SOLAR AND COINCIDENT WEATHER DATA FOR LARGE SCALE SOLAR DEPLOYMENT IN AUSTRALASIA

Trevor Lee[1], William Logie[2]

[1] Exemplary Energy, Canberra (Australia)

[2] Institut für Solartechnik SPF, Oberseestr. 10, 8640 Rapperswil (Switzerland)

1. Background

The Australian Solar Radiation Data Handbook (ASRDH) was first published in 1988 (Frick et al, 1988) following the pioneering work of Paltridge and Proctor (1976) and its preparation for wider use by Roy and Miller (1980).

Although it also calculates the irradiation of a range of engineering and architectural surfaces, each edition of this Handbook is different from their simpler predecessors - the so-called "Spencer Tables" (Spencer, 1974 and later) - that use completely clear skies to calculate irradiation levels. The "Spencer Tables" provide equivalent information for architectural surfaces for the specific case of a cloudless sky. By contrast, the data used for this Handbook are all statistical values (means and frequencies of occurrence) that account for the reduction, particularly in beam radiation, caused by actual cloud conditions. Similarly, in the early years, solar position and shading design were tackled with no explicit detail on the irradiation energy involved, as in Spencer and Philips (1983).

Alas, that first edition 1988 of the ASRDH incorporated a gross error in the algorithm for solar position that made it highly inaccurate for high tilt surfaces. The error was first revealed by Lee (1991) in *"Solar Progress"*, the quarterly journal of the Australian and New Zealand Solar Energy Society (ANZSES, the forerunner of AuSES) and subsequently explained (Frick and Leadbeater, 1992). The error was corrected later in 1992 with an interim 5¼ inch floppy disk ASRDH 2nd edition and a fully revised third edition subsequently published by the Energy Research and Development Corporation (ERDC), Canberra, (Lee et al, 1995). That edition incorporated the best available anisotropic sky algorithms for interpreting global, diffuse and direct solar measurements into the required architectural and design tables for a wide range of fixed and sun tracking surfaces.

That third edition of the ASRDH also built on the pioneering work of the Bureau of Meteorology (the Bureau or BOM) in its incorporation of isorad (contour) maps of capital city hinterlands prepared from satellite measurements of reflected radiation used to infer how much was reaching the ground anywhere over the Australian land mass (Nunez, 1990).

The ownership of the ASRDH edition 3 was passed to ANZSES upon the demise of the ERDC and, shortly after, ANZSES produced its software companion AUSOLRAD in 1997. However, that 3rd edition was forced to re-use the pre 1986 data from within the old Australian Climate Data Bank (ACDB) (Delsante, 1989) by the then priorities of the BOM - in process of changing all its data systems across to a new and better mainframe computer it had just acquired.

Industry and ANZSES pressure eventually convinced the Australian Government that this was unsatisfactory - especially for Adelaide, Brisbane, Canberra and Sydney which each had only three years worth of solar records in 1986. Subsequently, substantial inroads were made into the enhancement of the accuracy of solar measurement at the BOM despite constrained funding support (Forgan, 1996 and 1999).

A major enhancement project for the ASRDH commenced in July 2002 under a grant from the Australian Greenhouse Office's Renewable Energy Industry Development program and was completed by the end of 2005 (Lee, Snow and Stokes, 2005). The resultant publications were completed in the early months of 2006 at which point the current (4th) edition of the ASRDH and 2nd edition of AUSOLRAD became commercially available in hard copy and CD-ROM.

2. Geographic Scope

The current edition has data for only 28 sites[1] – six of which had no ground-based irradiation data but were inferred from a combination of historical records for cloud cover, sunshine hours and latterly satellite estimation. These were included for spatial completeness in addition to the 22 sites in the first two editions. A list of those 28 sites and their data qualities is included in Tab. 1 and shown in Fig. 1.

By contrast, the 80 Australian sites (Fig. 2, after Lee and Snow, 2008 and Energy Partners, 2008) and 16 New Zealand sites (Fig. 3, after NIWA, Liley et al, 2007) represent a huge potential improvement in the spatial accuracy of the solar data. To gain some appreciation of this, see Fig. 6 which shows a set of four seasonal snapshots of the variation around Australia's southernmost city, Hobart, Tasmania, as an example. See also DEWHA (2008) for the spatial distribution of that climate data and Energy Partners (2006) for details of the preparation and QA of the data itself.

As each site includes a comprehensive set of data tables, greater accuracy can be ascertained for regions nearby to those in the original set of 28 sites.

Recently, the BOM has begun to publish hourly data for virtually the whole of Australia (280,000 pixels of 5 x 5 km each) so that another 20 or so sites of special interest to the solar industry can be readily added.

3. Portrayal of Typical Years

The currently available graphical portrayal of 28 solar energy climates (as in **Error! Reference source not found.**) can now be applied to almost 100 sites across Australasia and can include hourly data (as in Morrison and Litvak, 1999) as well as the monthly means of those data. Additionally, this can be done with some improved accuracy for sites lacking separate terrestrial measurement of global, diffuse and direct irradiation (Boland, Brown and Ridley, 2008).

Currently available Reference Meteorological Years (RMYs) are based on the period 1967 to 2004 inclusive (i.e. the 39 years centred on 1987). Commercial building simulation is still commonly using data spanning 1967 to 1988 (ACADS-BSG, 2004) and this data is still mandated in the protocols for NABERS Energy ratings which are now required for disclosure to potential buyers or lessees of office buildings, BCA Class 5, over 2,000 m² NLA (NABERS, 2008 and CBD, 2010).

4. Analysis of Atypical Years

Tapping both the Australian and the New Zealand CDBs allows also the analysis of atypical years such as an indicative El Nino year or even the sunniest year ever (in up to 43 years) to cite just two examples. The scope of such analysis has been dealt with elsewhere (Lee and Stokes, 2006), (Ferrari and Lee, 2008) and (Lee and Snow, 2008). In essence, any targeted selection of data that is possible for the full climate data sets is capable of generating equivalent solar data tabulation.

5. Ersatz Future Climates

As large-scale systems typically operate for a lifecycle of 20 years, any renewable energy system is likely to experience a change over its effective functional lifetime. Lee and Ferrari (2008) described a method for producing RMY data sets for future climate scenarios by combining CSIRO climate projections with

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[1] Coincidentally, the Nationwide House Energy Rating Software (NatHERS) of the time had weather data for 28 sites, too, but only 18 of those coincided with the ASRDH sites.

baseline data representative of “current” climate. In this work, the CSIRO defines “current” as the period 1975 – 2004 (i.e. 30 years centred on 1990). As applied in BRANZ (2007), these Ersatz Future Meteorological Year files (EFMY) are created to ensure that plant systems are designed and financed with a consideration of a changing climate, by predicting the range of likely and foreseeable future system responses (as in Lee and Ferrari, 2008).

Given rates of climate change over a 1990 baseline and using up to 20 global climate change models, the CSIRO has provided coincident Projected Change Values (PCVs) that include maximum, minimum and mean, temperatures, relative humidity, wind speed and solar radiation (CSIRO, 2010). These PCVs can be interpolated on an hourly basis, whereby EFMYs can be created from the baseline.

In constructing these EFMYs two potential processes can be identified:

- “synthetic” EFMYs which adjust hourly values in a selected TMY in line with the CSIRO PCVs; and
- “realistic” EFMYs which take real historic months selected to target values that would align with CSIRO PCVs.

When choosing which production process, fully synthetic adjusted RMYs may be required because realistic EFMYs, which concatenate months that have actually occurred (and hence are intuitively more credible) may not actually exist due to historic correlations between the weather elements being incompatible with the projected future climate.

These resulting future climates can be used to simulate the effects of the change in energy output (or consumption). By simulating with these EFMY files against current weather files the costs and benefits that projected changes present can be ascertained and compared.

This work can now be adapted and focused to produce Ersatz Future Irradiation data based on these same forecasts. In doing so, these predictive climate data sets permit designers to better evaluate output in future years. As a project can take many years to complete, designers can use Ersatz Future Irradiation data to compare the estimated return on investment and hence viability of the project, between an initial set of “current” solar radiation data files and these Ersatz Future Irradiation data files. It may be observed that a plant site exposed to a future climate subject to either reduced or increased irradiance can be accounted for and optimised accordingly. Ersatz Future Irradiation could assist in identifying sites that were initially thought to be economically unviable but are projected to be feasible in the future.

Example of Building Space Conditioning

A simulation of a 3-storey office model in Adelaide was conducted to determine any performance differences between two predicted ersatz weather files and reference weather files. Both predicted weather files modelled warmest-case scenarios.

The annual energy consumption between the three simulations shows that heating load decreases by 13%in the year 2030 and by 34% in 2050. Theoretically, the assumption would be made that as temperatures are likely to increase, heating loads should generally decrease. Peak loads alternatively, show that cooling increases by 1.9% in 2030 and 5.8% in 2050. These results are in line with intuitive predictions.

Example of Solar Thermal Electric System

The US Government freeware simulator System Advisor Model (SAM) was used to analyse the energy output from a parabolic trough solar thermal electric system installed in the Adelaide climate zone. The Solar Collector Assembly (SCA) input unit used in this analysis is the SAM example Solargenix SGX-1. Each SCA is 100m long, 5m aperture and the aperture area is 470.3 m². There are a total of 1,889 SCAs which together have a peak capacity of 216,000 $kW_{electrical}$ and a solar field area of 2,665,190 m². Solar Salt is used as the Thermal Energy Storage Fluid. The annual gross electric output is 1,200,000,000 kWh.

Fig 7 and Fig 8 shows the monthly and annual Solargenix energy outputs in three climate scenarios.

6. Real-time Data

Real-time data can be applied to create real-year-to-date and other actual-year data sets that can be applied to:

- Model calibration using real time weather data coincident with other empirical measures like solar system output or building energy consumption or temperature (especially if unconditioned);
- Building or system monitoring for underperformance to indicate early restorative action; or
- Adjustment of actual output or consumption in a real year to allow direct comparison with performance in routine weather (the long term mean, or RMY).

Real Time Meteorological Year (RTMY) climate data files are created in the same format as RMYs. Once the solar investment has been committed, it is expected that the proponents would arrange their own site specific data collection using these techniques. However there would still be a demand for public or commercial access RTMYs for use in refining the performance of large scale buildings as in the "Energy Guidelines" (PCA, 2001). The benefits of these RTMYs can be extended to the simulation of commercial and residential buildings to assess the measured consumption in an actual month or year. In doing so, buildings can be monitored more accurately for deficiencies in performance to allow prompt restorative action.

7. Exemplary Australian Solar Energy Atlas

Currently a work in progress, a complete overhaul of the ASRDH (Edition 4) is expected to take the form of a completely electronic and graphical climate data delivery system. In contrast to the original 28 sites in the ASRDH, the tentatively named Exemplary Australian Solar Energy Atlas (ASEA) is expected to contain solar radiation data for 10,000 times more sites than its predecessor.

Each site is represented as a square pixel on a map of Australia. When Australia is subject to complete daylight there are approximately 280,000 pixels (see Fig. 1). The user can select points on the map that produces a value for irradiance, in W/m^2, at a location for a particular hour, day and month. The observable benefit of 278,000 sites allows solar plant designers to better compare the merits of nearby locations for a given region. In doing so, architects, engineers and designers will also be able to confidently estimate PV and other renewable energy system designs in more remote locations.

The data in the Exemplary ASEA originates from the Bureau of Meteorology (BOM) and is recorded on an hourly basis with separate values for Global Horizontal and Direct Normal Irradiance (GHI and DNI respectively). This data is currently being interpreted by Energy Partners. The project aims include facilitating a graphical interface between the data and end user for the myriad individual sites.

The Exemplary ASEA is a software package that incorporates the BOM data as well as many features of its predecessor, the ASRDH and AUSOLRAD. The Exemplary ASEA can take advantage of some of the features in the ASRDH in particular comprehensive data for the 28 previous sites. As a map, this would be overlaid above the original map. The database for the program is the hourly data derived from images scanned now by the GOES-9 and MTSAT-1R satellites and previously by the GMS-5 satellite as described in (BOM, 2010)[2]. This results in more ASRDH sites that can contribute to a reduction in the approximation currently required by geographic usually linear interpolation.

The Exemplary ASEA will allow the user to select a time zone, time and date and display a range of isorads (colour bands representative of an approximate irradiance interval, see Fig 4). Each of the estimated 278,000 pixel locations displays an irradiance value in a map of daytime Australia, represented as a 5km x 5km

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[2] Solar radiation data derived from satellite imagery processed by the Bureau from the GMS and MTSAT series operated by Japan Meteorological Agency and from GOES-9 operated by the National Oceanographic & Atmospheric Administration (NOAA) for the Japan Meteorological Agency.

square grid. Short time-lapse "movies" will also be possible. The data can be integrated over time to represent annual, seasonal and monthly means to visualize the national climate, a locale or to hone in on the climate of a particular site.

9. Conclusions

The 2008 update to the Australian Climate Data Bank (ACDB) and the 2007 creation of the New Zealand Climate Data Bank (NZCDB) presents an unprecedented opportunity for enhancing the accuracy and pertinence of solar radiation data available to researchers, educators and practitioners. Despite this, many alternative pathways can be seen to serve as an upgrade to the current solar radiation resource stream, each with the purpose of reducing the uncertainty in plant peak and average output estimation and benchmarking.

The majority of these revisions aim to reduce this uncertainty by increasing the number of sites. In addition to this, ersatz future and real time data can provide the end user with a better estimation of project viability, by reducing its uncertainty over its life.

As such, it represents a key underpinning of the expansion of solar and other renewable energy infrastructure investments now being planned with the financial and legislative backing of the Australian Government through its recently passed Renewable Energy Target (RET) legislation and the establishment of the recently committed A$3.2 billion Australian Renewable Energy Agency (ARENA) to consolidate support for renewable energy technology development as part of its package of measures for Australia's clean energy future.

Figures & Tables

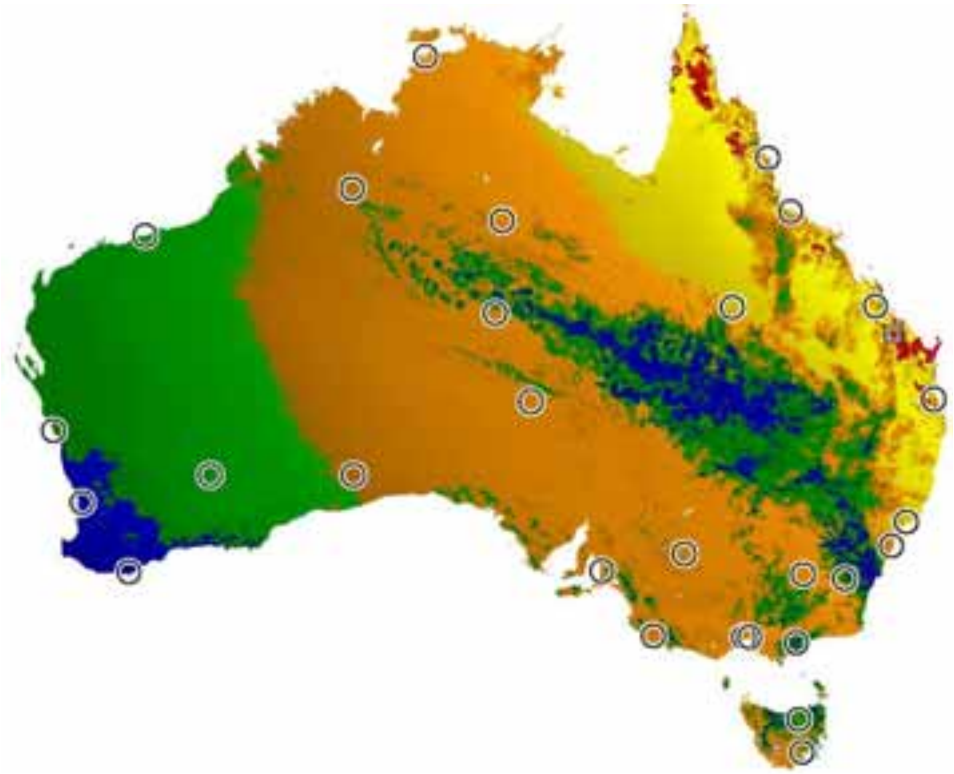

Fig. 1: Geographic Spread of the 28 Sites of the ASRDH Edition 4 (overlayed on a sample single-hour image from the Exemplary ASEA comprising nearly 280,000 pixels with individual values estimated from satellite observations)

Fig. 2: Geographic Spread of the 80 Sites of the ACDB 2008 (showing the extents of the 8 BCA climate zones before harmonisation with state and local government boundaries) See maps below for the working versions of this zoning:
National Map - http://www.abcb.gov.au/index.cfm?objectid=1DA57D93-6C4D-11DE-A2C2001B2FB900AA
Single State Map - http://www.abcb.gov.au/index.cfm?objectid=8EA6965A-6C4C-11DE-A2C2001B2FB900AA

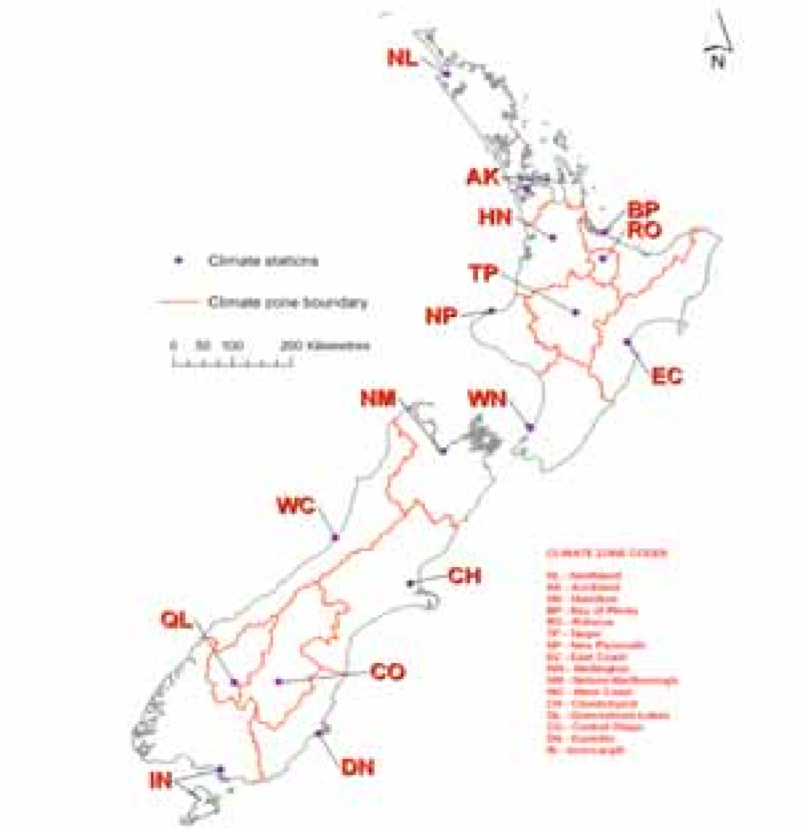

Fig. 3: Geographic Spread of the 16 Sites of the NZCDB 2007 (larger scale)

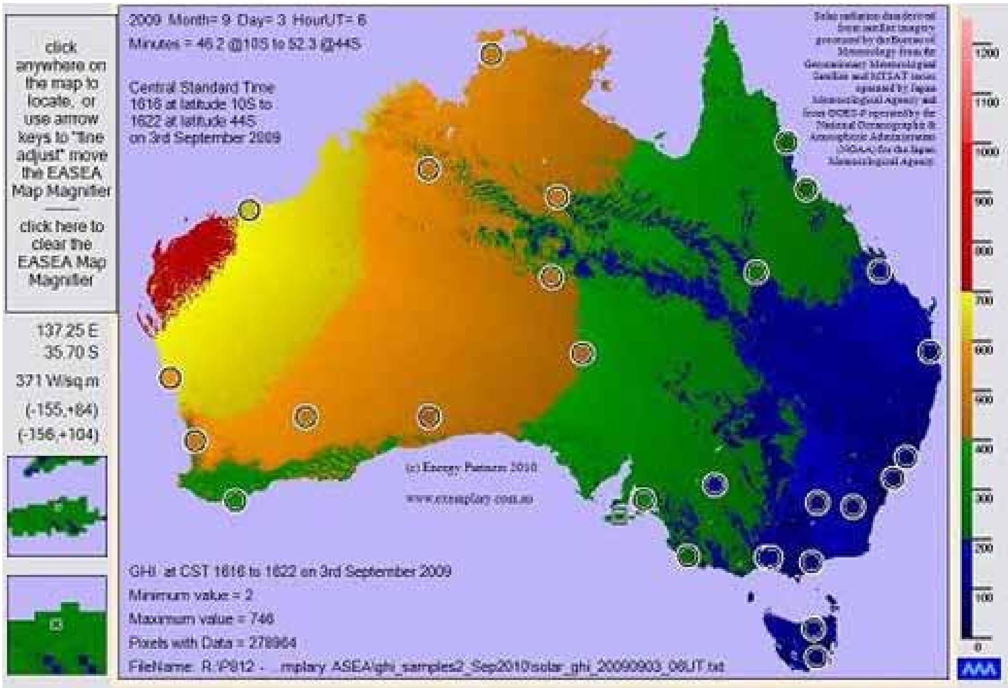

Fig 4: EASEA screenshot on 3rd September at 4PM Adelaide Time

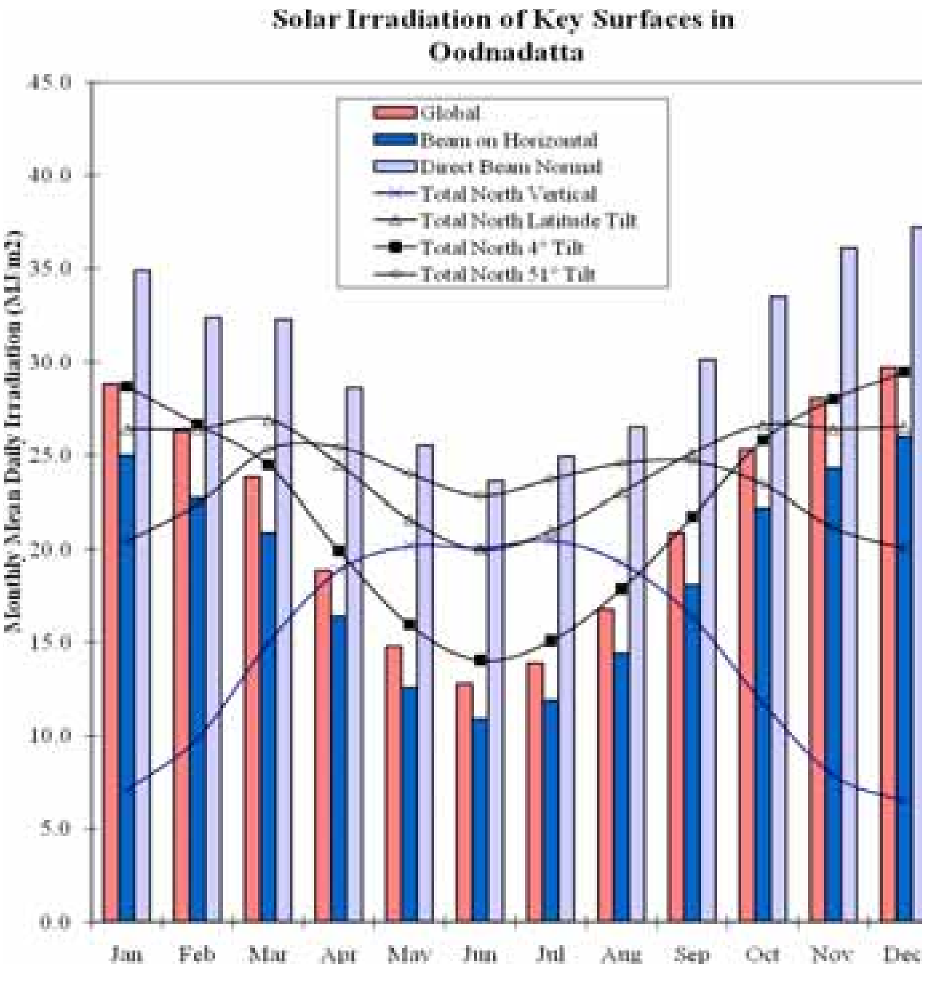

Fig 5: Sample Graphical Summary from ASRDH Edition 4

Tab. 1 Data collection sites used in 2006 Handbook with various details

State Terr	Location	Elevation	Data type	Data start date to May 2004	No. of days	% of days estimated data only
NSW ACT	Canberra City	571 m	G&D	Mar 1976	10,301	24.2%
	Sydney RO	4 m	G&D	Aug 1983	7,604	29.4%
	Wagga Wagga AMO	224 m	G&D	July 1968	13,111	13.1%
	Williamtown AMO	12 m	G	Dec 1968	12,960	28.8%
QLD	Brisbane AMO	6 m	G&D	Jan 1983	7,805	22.2%
	Cairns AMO	3 m	EST	Oct 1990	4,962	28.9%
	Longreach	195 m	G	July 1968	13,093	23.9%
	Rockhampton AMO	8 m	G&D	Feb 1973	11,437	11.6%
	Townsville	4 m	EST	Mar 1971	12,128	21.7%
SA NT	Adelaide AMO	11 m	G&D	Jan 1983	7,816	16.2%
	Alice Springs AMO	547 m	G&D	July 1968	13,112	4.1%
	Darwin AMO	35 m	G	Oct 1968	13,021	9.8%
	Mt Gambier AMO	63 m	G&D	July 1968	13,108	5.2%
	Oodnadatta AMO	113 m	G	May 1969	12,798	42.5%
	Tennant Creek	375 m	EST	Oct 1990	4,962	6.1%
VIC TAS	East Sale AMO	14 m	EST	Oct 1990	4,962	51.8%
	Hobart RO	8 m	G&D	Oct 1967	13,367	18.3%
	Launceston AMO	171 m	EST	Oct 1990	4,962	51.9%
	Laverton AMO	14 m	G&D	Feb 1968	13,258	17.1%
	Melbourne HO	123 m	G&D	Jan 1967	13,660	25.6%
	Mildura AMO	53 m	G&D	Jan 1969	12,929	3.0%
WA	Albany AMO	71 m	G&D	June 1968	13,143	27.0%
	Forrest AMO	157 m	G	Nov 1969	12,623	29.6%
	Geraldton AMO	35 m	G&D	June 1968	13,124	6.5%
	Halls Creek AMO	423 m	G	May 1969	12,809	22.0%
	Kalgoorlie	360 m	EST	Feb 1979	9,240	4.9%
	Perth RO	11 m	G&D	Feb 1973	11,437	17.5%
	Port Hedland	8 m	G&D	Sep 1968	13,048	22.8%

Legend for Data Sources (listed in descending order of accuracy):

Acronyms in Location Names

AMO indicates that the station is an Airport Meteorological Office

HO indicates that the station is Head Office of the Bureau of Meteorology, 150 Lonsdale Street, Melbourne

RO indicates that the station is Regional Office

Acronyms in Data Type

G&D Locations using both global and diffuse measurements

G Locations using global radiation measurements only, with the diffuse radiation estimated.

EST Locations using only estimated data from cloud cover records supplemented by satellite based daily global estimates from Oct 1990

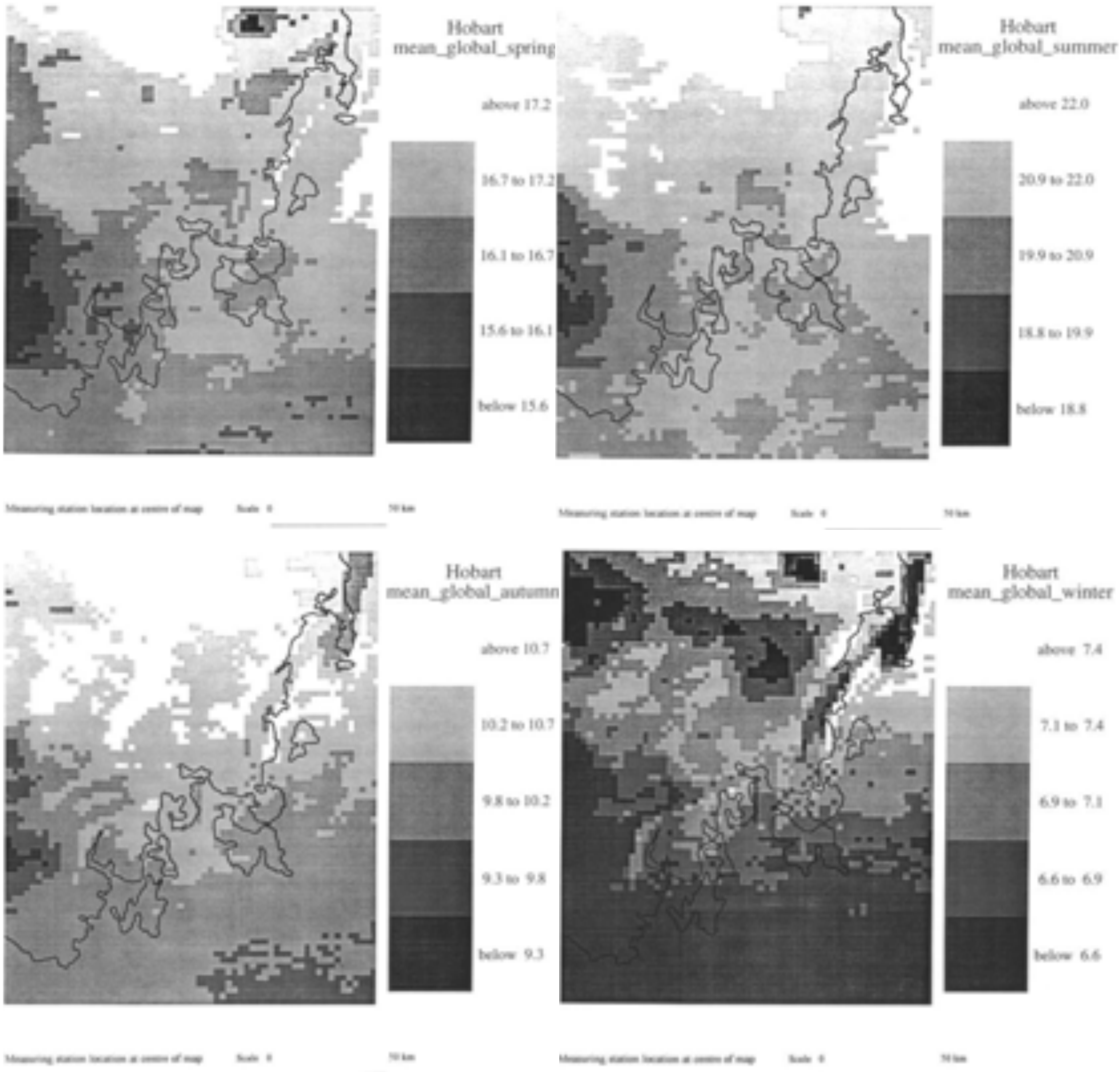

Fig. 6: Hobart as a Sample of the Spatial Variation Mapped for Capital Cities

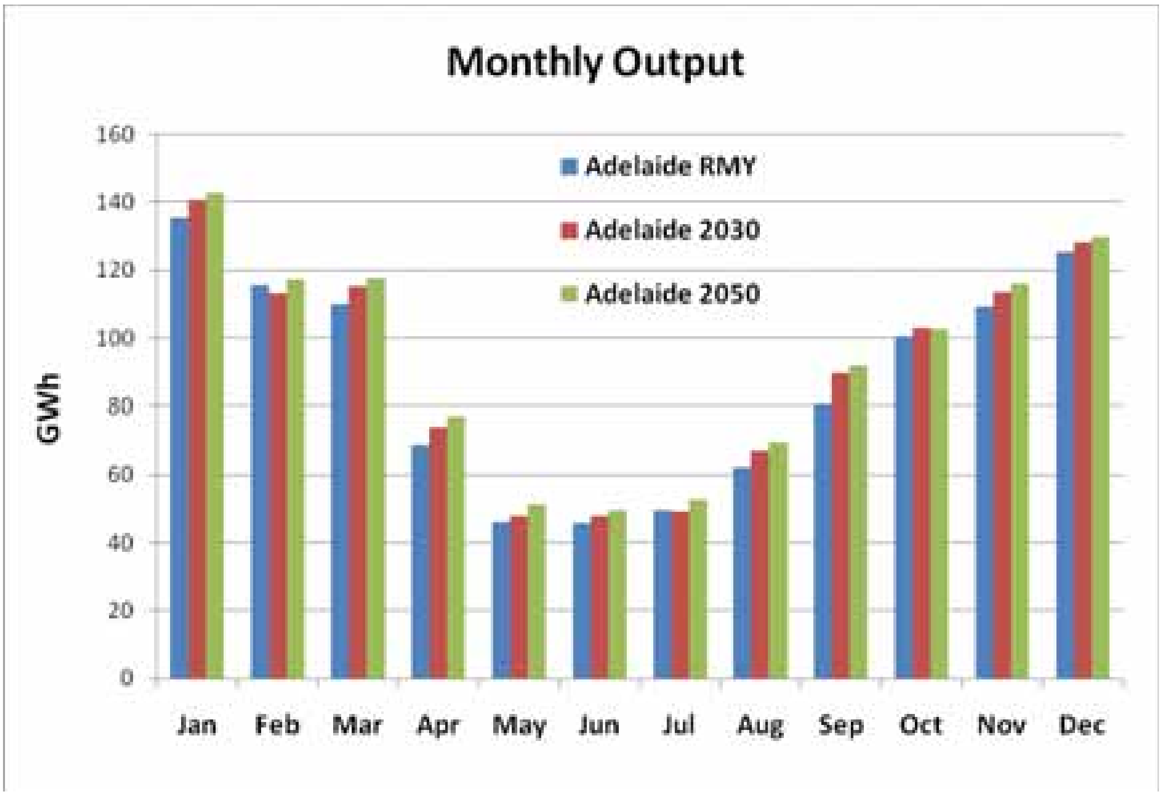

Fig 7: Renewable Energy Output for Parabolic System in the Adelaide climate

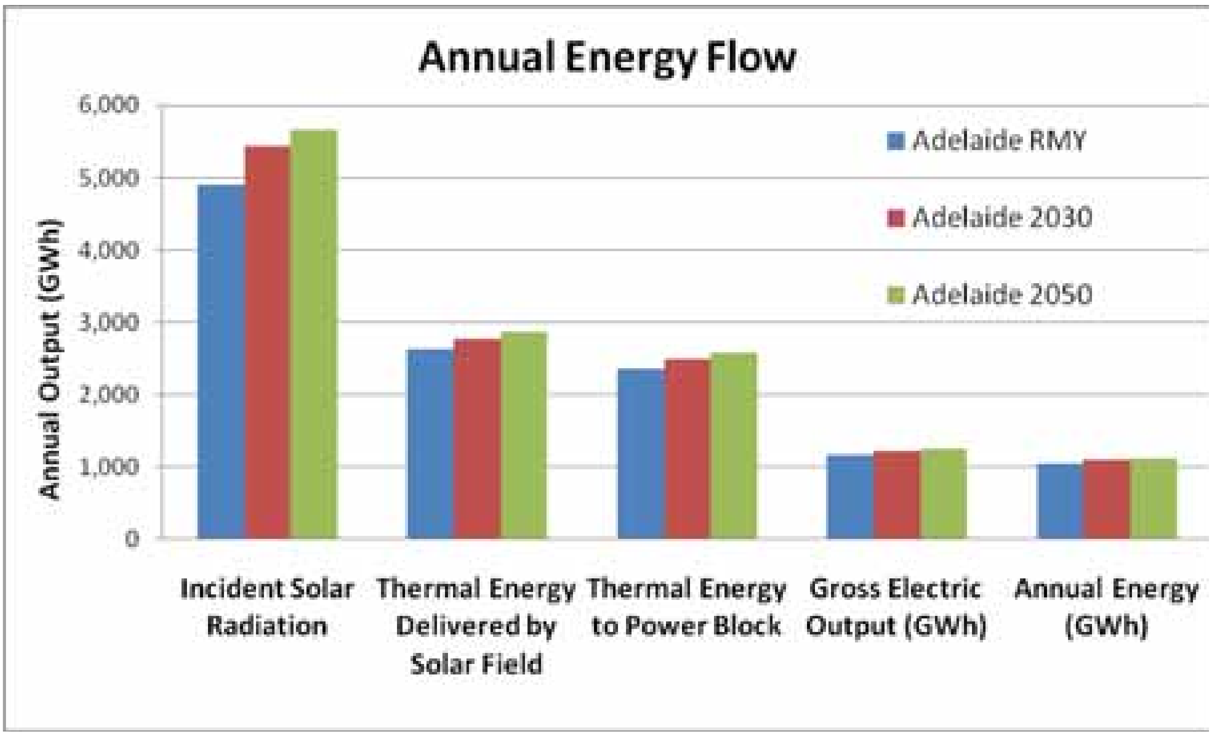

Fig 8: Annual forms of energy flow from Trough System in Adelaide over different climates.

5. Acknowledgements

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6. References

ACADS-BSG (2004), "Hourly Weather Data, sales brochure", Association for Computer Aided Design – Building Services Group, Melbourne.

Boland J, et al. (2008), "Models of diffuse solar radiation", Renewable Energy, 33.

BOM (2010), "Satellite Derived Global Solar Radiation", Bureau of Meteorology, Melbourne, http://reg.bom.gov.au/reguser/by_prod/radiation/

BOM (2010), "Gridded Hourly Solar Global Horizontal Irradiance Metadata", Bureau of Meteorology, Melbourne, (electronically published with the hourly solar global horizontal irradiance data)

BRANZ (2007) in association with CSIRO, Energy Partners, ANU-NCEPH and Artcraft Research, "An Assessment of the Need to Adapt Buildings for the Unavoidable Consequences of Climate Change", Report EC0893 for the Australian Greenhouse Office, Canberra. www.greenhouse.gov.au/impacts/ publications/buildings.html

CBD (2010), "Commercial Building Disclosure", Department of Climate Change and Energy Efficiency, http://cbd.gov.au/.

CSIRO (2010), "Future Climate Data for Building Regulation Energy Impact Assessment", Canberra, 2010.

Delsante, A.E. (1989), "Extension of Australian Climatic Data Bank and Outdoor Design Data" (NERDDC Project 984, Final Report), CSIRO, Division of Building, Construction and Engineering, Melbourne.

DEWHA, 2008, "NatHERS – Climate Zones and Climate Zone Map". Available at http://nathers.gov.au/about/climate-zones.htmlea

Energy Partners (2006a), "Australian Climate Data Bank", for Australian Greenhouse Office, Canberra, 2006

Energy Partners (2006b), "Development of Climate Data for Building Related Energy Rating Software", for Australian Greenhouse Office, Canberra, 2006 (unpublished)

Energy Partners (2008a), "Australian Climate Data Bank - Weather Data Enhancement for Reference Meteorological Years", for Australian Department of the Environment, Water, Heritage and the Arts, Canberra, 2008 (unpublished)

Energy Partners (2008b), "Development of Climate Data for Building Related Energy Rating Software", Report to the Australian Department of Environment, Water, Heritage and the Arts, Canberra (unpublished at the time of this conference)

Ferrari, D. and Lee, T.R. (2008), "Beyond TMY: Climate Data for Specific Applications", Proceedings of the ANZSES Solar '08 Conference, Sydney

Frick, RA. et al (1988), "Australian Solar Radiation Data Handbook", NERDDP/EG/88/714, Dept of Primary Industries and Energy, Canberra.

Frick, RA. and Leadbeater, M. (1992) "Sunless Springs and the ASRDH", Solar Progress, Vol 13 No 1.

Frick, RA. and Leadbeater, M. (1992) "Sunless Springs and the ASRDH", Solar Progress, Vol 13 No 1.

Forgan, B.W. (1996) "A New Method for Calibrating Reference and Field Pyranometers", Journal of Atmospheric and Oceanic Technology: Vol. 13, No. 3, pp. 638–645.

Forgan, B.W. (1999) "Application of WCRP/BSRN minute data to satellite exposure uncertainty". Bureau of Meteorology, Melbourne Australia

Lee, T.R (December 1991) “Defining the Solar Resource ... Just when we thought we had arrived”, editorial, Solar Progress, Vol 12, No 3&4

Lee, T.R., et al. (1995) “The Australian Solar Radiation Data Handbook (Edition 3)”, Energy Research and Development Corporation, Canberra

Lee, T.R, et al.. (2005) “The Australian Solar Radiation Resource Updated”, in proceedings of ANZSES Solar 2005, University of Otago, Dunedin

Lee, T.R, et al. (2006d) “The Australian Solar Radiation Data Handbook”, Energy Partners for ANZSES, Canberra

Lee, T and Ferrari, D (2008a), “Changing Climate - Creation of Ersatz Future Weather Data Files”. Proceedings of Solar 08, Sydney, 2008.

Lee, T and Ferrari, D (2008b), “Simulating the Impact on Buildings of Changing Climate - Creation and Application of Ersatz Future Weather Data Files”, Simbuild Conference, US-IBPSA, Berkeley CA, USA

Liley, J.B et al. D.S., 2007. “ Typical Meteorological Years for the New Zealand Home Energy Rating Scheme”. National Institute of Water & Atmospheric Research Ltd, Central Otago.

Morrison, Graham L. and Litvak, Alex, 1999. “Condensed Solar Radiation Data Base for Australia”. Report No 1/1999, Solar Thermal Energy Laboratory, University of New South Wales, Sydney, Australia

Muirhead, I., et al., 2010. Progress in Australian Solar Resource Assessment, paper 138, AuSES Solar 2010 Conference Proceedings, Canberra, Australia

NABERS (2008), “NABERS Energy and Water for offices - Validation Protocol”, Department of Environment, Climate Change & Water, Sydney, www.nabers.com.au

NREL 2011, System Advisor Model available at https://www.nrel.gov/analysis/sam/

Nunez, M. (February 1990) Satellite estimation of regional solar energy statistics for Australian capital cities, Bureau of Meteorology Study No 39.

Paltridge, G.W. and Proctor, D. (1976), “Monthly Mean Solar Radiation Statistics for Australia”, Solar Energy Journal, Volume 18 No 3, pp 235 243, Pergamon Press.

PCA (2001), “Energy Guidelines”, Property Council of Australia, Sydney 2001

Ridley, B and Boland, J. (2005) “Development of Climate Data for Building Related Energy Rating Software”, in proceedings of ANZSES Solar 2005, University of Otago, Dunedin

Roy, G.G., and Miller, S.G., (1980) “Data Handbook for Australian Solar Energy Designers”, University of WA

Spencer J. W. (1974) “Melbourne Solar Tables: Tables for Solar Position and Radiation for Melbourne in SI Units”, CSIRO, Division of Building Research Technical Paper (Second Series) No 7, (and other capital cities subsequently).

Spencer J. W. and Phillips R O. (1983) “Sunshine and Shade in Australasia”, fourth edition, Department of Transport and Construction Bulletin No 8, AGPS.