Profiling and characterisation of key weather variables and their implication on building design

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Abstract: Local climate is a critical element in the design of buildings. In this paper, ten years of historical weather data in Australia's all eight capital cities are analyzed to characterize the variation profiles of climatic variables. The method of descriptive statistics is employed. Either the pattern of cumulative distribution and/or the profile of percentage distribution are used to graphically illustrate the similarity and difference between different study locations. It is found that although the weather variables vary with different locations, except for the extreme parts, there is often a good, nearly linear relation between weather variable and its cumulative percentage for the majority of middle part. The implication of these extreme parts and the slopes of the middle parts on building design is also discussed.

Conference theme: Effective environments: thermal, luminous, sonic, haptic, hygienic
Keywords: weather variables, multiple year weather data, building design

1. INTRODUCTION

Any architectural realization concretizes a microcosm in more or less close connection with the environment to which it belongs (Gratia and De Herde, 2003). The goal of the design, renovation and construction of a building is therefore to achieve a microcosm in optimal agreement with its environment. Local climate is a critical element in the building design. It tends to not only influence the shapes and forms of the local buildings but also dictate the types of environmental control required (Lam, et al, 2005). The climate of a particular location is often described by the prevailing long-term weather conditions, including evolution of the sunshine and the temperatures, and mode of the winds and precipitations (Gratia and De Herde, 2003). The process of identifying, understanding and controlling the climatic influences at a building site is perhaps one of the most critical parts of building design (Hui, 1996).

For buildings in Australia, the design requirements will vary from location to location. For instance, in a warm humid climate, buildings designs are often required to promote air movement to keep people’s comfort. Streets and buildings are therefore designed to orient as much as possible to catch the breezes. A mix of buildings heights will also have positive effect. By contrast, in a hot dry climate, protection from the intense sun–shine becomes essential. In a temperate climate, the wind direction usually changes markedly with the season. Therefore, design a building which blocks cold winter winds, but allows cooling summer breezes is important (BOM, 1997).

In this paper, ten years of historical weather data in Australia are analyzed to characterize the variation profiles of climatic variables. The method of descriptive statistics is employed to study the key weather variables contained in the weather database. Either the pattern of cumulative distribution and/or the profile of percentage distribution for ten years weather data will be used to graphically illustrate the similarity and difference between different study locations. In addition to the dry bulb temperature (DBT), the profiles of other key weather variables will also be studied, which include: atmospheric pressure, wind speed and wind direction, air humidity, total cloud cover, and the total global solar irradiance on a horizontal plane. General distribution of weather variables will be profiled and compared between the different capital cities in Australia. Their implication in building design will also be discussed.

2. RESEARCH METHODOLOGY

2.1 Study locations

The Australian island continent features a wide range of climatic zones, from the tropical regions of the north, through the arid expanses of the interior, to the temperate regions of the south (ABS, 2005). The majority of the country is hot and dry. The sea exerts little moderating influence beyond the coast, and the highland area is too small and too low to have more than local effect (ASA, 2005). Most of the populations live in the coast cities.

In this paper, all the eight capital cities in Australia, including Adelaide, Brisbane, Canberra, Darwin, Hobart, Melbourne, Perth and Sydney, have been chosen for the study. These capital cities represent Australia's wide climate conditions including:

- Hot humid summer, warm winter (e.g. Darwin)
- Warm humid summer, mild winter (e.g. Brisbane)
- Warm temperate climate (e.g. Adelaide, Perth and Sydney)
- Mild temperate (e.g. Melbourne)
- Cool temperate climate (e.g. Canberra and Hobart)

2.2 Weather database

The hourly weather database used in this study is summarized in Table 1. This historic climatic data is supplied by ACADS-BSG, which is a consulting company based in Melbourne, Australia, and supplies weather data for building simulation to Australia, New Zealand, Hong Kong and Singapore.

Table 1: Information of studied sites in Australia

W.M.O Index No.	Locality	Latitude	Longitude	Elevation (m)	Years Between
94675	Adelaide	-34.9	138.6	47	1978-1987
94578	Brisbane	-27.4	153.1	4	1978-1988
94925	Canberra	-35.3	149.1	564	1978-1989
94121	Darwin	-12.5	130.8	27	1969-1973
94970	Hobart	-42.9	147.3	55	1968-1987
94868	Melbourne	-37.8	145	112	1967-1987
94608	Perth	-32	115.9	19	1972-1987
94768	Sydney	-33.9	151.2	42	1978-1987

The weather variables contained in the above Australian climatic database include the hourly records of the dry bulb temperature (DBT), humidity ratio, atmospheric pressure, wind speed and direction, cloud cover, global solar irradiance on a horizontal plane, diffuse solar irradiance on a horizontal plane and direct solar irradiance on a plane normal to the beam. Except for the last two parameters (diffuse and direct solar irradiance), all other meteorological parameters will be analyzed and compared for different locations studied in this paper.

2.3 Study approach and methods of characterisations:

In order to compare the difference and/or similarity of climatic feature between different locations, the method of descriptive statistics is employed in this paper to study and characterise the profiles of key weather variables contained in the weather database. Either the pattern of cumulative distribution and/or the profile of percentage distribution for study years will be used to graphically illustrate the similarity / difference between different selected locations.

Descriptive statistics can be defined as those methods involving the collection, presentation, and characterization of a set of data in order to properly describe the various features of that set of data (Levine, et al 1999). Through frequencies procedure of descriptive statistics analysis (eg, by SPSS software), a report of univariate statistics for data in the input range will be generated, which provides detailed information on the central tendency and variability of the input data. In this paper the pattern of cumulative distribution and/or percentage distribution will be used to compare the similarity and/or difference of weather patterns between different years and different locations. It will also be linked to building design.

3. RESULTS AND DISCUSSIONS

In order to understand the general distribution of weather variables for the study locations and their implication in building design, the general profiles of key weather variables from multiple years weather data are analyzed and illustrated in this section for all the eight state capital cities in Australia.

3.1 Dry bulb temperature:

Air temperature is a measure of the heat content of air and its changes, therefore reflecting the gain or loss of energy over time. The addition of energy produces increased molecular motion, resulting in higher temperatures (Sturman and Tapper, 2005). Three different temperature measurements, named as dry bulb temperature (the measure of molecular motion), wet bulb temperature (reflection of the cooling effect of evaporating water) and dew point temperature (the temperature below which moisture will condense out of the air) are often used in the psychrometric chart to represent different types of air properties. However, when people refer to the temperature of the air, they are usually referring to dry bulb temperature. Air temperature is undoubtedly the most important climatic parameter, with its variation being primarily controlled by incoming solar energy and outgoing earth energy (Guan et al, 2007).

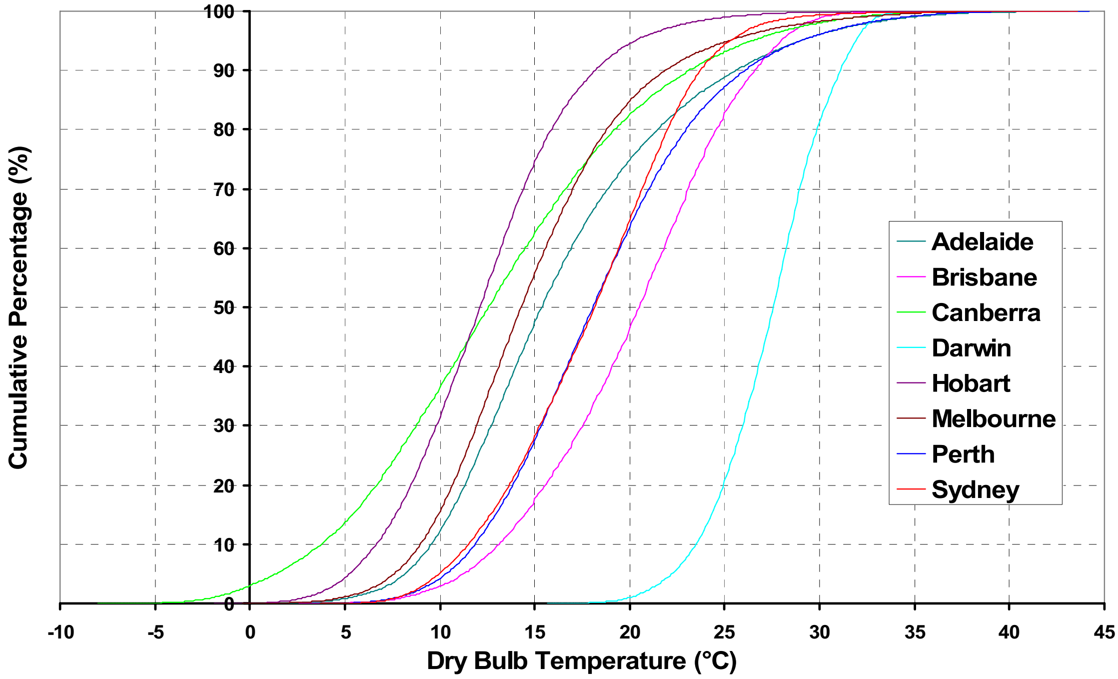


Figure 1: The cumulative distribution of DBT

The cumulative distribution of dry bulb temperature (DBT) is shown in Figure 1. It can be seen that although the DBT distributions vary with different locations, except for the extreme top and bottom 20% parts, there is always a nearly linear relation between DBT and its cumulative percentage for the middle 60% part. By comparing the slopes of these temperature profiles, the range of temperature changes over multiple–years can also be compared. With a flatter slope, this range of temperature change would be relatively greater. Typical examples include Canberra, Adelaide and Perth.

Table 2: A summary of descriptive statistic of DBT (ºC)

Location	Mean	Std. Deviation	Median	Minimum	Maximum
Adelaide	16.6	64	15.4	-0.4	44.2
Brisbane	20.2	51	20.5	2.6	38.5
Canberra	13.1	75	12.6	-8	38.7
Darwin	27.4	29	27.6	15.7	36.7
Hobart	12.4	46	12.2	-1.9	38.3
Melbourne	15.1	54	14.3	-0.4	43.1
Perth	18.6	56	18.1	3.8	44.2
Sydney	18.0	48	18.2	3.7	43.6

The implication of such wider temperature variation could be significant on building design, as wider extreme design temperature may be required for these cities. This can be demonstrated through the comparison between mean temperatures for multiple years in Table 2 with the corresponding (peak) design temperatures for air conditioning system in Table 3. It can be seen that for instance, although Canberra has much lower mean temperature (13.1°C) than Brisbane (20.2°C), it actually has higher summer design temperature (34.3°C) than Brisbane (31.9°C). The comparison between Perth and Darwin also illustrates this phenomenon. Although Perth has 8.8°C lower mean temperature than Darwin, it actually has 2.2°C higher summer design temperature than Darwin. This indicates the air conditioning systems in these cities will have to work longer hours at part-load and are utilized inefficiently in comparison with other cities.

Table 3: Outdoor design temperatures (Comfort or Non-Critical Process Installations) for the state capital cities in Australia (AIRAH, 1997).

Location	Outdoor Design Temperature (°C)			
	Summer		Winter	
	DBT (°C)	WBT(°C)	DBT (°C)	RH (%)
Adelaide	34.8	21.3	6.4	80
Brisbane	31.9	24.9	9.3	80
Canberra	34.3	19.6	–2.2	80
Darwin	34.4	27.7	18.1	80
Hobart	27.0	18.0	1.9	80
Melbourne	34.3	20.5	3.5	80
Perth	36.6	22.4	7.4	80
Sydney	31.1	22.7	7.2	80

Because outdoor design temperature is essentially determined by the extreme hot or cold part, the outdoor design cooling or heating temperature used for different cities may therefore not always correspond to people's general (average) perception. For instance, although Darwin and Brisbane have higher mean year temperatures than the other cities, their cooling design temperatures however may actually be lower than the other cities, such as Adelaide and Perth.

From Figure 1, it is also noted that except for Darwin, all Australian capital cites have more than 80% of hours when the outdoor temperature is lower than 25°C. This indicates the great potential of using outdoor air for "free cooling". In particular, for an internal load dominated building (eg, office building), because the amount of energy given off by people, equipment, and lights is usually considerably greater than the energy lost through the building envelope, cooling energy can be still required even in winter season (Gratia and De Herde, 2003 and Meredith, 2004). The adoption of economiser in air conditioning system for the use of outdoor air for "free cooling" or the use of mixed mode (or hybrid) ventilation can save considerable building cooling energy in this case.

3.2 Atmospheric pressure:

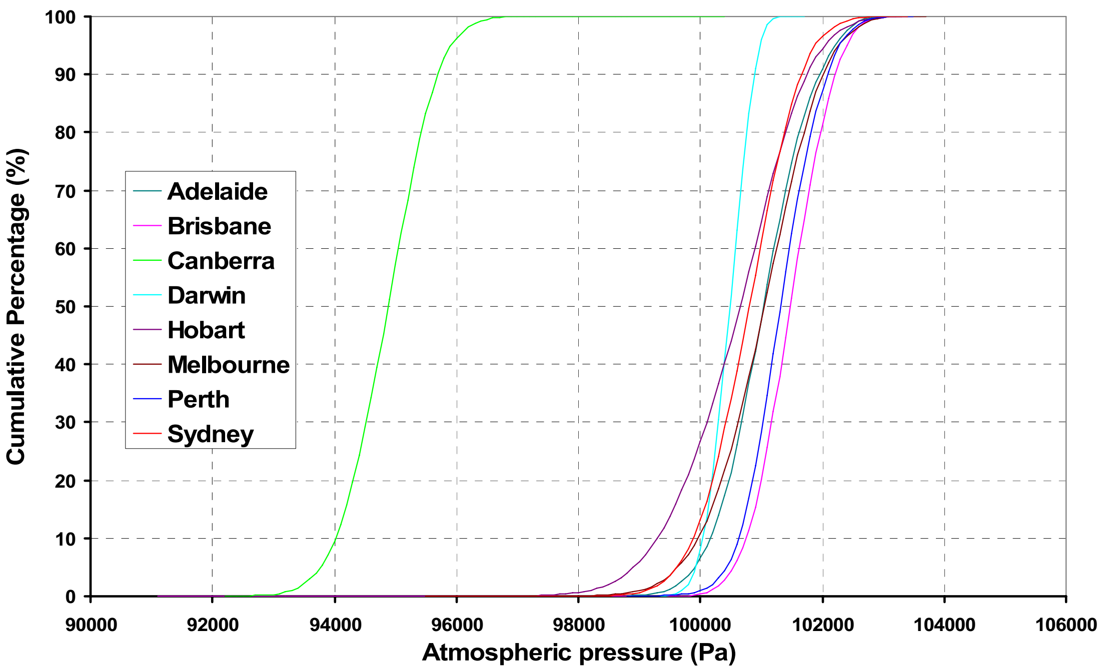


Figure 2: The cumulative distribution of atmospheric pressure

Air or barometric pressure is an important weather forecasting tool because of its close association with general weather situations and wind (Sturman and Tapper, 2005). One of the important features of the barometric pressure is that it could affect the evaporation and moisture saturation level of the air, and therefore influence the calculation of wet bulb temperatures and relative humidity (Degelman, 1991). Spatial and temporal variations of pressure are of fundamental importance, as they are closely linked to the horizontal and vertical airflow that produces the weather (Sturman and Tapper, 2005). Rising pressures usually indicates improving weather conditions; falling pressures may reflect impending inclement weather. For building services design, although the atmospheric pressure has no direct impact on the building thermal performance, it indirectly affects building thermal comfort and heat transfer calculations through its influence on the formulation of air humidity and wind characters.

The cumulative distribution of atmospheric pressure is shown in Figure 2. It can be seen that similar to DBT profiles, if both the top and bottom extreme parts are excluded, there is also a nearly linear relation between atmospheric pressure and its cumulative percentage for the middle part.

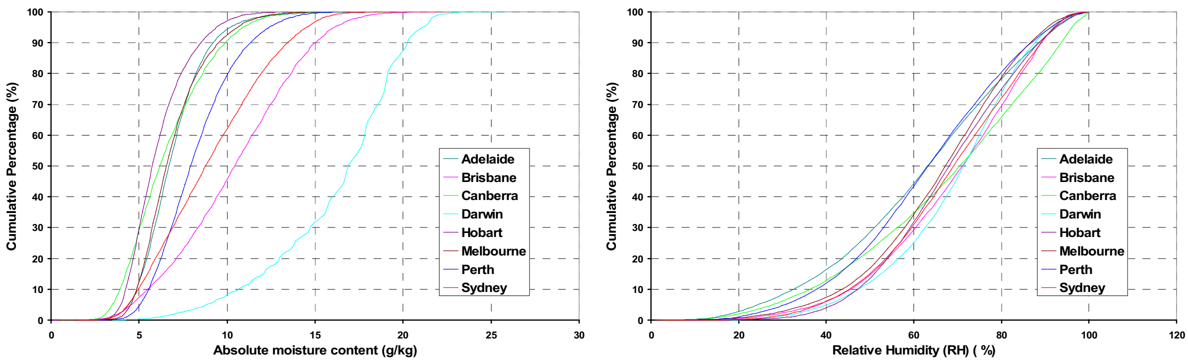
It also appears that Canberra has a remarkably lower atmospheric pressure than the other capital cities. This indicates the incorporation of local atmospheric pressure in the conversion of air humidity terms is particularly important for Canberra. If the standard atmospheric pressure (i.e. 101325 Pa) is still used for the air humidity conversion in Canberra, then the calculated results would introduce significant errors. Moreover, Darwin has significantly steeper distribution pattern than other cities. This indicates that it has a narrower range of variation in atmospheric pressure. This is similar to its variation profile for temperature.

3.3 Air humidity

Atmospheric air contains many gaseous components, such as dry air, as well as water vapour and miscellaneous contaminants, including smoke, pollen, and gaseous pollutants. Dry air exists when all water vapour and contaminants are removed from the atmospheric air. The composition of dry air is relatively constant, but small variation in the amounts of individual components may occur with time, geographic location, and altitude. Moist air is a binary (or two-component) mixture of dry air and water vapour. The amount of water vapour in moist air varies from zero (dry air) to a maximum (saturation), depending on the local temperature and pressure. The saturation condition is a state of neutral equilibrium between moist air and the condensed water phase.

In order to express air humidity, different climatic terms may be used, which include the humidity ratio or absolute humidity (*W*), relative humidity (*RH*), wet bulb temperature (T_{wet}) and dew point temperature (T_{dew}). Among these four variables, absolute humidity, which is an absolute measure of the amount of water vapour contained in the air, and relative humidity, which is the percentage of amount of water vapour actually in the air to the amount of water vapour the air can hold, are more often used in the practice. Given the dry bulb temperature (T_{dry}) and any one of the other four humidity related climatic terms (*W, RH,* T_{wet} *or* T_{dew}), the other three variables can be readily calculated.

The cumulative distribution of absolute humidity and relative humidity is shown in Figure 3. It can be seen that the variations between different cities are much broader for humidity ratio than for relative humidity. Although it may be found that the hotter region may generally have higher humidity ratio, their relative humidity is not necessarily higher too. For instance, Canberra has about 35% of time having RH above 80%. This is in comparison with Darwin which has only about 25% of time and Perth which has only about 20% of time having RH above 80%.



(a) (b)

Figure 3: The cumulative distribution of air humidity

Through the comparison between local temperature and its absolute moisture content, it can also be found from Figure 3 (a) that although Perth has a higher mean temperature than Sydney, it actually has clearly less absolute moisture content than Sydney. This shows that Perth has a drier air than that Sydney. Comparing Figure 3 (a) to Figure 1, it can also be found that Adelaide has a drier air than that Melbourne.

From Figure 3 (b), it can be seen that Perth and Adelaide are actually the two driest capital cities in Australia. It may also be noted that Canberra is actually a much more humid city than other cities in Australia. This may be attributed to the fact that, rather than having a high moisture content during the day, as seen in Figure 3 (a), Canberra is usually much colder at night. This (a higher RH at night) would however not have much impact on cooling loads during the daytime in Canberra.

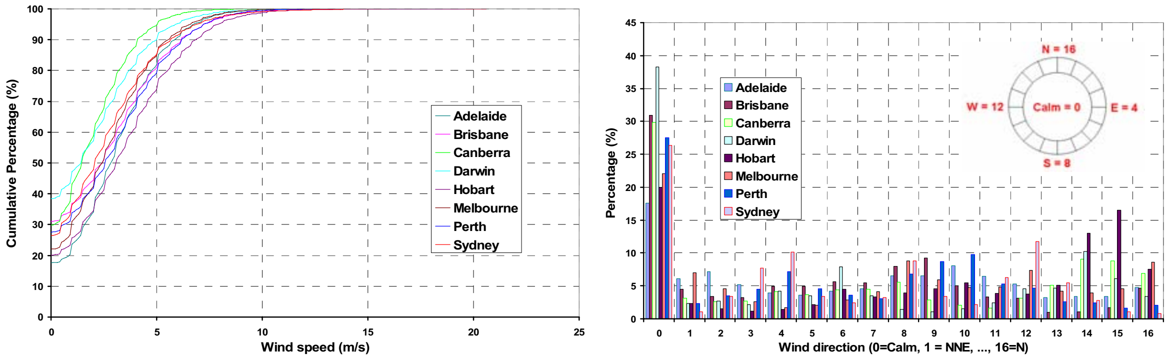
Humid or dry air has significant implication not only in the cooling load calculation for air conditioning system design, but also for people's perception in thermal comfort. In a warm and humid climate, considerable air movement may be required to keep people's comfort, while in a hot and dry climate, protection from the intense sunshine is essential.

3.4 Wind

Wind is the movement of air as a result of pressure and density gradients. It is a vector quantity, having both magnitude and direction (Sturman and Tapper, 2005). The sun’s radiation provides the energy that sets the atmosphere in motion, both horizontally and vertically (Aerographer's Mate, 2004). The rising and expanding of the air when it is warmed, or the descending and contracting of the air when it is cooled causes the vertical motion. The horizontal motion is caused by different temperatures due to the inequalities in gain and loss of heat. The differences in the type of surface, the differential heating, the unequal distribution of land and water, the relative position of oceans to land, forests to mountains, lakes to surrounding land, and the like, can cause different types of circulation of the air (Aerographer's Mate, 2004). The pressure variations produced by heat and humidity (with heat being the dominant force) create Earth’s winds through the flow of atmospheric mass from an area of higher pressure to an area of lower pressure.

Wind is the climatic element that transports heat and moisture from one location to another, so it is also important in the design of building HVAC system, in particular for the natural ventilation of buildings, that the effects of both air exchange for ventilation and wind pressure for infiltration be taken into account.

The cumulative distribution of wind speed and direction is shown in Figure 4. It can be seen from Figure 4(a) that Hobart (a coast city) has the highest wind speed, while Canberra (an inland city) has the lowest wind speed among the eight capital cities. It is also noted from Figure 4(b) that in Darwin, there is 38% of time being calm, no breeze at all. This is followed by Brisbane which has 31% of time being calm. The lowest rate of calm time is 17.5%, which occurs in Adelaide. The rates of calm time for other cities are between 20 to 30%.



(a) (b)

Figure 4: The cumulative distribution and percentage distribution of wind character

From Figure 4(b), it can also be seen that different cities may have different prevailing wind direction. For the eight capital cities, their dominated wind directions are (Figure 4):

- Adelaide – around either South–West (10) or North–East (2);
- Brisbane – around South–West (9) and South (8);
- Canberra – around North–West (14) and North North–West (15);
- Darwin – around either North–West (14) or South–East (6);
- Hobart – around North–West to North with North North–West (15) has the highest rate of time.
- Melbourne – around either South (8), or North (16) to North North–East (1), or West (12);
- Perth – around South–West (10) or East (4);
- Sydney – around West (12) or East (4).

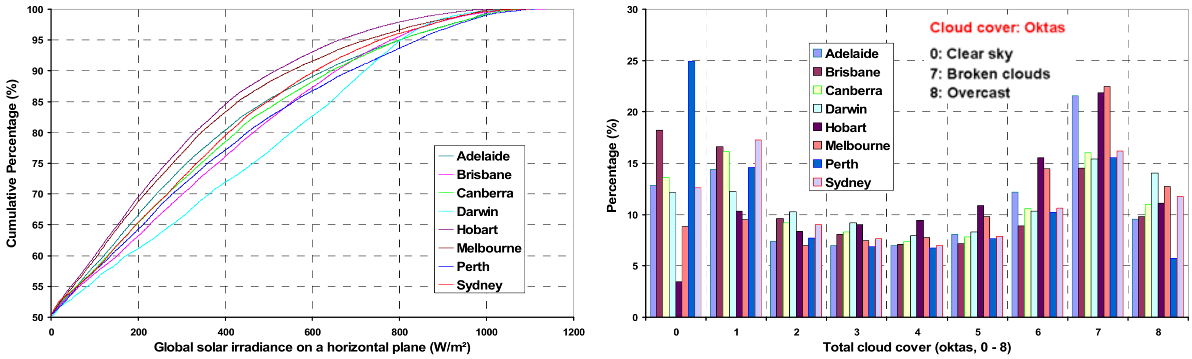
Overall, in comparison with other key weather elements, wind is generally much more “changeable” and more strongly influenced by the local factors. Moreover, wind measurement is also particularly sensitive to the site condition and the instrument used. It has been previously found that the effects of wind data on building thermal designs and energy analysis are difficult to define and quantify, but are generally believed to be relatively less important, except for in locations where severe wind conditions predominate (Lam et al, 2005). However, for natural ventilation buildings, wind data of both direction and speed is very important and would have significant implication on building design, especially for the calculation of ventilation air exchange and the possible infiltration.

3.5 Solar radiation

In certain sense, it may be reasonable to assume the Sun is the sole source of heat energy that is supplied to earth's surface and the atmosphere (Aerographer's mate, 2004). Solar radiation, which is defined as the total electromagnetic energy emitted by the Sun, drives almost every physical and biological cycle in the Earth's climate system (NASA, 2005). Solar radiation reaches the earth's surface either by being directly transmitted through the atmosphere ("direct solar radiation"), or by being scattered or reflected to the earth's surface ("diffuse sky radiation") (NSIDC, 2005). It is estimated that about 50 percent of solar (shortwave) radiation is reflected back into space, while the remaining is absorbed by the earth's surface and re-radiated as thermal infrared (longwave) radiation.

For a specific location, both direct and diffuse solar radiation are determined by the sun's position (or incident solar angle), sun-earth distance and the sky condition (i.e. cloud cover). The global solar irradiation, which is the sum of direct solar radiation and diffuse solar (sky) radiation, therefore varies throughout a year with monthly maximum solar radiation reaching the highest value in summer and falls to the lowest value in winter. During a day, the solar radiation heat gradually increases to reach its maximum at midday and then gradually decreases to zero after sunset, following the pattern of cosine bell. Different cities have different scales of variations in solar radiation, and reach different levels of daily peak solar radiation (Guan et al 2007). It is expected that the difference of peak solar radiation between different cities would be greater in winter time and smaller in summer time.

The cumulative distribution of global solar irradiance on a horizontal plane and total cloud cover for the eight capital cites in Australia is shown in Figure 5. It can be seen that because different cities have different latitudes and longitudes, their relative positions to the Sun could be quite different. Moreover, the sky condition (i.e. could cover) may also be different for the different cities. All these factors have contributed to the different rates of solar irradiation to the different cities.



(a) (b)

Figure 5: The cumulative distribution and percentage distribution of solar radiation and could cover

From Figure 5(a), it can be seen that Darwin has the highest solar irradiance, while Hobart has the lowest solar irradiance. It is also noted that although Darwin may have the largest amount of solar irradiation, Perth and Canberra may receive stronger peak solar irradiation than Darwin (see the top 5% part). This result is consistent with the finding by Guan et al (2007) which showed that Darwin has relatively low monthly peak solar radiation in the summer period.

From Figure 5 (b), it is also found that 25% of time in Perth has clear sky, which is followed by Brisbane with 18% of time having clear sky. By contrast, Hobart only has 3.5% of time having clear sky. In comparison, Adelaide, Hobart and Melbourne have higher broken clouds (7 oktas) than the other cities. Darwin has the highest rate of overcast.

4. CONCLUSION

Through the statistic analysis of climatic parameters, the general distribution profile of weather variables for the eight capital cities in Australia has been investigated. It has been found that although the weather variable distributions vary with different locations, except for the top and bottom extreme parts, there is generally a good, nearly linear relation between the weather variable and its cumulative percentage for the majority of middle part.

By comparing the slopes of these distribution profiles, it may be possible to determine the relative range of changes of the particular weather variables for a given city. With a flatter slope, the range of weather variable change over multiple–years would be relatively greater. Using the dry bulb temperature (DBT) as an example, this can have significant implications on the design of buildings, particularly in terms of design heating and cooling temperatures for HVAC systems and the potential of using outdoor air for “free cooling”.

Furthermore, the extreme part of the above distribution profile can also a have significant effect on the design of buildings. Because outdoor design temperature is essentially determined by the extreme hot or cold part, the outdoor design cooling or heating temperature used for different cities may therefore not always be consistent with people’s general (average) perception. For instance, although Perth has 8.8°C lower mean temperature than Darwin, it actually has 2.2°C higher summer (peak) design temperature than Darwin. This indicates the air conditioning systems in these cities will have to work longer hours at part load and utilized inefficiently in comparison with other cities.

In addition to the dry bulb temperature (DBT), the profiles of other key weather variables have also been studied, which include: atmospheric pressure, wind speed and wind direction, air humidity, total cloud cover, and the total global solar irradiance on a horizontal plane. In particular, it has been found that Canberra has a remarkably lower atmospheric pressure than other capital cities. This indicates the incorporation of local atmospheric pressure in the conversion of air humidity terms is particularly important for Canberra. If the standard atmospheric pressure (i.e. 101325 Pa) is still used for the air humidity conversion in Canberra, significant errors may be introduced. For air humidity, the variations between different cities are much broader for humidity ratio than for relative humidity.

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