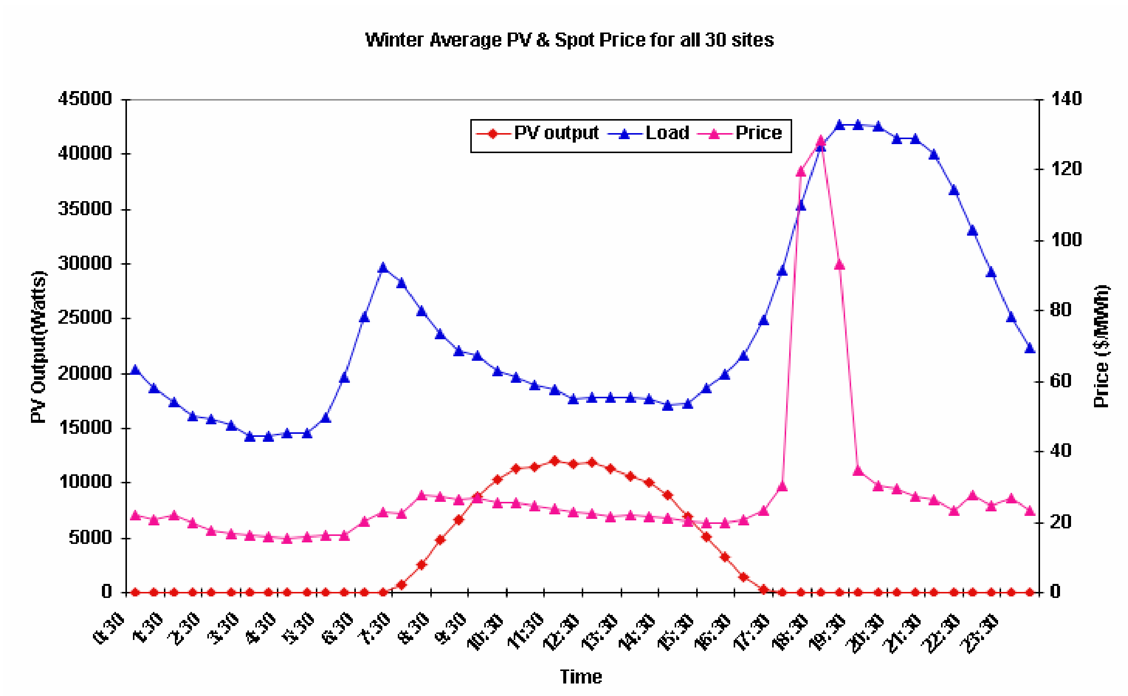

Figure 52 Winter average total 30 site PV output & spot price – July 2004 to June 2005

The Winter NEM price also shows strong correlation with load.

Discussion

The results of this analysis highlight a number of issues regarding the deployment of PV, its placement and its usefulness to the electricity supply industry.

Newington was designed and built as an energy efficient, solar powered suburb. However, the homes were purposely marketed to the general public and not especially targeted at ‘green’ consumers. Hence current house occupants may have little awareness or understanding of the solar or energy efficiency features included. With two of the 30 monitored PV systems not functioning, it is clear that at least some occupants are either unaware of the performance they should expect from their PV systems, or do not know how to go about seeking maintenance. The passive solar design features of the homes are not being well utilised, with high levels of electrical heating and cooling evident in some homes. In addition, and in line with community trends generally in the time since the homes were designed, there is evidence of retrofit with or additions of high energy using appliances. It would seem that inclusion of energy efficiency and solar features in homes should be accompanied by ongoing energy awareness and information exchange, and also by routine inspection and maintenance services.

The performance of the Newington PV systems is slightly lower than would be expected, because of the non-functional systems and for other reasons. Rooftop PV systems in Australia are subject to high temperatures and hence to reduced output. Roof integration, with its inherent reduction in air circulation behind the panels, may exacerbate this problem, although it will always be present. With little or no maintenance undertaken since the systems were installed, it is difficult to assess whether or not minor problems are causing some of the reduction in output.

Residential electricity loads are, in general, not well matched to PV output, since they tend to be high early and late in the day, at times when PV output is not available. For net metered systems, this is not an issue for the system owners, since PV can be exported during times of low household load. However, for the feeders servicing residential areas, PV serves to exaggerate the peak loads. Nevertheless PV output can be very well matched to substation loads, if the latter have a mix of commercial and daytime industrial loads. PV output contributes well to the Homebush Bay substation load over the year and during peak periods. It would be sensible to examine substation load profiles when planning for PV deployment, as this could enable targeting sites where PV contributions would be most useful to the network. Any assessment of PV’s usefulness in meeting peaks should take into account the fact that it is acceptable for loads to exceed the network’s capacity a small percentage of the time.

Under present arrangements, electricity retailers bear some cost of net-metered PV, because although they avoid generation costs and TUOS and DUOS, they miss out on their margin, which covers administration costs and profit. Networks operators serve to benefit from targeted placement, and generally charge customers for connecting to the grid. Consideration of these issues would be recommended in future government programs.

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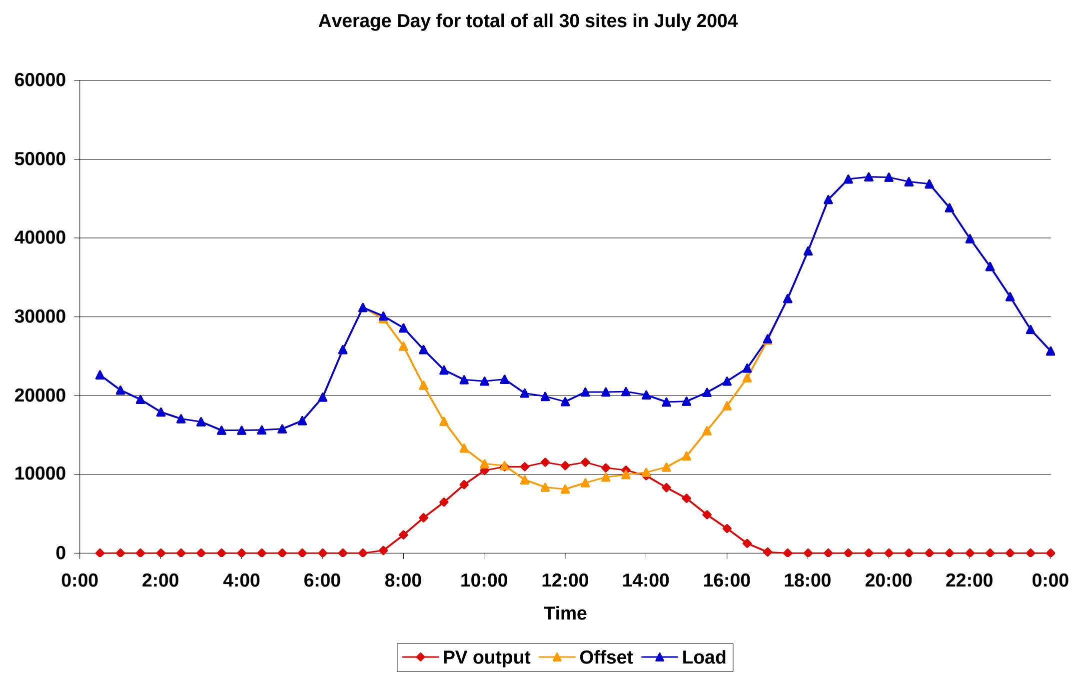
Lee, T, Oppenheim, D.& Williamson, T. (1995), *Australian Solar Radiation Data Handbook*, ERDC 249.

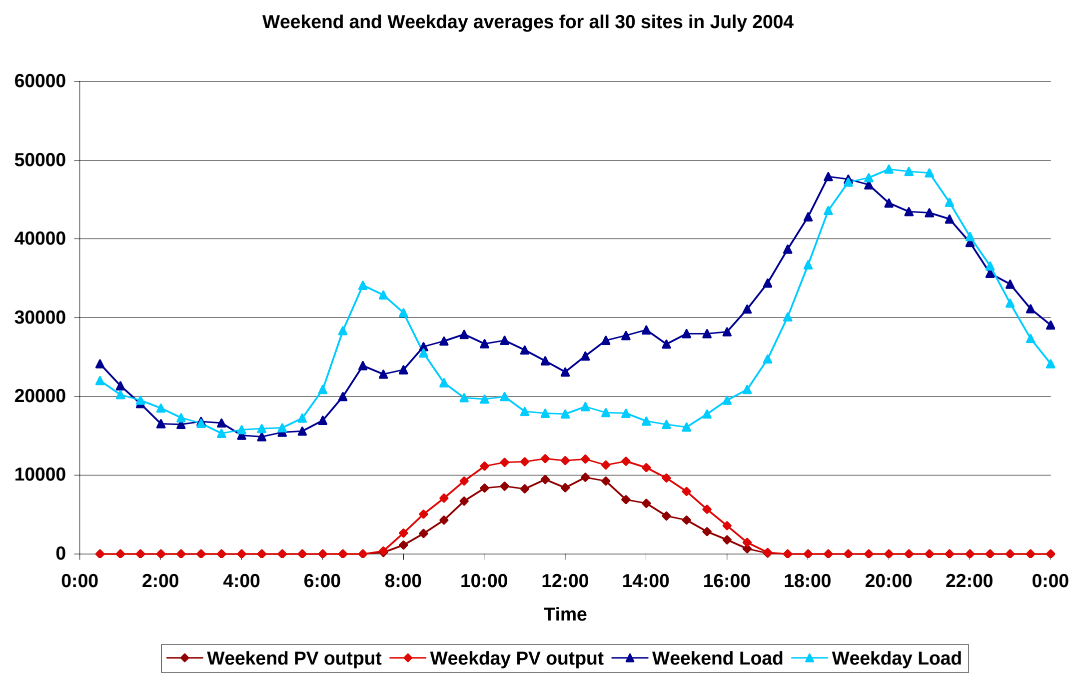
MEU (2002) *2000/01 NSW Electricity Network Performance Report*, Ministry of Energy and Utilities, NSW Government.

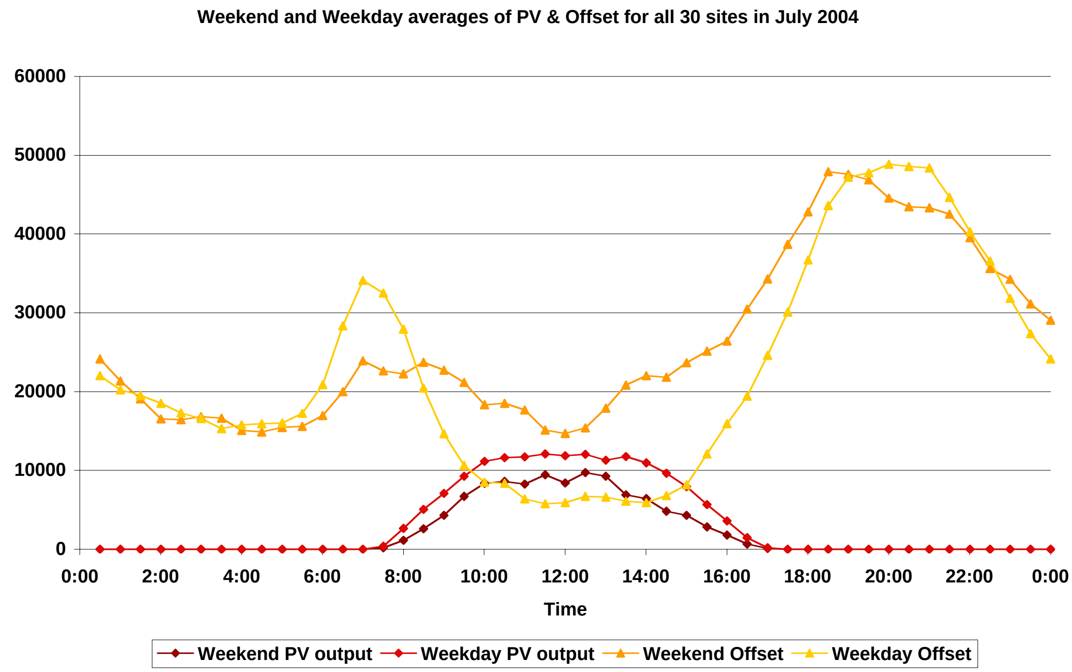
Watt, M., Oliphant, M., Outhred, H. & Collins, R. (2003), "Using PV to Meet Peak Summer Electricity Loads", *Proceedings of Destination Renewables, 41st Conference of the Australian and New Zealand Solar Energy Society*, Melbourne, November, 2003.

Appendix A

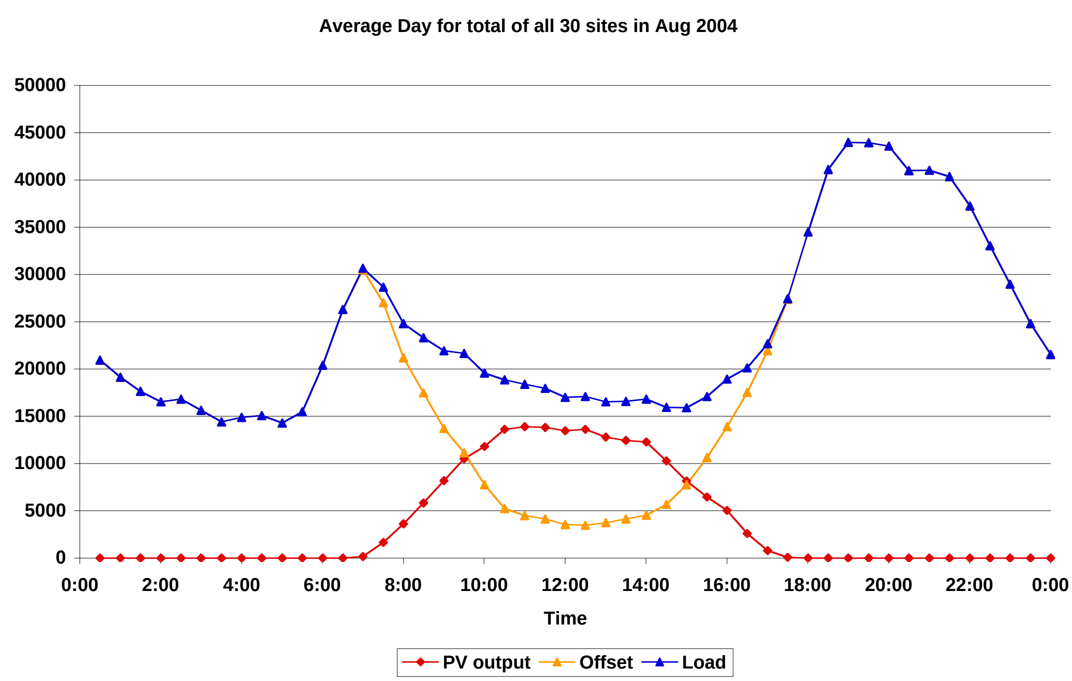
Average July Profiles for total of all 30 Sites

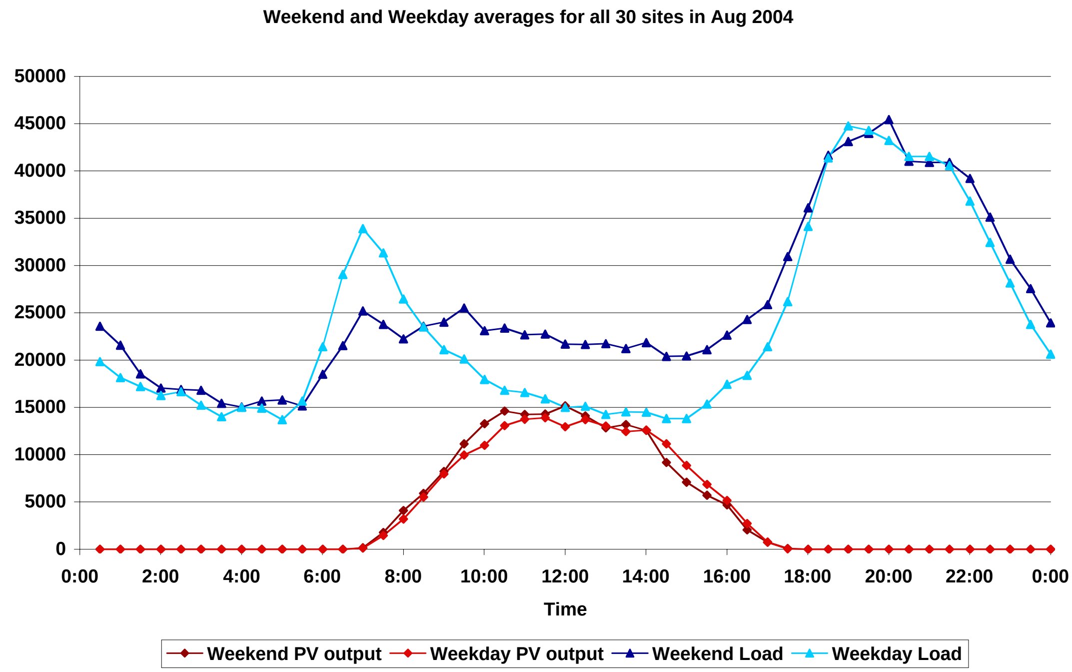


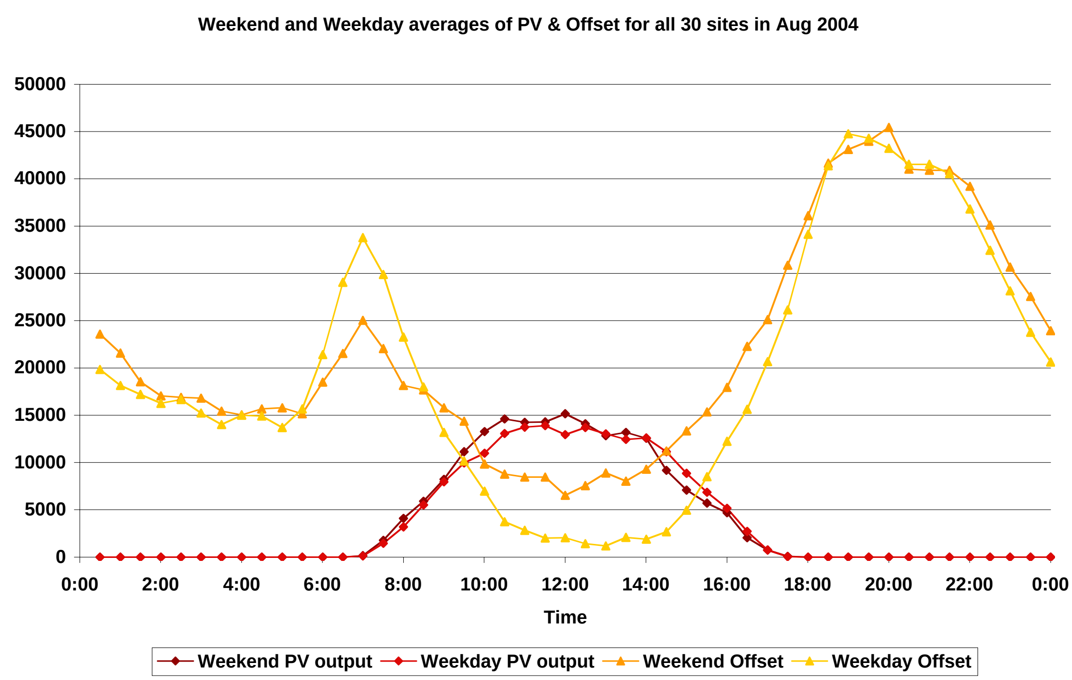




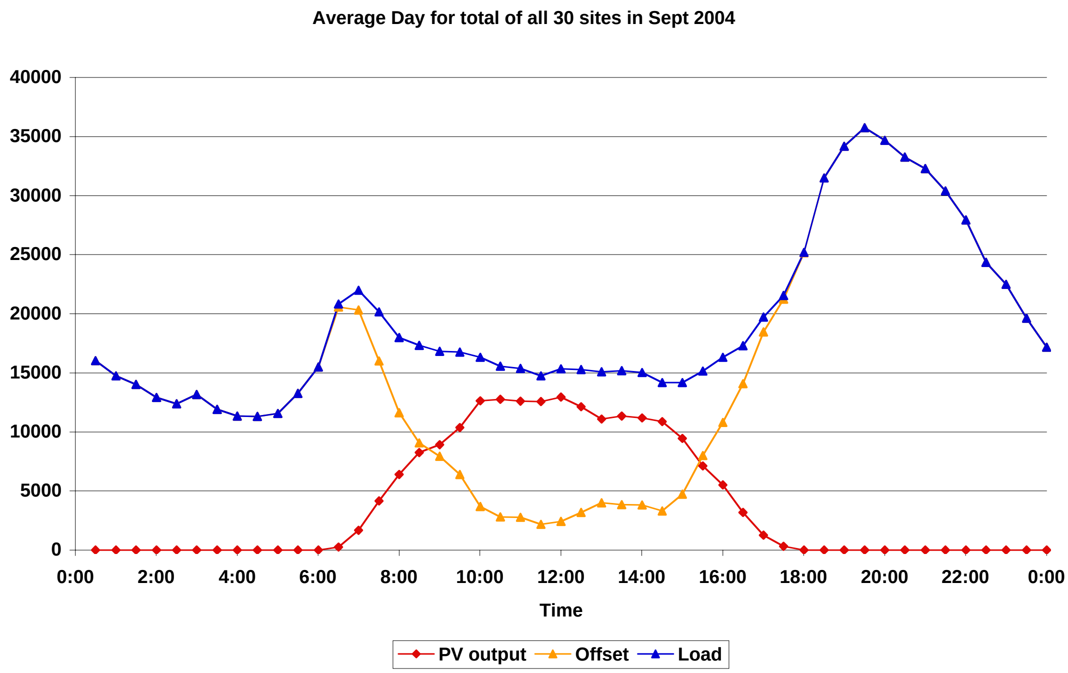
Average August Profiles for total of all 30 Sites

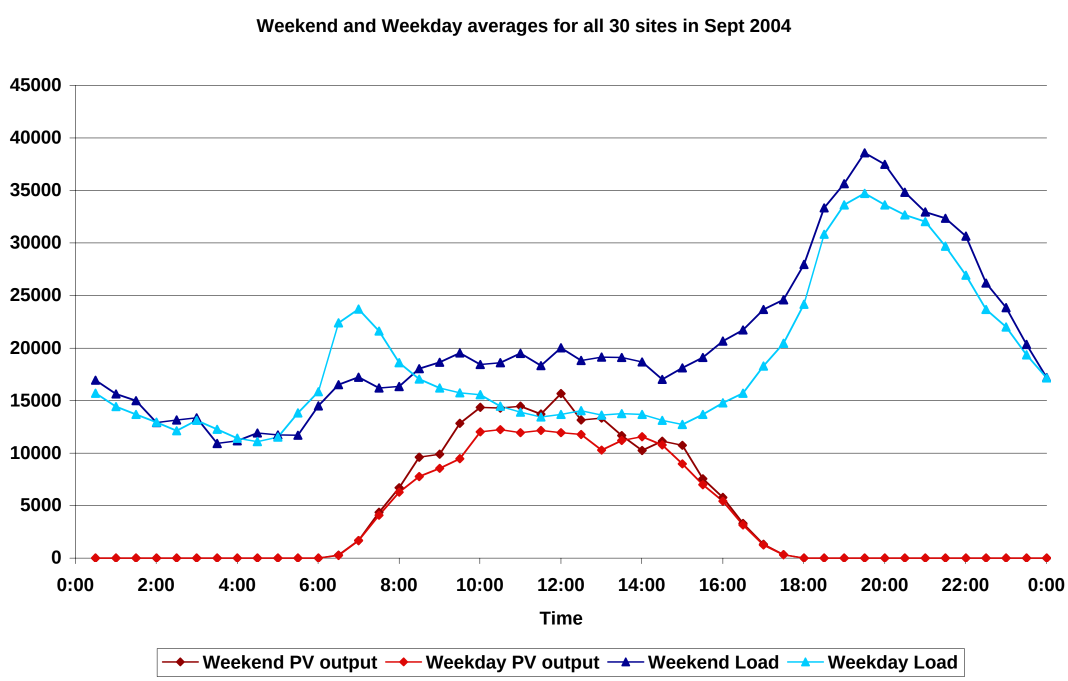


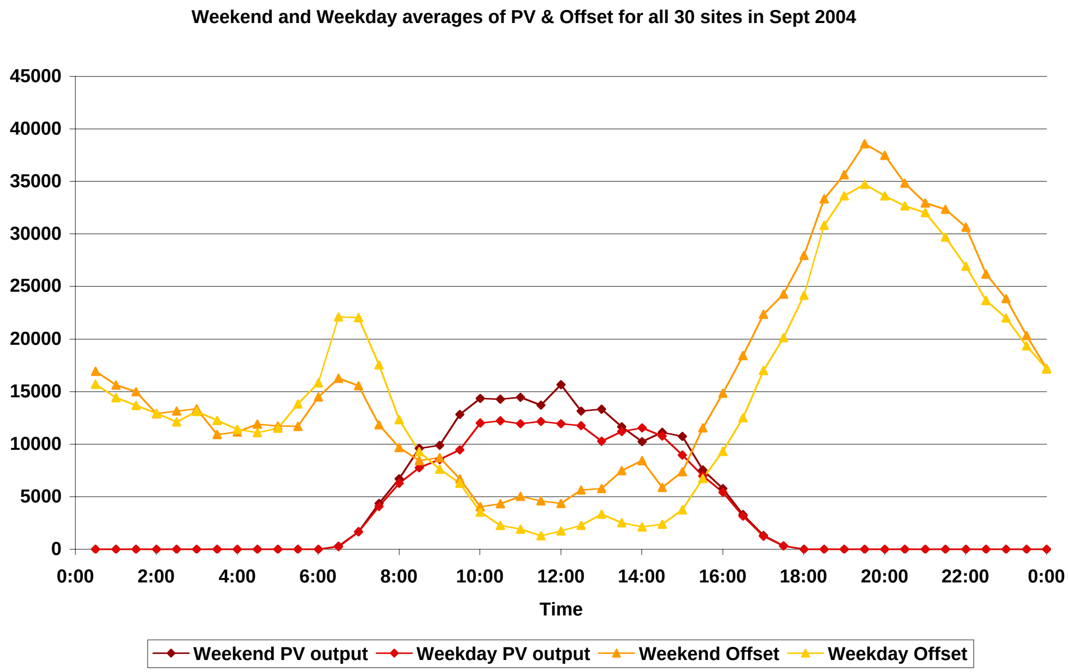

Weekend and Weekday averages for all 30 sites in Aug 2004
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Weekend PV output
Weekday PV output
Weekend Load
Weekday Load


Weekend and Weekday averages of PV & Offset for all 30 sites in Aug 2004
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Weekend PV output
Weekday PV output
Weekend Offset
Weekday Offset

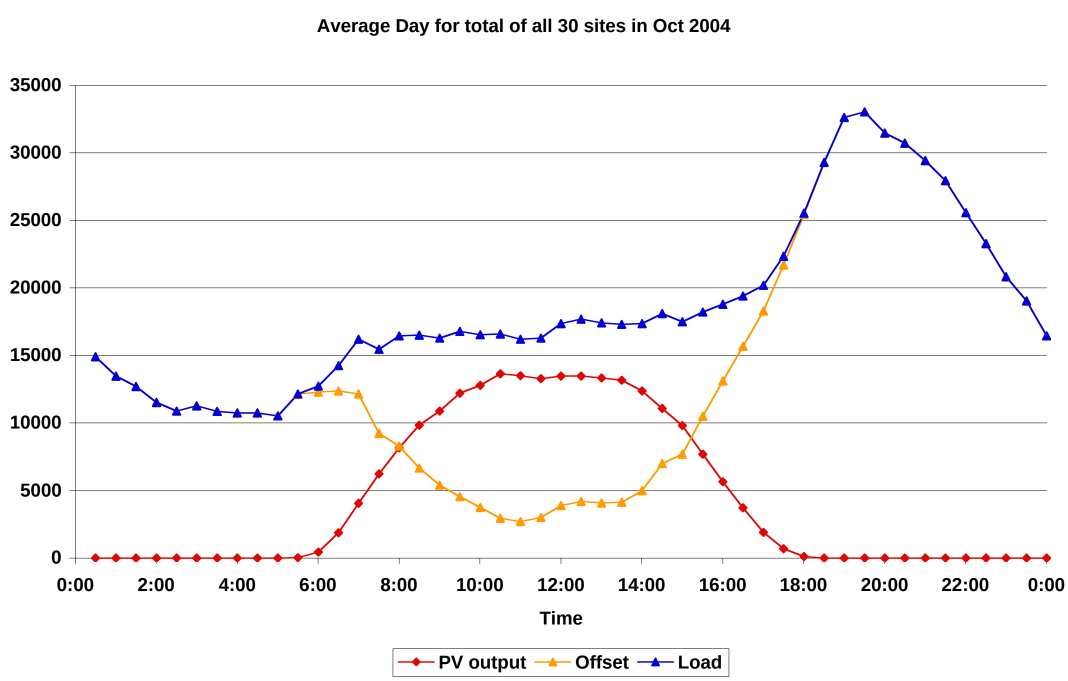
Average September Profiles for total of all 30 Sites



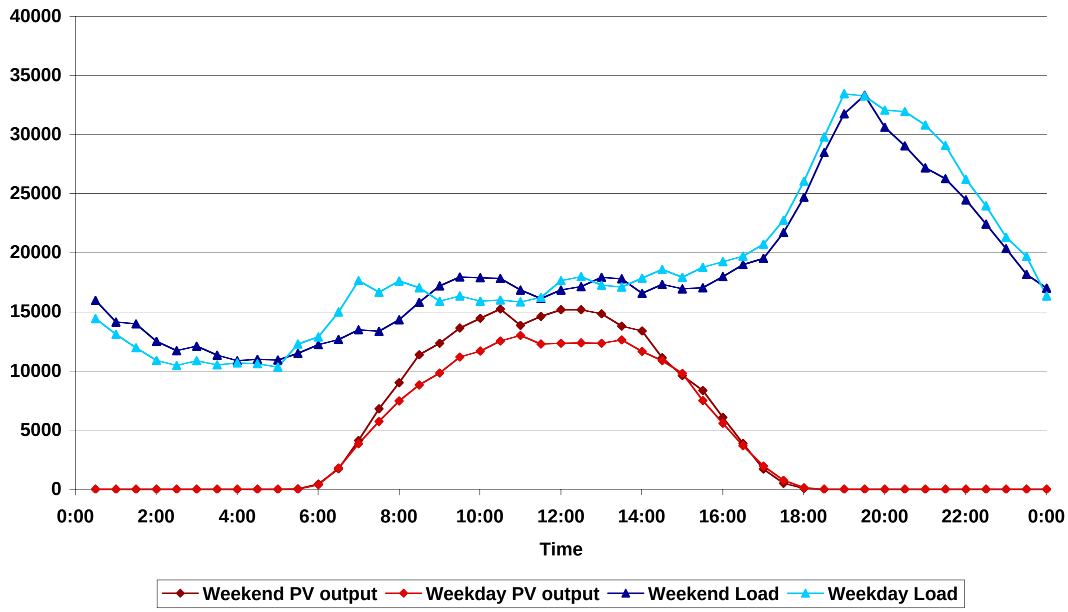




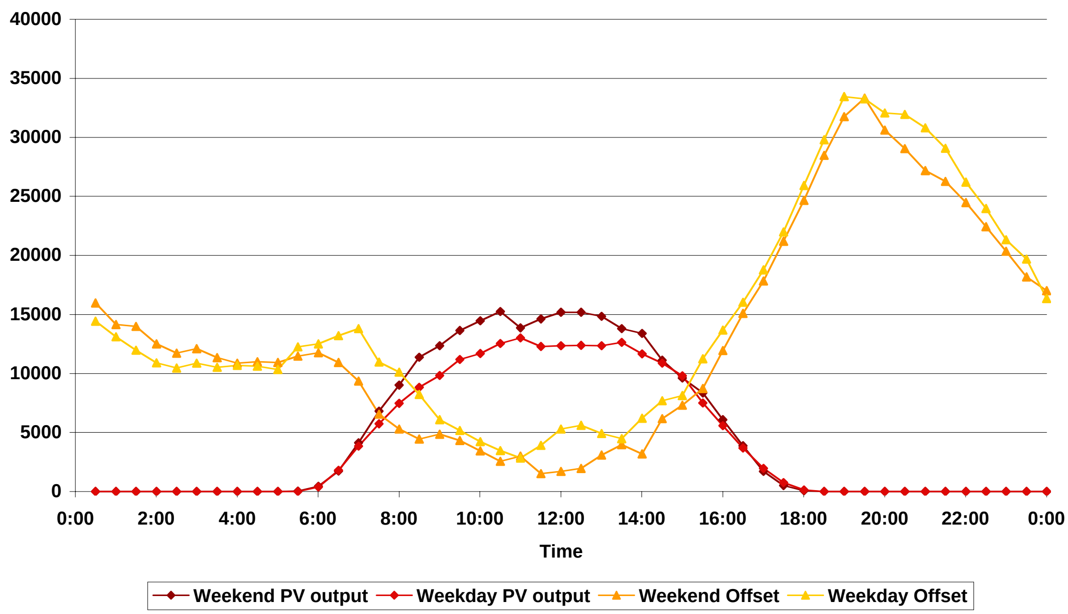
Average October Profiles for total of all 30 Sites



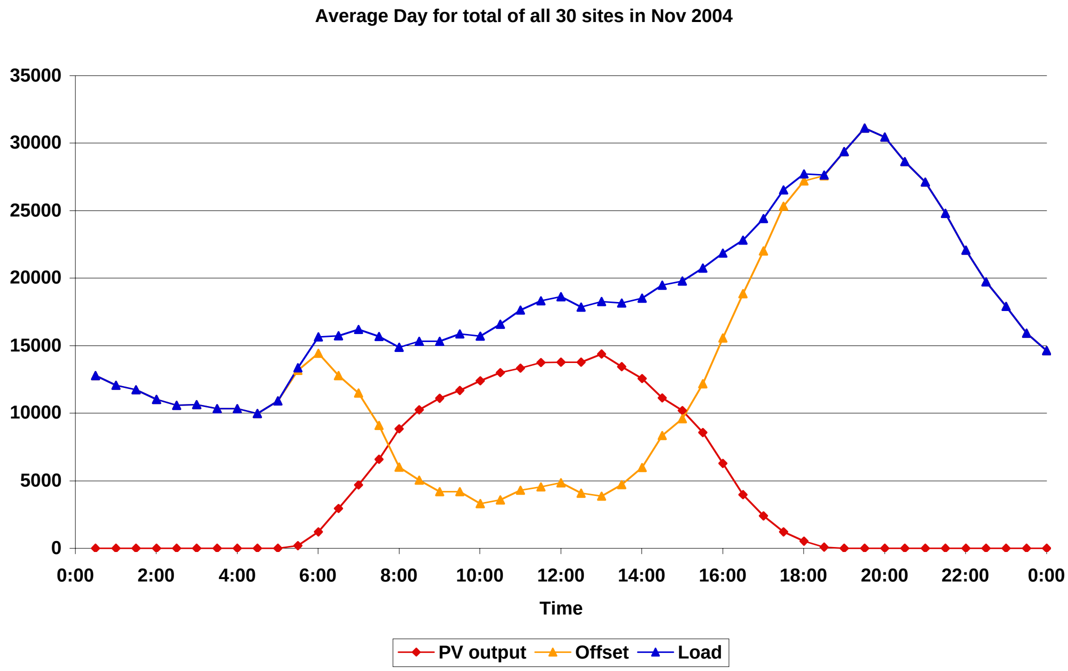
Weekend and Weekday averages for all 30 sites in Oct 2004

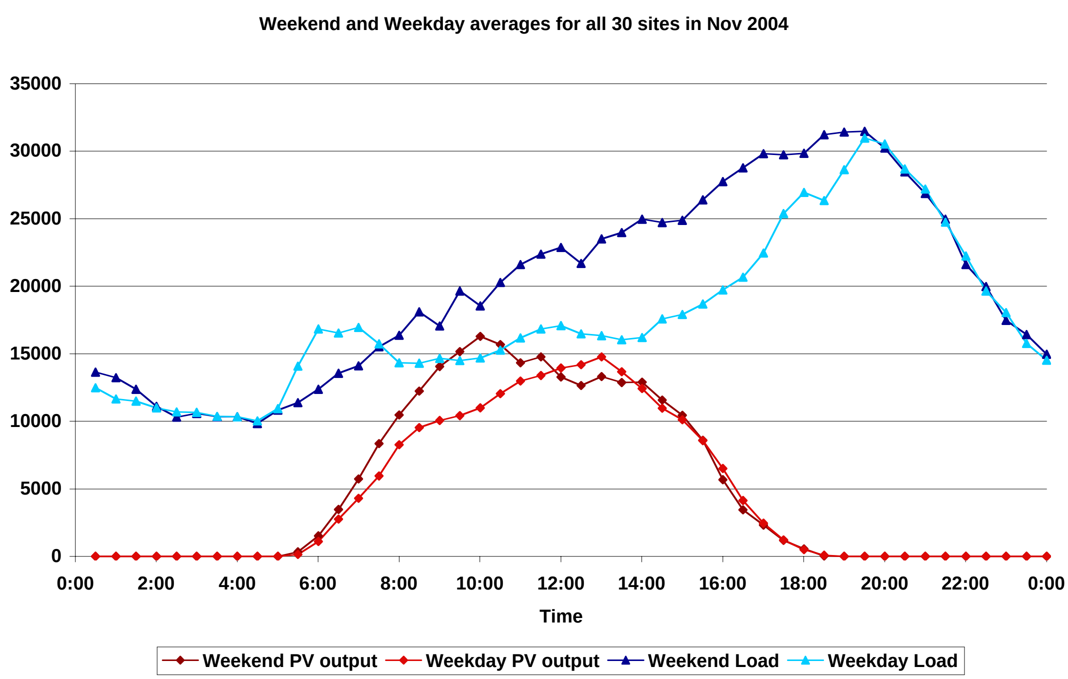


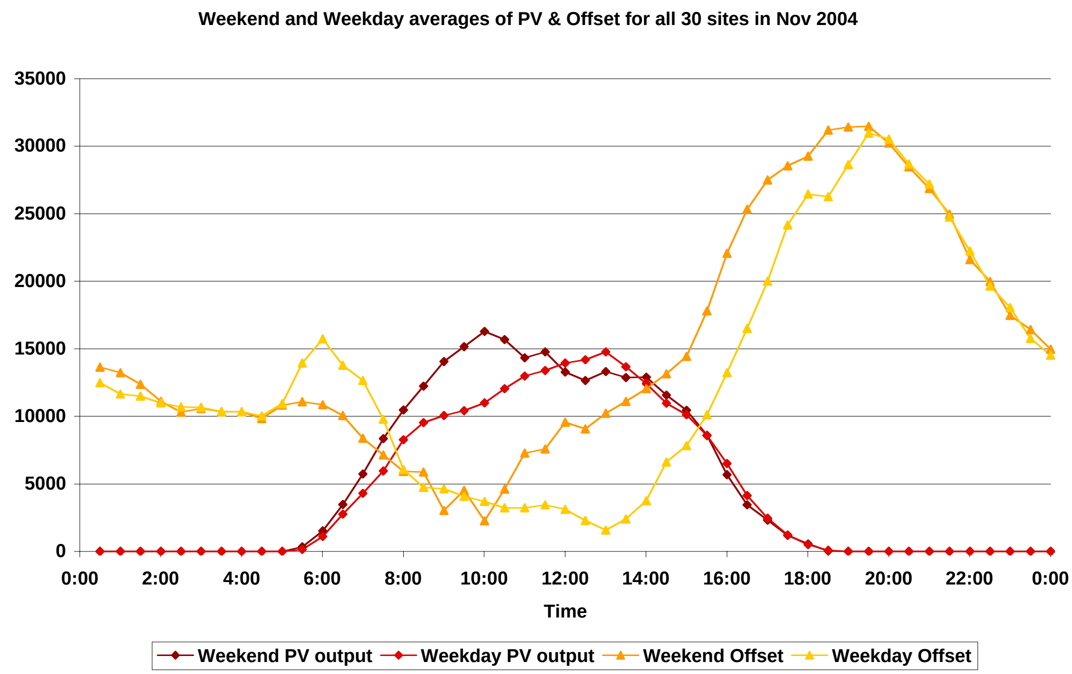
Weekend and Weekday averages of PV & Offset for all 30 sites in Oct 2004



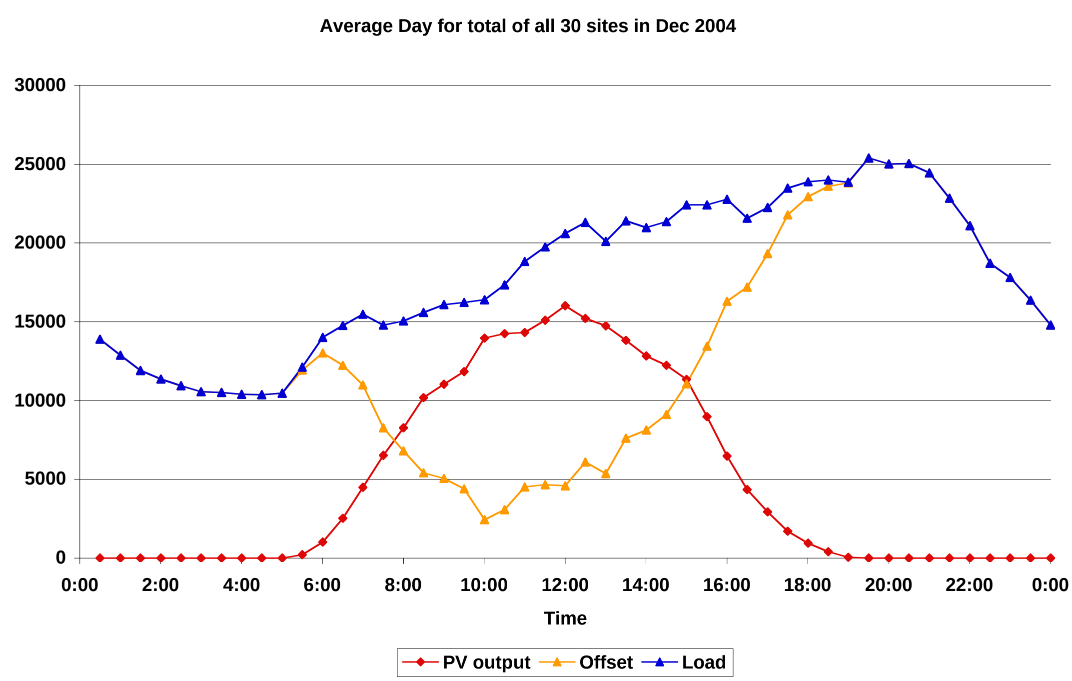
Average November Profiles for total of all 30 Sites



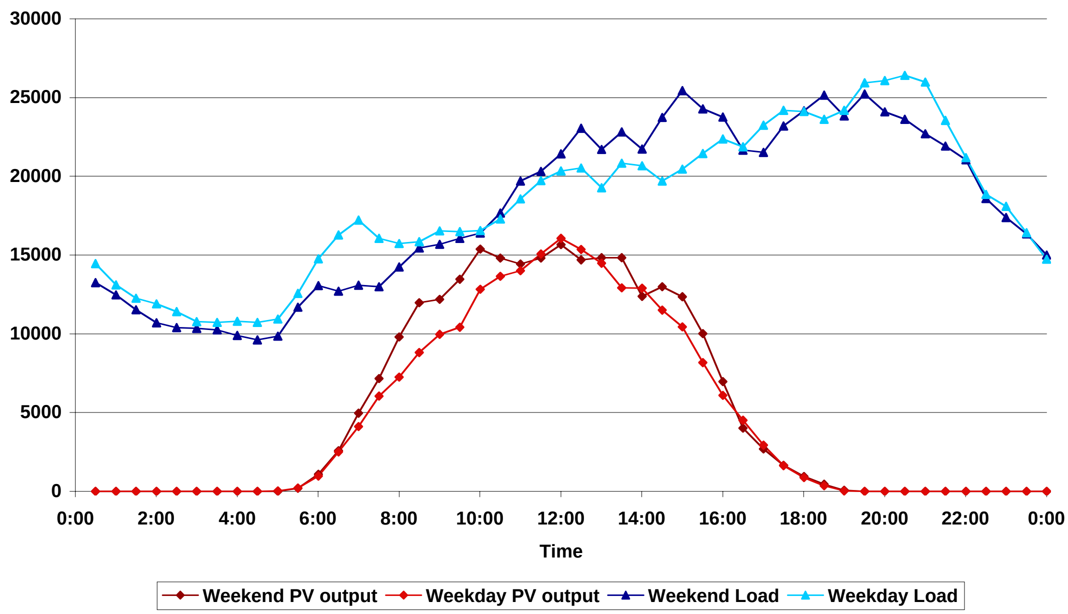




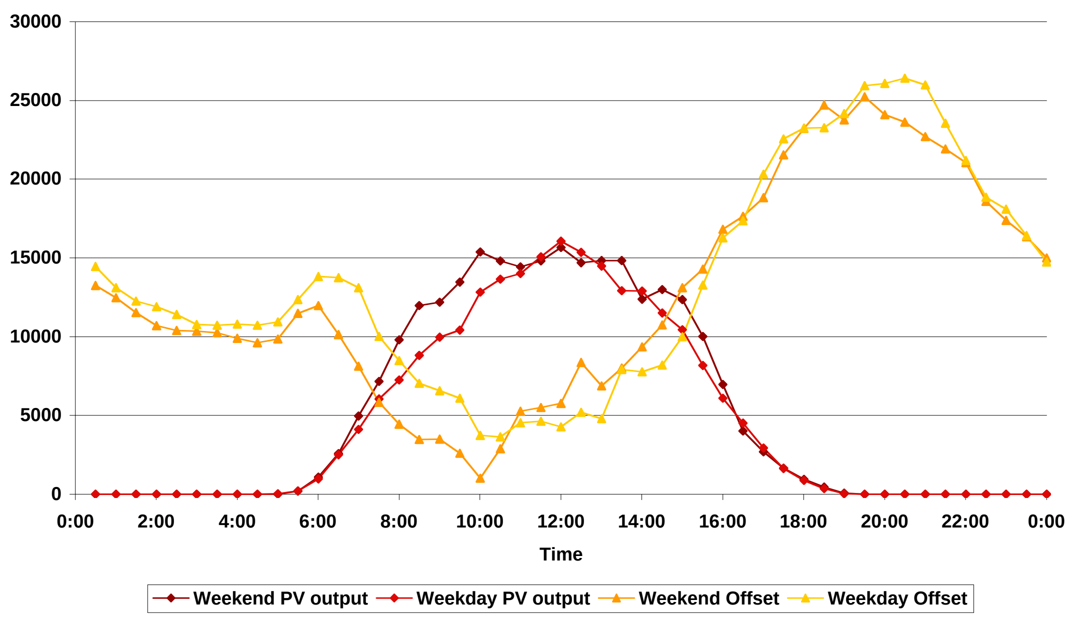
Average December Profiles for total of all 30 Sites



Weekend and Weekday averages for all 30 sites in Dec 2004

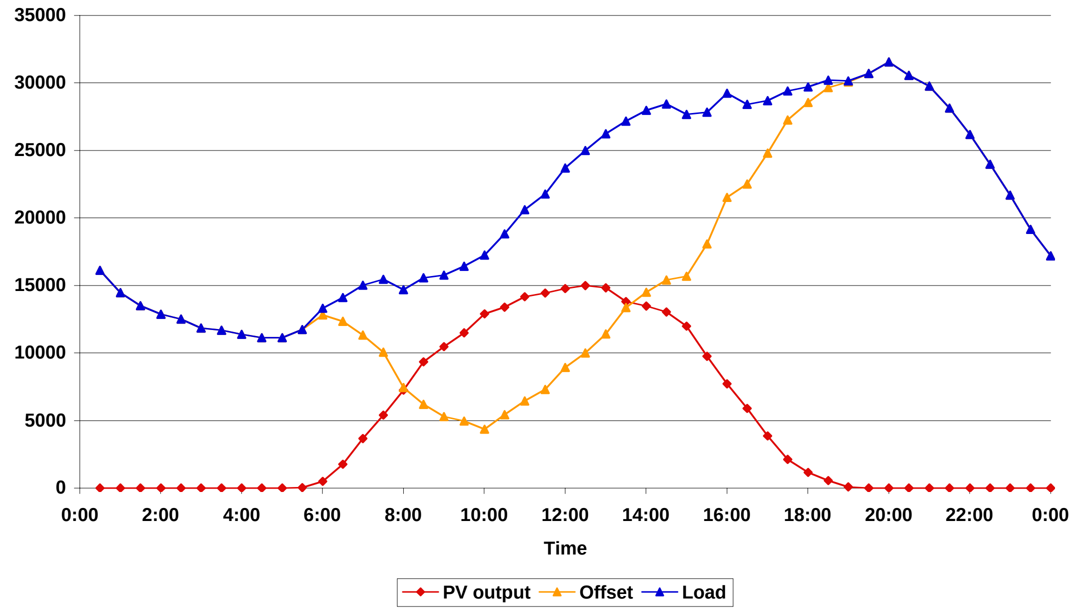


Weekend and Weekday averages of PV & Offset for all 30 sites in Dec 2004

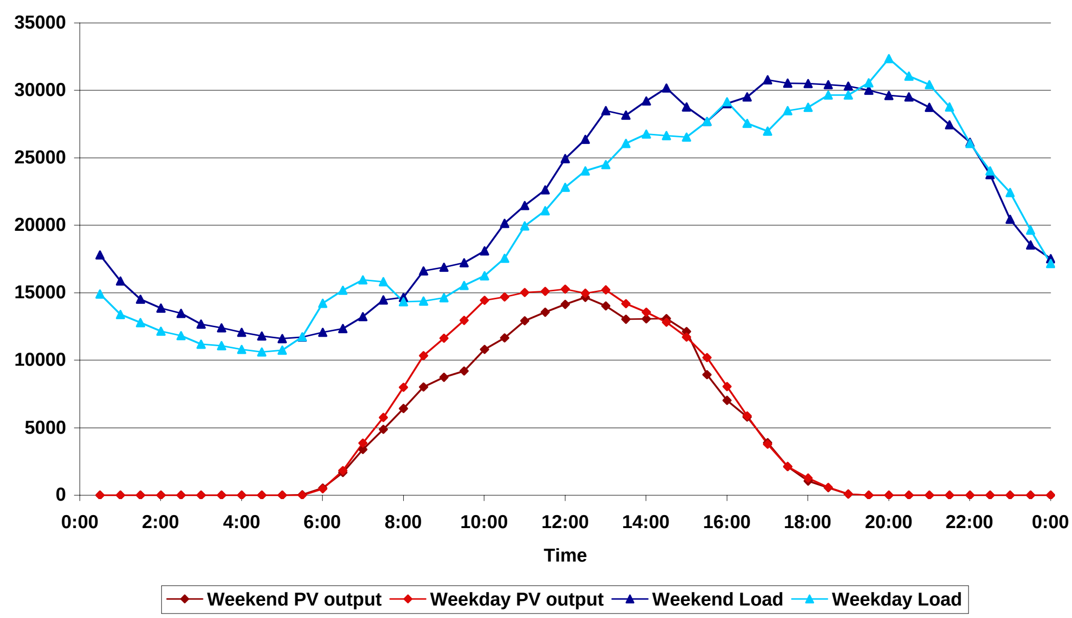


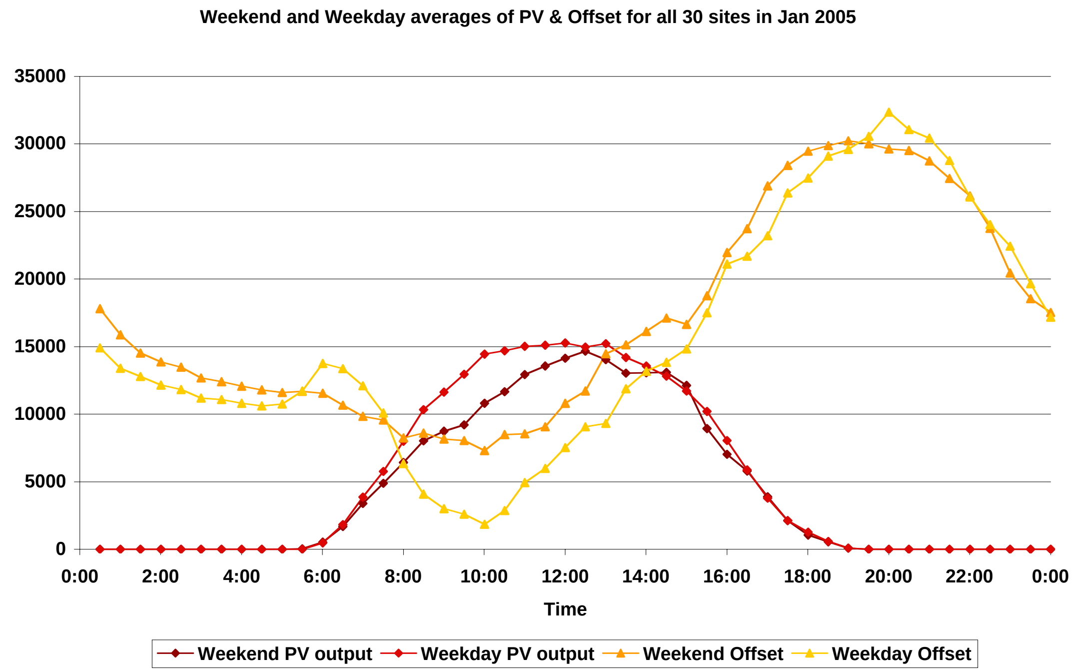
Average January Profiles for total of all 30 Sites

Average Day for total of all 30 sites in Jan 2005

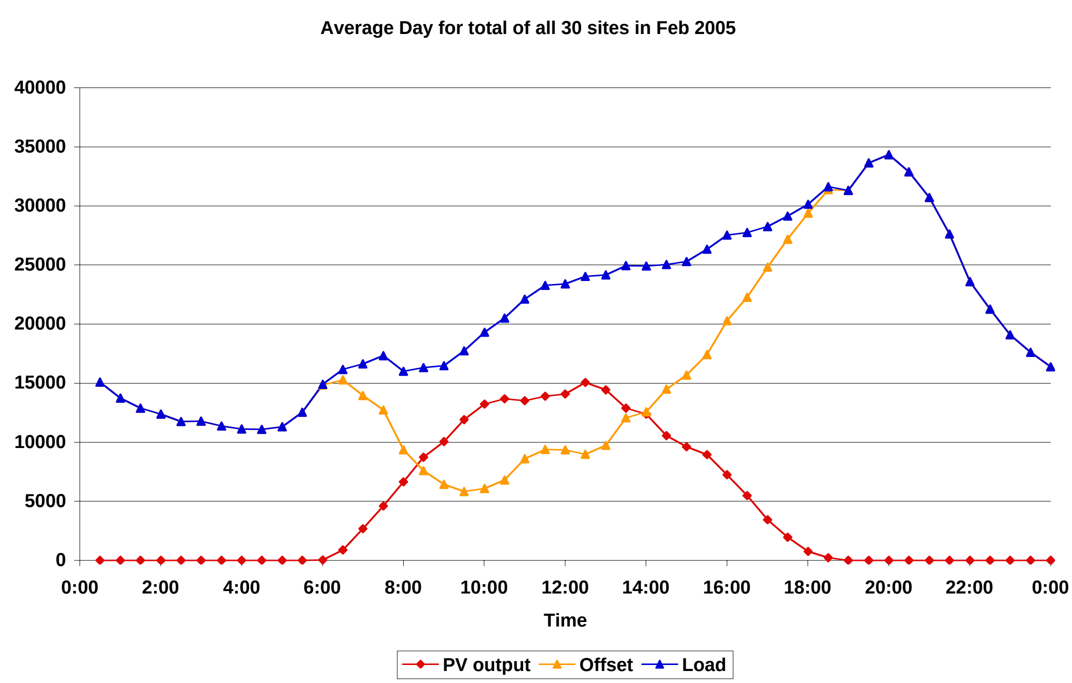


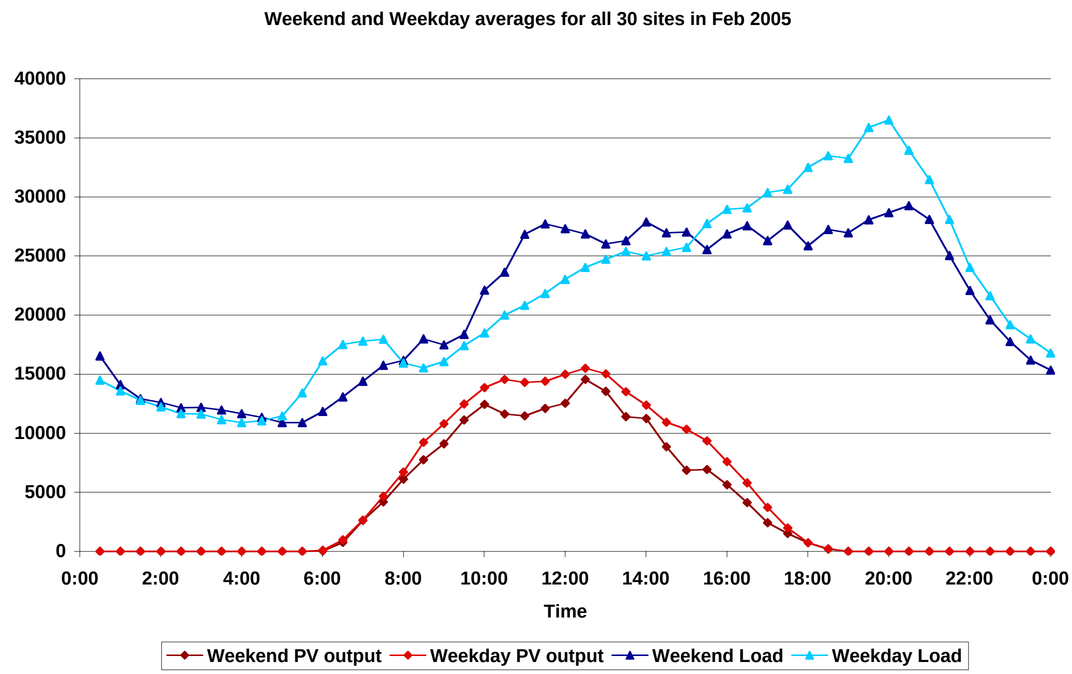
Weekend and Weekday averages for all 30 sites in Jan 2005





Average February Profiles for total of all 30 Sites




Weekend and Weekday averages for all 30 sites in Feb 2005
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30000
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15000
10000
5000
0
0:00
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4:00
6:00
8:00
10:00
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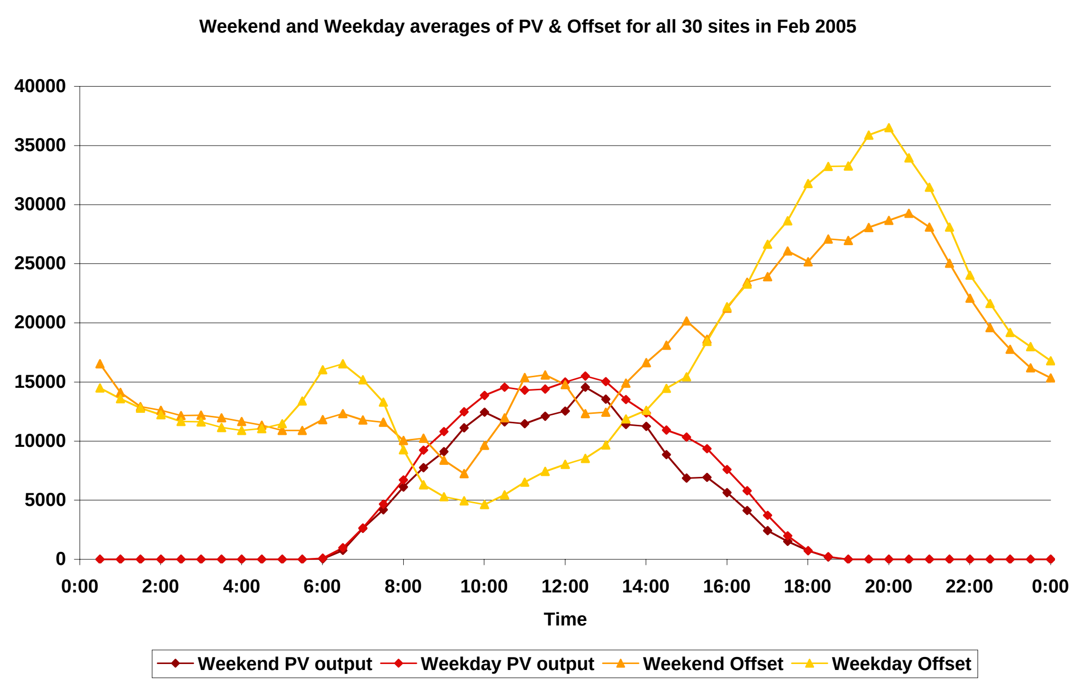
22:00
0:00
Time
Weekend PV output
Weekday PV output
Weekend Load
Weekday Load


Weekend and Weekday averages of PV & Offset for all 30 sites in Feb 2005
40000
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30000
25000
20000
15000
10000
5000
0
0:00
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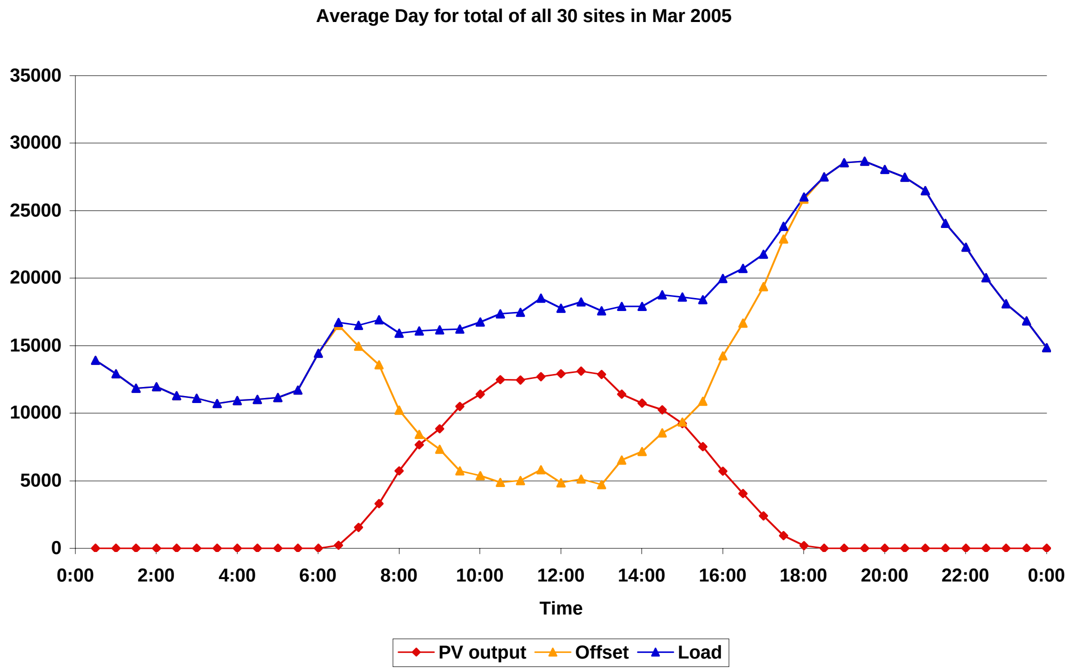
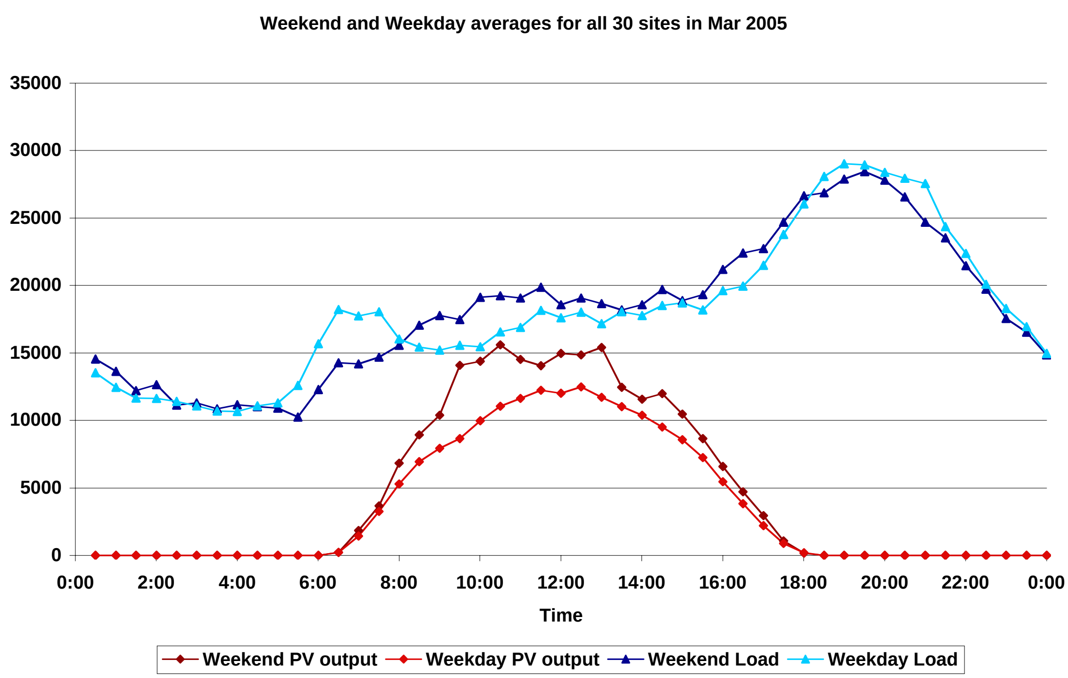
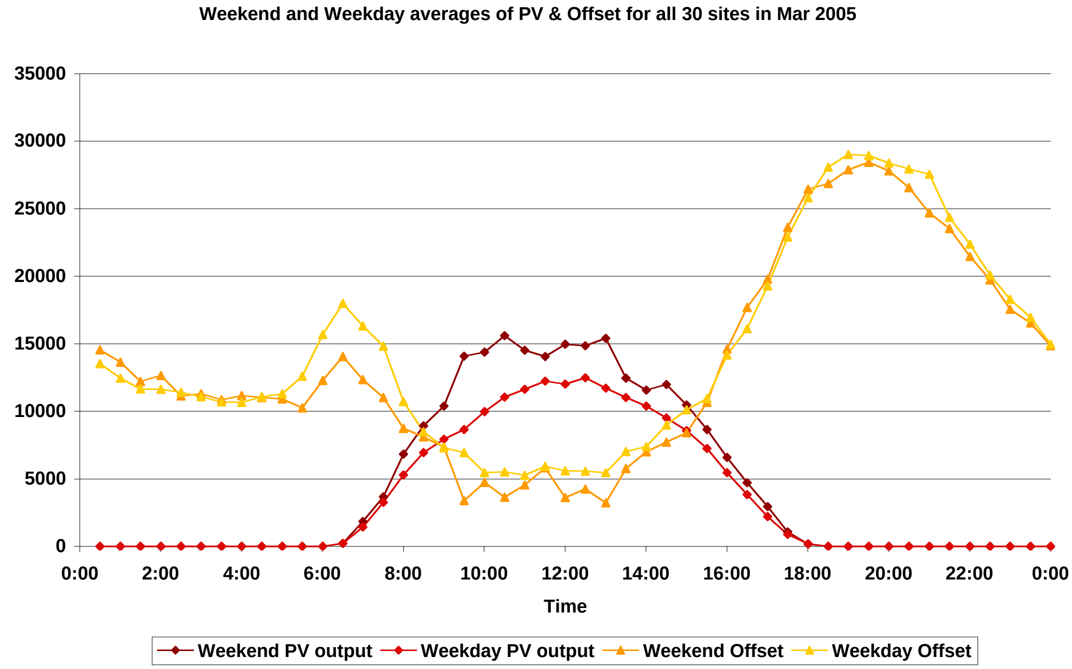
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Weekend PV output
Weekday PV output
Weekend Offset
Weekday Offset

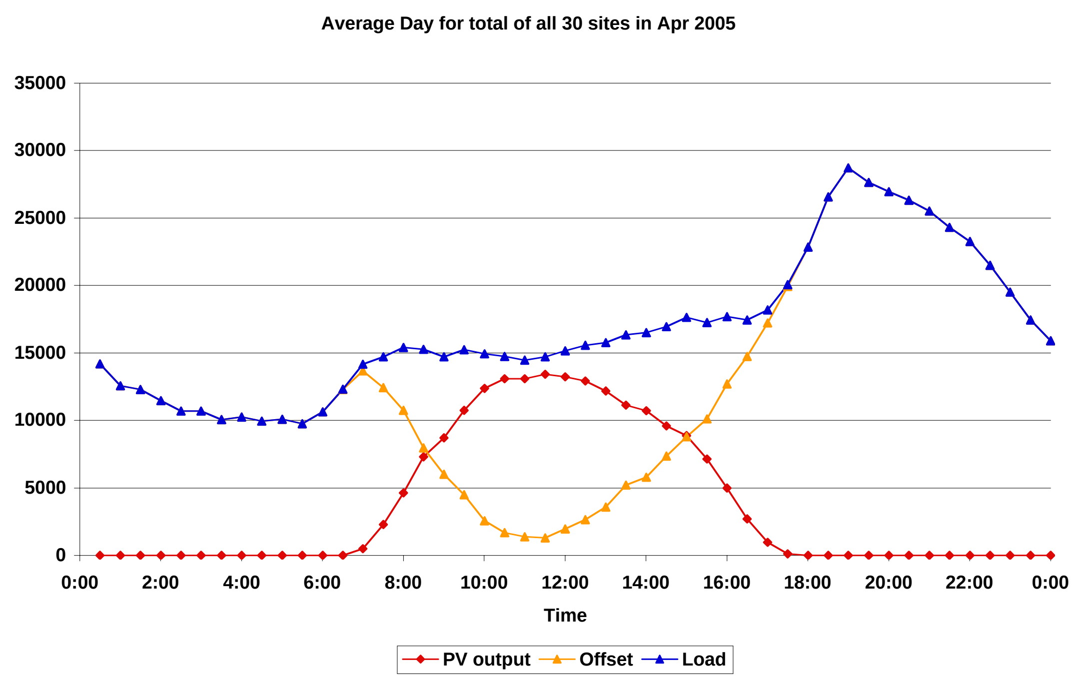
Average March Profiles for total of all 30 Sites

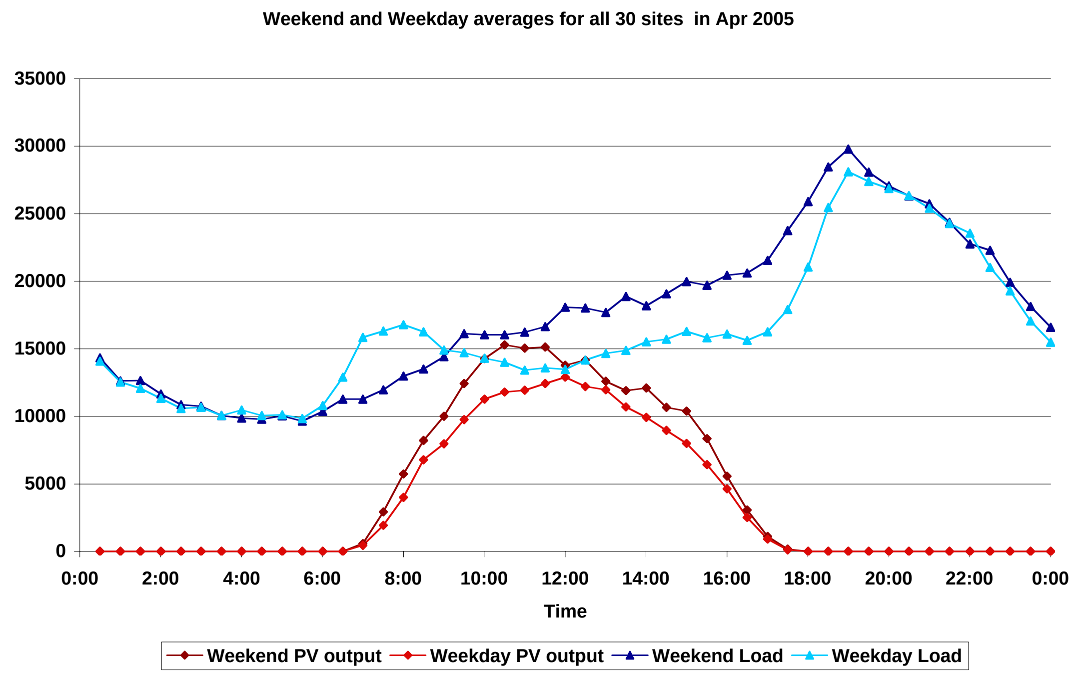


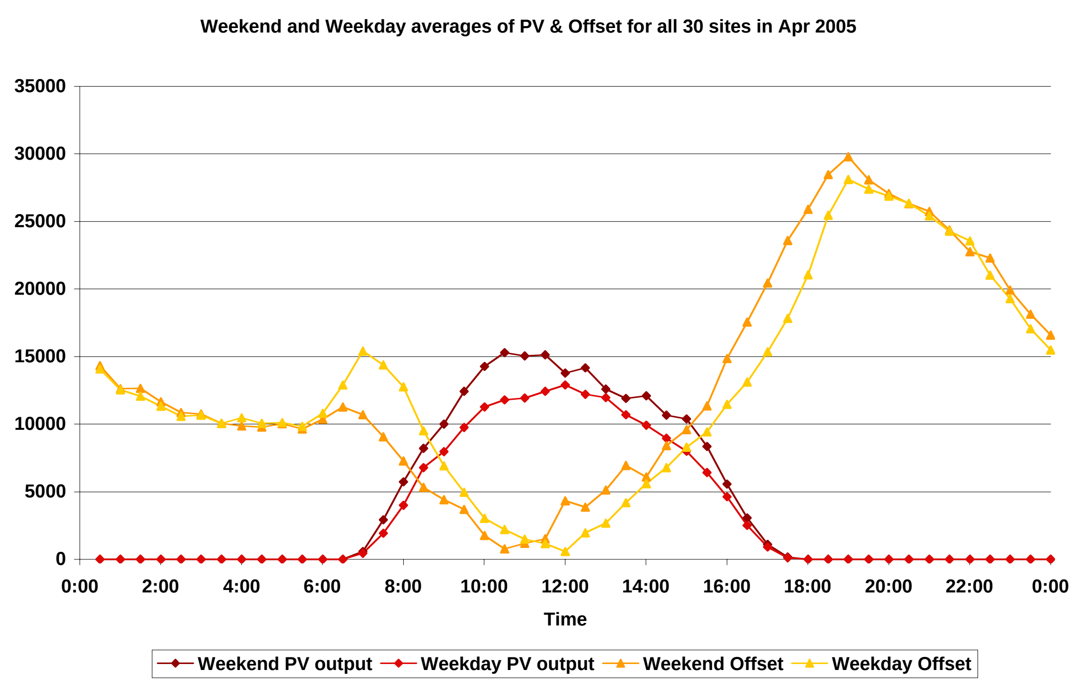




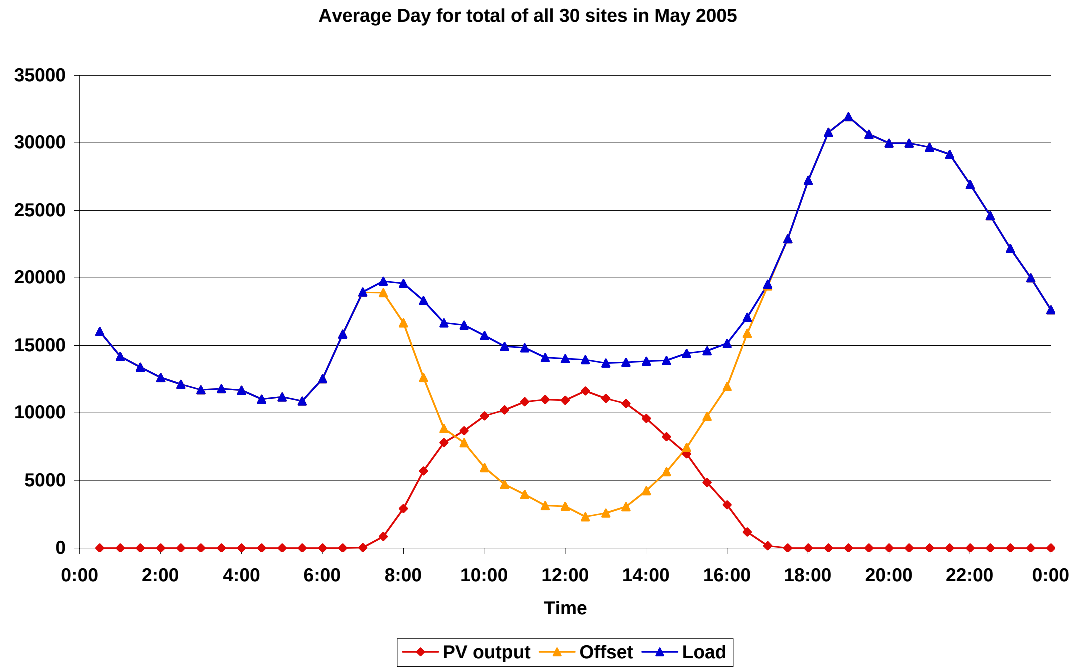
Average April Profiles for total of all 30 Sites

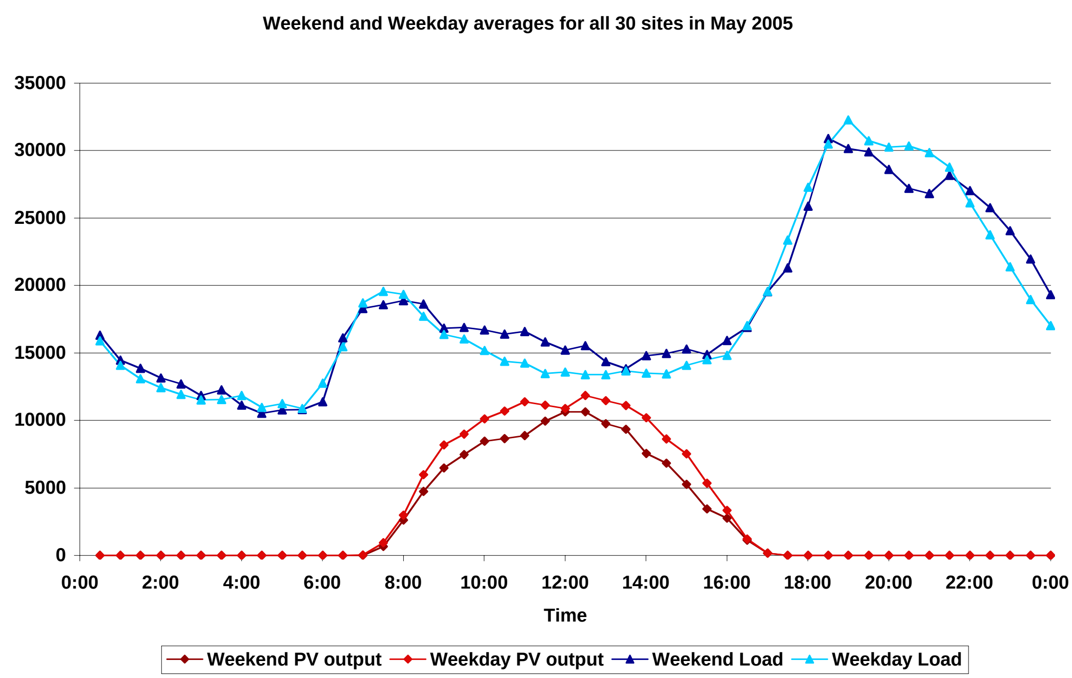


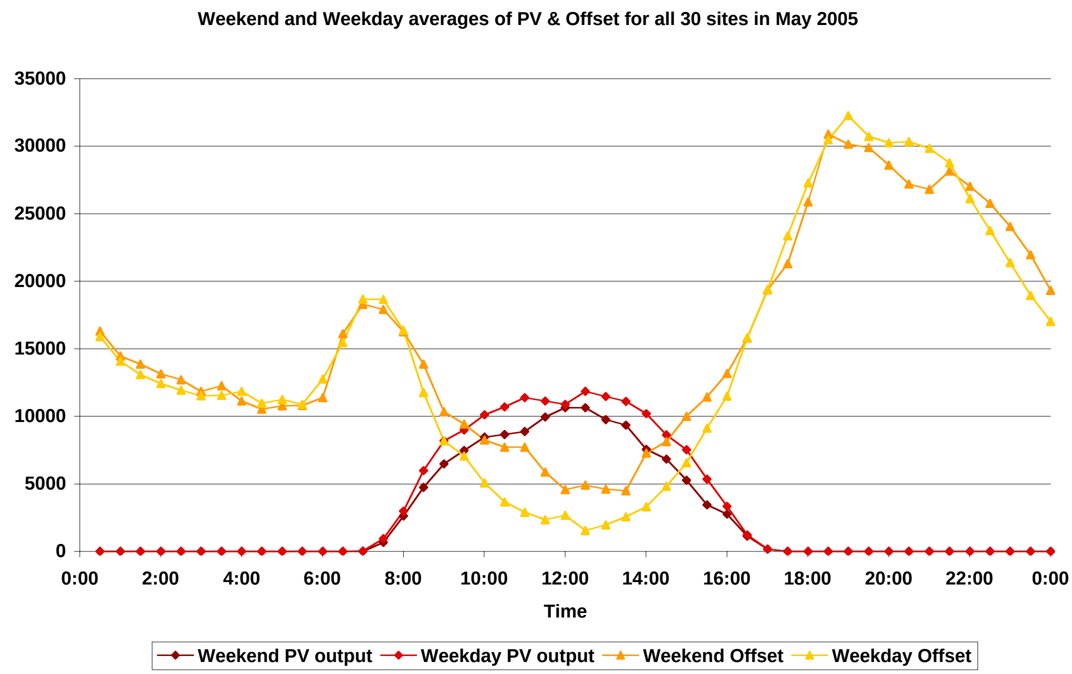

Weekend and Weekday averages for all 30 sites in Apr 2005
35000
30000
25000
20000
15000
10000
5000
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Weekend PV output
Weekday PV output
Weekend Load
Weekday Load


Weekend and Weekday averages of PV & Offset for all 30 sites in Apr 2005
35000
30000
25000
20000
15000
10000
5000
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
Time
Weekend PV output
Weekday PV output
Weekend Offset
Weekday Offset

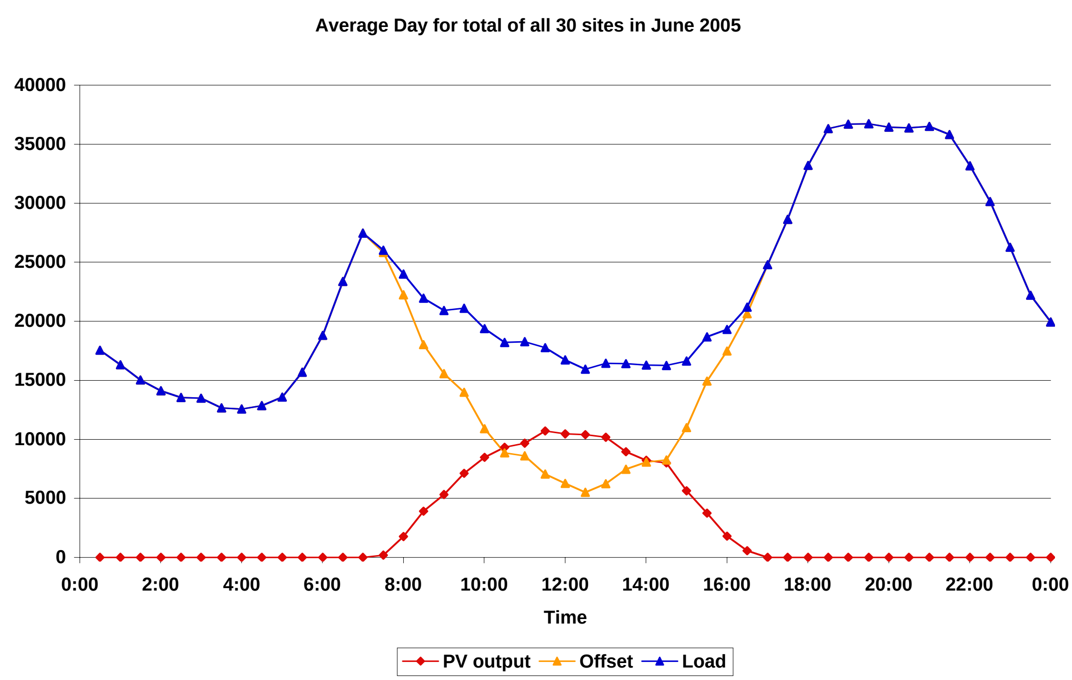
Average May Profiles for total of all 30 Sites



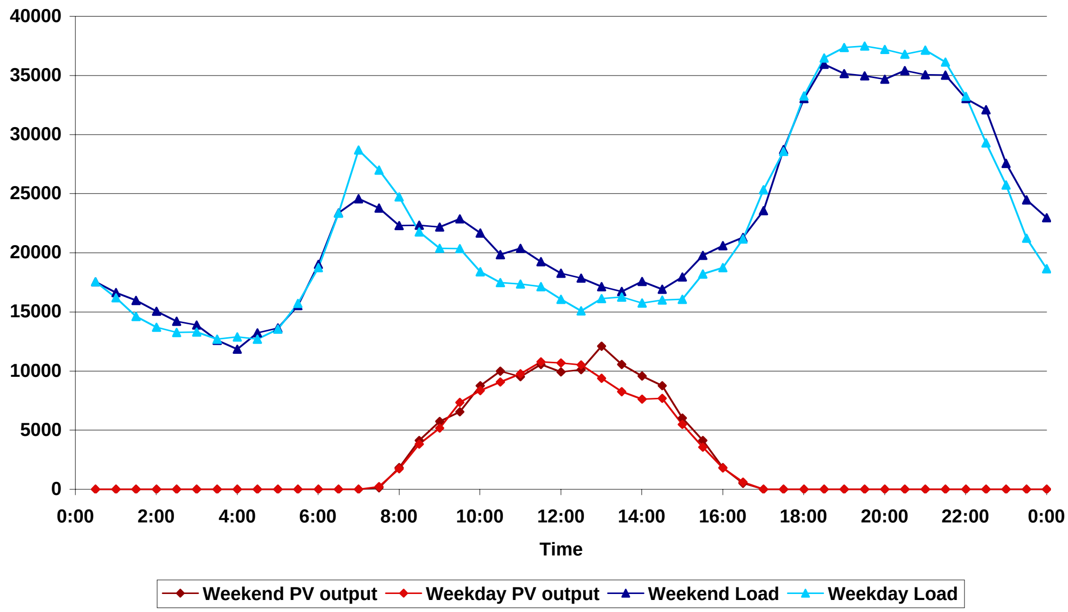




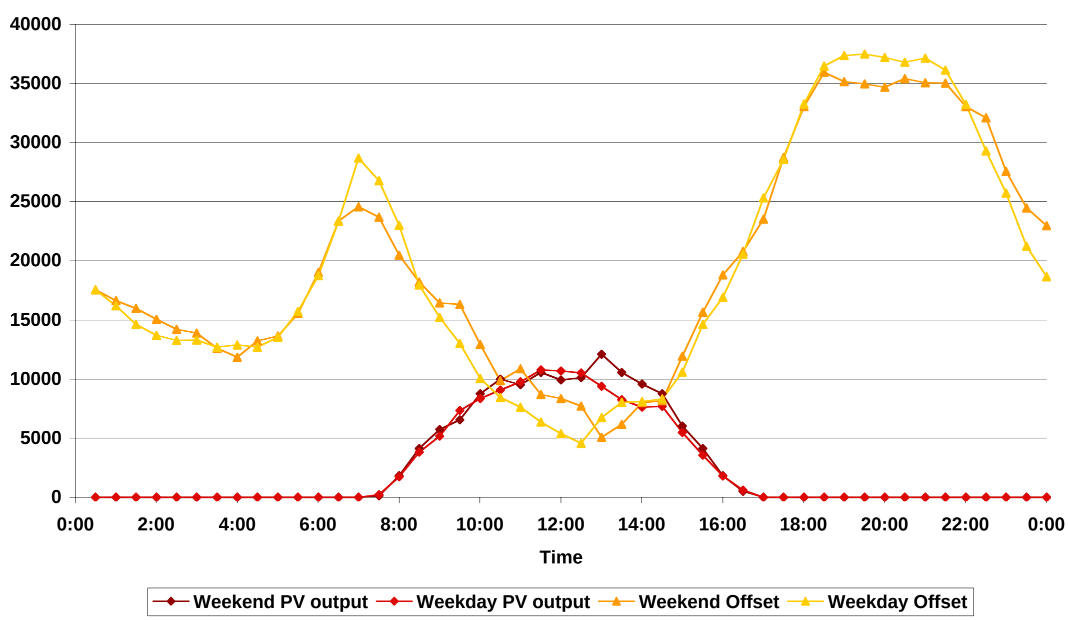
Average June Profiles for total of all 30 Sites



Weekend and Weekday averages for all 30 sites in June 2005

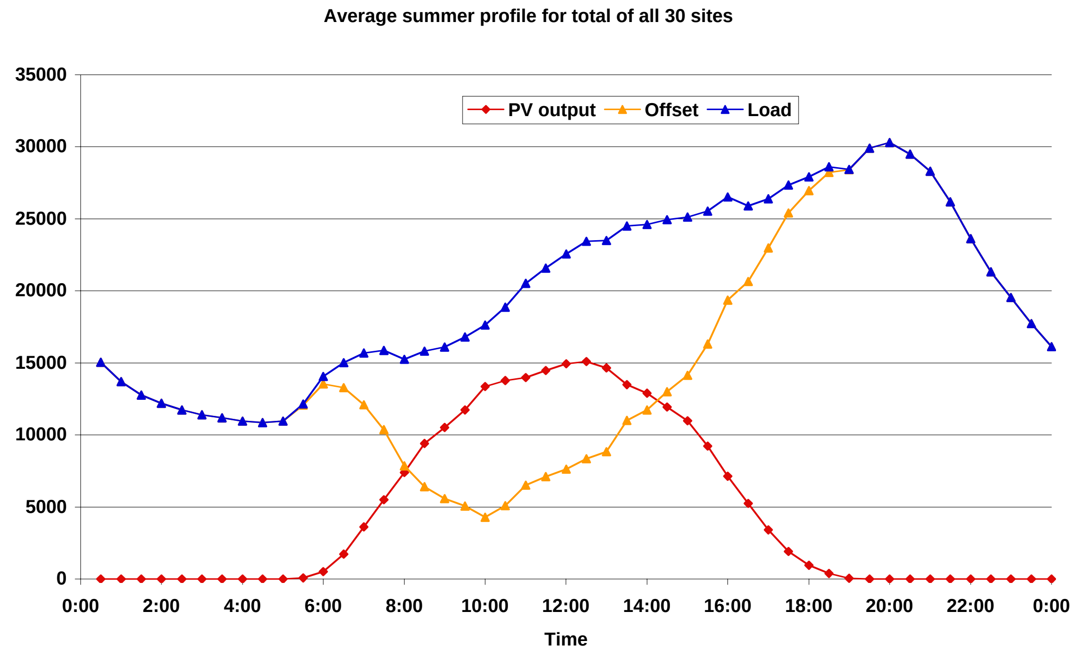


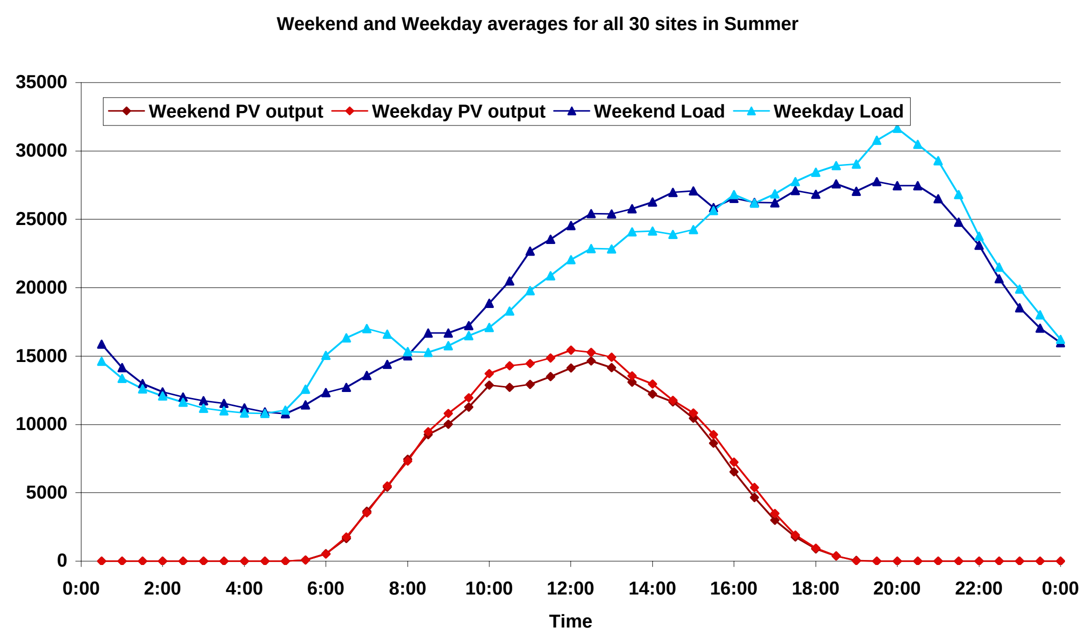
Weekend and Weekday averages of PV & Offset for all 30 sites in June 2005

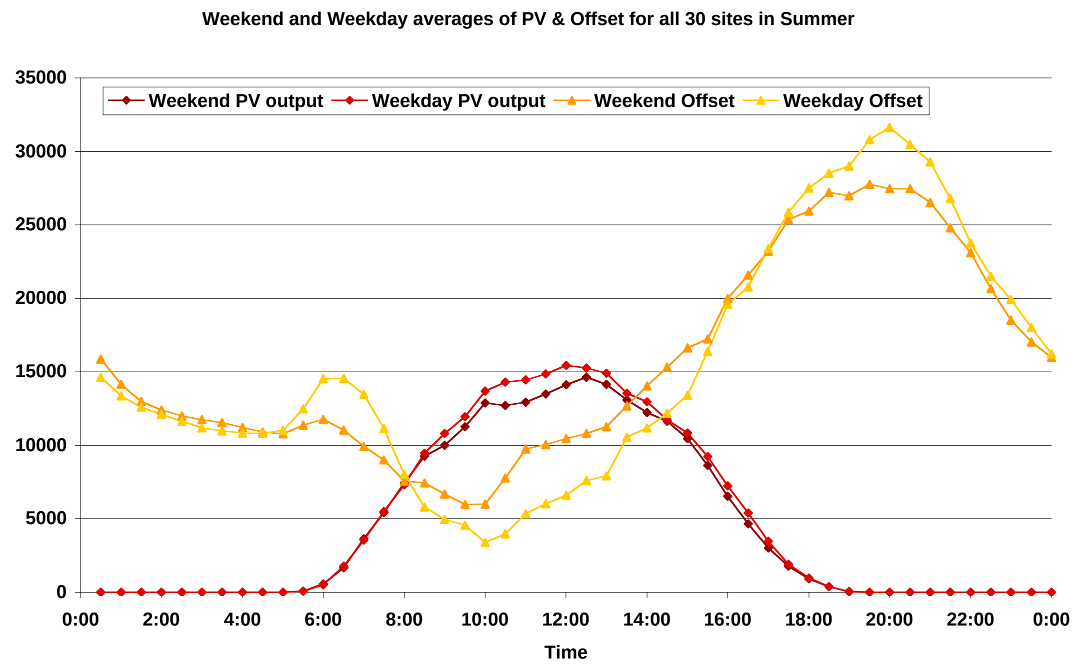


Appendix B

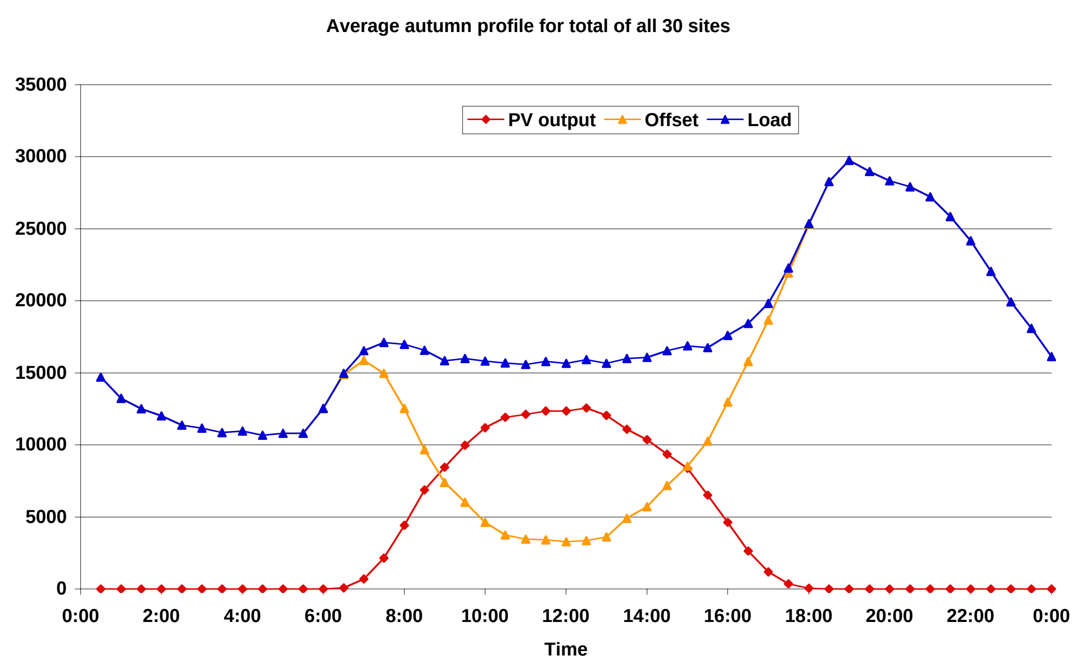
Average Summer Profiles for all 30 Sites



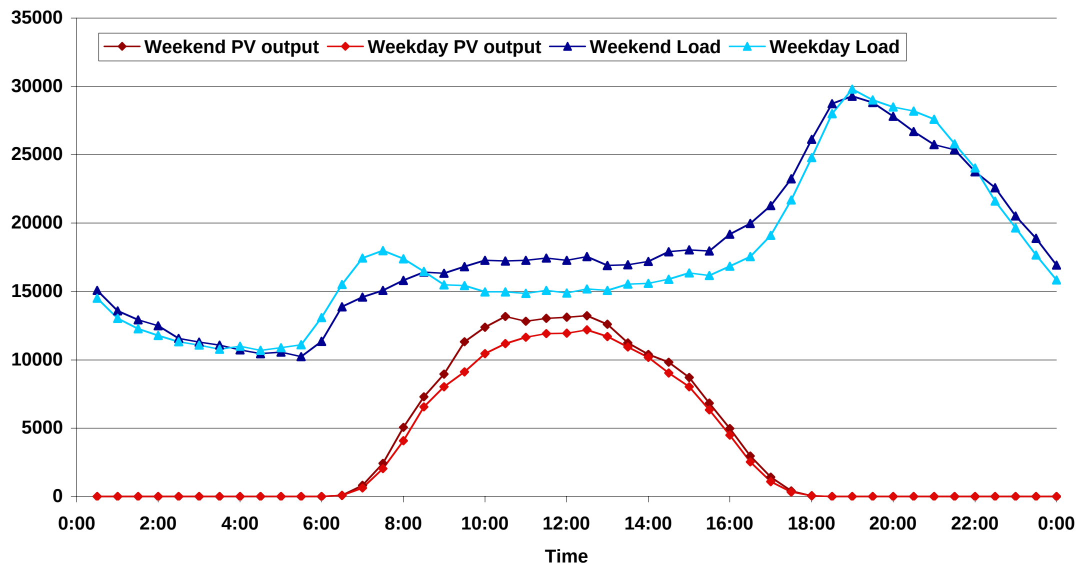




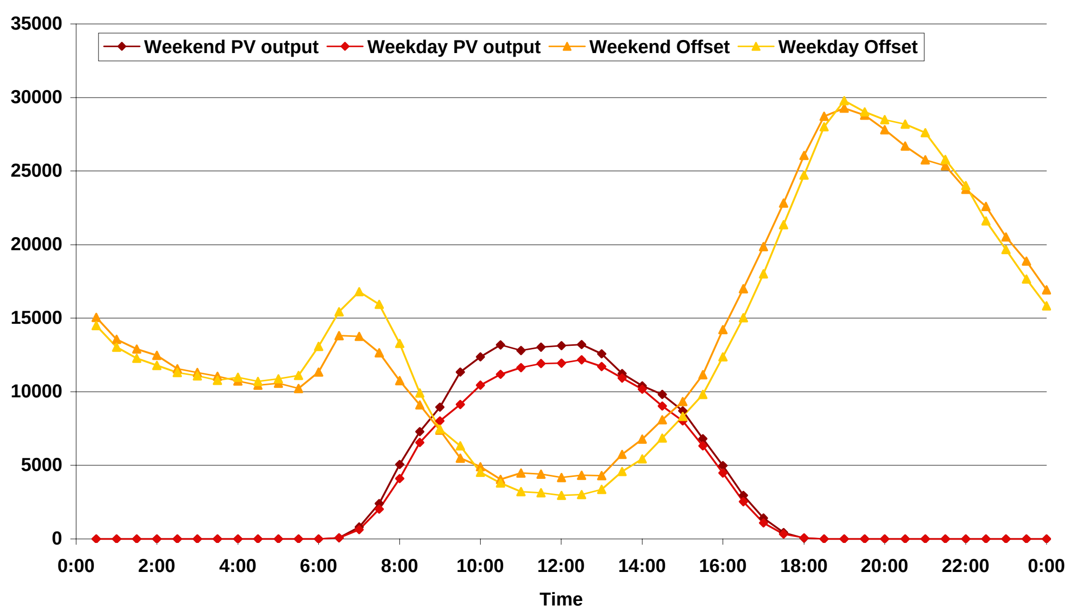
Average Autumn Profiles for all 30 Sites



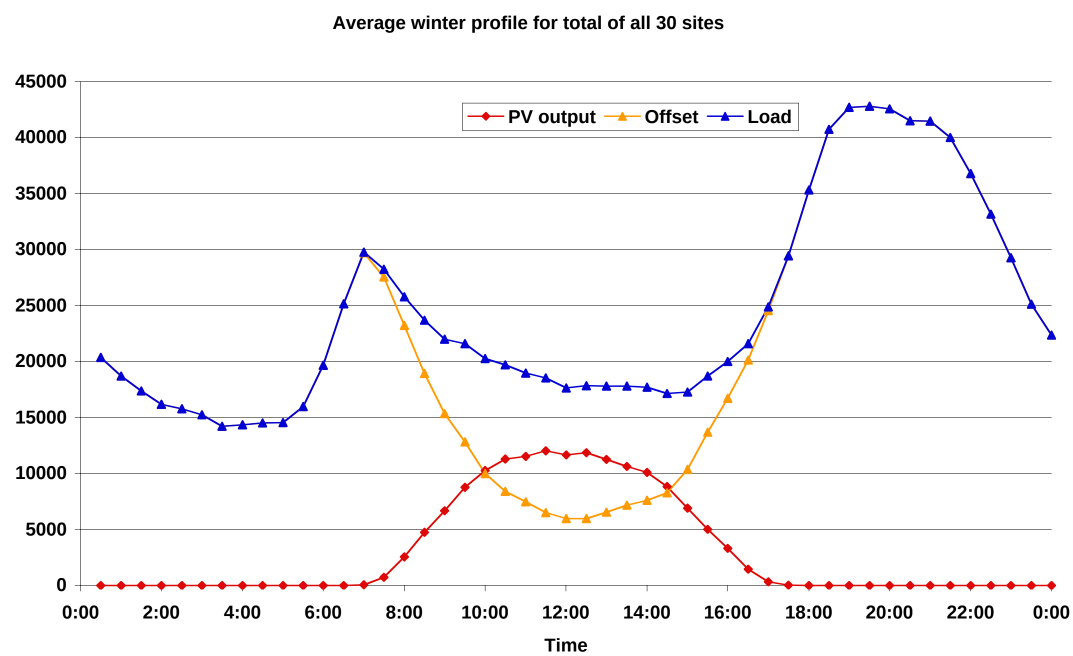
Weekend and Weekday averages for all 30 sites in Autumn

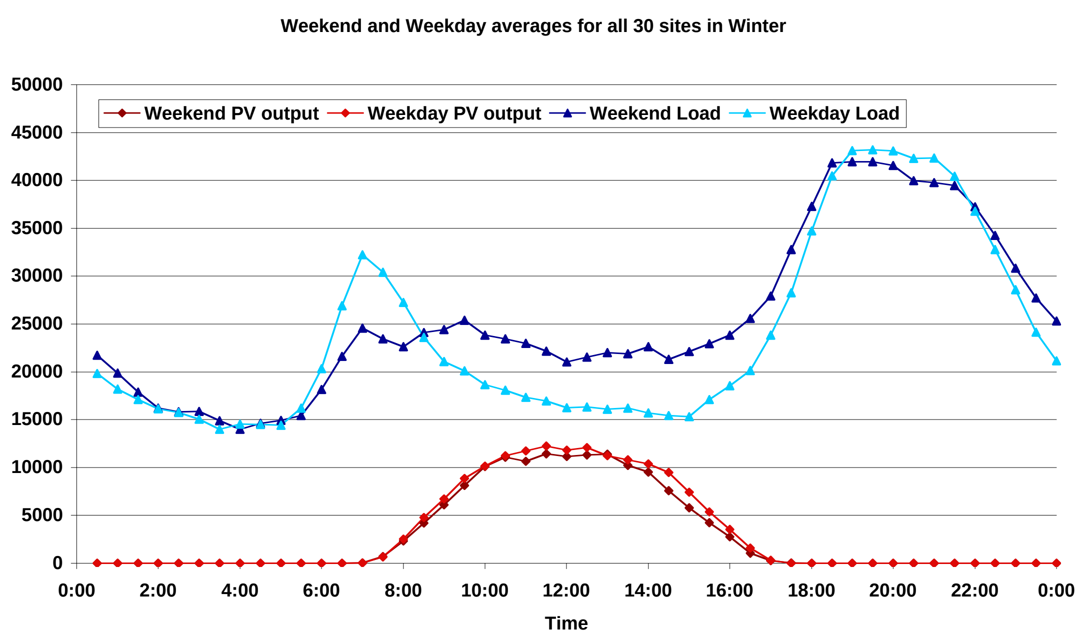


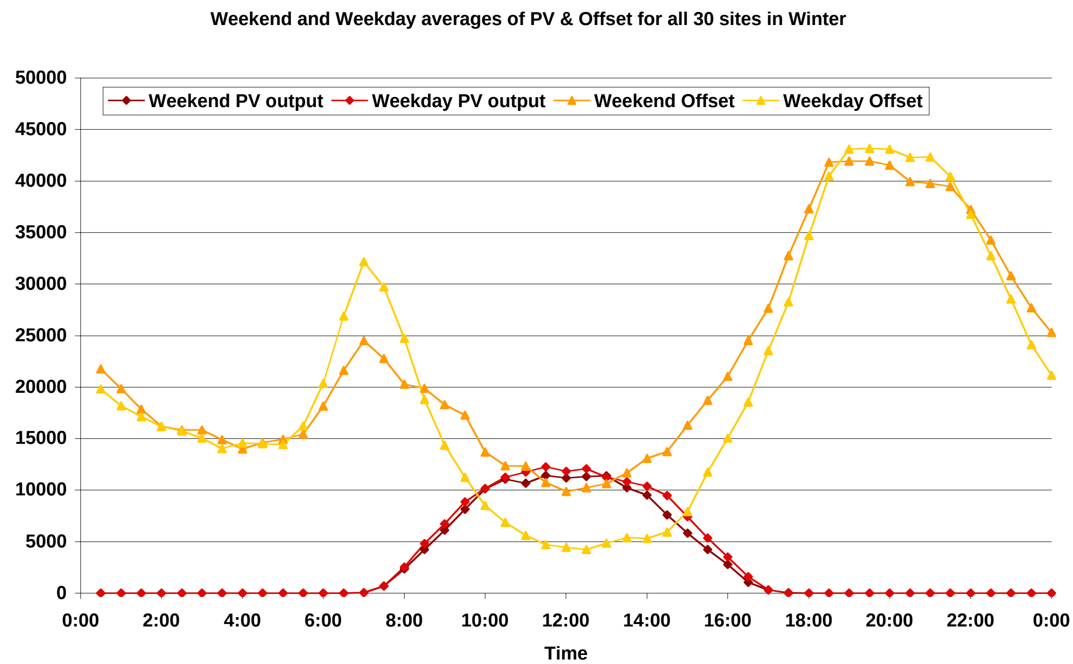
Weekend and Weekday averages of PV & Offset for all 30 sites in Autumn



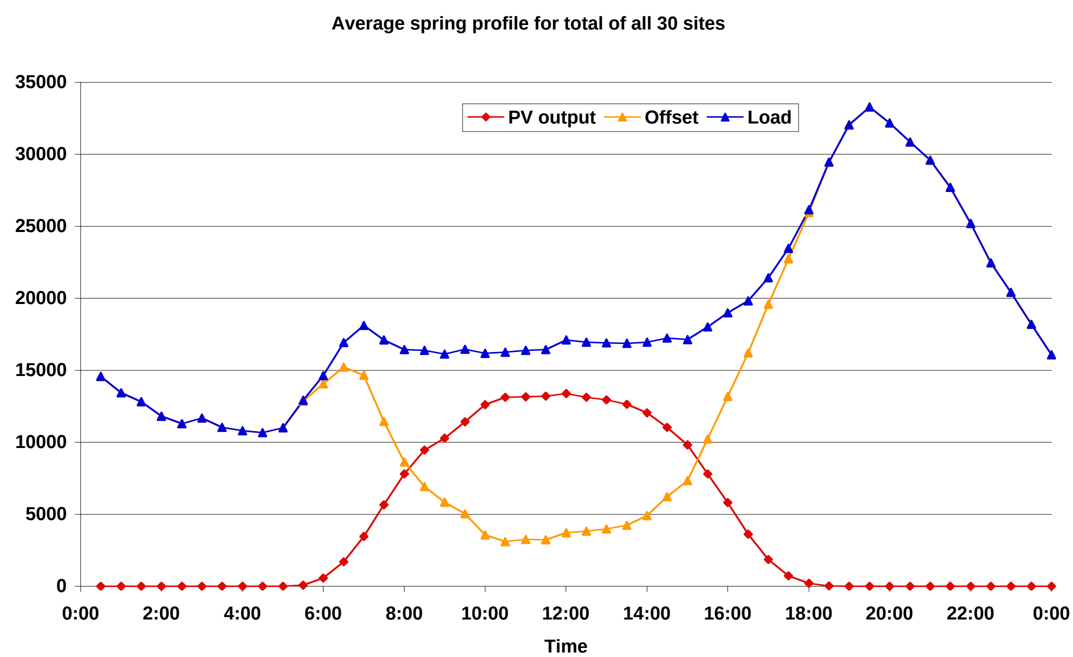
Average Winter Profiles for all 30 Sites



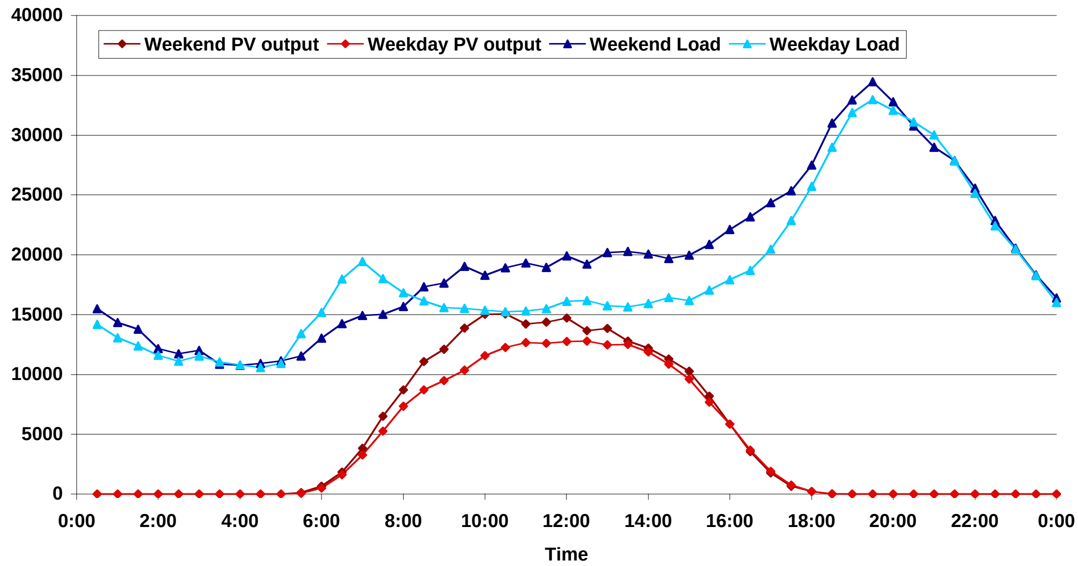




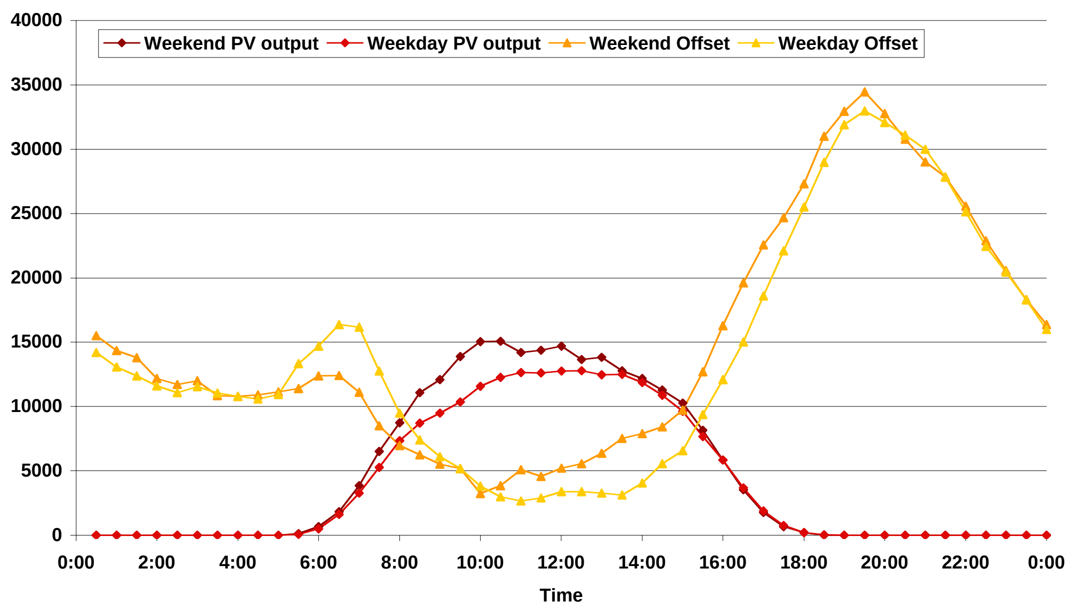
Average Spring Profiles for all 30 Sites



Weekend and Weekday averages for all 30 sites in Spring

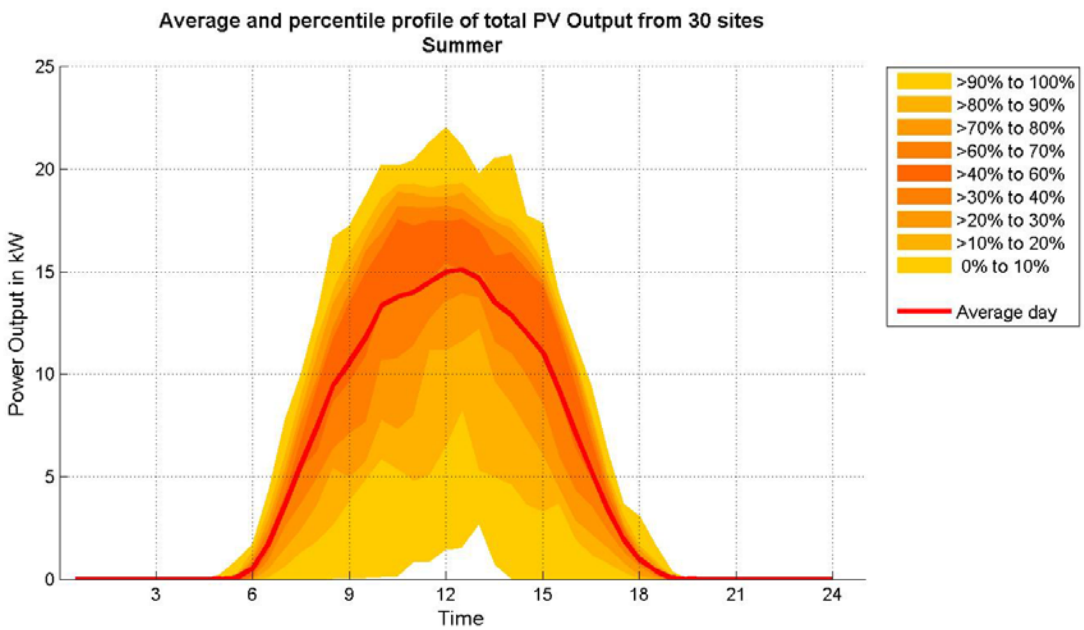


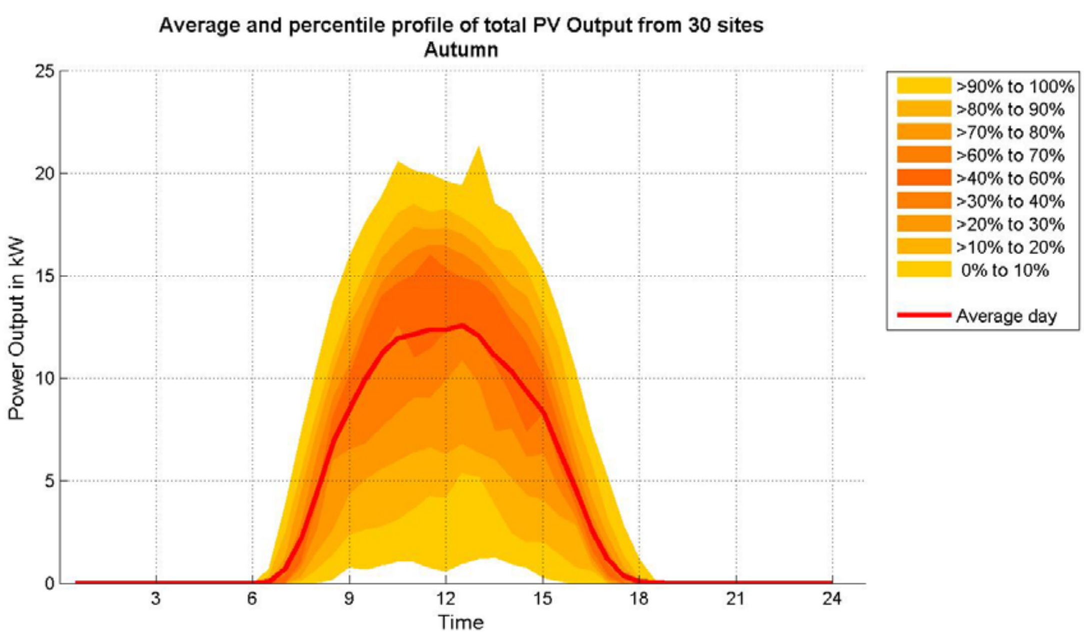
Weekend and Weekday averages of PV & Offset for all 30 sites in Spring

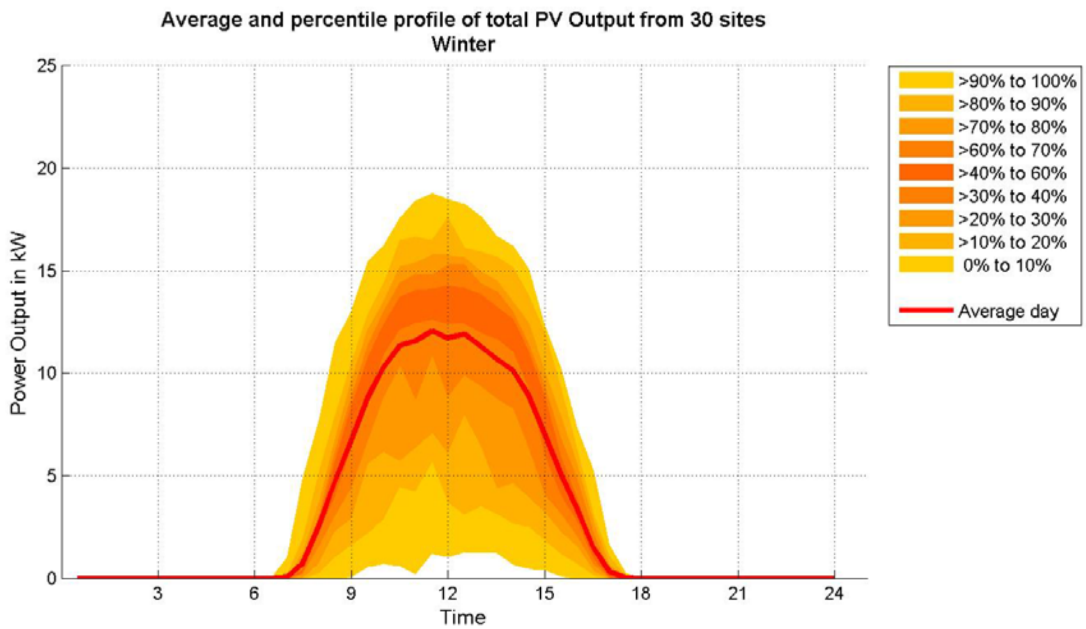


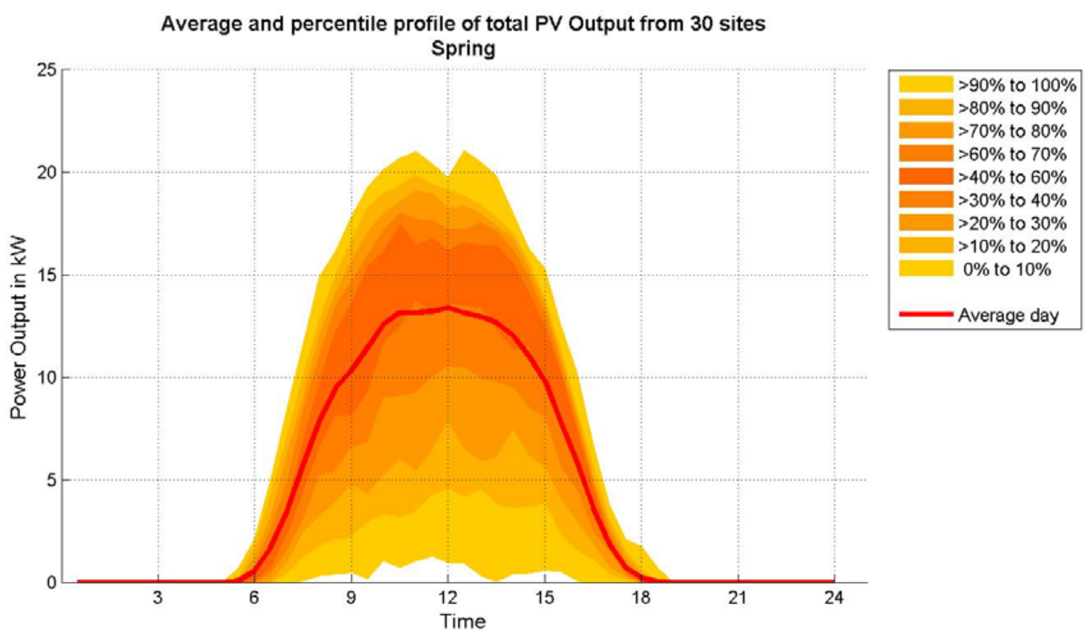
Appendix C

Seasonal average and percentile profiles of total PV output from 30 sites



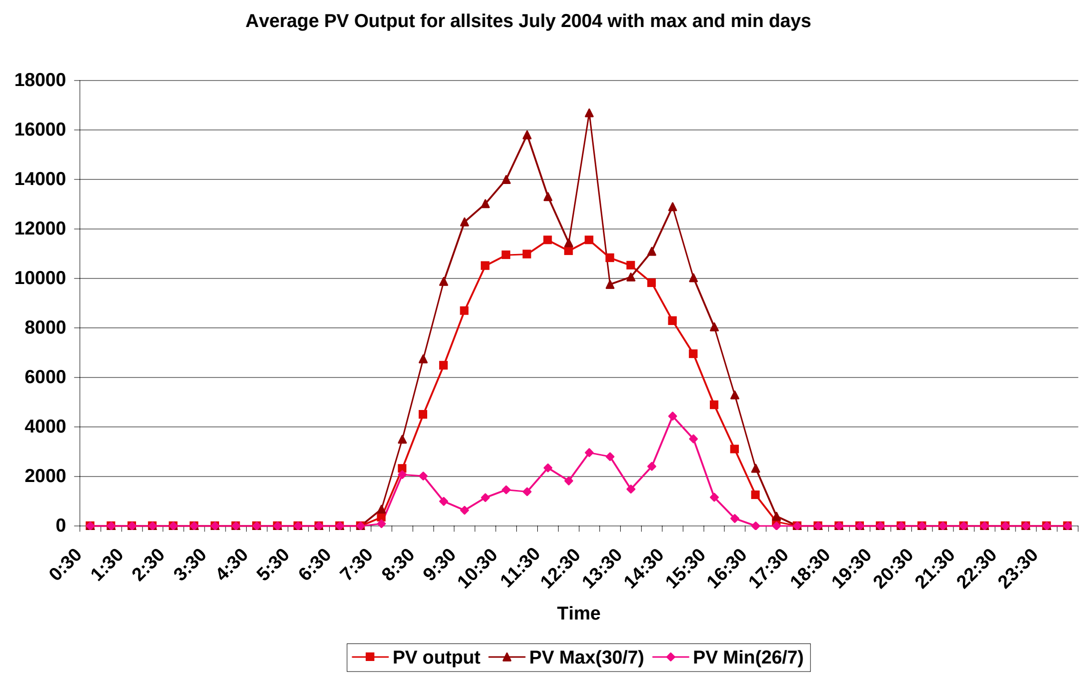


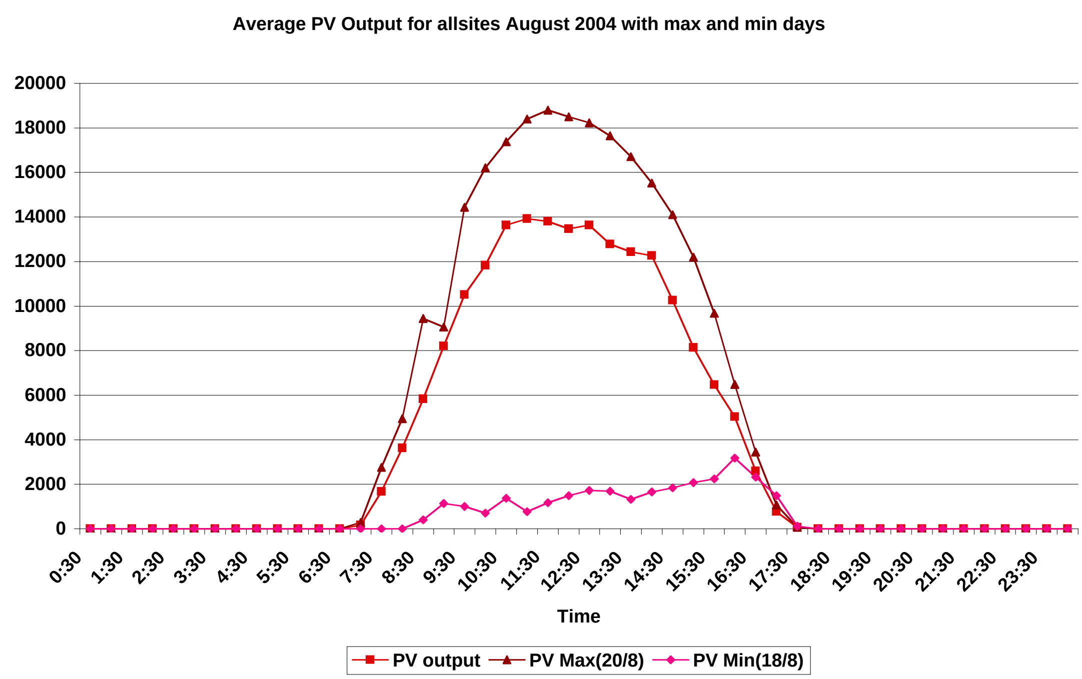

Average and percentile profile of total PV Output from 30 sites
Winter
Power Output in kW
Time
>90% to 100%
>80% to 90%
>70% to 80%
>60% to 70%
>40% to 60%
>30% to 40%
>20% to 30%
>10% to 20%
0% to 10%
Average day

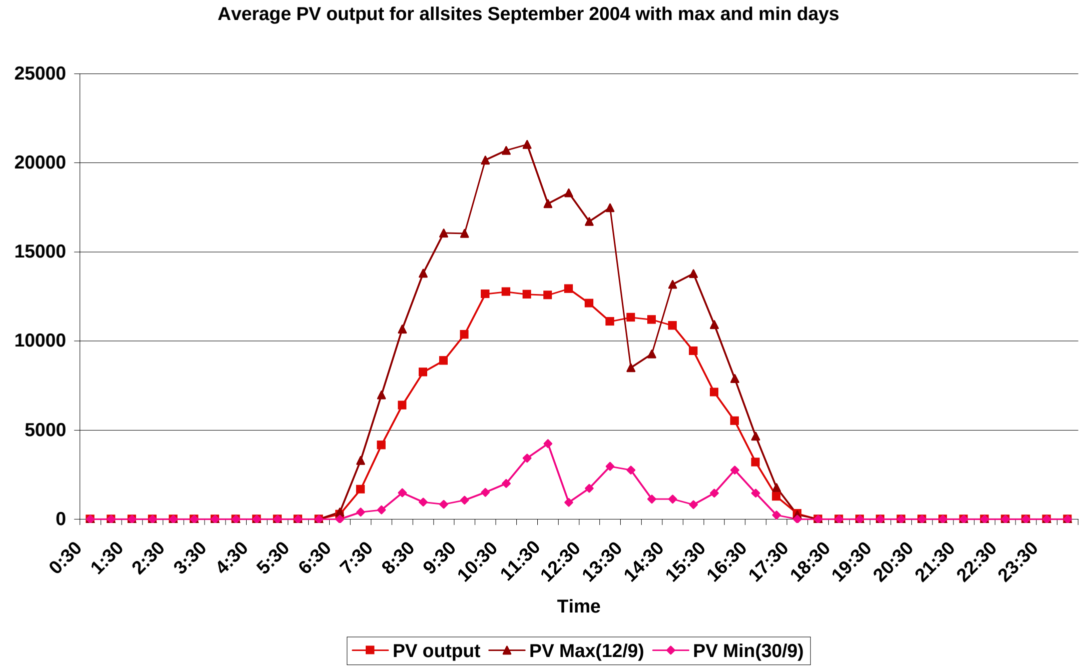

Average and percentile profile of total PV Output from 30 sites
Spring
Power Output in kW
Time
>90% to 100%
>80% to 90%
>70% to 80%
>60% to 70%
>40% to 60%
>30% to 40%
>20% to 30%
>10% to 20%
0% to 10%
Average day

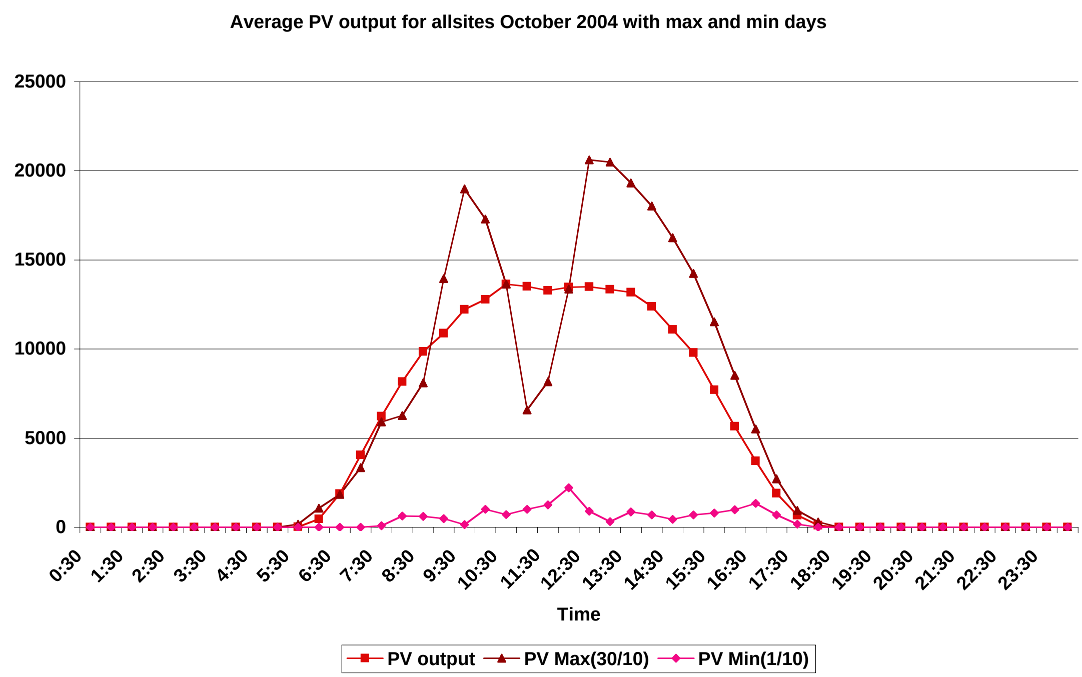
Appendix D

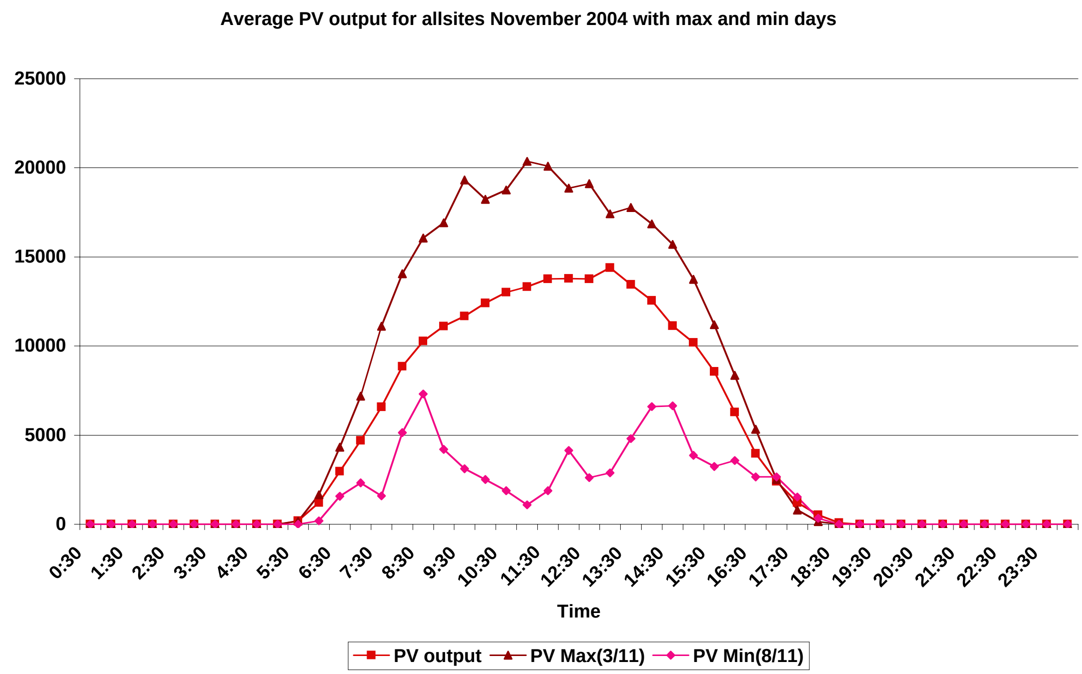
Monthly profiles of total PV output averaged for 30 sites with max and min

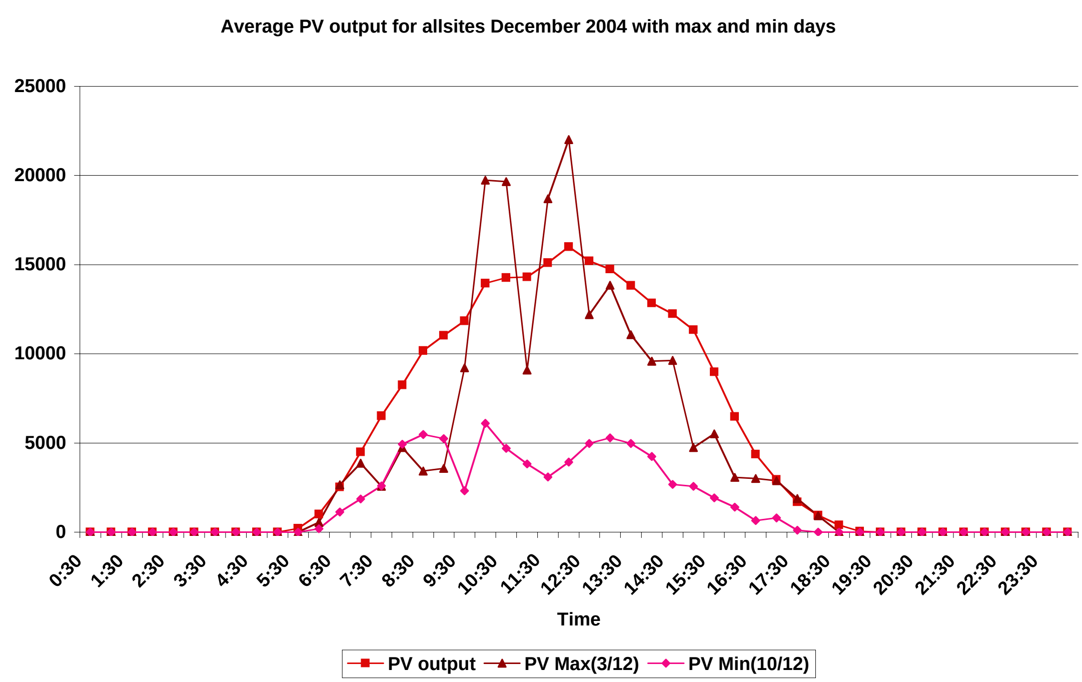


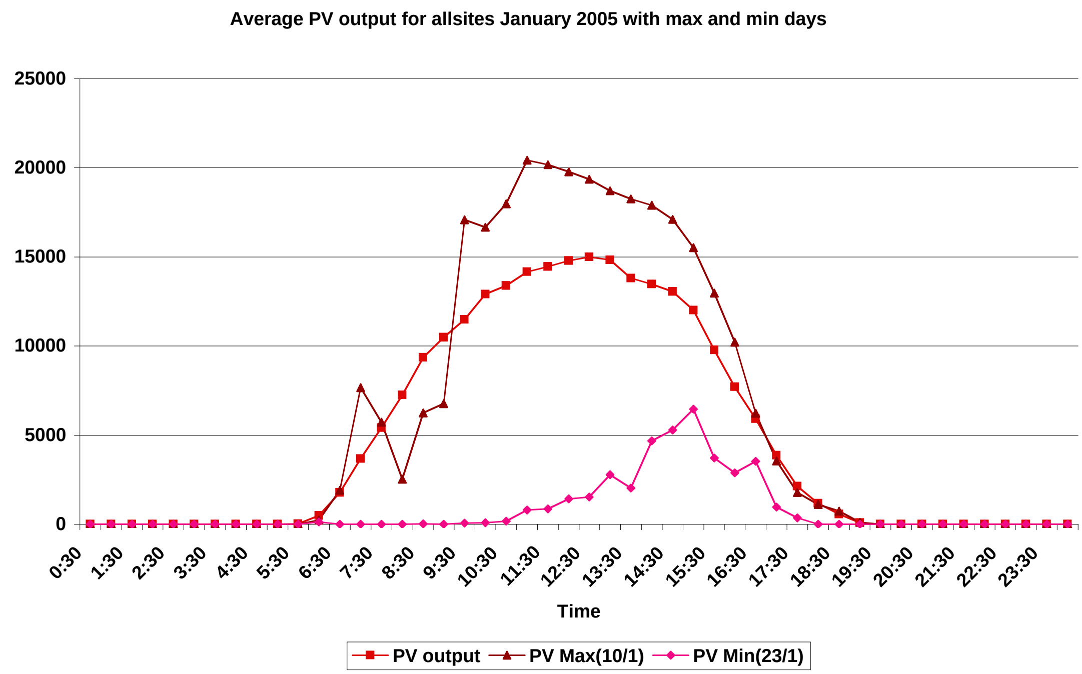



Average PV output for allsites September 2004 with max and min days
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(12/9)
PV Min(30/9)

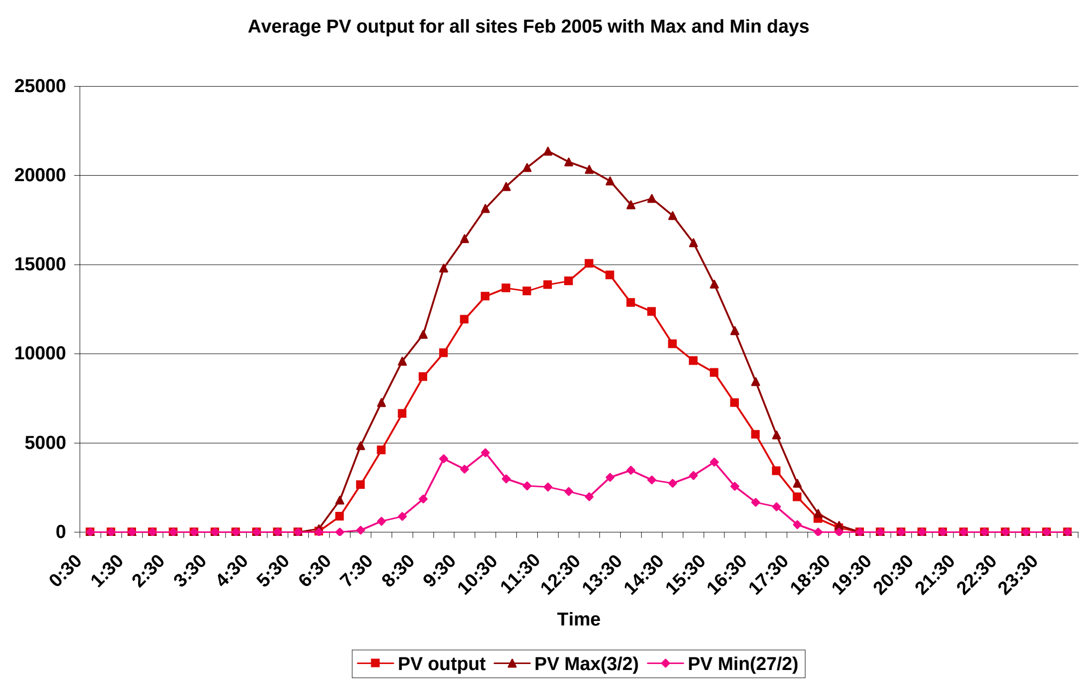

Average PV output for allsites October 2004 with max and min days
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(30/10)
PV Min(1/10)


Average PV output for allsites November 2004 with max and min days
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(3/11)
PV Min(8/11)

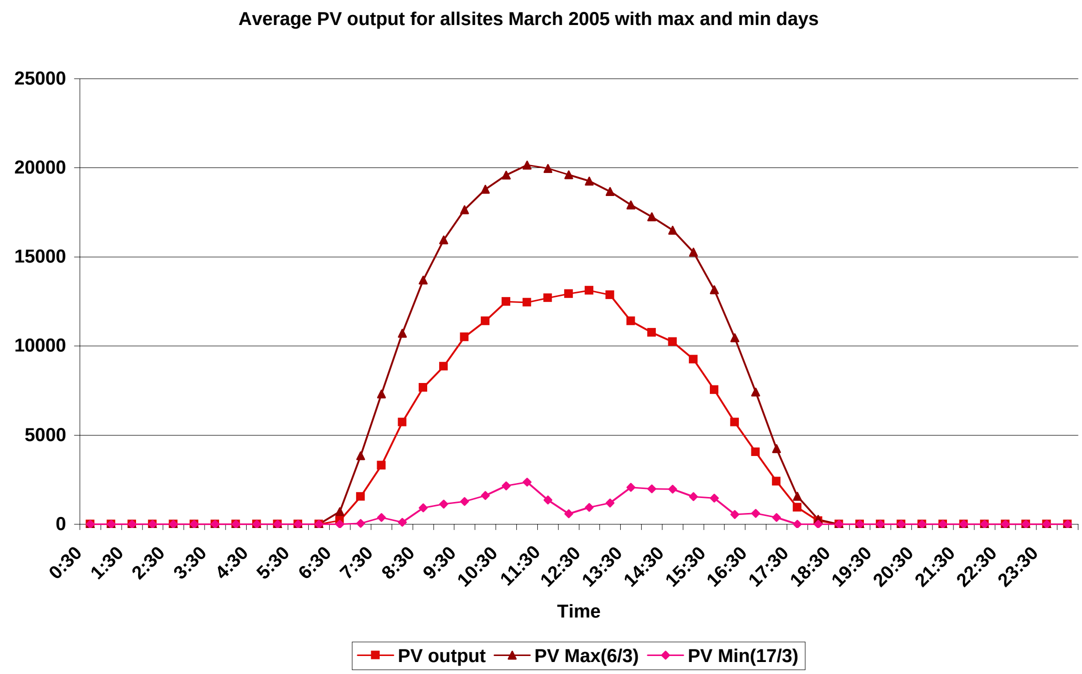

Average PV output for allsites December 2004 with max and min days
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(3/12)
PV Min(10/12)

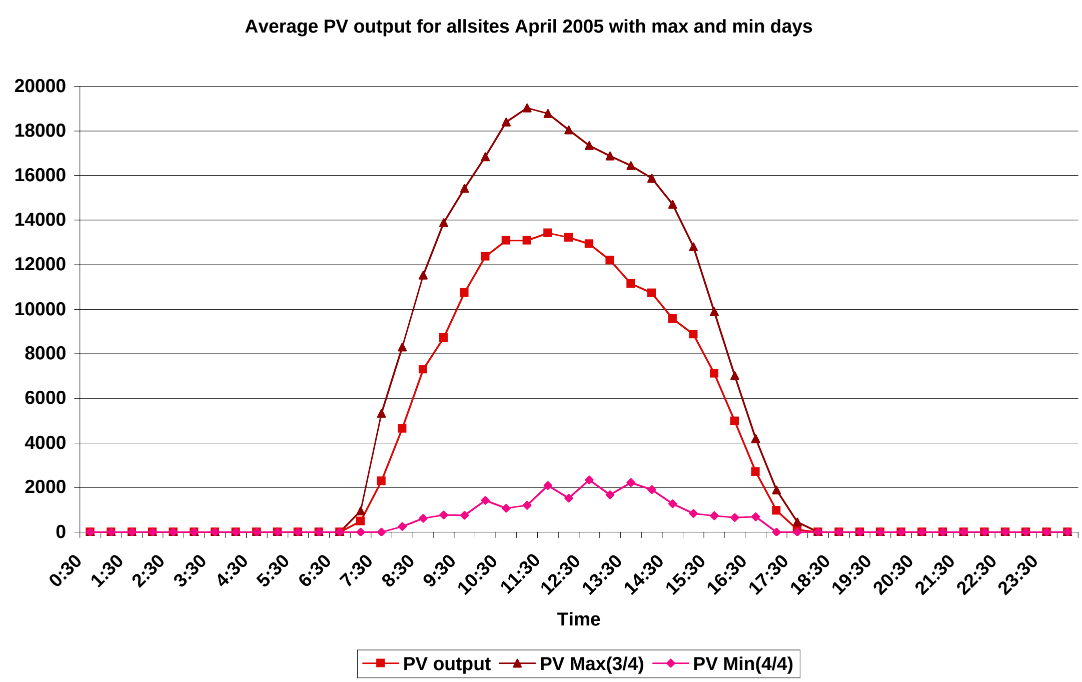


Average PV output for allsites January 2005 with max and min days
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(10/1)
PV Min(23/1)

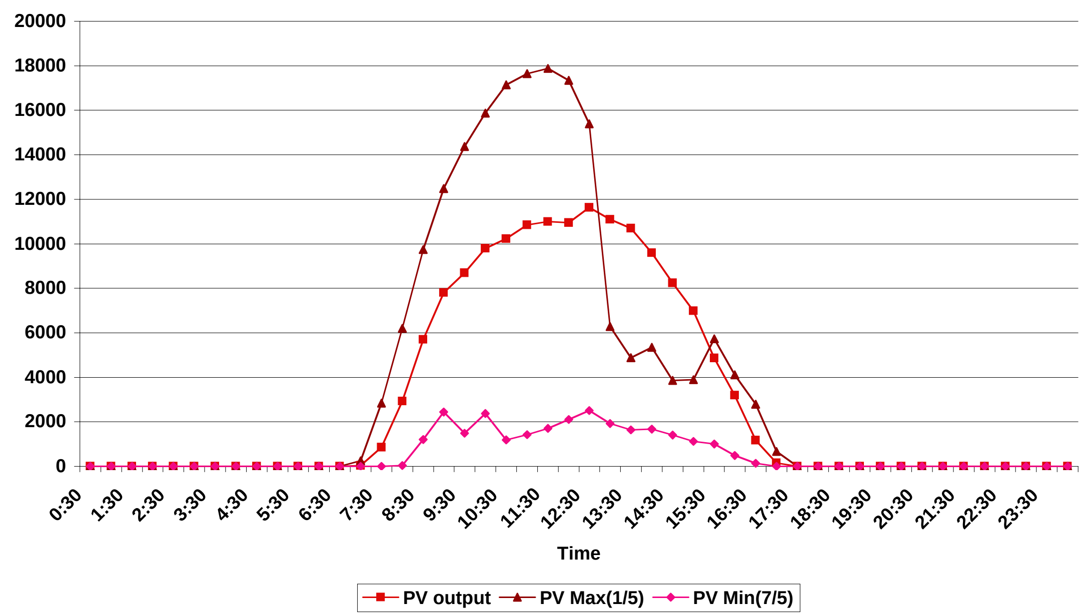


Average PV output for all sites Feb 2005 with Max and Min days
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(3/2)
PV Min(27/2)

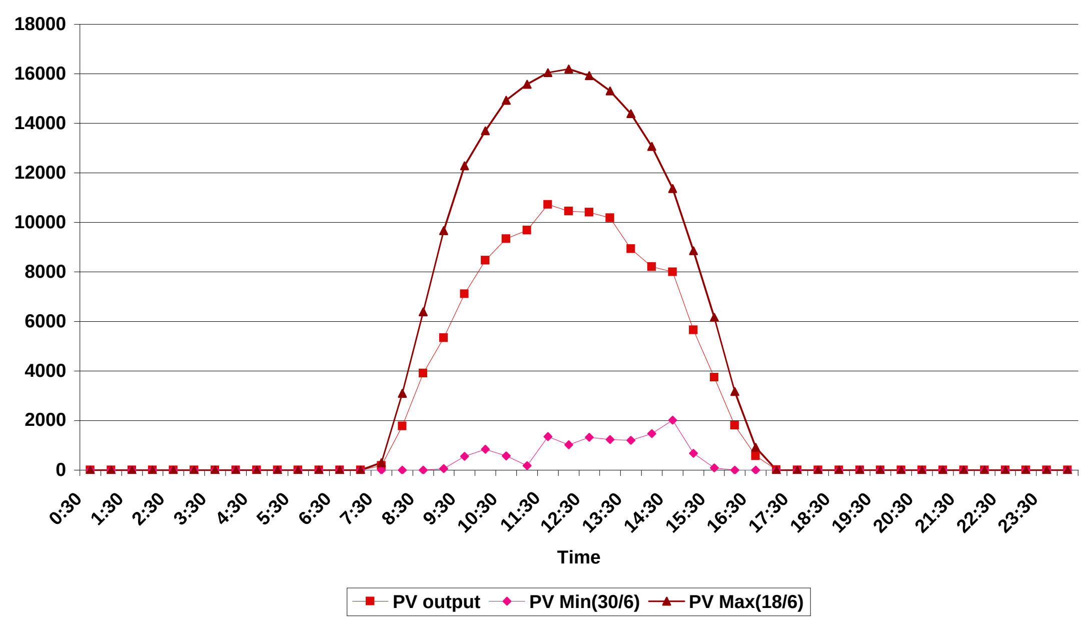

Average PV output for allsites March 2005 with max and min days
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(6/3)
PV Min(17/3)


Average PV output for allsites April 2005 with max and min days
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
PV output
PV Max(3/4)
PV Min(4/4)

Average PV output for allsites May 2005 with max and min days

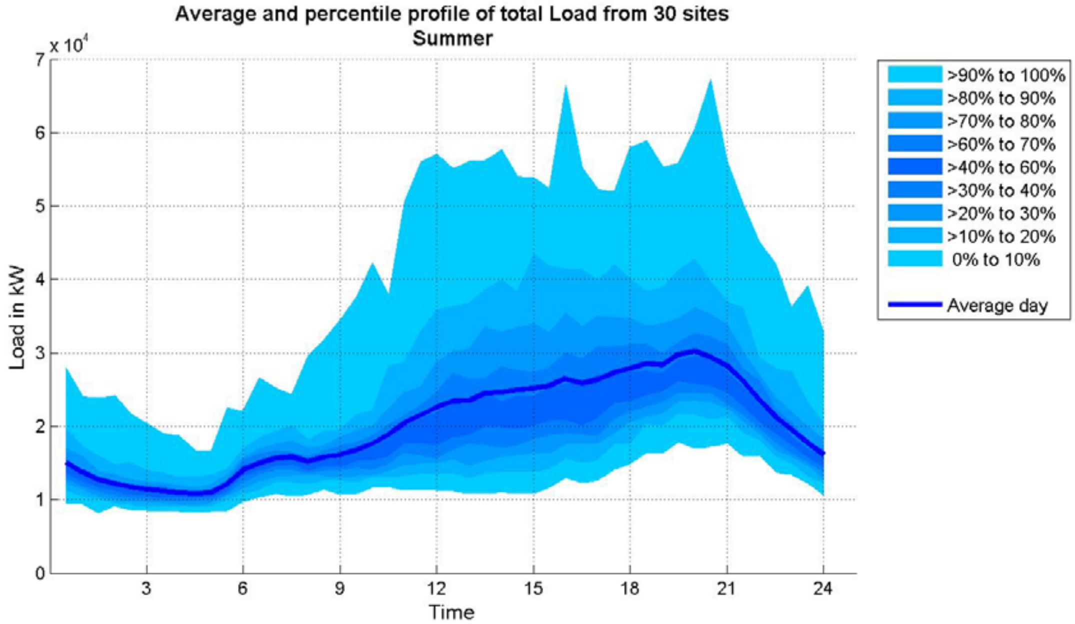


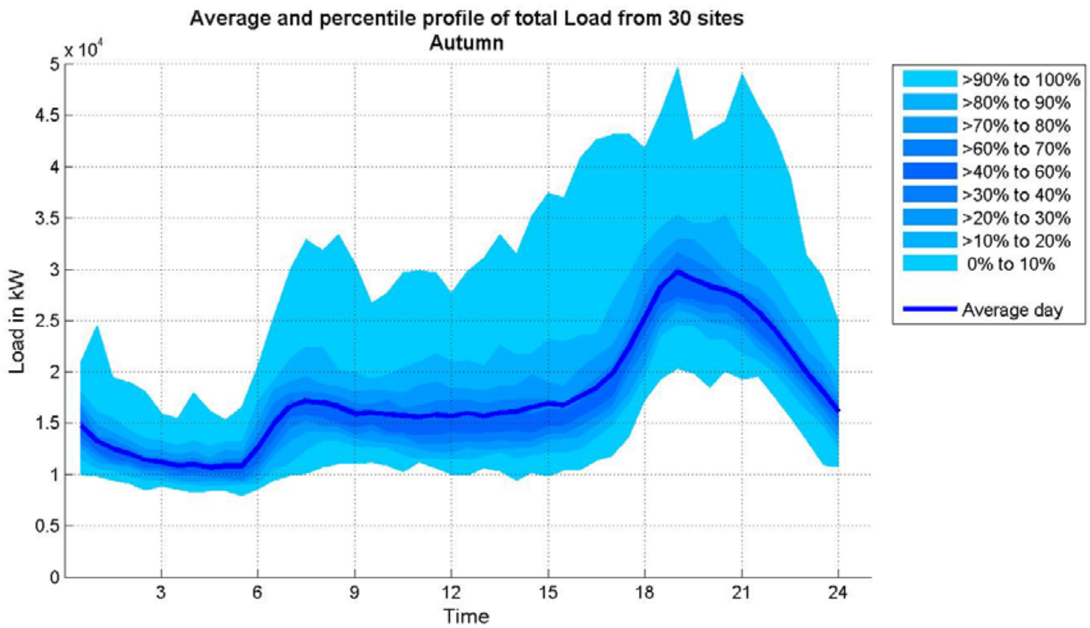
Average PV Output for allsites June 2005 with Min and Max Days

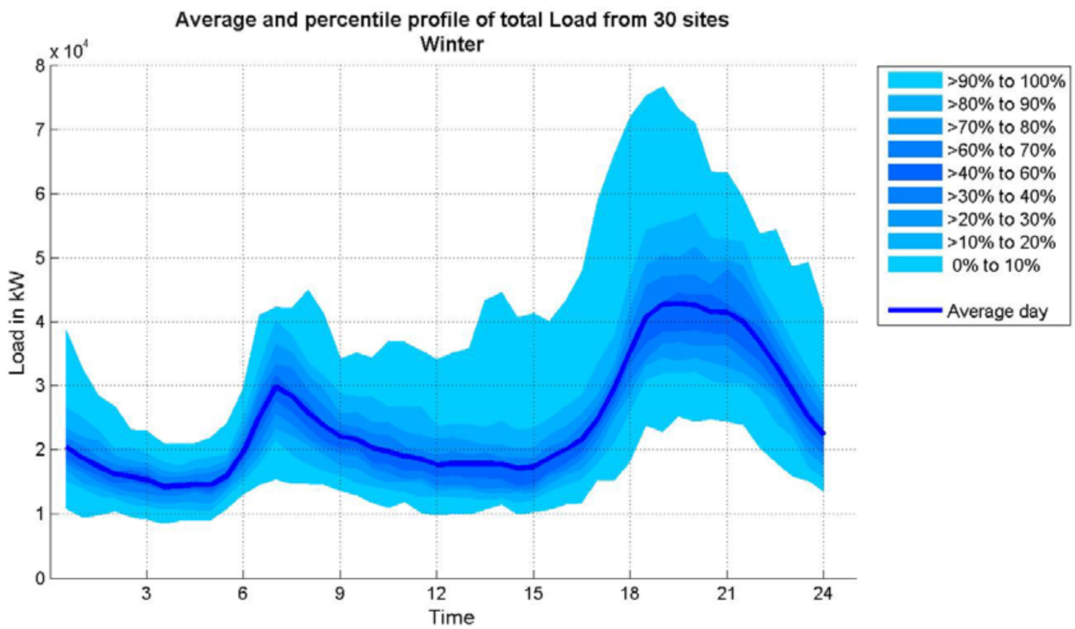


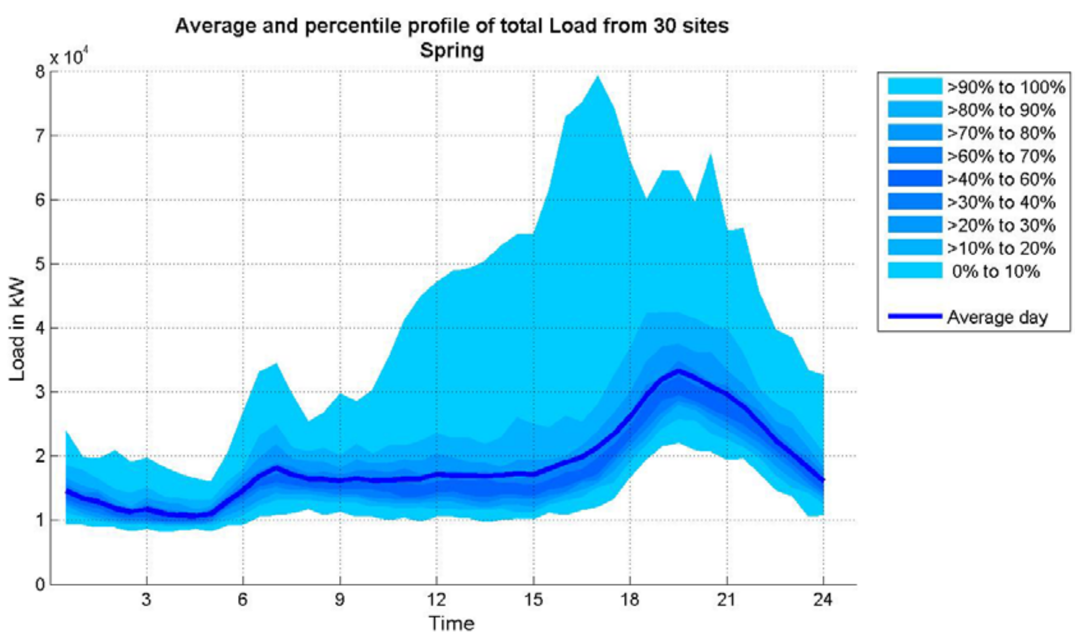
Appendix E

Seasonal average and percentile profiles of the 30 site load



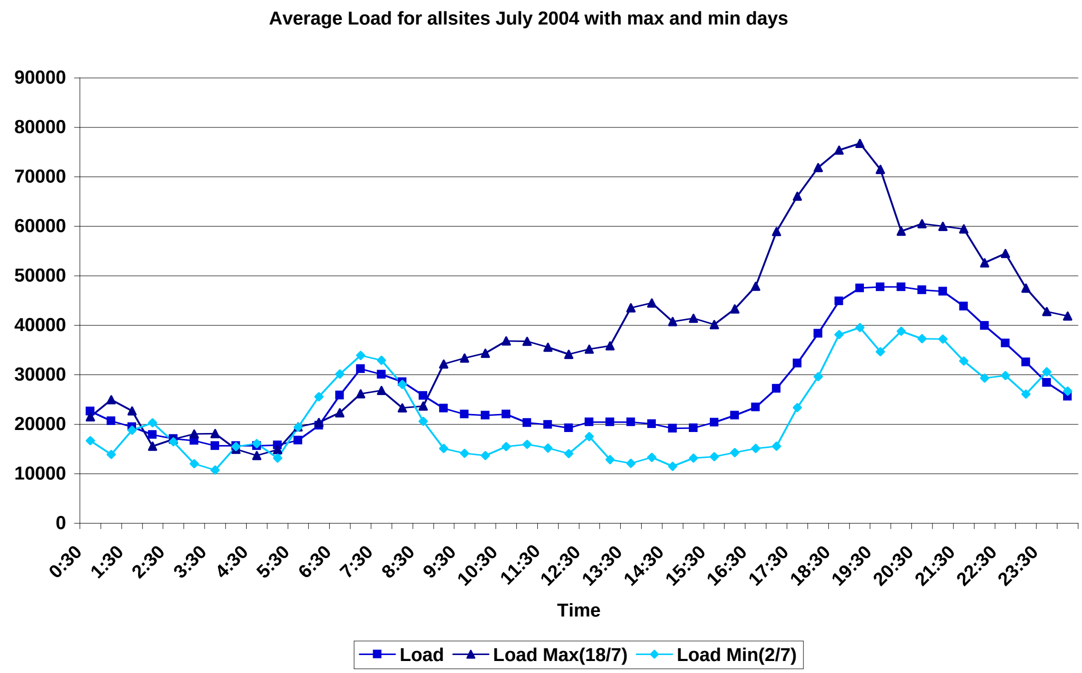


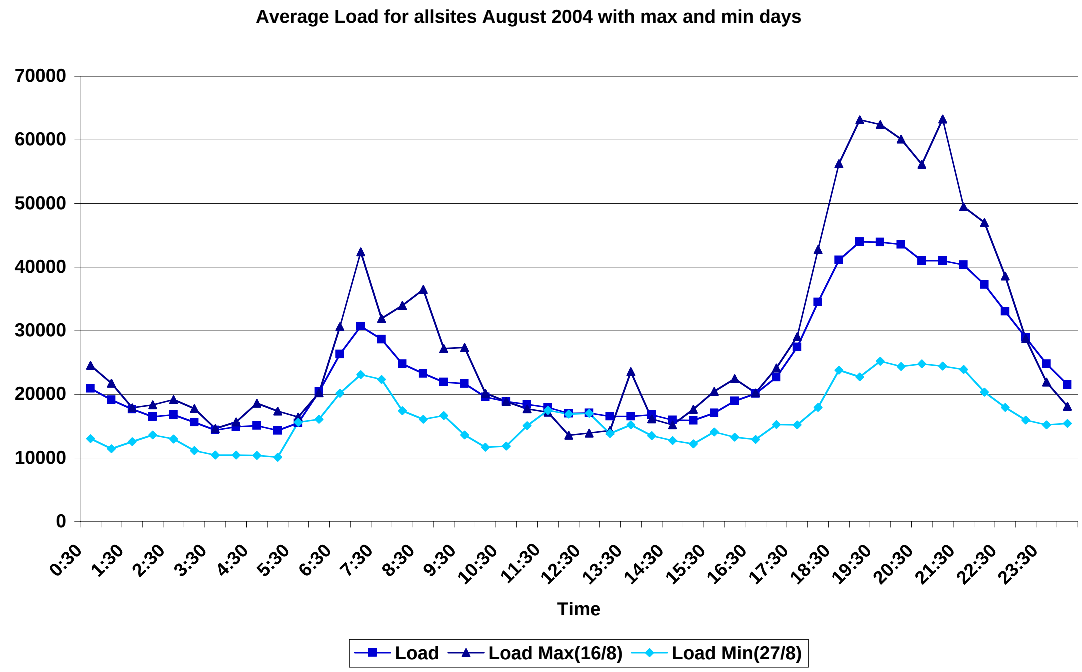

Average and percentile profile of total Load from 30 sites
Winter
x 10^4
Load in kW
Time
>90% to 100%
>80% to 90%
>70% to 80%
>60% to 70%
>40% to 60%
>30% to 40%
>20% to 30%
>10% to 20%
0% to 10%
Average day

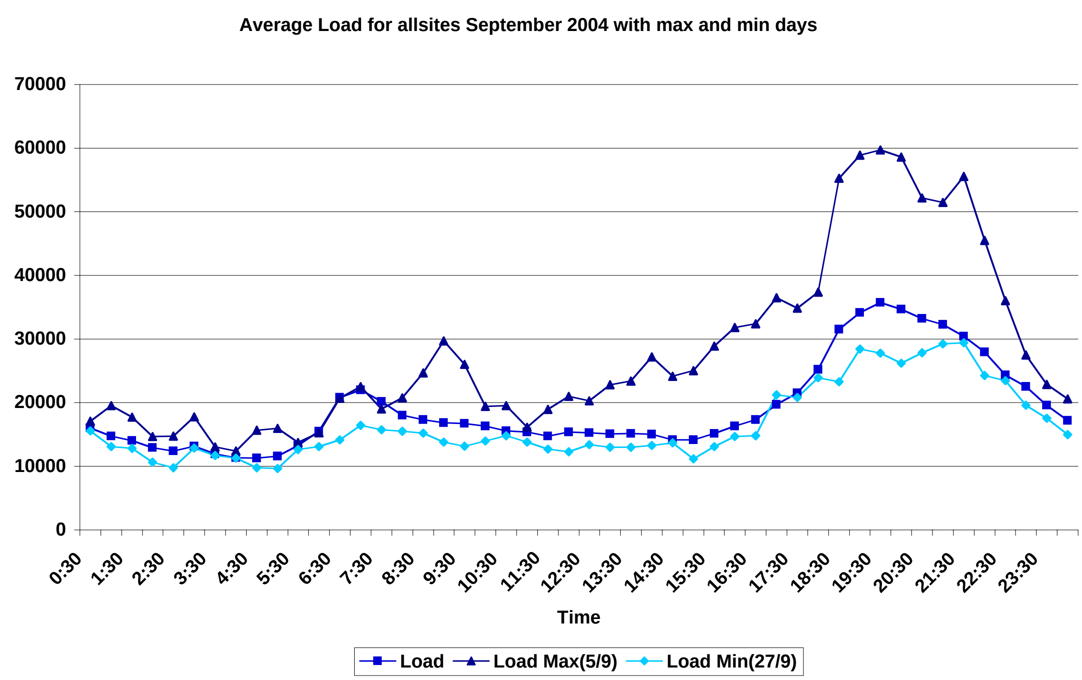

Average and percentile profile of total Load from 30 sites
Spring
x 10^4
Load in kW
Time
>90% to 100%
>80% to 90%
>70% to 80%
>60% to 70%
>40% to 60%
>30% to 40%
>20% to 30%
>10% to 20%
0% to 10%
Average day

Appendix F

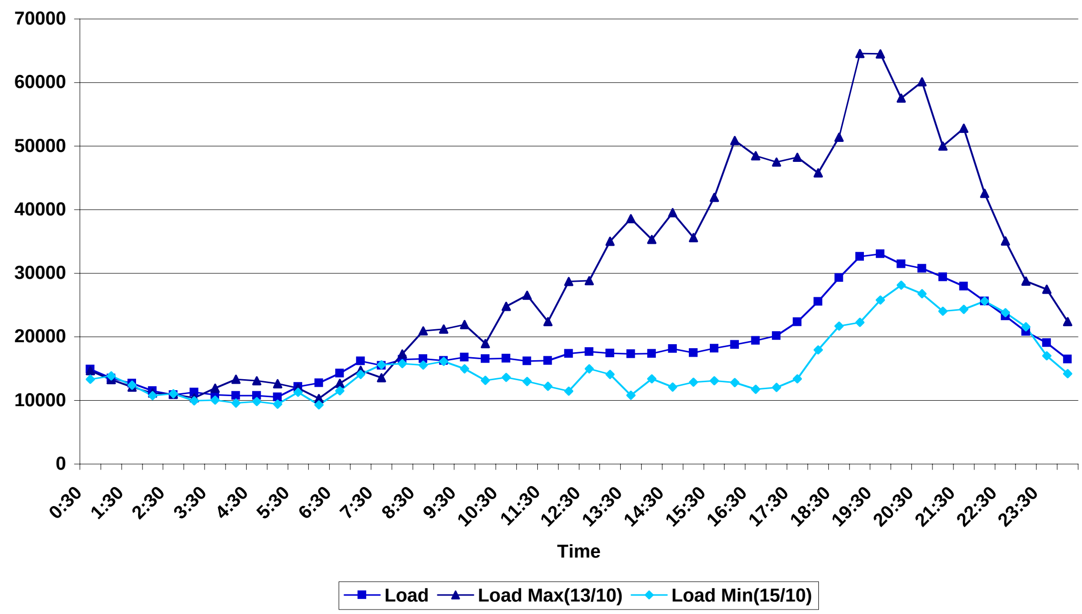
Load Variability during Monthly Profiles for all 30 Sites



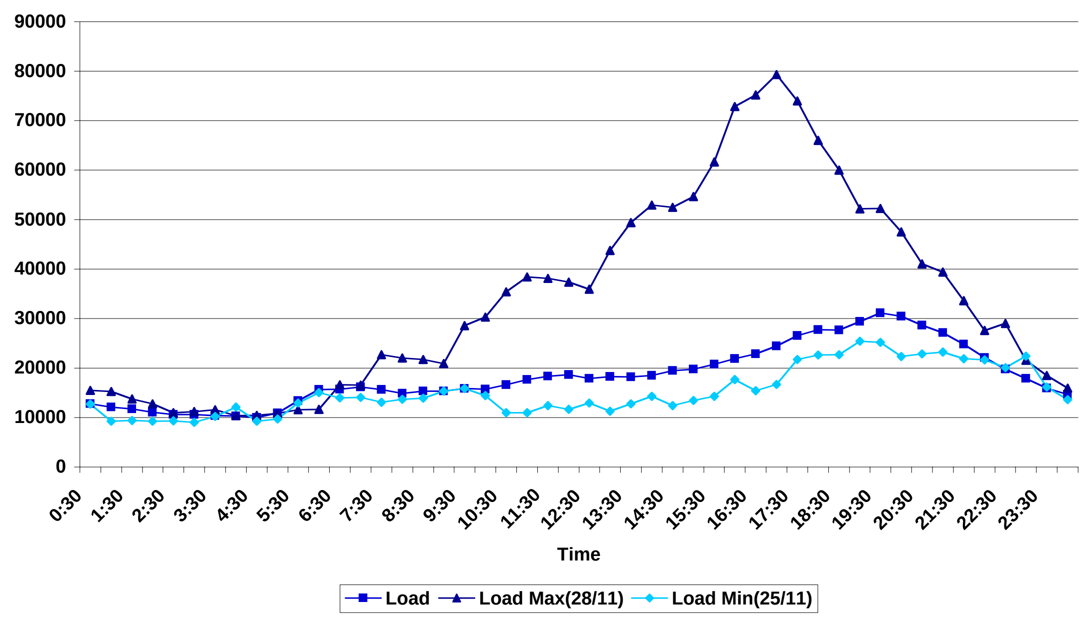

Average Load for allsites August 2004 with max and min days
70000
60000
50000
40000
30000
20000
10000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
Load
Load Max(16/8)
Load Min(27/8)


Average Load for allsites September 2004 with max and min days
70000
60000
50000
40000
30000
20000
10000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
Load
Load Max(5/9)
Load Min(27/9)

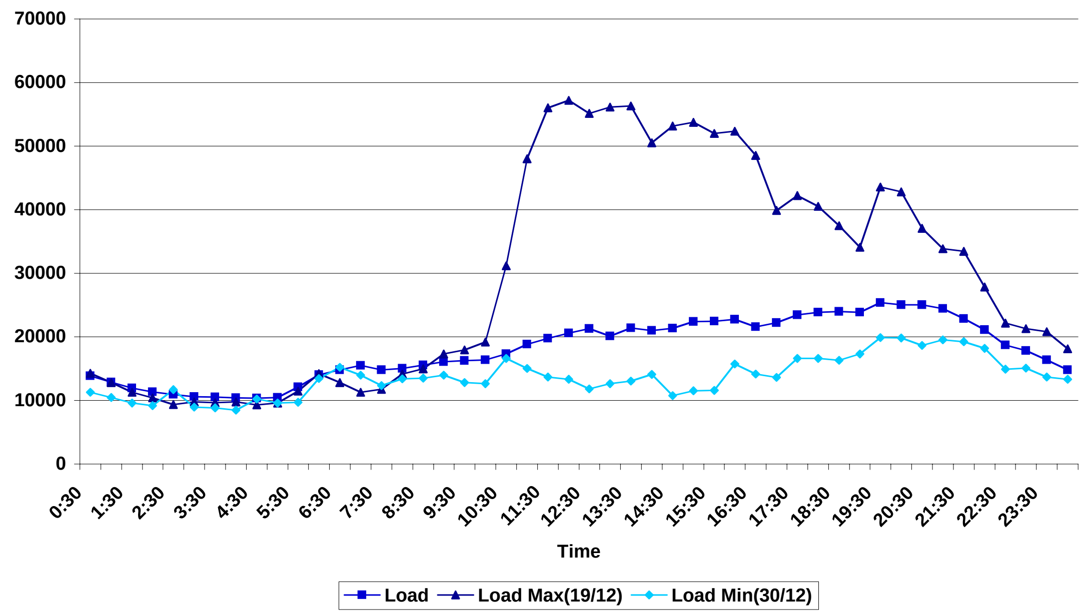
Average Load for allsites October 2004 with max and min days



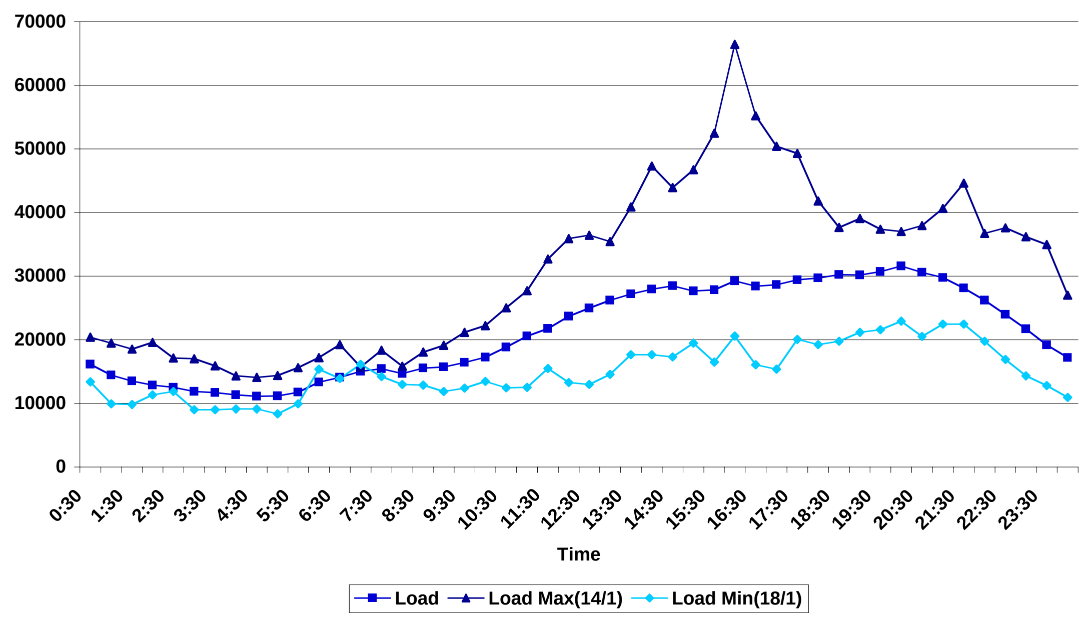
Average Load for allsites November 2004 with max and min days

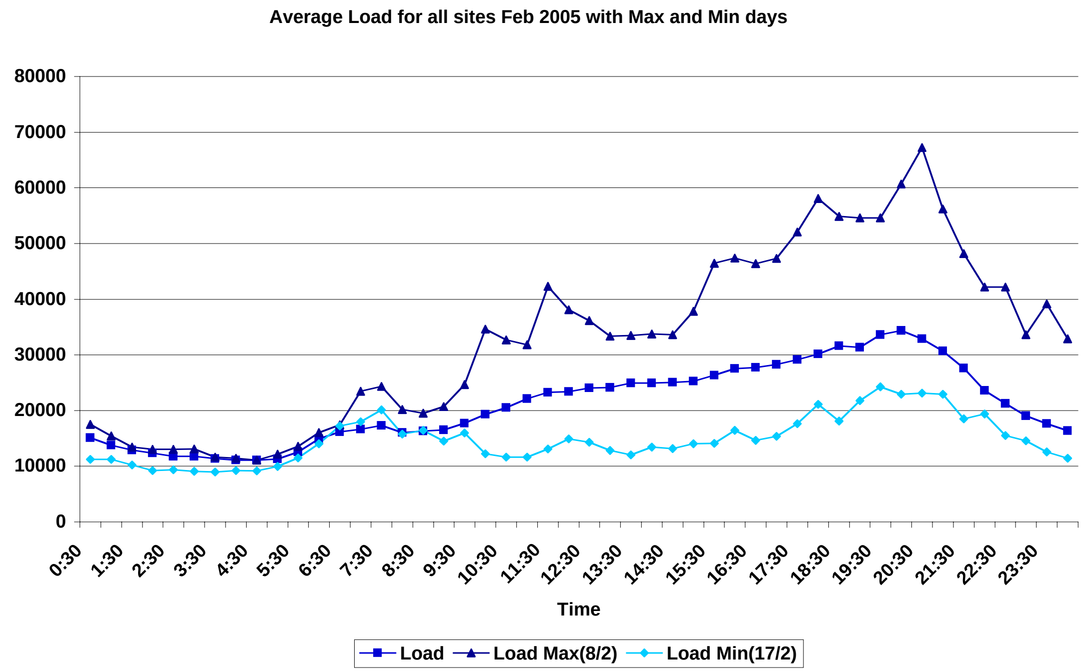


Average Load for allsites December 2004 with max and min days

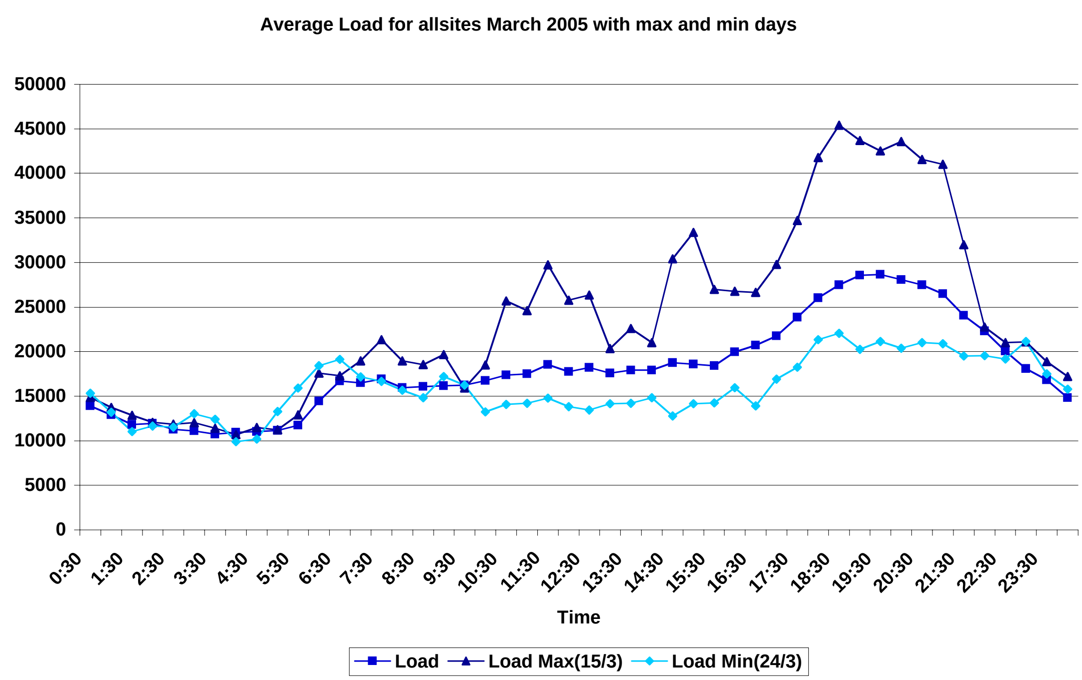


Average Load for allsites January 2005 with max and min days

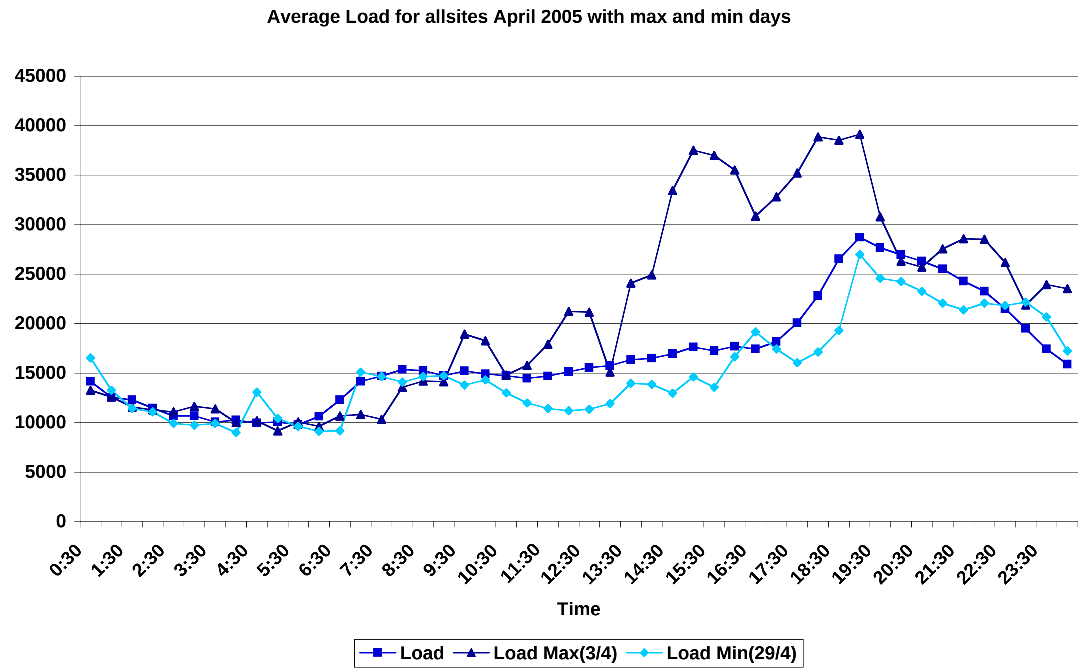




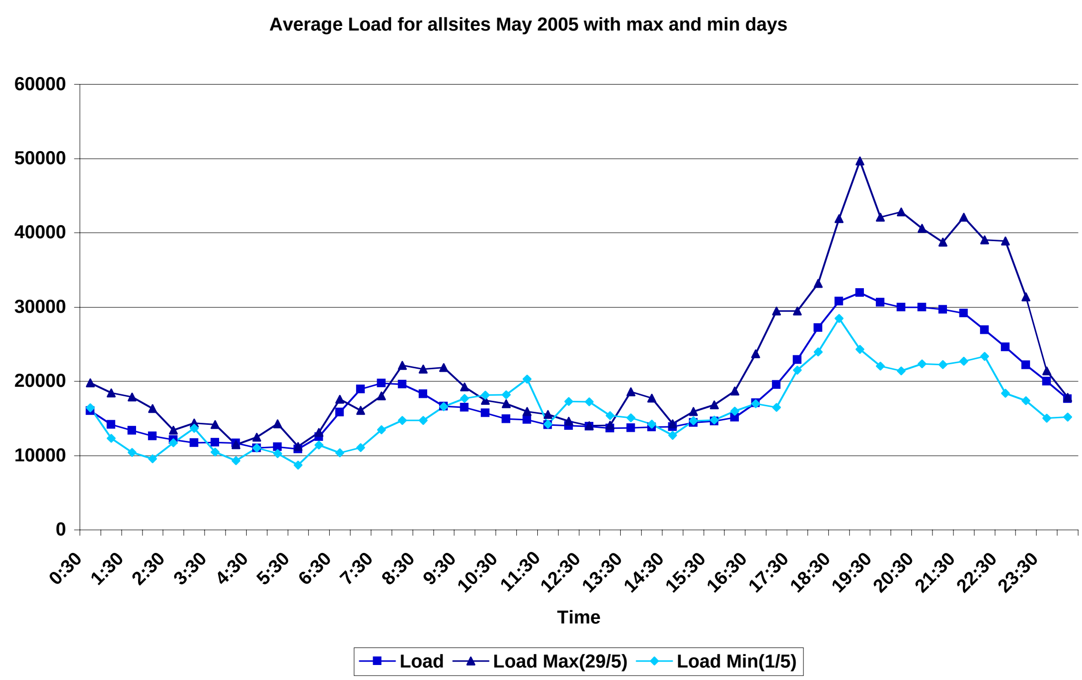
Average Load for all sites Feb 2005 with Max and Min days
80000
70000
60000
50000
40000
30000
20000
10000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
Load
Load Max(8/2)
Load Min(17/2)



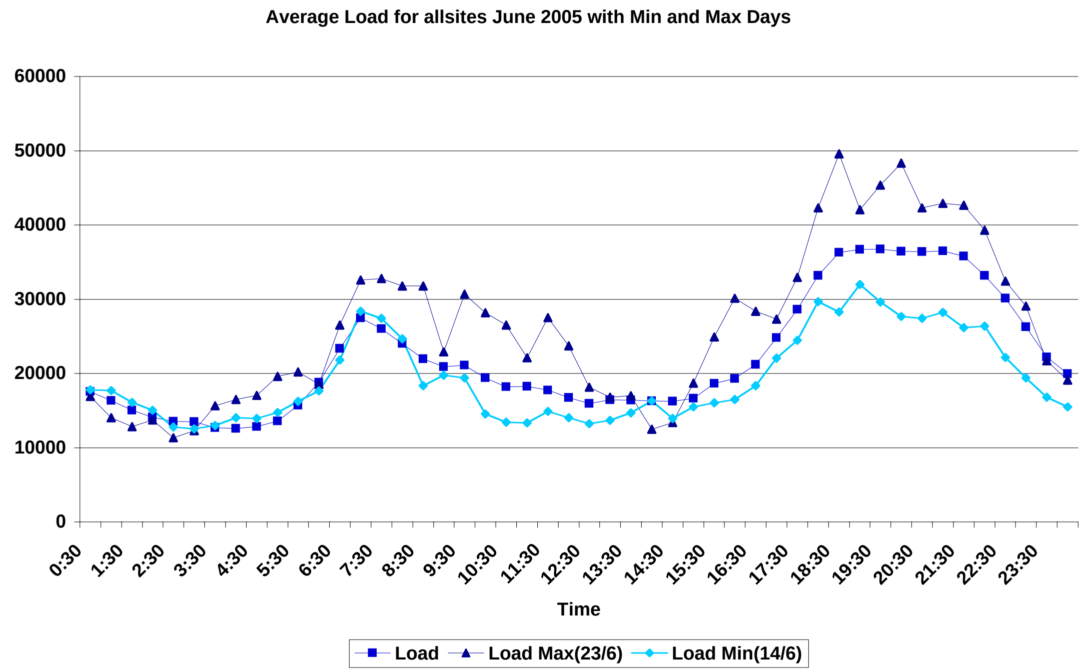
Average Load for allsites March 2005 with max and min days
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
Load
Load Max(15/3)
Load Min(24/3)



Average Load for allsites April 2005 with max and min days
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
Load
Load Max(3/4)
Load Min(29/4)

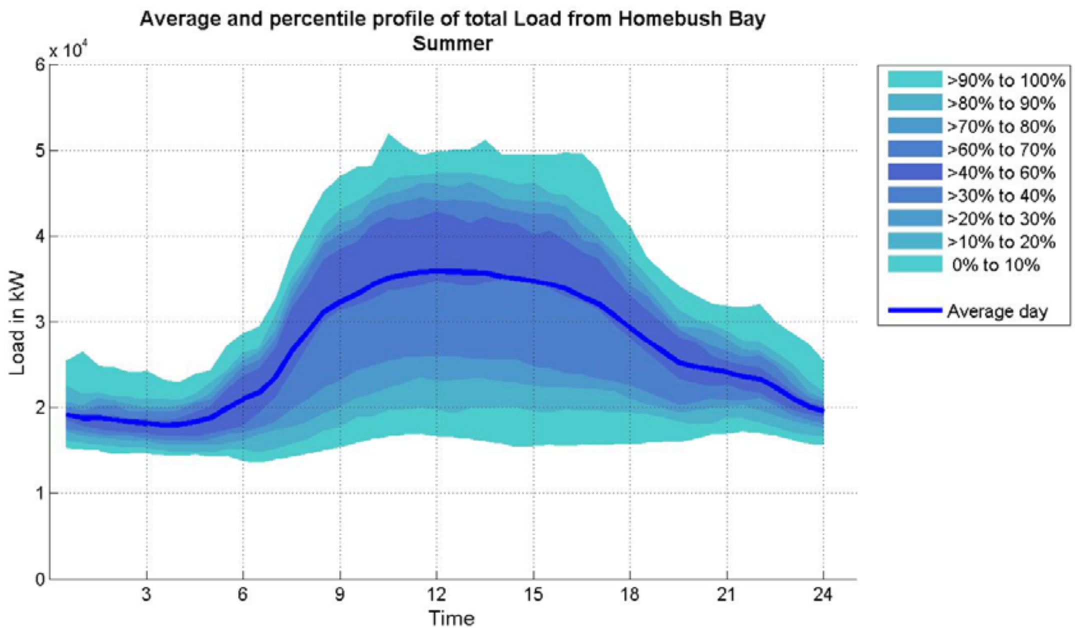


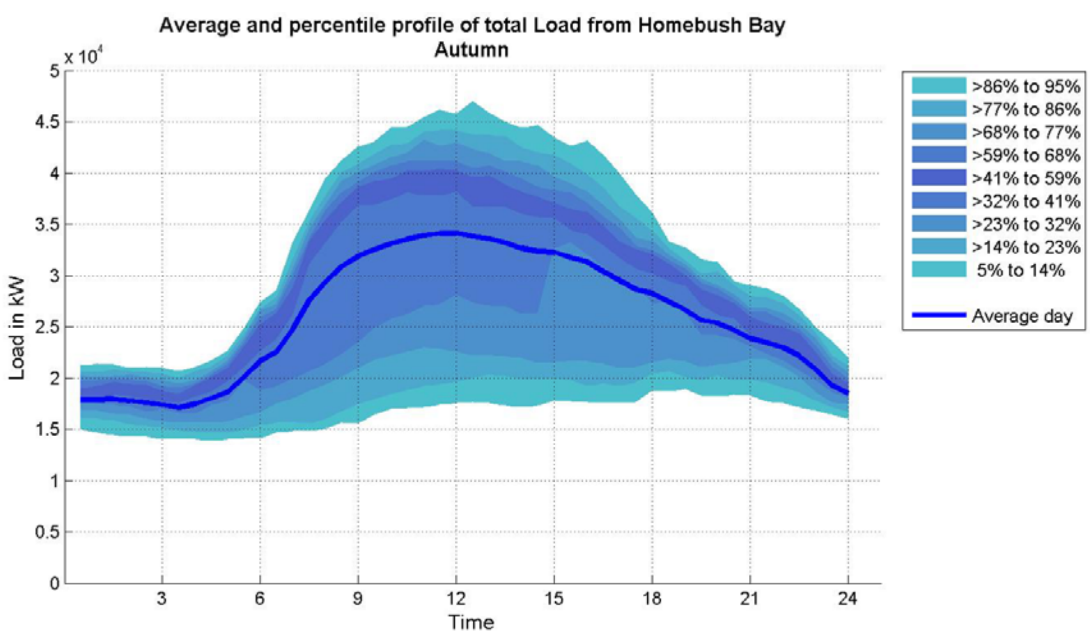
Average Load for allsites May 2005 with max and min days
60000
50000
40000
30000
20000
10000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
Load
Load Max(29/5)
Load Min(1/5)

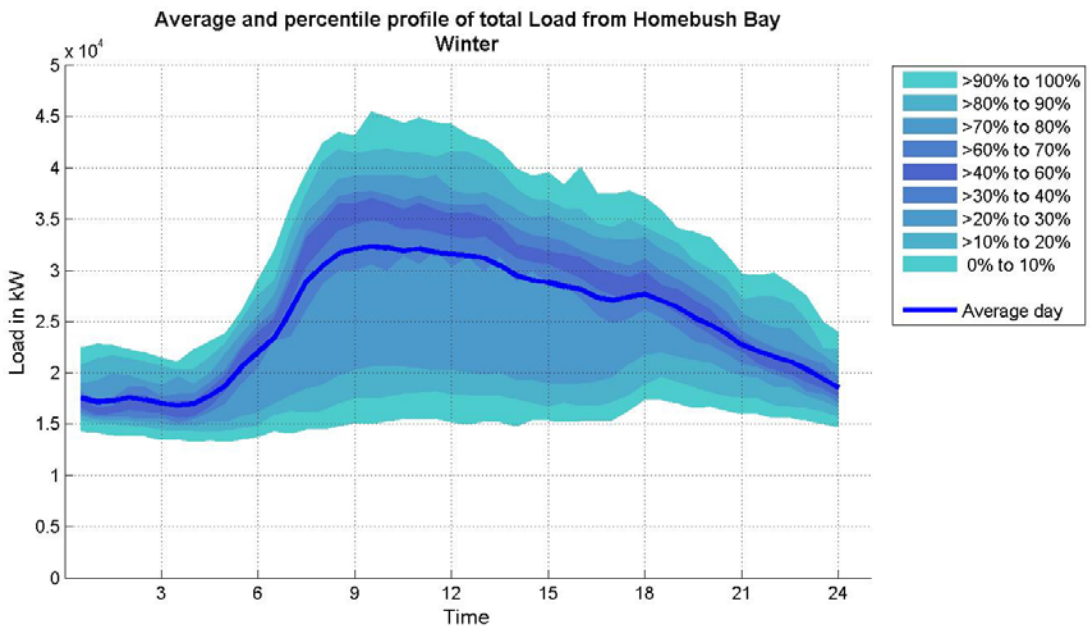

Average Load for allsites June 2005 with Min and Max Days
60000
50000
40000
30000
20000
10000
0
0:30
1:30
2:30
3:30
4:30
5:30
6:30
7:30
8:30
9:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time
Load
Load Max(23/6)
Load Min(14/6)

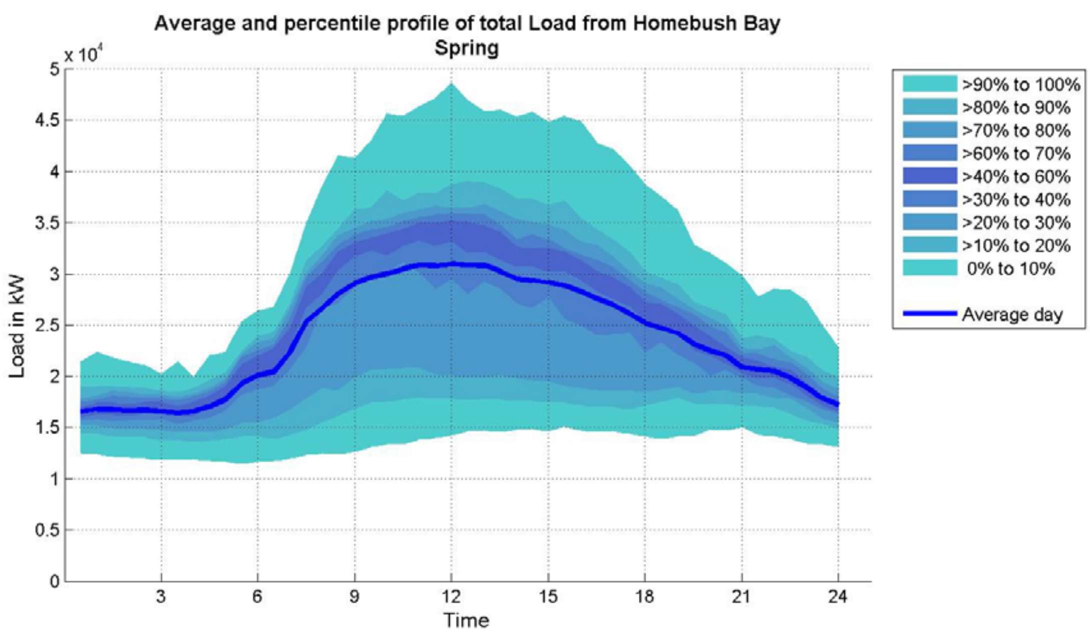
Appendix G

Seasonal average and percentile profiles of the Homebush Bay load






Average and percentile profile of total Load from Homebush Bay
Winter
x 10^4
Load in kW
Time
>90% to 100%
>80% to 90%
>70% to 80%
>60% to 70%
>40% to 60%
>30% to 40%
>20% to 30%
>10% to 20%
0% to 10%
Average day


Average and percentile profile of total Load from Homebush Bay
Spring
x 10^4
Load in kW
Time
>90% to 100%
>80% to 90%
>70% to 80%
>60% to 70%
>40% to 60%
>30% to 40%
>20% to 30%
>10% to 20%
0% to 10%
Average day