Maximising the sun

1. Introduction

South Africa is blessed with some of the best quality solar radiation in the world (Figure 1). In the light of this many exciting opportunities exist to utilize the sun to its full potential in the design of energy efficient buildings. Passive solar buildings aim to maintain interior thermal comfort throughout the sun's daily and annual cycles whilst reducing the requirement for active heating and cooling systems. Passive solar building design is one part of green building design and does not include active systems such as mechanical ventilation or photo voltaic cells.

The opportunities for passive solar building design has as a scientific basis a combination of climatology, thermodynamics (especially heat transfer) and human thermal comfort for inhabitable buildings. Specific attention should be paid to the site and location of the dwelling, the prevailing climate, design and construction, solar orientation, placement of glazing and shading elements and incorporation of thermal mass where appropriate. Whilst these factors can be used in any building the ideal solution requires careful quantification and integration of abovementioned principles. In previous articles the advantages of computer simulation and virtual building performance prediction has already been explored to improve building design.

This article aims to concentrate on solar radiation, explore the various methods and quantify the benefits that might be gained in the appropriate use of these methods.

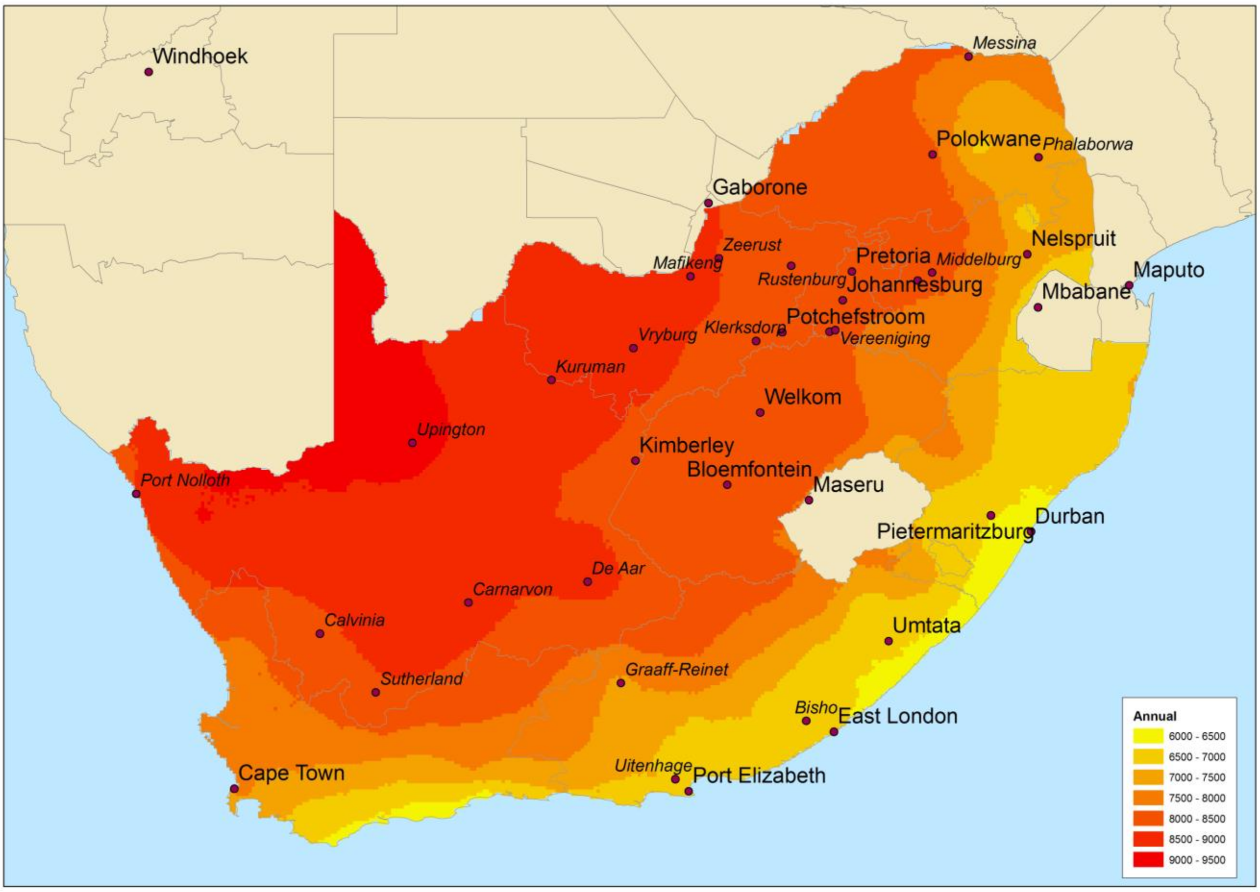


Figure 1: Annual incoming direct plus diffuse solar shortwave radiation received on a horizontal surface in South Africa. (MJ/m²/yr) (CSIR, 2010)

2 Solar position

2.1 Solar movement

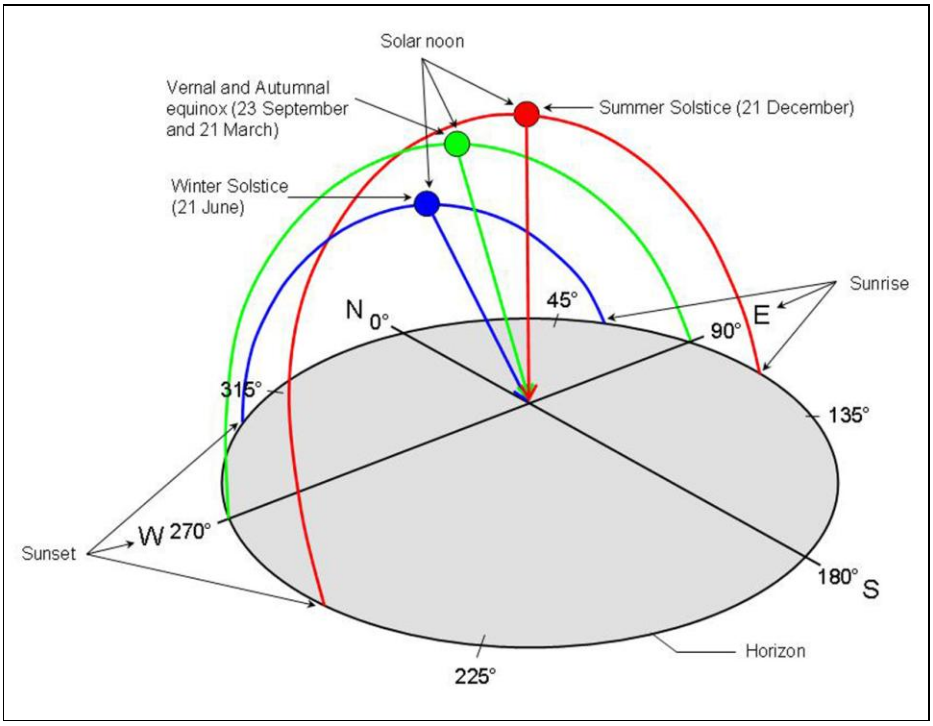


Figure 2: Sun's apparent path in the sky during different seasons (Pretoria) (Author)

Before discussing building solar design considerations and simulations, it is important to have an understanding of the path followed by the sun in its daily and annual movement across the sky. The sky can be conceived as being a hemispherical shell covering the plane on which we stand (Figure 2). The sun, during the course of a day follows a circular arc which is symmetrical about the vertical plane running north and south through the observing position. At solar noon, the sun occupies its greatest altitude for the day. Between the Vernal Equinox and Summer Solstice the sun rises south of east and sets south of west in Pretoria. On the equinoxes (Vernal and Autumnal) the sun rises exactly east and sets exactly west. From the Autumnal to Vernal Equinox the sun rises north of east and sets north of west.

It must be noted that the time of solar noon, when the sun is at its greatest altitude, is different to Universal Time. In common civil usage, UT refers to a time scale called Coordinated Universal Time (UTC), which is the basis for the worldwide system of civil time. This time scale is kept by time laboratories around the world, including the U.S. Naval Observatory, and is determined using highly precise atomic clocks. The International Bureau of Weights and Measures makes use of the data from the timing laboratories to provide the international standard UTC which is accurate to approximately a [1]nanosecond (billionth of a second) per day. Universal Time (UT) is therefore a special averaged clock timescale originally based on the rotation of the earth. It is a modern continuation of Greenwich Mean Time (GMT), i.e., the mean solar time on the meridian of Greenwich. GMT is sometimes used loosely as a synonym for Coordinated Universal Time **(**UTC) (Wikipedia, 2010). The South African time zone has a 2h00 offset from UTC, i.e. it is 2h00 ahead.

To relate solar time and clock time involves two time corrections. Firstly, there is a correction of a constant amount, which depends on the longitude of the site. It is determined by allowing one minutes of time for each quarter degree difference in longitude between the longitude of the site and longitude 30° east (in South Africa). It is subtracted from standard time if the longitude of the site is less than 30° east and it is added if the longitude is greater than 30° east.

The second correction, known as the equation of time, varies cyclically from day to day. This is due to the non-uniformity in the movement of the earth along its orbit around the sun. Figure 3 below illustrates the equation of time for 2010.

Besides its daily movement, the sun has a second apparent motion, which the observer will only notice as day follows day and the sun is seen to travel along slightly different planes each day. Within a period of a year the sun slowly moves between the winter solstice and summer solstice points through an angle that is double the earth's axial tilt (discussed below). The angular difference of the sun from the celestial equator at

[1] The length of a UTC second is defined in terms of an atomic transition of the element cesium under specific conditions, and is therefore not directly related to any astronomical phenomena. (USNO, 2010).

any time is termed the sun's declination. The celestial equator is an extension of the earth's equator onto the hemispherical shell mentioned above. (Figure 5).

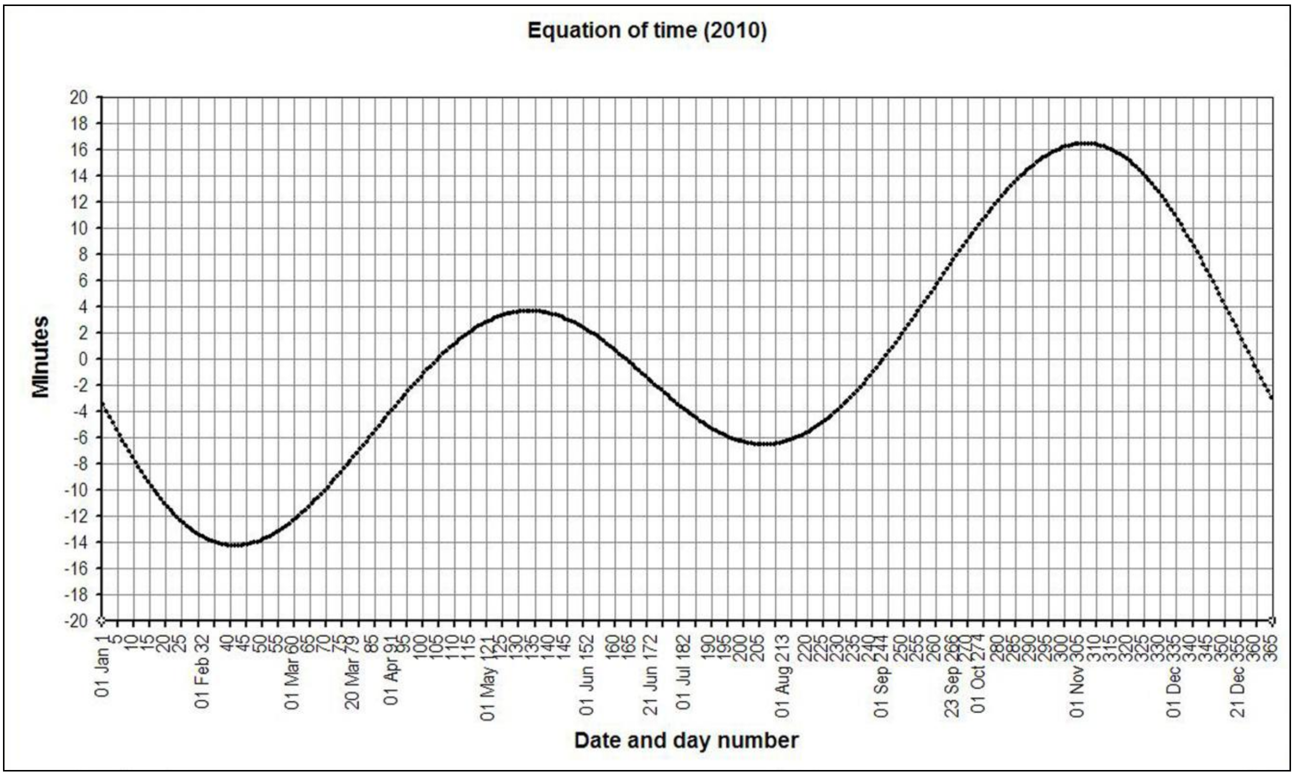


Figure 3: Equation of time calculated for 2010 (Author)

The angle of the Earth's axial tilt (obliquity) varies with respect to the plane of the Earth's orbit. These slow 2.4° obliquity variations are roughly periodic, taking approximately 41,000 years to shift between a tilt of 22.1° and 24.5° and back again. At the moment the earth axial tilt or obliquity (ε) is 23° 26' 21.4119" or 23.43928108° as defined by the International Astronomical Union in 1976 for epoch [2]J2000.0. Different sources give slightly different angles, because different algorithms are used to calculate it, however this will not make a significant difference in architectural design.

When the obliquity increases, the amplitude of the seasonal cycle in insolation (incoming solar radiation) increases. In this case summers in both hemispheres will receive more radiative flux from the Sun, and the winters less radiative flux. (Wikipedia, 2010) The tilt is currently in the decreasing phase of its cycle, and will reach its minimum value around the year 10,000 A.D. or Common Era (C.E.). In addition to this steady decrease, there are also much smaller short term (18.6 years) variations also affected by Sun's gravitation in its depleting angle relative to Earth's, known as nutation. (Payne-Gaposchin, 1970)

In the past manual methods have been used to calculate the solar position. On the basis of this the shade position and extent could be determined for a particular instant in time. (CSIR, 2004). With the advent of sophisticated 3D Building Information Modeling (BIM) packages such as *Revit,* building analysis packages such as *Ecotect* and numerous websites such as NOAA making available on-line accurate solar position calculators it is recommended that this rather be used. With software support the amount of overshadowing and the daily or yearly extent of shadows can be very accurately calculated.

[2] The point at which the Sun crosses the equatorial plane moving from south to north 12h00 hours Terrestrial Time on 1 January 2000. (IAU, 2010)

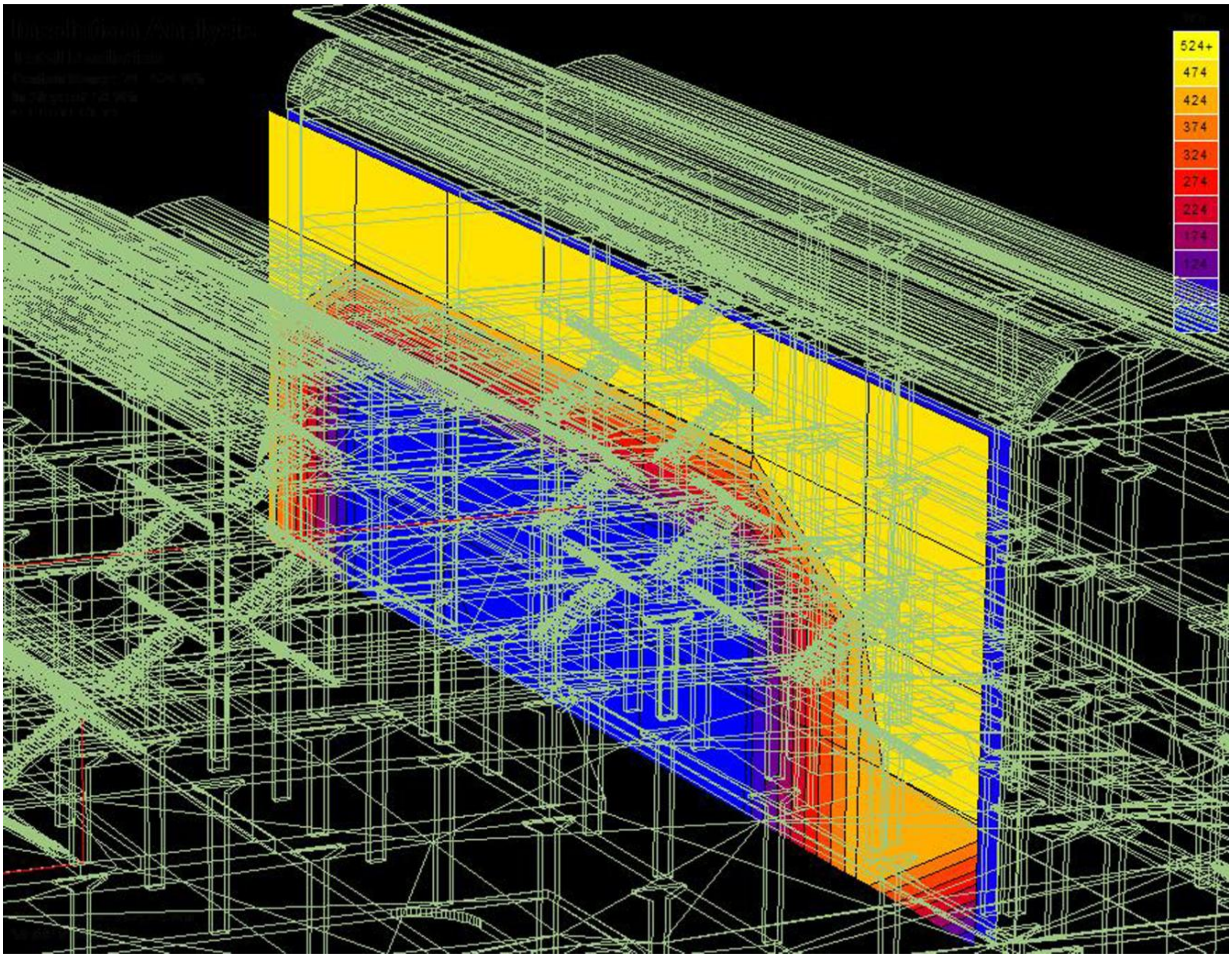


Figure 4: Insolation calculation performed for University of Fort Hare building in East London for Winter Solstice between 11h30 and 12h30 (Solar noon) (Author)

Furthermore advanced insolation (Figure 4) calculations can be performed that take account of overshadowing of other buildings. This is very time consuming if not almost impossible by hand. The specific latitude is important for solar angle calculation and the longitude to determine the time offset from the standard meridian in order to relate solar time to clock time. In South Africa the standard meridian is 30° west. The most convenient and accurate way to obtain a building’s latitude and longitude as well as the specific site or building orientation (azimuth) is by using Google Earth.

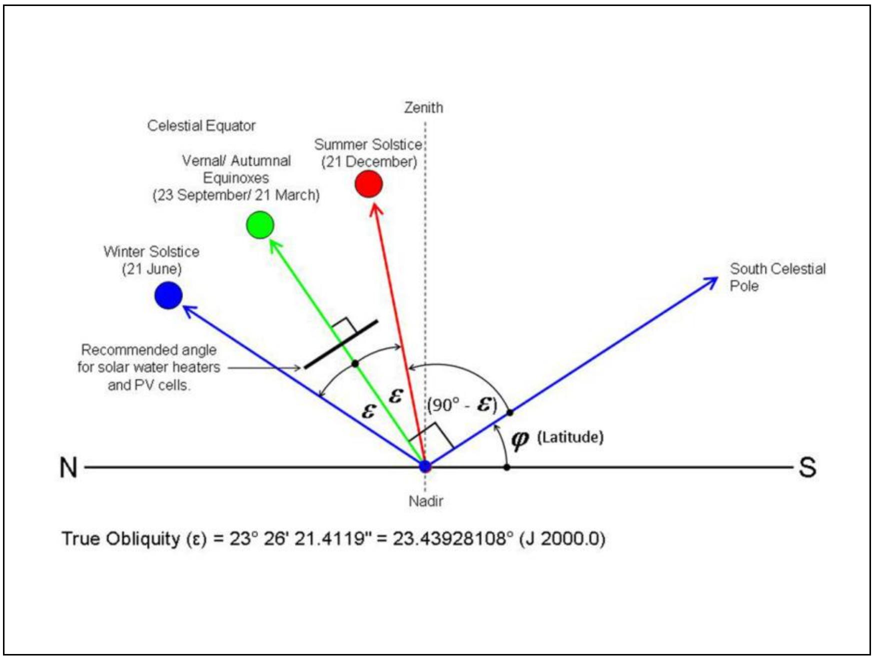


Figure 5: Calculation of solar angles at solar noon. The equinox angles are the same as the celestial equator. (Author)

It is recommended that equipment using solar radiation such as solar water heaters and photo voltaic cells be mounted north facing with an angle equivalent to the latitude as indicated in Figure 5. The reason for this is to favor the weaker winter sun. Solar water heaters are not particularly sensitive to solar angle (see Angle of incidence), however Photo Voltaic cells require more accurate positioning. Some publications recommend for stand alone PV systems, where winter operation is crucial, to use the latitude angle plus 15°, thus favoring the winter sun. In the case of grid connected systems an angle of latitude minus 10° to maximize the amount of energy produced annually. Before deciding on an angle it is in all cases it is recommended to follow a rational approach. (Department of Climate Change and Energy Efficiency, Australia, 2010) Another method is to use adjustable angle frames to maximize annual output.

2.2 Angle of incidence

When radiation from the Sun strikes the surface of an object at a normal angle, the energy density per unit area will be much higher than if the radiation struck from an oblique angle. This effect can be calculated using the cosine law, where the radiant energy from the Sun is multiplied by the cosine of the incidence angle.

The incidence angle is always calculated relative to the surface normal of each plane. Radiant energy density is at its maximum at normal incidence when the incidence angle approaches zero. It is at its minimum at oblique incidence when the incidence angle approaches 90°.

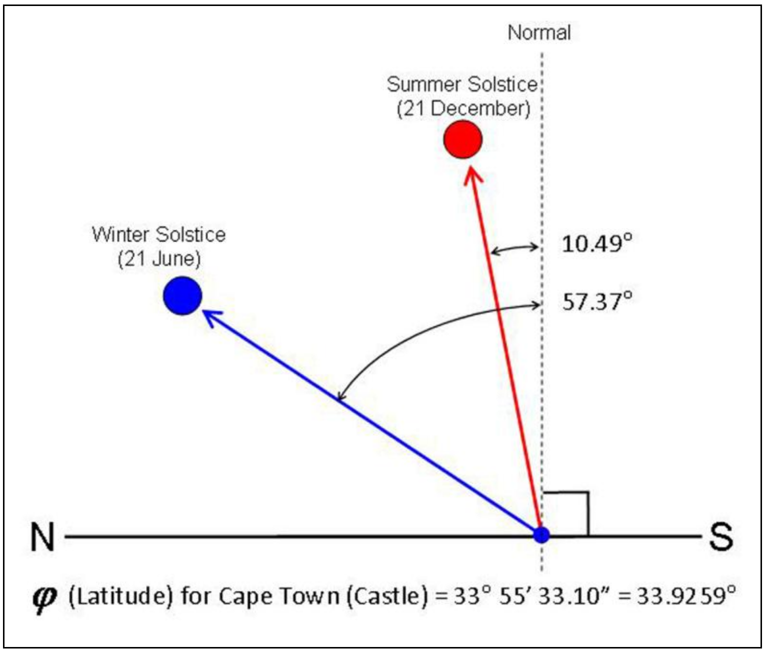


Figure 6: The difference radiation for Winter and Summer Solstice in Cape Town (Author)

Consider Figure 6 above with Cape Town as an example. At solar noon on 21 December when the radiation is at an angle of 10.49° to the normal incidence 98.32% (cos(10.49) of the energy would be imparted to the surface. However at solar noon, on 21 June when the radiation is at 58.37° to the normal, only 53.92% (cos(57.37) would be imparted to the surface. It follows that at 0° cos(0) it would impart 100% and at 90° it would impart 0% (cos(90)) as it no longer strikes the surface at this oblique angle.

3 Orientation

The orientation and spacing (Holm, 2007) of buildings has a direct impact on the energy requirements and availability of natural daylight and shade (CSIR, 2004). Good orientation reduces the need for auxiliary heating and cooling. If possible choose a site or home with good orientation for the particular climatic conditions. The SANS 204 norm gives normative examples (Figure 7) of the effect of orientation on energy consumption for six South African cities in comparison to the optimal True North orientation. (SANS 204, 2008).

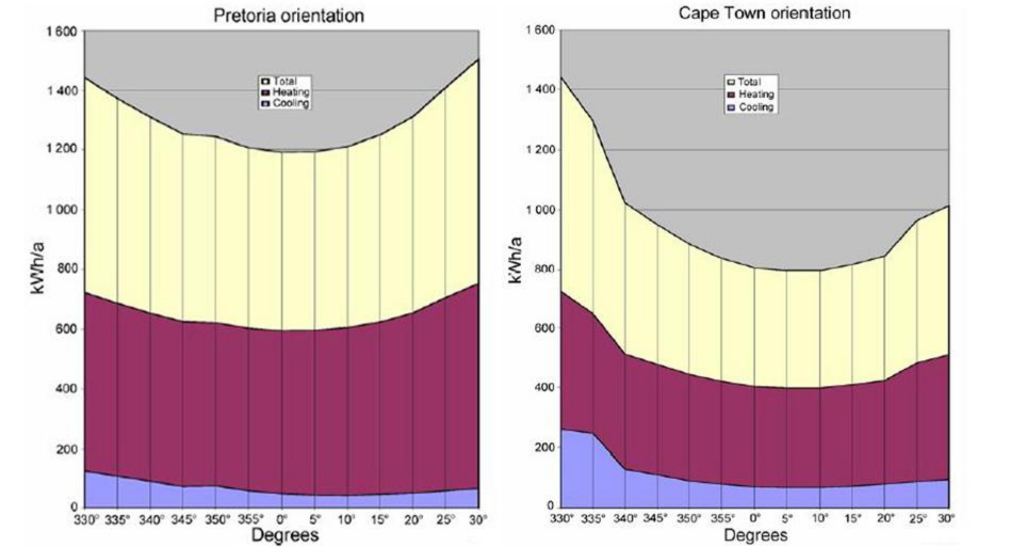


Figure 7: Optimal orientation True North +15° E and -10° W for Pretoria and +20° E and -8° W for Cape Town (SANS 204, 2008)

When the designer decides on the best orientation for specific rooms in a building it is recommended that the operational hours of the building and also the use of the various individual spaces are considered. For example primary schools in South Africa operate during first half of the day. In this case an orientation east of north might be better to ensure that the classrooms heat up sooner in winter. The designer should clearly define the aims with regards sun and shade and then act according to the results and indications of simulations.

In high humidity climates and hot dry climates with no winter heating requirements the orientation should generally aim to exclude sun year round and maximize exposure to cooling breezes. In all other climates a combination of passive solar heating and passive cooling is required. The optimum degree of solar access and the need to capture cooling breezes will vary with climate.

Orientation for passive heating is about using the sun as a source of free building heating. The basic aim is to let winter sun in and exclude unwanted summer sun. This can be done with relative ease on northern elevations by using shading devices to exclude high angle summer sun and admit low angle winter sun. The other elevations especially east and west require a different approach.

4 Shading and glare

4.1 Solar protection methods

Figure 8: Typical office building being built within the last decade in Pretoria with good northern solar protection. (Author)

Many different traditional shading methods exist for reducing the effects of the sun's glare, such as lattices, pierced screens as used at the Tāj Mahal and blinds of split bamboo as used in Japan. These are shades used outside the windows that are similar in effect to interior venetian blinds and louvre drapes. The French architect Le Corbusier made the name brise-soleil (French: break-sun, from *briser* to break + *soleil* sun) popular when he developed the idea of a sun-breaker first proposed for the Durand project in Algiers in 1933. (Encyclopedia Britannica, 2010). Oscar Niemeyer also used brise-soleil extensively. A good example is the Yacht Club in Belo Horizonte built in 1940. The west facade is protected by Brise-soleil, designed in two bands one above the other and on several levels, showing the versatility that this architectural element allows. (Figure 9)

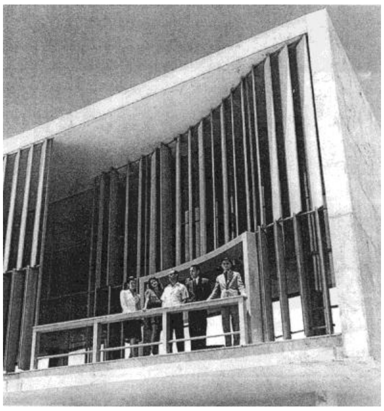


Figure 9: Oscar Niemeyer's use of brise-soleil at Belo Horizonte Yacht Club in 1940. (wikiarquitectura, 2010)

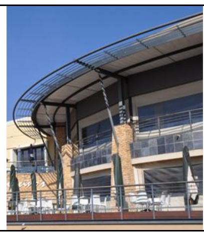
Appropriate shading of the building and outdoor spaces reduces summer temperatures, improves comfort and saves large amounts of energy. Direct solar radiation in South Africa can generate the same heat as a mobile gas fired heater per m². (1 000 w/m²). Shading can block a large percentage of excess heat when used correctly. An exploratory survey of new and older buildings in Pretoria indicates that architects understand the need for solar protection, but in many cases are not applying the correct measures for the different elevations of the buildings or failed to quantify the desired effect. For example many instances have been noted where horizontally projected fixed shading is used on the eastern and western facades (See

Table 1, north example) where this measure will not be entirely effective especially with the low solar angles from these directions (Department of Climate Change and Energy Efficiency, Australia, 2010).

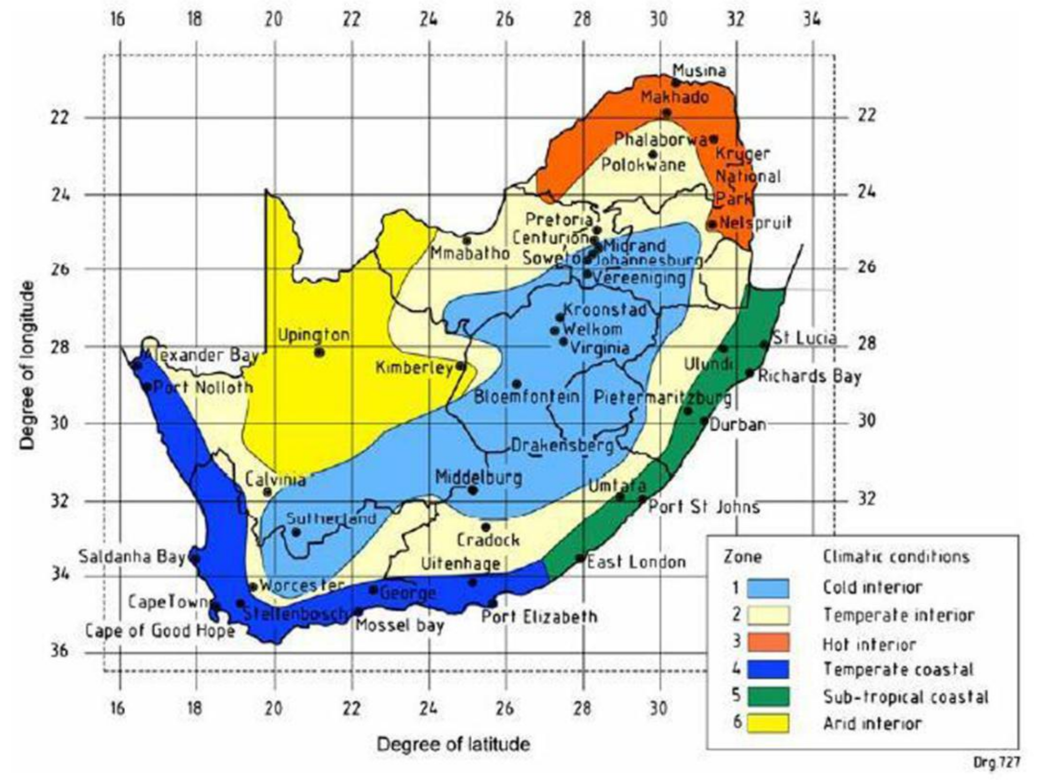
Radiant heat from the sun passes through glass and is absorbed by building elements and furnishings, which then re-radiate it. Re-radiated heat has a longer wavelength and cannot pass back out through the glass as easily, also known as green house effect. In most climates, trapping radiant heat is desirable for winter heating but must be avoided in summer. (Department of Climate Change and Energy Efficiency, Australia, 2010)

Shading requirements vary according to climate and house orientation. A general rule of thumb is described in the table below:

Table 1: Suggested shading type for different orientations. (Department of Climate Change and Energy Efficiency, Australia, 2010)

Orientation	Suggested shading type	Examples
North	Overhangs, fixed or adjustable shading placed horizontally above window, perpendicular to the façade or projecting horizontally from the façade.	 
East and West	Adjustable vertical or horizontal screens outside the window or façade and mounted in the same plane.	 
North-East and North-West	Adjustable shading.	
South-East and South-West	Planting.	

4.2 Windows and solar exposure



1	2	3
Zone	**Description**	**Major centre**
1	Cold interior	Johannesburg, Bloemfontein
2	Temperate interior	Pretoria, Polokwane
3	Hot interior	Makhado, Nelspruit
4	Temperate coastal	Cape Town, Port Elizabeth
5	Sub-tropical coastal	East London, Durban, Richards Bay
6	Arid interior	Upington, Kimberley

Figure 10: Climatic zone map (SANS 204-2, 2008)

The SANS 204-2 (2008) standard recognizes six main climatic regions in South Africa (Figure 10). The chapter about fenestration in said norm provides a detailed description of the calculation of conductance and solar heat gain for glazing elements supported by extensive look-up tables and diagrams.

For each of the six climatic zones tables are provided that gives the solar exposure factors and coefficients (SHGC) for various overhang/ height (P/H) factors for eight main orientation sectors. The standard is very useful for initial desktop calculations. It is clear from SANS 204-2 (2008) what the beneficial impact of fenestration design in combination with appropriate sun protection could be. This should be quantified with more detailed calculations preferably with simulation software once the designer has determined the sun protection devices that will be used.

5 Conclusions

In general South Africa and Pretoria specifically has high quality sunshine and solar radiation as well as a good climate. Many exciting opportunities exist to use the sun in the design of energy efficient buildings using the leitmotiv of the past in a modern context and supported by modern simulation software.

A photographic excursion indicated that architects are aware of sun protection measures, but are in many cases did not pay enough attention to the design not using it correctly.

Advanced software products make it now far easier to qualify and quantify the effect of a particular building design before construction. Simulation makes it feasible to test various design scenarios or research hypotheses. A good understanding of the basic principles will lead to far better “sun aware” architecture.

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