NEW AIR CONDITIONING DESIGN TEMPERATURES FOR QUEENSLAND, AUSTRALIA

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ABSTRACT

This paper presents results of a detailed analysis of meteorological data to determine air conditioning design temperatures dry bulb and wet bulb for hundreds of locations throughout Queensland, using the tenth-highest daily maximum observed per year. This is a modification of the AIRAH 1997 method that uses only 3:00pm records of temperature. In this paper we ask the reader to consider Australian Bureau of Meteorology official "climate summaries" as a benchmark upon which to compare various previously published comfort design temperatures, as well as the new design temperatures proposed in the present paper. We see some possible signals from climate change, but firstly we should apply all available historical data to establish outdoor design temperatures that will ensure that cooling plant are correctly sized in the near future. In a case-studies of Brisbane, we find that inner city temperatures are rising, that airport temperatures are not, and that suburban variability is substantially important.

Keywords: air conditioning design, Queensland, climate data

Background

Results of the present paper are abridged in Table 1, in comparison with design temperatures for eight key sites previously published by AIRAH, and five by ASHRAE. The Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH) and the American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE) were established in the early 20th century to promote the science and practice of air conditioning in USA and Australia, respectively. The Australian Commonwealth Works Department (Comm Works) amended and acquired copyright to a southern hemisphere version of the Carrier *Handbook of Air Conditioning System Design* (Carrier International Corporation 1972) since 1973, and AIRAH added content in 1997, in a key design aid of the Australian industry often referred to as "DA9".

Earliest DA9 design temperatures for Australia (Weiss and Thompson 1974, Wickham 1982 & '88) provided Queensland data limited to seven sites: Brisbane, Cairns, Charleville, Cloncurry, Rockhampton, Toowoomba, Townsville. These design temperatures could not consider warming in the past 30 years, as they were based on records before 1973. Delsante and Mason (1990) explain how AIRAH commissioned the Australian Bureau of Meteorology (BOM) to review datasets through 1988 at 100 Queensland locations, and similar numbers in other states. Most recently, in a world-wide study, ASHRAE (2005) commissioned an analysis of 30 Queensland locations with datasets ending 2001, restricted to localities having at least eight years hourly data.

A key principle is that extreme weather events should not dictate air conditioning system sizing because they may be unique events, classified as statistical outliers. Outliers are entries that deviate so much from comparable observations that they are practically irreconcilable. Probability distribution tails are theoretically endless, but incredibly thin in the extreme. Air conditioning engineering practice prescribes an allowance of some small percentage of operating hours when indoor temperatures are allowed to float.

Recently published thermal comfort standards have recognised that residents of temperate climates accept 27° to 30°C as "comfortable" in summer, and that native populations of tropical countries will accept over 33°C if sufficient air flow is in their personal control (Khedari and Yamtraipat 2000 and Nicol, et al. 1999). Floating indoor temperatures during hot weather is not a new operational policy in Queensland, given that the *Factories and Shops Act* limited the difference between outdoor and indoor temperature to 8K in order to prevent "thermal shock" when staff proceed home from their place of work – but this law was repealed in 1995 without subsequent government regulation of temperatures. More recent standards nominate air conditioning design indoor temperatures that balance occupant comfort in hot weather and operational efficiency during less extreme weather (ISO 1995 and Brager & de Dear 2000). A tool to establish inside comfort design temperatures for various occupancies has been funded by ASHRAE and posted on the internet at http://atmos.es.mq.edu.au/~rdedear/pmv/ (de Dear 1999).

Major motivations for allowing inside temperatures to float are a desire for lower capital and operating costs, and to reduce the cycling on-and-off of compressors when design capacity is greater than actual outdoor-indoor temperature difference. ASHRAE 55-2004 was based on international research partially based in Australia as well as several other industrialised countries such as USA and Singapore, and is now being applied in the design of a naturally ventilated Federal Government office building in San Francisco, California. ASHRAE Standard 55-2004 provides that air conditioning systems may be designed to provide 27°C without perceptible air motion, and that personally controlled naturally ventilated building are allowed to float a bit over 30°C when occupants are adapted to hot weather. The role of the present paper is to determine: what should be the outside design temperature (dry bulb/wet bulb) for design of naturally ventilated and air conditioning systems in any particular location in Queensland, Australia? To answer this question we start by comparing established design temperature approaches published by ASHRAE and AIRAH.

ASHRAE 1993 had adopted the practice of designing plant to be fully loaded 1% of the American "summer season" (30 hours in months June-September). More recently ASHRAE 2001 redefined this level to 0.4% of annual hours (35 hours per annum) to facilitate air conditioning design in tropical countries, such as Singapore, as well as temperate climates in both hemispheres. Recent research commissioned by ASHRAE has developed algorithms to

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estimate design temperatures from records of daily maxima (Kunkel 2002) and the effect of less than 30 years period-of-record (Colliver and Gates 2000), but neither of these directly address the issues of inter-annual variability (El Niño) and climate change. But now the BOM website reveals Queensland maximum temperatures have risen about 1K since 1970 <www.bom.gov.au/silo/products/cli_chg/>.

Australian designers working with handbooks published by AIRAH use the tenth-highest-temperature observation in a year for "comfort design" – that temperature which is equalled or exceeded only ten days per year (Carrier 1972, Weiss and Thompson 1974). This allows building temperatures to "float" no more than ten days per year. Design temperature (plant capacity) is further raised to account for inter-annual variability – determined by adding the standard deviation of inter-annual variability of the annual tenth-highest-daily-maximum. Later in this paper we find that this inter-annual variability is generally between 0.6 to 1.2K in Queensland, Australia. This later term is the standard deviation of the annual tenth-highest-daily-maxima, and requires that the design temperature be established such that it is exceeded only five to nine times in an average year so that is rarely exceeded more than ten days in a hotter-than-average year.

Early editions of DA9 (Weiss and Thompson 1974, Wickham 1982) elaborated that a design temperature having a "standard deviation" four days/year was required in the case of Sydney's Mascot Airport. In the present paper we find the standard-deviation-of-days-exceeded in the range one to five days/year, depending on locale.

Case studies in Brisbane

To illustrate the Australian approach to establishing air conditioning design temperatures, consider Brisbane, the state capital of Queensland. The Australian Bureau of

BRISBANE AERO (EAGLE FARM) 1950 – 2000	BRISBANE REGIONAL OFFICE 1851 – 1986	CAIRNS AERO 1942 – 2004	CHARLEVILLE AERO 1942 – 2004	CLONCURRY AERO 1939 – 1975	ROCKHAMPTON AERO 1939 – 2004	TOOWOOMBA 1957 – 1998	TOWNSVILLE AERO 1940 – 2004
27.417°S 153.114°E	27.477°S 153.030°E	16.873°S 145.745°E	26.415°S 146.254°E	20.671°S 140.508°E	23.376°S 150.476°E	27.582°S 151.930°E	19.247°S 146.766°E
40223	40214	31011	44021	29009	39083	41103	32040
Australian Bureau of Meteorology station ID numbers and record periods noted above.							
We propose new design dry bulb (db) and mean coincident wet-bulb (cwb) temperatures (among 204 sites):							
32.4 db 21.5 cwb	33.8 db 21.9 cwb	34.1 db 25.1 cwb	40.0 db 21.5 cwb	42.2 db 22.6 cwb	36.6 db 24.1 cwb	33.4 db 20.7 cwb	34.3 db 23.8 cwb
Compared to previously published "comfort design" temperatures (°C) for air conditioning:							
Comm Works in Association with AIRAH 1974, '82, '88 comfort design dry and wet temperatures:							
31.0 db 25.0 wb		33.0 db 26.5 wb	39.0 db 24.0 wb	41.0 db 25.5 wb	36.0 db 26.5 wb	31.0 db 22.0 wb	32.0 db 26.0 wb
AIRAH DA9 1997 design dry bulb and coincident wet bulb temperatures (among 100 sites):							
31.9 db 23.4 cwb	30.8 db 22.8 cwb	32.8 db 25.3 cwb	39.4 db 20.0 cwb	40.8 db 20.5 cwb	35.0 db 23.1 cwb	31.1 db 20.5 cwb	32.8 db 24.7 cwb
ASHRAE 2005 design dry bulb and coincident wet bulb temperatures (among 30 sites):							
31.1 db 22.5 cwb		32.9 db 25.3 cwb	38.5 db 19.4 cwb		35.1 db 22.9 cwb		33.2 db 24.6 cwb

Table 1 - air conditioning design temperatures compared at eight locations

Meteorology (BOM) has been making long-time daily observations in the city centre, at the bayside airport, and at numerous post offices and cooperating research stations in southeast Queensland, but many of these sites were relocated as Brisbane has developed due to rapid population growth. Automated hourly observations have been established only since around about the turn of the millennium, and so there have not yet 30 years of hourly data ideally expected by ASHRAE. However there have been long three-hourly observations at special locations such as major airports, and the regional office of BOM in Brisbane, but these often missed midnight and 3:00am readings. Hourly observations will now be continuous with installation of automatic sensors at the new bayside Airport from 1995 and in the city from 2000. We use the new airport dataset to illustrate differences between hourly and daily datasets, but we must use the old city dataset to illustrate long-term climate change trends.

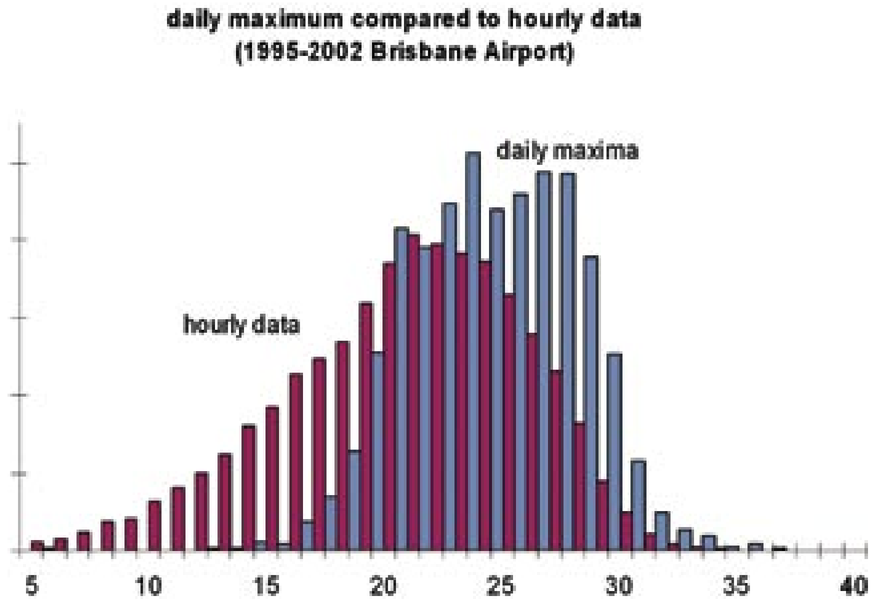

Figure 1 - histograms of hourly observations and daily maxima in 1°C bins

Refer to the Australian comfort design method in Figure 1 (previous page) as "daily maxima", in contrast to ASHRAE's "hourly data" method, in a case-study of the new Brisbane airport. Figure 1 is a temperature histogram sorting observations by whole degrees. The ASHRAE method takes the upper 0.4% tail of hourly data to establish design temperature of 32°C, the same result is obtained by taking of the upper 2.15% tail of daily maximums. That is to say the same result is found in the case of Brisbane airport by taking that temperature which is not exceeded more than eight days/year, allowing for two days/year standard deviation.

The forgoing histograms are an illustrative example rounding to whole degrees, but reassure us that the Australian daily-maximum method provides comparable design temperature as the ASHRAE hourly method. This is a valuable result, since so few locations in Australia have three-hourly climate data, and almost none have 30 years of hourly data called for by ASHRAE. Better yet, we benefit from the Australian approach because we are looking directly at inter-annual variability that ASHRAE ignores. So the Australian methodology has the capacity to detect global warming and local urban heat island effects.

Consider long term records of the Regional Office of the Bureau of Meteorology station at Wickham Terrace 1888-1987 and re-established at Kangaroo Point in 1999. Figure 2 plots the tenth highest daily maximum at Wickham Terrace for the century from 1887. The "big picture" afforded by a century of daily maximum data gives a clear view of long term cooling and warming trends at any particular location. This plot is typical of most Queensland locations having long time series records, in that warming has been increasing since about 1970, following cooling during World Wars and Great Depression. The trend is not unlike global industrial productivity, as half of global industry CO_2 emissions have been since 1974 (Marland, et al. 2005). Seeing trends in the timeline of the tenth-highest daily maxima is an advantage of Australian design temperature estimation method, but this has not been identified in previous publications.

Kangaroo Point has returned complete datasets for all years since 2000, of which we have found the average tenth-highest daily maximum of the

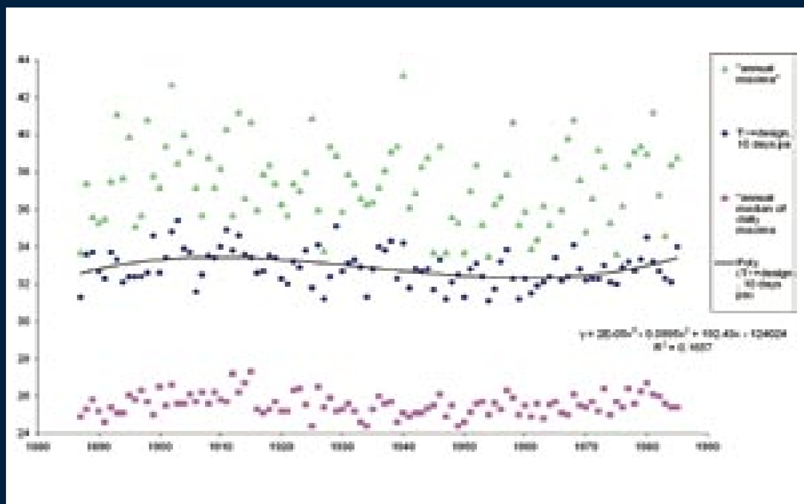

Figure 2 - Brisbane Regional Office (BOM 040214) century perspective

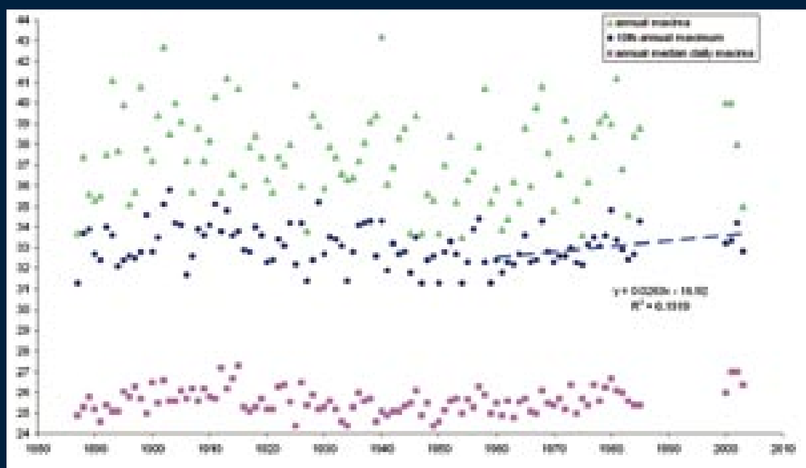

Figure 3 - Brisbane Regional Office composite of sites (BOM 40214 and 40913)

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first four years is 33.2°C with a standard deviation of 0.6°C which would suggest a design temperature of 33.8°C would be appropriate for Brisbane's inner city. But we did not have the 2004 data, which may have included record breaking maximums. So we splice the old and new datasets over the latest available 30 years of records and present a linear regression trendline in Figure 3. R^2 shows 19% of the inter-annual variability of Brisbane city temperature is explained by a rising slope of ¼°C per decade –amounting to over 1°C in the regression period 1960-2003. The warming trend is greater than the long term standard deviation of 0.7°C. Assuming Kangaroo Point and Wickham Terrace fairly represent the city, we can conclude that warming in Brisbane city is significant. By contrast, there is no significant trend for Brisbane airport data where regression shows a cooling slope of 0.05°C per decade, while the long term standard deviation is 0.7°C.

With the exception of Brisbane city we have found that the standard deviations of inter-annual variability are generally greater than the linear regressions of available data. This finding indicates that it is more important to account for inter-annual variability of heat waves as a recurring risk management problem for air conditioning engineers. So we recommend the practice of adding the standard deviation to the historic mean of the tenth-highest record per year to establish the dry bulb design temperature. We have taken the daily maximum in all of the forgoing, and at this point we should identify that AIRAH has been using 3:00pm data as a surrogate for daily maximum temperatures.

To illustrate the Australian comfort design temperature method as employed by AIRAH, we sorted daily 3:00pm temperature observations from the Brisbane Regional Office by year, and then found the temperature equalled or exceeded ten days in each year. One might hope to find only nine days exceeding this target, but in some years there were more than one record equal to the target, and so the number of days meeting the criteria was occasionally greater. tenth-highest maximum temperatures plot as solid diamonds in Figures 4, 5 and 6, but nomination of design temperature is adjusted differently in the three plots of 18 years of observations at Brisbane Regional Office (BOM station 40214). This period of record is possibly very similar to that which was available when DA9 was first developed published, although only airport data were included then.

The inter-annual average of tenth-highest 3:00pm temperature was averaged to provide an intermediate design temperature nomination plotted in Figure 5. The number of days per year with 3:00pm temperatures exceeding the intermediate benchmark varies above and below nine days per year. In seven years the intermediate design exceeded ten days/year, so the design needs to be higher.

In Figure 6 the standard deviation (RMS) of the tenth-highest record has been added onto the intermediate benchmark. Now the number of days per year with 3:00pm temperatures exceeding the improved benchmark only once exceeds the design ten days in one year –the Australian objective for design temperatures.

Wet bulb design temperatures cannot be derived from daily maxima datasets, and require reference to hourly temperature-humidity archives where available. These data are available for a lesser number of meteorology stations with hourly data since automatic weather stations were established and occasional three-hourly data by human observers. The 1955-1972 data-series from Brisbane Regional Office are concurrent with three-hourly coincident dry and wet bulb records.

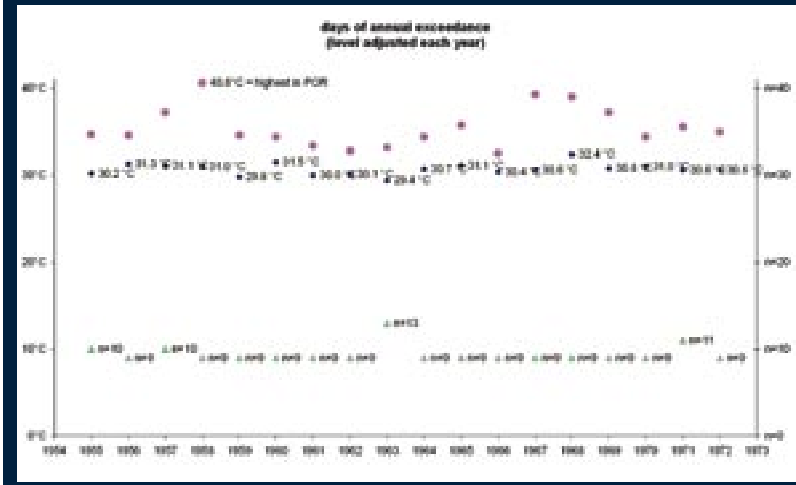


Figure 4 - temperatures at 3:00pm exceeded 10 days/year (tail = 9 ÷ 365¼ = 2.5%)

In the present example we have searched through the coincident-hourly data for occurrences of dry bulb within one degree of our 31.4°C design dry bulb, selecting coincident wet-bulbs, and took the overall average: 22.8°C wb.

The visa-versa case is needed to design evaporative cooling systems, where wet-bulb temperature is taken from the inter-annual mean of the tenth-highest wet bulb each year plus the standard deviation of inter-annual variations. Both coincident pairs of wet and dry bulb design temperatures are plotted on psychometric chart of Figure 7 as a case-study of Brisbane Regional Office.

For other locations we only tabulated design dry-bulbs and coincident wet-bulbs.

The forgoing design temperatures for Brisbane illustrate how we believe AIRAH's previously published design temperatures could have been determined in their latest publication (AIRAH 1997). But we find that DA9 (DTC-AIRAH 1982) design wet bulb temperatures were substantially higher than the coincident wet bulb temperatures offered by AIRAH 1997,

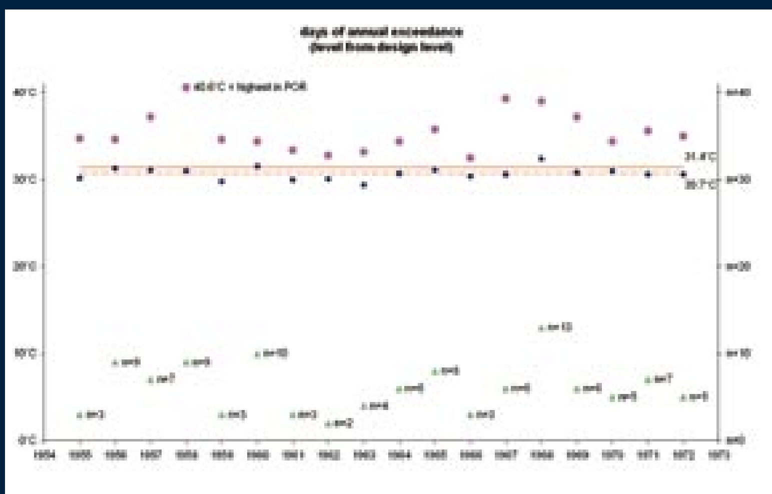


Figure 6 - finally raise the design level by the RMS of inter-annual variability

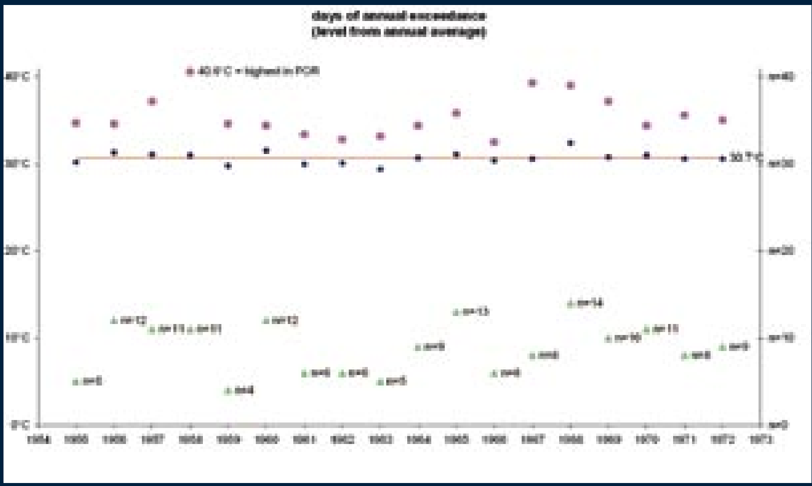


Figure 5 - take inter-annual average, and check the exceedance each year

ASHRAE 2005, and the present paper. DA9 elaborated that outdoor design relative humidity was taken as 80%. The more recently published AIRAH 1997 and ASHRAE 2005 explicitly give coincident wet bulb temperatures, but AIRAH 1997 recommends using their design wet bulb for comfort design –rather than the mean-coincident-wet-bulb associated with their design dry bulb. AIRAH 1997 may inflate the design comfort cooling load. And so we respond with slightly higher design dry bulb temperatures to be matched with corresponding mean coincident wet bulbs.

Proposal to consider daily maxima rather than only 3:00pm data

This paper proposes a slightly modified approach to that of AIRAH 1997. Begin by looking closely at hourly data for the first month of the hourly dataset in the new Brisbane airport: January 1996, in Figure 8. Notice the clustering of data around "hot days" and "cooler days" as you might call them, all the while there is a consistent pattern of minimum temperature at 5:00am rising steadily until midday, and then cooling during the afternoon and night.

The hourly temperature was normalised as a fraction of daily range for the seven years 1996 through 2002, resulting in the second graphic distillation of mean hourly temperature bracketed by a standard deviation above and below in Figure 9.

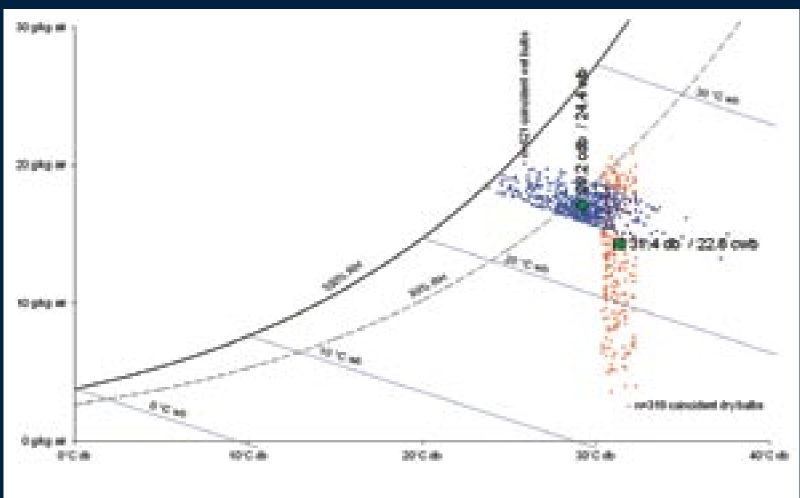
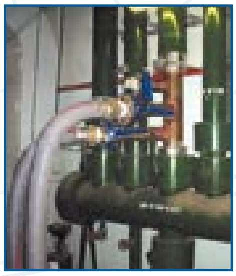
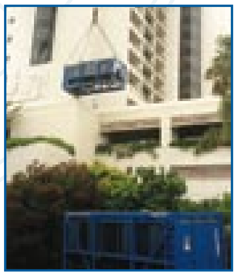


Figure 7 - mean coincident wet bulb is taken from records within 1K of 31.4°C design dry bulb temperature, and mean coincident dry bulb within 1K of 24.4°C design wet bulb temperature in a special case study of Brisbane 1955-1972.





AIRAH's DA9 handbook (Wickham 1982, '88, '97) explains that daily maximum is assumed to occur at 3:00pm each day. This assumption is not generally correct, as we illustrate in Figure 6 the maximum daily temperature in Brisbane often occurs around 1:00pm. Be aware that Queensland has always been locked into Eastern Standard Time (EST = GMT+10) without daylight savings, and at the longitude of Brisbane solar noon occurs at 11:48am. By contrast, we used meteorological records for Queensland using maximum-thermometers and hourly automatic weather station records, rather than arbitrary bias for 3:00pm readings. Consequently AIRAH's previously published design temperatures are biased lower than those that we have proposed in the present paper.

We propose to the Australian community that design temperatures should be based on the tenth-highest daily maximum temperature rather than the tenth highest 3:00pm readings. Furthermore we propose to restrict years under consideration to those with at least 250 days of complete observations, allowing for use of archives of manned observations five days per week less ten public holidays per year. Delsante and Mason (1990) explain that previous design temperatures determined for AIRAH did not exclude incomplete datasets. Failure to remove incomplete years from consideration would also bias results.

The present paper employs a method similar to ASHRAE 2005 *only* in that design wet bulbs are taken as mean coincidence of the design dry bulb.

In the present paper we have taken our design dry bulb temperatures from the daily-maxima archive and then searched through the coincident-hourly data for occurrences of dry bulb within one degree of our design dry bulb, and then selected the mean coincident wet-bulbs, and took their overall average.

We purchased daily minimum and maximum temperature archives sold and delivered on compact disk (CD) by (BOM 2004a). Wet bulb design temperatures cannot be derived from either of these sources, but rather require detailed analysis of hourly coincident temperature-humidity-pressure archives available from a lesser number of meteorology stations archived on coincident-hourly CD (BOM 2004b). We have taken our design dry bulb temperatures from the min-max CD and then searched through the coincident-hourly CD for all occurrences of dry bulb within 1°C of our design target, and then determined the mean coincident wet-bulb temperature.

Be aware that the period-of-record of the coincident-hourly CD is not necessarily the same as the min-max CD, as the daily minimum and maximum records have been manually recorded by 9:00am observations of sinking/floating marker thermometers. In many cases the period-of-record of the min-max CD began in the 19th century, but many of the coincident-hourly records began near the end of the 20th century with the advent of automatic weather stations (AWS).

Results in comparison with alternative design temperatures

We suggest that Bureau of Meteorology "climate summaries" may offer an objective benchmark to compare the findings of the present paper with both ASHRAE and AIRAH publications. But first we expect the reader to directly compare these previously published comfort design temperatures with our results mindful that they are higher temperatures than has been previously published.

We offer the modified-Australian approach specifically to assist in the design of natural ventilation, evaporative cooling, and air conditioning systems in Queensland that do not receive complaints much more than ten days in one year.

Table 2 presents a short list of 30 locations, with the results of the present research compared to the new ASHRAE 2005 Handbook CD and AIRAH 1997 DA9. We offer higher design temperatures than both alternatives. This difference is at least partly owing to our concern for inter-annual variability, and also to our use of daily-maximum temperature rather than only the 3:00pm readings.

A full list of our findings of 225 locations in Queensland is presented in the appendix to the present paper (due to space constraints, this appendix has not been published here but can be downloaded from www.airah.org.au).

Benchmarking design dry bulb temperatures against "climate summaries"

Consider a simplified method of estimating air conditioning design dry bulb temperatures, whereby inter-annual variability is ignored, and only the design dry-bulb temperatures may

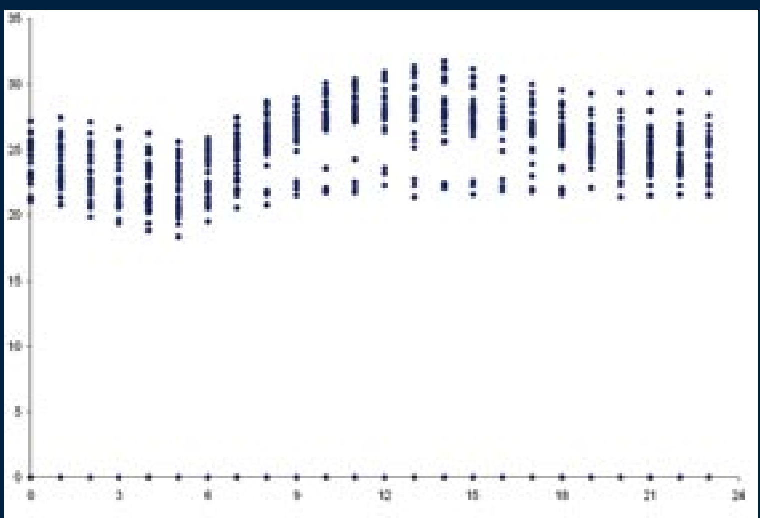


Figure 8 - hourly temperature data – January 1996 new Brisbane airport

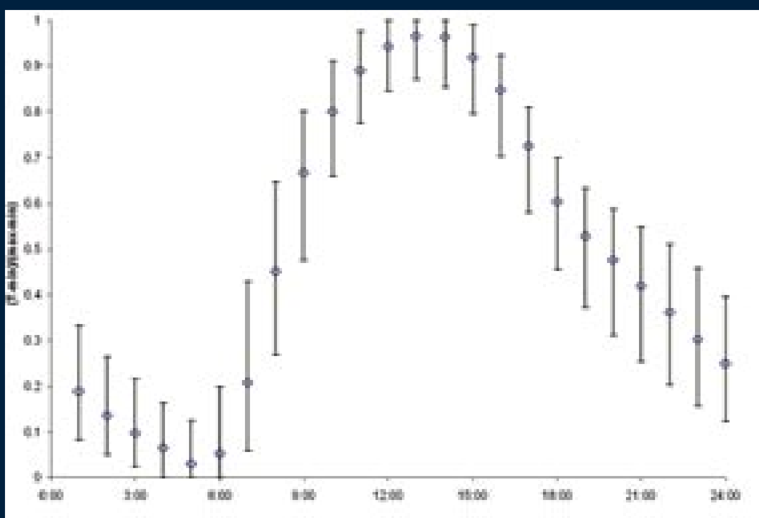


Figure 9 - median daily range +/- RMS (new Brisbane airport 1996-2002)

be interpolated from the “climatic summaries” provided by the Australian Commonwealth Bureau of Meteorology (BOM) website <http://www.bom.gov.au/climate/averages/tables/ca_qld_names.shtml> free of charge or sold on CD (BOM 2004c). The reader may compare these results against the rigorous analysis of inter-annual variability in daily data compared over several years that is also presented later in the present paper.

Find the Australian Commonwealth Bureau of Meteorology (BOM) web pages:

QLD: www.bom.gov.au/climate/averages tables/ca_qld_names.shtml

NSW: www.bom.gov.au/climate/averages/tables/ca_nsw_names.shtml

VIC: www.bom.gov.au/climate/averages/tables/ca_vic_names.shtml

TAS: www.bom.gov.au/climate/averages/tables/ca_tas_names.shtml

NT: www.bom.gov.au/climate/averages/tables/ca_nt_names.shtml

SA: www.bom.gov.au/climate/averages/tables/ca_sa_names.shtml

WA: www.bom.gov.au/climate/averages/tables/ca_wa_names.shtml

To estimate air conditioning design dry bulb temperatures from BOM official “climatic summaries”, you need to curve-fit an estimate of the average tenth-highest maximum daily observation per year. We have done this by interpolating on a standard normal distribution NORMSDIST between the probabilities of exceeding 30°C, 35°C, and 40°C with respect to a target NORMSDIST(-1.92) = 2.74% = 10 days divided by 365.25 days.

The standard no $f(z)=\frac{1}{\sqrt{2\pi}}e^{-\frac{z^2}{2}}$ nction is

(eqn 1)

We used MS Excel NORMSINV iterative solution for the inverse of the standard normal distribution for the established probabilities of reaching 30°C, 35°C, 40°C, and for highest record temperature we used the inverse of period of record. Together with the mean daily maximum (probability = 50%), these were used to determine the coefficients of equation 2, a quadratic solution of second-order curve-fitting data from any particular “climatic summary” published by BOM.

$design_{10d/y}$ = $(-m_1\text{-SQRT}(m_1^2\text{-}4\cdot m_2\cdot(b\text{-}1.92)))/(2\cdot m_2)$ (eqn 2)

where m_2 = INDEX(LINEST(y,x^{1,2}),1,1)

m_1 = INDEX(LINEST(y,x^{1,2}),1,2)

b = INDEX(LINEST(y,x^{1,2}),1,3)

with MS Excel linear regression of x = {mean,30°, 35°, 40°, highest_record} and y ={0,NORMSINV(d/$y_{T\geq30°}$), NORMSINV(d/$y_{T\geq35°}$), NORMSINV(d/$y_{T\geq40°}$), EXTREME}

wherein EXTREME = NORMSINV(1/POR) with POR = 365.25 × years_of_record.

Alternative design temperatures can be evaluated by equation 3 for the number of days per year (DPY) that a particular design temperature may be reached.

$DPY_{T\geq design}$ =365.25*NORMSDIST (m_2* T_{design}^2 2+m_1 *T_{design}+b) (eqn 3)

The benchmark has been applied to 199 Queensland locations with official climate summaries, of which eight are compared in Table 3 (next page) against previously published temperatures by AIRAH and ASHRAE.

The simple analysis of recent BOM “climatic summaries” ignores the standard deviation of inter-annual variability, yet it still detects 0.4 to 1.8K increase above previously published dry-bulb design temperatures in the seven centres of Queensland, except Rockhampton appears to have cooled 0.4K and Brisbane Regional Office has warmed 2.3K – presumably an urban heat island effect.

AIRAH DA9 Chapter 2 “Design Conditions” in Wickham (editor) 1982 *Air conditioning Systems – Load Estimation & Associated Psychrometrics* (Department of Transport and Construction - Commonwealth Works) states that comfort air conditioning design temperatures should be chosen based on 3:00pm temperatures which are individually exceed on ten days in the year, and that there should be an allowance for the standard deviation of inter-annual variability. We found that this inter-annual variability is generally between 0.6 to 1.2K in most Queensland localities, and so the design temperatures derived from “climatic summaries” should be further increased unless comprehensive meteorological datasets can be analysed for localities of interest. In Figure 10 the results of the design temperatures of present paper and previously published design temperatures are benchmarked against Australian Bureau of Meteorology “climate summaries” to measure the average annual exceedence. Only a small fraction of the design temperatures proposed in the present paper exceed ten days per year by at most one day, and the vast majority is exceeded in the range of five to nine days/year – with an average of seven days/year. By contrast, published ASHRAE and AIRAH design temperatures are exceed an average about 20 days/year, in an average year, and worse in hot years.

Application of Climate Summaries to Suburban Variability

AIRAH's DA9 warns that design temperatures based on airport observations are not representative of urban micro-climates. Recent compilations by BOM of "climatic summaries" at many suburban locations provide the air conditioning designer with

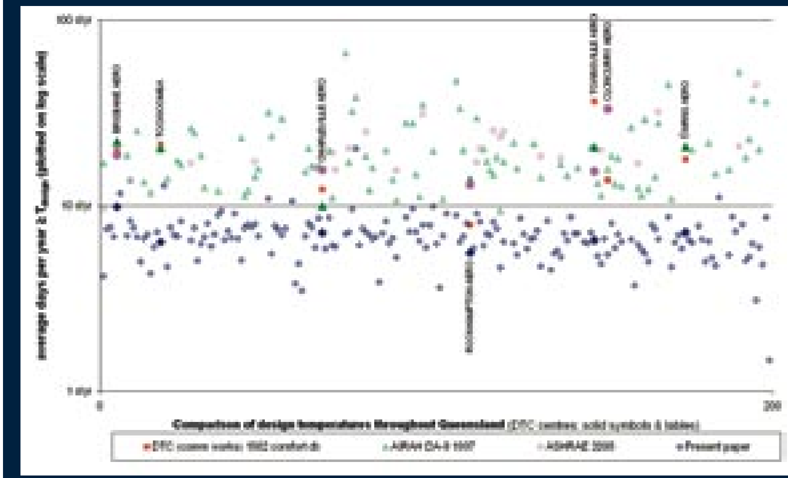


Figure 10 - average number of days/year that alternative design temperatures were exceed, benchmarked against Bureau of Meteorology "climate summaries".

	reference number		ASHRAE 2005		AIRAH 1997		present paper	
Station name	**WMO**	**BOM**	**Db**	**cwb**	**db**	**cwb**	**db**	**cwb**
ARCHEFIELD	94575	40211	33.1	/ 23.0	33.1	/ 22.7	34.1	/ 23.4
BIRDSVILLE POLICE STN	94482	38002	42.5	/ 21.4	43.1	/ 21.5	44.2	/ 22.9
BOULIA AIRPORT	94333	38003	41.1	/ 21.6	41.8	/ 21.1	43.3	/ 23.6
BOWEN AIRPORT	94366	33257	32.5	/ 25.8	32.6	/ 26.4	34.0	/ 26.2
BRISBANE AERO	94578	40842	31.1	/ 22.5	30.8	/ 22.8	32.4	/ 21.5
CAIRNS AERO	94287	31011	32.9	/ 25.3	32.8	/ 25.3	34.1	/ 25.1
CAPE MORETON LIGHT	94594	40043	27.7	/ 23.5	27.0	/ 24.0	28.7	/ 24.0
CHARLEVILLE AERO	94510	44021	38.5	/ 19.4	39.4	/ 20.0	40.0	/ 21.5
COOKTOWN MISSION STRIP	94283	31209	34.1	/ 25.9	32.5	/ 26.8	34.5	/ 26.7
COOLANGATTA	94592	40717	29.1		28.9	/ 23.9		
CUNNAMULLA POST OFFICE	94500	44026	39.5	/ 21.2	39.9	/ 20.2	41.0	/ 22.4
EMERALD AIRPORT	94363	35264	37.7	/ 21.8	37.7	/ 22.8	39.9	/ 23.8
GAYNDAH POST OFFICE	94543	39039	35.3	/ 22.9	36.0	/ 22.6	37.9	/ 23.8
GEORGETOWN POST OFFICE	94275	30018	38.4	/ 21.7	38.8	/ 22.0	39.6	/ 22.4
GLADSTONE RADAR	94380	39123	32.2	/ 24.9	32.0	/ 25.1		
GOLD COAST SEAWAY	94580	40764	29.1	/ 22.6	30.1	/ 23.8		
LONGREACH AERO	94346	36031	39.8	/ 20.6	40.9	/ 20.5	41.9	/ 21.5
MARYBOROUGH	94567	40126	32.5	/ 24.0	32.8	/ 23.6	34.2	/ 24.6
MOUNT ISA AERO	94332	29127	39.5	/ 19.8	39.9	/ 20.0	41.2	/ 21.1
NORMANTON	94267	29041	37.9	/ 21.8	38.1	/ 21.9	39.8	/ 22.8
QUILPIE AIRPORT	94494	45015	39.9	/ 20.2	40.9	/ 20.9	41.8	/ 22.4
RICHMOND POST OFFICE	94340	30045	40.2	/ 21.2	41.0	/ 22.9	42.0	/ 23.1
ROCKHAMPTON AIRPORT	94374	39083	35.1	/ 22.9	35.0	/ 23.1	36.6	/ 24.1
ROMA AIRPORT	94515	43091	37.4	/ 21.0	38.1	/ 21.3		
ST LAWRENCE POST OFFICE	94369	33065	33.5	/ 24.5	32.6	/ 23.4	34.5	/ 24.7
TOWNSVILLE AERO	94294	32040	33.2	/ 24.6	32.8	/ 24.7	34.3	/ 23.8
URANDANGIE	94329	37043	41.6	/ 21.3	42.0	/ 20.7	43.4	/ 23.6
WEIPA AERO	94170	27045	35.2	/ 22.6	35.6	/ 23.8	37.6	/ 23.6
WINDORAH POST OFFICE	94488	38024	41.4	/ 20.9	42.0	/ 21.6	43.0	/ 22.7
WINTON POST OFFICE	94339	37051	40.1	/ 20.8	41.4	/ 21.8	42.2	/ 22.4

Table 2 - ASHRAE 2005 Queensland design temperatures, compared to an extract of the present research findings

BRISBANE AERO 1949 – 2000	BRISBANE REGIONAL OFFICE 1887 – 1986	CAIRNS AERO 1942 – 2004	CHARLEVILLE AERO 1942 – 2004	CLONCURRY AERO 1939 – 1975	ROCKHAMPTON AERO 1939 – 2004	TOOWOOMBA 1957 – 1998	TOWNSVILLE AERO 1940 – 2004
27.417°S	27.477°S	16.873°S	26.415°S	20.671°S	23.376°S	27.582°S	19.247°S
153.114°E	153.030°E	145.745°E	146.254°E	140.508°E	150.476°E	151.930°E	146.766°E
40223	**40214**	**31011**	**44021**	**29009**	**39083**	**41103**	**32040**

Using “Climate Summaries” from Australian Bureau of Meteorology station ID numbers above, estimate design temperatures for an inter-annual average of the tenth-highest daily maximum:

32.2 °C	33.1 °C	33.7 °C	39.4 °C	41.4 °C	35.6 °C	32.6 °C	33.8 °C
10 d/y	10 d/y	10 d/y	10 d/y	10 d/y	10 d/y	10 d/y	10 d/y

DTC (Commonwealth Works) in Assn with AIRAH 1982 comfort design drybulb temperatures:

31.0 db		33.0 db	39.0 db	41.0 db	36.0 db	31.0 db	32.0 db
20 d/y		18 d/y	12 d/y	14 d/y	8 d/y	21 d/y	36 d/y

Estimated annual days that equal or exceed DTC-AIRAH 1982 design db temperatures

AIRAH Handbook 2000 comfort design dry bulb temperatures:

	30.8 db	32.8 db				31.1 db	32.8 db
	31 d/y	21 d/y				20 d/y	21 d/y

Estimated annual days that equal or exceed AIRAH Handbook 2000 design db temperatures

Table 3 - alternative designs benchmarked against Climate Summaries

a better estimate of micro-climate. Figure 11 illustrates a cross section through Brisbane from coast to dividing range. The reader could easily generate such for many locations throughout Australia, by exploiting the climatic summaries posted on the BOM website. The dramatic “take home message” of these plots of inter-suburban variability are that proper selection of representative suburban data is more substantial than the rate of climate change detected in the exceptionally long term records from our case-study of the BOM Regional Office in the Brisbane inner city.

The appendix (available from www.airah.org.au) summarises our comprehensive analysis of 225 locations in Queensland, of which 204 yielded coincident wet bulb temperatures.

Acknowledgement

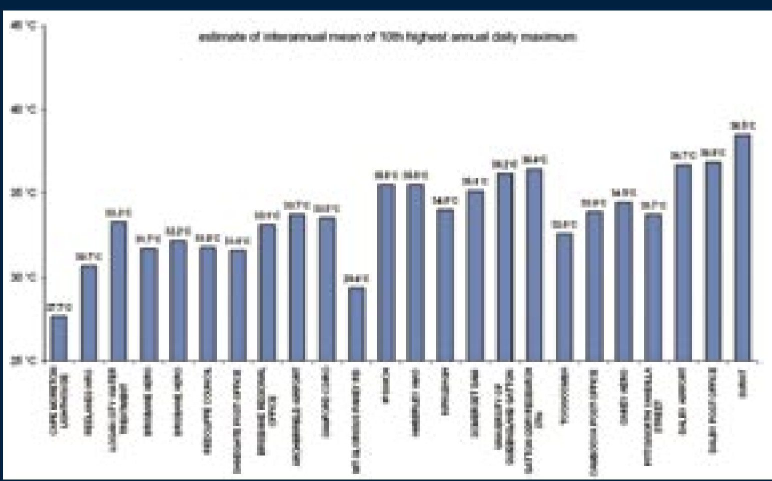


Figure 11 - variability of design temperature in various localities near Brisbane

The authors are indebted to the Commonwealth Bureau of Meteorology for maintaining long term observations of climate at hundreds of locations throughout the State of Queensland.

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The appendix to this paper with analysis of 225 Queensland locations is available from www.airah.org.au