UNDERSTANDING CLIMATE FOR ENERGY EFFICIENT OR SUSTAINABLE DESIGN

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ABSTRACT

Understanding climate is a pre-requisite for energy efficient or sustainable architecture. It provides vital information to optimize natural energies to create comfortable living conditions. Since climatic data is often very technical, its implication in building design is often limited. There are climate classifications to provide a general outlook of climatic condition of a place. However, a building designer needs more precise information regarding climate, so a rigorous climate analysis is necessary.

For this study, long term averages of temperature, humidity, rainfall, sky condition data are retrieved from the website of the Bureau of Meteorology, Australia. This study analyzed wind data in detail and developed wind roses for different times, using wind data record of the Bureau of Meteorology. This study has used climate data sheet, Mahoney tables, Bioclimatic chart, Building Bioclimatic chart and wind roses to understand the climate and to formulate strategies for planning and building design. This paper identifies options of integrating climatic considerations as an integral part of planning and building design taking the case study of Perth, Australia.

Key words: Climate analysis, sustainable design, energy efficient design, design strategies

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INTRODUCTION

"Sustainable architecture" might be a modern terminology, but our ancestors had achieved a comfortable environment in their traditional dwellings, addressing the same fundamental issues that the current concept of sustainability deals with. Over many centuries, various designs and building techniques have developed across the world in different climatic zones, bringing forth structures that provide more or less a comfortable living condition without the use of sophisticated mechanical devices.

Most building technicians in the past were familiar with the climate in which they were building. They were aware of the ways they could benefit from certain climatic features and overcome those that were less favorable, by opting for appropriate building shapes, location, orientation and the use of appropriate building materials. Strong economy and invention of new climate modifying technologies liberated designers from climate and local resource constraints. Architecture, thus, gradually became divorced from nature. This attitude led to an irresponsible use of energy resources that cannot continue without resulting in grave ecological consequences (Gonzalo and Habermann, 2006).

This paper identifies options of integrating climatic considerations as an integral part of planning and building design in Perth, Australia. Climatic data is obtained for Perth and analyzed to formulate design strategies. Climate information for this study has been accessed from the database of Bureau of Meteorology, Australia. This study has used comfort analysis tools such as Bioclimatic chart, Building Bioclimatic chart to identify necessary actions to be undertaken in order to achieve a comfortable living condition. Wind roses corresponding to different times are used to understand the wind flow at different times and different seasons. Preliminary design recommendations are obtained from Mahoney tables, which serve as guidelines to formulate elaborate strategies for planning and building design in Perth.

CLIMATE AND ITS ROLE IN DESIGN

In order to exploit the climate to comply with the thermal needs of a building, it is critical to analyze the climate type within which the site is located and to collate relevant data that will inform an appropriate strategic design. The different climate regions of the world are commonly categorized in terms of their thermal and seasonal characteristics (e.g. hot-dry, warm-humid, composite, moderate and cold). Each region requires distinctive design responses, which are frequently reflected in the vernacular building practices and architecture of the region.

It is important to note that even within the same climate zone; a wide range of distinct climate characteristics can be found. In order to define local climate more precisely than simply according to the generic typologies, detailed information about the local air temperature, humidity and wind patterns is required. It is possible to obtain detailed information on weather of a place from weather stations. This information is based on hour after hour monitoring of weather over several decades, although, not all of that information might be relevant for design purposes. The requirement of details depends upon the potential design implications and the level of environmental analysis that needs to be performed. For example, large diurnal temperature variations in hot dry climates are, as important as, the average daily temperatures, since they will influence the design strategy for maintaining comfort by exploiting the time lag characteristics of thermal mass. Conversely, in warm humid climates, the diurnal swings are much smaller and air movement is essential to define comfort. As a result, it is important to know wind speed and directions at different times in a day (Gonzalo and Habermann, 2006).

METHODOLOGY OF THE STUDY

This paper is a part of a larger study, which aims to develop design guidelines for designers/ builders to help them in the selecting design options and building elements that are climatically suitable and efficient from energy use and conservation point of view. The study will cover the major population locations within Australia such that it covers all the states and major cities which are distinctly different in climatic conditions.
The study is carried out in two steps: climate analysis, and recommendations for building design and planning. In climate analysis, climate data from the Bureau of Meteorology, Australia for each of the locations are arranged in a climatic summary sheet; comfort condition for each location is investigated using Bioclimatic charts and Building Bioclimatic charts; and wind roses are prepared to understand the wind flow in different times across different seasons. Final design guidelines are based on, preliminary recommendations from Mahoney tables which formulate design strategies using temperature, humidity and rainfall; and detailed climatic analysis from the first step.
This paper presents the case study of Perth taking the same methodology of climatic analysis with site specific recommendations.

CASE STUDY: PERTH

Climate data for the purpose of this paper is obtained for Perth Airport. Climate data over a period of 63 years have been used for analysis.

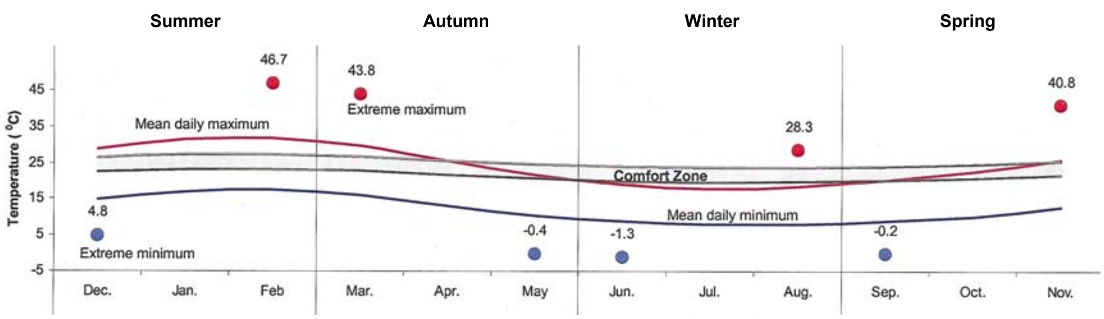

Fig.1. Temperature profile across seasons

Perth experiences a Mediterranean climate, characterized by hot, dry summers and mild, wet winters. These seasons extend into autumn and spring months, which are transitional periods between the two main seasons. Mean monthly air temperature ranges from 32°C in February to 18°C in July. The highest temperature ever recorded is 46.7°C in February; however, the temperature exceeds 40°C only three days per year on an average. The average minimum temperature ranges from just 8°C in July and August to 17°C in January and February. The lowest temperature ever recorded is –1.3°C in June.

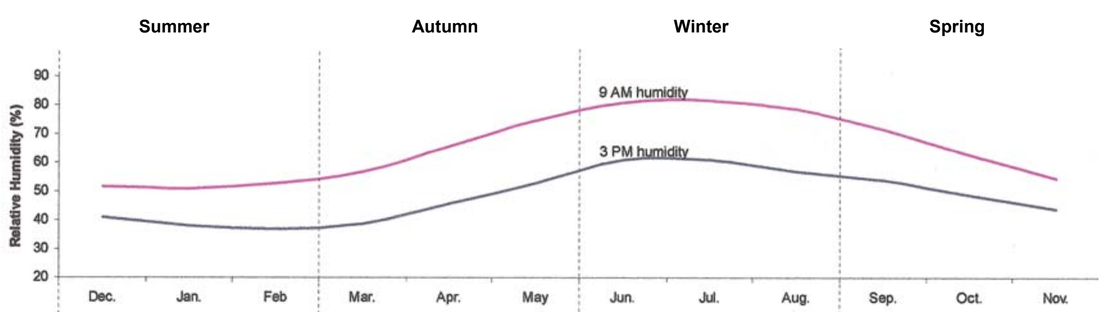

Fig.2. Relative humidity in 9 AM and 3 PM across seasons

Usually humidity is expressed in percentage i.e. relative humidity. Relative humidity is the ratio of the water vapor pressure to the vapor pressure of saturated air at the same temperature. The moisture-holding capacity of air increases with air temperature.

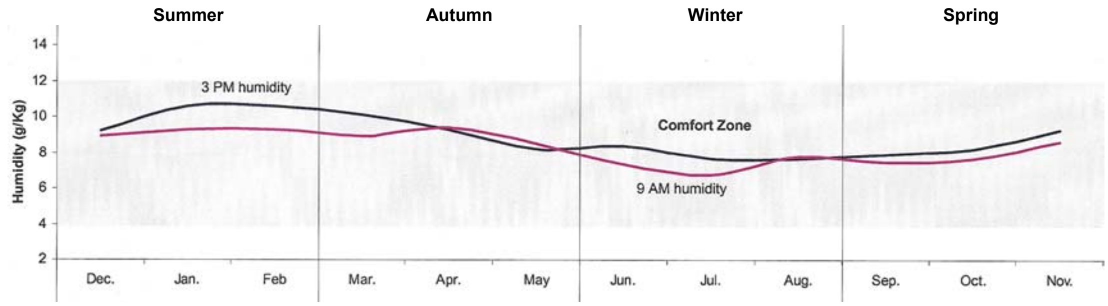

Fig.3. Specific humidity in 9 AM and 3 PM across seasons

In this paper humidity comfort zone has been expressed in specific humidity i.e. the ratio of the mass of water vapour (gm) to the mass of dry air (Kg). It is generally accepted that humidity ratio of 4-12 g/Kg is considered as a comfortable humidity level (Szokolay, 1986). The morning and afternoon humidity levels in Perth are found within the comfort zone. Summer months are hot and winter months are cold but humidity levels are always in the acceptable range across seasons.

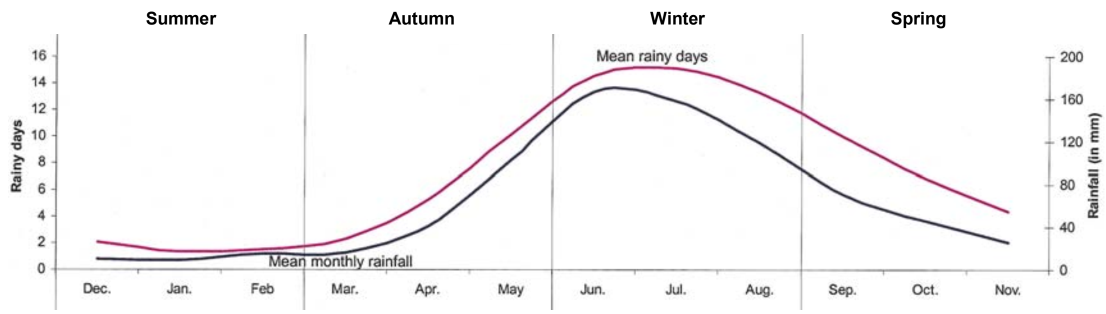

Fig.4. Mean rainfall and rainy days across seasons

Of the annual mean rainfall of 767 mm, which is approximately 87 days of rainfall, about 70% usually fall between May and September. It rains more frequently during winter with 150 mm rainfall in an average of 14 rainy days in a month. In contrast, the total summer rainfall is just 35 mm with an average of 2 rainy days in a month. Hence, it is not unusual in Perth to have extended dry periods during summer.

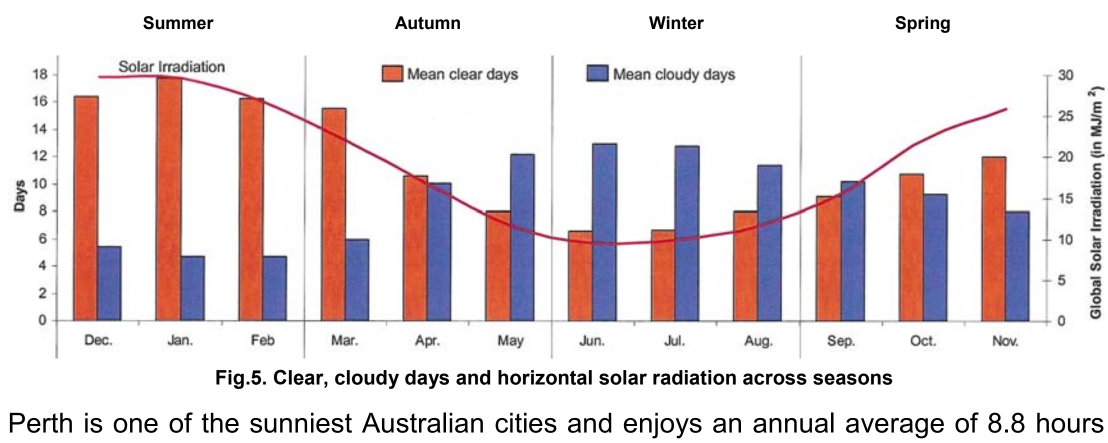

Fig.5. Clear, cloudy days and horizontal solar radiation across seasons

Perth is one of the sunniest Australian cities and enjoys an annual average of 8.8 hours of sunshine per day. In predominantly clear days of summer, the average daily sunshine duration exceeds 11 hours. As winter months get substantial rain, the sky in winter is cloudy for about 12 days in a month. In summer, horizontal solar radiation is the highest.

Cloudy conditions and low sun angle, results in low winter horizontal solar radiation in Perth.

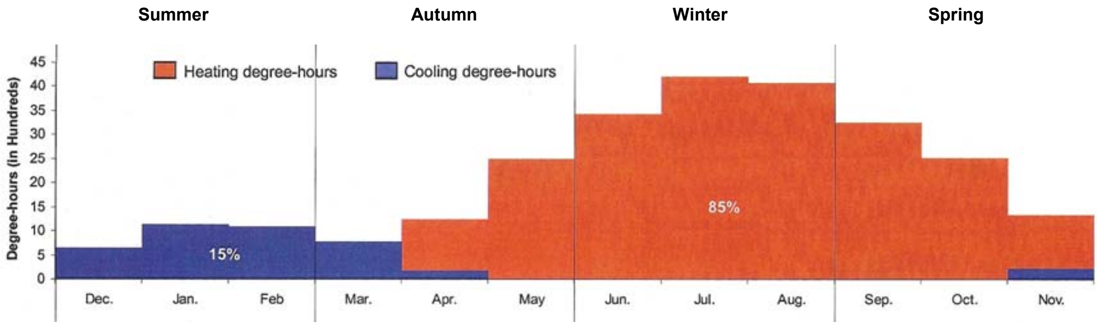

Fig.6. Heating and cooling degree hours across seasons

Requirements of heating or cooling are best described by heating/ cooling degree hours. Heating/ cooling degree hours are the sum of every hour, multiplied by the number of degrees the outside temperature is above or below the comfort temperature. Upper comfort temperature is set according to the neutral temperature (Szokolay, 1982) for each month to respond to the changing characteristics of the climate. Lower comfort temperature has been taken 18°C for the year round.

Summer and early autumn months require cooling; from mid autumn to spring, heating demand is very high in Perth. In total, 85% of the time has heating demand and 15% of time has cooling requirements.

Wind is mainly easterly in the morning due to the effect of land mass; and south westerly in the afternoon due to afternoon sea breezes. Winter morning wind comes from the north and changes its course towards the west and south-west in the afternoon. The westerlies are associated with the bulk of the annual rainfall. The average wind speed in winter is considerably lower than in summer. The wind effect is described in detail in the later section of the paper.

COMFORT ANALYSIS AND STRATEGIES FOR COMFORTABLE CONDITIONS

Evaluating the human-comfort condition is a complex process. There are various environmental and physiological factors that affect the comfort condition of an individual. The effect of climate is evaluated considering the physiological condition of a normal individual. Various climatic parameters are combined to form the thermal index to express their

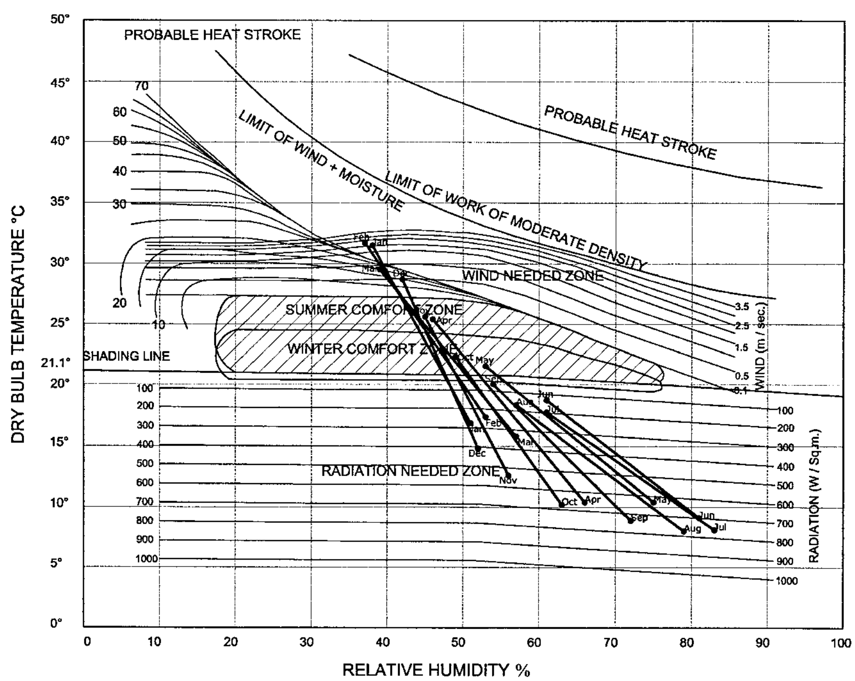

Fig.7. Bioclimatic chart for Perth

effect on man. In this study, the Bioclimatic chart (Olgyay, 1962) and Building Bioclimatic chart (Givoni, 1976) are used to evaluate the comfort condition and to formulate strategies to respond to it. Bioclimatic approaches to architecture are attempts to create comfortable conditions in buildings by understanding the microclimatic characteristics and resulting design strategies that include natural ventilation, daylight, and passive heating and cooling.

The Bioclimatic chart proposed by Olgyay (1962) is very effective for analyzing the comfort condition. The chart checks if a particular temperature–humidity relationship falls into the comfortable zone; and also reveals strategies to achieve comfortable conditions. It provides recommendations on, for example, need of radiation under a cold condition, and wind flow or humidification with wind flow under a hot condition. However, the Bioclimatic chart is limited in its applicability, since the analysis of physiological requirements is based on outdoor climate. Later, Givoni (1976) used the Psychrometric chart as the basis for defining the comfort zone and stretched out the probable extent of outdoor conditions under which certain passive control techniques could ensure indoor comfort.

The Building Bioclimatic chart derived by Givoni (1976) provides suggestions for building design considering the local climatic conditions. Various control strategies, which ultimately lead to a climate-sensitive design, are suggested. Szokolay (1986) defined *control-potential zone* to describe the range of outdoor atmospheric conditions within which indoor comfort could be achieved by the various passive control techniques. In the Psychrometric chart, different zones are plotted to indicate different strategies depending upon the monthly temperature–humidity relationship.

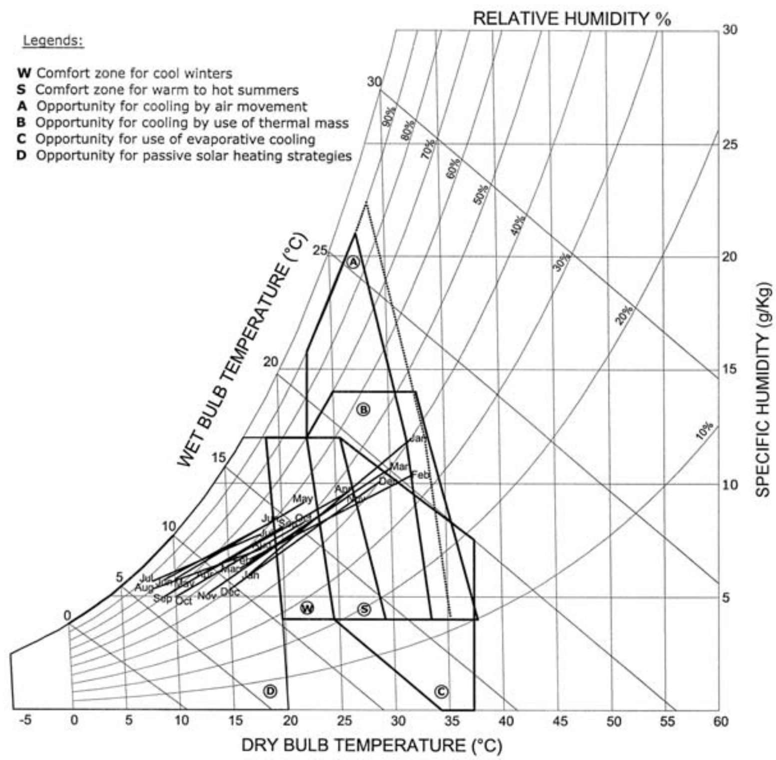

Fig.8. Building Bioclimatic chart for Perth

To identify the comfort condition for Perth, the climatic data of all months are plotted in both the Bioclimatic chart and Building Bioclimatic chart, as shown in Fig.7 and 8. Two points of each line represent mean minimum temperature with the 9 AM relative humidity and the mean maximum temperature with the 3 PM relative humidity. Both the comfort charts clearly indicate that buildings in Perth require cooling for four months from December to March, as the lines cross the comfort range. In January and February, wind speed up to 2.5 m/s can create a comfortable condition in daytime. Similarly, thermal mass is also helpful in cooling building from December to March. Night temperature remains just below the comfort range and are usually pleasant in summer months. Over all, building design strategies should make provisions for thermal mass and air movement for that period.

The daytime temperature-humidity relationship shows that April, May, October and November are comfortable, but the nighttime temperature falls below the comfort limit. Passive solar heating strategies are suggested to offset nighttime falling temperature. Similarly, June, July, August and September are colder months and require some sort of heating to make the situation comfortable. During this period, passive solar heating strategies help to maintain room temperature within comfortable range.

In short, buildings in Perth need to adjust to a large range of thermal conditions which includes utilizing both heating and cooling. It can be achieved through the judicious use of radiation and wind effects along with thermal mass.

WIND ANALYSIS

Wind is the motion of air relative to the surface of Earth and is one of the most highly variable climatic elements, both in speed and direction. General wind patterns are defined by the atmospheric pressure distribution, but locally wind can be strongly affected by several factors, such as, time of day (e.g. sea breezes), height above the ground and the surrounding terrain. Wind roses are used to represent wind information. They give wind direction, wind speed at varying intensities and the percentage of time wind blows from a certain direction.

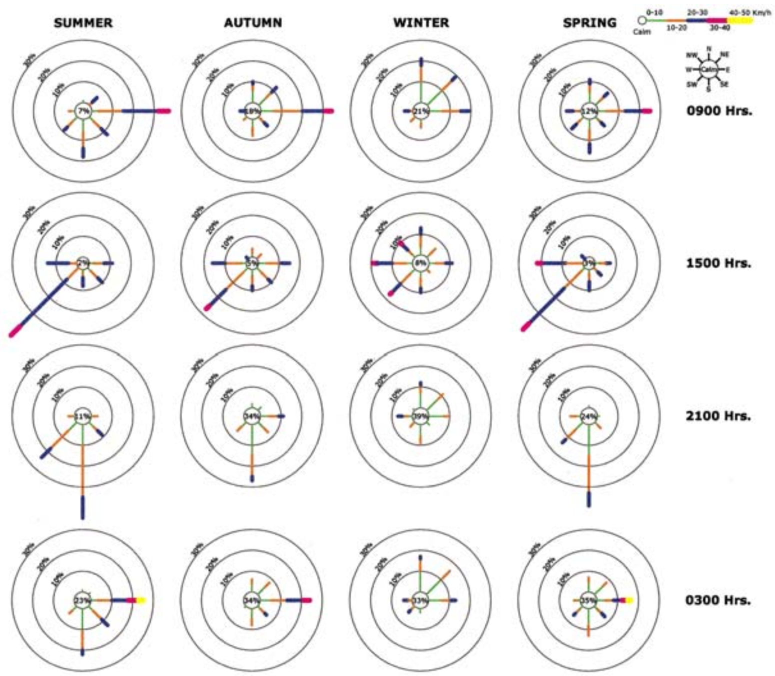

Fig.9. Wind roses for different times in different seasons for Perth

For the purpose of this study, hourly (more generally every three hours starting from midnight) wind speed record from Bureau of Meteorology, Australia has been used in preparing wind roses for corresponding hours. Earlier, wind data represented wind pattern into sixteen directions but the latest equipments make it possible to record data to the resolution of one degree. For building design purposes, however, eight directions and seasonal wind roses give all the information necessary for a designer.

Perth experiences three distinct wind patterns during a day in summer, autumn and spring. Morning wind is largely dominated by breeze coming from the land in the east. Wind direction starts to change towards south and west during noon; and constant strong wind blows from south-west direction in the afternoon. The afternoon wind is caused by sea breeze and can be used to cool off buildings. This south westerly wind in Perth is well known by the name of “Fremantle Doctor”. This westerly wind changes its course towards south by 9 PM. Winter wind is relatively less intense and dispersed into all possible directions. The wind roses clearly show that the intensity of wind is much stronger in summer than in autumn and spring.

Although the general requirement of wind is already suggested by the Bioclimatic and Building Bioclimatic charts, those charts do not specify the time of the day at which the wind is required. Hence, hourly temperatures for different months are generated with the

help of maximum and minimum temperatures, considering that the maximum temperature occurs at 3 PM and minimum temperature occurs at 5 AM (Krishan, *et al*., 2001).
Shaded areas in the hourly temperature table indicate the time when cooling may be needed. The cooling temperature is set to the lower comfort limit, which is 18°C temperature higher than these may require cooling.

Table: 1. Hourly temperature profile in Perth

Season	**Winter**			**Spring**			**Summer**			**Autumn**		
Hours	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	10.4	9.4	9.4	10.4	11.8	14.3	16.6	18.8	19.3	17.6	14.6	11.9
2	9.9	8.9	8.8	9.8	11.2	13.6	15.9	18.1	18.6	16.9	14.0	11.3
3	9.5	8.5	8.4	9.3	10.7	13.1	15.4	17.5	18.0	16.4	13.5	10.8
4	9.2	8.2	8.1	9.0	10.3	12.7	14.9	17.0	17.5	15.9	13.1	10.5
5	9.1	8.1	8.0	8.9	10.2	12.6	14.8	16.9	17.4	15.8	13.0	10.4
6	9.3	8.3	8.2	9.1	10.4	12.9	15.1	17.2	17.7	16.1	13.3	10.6
7	9.8	8.8	8.7	9.7	11.1	13.5	15.8	17.9	18.4	16.8	13.9	11.2
8	10.7	9.7	9.7	10.7	12.2	14.7	17.0	19.3	19.7	18.0	15.0	12.2
9	11.9	10.9	11.0	12.1	13.7	16.4	18.9	21.2	21.6	19.8	16.6	13.6
10	13.4	12.4	12.6	13.8	15.6	18.4	21.0	23.4	23.7	21.9	18.5	15.3
11	15.0	14.0	14.3	15.7	17.6	20.6	23.3	25.9	26.2	24.2	20.6	17.2
12	16.6	15.6	16.0	17.5	19.6	22.7	25.6	28.2	28.5	26.4	22.6	19.0
13	17.7	16.7	17.3	18.9	21.1	24.3	27.3	30.0	30.2	28.1	24.1	20.4
14	18.5	17.5	18.1	19.8	22.0	25.3	28.4	31.2	31.4	29.2	25.1	21.3
15	18.8	17.8	18.4	20.1	22.4	25.7	28.8	31.6	31.8	29.6	25.5	21.6
16	18.5	17.5	18.1	19.8	22.0	25.3	28.4	31.2	31.4	29.2	25.1	21.3
17	17.8	16.8	17.4	19.0	21.2	24.4	27.4	30.1	30.4	28.2	24.3	20.5
18	16.8	15.8	16.2	17.7	19.8	22.9	25.9	28.5	28.8	26.7	22.9	19.2
19	15.5	14.5	14.9	16.3	18.3	21.2	24.0	26.6	26.9	24.9	21.3	17.8
20	14.2	13.2	13.5	14.8	16.7	19.5	22.2	24.7	25.0	23.1	19.6	16.3
21	13.2	12.2	12.4	13.6	15.3	18.1	20.7	23.1	23.4	21.6	18.3	15.1
22	12.2	11.2	11.3	12.5	14.1	16.8	19.3	21.6	22.0	20.2	17.0	14.0
23	11.4	10.4	10.5	11.6	13.1	15.7	18.2	20.4	20.9	19.1	16.0	13.1
24	10.8	9.8	9.9	10.9	12.4	15.0	17.3	19.5	20.0	18.3	15.3	12.4

To facilitate the ventilation for cooling, wind is necessary at almost all times in summer, morning to evening in autumn and noon to evening during spring months. From the analysis attained cooling in summer and autumn can be assured by having openings towards east, south-west, and south. Morning wind comes from east, afternoon wind comes from south-west and night wind blows from south direction. In spring, south-west wind needs to be secured for noon to evening cooling. In winter, cold wind coming from north and west needs to be blocked as outdoor temperature is already below the comfort level.

DESIGN RECOMMENDATIONS FROM MAHONEY TABLES

The Mahoney tables (Koenigsberger, et al., 1973) provide results of thermal comfort analysis using primarily temperature and humidity, and make recommendations for pre-design guidelines. Combination of temperature and humidity helps to identify the thermal stress conditions i.e. *comfortable*, *hot* and *cold,* for mean temperatures within, above and below the thermal stress comfort limit, respectively. Once the local climatic conditions have been analyzed and the indoor comfort limits classified, remedial actions or strategies are suggested to arrive at acceptable pre-design conditions for better 'indoor' climate. The Mahoney tables involve six indicators i.e., three humid indicators and three arid indicators. The Mahoney tables indicate remedial action involving air movements for humid conditions. Excess downpours may affect the building structure, so adequate rain protection is also advised. Similarly, for hot and arid conditions, thermal capacity is one of the options for making the indoor space comfortable. Climatic zones with nighttime temperature above the comfort limit are advised to make a provision for outdoor sleeping. An arid climate with lower temperature needs protection of the building from cold wind.

The design specifications from Mahoney tables which are very useful for architects and planners in the initial building design stages for Perth are:
Layout: A building will benefit from winter solar radiation for heating if it is oriented on north and south axis (long axis on east-west).
Spacing: Compact layout of estates with adjoining houses for mutual sheltering.
Air movement: Mahoney tables suggest air movement if there is high level of humidity. Perth has got humidity in comfort range so air movement is provisional.
Openings: Small openings with 15 – 25% of wall area are enough to maintain ventilation without substantial heat gain through openings.
Position of openings: Openings should be in windward side at body height and also in the internal walls to facilitate ventilation in the rooms on the leeward side of the prevalent wind flow.
Protection of openings: Openings should be protected from sun in overheated period in summer and also from rain.
Walls and roofs: Extreme diurnal temperature variation and heating requirement in the evening and at night time needs heavy external and internal walls and roofs with time lag of more than eight hours
Outdoor sleeping: Summer months need provisions for outdoor sleeping
These preliminary recommendations are further elaborated combining wind, solar radiation and rainfall parameters to come up with design strategies specifically for Perth.

DESIGN STRATEGIES

The design strategies are formulated considering the comfort analysis and preliminary recommendations from Mahoney tables. Design strategies are meant to be comprehensive and schematic in helping the design process so that no major opportunities are missed, at the same time, they have to be few such that they can be easily memorized.
Following are the specific design recommendations for Perth:

Street layout

Orientation and layout of streets have significant effects on accessing sun and wind in buildings. To maximize cross ventilation and air movement in streets, primary avenues in Perth should be oriented towards 25 degree west of south. It helps to secure both prevailing afternoon wind and night breezes in summer; and winter solar exposure on the north facade. Major street orientation within the angle of approximately 20-30 degree on either direction of the prevailing breezes is highly recommended (Brown and DeKay, 2001).

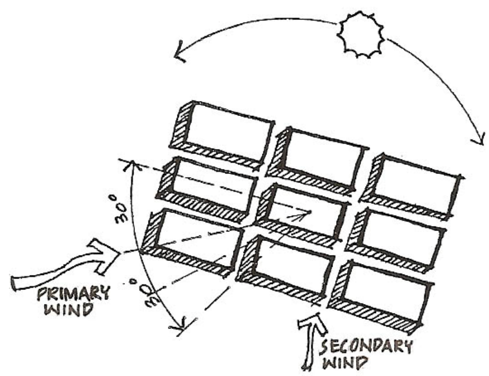

Fig.10. Street layout considering sun and wind movement

(Source: Brown and Dekay, 2001, *modified*)

Securing neighborhood sunshine

Buildings in Perth require solar radiation in winter months. An ideal organization of streets, open spaces, and building for solar utilization at maximum density is to elongate buildings in the east – west direction and spacing in the north – south direction. This placement allows buildings facing north to collect sun, and they are far enough apart not to shade each other. However, because of the topography or pre-existing conditions, many streets do not have an east west orientation so the figures 11, 12 and 13 show several variations in buildings and open space layout, along with their implication for solar access.

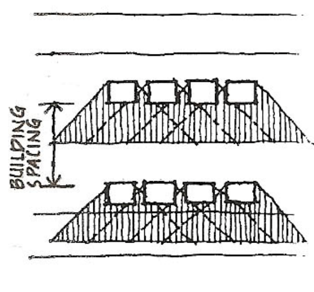

Fig.11. East –west lot arrangements

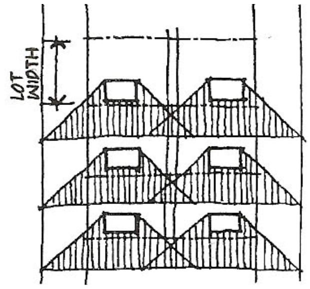

Fig.12. North –south lot arrangements

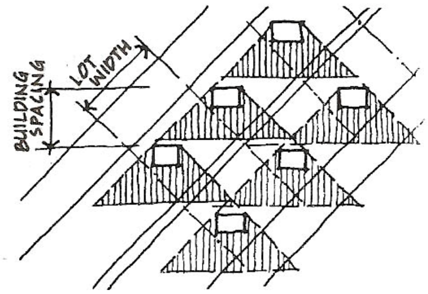

Fig.13. Non cardinal streets, lot arrangements

(Source: Brown and Dekay, 2001, *modified*)

Building orientation

In Perth, building should be oriented to maximize solar access in winter months and to facilitate wind flow in summer months. Building running long on east – west axis with 25 degree orientation towards east of north ensures winter solar access and is able to cut off unwanted solar gain in north façade during summer months. This orientation angle facilitates both afternoon and evening wind flow across building.

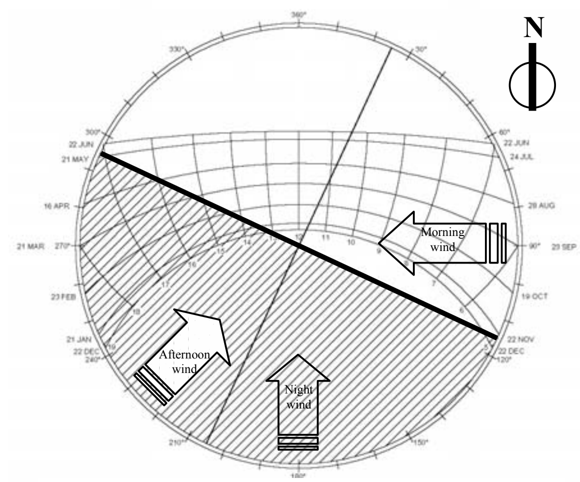

Fig.14. Building orientation ensuring solar access in winter and wind movement in summer

Building structure

Perth requires cooling in summer months and heating in winter months. The large range of thermal conditions requires utilization of both radiation and wind effects, as well as, protection from them. Hence, dual role is required of the structure. Thermal mass helps to store daytime heat during the day and release it at night to balance room temperature in winter months. Thermal mass can be used to absorb heat from a room during the day and to cool off the radiated heat at night with ventilation in summer months. For this, there must be enough mass in the building to absorb the heat gains, and the mass must be distributed over enough surface area so that it can absorb the heat quickly and keep the interior air temperature comfortably low. The opening must be large enough to allow cool outside air to flow past the mass to remove the heat accumulated during the day and carry it outside the building.

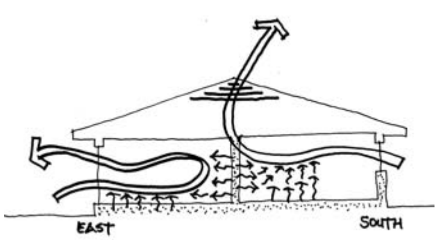

Fig.15. Effective ventilation helps to cool off thermal mass in summer

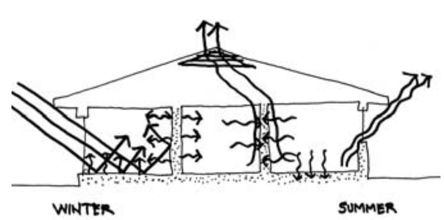

Fig.16. Use of thermal mass in winter and summer months

Roof design

Summer horizontal solar radiation is very high in Perth and longer hours of sunshine impart maximum heat flux from roof. Double roof with outer layer lightweight, highly reflective surface, insulated from inside, helps to keep the heat out from entering the building envelope. Ventilation between two layers will dissipate the heat trapped in the gable space. Slope roof is beneficial to collect rainwater and also to provide shade for windows and protection from rain.

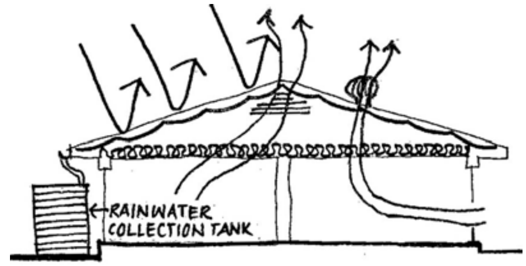

Fig.17. Roof design

Windows and ventilation

Ventilation during daytime in summer must be kept to the minimum, as the outside air is hot and dry; but good cross ventilation is preferable at night. Medium sized openings are needed to ensure good cross ventilation during summer and to permit the penetration of sun in winter. Windows should face north and south to prevent low angle sun and the openings on these directions also help to facilitate night cooling breezes moving inside the building. Building should be preferably single banked; if double banked, adequate provision must be made for good cross ventilation.

Fig.18. Arrangement of openings for wind flow in a double banked building

(Source: Brown and Dekay, 2001, *modified*)

Outdoor spaces

In summer months, outdoor spaces towards south are very useful as prevailing evening breeze comes from south west in Perth. Outdoor sleeping is recommended in Perth for two months in summer. Winter months require sun tempering as daytime temperature remains below comfort range. Outdoor space towards the eastern part of a building, securing solar access from north and protecting it with westerly breezes is very useful.

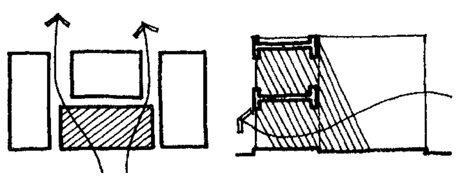

Fig.19. Location of outdoor space for summer

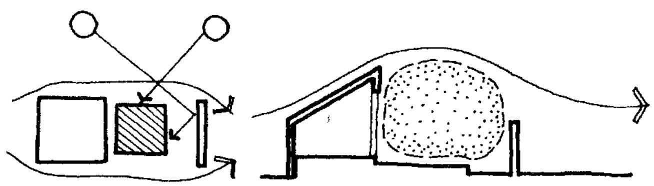

Fig.20. Location for outdoor space for winter

(Source: Brown and Dekay, 2001, *modified*)

Shading devices

Shading devices are required on the openings to protect from extreme solar radiation during summer months, but these devices should let in winter radiation in a living area. Vertical and horizontal shading devices can be used for the purpose. Deciduous trees can also be good for shading, allowing winter sun to the living areas but blocking the summer sun. In Perth, prevailing summer wind comes from south –west so north façade can be effectively shaded by plantations.

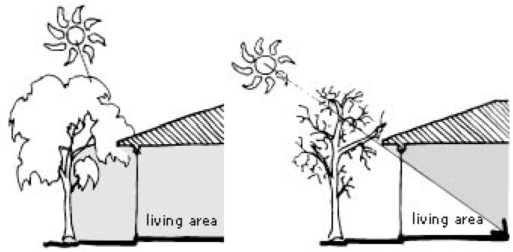

Fig.21. Shading arrangement by a tree

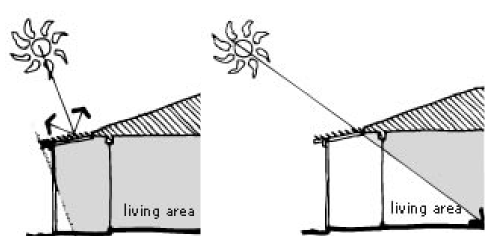

Fig.22. Shading arrangement by trellis

(Source: Your Home Technical Manual, 2005)

Courtyard option

Courtyard arrangement is an option for shading in summer and protection from cold winds in winter. Inward looking layout can benefit from microclimatic advantages. In summer months, courtyard with water feature helps in cooling the surroundings.

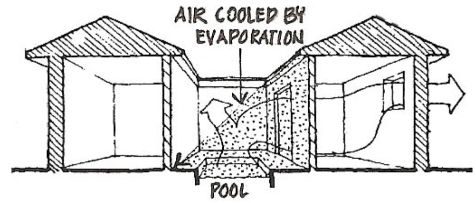

Fig.23. Summer cooling with pool in the courtyard

(Source: Your Home Technical Manual, 2005, *modified*)

CONCLUSION

Climate has an obvious impact on building design and planning. Energy efficient and sustainable design practice should be able to integrate the natural energies (i.e. solar radiation and wind) as parts of its design features. Consideration of the climate starting as early as, in layout of the streets, allocation of building lots, orientation of buildings and in day to day operation of the building, helps to maximize the use of natural energy to achieve comfort conditions. This study reveals specific planning and building design ideas for Perth which can make use of natural energies to achieve comfortable living condition in a building. Winter and nighttime heating can be met by incorporating solar energy and use of thermal mass while summer cooling can be achieved with the use of cool breezes. Wind direction at different time across seasons help designers/ urban planners to orient building and openings to catch the cooling breezes.

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