Solar Radiation Data for Over 100 Australian Sites

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ABSTRACT

For over two decades, the renewable energy fraternity has had access to solar radiation data for only 28 sites covering the whole continent through the ANZSES and now AuSES "Solar Radiation Data Handbook" (ASRDH). Those sites comprised 22 where accurate measurement had been undertaken and another 6 inferred from the inferior but workable sources of Sunshine Hours and Cloud Cover data which had been the source of the very earliest publication in this field in 1976.

The current publication, edition 4, presents in 5 volumes the data collected by the Australian Bureau of Meteorology (BOM) on horizontal surfaces (Global, Diffuse and Direct Horizontal) and sun-tracking surfaces (Direct Normal) which was processed to provide irradiation tables of surfaces of architectural and engineering significance giving monthly mean values by the hour as well as tables of frequency of occurrence of low irradiation to allow the design of storage systems.

This paper describes the project now nearing completion to use the BOM's recently released satellite-inferred hourly data for Global and Direct Normal values going back over more than a decade to expand the list of sites to 99: 79 coinciding with the locations chosen by the building industry for its Australian Climate Data Bank (ACDB) and another 20 chosen by anecdotal survey to cover remaining sites of interest to the renewable energy industry. Any number of sites, from the 278,000 available can be similarly processed should the demand arise.

The new edition also has new tables

Keywords* : climate, *radiation data, solar energy, solar, solar angles, clear sky

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 they also calculate 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 the first four editions of 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.

Thus, the current (4th) edition of the ASRDH contains data for just the same 28 sites as the previous edition, see Fig. 1, but covering a longer time period (up to 2004).

In 2010, the BOM released hourly data for virtually the whole of Australia (almost 280,000 pixels of approximately 5 x 5 km each) inferred from satellite images processed together with high quality ground based data from a small number of BOM sites.

2. The Data Sources

In 2010, the BOM released gridded GHI+DNI (Global Horizontal Irradiance and Direct Normal Irradiance in watts per square metre) hourly data for virtually the whole of Australia with a grid based on intervals of 0.05 degrees for both latitude and longitude (almost 280,000 pixels of approximately 5 x 5 km each but omitting off-shore islands).

In the BOM's own words, this is 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.

Previously, the BOM had only released daily total GHI satellite data, not hourly data, and it was that daily data from which the hourly data were inferred for the Australian Climate Data Bank (ACDB).

Exemplary Energy was able to be one of the first customers for the new BOM hourly GHI+DNI data, which covered from 1998 to mid 2001 and from mid 2003 to 2010 (with the two year gap caused by an unscheduled lack of a suitable satellite during that time).

The Exemplary Australian Solar Energy Atlas (EASEA, inhouse Exemplary Energy software) was quickly developed to visualise the GHI+DNI data on a PC screen, without an expensive GIS system.

The extraction of Time Series for individual locations ("pixels") was perfected so as to allow the extraction of hourly data for any of the almost 280 thousand possibilities, with the data interpolated to values at exactly on-the-hour local standard time.

The interpolation method relies on theoretical Clear Sky values calculated using ASHRAE (2009) methods, with the ASHRAE 2009 Clear Sky data (TauB and TauD monthly values, interpolated to daily values) for the most suitable site as selected from the almost three hundred ASHRAE 2009 sites in Australia. The selection of the ASHRAE model for Australian applications from among the contenders is described by Lee and O'Brien (2010).

So these two data sources - the GHI+DNI hourly data released by the BOM in 2010 and the ASHRAE 2009 Clear Sky model and data - provide “state of the art” foundations for the 5th edition of the ASRDH.

3. Geographic Scope — Site Selection for the 5th edition of the ASRDH

The current fourth edition of the ASRDH has data for only 28 sites with locations as shown in Fig. 1.

By contrast, there were some 80 Australian sites (Fig. 2, after Lee and Snow, 2008 and Energy Partners, 2008) chosen by the building industry for its Australian Climate Data Bank (ACDB).

The soon-to-be-released 5th edition of the ASRDH was planned to expand the list of sites to 100: 80 coinciding with the locations chosen by the building industry for the ACDB and another 20 chosen by anecdotal survey to cover remaining sites of interest to the renewable energy industry, as shown in Fig. 3 and in Fig. 4.

The slightly lower total number of 99 sites was reached after due consideration of the case of ACDB site Willis Island which lies outside the area covered by the BOM's hourly GHI+DNI data.

4. New Tables — Solar Angles and Clear Sky Data

The new 5th edition of the ASRDH will contain new Clear Sky tables based on ASHRAE 2009 methods.

The new Clear Sky tables signal a return of the concept employed by the so-called “Spencer Tables” (Spencer, 1974 and later), using ASHRAE 2009 Clear Sky values to calculate irradiance and irradiation levels. It must be noted however that these values are not peak but rather indicative values for cloudless conditions in the respective locations. They are calculated with normal conditions of water vapour and aerosols in the atmosphere and allowing for the lesser Air Mass over locations of high elevations but they do not represent values for extraordinarily clear days which will admit in the order of 10% to 15% more irradiance.

Two further new tables will show Solar Angles: Azimuth and Altitude. The new Solar Angles tables also signal the return of an old concept, intended for use by architects as well as engineers in checking for obstructions and temporal geometries of sun-tracking systems.

5. Time Series Extraction — Time Correction and Capping of High Values

The extraction of Time Series was performed to create hourly data, with the data interpolated minute-by-minute to values at exactly on-the-hour local standard time (i.e., daylight saving is ignored).

This “time correction” was required because the BOM data is instantaneous values at various times of day (depending on the date and the latitude), for example at 20 minutes to the hour, while ASRDH tables display values aggregated over the sixty minutes centred around "on the hour local time".

This Time Series Extraction was done for 99 sites, over a period of months, creating sets of hourly values for the twelve year period.

The interpolation method relies on theoretical Clear Sky values calculated using ASHRAE 2009 methods, with the ASHRAE 2009 Clear Sky data (TauB and TauD monthly values, interpolated to daily values) for the most suitable site as selected from the almost three hundred sites in Australia for which data have been published by ASHRAE.

These Clear Sky values were also used for capping BOM's estimated values at 110% Clear Sky. Also DHI was capped at 90% of GHI because the GHI estimates are the more reliable of the two and the tables need to use DNI and GHI values which were mutually consistent. These upper bounds (caps) were applied in conjunction with time correction and irradiation interpolation and then accumulated to the 60 minutes centred on terrestrial Standard Time on the hour. This is the same convention as the ACDB. It should be noted, however, that the alternative convention in the TMY format (Marion and Urban, 1995) of accumulating the data for the 60 minutes preceding the hour can also be readily accommodated by this methodology.

6. AuSolRad version 3

AuSolRad version 3 is the update of the software companion to the ASRDH, to be released with its 5th edition. It adds the new tables and allows the choice of units between MJ, kWh and PSH (Peak Sun Hours) and retains the following key characteristics which set it apart from the ASRDH which is necessarily constrained by its handbook format:

User selects:

- orientation in 1° increments
- tilt in 1° increments (including facing down)
- Depth of overhang
- Reflectivity of the "ground"

AUSOLRAD produces:

- Tables for all geometries of engineering and architectural interest including single and double axis tracking
- NO frequency tables for storage design optimisation

AuSolRadv3 also displays the new Clear Sky tables and the new Solar Angles tables as well as exporting them for manipulation and/or presentation by the user.

Data files for AUSOLRADv1 and AUSOLRADv2 were called .TYP files and were at the time considered large (115 kilobytes) with only so many fitting on a floppy disc.

Data files for AUSOLRADv3 are called .TYP2 files and are almost double the size (with expansion to contain Clear Sky values) at 183 kilobytes with potentially room for thousands on one compact disc.

AuSolRadv3 will display the Clear Sky values as part of an enlarged screen display of daily data.

AuSolRadv3 retains the simplicity and speed of operation of its predecessors, remaining as a text based delivery system which may be a project for future development into graphical delivery of information (even now, AuSolRad's easy export functions allow use of Excel or other graphical delivery system for this purpose).

7. Future Developments and Ancillary Services

Further sites

While the new edition covers nearly 100 sites, there is no longer any practical constraint on the number that can be treated this way except for the limitations on the number of BOM sites (over 1,000 anyway) from which the surface data can be accessed to generate the values published in Table 1. Climatic Averages. Accordingly, the generation of tables for any location can be undertaken to meet future demand and comprise the addition of extra .TYP2 files for direct use in AuSolRadv3 on a fee for service or fee for download basis.

Ersatz Future Data

With the provision by CSIRO of PCVs (Projected Change Values) for the 4 weather elements tabled in the ASRDH (temperature, humidity, wind and solar) Tables can be generated for 2030 and 2070 (high and low emissions scenarios) for publication in a similar form to those of the “further sites”.

8. Conclusions

The 2011 update to the Australian Solar Radiation Data Handbook (ASRDH) is an enhancement of the accuracy and pertinence of solar radiation data available to researchers, educators and practitioners.

The soon-to-be-released 5th edition of the ASRDH can be seen to serve as an upgrade to the current solar radiation resource stream, with the purpose of reducing the uncertainty in plant peak and average output estimation and benchmarking.

The aim is to reduce this uncertainty for practitioners by increasing the number of sites.

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 which include the introduction of a Carbon Tax.

Figures and Tables

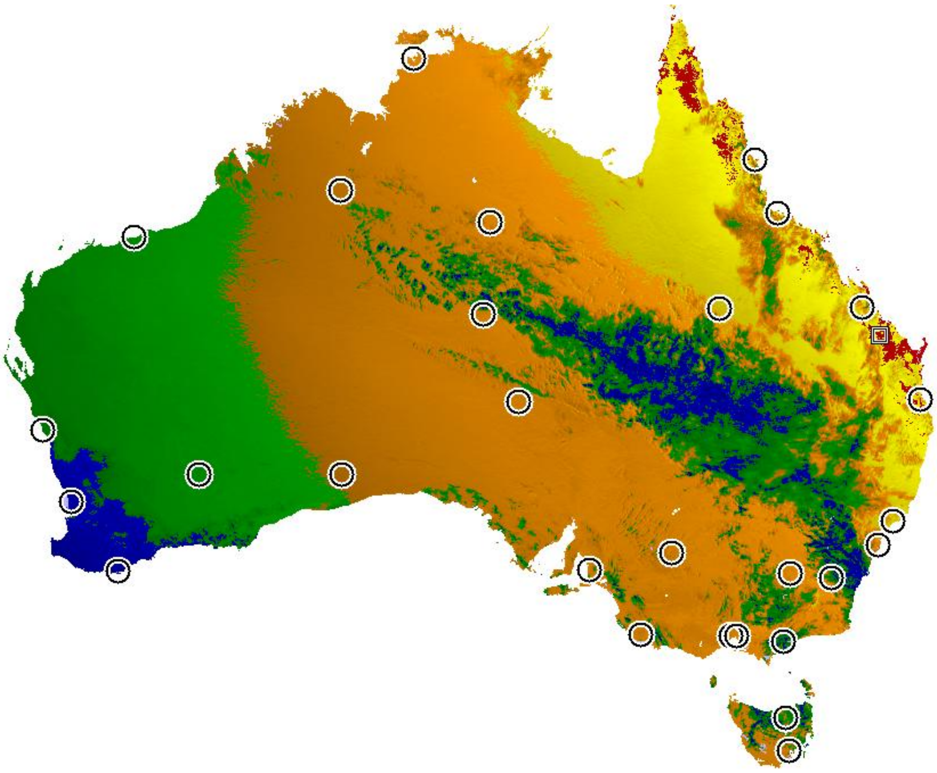

Fig. 1: Geographic Spread of the 28 Sites of the ASRDH Edition 4 (overlayed on a sample single-hour image from the Exemplary ASEA comprising nearly 280,000 pixels with individual values estimated from satellite observations)

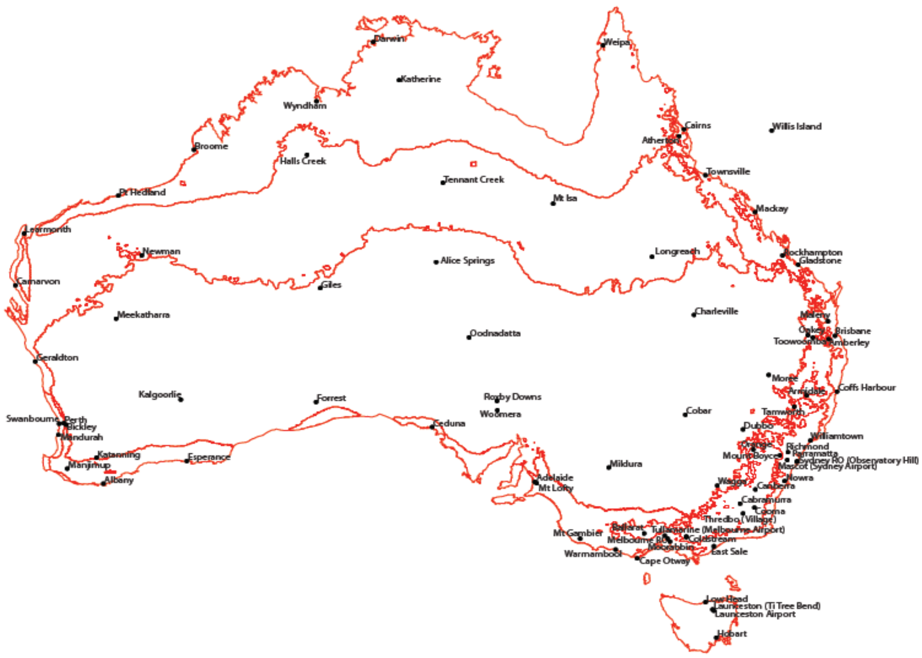

Fig. 2: Geographic Spread of the 80 Sites of the ACDB 2008
(showing the extents of the 8 BCA climate zones before harmonisation with state and local government boundaries)

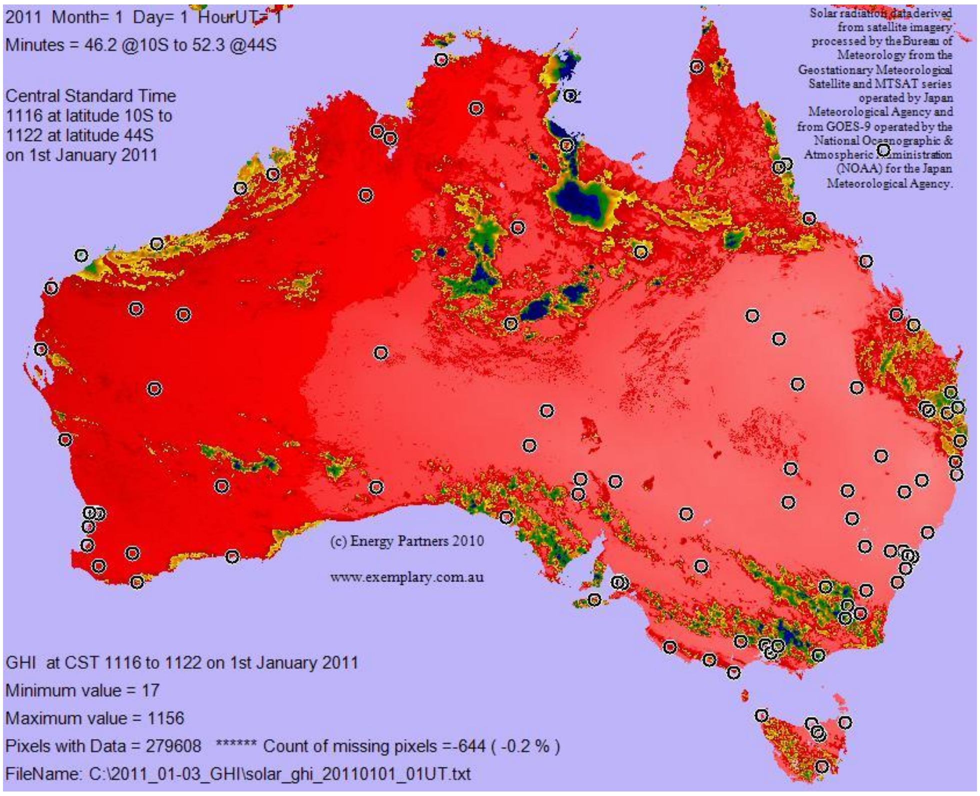

Fig. 3: Geographic Spread of 99 Sites of the ASRDH Edition 5 plus Willis Island (overlayed on a sample single-hour image from the Exemplary ASEA comprising nearly 280,000 pixels with individual values estimated from satellite observations)

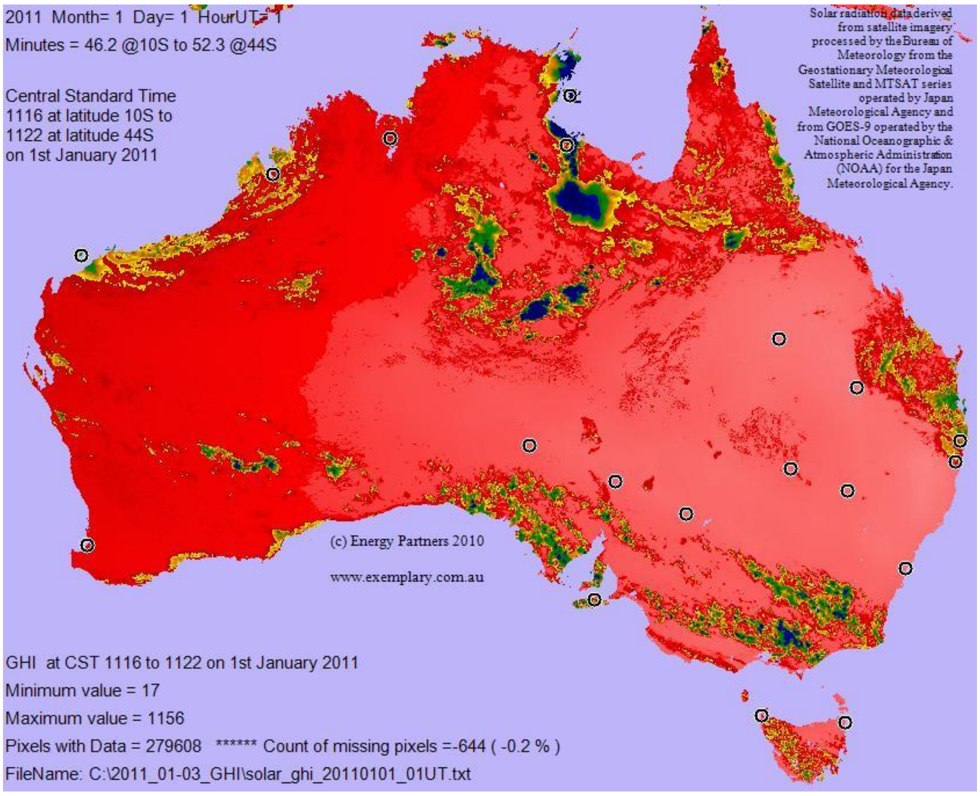

Fig. 4: Geographic Spread of the 20 extra ASRDH Edition 5 sites (extra in addition to the 80 Sites of the ACDB 2008) (overlayed on a sample single-hour image from the Exemplary ASEA comprising nearly 280,000 pixels with individual values estimated from satellite observations)

Table 1: List of Tables for ASRDH Edition 5 (new tables in *red italics*)

Table 1	Climatic averages (fully revised using BOM ground station data)
Table 2.1	Average hourly clearness index
Table 2.2	*Average hourly Clear Sky clearness index*
Table 2.3	*Solar Altitude*
Table 2.4	*Solar Azimuth*
Table 2.5	*Average Clear Sky global hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a horizontal plane for each month*
Table 2.6	*Average Clear Sky direct beam hourly irradiance (W/sq.m.) and daily irradiation (MJ/m²) on a horizontal plane for each month*
Table 2.7	*Average Clear Sky total hourly irradiance (W/sq.m.) and daily irradiation (MJ/m²) on a north facing plane inclined at latitude angle for each month*
Table 2.8 (… 2.11)	***Average Clear Sky total hourly irradiance (W/sq.m.) and daily irradiation (MJ/m2) on a north (… west) facing vertical plane for each month***
Table 3.1	Average global hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a horizontal plane for each month
Table 3.2	Average diffuse hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a horizontal plane for each month
Table 3.3	Average direct beam hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a horizontal plane for each month
Table 3.4	Percentage of days when daily global irradiation on a horizontal plane is at least as large as the value given for each month
Table 3.5	Percentage of daily global irradiation on a horizontal plane at least as large as the value given for each month
Table 3.6	Percentage of days when daily direct beam irradiation on a horizontal plane is at least as large as the value given for each month
Table 3.7	Percentage of daily direct beam irradiation on a horizontal plane is at least as large as the value given for each month
Table 3.8	Average number of hours per day in which the global and direct irradiance on a horizontal plane exceeds the specified values (W/m²)
Table 4.1 (… 4.4)	Average total hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a north (… west) facing vertical plane for each month
Table 4.5	Average total hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a north facing plane inclined at latitude angle for each month
Table 4.6	Average total hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a north-south axis tracking plane by hour for each month
Table 4.7	Average direct beam hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a north-south axis tracking plane by hour for each month
Table 4.8	Average total hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a sun tracking plane for each month
Table 4.9	Average direct beam hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a sun tracking plane for each month
Table 4.10	Average total hourly irradiance (W/m²) and daily irradiation (MJ/m²) on an east-west axis tracking plane for each month
Table 4.11	Average direct beam hourly irradiance (W/m²) and daily irradiation (MJ/m²) on an east-west axis tracking plane for each month
Table 5.1 (… 5.12)	Average daily total irradiation (MJ/m²) on an inclined plane during January (… December)
Table 5.13	Average annual daily total irradiation (MJ/m²) on an inclined plane
Table 6.1 (… 6.4)	Average hourly (W/m²) and daily (MJ/m²) solar heat gain factor through a north (… west) facing window for each month
Table 7.1 (… 7.8)	Proportional occurrence (%) of sequence of days for which the daily global irradiation is less than 2.5 (… 20) (MJ/m²)

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