



Developing HVAC design conditions for Australian locations with hourly meteorological data

Eric Laurentius Peterson, PhD, RPEQ, Affil.AIRAH

The University of Queensland and Victoria University

J. Ben Liley

National Institute of Water & Atmospheric Research, NIWA Lauder, New Zealand

ABOUT THE AUTHORS

Eric is employed by University of Queensland and Victoria University. Having spent a decade working as a Building Services Engineer (BSc Mechanical Engineering with a thermo-fluids stream), Eric moved into postgraduate research and university teaching (Environmental Engineering PhD). He has worked widely in consulting and industry as well as research and teaching. Recent work includes sustainable building engineering for Queensland Department of Housing and Public Work and sustainable infrastructure management for Sunwater (Queensland Water Resources Commission), Lectureships in Architectural, Civil and Mechanical Engineering at Victoria University, Construction Engineering at the University of the Sunshine Coast, and most recently teaching thermal performance assessment at the University of Queensland.

Ben Liley is an atmospheric scientist at New Zealand's National Institute of Water and Atmospheric Research site at Lauder in Central Otago. The station measures atmospheric composition and solar radiation by a variety of methods, and Ben studies the effect of clouds, aerosol, and atmospheric gases on solar radiation. Measuring and understanding the flux of solar radiation through the atmosphere is essential for models of climate and atmospheric chemistry and for predicting the effects on humans and their environment. Ben has developed methods to assess available solar energy, and combined this with other climate data in support of tools to assess energy demands of the built environment. He has recently undertaken a major revision of the climate data files used in the Nationwide House Energy Rating Scheme for the Australian Department of Climate Change and Energy Efficiency.

Ben contributes the latest NatHERS and NZ HERS climate zone files (98 base stations covering Australia and New Zealand) from which Eric extracts HVAC Design Data posted at a website for use by the HVAC industry "Australian HVAC system design data website" <<http://uq.id.au/e.peterson/>>.

ABSTRACT

Design data for 80 Australian locations have been developed at The University of Queensland in collaboration with New Zealand's National Institute of Water and Atmospheric Research (NIWA) in a major revision of the climate data files used in the Nationwide House Energy Rating Scheme (NatHERS) for the Commonwealth Department of Resources, Energy & Tourism (DRET). Design



data have been distilled from meteorological records to represent design conditions that are exceeded only rarely. The design data are temperature, humidity and solar radiation coincident with extreme events. Design data are required for calculation of peak thermal demand of the built environment. These data are essential to the design of heating, ventilation and air-conditioning (HVAC) systems. Australian HVAC system design data website <<http://uq.id.au/e.peterson/>> now serves an updated tabulation of design conditions HVAC designers working on projects in the vicinity of 80 locations around Australia, and establishes a methodology to extend to hundreds of other locations with automatic weather stations.

INTRODUCTION

HVAC system efficiency can be improved by exploiting the annals of the Australian Climate Data Bank (ACDB) that documents climate variability at 80 locations around Australia from 1967 through 2011. In contrast, mid-20th-century design temperatures are listed in Table 1 of the AIRAH Handbook “DA09 Air Conditioning Load Estimation Application Manual” currently in-press.

DA09 Table 1 and Table 1A includes 60 hourly stations in Australia from which HVAC systems can be designed to suit critical conditions, while synthetic data was offered in DA09 Appendix Table 2 to cover 600 locations. DA09 Table 1 & 1A design conditions are generally based on 10 years of hourly observations, excluding meteorological data subsequent to the Australian Bicentennial (1988).

CSIRO’s Walsh, et al. (1983) developed the first ACDB comprising 18 stations for use in heat transfer calculations in buildings. Solar radiation and meteorological parameters were merged to be as coincident as possible but wet-bulb temperatures were not included in earlier versions of the ACDB. NIWA has now included thermodynamic wet-bulb in the latest ACDB version since the coincidence of dry- and wet-bulb conditions have been essential to the design of HVAC systems since the invention of the air-conditioning process by Carrier (1902) and dissemination of psychometric analysis [7].

Australian HVAC system design data website <http://uq.id.au/e.peterson/> now increases the temporal coverage of HVAC design data by exploiting the ACDB, being a set of 80 high quality annals of hourly meteorological data that generally span 45 years (1967-2011) developed by Liley et al.[1]. This provides HVAC designers with design data to detail the current climate at 80 key locations, and track local changes with respect to the past 45 years in order to inform likely conditions mid-century-21. The methods presented here can be adapted to increase spatial coverage to 600 locations by working with the Bureau of Meteorology to process automatic weather station data.

In other cases, the Queensland Government’s SILO database of thousands of rain gauges instrumented with daily minimum and maximum temperature records can be used to estimate HVAC design conditions. This is delivered from the rainwater harvesting and demand calculator that has been developed at <http://rainwater.vpac.org/> and by selecting the “evaporative cooling”. The use of daily maximum observations to estimate design conditions was detailed by Peterson et al. [2].



DA09 includes 14 hourly stations that are not covered by the ACDB because they were closed manual stations. Consequently we will need to process Bureau of Meteorology automatic weather station data near the older manned stations to complete revision of Table 1 at these locations. A case study of urban heat island effects in the Brisbane capital city central business district illustrates the issues.

Key gains from the Australian HVAC system design data website <http://uq.id.au/e.peterson/>:

- DA09 includes 46 hourly stations that are covered by the ACDB (validation).
- ACDB adds the most recent 25 years since the Australian Bicentennial (climate change).
- The ACDB adds 34 hourly stations to the set established by DA09 (greater spatial span).
- The ACDB provides coincident solar radiation data as well as wet and dry bulb values.

Additional Outcome – Design Day files

The Australian HVAC system design dataset <http://uq.id.au/e.peterson/> includes “Design Day” files in three versions “DB”, “WB” and “CR”, each consisting of 24 hour drybulb-wetbulb pairs for each month (January through December), for each site. These 240 “Design Day” files are distributed in an ASCII format that is readily imported into ACADS-BSG CAMEL software, but could readily be converted to serve other HVAC system modelling software such as US DOE EnergyPlus.

METHODOLOGY

The processing of ACDB datasets was developed in MatLab computer script that could be given over the Bureau of Meteorology for integration into their ongoing analysis of automatic weather stations.

An example of outputs for processing of ACDB data into AIRAH DA09 “Outside Design Conditions” Table 1 format is provided as a case study of Tullamarine Airport (Melbourne). We based the analysis on the ten years DA09 data 1974-1984 as used in the current DA09 Table 1 for validation:

LOCATION		Option 1 Dry summer	Option 2 Wet summer	24 hour	8AM-6PM
		design DB / coinc WB	coinc DB / design WB	DB / WB	DB / WB
Tullamarine (Melbourne Airport) TU		36.0 DDB / 18.4 CWB	29.4 CDB / 20.4 DWB	37.0/20.4	38.0/20.8
CZ 60 post 3020 BoM 86282 WMO 94866				¼ %	¼ %

Winter (8AM)	24 hour	8AM-6PM	Elev	Lat	Long	Daily	Yearly	Data
comfort	criticl	criticl	(m)	(°)	(°)	Range	Range	Years
2.0 °C	2.0 °C	3.0 °C	118.8	-37.67	144.83	13.0 °C	34.0 °C	1975-1984
	¼ %	¼ %						



For the entire dataset for Tullamarine Airport (45 years from 1967-2012) results are as follows:

LOCATION	Option 1 Dry summer design DB / coinc WB	Option 2 Wet summer coinc DB / design WB	24 hour DB / WB	8AM-6PM DB / WB
Tullamarine (Melbourne Airport) TU CZ 60 post 3020 BoM 86282 WMO 94866	35.4 DDB / 17.8 CWB	27.6 CDB / 20.4 DWB	36.0/20.5 ¼ %	38.0/20.9 ¼ %

Winter(8AM) comfort 2.9 °C	24 hour criticl 2.0 °C ¼ %	8AM-6PM criticl 3.6 °C ¼ %	Elev (m) 118.8	Lat (°) -37.67	Long (°) 144.83	Daily Range 12.5 °C	Yearly Range 32.5 °C	Data Years 1967-2011
----------------------------------	-------------------------------------	-------------------------------------	----------------------	----------------------	-----------------------	---------------------------	----------------------------	----------------------------

Method of serving data suitable for a range of applications (CAMEL and EnergyPlus)

Australian HVAC system design website serves the three design-day files for Tullamarine Airport:

TU_60_DB - Intended to represent DA09 “Option 1” Dry summers selected by DB.

TU_60_WB - Intended to represent DA09 “Option 2” Wet summers selected by WB.

TU_60_CR - Intended to represent DA09 “Design Values” selected for DB and WB.

“CR” files are provided in accordance with AIRAH DA09 “Design Values” - being a synthetic combination of design DB with design WB that is climatologically unlikely or at least very rare and so may be desirable for more critical applications.

The percentage of design conditions exceeded at any of the 80 ACDB sites is available by clicking “Location Summary” of the Australian HVAC system design data <<http://uq.id.au/e.peterson/>>.

Table A provides an example from the location summary for Tullamarine, where “Design Values” were exceeded 0.56% of the time with respect to coincident wet- and dry-bulb conditions - very near ASHRAE’s stringent design confidence percentile 0.4%. Meanwhile while “Option 1” was exceeded 2.71% and “Option 2” 3.28% - comparable to ASHRAE’s least stringent 2% level of design.

Option 1 Dry summer design DB / coinc WB 35.4 DDB / 17.8 CWB		Option 2 Wet summer coinc DB / design WB 27.6 CDB / 20.4 DWB	
percentage of hourly data exceeding levels			
design DB 0.31 %	coinc WB 2.59 %	coinc DB 3.15 %	design WB 0.27 %
design DB & coinc WB 2.71 %		coinc DB & design WB 3.28 %	
design DB concurrent with design WB 0.56 %			

Table A: Hours exceeding design temperatures at Tullamarine 1967-2011



For example, ACDB zone 60 Tullamarine (Melbourne Airport) from 45 years (1967-2011) is documented on website <<http://www.uq.id.au/e.peterson/>> “Location Summary” reporting 35.4 °C Design DB = mean of 10th highest 3PM each year + (standard deviation x 1.63).

Tullamarine design DB was exceeded 10 days/year, including 3.5 days/year standard deviation. “Dry Design Day” curves for Tullamarine were derived with extreme value of 5.59% from hour/month bins. Meanwhile Tullamarine was allocated 20.4° Design WB = mean of 10th highest 3PM each year + (standard deviation x 2). This design WB was exceeded 10 days/year, including 4.5 days/year standard deviation. “Wet Design Day” curves were derived with extreme value of 3.23% from hour/month bins. For the example of Tullamarine the combination of design DB and design WB “Design Values” were exceeded 0.56 % of hours - this is comparable with capital cities listed in Table B below. The design values derived in the present report are generally more stringent than those nominated by ASHRAE, and closely approach the 0.25% “Critical” conditions tabulated in DA09 [6,3].

ID	Zone	Location	“Option 1”	Option 2”	“Design Values”
DA	1	Darwin	0.11 %	0.11 %	0.22 %
BR	10	Brisbane	0.25 %	0.29 %	0.51 %
PE	13	Perth	0.25 %	0.37 %	0.61%
AD	16	Adelaide	0.28 %	0.38 %	0.64%
SY	17	Sydney	0.33 %	0.42 %	0.72%
ME	21	Melbourne	0.30 %	0.37 %	0.64%
CA	24	Canberra	0.23 %	0.31 %	0.52%
HO	26	Hobart	0.38 %	0.35 %	0.65%

Table B: Percentile of hours exceeded during 45 years in Australian capital cities

The percentage of hours design conditions are exceeded at any of the 80 ACDB sites is linked at the “Location Summary” of the Australian HVAC system design data website.

To illustrate the combined impact of design DB concurrent with design WB consider the following two plots of the 24 hour x 12 month “Design Values” design day “CR”.

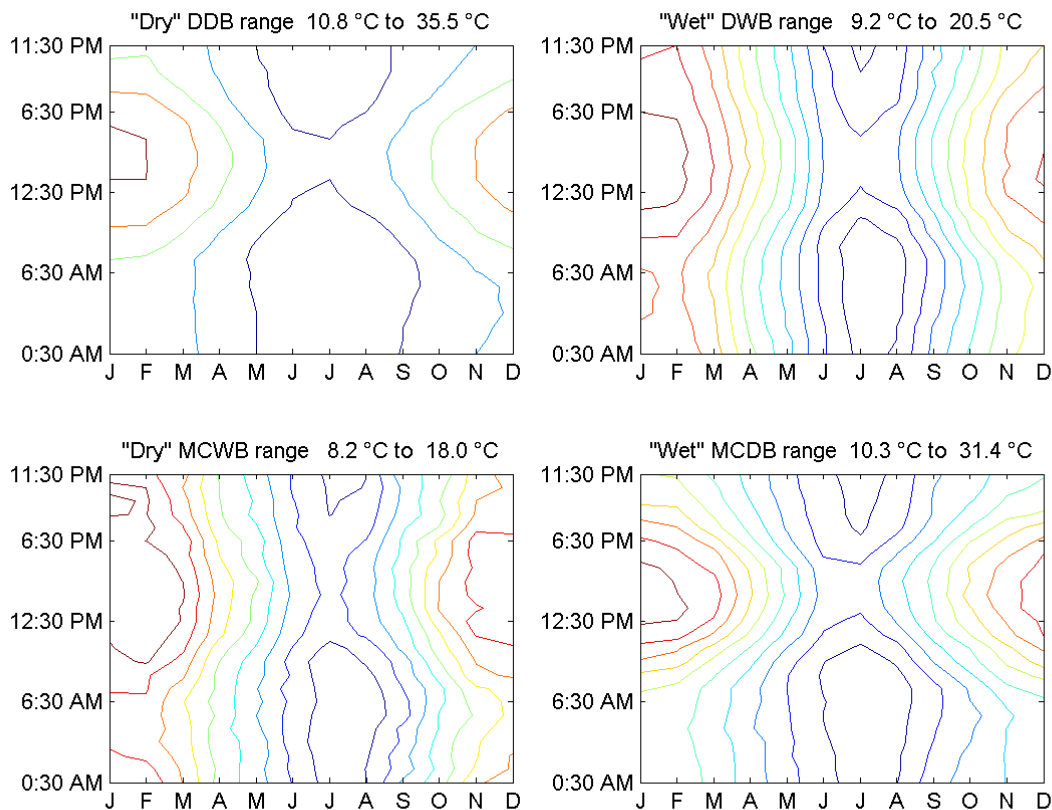


Figure 1: Tullamarine airport design wet-bulb(upper left) and design dry-bulb (upper right) and mean coincident wet-bulb (lower left) and mean coincident dry-bulb (lower right) 24 hour x 12 month

“Option 1”, “Option 2”, and “Design Values” files were generated by sorting the wet-bulb and dry-bulb data into bins (24 hours x 12 months). Record was made of the number exceeding the design DB and design WB within each bin, and from this the month of worst-case is determined. Option 1 “DB” Design Day files have applied a fixed percentage in 24 hour/12 month bins, individually adjusted at each of the 80 ACDB sites such that the dry-bulb design temperature at 3PM is exceeded just 10 days per year – including the standard deviation of exceedances. In the case of Tullamarine Airport, Dry Design Day is the 5.59% from hour/month bins near the end of the “Location Summary”.

Option 2 “WB” Design Day files have applied a fixed percentage into the bins, adjusted at each ACDB site such that wet-bulb design temperature at 3PM is exceeded just 10 days per year – including the standard deviation of exceedances. In the case of Tullamarine Airport, Wet Design Day is 3.23% from hour/month bins at the end of the “Location Summary”.

Averaged over many years, design temperatures are exceeded only about six or seven days per year. The design wet-bulb temperature is only expected to be exceeded ten times in a humid “La Niña” year. The design dry-bulb is expected to be exceeded ten times only in the course of a dry “El Niño” year.

One level of criticality can be obtained by joining the design dry and wet-bulb temperatures at once, reducing risk of overheating – but increasing risk of ineffective control of humidity and poor energy efficiency. For even more extreme aversion of overheating two additional levels of critical design conditions are provided in Table C below (in the format of DA09 Table 1) for conditions that are not exceeded more than 0.25% of hours – with a choice of either 24 hours or 8:00 AM through 6:00 PM.

LOCATION	Opt 1 Dry DDB / CWB	Opt 2 Wet CDB / DWB	24 hour DB / WB	8am-6pm DB / WB
Darwin (airport) DA	34.7 / 22.4	30.5 / 27.4	34.3/27.2	34.8/27.3
Brisbane (airport) BR	31.6 / 21.6	27.9 / 24.9	31.6/25.1	32.8/25.4
Perth (airport) PE	38.2 / 19.0	29.3 / 21.5	38.3/21.9	39.8/22.3
Adelaide AD	38.0 / 18.6	29.3 / 20.9	38.3/21.4	39.7/21.8
Sydney (Obs Hill) SY	31.9 / 19.1	26.0 / 22.6	32.6/23.0	34.7/23.3
Melbourne (CBD) ME	35.5 / 18.2	27.5 / 20.3	36.0/20.7	37.7/21.0
Canberra (airport) CA	34.6 / 17.1	26.0 / 19.5	34.5/19.8	35.9/20.2
Hobart HO	28.3 / 16.3	24.1 / 18.3	29.5/18.7	31.6/19.1
Tullamarine (airport) TU	35.4 / 17.8	27.6 / 20.4	36.0/20.5	38.0/20.9
	comfort	comfort	critical	critical

Table C: Results (abridged from <http://www.uq.id.au/e.peterson/> link to “ACDB Table 1”)

CASE STUDY

All of the Design Day files posted at the Australian HVAC design data website have been tested at the Queensland Department of Housing and Public Works using CAMEL version 5.10.3D software. CAMEL did not run unless the daily range is at least 10 degrees (in first line to the left of latitude S), which was the case for Tullamarine but apparently must be edited by the user for other locations. The following are the first nine lines of the “Dry” (Option 1) Design Day file for Tullamarine Airport:

```
TU_60_DB 12.5 37.7S
6AM DB 23.0 23.5 21.0 18.0 14.3 12.0 11.0 11.7 14.0 16.1 19.0 20.6
WB 15.6 15.5 14.3 12.8 11.0 9.6 8.5 8.4 9.5 12.1 13.1 14.3
7AM DB 23.9 23.2 21.0 18.0 14.5 12.0 11.0 11.3 14.0 16.2 19.8 21.7
WB 15.7 15.8 14.1 12.5 11.3 9.7 8.6 8.4 9.6 11.8 13.5 14.2
8AM DB 25.0 24.1 21.0 17.7 14.0 11.7 11.0 11.0 14.0 17.0 21.2 23.5
WB 16.1 16.1 14.4 12.7 11.0 9.5 8.7 8.3 10.0 11.7 13.9 14.2
9AM DB 27.0 26.9 23.0 18.7 14.4 12.0 10.8 12.0 15.0 19.0 23.0 25.3
WB 16.6 16.1 15.2 12.6 11.3 9.9 8.2 8.6 10.4 12.4 14.8 15.1
```

A desktop study was provided of a demountable twin classroom, to benchmark the results of ACDB Design-Day files. Plans of a 158 m² demountable building with veranda were found on the internet. The metal clad construction was assumed to be R1.5 insulated on the ceiling, walls, and under floor. Windows were assumed to be single glazed with aluminium frames. It was assumed to be aligned with veranda facing due east, and elevated. The building air conditioning load was calculated with

CAMEL’s inbuilt COMFORT and CRITICAL conditions for Tullamarine Airport, and also with the three Design-Day files TU_60_DB.txt, TU_60_WB.txt and TU_60_CR.txt as posted on the Australian HVAC system design data website, with results presented in table D below, where a coil by-pass factor of 0.15 was assumed. Internal loads were based on 1.6 kW of lighting and 79 persons. In accordance with Queensland Government Project Services Chief Engineer’s assessment of primary school occupancy, a requirement of 5 litres per second of conditioned fresh air was provided for each student in the load calculation. Indoor conditions were targeted to 24°C at 50% relative humidity.

	CAMEL standard COMFORT Concurrent WB and DB	CAMEL standard CRITICAL 24 hr 0.25%	ACDB “Dry Summer” Design DB with mean coincid WB	ACDB “Wet Summer” Design WB with mean coincid DB	ACDB “moderately critical” concurrent design DB & design WB
Design conditions	34.3/20.5	36/21	35.4/17.8	27.6/20.4	35.4/20.4
Aver. Daily Range	12.9	ref ACADS-BSG	12.5	12.5	12.5
kW GTH	27.6	32.7	25.3	29.9	28.9
L/s supply	1498	1729	1494	1289	1544
peak time	3 PM January	3 PM January	4 PM January	4 PM January	4PM January
On-coil DB/WB	26.8/18	27.4/18.3	27.0/17.0	26.3/18.1	26.9/18
Off-coil DB/WB	13.5/12.3	13.8/12.5	13.1/11.6	13.1/12.0	13.6/12.4
Apparatus dew pt	11.3°C	11.3°C	11.7°C	10.8°C	11.2°C
Luvata Coils ver 9.1 cooling selection	1100 mm x 600mm 8-row R134a DX	1200 mm x 600mm 8-row R134a DX	1100 mm x 600mm 8-row R134a DX	1600 mm x 500mm 12-row R134a DX	1300 mm x 600mm 12-row R134a DX

Table D: Results of case study use of Tullamarine (TU 60) HVAC system Design Day files in CAMEL

The *basecase* CAMEL nominal COMFORT (DA09 3rd edition “Design Values”) is current practice for sizing air conditioning if a DHPW school was located at Tullamarine Victoria. Hypothetically, a design brief for “special-needs facility for students intolerant of heat” could cause an designer to use CAMEL 24 hour CRITICAL, finding an estimate of 18% higher grand total heat (GTH) and 15% higher supply air specification. Application of ACDB Option 1 “Dry” data as input to CAMEL results in 27% lower estimate of GTH and 16% lower supply air specification. Application of ACDB Option 2 “Wet” data as input into CAMEL estimates 17% higher GTH and 14% lower supply air specification. Recent climate data in the form of ACDB “moderately critical” input into CAMEL results in the same GTH as CAMEL standard COMFORT, but 17% lower supply air requirement.

If Option 2 “Wet” Luvata coil selection is locked, then the Option 1 “Dry” duty is confirmed with 6% spare capacity, and “Design Values” duty is delivered with 10% spare capacity. Option 2 “Wet” duty cannot be achieved if either the Option 1 “Dry” or “Design Values” coil selections are locked. If the “Design Values” coil selection is locked, then the Option 1 “Dry” duty is just about satisfied,

but the Option 2 “Wet” duty cannot be achieved. Therefore, in the case study of a twin-classroom school building notionally installed at Tullamarine, the Option 2 “wet” duty is most critical to ensure proper cooling coil selection. In any situation Luvata “Coils for Windows 9.1” can use particulars of CAMEL outputs from both ACDB “Option 1” and “Option 2” to determine one coil that serves both duties.

DISCUSSION

The above case-study of tabulated in Table D above is offered for a single building notionally deployed at Tullamarine. This example indicates that the Option 2 “WB” (warm-humid La Niña) Design Day file can be used to selected a cooling coil that also fully serves loads calculated with Option 1 “DB” (hot-dry El Niño) as well as the moderately critical “design values” (CR) duty. To answers the sceptic’s question “how can you select one coil with 2 duty points?”, one coil can be found to serve both sets of requirements. It is interesting that in the above case study a coil selected with the ACDB “moderately critical” TU_60_CR.txt Design Day file input to CAMEL and then used by Luvata Coils failed to deliver the Option 2 “WB” duty. In this case, oversizing would have prevented effective dehumidification performance during sultry monsoonal weather. Inspection of the ACDB Option 1 process in the CAMEL psychrometric plot suggests that an evaporative cooler could maintain 24°C at >80% relative humidity if air quantities were tripled. Inspection of the ACDB Option 2 processes on the CAMEL psychrometric plot makes it clear that the dehumidification is called for to maintain comfort during humid weather. Therefore the second duty is obviously the DB a sample of design temperatures distilled from the ACDB for the Australian capital cities and also for Tullamarine Airport outside Melbourne. Be aware there are additional stations in the vicinity of the above that may exhibit significant urban heat island effects. A detailed report on the analysis of each ACDB site can be found by clicking the corresponding “Location Summary”. The rate of climate change was found to be warming 2.3°C per century averaged over the 80 locations, but with locality standard deviation $\pm 3.5^\circ\text{C}$ per century, with a few sites cooling.

“CR” files used in CAMEL give higher estimates than the “comfort” mode of program CAMEL since “Design Values” for Tullamarine have increased from 34.6/20.4 to 35.4/27.6 (design db/design wb).

“Option 1” loads are smaller and “Option 2” loads are higher, but with lower air quantity for the “WB” file. Humidity control can fail if outdoor air coil is not selected for required load at low flow.

Armed with up-to-date high quality coincident hourly dry- and wet-bulb data for the past 45 years it is now hoped that designers will be confident to avoid the oversizing inherent with use of the “CR” files, but rather to provide redundancy in HVAC system fresh air intake to consider for both El Niño (“DB”) and La Niña (“WB”) conditions. The authors suggest that more efficient cooling and dehumidification would be achieved if these two processes were considered in light of the more realistic “DB” and “WB” Design Day files offered at the Australian HVAC system design data website.



The last revision of AIRAH DA09 [3] introduced Options 1 and 2 after ASHRAE [4] had been publishing similarly alternative paired wet- and dry-bulb design data. The third edition of DA09 [3] offered the pairs with a warning, “the use of Option 1 and Option 2 in isolation is not recommended, but experienced designers may wish to use them...for inland or tropical installations or for analysing performance of components such as cooling towers or evaporative condensers”.

ASHRAE [4,5] design conditions are tabulated for both annual and monthly time scales (January through December), using different percentage thresholds as appropriate to provide a suitable range of risk. ASHRAE design dry bulb values are presented with their coincident wet bulb values, and design wet bulb values similarly presented with their coincident dry bulb values. Using these pairs to analyse load and system requirements represents a more complex HVAC system designs sized to match heat and moisture conditions during normal heat waves. But this approach suggests that HVAC designers should be formally briefed to provide for redundancy to handle both Option 1 “Dry” and Option 2 “Wet” conditions in the design of air handling units serving fresh air indoors.

In all editions of DA09 [3,6], dry- and wet-bulb have been tabulated for critical processes based on all plant operating hours not exceeded on 0.25%, both for a 24 hour basis and a 10 hour (8am-6pm) basis. ASHRAE [5] presents cooling design data as percentiles of 0.4, 1, 2 and 5% of hourly observations that are exceeded 35, 88, 175 and 438 hours per year respectively. For monthly conditions, ASHRAE tabulates 0.4, 2, 5 and 10% design values (exceeded 3, 14, 36, or 72 hours per month respectively). ASHRAE states that the 0.4% annual condition is roughly equivalent to the 2% monthly condition for the hottest months. The 0.4% monthly value for the hottest month will therefore be more extreme than the most extreme annual value. McGraw-Hill published their 1972 “Handbook of Air Conditioning System Design” upon which the Australian Department of Housing and Construction based the first edition of DA09, so it is worthwhile noting that they subsequently have been publishing of “Handbook of Air Conditioning and Refrigeration” (Wang 2001 2nd edition), recommending the 0.4% annual design dry-bulb with mean coincident wet-bulb for “strict control of indoor environmental parameters”. Wang [9] states “It is not economical to choose that annual maximum or annual minimum values as the design data.”, and uses the 1% values in example loads.

RECOMMENDATIONS FOR FURTHER WORK

In the first instance additional ACDB design files should be developed for Brisbane CBD heat island mapped in Figure 2 and modelled in Figure 3 with the Queensland Government SILO PPD. An automatic weather station has been monitoring hourly conditions in the vicinity since 1999, and so add confidence to the dry- and wet-bulb combinations that develop in Brisbane further inland than the bayside airport. The methodology developed in the process could be ported to the Bureau of Meteorology for extension of coverage to most all of the 600 locations currently listed in AIRAH DA09, and elsewhere. In the meantime the SILO PPD is available at over a thousand stations to indicate the local patterns of change in design conditions. Doing so accepts that the practice of using 3pm data restricts the number of sites where design temperatures can be readily determined.

Detailed findings from the 80 ACDB sites shows results from SILO are comparable with those from the 3PM values in the ACDB.

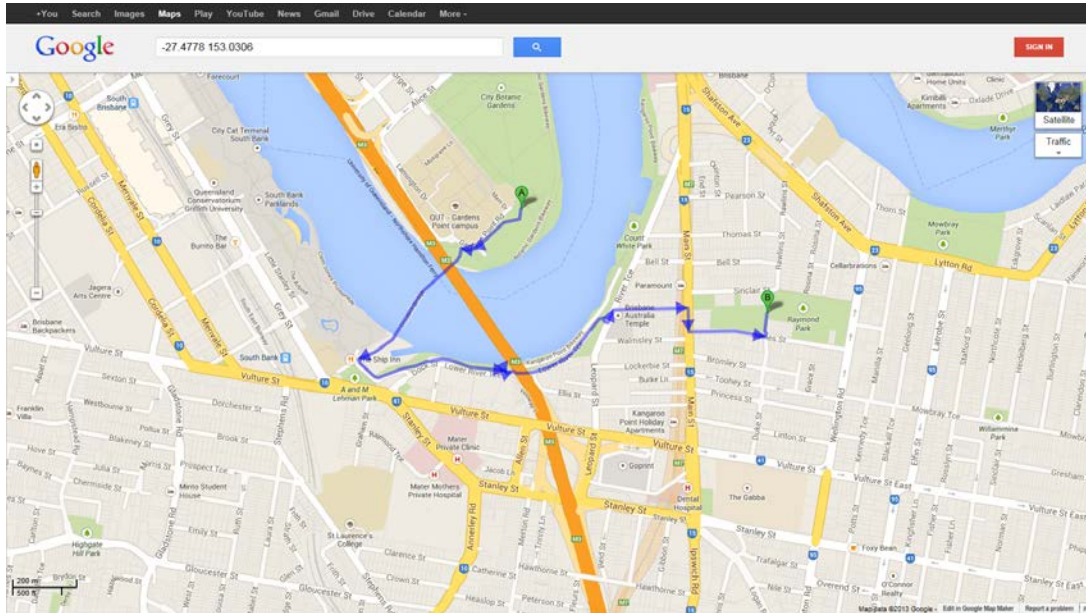


Figure 2: Brisbane Central Business District may be influenced by evaporative cooling of the river. Note the historic weather station at map point A was on the grounds of the old Queensland Botanic Gardens adjoining Parliament & QUT, and the automatic weather station was later established near the ‘Gabba stadium.

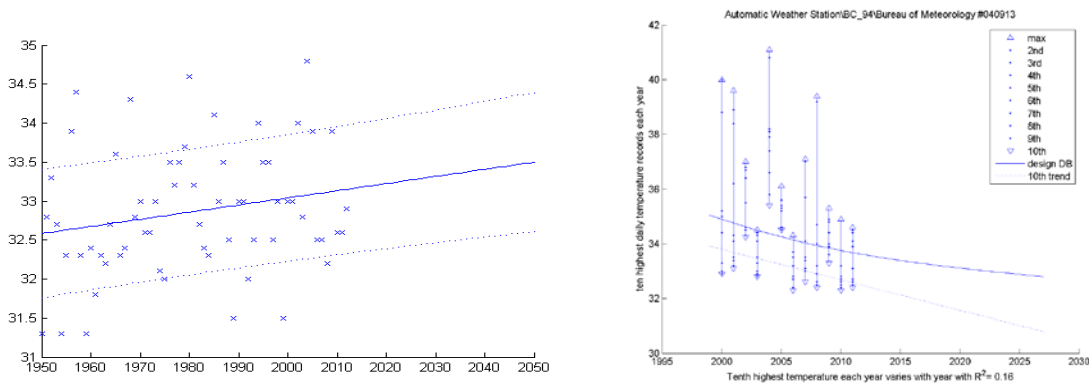


Figure 3: Brisbane Central 10th rank annual temperature regression \pm standard estimate error on the left, compared to the graph previously presented as Figure 1 (right above). Recent trend from automatic weather station result include quadratic error estimate to ensure forecast design dry-bulb is not underestimated. The historic weather station (map point A) was on the grounds adjoining Parliament & QUT, and the automatic weather station (map point B) was established near the ‘Gabba stadium.

The Brisbane AWS trend contradicts the PPD trend for a nearby location in Brisbane CBD heat island. The contradiction is resolved since the automatic weather station has only been monitoring hourly conditions in the vicinity since 1999, while SILO PPD includes manual observations that have proceeded since Queensland Colonial Government. The methodology of extracting automatic

weather station data should not be ported to the Bureau of Meteorology website without reference to either the ACDB or SILO PPD to provide sufficient background to suit trending forecasts. For now we should only consider locations with longer automatic weather station archives, such as Adelaide as documented in Figure 4 (Map) and Figure 5 (coastal and CBD automatic weather station plots).

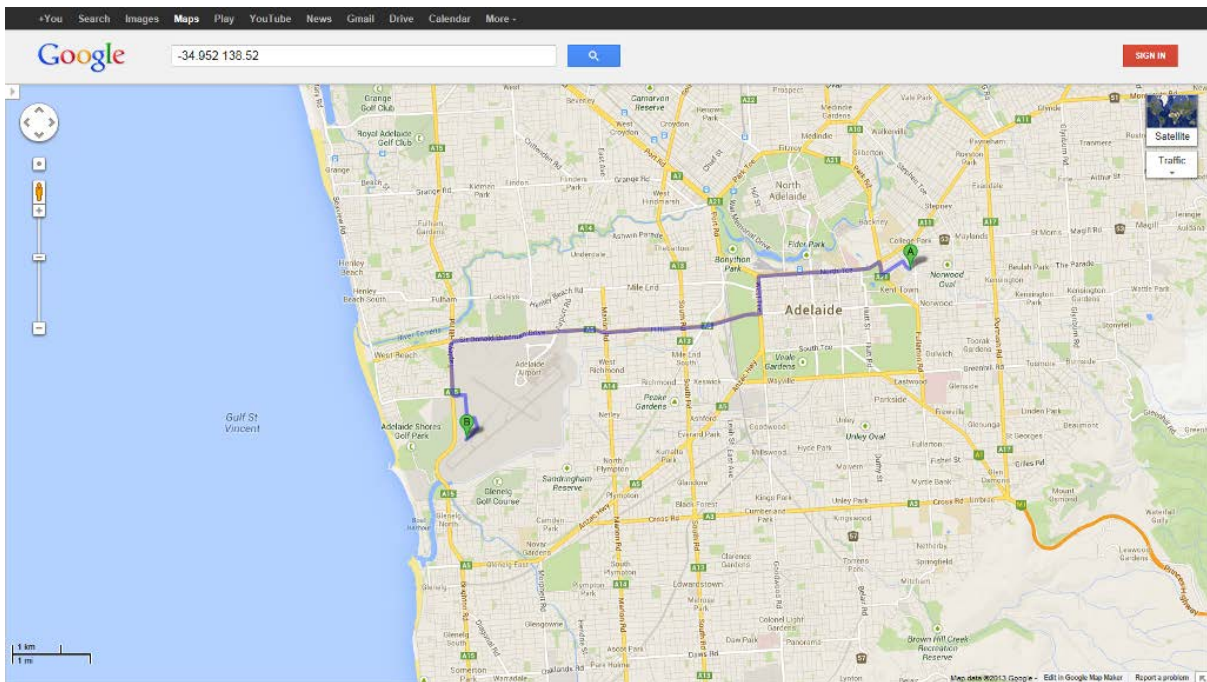


Figure 4: Adelaide Coastal (AC 75 at map mark B) versus Adelaide City (AD 16 at map mark A)

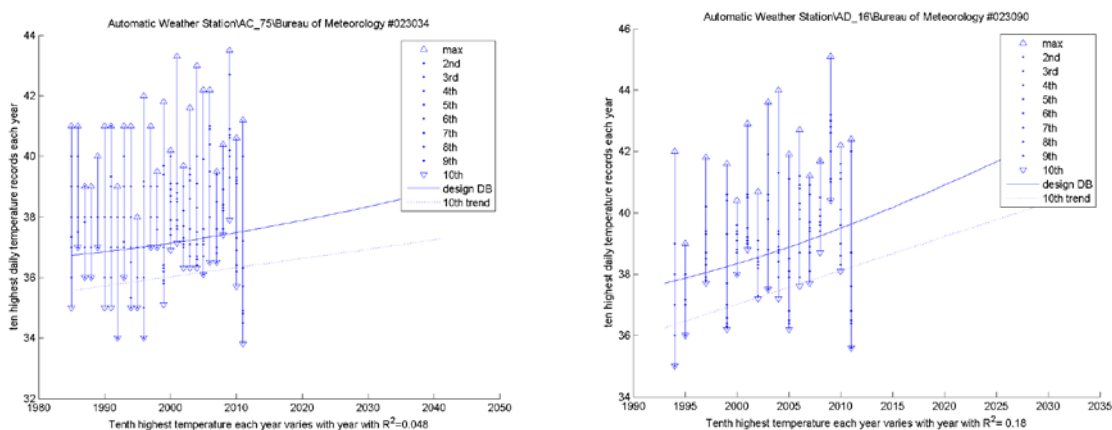


Figure 5: Adelaide Coastal (AC 75 at map mark B) versus Adelaide City (AD 16 at map mark A)



ACDB Table 2 reports Adelaide Coastal and CBD Option 1 design DB has been assessed as 36.6°C and 37.9°C, respectively. The coastal site DDB has been rising 1.7°C per century (R^2 0.18) tracking towards 37.7 °C circa year 2050. Meanwhile the CBD site has been rising 5.5°C per century (R^2 0.49) and is tracking towards 41.2 °C circa year 2050. The automatic weather station projection in Figure 3 confirms the trend, but not the magnitudes. Beware that CDB automatic weather station has not been tracking the trend as long as the ACDB time series that NIWA has merged earlier manual observations from the Bureau of Meteorology, and so Table 2 is a better source of forecasting.

Initial investigations and analysis of the relationship between daily maximum and minimum values and hourly data has been carried out and are reported in the “Location Summary” for the 80 ACDB sites that is presently served from <http://www.uq.id.au/e.peterson/>. The case study of Brisbane CBD’s automatic weather station will add one more to the list, but strategically the University of Queensland has submitted a request to the Bureau of Meteorology to discuss potential options for them to automatically post design data from their website. So far the Bureau has supplied raw data which University of Queensland has posted on the design data website for research. The algorithm that proves to convert the raw data into design conditions for the HVAC industry will be given to the Bureau of Meteorology to implement automatically, if funding can be obtained.

SUMMARY

This project has been successful in providing up-to-date design condition data suitable for a range of applications, and in quantifying trend change in extreme conditions due to global warming and urban heat island effects. Additionally, processes have been identified that would allow for both extension of recent design condition data to hundreds of sites as well as more frequent, efficient updates through potential automated processing of raw data from BOM.

ACKNOWLEDGMENT

This work was funded by the Commonwealth Department of Resources, Energy and Tourism.



REFERENCES

1. Liley, J.B., Nagle, P. and Grant, I.; “Australian climate data for building energy simulation”, AIRAH Building Simulation Workshop Melbourne April 18, 2013.
2. Peterson, E.L., Williams, N., Gilbert, D., and Bremhost, K.; “New air conditioning design temperatures for Queensland, Australia”, AIRAH Ecolibrium, Vol. 5, No. 1, pp.26-36 (2006)
3. Wickham, F.A. (3rd ed); “Design Aid 9 – Load Estimation & Psychrometrics”, AIRAH, 1998.
4. ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, 1993.
5. ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, 2009.
6. Wickham, F.A. (2nd ed); “Air conditioning systems : load estimation and associated psychrometrics”, Canberra, A.C.T.: Australian Government Publishing Service, 1988.
7. Carrier, Willis Haviland. “Rational Psychrometric Formulae: Their Relation to the Problems of Meteorology and of Air Conditioning”. American Society of Mechanical Engineers Conference, 1911.
8. Wang, S.K.; Handbook of air conditioning and refrigeration. (2nd ed) McGraw Hill, New York.



Appendices (Tables 1, 2, and 3). Please find other data at <http://uq.id.au/e.peterson/>

ID	LOCATION	Option 1 Dry summer		Option 2 Wet summer		24 hour 0.25%		8AM-6PM 0.25%		Winter(8AM) comfort	24 hour 8AM-6PM 0.25%		Elev (m)	Lat (o)	Long (o)	Daily Range	Yearly Range	Data Years
		design DB / coinc WB	coinc DB / design WB	coinc DB / design WB	DB / WB	DB / WB	critical	critical										
1	Darwin DA	34.7 DDB / 22.4 CWB	30.5 CDB / 27.4 DWB	34.3/27.2	34.8/27.3	16.8 DB	16.7 DB	18.3 DB	35.0	-12.42	130.89	6.9 DB	17.9 DB	1967-2011				
2	Pt Hedland HE	42.0 DDB / 20.2 CWB	32.0 CDB / 27.9 DWB	41.5/27.8	42.8/28.0	11.0 DB	9.5 DB	15.2 DB	8.4	-20.37	118.63	14.9 DB	31.0 DB	1967-2011				
3	Longreach LO	41.5 DDB / 19.6 CWB	29.2 CDB / 24.9 DWB	41.2/24.9	42.0/25.1	3.5 DB	3.1 DB	6.8 DB	192.5	-23.44	144.28	13.7 DB	38.0 DB	1967-2011				
4	Carnarvon CR	38.4 DDB / 20.2 CWB	29.8 CDB / 25.8 DWB	37.9/25.7	39.7/25.9	7.8 DB	7.6 DB	10.9 DB	8.0	-24.89	113.67	11.3 DB	30.6 DB	1967-2011				
5	Townsville TO	33.8 DDB / 23.3 CWB	29.9 CDB / 26.7 DWB	33.7/26.7	35.0/26.9	10.9 DB	9.3 DB	14.5 DB	9.1	-19.25	146.77	6.0 DB	22.9 DB	1967-2011				
6	Alice Springs AL	41.0 DDB / 18.2 CWB	27.1 CDB / 23.2 DWB	40.6/23.3	41.4/23.4	-0.4 DB	-0.6 DB	2.9 DB	547.0	-23.80	133.89	12.2 DB	41.4 DB	1967-2011				
7	Rockhampton RO	36.1 DDB / 21.7 CWB	29.0 CDB / 25.6 DWB	35.9/25.6	37.1/25.8	6.7 DB	5.4 DB	10.0 DB	15.1	-23.38	150.48	10.9 DB	29.4 DB	1967-2011				
8	Moree MO	37.9 DDB / 19.0 CWB	28.5 CDB / 23.0 DWB	37.8/23.1	39.0/23.5	0.3 DB	0.1 DB	3.7 DB	218.5	-29.49	149.85	13.0 DB	37.6 DB	1967-2011				
9	Amberley AM	35.7 DDB / 20.9 CWB	29.1 CDB / 24.7 DWB	35.4/24.8	36.9/25.1	1.2 DB	0.5 DB	5.8 DB	31.0	-27.63	152.71	11.3 DB	34.5 DB	1967-2011				
10	Brisbane BR	31.6 DDB / 21.6 CWB	27.9 CDB / 24.9 DWB	31.6/25.1	32.8/25.4	4.9 DB	5.6 DB	10.0 DB	9.5	-27.39	153.13	7.6 DB	24.7 DB	1967-2011				
11	Coffs Harbour CH	30.4 DDB / 20.9 CWB	26.8 CDB / 24.0 DWB	30.5/24.0	32.1/24.3	4.7 DB	3.4 DB	8.3 DB	6.0	-30.31	153.22	6.6 DB	25.1 DB	1967-2011				
12	Geraldton GE	39.9 DDB / 19.3 CWB	28.6 CDB / 22.9 DWB	39.7/23.1	41.1/23.3	6.3 DB	5.0 DB	8.6 DB	35.0	-28.80	114.70	14.9 DB	33.6 DB	1967-2011				
13	Perth PE	38.2 DDB / 19.0 CWB	29.3 CDB / 21.5 DWB	38.3/21.9	39.8/22.3	4.4 DB	3.5 DB	6.9 DB	20.0	-31.93	115.98	14.1 DB	33.8 DB	1967-2011				
14	Armidale (old Tamworth) AA	31.2 DDB / 15.9 CWB	24.8 CDB / 19.5 DWB	30.9/19.2	32.1/19.8	-0.9 DB	-2.4 DB	1.0 DB	1079.6	-30.53	151.62	11.2 DB	32.1 DB	1967-2011				
15	Williamtown WE	35.4 DDB / 20.3 CWB	28.1 CDB / 23.5 DWB	35.7/23.7	37.7/24.2	4.4 DB	3.0 DB	6.5 DB	8.0	-32.79	151.84	12.8 DB	31.0 DB	1967-2011				
16	Adelaide AD	38.0 DDB / 18.6 CWB	29.3 CDB / 20.9 DWB	38.3/21.4	39.7/21.8	4.6 DB	4.0 DB	6.2 DB	51.0	-34.92	138.62	10.7 DB	33.4 DB	1967-2011				
17	Sydney RO (Observatory Hill) SY	31.9 DDB / 19.1 CWB	26.0 CDB / 22.6 DWB	32.6/23.0	34.7/23.3	6.8 DB	6.6 DB	7.6 DB	40.2	-33.86	151.21	9.5 DB	25.1 DB	1967-2011				
18	Nowra NO	33.7 DDB / 19.2 CWB	27.2 CDB / 22.7 DWB	34.2/22.9	36.5/23.5	4.9 DB	3.9 DB	6.4 DB	105.0	-34.95	150.54	12.4 DB	28.8 DB	1967-2011				
19	Charleville CV	30.4 DDB / 18.3 CWB	27.6 CDB / 23.4 DWB	30.5/23.5	32.0/23.7	0.1 DB	-0.2 DB	4.0 DB	303.3	-26.43	146.26	12.0 DB	39.7 DB	1967-2011				
20	Wagga WA	37.8 DDB / 18.3 CWB	28.0 CDB / 21.1 DWB	38.0/21.4	39.2/21.8	-1.0 DB	-1.0 DB	0.0 DB	213.0	-35.16	147.46	13.9 DB	38.8 DB	1967-2011				
21	Melbourne RO ME	35.5 DDB / 18.2 CWB	27.5 CDB / 20.3 DWB	36.0/20.7	37.7/21.0	3.9 DB	3.3 DB	4.3 DB	32.2	-37.81	144.97	11.6 DB	31.6 DB	1967-2011				
22	East Sale SE	33.8 DDB / 18.6 CWB	27.3 CDB / 21.0 DWB	34.4/21.0	36.6/21.6	-0.3 DB	-0.6 DB	0.8 DB	8.2	-38.12	147.13	11.4 DB	34.1 DB	1967-2011				
23	Launceston (Ti Tree Bend) LT	28.4 DDB / 17.4 CWB	24.5 CDB / 19.6 DWB	28.7/19.6	30.0/20.3	-0.6 DB	-0.7 DB	-0.3 DB	5.0	-41.42	147.12	10.2 DB	29.0 DB	1981-2011				
24	Canberra CA	34.6 DDB / 17.1 CWB	26.0 CDB / 19.5 DWB	33.6/22.6	34.9/22.8	4.0 DB	3.5 DB	5.0 DB	580.0	-35.31	149.20	15.7 DB	31.9 DB	1967-2011				
25	Cabramurra (old Alpine) CA	25.6 DDB / 13.6 CWB	20.4 CDB / 16.2 DWB	25.6/16.2	26.9/16.7	-3.3 DB	-4.7 DB	-3.8 DB	1482.4	-35.94	148.38	7.7 DB	28.8 DB	1967-2011				
26	Hobart HO	28.3 DDB / 16.3 CWB	24.1 CDB / 18.3 DWB	29.5/18.7	31.6/19.1	2.2 DB	1.7 DB	2.4 DB	51.4	-42.89	147.33	9.6 DB	26.1 DB	1967-2011				
27	Mildura MI	39.8 DDB / 18.9 CWB	29.0 CDB / 21.2 DWB	40.1/21.9	41.4/22.2	0.7 DB	0.7 DB	2.0 DB	52.8	-34.24	142.09	14.9 DB	39.1 DB	1967-2011				
28	Richmond RI	37.5 DDB / 20.1 CWB	29.0 CDB / 23.3 DWB	38.0/23.4	39.0/23.9	-0.3 DB	-0.2 DB	2.1 DB	20.0	-33.60	150.78	15.1 DB	37.8 DB	1967-2011				
29	Weipa WP	36.5 DDB / 21.8 CWB	30.4 CDB / 27.5 DWB	35.9/27.3	36.3/27.6	16.6 DB	16.2 DB	19.5 DB	19.0	-12.68	141.92	10.3 DB	19.9 DB	1967-2011				
30	Wyndham WY	41.8 DDB / 22.1 CWB	32.2 CDB / 27.6 DWB	41.3/27.5	43.0/27.5	16.4 DB	12.3 DB	19.1 DB	4.3	-15.51	128.15	10.2 DB	25.4 DB	1967-2011				
31	Willis Island WS	31.9 DDB / 25.9 CWB	29.5 CDB / 27.4 DWB	31.6/27.3	32.0/27.6	21.8 DB	20.9 DB	21.7 DB	8.1	-16.29	149.97	3.9 DB	10.1 DB	1967-2011				
32	Calms CA	33.3 DDB / 24.3 CWB	29.0 CDB / 26.8 DWB	33.6/26.6	34.9/27.4	13.9 DB	12.9 DB	16.4 DB	8.3	-31.45	148.75	11.8 DB	41.2 DB	1967-2011				
33	Broome BM	38.6 DDB / 19.8 CWB	31.2 CDB / 28.1 DWB	38.1/28.1	39.3/28.2	12.3 DB	9.8 DB	16.1 DB	9.0	-17.95	122.24	10.3 DB	26.3 DB	1967-2011				
34	Learmonth LM	42.3 DDB / 20.5 CWB	30.2 CDB / 26.5 DWB	41.9/26.2	43.0/26.5	9.0 DB	8.5 DB	12.7 DB	5.5	-22.24	114.10	15.4 DB	33.3 DB	1976-2011				
35	Mackay MA	32.4 DDB / 25.0 CWB	29.5 CDB / 26.8 DWB	32.1/26.7	33.8/27.1	10.2 DB	9.1 DB	12.3 DB	36.3	-21.12	149.22	5.7 DB	22.2 DB	1967-2011				
36	Gladstone GL	34.0 DDB / 24.3 CWB	30.7 CDB / 26.9 DWB	33.6/26.6	34.9/27.1	10.8 DB	10.4 DB	11.7 DB	75.2	-22.86	145.26	8.1 DB	32.2 DB	1967-2011				
37	Halls Creek HA	41.1 DDB / 19.0 CWB	28.2 CDB / 24.7 DWB	40.6/24.6	41.3/24.6	11.9 DB	9.8 DB	13.8 DB	423.9	-18.23	127.66	11.4 DB	29.2 DB	1967-2011				
38	Tennant Creek TE	40.6 DDB / 18.8 CWB	27.7 CDB / 24.7 DWB	40.4/24.5	41.0/24.5	9.0 DB	9.0 DB	10.3 DB	377.1	-19.64	134.18	11.4 DB	31.6 DB	1967-2011				
39	Mt Isa IS	40.6 DDB / 19.0 CWB	28.0 CDB / 24.8 DWB	40.3/24.6	41.0/24.6	4.9 DB	4.4 DB	8.9 DB	340.9	-20.68	139.49	12.2 DB	35.7 DB	1967-2011				
40	Newman NE	43.1 DDB / 19.9 CWB	33.0 CDB / 24.6 DWB	42.6/24.5	43.7/24.7	1.9 DB	1.3 DB	7.8 DB	524.5	-23.42	119.80	11.8 DB	41.2 DB	1967-2011				
41	Giles GI	40.9 DDB / 17.8 CWB	27.5 CDB / 22.9 DWB	40.7/23.0	41.3/23.0	3.9 DB	3.7 DB	4.9 DB	599.0	-25.03	128.30	10.7 DB	37.0 DB	1979-2011				
42	Meekatharra MT	42.0 DDB / 18.2 CWB	27.9 CDB / 22.7 DWB	41.7/23.0	42.4/23.0	5.0 DB	4.6 DB	7.4 DB	519.0	-26.61	118.54	12.4 DB	37.0 DB	1967-2011				
43	Oodnadatta OO	42.5 DDB / 19.3 CWB	30.6 CDB / 23.2 DWB	46.0/23.7	46.4/23.9	2.9 DB	3.0 DB	5.1 DB	117.0	-27.56	135.45	12.6 DB	39.6 DB	1967-2011				
44	Kalgoorlie KA	41.0 DDB / 18.8 CWB	28.0 CDB / 23.8 DWB	40.7/23.7	42.0/24.1	4.0 DB	3.5 DB	5.0 DB	110.0	-27.79	115.17	11.7 DB	38.6 DB	1967-2011				
45	Woomera WO	41.0 DDB / 18.7 CWB	30.1 CDB / 21.4 DWB	41.2/22.3	42.4/22.5	4.0 DB	3.9 DB	5.4 DB	168.5	-31.16	136.81	13.7 DB	37.0 DB	1967-2011				
46	Cobar CO	39.5 DDB / 18.6 CWB	28.2 CDB / 21.9 DWB	39.7/22.4	40.7/22.6	2.1 DB	2.0 DB	3.7 DB	263.6	-31.48	145.83	12.7 DB	37.4 DB	1967-2011				
47	Bickley BI	36.4 DDB / 18.5 CWB	28.6 CDB / 21.6 DWB	36.1/21.9	37.5/22.6	4.0 DB	3.5 DB	5.3 DB	384.0	-32.01	116.14	14.5 DB	32.4 DB	1994-2011				
48	Dubbo DU	37.9 DDB / 19.9 CWB	33.0 CDB / 22.8 DWB	36.6/22.3	38.3/23.7	6.0 DB	5.7 DB	7.6 DB	41.0	-31.96	115.76	12.0 DB	31.3 DB	1994-2011				
49	Katanning KT	36.9 DDB / 18.3 CWB	29.2 CDB / 20.3 DWB	37.0/20.7	38.5/21.2	3.1 DB	1.5 DB	4.6 DB	321.0	-33.69	117.61	16.1 DB	33.8 DB	1967-2011				
50	Oakey OA	35.3 DDB / 20.7 CWB	30.2 CDB / 24.0 DWB	34.9/24.0	36.1/24.1	-1.4 DB	-2.3 DB	3.3 DB	406.7	-27.40	151.74	11.9 DB	36.7 DB	1967-2011				
51	Forrest FO	41.4 DDB / 18.5 CWB	30.0 CDB / 21.4 DWB	41.6/21.8	43.0/22.2	3.4 DB	1.4 DB	6.9 DB	160.0	-30.84	128.11	18.2 DB	38.0 DB	1967-2011				
52	Swanbourne SW	37.3 DDB / 19.5 CWB	27.9 CDB / 22.8 DWB	36.6/22.3	38.3/23.7	6.0 DB	5.7 DB	7.6 DB	41.0	-31.96	115.76	12.0 DB	31.3 DB	1994-2011				
53	Ceduna CE	40.4 DDB / 18.6 CWB	28.9 CDB / 21.2 DWB	40.6/21.6	42.2/22.1	1.8 DB	1.3 DB	4.1 DB	15.7	-32.13	133.70	15.5 DB	38.6 DB	1967-2011				
54	Mandurah MD	36.2 DDB / 19.2 CWB	28.2 CDB / 22.1 DWB	36.1/22.3	37.4/22.6	6.5 DB	5.2 DB	7.9 DB	3.5	-32.52	115.71	12.6 DB	29.7 DB	1988-2011				
55	Esperance EP	35.3 DDB / 17.9 CWB	25.9 CDB / 20.3 DWB	35.4/20.6	38.0/21.0	6.4 DB	5.6 DB	7.7 DB	27.0	-33.83	121.89	14.9 DB	28.9 DB	1967-2011				
56	Mascot (Sydney Airport) MA	33.3 DDB / 18.9 CWB	26.4 CDB / 22.8 DWB	34.0/22.9	36.0/23.2	5.0 DB	5.0 DB											



Table 2 Coincident conditions of the 3PM design dry bulb Alternative design dry bulb values

NATHERS zone abbrev id	base station			coinc dGHI (Wh/sqm)	coinc maximum DB	coinc minimum DB	coinc range of DB	coinc time of max DB	coinc time of min DB	ASHRAE style DDB				alternative design dry bulb		~year 2050 DDB	
	post code	automatic BoM id	stn WMO id							1 DDB	0.4% DDB	1.0% DDB	2.0% DDB	design dry bulb DDB	oc/100y(R^2)		
DA	1	800	14015	94120	6908	34.4	25.4	9.1	15:18	05:58	34.7	34.0	33.5	33.0	34.7	0.1 (0.04)	34.8
HE	2	6721	4032	94312	7893	42.5	24.8	17.7	14:12	05:30	42.0	40.8	39.3	37.9	42.1	0.2 (0.03)	42.2
LO	3	4730	36031	94346	8198	41.6	24.2	17.4	15:36	06:11	41.5	40.7	39.3	38.1	41.8	-1.3 (-0.14)	41.0
CR	4	6701	6011	94300	7612	40.0	23.7	16.3	13:48	05:04	38.4	36.8	34.2	32.3	38.6	0.4 (0.03)	38.8
TO	5	4810	32040	94294	7338	33.8	25.0	8.8	14:30	05:43	33.8	33.1	32.2	31.5	33.9	0.7 (0.10)	34.3
AL	6	870	15590	94326	8229	41.1	23.9	17.2	15:48	06:06	41.0	40.0	39.0	37.8	41.0	0.3 (0.04)	41.1
RO	7	4700	39083	94374	7493	36.3	22.6	13.6	15:36	05:36	36.1	35.1	33.7	32.5	36.2	0.6 (0.07)	36.5
MO	8	2400	53115	95527	7924	38.3	22.3	16.0	16:24	05:49	37.9	37.0	35.4	34.0	38.0	1.6 (0.16)	39.0
AM	9	4306	40004	94568	7676	36.0	19.8	16.2	15:24	05:30	35.7	34.7	32.9	31.5	35.8	2.1 (0.24)	37.1
BR	10	4000	40842	94578	7308	31.8	21.5	10.3	14:18	05:27	31.6	31.0	29.9	29.0	31.7	-1.6 (-0.28)	30.8
CH	11	2450	59040	94791	6903	31.5	20.3	11.2	14:18	04:13	30.4	29.6	28.0	27.1	30.6	3.1 (0.41)	32.5
GE	12	6530	8051	94403	7965	40.6	21.4	19.2	14:18	02:23	39.9	38.7	36.4	34.0	40.0	-0.8 (-0.09)	39.5
PE	13	6000	9021	94610	7875	38.7	21.5	17.2	15:36	03:03	38.2	37.4	35.3	33.4	38.5	2.6 (0.29)	40.1
AA	14	2350	56238	95773	7344	31.3	17.4	13.9	15:12	04:13	31.2	30.2	28.6	27.1	31.3	-1.7 (-0.17)	30.3
WE	15	2300	61078	94776	7691	35.7	18.0	17.6	15:06	05:32	35.4	34.4	32.0	29.8	35.7	1.7 (0.14)	36.7
AD	16	5000	23090	94675	7755	38.5	23.2	15.3	15:36	03:04	38.0	37.3	34.9	32.8	37.9	5.5 (0.49)	41.2
SY	17	2000	66062	94768	6691	32.7	20.1	12.6	14:48	04:02	31.9	31.4	29.0	27.3	32.1	2.7 (0.25)	33.7
NO	18	2541	68072	94750	7034	34.3	16.3	18.0	15:00	03:40	33.7	33.0	30.3	28.2	33.9	1.5 (0.13)	34.8
CV	19	4470	44021	94510	7696	40.0	24.2	15.9	16:06	06:11	39.8	39.0	37.6	36.2	39.9	0.3 (0.03)	40.0
WA	20	2650	72150	94910	7717	38.2	20.9	17.3	15:54	05:14	37.8	37.0	35.0	33.0	38.0	3.3 (0.24)	40.0
ME	21	3000	86071	94868	7428	36.2	18.2	18.0	16:06	02:22	35.5	34.9	32.2	29.7	35.8	2.1 (0.18)	37.1
SE	22	3852	85072	94907	6708	34.2	13.7	20.5	14:48	05:00	33.8	32.9	29.6	26.8	34.0	2.1 (0.17)	35.3
LA	23	7250	91237	94969	6647	28.6	14.6	13.9	15:30	05:11	28.4	27.9	26.1	24.6	28.5	2.3 (0.19)	29.7
CT	24	2600	70014	94926	7904	35.2	15.5	19.7	15:54	05:33	34.6	33.6	31.4	29.3	35.0	1.6 (0.10)	36.0
CM	25	2629	72161	95916	7275	25.6	16.1	9.5	15:42	03:54	25.5	24.9	23.2	21.7	25.7	3.2 (0.30)	27.6
HO	26	7000	94029	94970	6295	28.9	14.4	14.5	15:12	02:14	28.3	28.2	25.4	23.4	28.7	3.0 (0.31)	30.5
MI	27	3500	76031	94693	7770	40.5	22.3	18.2	16:00	04:38	39.8	39.2	37.0	34.9	39.9	2.4 (0.20)	41.4
RI	28	2753	67105	95753	7397	38.0	17.9	20.1	15:42	05:04	37.5	36.1	33.6	31.3	37.5	1.4 (0.10)	38.4
WP	29	4874	27045	94170	7267	36.4	23.4	13.0	15:30	06:22	36.5	35.4	34.6	33.8	36.5	3.5 (0.61)	38.6
WY	30	6740	1006	95214	7321	41.9	29.2	12.7	15:00	04:47	41.8	40.9	39.8	39.0	41.9	1.5 (0.24)	42.9
WS	31	4871	200283	94299	7045	31.7	27.2	4.5	14:12	04:07	31.9	31.4	30.9	30.4	31.9	0.4 (0.10)	32.2
CN	32	4870	31011	94287	7311	33.3	24.3	8.9	14:24	05:39	33.3	32.7	31.9	31.2	33.5	0.1 (0.01)	33.5
BM	33	6725	3003	94203	7159	38.9	24.0	14.9	14:42	05:19	38.6	37.3	36.0	34.7	38.6	-0.3 (-0.04)	38.4
LN	34	6707	5007	94302	8216	42.5	23.9	18.6	15:24	05:55	42.3	41.1	39.4	37.9	42.3	0.2 (0.03)	42.4
MK	35	4740	33119	94367	7725	32.5	24.8	7.7	14:06	05:34	32.4	31.7	30.8	30.1	32.4	2.7 (0.44)	34.0
GL	36	4680	39123	94380	7524	34.2	24.3	10.0	14:00	05:34	34.0	32.9	32.0	31.1	33.9	0.9 (0.14)	34.5
HA	37	6770	2012	94212	7789	41.0	27.3	13.7	15:00	05:33	41.1	40.1	39.2	38.2	41.1	-0.1 (-0.02)	41.0
TE	38	860	15135	94238	8093	40.6	27.6	13.1	16:24	06:34	40.6	40.0	39.0	38.0	41.2	3.3 (0.25)	43.2
IS	39	4825	29127	94332	8036	40.6	23.7	16.9	15:48	06:23	40.6	39.9	38.8	37.7	40.7	-0.5 (-0.07)	40.4
NE	40	6753	7176	94317	7940	43.1	28.2	14.9	15:30	05:31	43.1	42.0	40.8	39.6	43.3	0.4 (0.04)	43.5
GI	41	6438	13017	94461	8029	41.3	28.1	13.3	16:42	04:35	40.9	40.2	39.1	38.0	41.0	-2.9 (-0.34)	39.4
MT	42	6642	7045	94430	8099	42.0	27.5	14.5	15:48	06:12	42.0	41.2	40.0	38.8	41.9	2.7 (0.40)	43.5
OO	43	5734	17043	94476	7384	42.4	29.2	13.2	16:00	05:53	42.5	45.3	44.1	42.3	45.1	1.4 (0.09)	45.9
KA	44	6430	12038	94367	7639	40.6	23.3	17.2	15:48	02:37	40.3	39.5	37.6	35.6	40.5	2.4 (0.25)	41.9
WO	45	5720	16001	94659	8026	41.4	25.3	16.2	15:54	05:15	41.0	40.5	38.7	37.0	41.2	3.2 (0.32)	43.1
CO	46	2835	48027	94711	7829	39.9	25.2	14.7	16:06	05:42	39.5	39.0	37.1	35.6	39.7	4.1 (0.37)	42.2
BI	47	6076	9240	95610	8043	37.0	20.1	16.9	15:30	04:33	36.4	35.2	33.4	31.6	36.6	1.9 (0.10)	37.5
DU	48	2830	65070	95719	8069	38.2	21.9	16.4	16:06	04:45	37.9	36.9	35.0	33.2	37.9	3.7 (0.30)	40.1
KT	49	6317	10916	94641	7237	37.4	17.5	19.8	15:48	04:37	36.9	36.1	33.7	31.5	37.1	1.2 (0.13)	37.9
OA	50	4401	41359	94552	7162	35.2	21.7	13.5	15:18	05:13	35.3	34.7	33.7	32.3	35.4	1.8 (0.19)	36.5
FO	51	6434	11052	95646	7878	41.7	19.6	22.1	14:54	04:44	41.4	40.7	38.3	35.9	41.5	1.2 (0.13)	42.2
SW	52	6010	9215	94614	7782	38.0	21.6	16.4	15:12	04:17	37.3	35.6	33.1	31.0	37.3	7.6 (0.36)	40.9
CE	53	5690	18012	94653	7656	41.1	19.4	21.7	15:18	03:25	40.4	39.5	36.7	33.8	40.4	1.5 (0.15)	41.3
MD	54	6210	9977	94605	7715	36.4	21.0	15.5	15:24	04:56	36.2	35.3	33.2	31.3	36.5	-7.5 (-0.40)	32.7
EP	55	6450	9789	94638	6486	36.5	16.3	20.2	14:42	04:34	35.3	33.9	30.3	27.6	35.9	9.3 (0.53)	41.5
MA	56	2020	66037	94767	6939	34.0	19.3	14.7	15:00	03:33	33.3	33.0	30.0	28.0	33.6	1.9 (0.17)	34.8
MJ	57	6258	9573	94617	7239	34.6	18.0	16.5	15:42	04:52	33.9	33.0	30.7	28.6	34.2	2.1 (0.19)	35.5
AB	58	6330	9741	94802	6613	32.4	14.7	17.7	14:18	05:05	31.4	30.6	27.7	25.5	31.7	1.1 (0.11)	32.3
ML	59	5240	23842	95678	7848	31.4	21.3	10.1	16:36	-6:17	30.9	30.8	28.9	27.1	30.8	10.9 (0.55)	36.3
TU	60	3020	86282	94866	7545	36.1	16.6	19.5	16:18	03:28	35.4	35.0	32.0	29.5	35.9	-0.5 (-0.04)	35.6
MG	61	5290	26021	94821	7304	35.3	14.5	20.9	15:00	03:23	35.0	34.4	31.3	28.4	35.2	-0.1 (-0.00)	35.2
MR	62	3189	86077	94870	6981	34.8	16.4	18.4	15:30	04:08	34.4	34.0	31.3	28.6	35.3	13.3 (0.61)	43.4
WR	63	3280	90186	94837	6755	35.0	15.0	20.0	15:00	03:15	34.0	32.9	29.5	26.4	34.0	9.9 (0.46)	39.1
OT	64	3220	90015	94842	6127	30.2	16.7	13.5	15:36	-3:27	29.0	30.2	27.0	24.2	29.4	8.1 (0.59)	34.3
OR	65	2800	63303	95726	7237	31.7	15.7	16.0	15:24	04:52	31.4	30.4	28.6	26.8	31.6	6.3 (0.43)	35.4
BA	66	3350	89002	94852	6471	33.5	19.8	13.7	15:48	03:49	33.4	32.9	31.2	29.2	33.6	2.1 (0.17)	34.9
LD	67	7253	91293	95964	5772	24.5	16.4	8.1	14:54	02:41	24.5	23.6	22.4	21.4	24.4	-6.1 (-0.62)	20.7
LU	68	7120	91311	95966	6890	28.5	13.0	15.5	15:24	05:10	28.2	27.5	25.4	23.7	28.2	1.9 (0.21)	29.3
TH	69	2625	71041	95908	6976	27.0	12.5	14.6	14:48	03:27	26.4	25.3	23.4	21.5	26.5	1.7 (0.11)	27.5
TW	70	4350	41529	95551	7689	33.2	19.8	13.4	15:48	04:30	32.9	31.9	30.1	28.7	32.9	2.2 (0.24)	34.2
AT	71	4883	31210	94288	7159	34.7	21.7	13.0	15:06	05							



days. Table 2 further reports coincident daily minimum of 16.6°C tended to occur at 3:28 AM on days experiencing such a 3PM design DB.

Table 3 Coincident conditions of the 3PM design wet bulb Alternative design wet bulb values

NatHERS zone abbrev id	base station				coinc dGHI (Wh/sqm)	coinc maximum WB	coinc minimum WB	coinc range of WB	coinc time of max WB	coinc time of min WB	Table 1 DWB	ASHRAE style DWB			alternative design wet bulb		-year 2050 DWB
	post code	automatic BoM id	stn WMO id	stn WMO id								0.4%	1.0%	2.0%	DWB	oc/100y(R*2)	
DA	1	800	14015	94120	6353	27.2	23.9	3.3	15:30	-3:05	27.4	30.1	29.7	29.5	27.4	0.6 (0.21)	27.7
HE	2	6721	4032	94312	7424	27.9	23.1	4.8	15:42	-4:07	27.9	31.9	31.4	30.9	27.9	0.7 (0.23)	28.4
LO	3	4730	36031	94346	5597	25.0	21.0	4.0	16:00	-1:51	24.8	29.1	29.0	29.2	24.9	3.0 (0.43)	26.8
CR	4	6701	6011	94300	7217	25.8	21.6	4.3	16:12	-4:15	25.8	29.6	29.1	28.6	25.7	-0.7 (-0.13)	25.3
TO	5	4810	32040	94294	6364	26.6	23.7	2.9	16:06	-3:16	26.7	29.7	29.2	28.9	26.7	1.6 (0.43)	27.7
AL	6	870	15590	94326	5221	23.5	19.9	3.7	16:54	-4:33	23.2	27.1	27.2	27.6	23.3	3.2 (0.37)	25.2
RO	7	4700	39083	94374	5836	25.7	22.5	3.1	15:42	-2:12	25.6	28.7	28.2	27.9	25.7	0.9 (0.21)	26.2
MO	8	2400	53115	95527	6504	23.3	18.9	4.3	15:54	-2:59	23.0	28.5	28.1	27.7	23.0	0.1 (0.01)	23.0
AM	9	4306	40004	94568	5921	24.8	20.8	4.0	16:18	-1:53	24.7	28.7	28.0	27.4	24.7	-0.7 (-0.15)	24.2
BR	10	4000	40842	94578	6496	25.0	21.1	3.8	16:24	-3:22	24.9	27.8	27.3	26.8	24.9	0.7 (0.16)	25.3
CH	11	2450	59040	94791	6523	24.0	19.9	4.1	15:18	00:36	24.0	26.6	26.1	25.5	24.0	0.2 (0.06)	24.1
GE	12	6530	8051	94403	6851	23.1	18.4	4.7	15:36	-2:45	22.9	28.5	27.6	26.9	23.0	0.3 (0.06)	23.2
PE	13	6000	9021	94610	6802	21.7	16.4	5.3	15:48	00:18	21.5	29.3	28.6	28.0	21.7	-0.3 (-0.07)	21.5
AA	14	2350	56238	95773	6419	19.8	14.7	5.1	14:42	02:00	19.5	23.9	22.7	21.9	19.2	8.6 (0.57)	24.4
WE	15	2300	61078	94776	6665	23.6	18.9	4.6	15:42	00:52	23.5	27.9	26.9	26.0	23.5	0.5 (0.14)	23.9
AD	16	5000	23090	94675	6420	21.1	16.0	5.1	16:12	-2:25	20.9	29.3	29.1	28.6	21.1	0.9 (0.15)	21.7
SY	17	2000	66062	94768	6169	22.7	19.3	3.4	16:06	-4:35	22.6	26.2	25.5	24.9	22.8	0.8 (0.22)	23.2
NO	18	2541	68072	94750	6524	22.8	17.2	5.6	15:30	01:05	22.7	27.0	25.8	24.8	22.7	0.1 (0.02)	22.8
CV	19	4470	44021	94510	6396	23.8	20.0	3.7	16:48	-3:35	23.4	27.5	27.5	27.6	23.4	2.1 (0.33)	24.7
WA	20	2650	72150	94910	5977	21.4	16.6	4.8	15:48	-1:07	21.1	28.0	27.7	27.5	21.1	-0.8 (-0.13)	20.6
ME	21	3000	86071	94868	6180	20.5	15.7	4.9	16:36	-3:10	20.3	27.5	26.7	25.8	20.5	1.6 (0.29)	21.4
SE	22	3852	85072	94907	6088	21.1	15.4	5.8	14:54	01:39	21.0	26.8	25.4	24.1	21.0	-1.3 (-0.24)	20.2
LT	23	7250	91237	94969	5726	19.6	13.0	6.6	15:00	00:08	19.6	24.1	23.2	22.2	19.9	-1.3 (-0.09)	19.2
CA	24	2600	70014	94926	6308	19.8	14.8	4.9	16:00	-1:59	19.5	25.8	25.2	24.5	19.6	1.8 (0.34)	20.6
CM	25	2629	72161	95916	5760	16.5	11.2	5.3	15:30	00:56	16.2	20.0	19.7	19.4	16.0	9.3 (0.73)	21.6
HO	26	7000	94029	94970	5525	18.5	13.0	5.5	16:12	-4:29	18.3	23.9	22.5	21.3	18.2	-0.7 (-0.13)	17.8
MI	27	3500	76031	94693	6301	21.5	16.4	5.1	16:24	-2:57	21.2	29.0	29.6	29.9	21.4	0.7 (0.09)	21.8
RI	28	2753	67105	95753	5871	23.7	18.7	5.0	15:42	00:42	23.3	28.8	27.4	26.6	23.4	1.1 (0.21)	24.0
WP	29	4874	27045	94170	5952	27.3	23.9	3.4	15:18	01:52	27.5	30.0	29.7	29.3	27.4	-0.3 (-0.09)	27.2
WY	30	6740	1006	95214	6556	27.6	24.0	3.7	18:00	-3:36	27.6	31.9	31.5	31.3	27.6	1.5 (0.40)	28.5
WS	31	4871	200283	94299	6097	27.2	25.0	2.2	14:24	00:23	27.4	29.2	29.0	28.7	27.4	0.6 (0.23)	27.8
CN	32	4870	31011	94287	6474	26.6	23.4	3.2	15:36	01:38	26.8	29.6	29.2	28.8	26.8	1.5 (0.44)	27.7
BM	33	6725	3003	94203	6985	28.0	24.4	3.6	16:30	-3:19	28.1	31.1	30.8	30.6	28.2	0.5 (0.17)	28.5
LM	34	6707	5007	94302	6622	26.5	21.9	4.5	15:48	-5:50	26.5	29.9	29.7	29.6	26.4	0.7 (0.10)	26.8
MK	35	4740	33119	94367	6690	26.7	23.7	3.1	14:18	00:28	26.8	29.2	28.6	28.2	26.8	1.9 (0.47)	27.9
GL	36	4680	39123	94380	6883	26.9	23.0	3.9	14:12	00:46	26.9	30.0	29.1	28.4	26.7	0.6 (0.10)	27.1
HA	37	6770	2012	94212	5503	24.7	21.4	3.3	16:54	-2:32	24.7	28.1	27.9	27.9	24.7	1.7 (0.55)	25.8
TE	38	860	15135	94238	5172	24.7	21.9	2.8	17:30	-2:36	24.7	27.7	27.6	27.7	25.1	4.7 (0.53)	27.9
IS	39	4825	29127	94332	5324	24.8	21.5	3.4	17:06	-1:25	24.8	27.8	27.8	27.8	24.9	3.2 (0.59)	26.9
NE	40	6753	7176	94317	6634	24.4	21.6	2.8	15:24	03:48	24.6	32.9	32.2	31.3	24.4	-0.7 (-0.09)	24.0
GI	41	6438	13017	94461	5426	23.2	19.5	3.7	17:36	-4:34	22.9	27.5	27.7	28.2	23.0	2.6 (0.22)	24.4
MT	42	6642	7045	94430	6272	23.3	19.7	3.5	17:36	-3:43	22.7	27.9	28.3	29.4	22.5	3.1 (0.33)	24.4
OO	43	5734	17043	94476	6529	23.6	20.0	3.6	17:24	00:23	23.2	30.6	30.7	36.2	23.0	0.6 (0.06)	23.3
KA	44	6430	12038	94367	6771	21.1	15.9	5.1	16:48	-3:47	20.7	29.0	29.5	29.7	20.9	1.3 (0.21)	21.6
WO	45	5720	16001	94659	6494	22.0	17.1	4.8	17:30	-2:45	21.4	29.9	30.9	31.1	21.5	1.0 (0.12)	22.1
CO	46	2835	48027	94711	6055	22.3	18.2	4.1	16:12	-2:31	21.9	28.2	28.1	28.3	22.1	2.5 (0.34)	23.6
BI	47	6076	9240	95610	7548	22.0	15.1	6.8	15:54	01:37	21.6	27.9	26.9	27.2	21.3	-10.2 (-0.44)	16.5
DU	48	2830	65070	95719	6477	22.4	17.1	5.3	15:30	01:15	22.3	28.6	28.1	27.7	22.4	0.6 (0.08)	22.8
KT	49	6317	10916	94641	6529	20.5	14.5	6.1	15:48	01:28	20.3	29.1	28.1	27.1	20.4	-2.4 (-0.33)	18.9
OA	50	4401	41359	94552	6467	24.0	22.1	1.8	13:42	04:49	24.0	30.1	29.7	28.6	23.3	-3.1 (-0.38)	21.4
FO	51	6434	11052	95646	6403	21.8	15.9	5.9	15:36	00:02	21.4	30.1	30.1	29.1	21.4	2.9 (0.42)	23.2
SW	52	6010	9215	94614	7081	23.0	17.2	5.8	15:30	00:10	22.8	27.8	26.4	25.8	23.0	-4.0 (-0.25)	21.1
CE	53	5690	18012	94653	6601	21.6	15.6	6.0	15:30	01:55	21.2	28.9	28.2	27.1	21.3	0.4 (0.06)	21.5
MD	54	6210	9977	94605	6781	22.3	17.3	5.0	16:12	-1:07	22.1	28.0	27.2	26.7	22.1	1.6 (0.16)	22.9
EP	55	6450	9789	94638	6452	20.4	15.3	5.1	15:42	00:18	20.3	25.9	24.5	23.7	20.6	1.0 (0.16)	21.2
MA	56	2020	66037	94767	6239	22.9	19.2	3.7	16:06	-4:16	22.8	26.3	25.3	24.9	22.9	1.0 (0.27)	23.5
MJ	57	6258	9573	94617	6879	19.6	14.3	5.2	15:48	01:42	19.5	29.6	28.4	26.9	19.3	3.8 (0.57)	21.6
AB	58	6330	9741	94802	6249	20.1	15.2	4.9	15:00	-1:27	20.0	25.3	23.9	22.8	20.0	-0.5 (-0.14)	19.7
ML	59	5240	23842	95678	6597	18.3	12.9	5.4	16:42	-3:59	17.8	24.4	23.8	23.0	17.8	-2.2 (-0.13)	16.7
TU	60	3020	86282	94866	6236	20.7	15.0	5.8	16:12	00:33	20.4	27.5	26.6	25.4	20.4	-1.4 (-0.23)	19.6
MG	61	5290	26021	94821	6096	19.7	13.6	6.1	15:36	00:57	19.4	27.2	26.1	24.9	19.5	0.8 (0.14)	19.9
MR	62	3189	86077	94870	6291	21.1	15.3	5.8	15:12	01:08	21.0	27.5	26.5	25.5	21.1	5.1 (0.50)	24.1
WR	63	3280	90186	94837	6225	20.8	13.1	7.8	15:42	01:32	20.4	27.0	25.5	24.1	20.4	6.0 (0.64)	23.6
OT	64	3220	90015	94842	5697	19.4	14.9	4.5	15:12	-1:22	19.3	24.5	22.6	21.3	19.4	-1.5 (-0.25)	18.5
OR	65	2800	63303	95726	6256	19.6	14.3	5.3	15:06	01:35	19.4	24.4	23.5	22.8	19.5	3.7 (0.46)	21.8
BA	66	3350	89002	94852	5854	19.3	13.2	6.2	15:36	00:53	19.1	25.5	25.1	25.3	19.2	4.0 (0.48)	21.6
LD	67	7253	91293	95964	5355	19.5	14.9	4.6	15:54	-3:29	19.5	22.0	21.2	20.5	19.5	-0.9 (-0.16)	18.9
LU	68	7120	91311	95966	5426	18.7	12.8	5.8	15:24	-2:58	18.5	23.7	22.4	21.4	18.5	0.5 (0.08)	18.8
TH	69	2625	71041	95908	6570	16.5	10.3	6.2	16:00	02:19	16.5	22.4	21.3	19.6	16.3	4.7 (0.42)	19.1
TW	70	4350	41529	95551	6192	24.2	17.2	7.0	15:06	03:33	24.0	26.7	25.9	25.1	22.8	-1.7 (-0.23)	21.8
AT	71	4883	31210	94288	5648	24.3	21.5	2.9	15:36	01:32	24.4						



For example of Tullamarine “comfort” DWB was found to be 20.4°C while the ASHRAE levels were 27.5°C, 26.6°C and 25.4°C (for 0.4%, 1% and 2% risk levels). The DWB for Tullamarine is also alternatively tabulated without prejudice to 3PM as 20.4°C and shows a local trend of wetbulb change -1.4 °C per century. Table 3 also reports 6236 Wh/sqm daily global horizontal radiation was coincident with DWB and that a maximum of 20.7°C tended to occur at about 4:18 PM on such days. Table 2 further reports a coincident daily minimum of 15°C wb tended to occur at 12:33 AM on days experiencing such a 3PM design WB.