Sun and shade

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1.0 Introduction

South Africa is blessed with some of the best quality sunshine in the world but at the same time has some of the most intense solar radiation. There are therefore many exciting opportunities to utilize the sun to its full potential in the design of energy efficient and comfortable buildings. Previous chapters discussed various sun related aspects such as possible corrective actions in a very hot naturally ventilated office during the hottest summer in Pretoria (Conradie, 2016b), the optimisation of daylight in South Africa, the general weak thermal performance of fenestration (Conradie *et al*., 2015a), the use of glass in buildings (Conradie *et al*., 2015a), maximising use of the sun (Conradie, 2011) and passive design strategies (Conradie, 2013). Some of the articles were qualitative and others quantitative. There is a general paucity of information with regards the amount of incident solar radiation on the various building surfaces in the different climatic regions, cities and latitudes in South Africa.

Bioclimatic and other analyses of the major cities indicated clearly that appropriate solar protection is the single most important measure in all climatic regions. 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.

This chapter continues on the basis of previous research, mentioned above, to quantify the energy benefits when various solar protection measures are applied to the different (east, north, west and south) and roof in all the climatic regions of South Africa. At the moment it is rather difficult to obtain such quantified information. The article also investigates the changes in solar protection, such as overhang sizes that will be required with an A2 scenario (business as usual) of climate change. An A2 climate change scenario as described by the Intergovernmental Panel on Climate Change (IPCC, 2000) is where the Representative CO_2 Concentration Pathways (RCPs) are set to increase to 950 ppm, from a current basis of 400 ppm, by the year 2100 and even higher to 1 200 ppm after the year 2100. This RCP8.5 scenario corresponds to an energy increase of +8.5 W/m² by 2100. Insights are also provided how the overheated period can be determined when facades and especially windows need to be shaded. The article also touches on different types of solar radiation such as diffuse and direct and different types of shade such as the umbra, penumbra and antumbra. It continues with a discussion how the overhang sizes could be calculated to provide shading at the correct time of day and year.

2.0 Methodology

The purpose of this chapter is firstly to determine the direct solar radiation on the various surfaces (east, west, north, south and roof) of a building in a representative range of cities/ towns (13) in South Africa. As an additional alternative check a bioclimatic analysis is used to quantify the number of hours that sun shading of windows will be beneficial in the various locations. Solar protection measures such as overhangs and vertical fins are then applied to these surfaces to determine the potential benefit. Lastly, as a worked example, the critical solar angles were calculated to achieve better solar control for Pretoria, currently and with an A2 climate change. Urban heat islands (UHI), albedo and shade are also discussed as it is closely related.

To support the solar radiation, bioclimatic analysis and the recommended solar angle calculations detailed weather files were generated with the *Meteonorm* software for 13 cities using typical meteorological years based on measured data. A second set of weather files were generated to quantify the effect of climate change up to the year 2100 using an A2 climate change scenario of the Special Report on Emission Scenarios (SRES) for the period 1961-2100 using the first set as a baseline. An A2 scenario can also be described as Business As Usual (BAU). Recent climatic research indicates that this is unfortunately the most likely scenario for South Africa. Using these weather files a comprehensive bioclimatic analysis was run by means of *Climate Consultant* 6.0 and *Ecotect v5.60* to determine the direct solar radiation and to quantify the potential savings that appropriate solar protection measures will realise. The results are presented in normalized tables to make application more universally applicable.

3.0 Background

Cities contribute significantly to global greenhouse gas emissions and on the other hand are also adversely affected by the effects of climate change caused by these emissions such as the complex problem of UHI effect. At the moment about half of the world's population live in cities. That is likely to increase to 70% by 2050. Cities use as much as 80% of all energy production worldwide (The International Bank for Reconstruction and Development & World Bank, 2010: 15). To address this situation a range of carbon emission mitigation strategies have been developed including:

- Use of renewable energy
- Commercial and residential energy efficiency

- Solar water heater subsidy
- Limits on less efficient vehicles
- Passenger modal shift
- Waste management
- Land use
- Escalating CO_2 tax (Gibberd, 2015)

Three levels of intervention can be distinguished. These are at building, neighbourhood and urban level. Previous research indicated that in a hot country such as South Africa the most important factors at building level are building orientation and solar shading at appropriate times (Conradie, 2016a: 38-41). The general principle is that the sun should help to heat buildings in winter and should therefore be allowed to penetrate the building at this time. However in summer the building and especially the windows should be protected against direct solar radiation. The appropriate use of glass is closely related to the latter. Other factors such as building shape, building depth, insulation, opening areas, air tightness and correct use of mechanical systems are also important. It is also beneficial to use cool roofs and surfaces in its various forms such as green, blue and reflective cool roofs (typically white roofs). At neighbourhood and urban level the use of plants and street trees (Stoffberg *et al*., 2010: 9) are a good method to reduce the UHI due to a combination of shade and evaporative cooling (Stoffberg *et al*., 2010: 9).

Table 1 below indicate the Heating and Cooling Degree Day category that the various cities and towns fall in. Table 1 should be read in conjunction with Figure 1. It also quantifies the number of hours that solar protection will be beneficial, currently and with an A2 climate change scenario. The latter figures were calculated by means of a bioclimatic analysis with *Climate Consultant 6.0* using weather files generated by means of *Meteonorm v7.2.1*. Table 1 therefore provides the baseline for the calculations performed later in the chapter.

Table 1: Quantified benefit of solar protection for various cities and towns in various climatic regions

City/ Town	**Heating Degree and Cooling Degree Day category**[1]							**Solar protection (hours)**	
	1 Medium Medium	**2 Medium Low**	**3 Low High**	**4 Low Low**	**5 Low Medium**	**6 High Low**	**7 High Medium**	**2009**	**2100**[2] **(A2)**
Bloemfontein	■							1214	1899
Cape Town				■				729	1282
Durban					■			1436	2128
East London					■			871	1481
George				■				588	1128
Johannesburg	■							530	1532
Kimberley	■							1560	2165
Port Elizabeth				■				676	1588
Pretoria ForumForum					■			1327	2109
Pretoria Irene	■							963	1999
Roodeplaat					■			1361	2300
Upington					■			2017	2453
Polokwane (Pietersburg					■			1268	2134

[1] See Figure 1 below for the various heating and cooling zones.

[2] Weather files with an A2 climate change scenario as defined by the IPCC (2000) has been used to calculate these values.

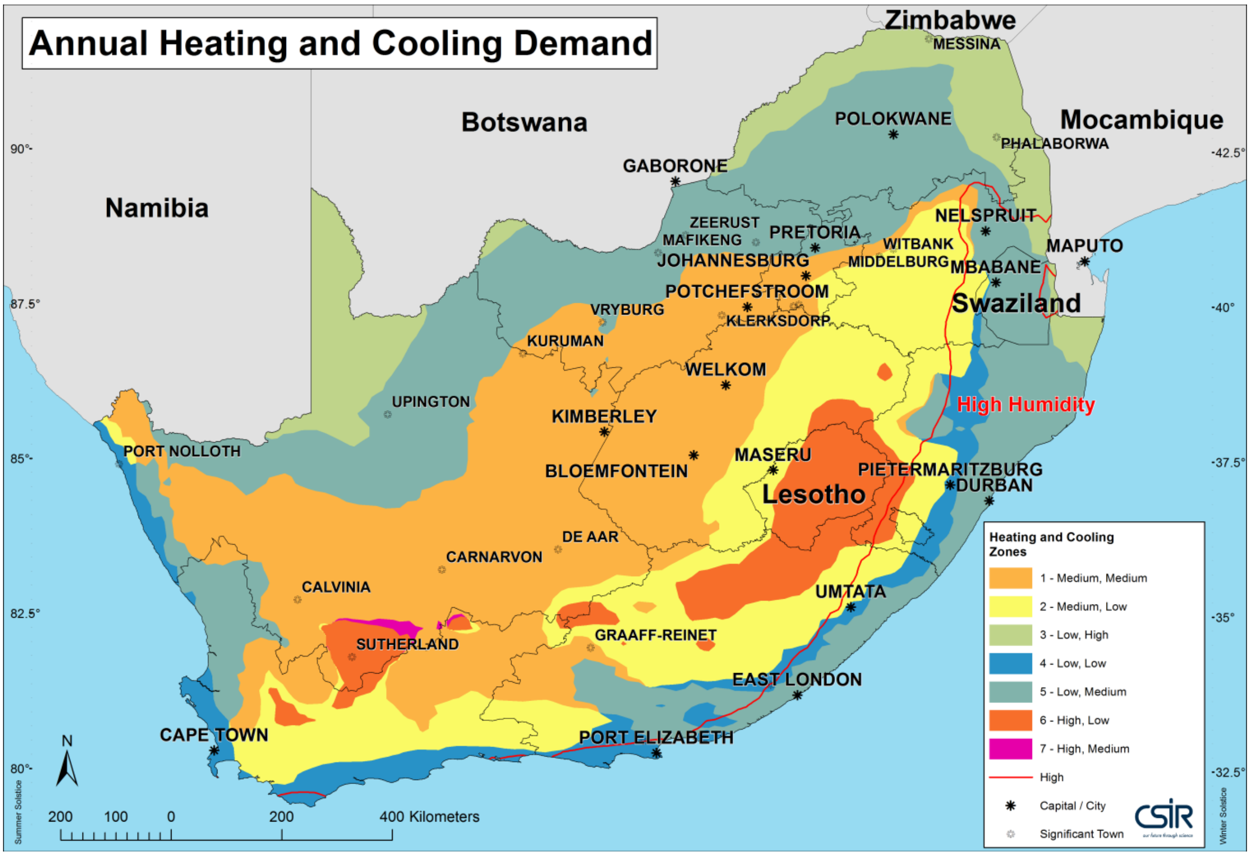


Figure 1: Combined heating and cooling low, medium and high (LMH)-zone map with summer and winter humidity lines for South Africa (Conradie et al., 2015a).

4.0 Urban heat islands

As city inhabitants know, it is quite often hotter in the city than surrounding rural areas. The term heat island is used because the city literally lies in a sea of cooler surrounding rural air. UHIs are caused by the storage of solar energy in the hard urban construction materials that are quite often dark in colour (Table 2) and having a significant heat storage capacity. This energy is released during the night. The UHI effect was first observed by Luke Howard (1833: 2) in his accurate urban climate studies of 1806 to 1830. It is documented in his book *The climate of London*. At this stage Howard (1833: 2-3) had already observed a UHI effect of between 0.816 °C and 0.977 °C in London. The two maps of South Africa, included below, indicate that we are currently beginning to reach these levels. The amount of energy under the urban canopy can be expressed as follows (Howard, 1833: 8)[3]:

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S \qquad (1)$$

Where:

Q^* is the net radiation

Q_F is the heat added by anthropogenic (human) activities

Q_H is the sensible heat exchange

Q_E is the latent heat exchange

ΔQ_S represents energy added to, or taken from, the urban fabric

The net radiation term can be broken up into solar (shortwave) and terrestrial (longwave) radiation.

$$Q^* = K^* + L^* \qquad (2)$$

[3] In the forward of the IAUC edition of Howard's 1833 book.

Research indicates (Sun *et al*., 2014: 174) that the UHI is the strongest at night under calm and clear skies. Under these conditions, those terms requiring turbulence, i.e. (Q_H, Q_E) are at a minimum and there is no solar radiation available. Further, with few exceptions, Q_F is generally insignificant. Under these conditions the formula can be simplified to:

$$L^* = \Delta Q_S \tag{3}$$

Abovementioned implies that when the urban temperature effect is the greatest, it is primarily a product of cooling driven by loss of longwave radiation to the sky which is offset by the withdrawal of heat from construction material storage that was accumulated during the day.

In urban areas, the canopy surfaces (building walls and street surfaces) have limited exposure to the sky and consequently longwave cooling (L^*) at night is significantly reduced. The urban construction materials are also impervious and dense. Such materials have a high thermal conductance and heat storage capacities, that were accumulated during the day and that is available for release at night.

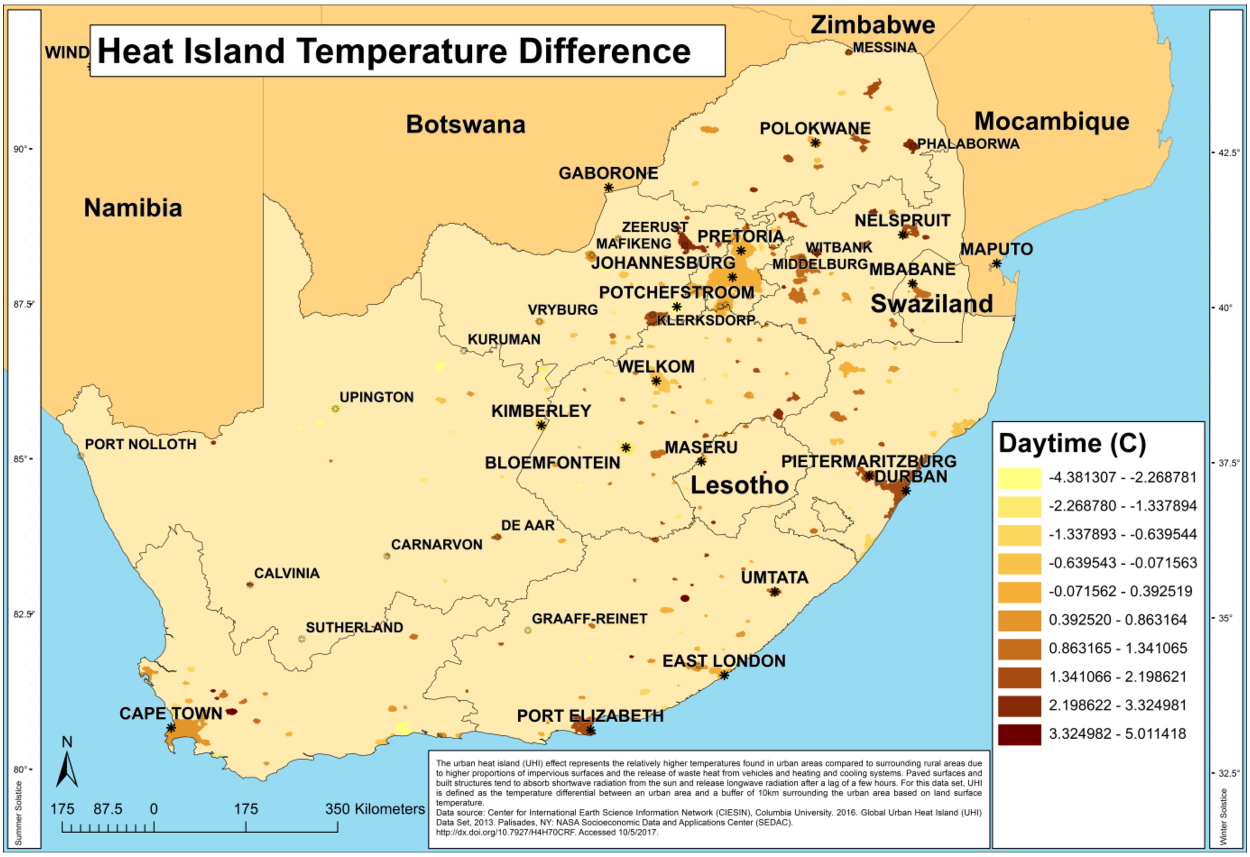


Figure 2: Daytime heat island temperature difference between an urban area and a buffer of 10 km surrounding the urban area based on land surface temperature. (Produced by CSIR based on data from Columbia University, 2016).

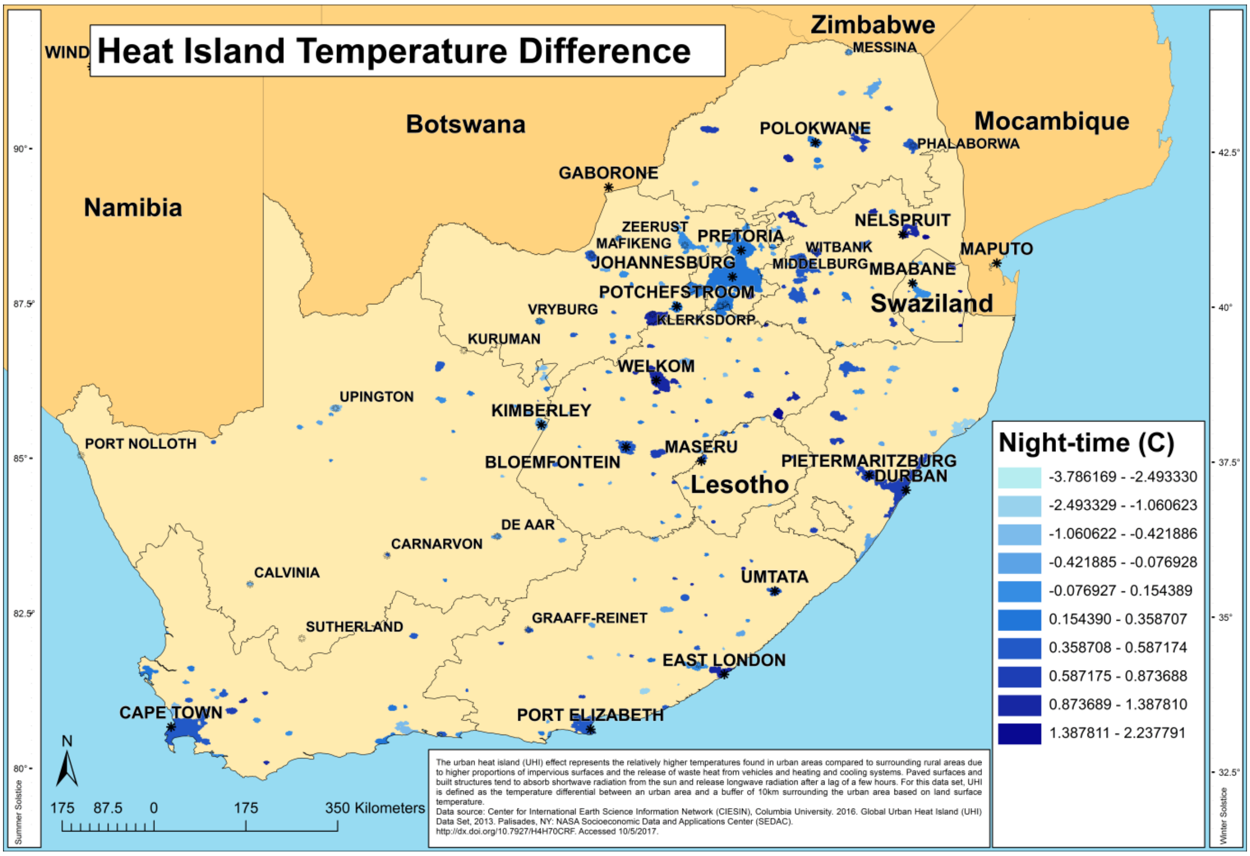


Figure 3: Night-time heat island temperature difference between an urban area and a buffer of 10 km surrounding the urban area based on land surface temperature. (Produced by CSIR based on data from Columbia University, 2016).

Effective strategies that can be used to reduce UHI are cool roofs, green roofs, use trees/ plants and cool pavements or even roads. The use of more plants and trees in streets is a very effective measure to reduce local exterior temperature with the combination of shade and evaporative cooling. (Van Hove *et al*., 2014: 52-53).

5.0 Albedo

Albedo greatly affects the amount of diffuse radiation that will penetrate windows if buildings are surrounded by lightly coloured highly reflective surfaces. This could render carefully calculated solar protection devices less effective. It is therefore important that buildings are surrounded by surfaces of appropriate albedo and heat storage capacity. Albedo is also one of the most significant factors affecting pavement induced UHIs. Several studies have shown albedo's significant effect on air temperature and building energy usage. Albedo depends on the optical properties of the material constituents of the surface layer of the pavement, which can change over time or with additives (Sen *et al*., 2016).

The albedo can be calculated by means of an albedo meter such as a commercially available *Hukseflux* meter*.* Essentially it consists of two light meters, the one points upwards and the other downwards. The equipment measures the difference between the incident and reflected light from the surface being measured. This equipment is rather expensive and not readily available. An alternative method to measure albedo is to use a digital camera or smartphone to take a photograph of the surface together with a reference surface of known albedo such as an A4 sheet of white paper. This method has been described by Gilchrist (n.d.).

The author calculated the albedo values of ten common surfaces below (Table 2) by means of the integral digital camera in a smartphone. A standard A4 sheet of white office paper of known albedo (0.65) was placed alongside the surface to be measured (Gilchrist, n.d.). In formula (5) this is the factor used to calculate the absolute albedo. A photograph of both surfaces (office paper and surface to be measured) was then taken and loaded onto a computer. The *ImageJ* software available from the https://imagej.nih.gov/ij/ website was used to compare the light and dark halves of the image. The following calculations were done:

$$Albedo_{rel} = \frac{B_{unknown}}{B_{reference}} \qquad (4)$$

Where:

$B_{unknown}$ is the average brightness of an unknown surface

$B_{reference}$ is the average brightness of a known reference surface

Once the relative albedo has been calculated the absolute albedo can be determined by means of the following calculation:

$$Albedo_{abs} = Albedo_{rel} \times 0.65 \quad (5)$$

For example to calculate the albedo of a patch of Kikuyu lawn substitute the values as illustrated in Figure 4 into the formula 4.

$$Albedo_{rel} = \frac{58.620}{226.395} \quad (6)$$

Multiply the answer with the known albedo of a piece of white paper to determine the absolute albedo. Please refer to Table 2 where the absolute albedo as used in the example has been listed.

$$Albedo_{abs} = 0.2589 \times 0.65 \quad (7)$$

$$Albedo_{abs} = 0.1683 \quad (8)$$

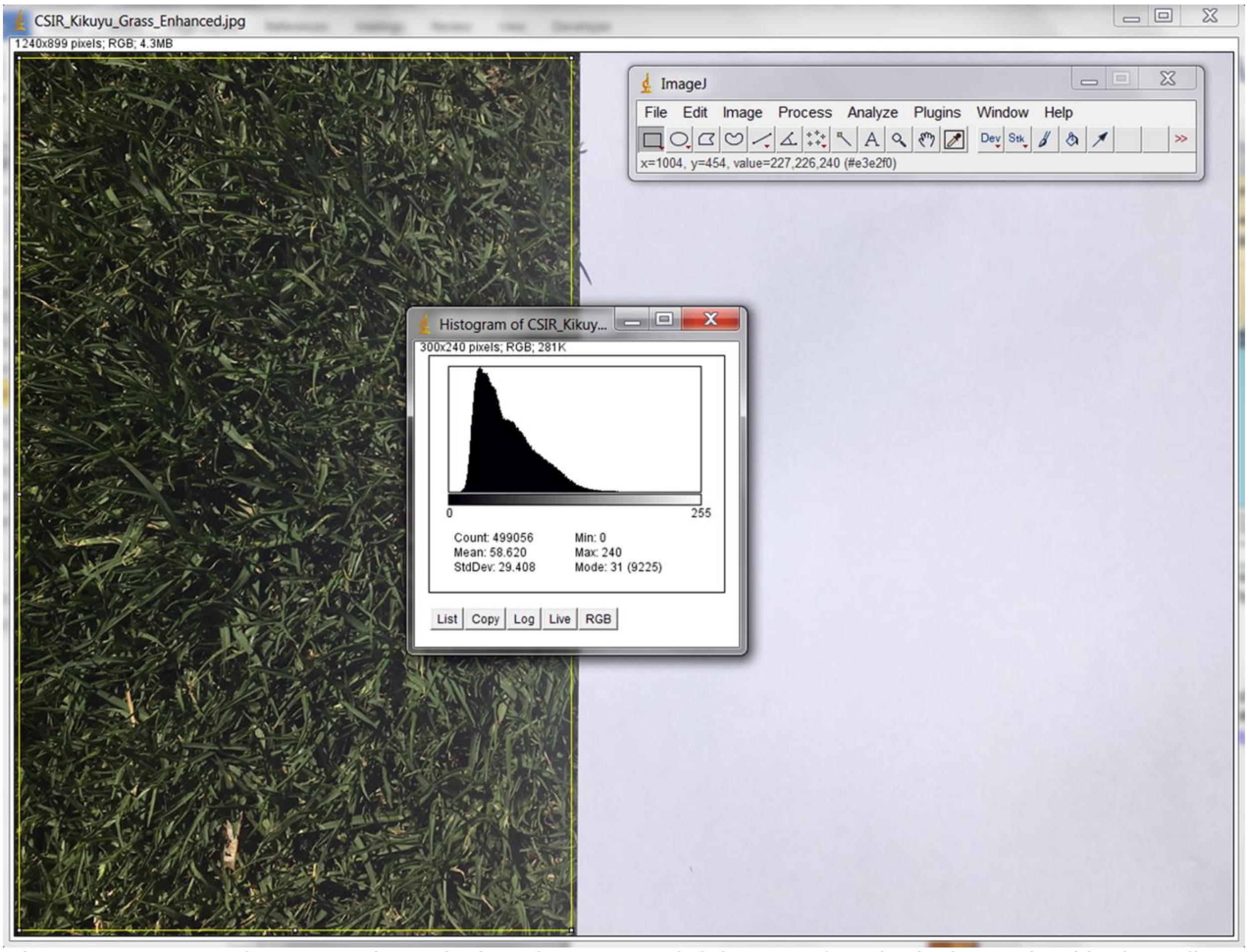
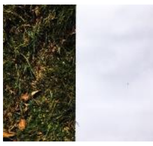
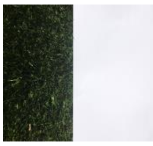
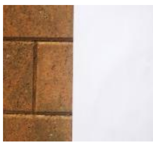


Figure 4: ImageJ software used to calculate the average brightness of each pixel contained in the yellow rectangle.

Table 2: Albedos of some common surfaces (Calculated by Author)

Material	Image	Albedo
Asphalt (Weathered)		**0.2307**
Brick (Nigel Iron Spot rockface)		**0.3206**
Ceramic paving tiles (Light coloured)		**0.4076**
Clay paving tiles (Red)		**0.2249**
Concrete (Weathered)		**0.2930**
Grass (Rough)		**0.1880**
Grass (Pennisetum clandestinum) (Kikuyu)		**0.1683**
Paving (Sand coloured concrete paving)		**0.3134**
Paving (Peach coloured clay)		**0.3217**
Sandy Soil (Red)		**0.2471**

It is interesting to note that although the Kikuyu grass has a low albedo of 0.1683 and therefore absorbs a significant amount of incident radiation, it doesn't heat up itself like the other surfaces that have a high heat storage capacity. Natural surfaces such as vegetation around buildings are therefore a very good way to keep surfaces cool and also avoid secondary indirect reflection causing glare and the transmission of additional heat into buildings.

6.0 The use of shading

One of the measures to ensure energy efficiency is the use of correctly engineered shading devices. The need for shading is the most important measure for protecting buildings from overheating when cooling is required (Kirimtat *et al*., 2016). Shading of windows and other building elements are very important to ensure a comfortable interior. In literature, numerous studies on shading devices integrated into buildings have been undertaken so far. Awareness of the use of shading devices in scientific studies started to develop since 1996 (Kirimtat *et al*., 2016). Simulation modelling became very efficient to study energy performance of buildings in the last few decades. There are various shading devices studied in literature. According to Kirimtat (2016) venetian blinds, mainly used in office buildings, are the most commonly studied. This is followed by fixed external louvres, roller shades and overhangs/ light shelves. Lesser studied types are vertical blinds/ fins, deciduous plants and egg crates. A study in the tropical climate of Uganda indicate that shading strategies are very effective during the hottest periods of the year reducing the risk of extreme overheating by up to 52% (Hashemi *et al*., 2017). The research undertaken for this chapter indicate that with appropriate shading devices reductions in the incident kWh/m²/annum of 57.63% (Eastern façade), 52.45% (Western façade), 38.47% (Northern façade) and 26.67% is easily achievable. The roof can be protected in different ways for example by ventilated shading and cool roofs. In the former case 69.61% can be realised with a ventilated shading device placed 500 mm above the roof. A previous chapter (Conradie, 2016b) explored the benefits of using white or cool roofs.

There are essentially three different types of shadow recognized in astronomy, i.e. the *umbra*, *penumbra* and *antumbra*. These types are the three distinct parts of a shadow created by a light source such as the sun. These Latin terms are quite often used to describe shadows cast by celestial bodies, but they are also applicable in the built environment (Wikipedia, 2017).

The *umbra* is the innermost or darkest part of the shadow (Latin for “shadow”) where the light source is completely blocked by the occluding body. This would rarely be achieved in buildings even with properly engineered shading devices, because there is over and above the direct radiation also a significant amount of diffuse radiation especially if the surrounding pavement surfaces are highly reflective. The *penumbra* (from the Latin *paene* "almost, nearly") is the region in which only a portion of the light source is obscured by the occluding body. This type of shade is what would most often be the case in buildings. The *antumbra* (from Latin *ante*, "before") is the region from which the occluding body appears entirely contained within the disc/ shape of the occluding body (Figure 5). The *antumbra* is useful when the designer wants reduce glare, but do not necessarily want to shade the specific space. The latter is applicable in the case of early morning or late afternoon sun especially in summer when the sun is at a very low angle above the horizon and especially on eastern, western and southern facades.

To be effective in buildings shading devices should provide at least *penumbral* shadow, but ideally *umbral* shadow at the right time. *Antumbral* shadow is not of much practical use or benefit as the observer is not actually shaded but just sees the shadow on an occluding object against the backdrop of light. However its main purpose is to reduce glare.

Figure 5: The three types of shadow are visible in this photograph of Stonehenge taken on 16 October 2012 at 10h38. The shadows cast on the ground are umbrae with very faint penumbrae outlines. The dark vertical backs of the standing stones are all antumbrae as they are seen against the late morning sun without the author being in their shade. The blocks are surrounded by an efficient low albedo surface (Author).

7.0 Solar control

A model as illustrated below was created in *Ecotect* to calculate the figures in Table 3. Table 3 contains sub-headings for the eastern, western, northern and southern facades as well as the roof. Under each of these headings two sub-columns list the amount of direct incident solar gain on the various surfaces without any solar protection (column U) and with a solar protection device (column P).

In Figure 6 the two northern overhangs are both 1 595 mm and the vertical facades 3 000 mm giving a total building height of 6 000 mm. The optimal overhang size has been precisely calculated using weather files from the *Meteonorm v7.2* software for Pretoria Forum weather station based on a critical solar elevation angle above the northern horizon of 62° (Figure 8) to exclude the sun between 17 September and 25 March (Table 4). Table 4 indicates that the overhang sizes would need to be increased with climate change (Table 4). The vertical fins on the eastern and western facades have been placed at an angle of 30° to the façade and are 1 650 mm wide. It is assumed that the designer is going to use some glass on the eastern and western facades, otherwise the extensive solar protection would not have been necessary.

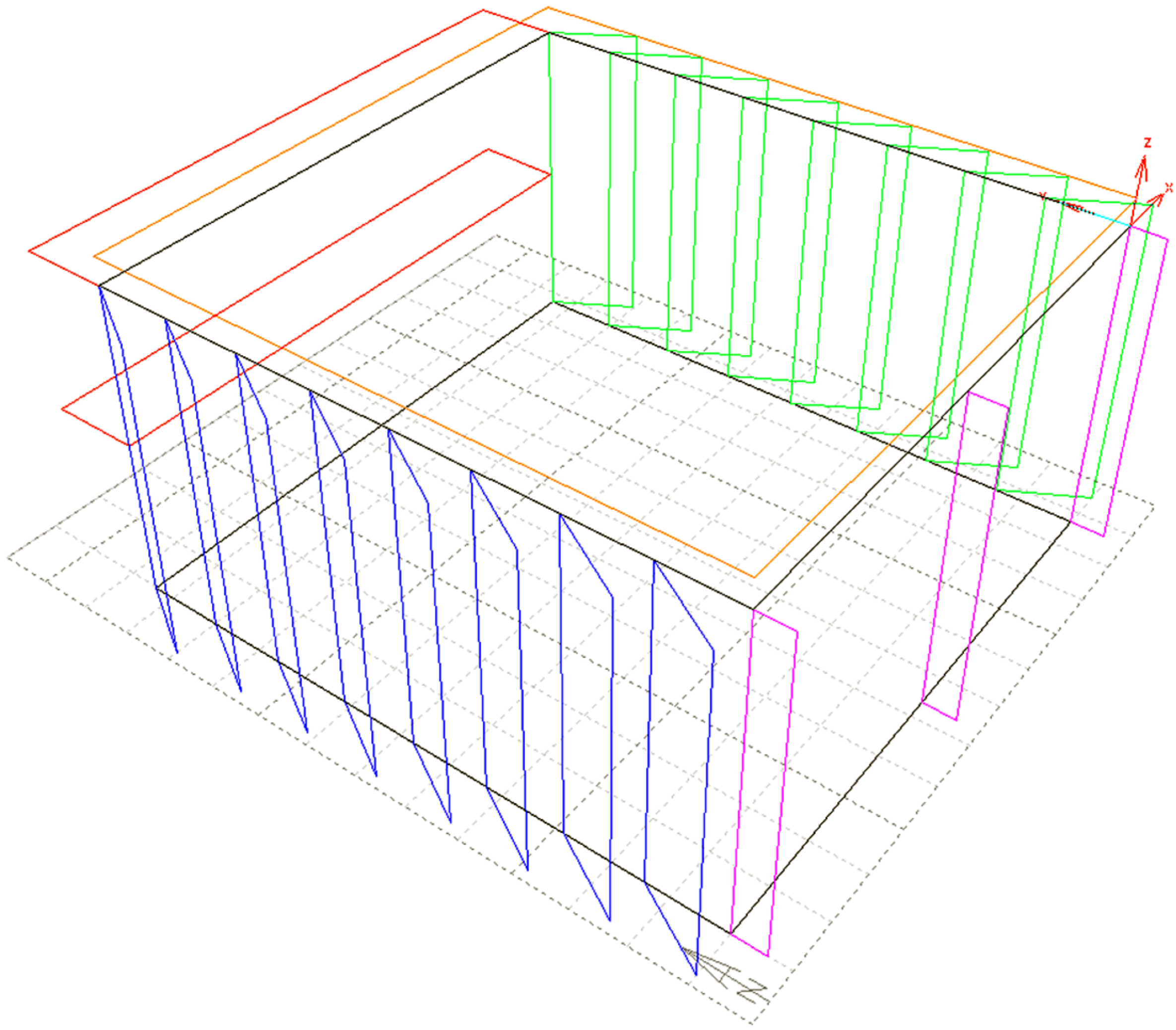


Figure 6: Ecotect simulation model used to simulate direct incident solar radiation and quantify the effect of solar protection devices.

The analysis in Table 3 below clearly indicates the significant amount of direct incident solar gain on the various roof surfaces if they are not protected by means of shading or a cool surface. The unprotected roof values for the different cities are listed under the U-column of Roof. The P-column indicates the significant reduction in direct incident solar gain when the roof surface is protected by a shading device. In this case a second ventilated roof has been placed 500 mm above the concrete slab of the building. In the case of Bloemfontein this reduces the direct incident solar gain on the roof by 1 097 kWh/ m²/ annum. Other efficient protection methods such as a white or cool roof can be considered.

Table 3: The amount of direct incident solar gain per roof surface in kWh/ m²/ annum. The values in column U is for unprotected surfaces and in column P for correctly engineered protected roof surfaces (Author).

City/ Town	**Total kWh/ m²/ annum per building surface**									
	East		**West**		**North**		**South**		**Roof**	
	U	**P**	**U**	**P**	**U**	**P**	**U**	**P**	**U**	**P**
Bloemfontein	884	400	606	287	906	558	67	48	1565	468
Cape Town	776	350	519	246	786	462	57	39	1366	401
Durban	493	219	301	143	571	362	29	21	854	256
East London	554	249	372	176	654	418	35	24	964	301
George	672	301	453	213	745	461	46	31	1148	349
Johannesburg	759	340	501	238	748	461	57	41	1346	393
Kimberley	840	382	559	267	823	501	67	48	1457	434
Port Elizabeth	649	292	435	205	746	472	41	28	1130	351
Pretoria Forum	786	333	490	233	733	451[4]	60	44	1349	410
Pretoria Irene	786	353	483	229	757	467	55	40	1362	399
Roodeplaat	775	348	481	228	740	457	54	39	1361	397
Upington	949	435	665	315	959	574	74	54	1775	506
Polokwane (Pietersburg	780	360	524	247	763	459	62	44	1474	410

Figure 7: Examples of solar protection in South Africa. The building top left used vertical fins to protect a north-eastern facade. The building top right used small horizontal solar protection inappropriately on the western façade. Bottom left and right illustrate two types of solar shielding screens on the building northern facades.

[4] The northern façade overhang for Pretoria has been accurately calculated based on analyses with *Climate Consultant 6.0*, a solar angle calculator and simulations in *Ecotect v5.60*. Due to time constraints this hasn't been done accurately for the northern overhangs of other cities and towns reflected in the table. However the values for the other cities are indicative of what can be realised for the northern overhangs. The values for the east and west facades as well as the roof are accurate in all cases. In all cases including Pretoria, the fin sizes on the southern façade are illustrative and would require further research to calculate accurately.

Figure 7 illustrate some examples of solar protection in South Africa. The top left building has vertical fins on a north-eastern façade. These fins are more suitable to protect eastern or western facades. In this case the designer made a compromise. The building top right inappropriately used narrow horizontal solar protection screens on the western façade. These are totally inefficient in the current location and are more suitable for the northern façade. The bottom left illustrates a building that has fine metal meshes to protect the eastern, northern and western facades. Screens are a very efficient solar protection measure however they exclude the sun in winter when it is really beneficial in passively heating the building and could also compromise the availability of natural daylight. The illustration bottom right is a different type of screen having the same advantages and disadvantages as the illustration bottom left.

Table 4: The critical angles and date ranges when solar protection should be applied to the northern facade of a building in the three climatic zones of Pretoria (Author).

	Cwb (Irene)		**Cwa (Pretoria Forum)**		**BSh (Roodeplaat)**	
Simulation period	**2009**	**2100**[5]	**2009**	**2100**[5]	**2009**	**2100**[5]
Optimal critical northern solar noon elevation[6]	67°	57°	62°	56°	60°	55°
Estimated solar protection date range[7]	30 Sep to 12 Mar	4 Sep to 7 Apr	17 Sep to 25 Mar	1 Sep to 10 Apr	12 Sep to 30 Mar	29 Aug to 13 Apr
Exposure/ Shaded (Hours)						
Warm/ hot > 27 °C:						
exposed	36	146	34	163	35	213
shaded	202	985	453	1 079	473	1 208
Comfort > 20 °C < = 27 °C:						
exposed	432	476	420	477	364	486
shaded	838	524	815	479	836	375
Cool/ cold <= 20 °C:						
exposed	716	360	615	312	633	244
shaded	328	61	215	42	211	26

The first set of simulations (Summarized in Table 3 under columns marked U) was to determine the amount of direct solar gain on the various unprotected building surfaces, normalized to kWh/ m²/ annum. These simulations were therefore undertaken without any solar protection overhangs or fins. For the second set of simulations (Summarized in Table 3 under the columns marked P) overhangs, fins and a shaded roof were introduced.

The northern overhang used in these simulations was accurately calculated as for the central Pretoria (Pretoria Forum) weather station (Table 4). This overhang size was used for the other cities as well. To be more precise the actual solar optimal critical solar noon elevation angles for the other cities should also be determined by means of the method discussed in detail below and illustrated in Figure 8. From these angles the shaded and exposed period can be accurately determined as well as the correct size (horizontal projection width) of the northern horizontal overhangs.

[5] A weather file with an A2 climate change scenario as defined by the IPCC (2000) has been used to calculate these values.

[6] This is the critical northern elevation solar angle that determines the angle where solar protection should be applied or when the solar penetration should be allowed into the building depending on the time of year.

[7] These dates define the period when the building should be protected against direct solar penetration on the northern façade. With climate change these date ranges become significantly longer and the overhang needs to be wider.

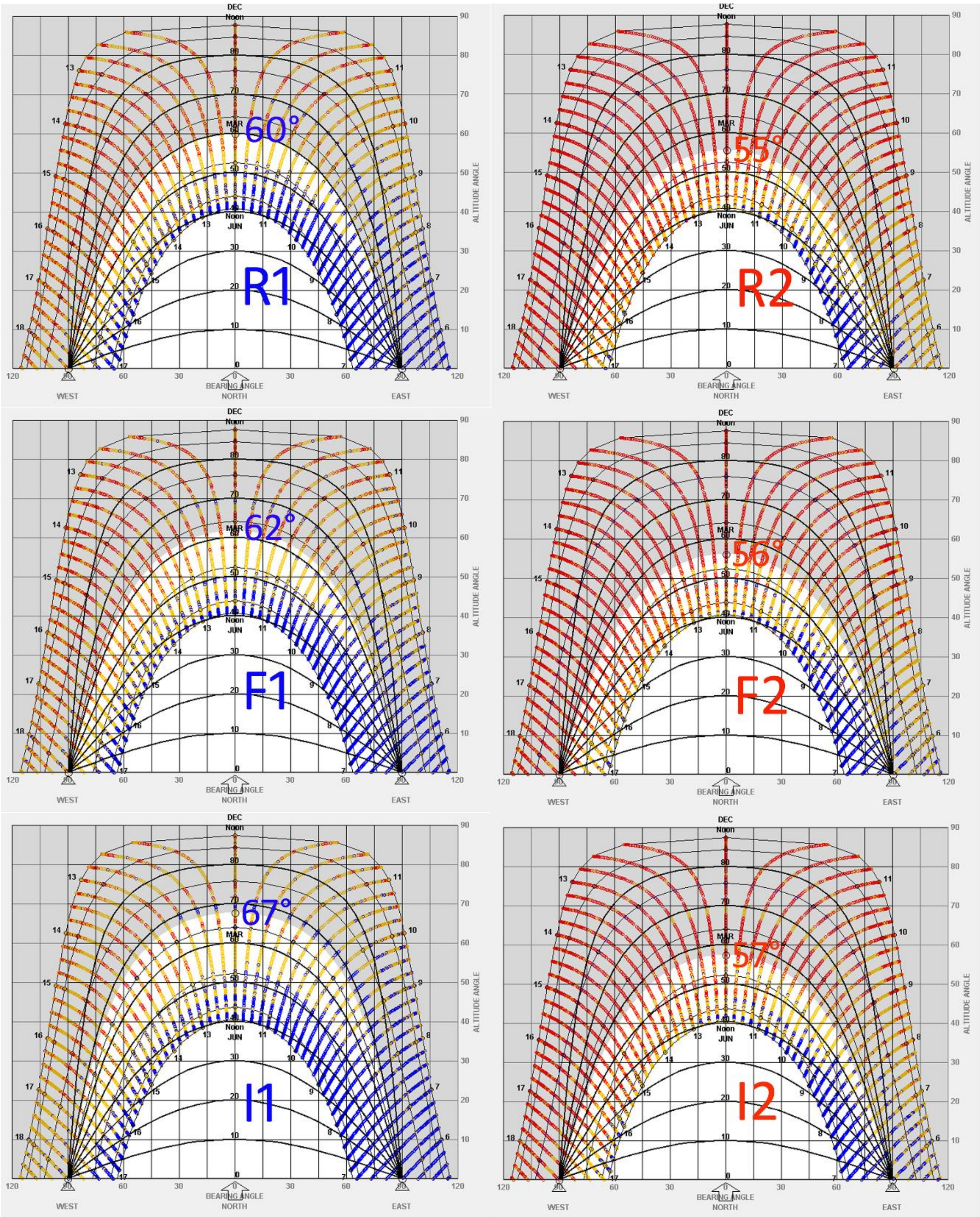


Figure 8: Calculated optimal critical solar noon elevation angles for the current climate (angles written in blue) and with climate change (angles written in red). The top row is for Roodeplaat (R1 and R2) (BSh), the middle row for central Pretoria (Pretoria Forum, F1 and F2) (Cwa) and the bottom row Irene (I1 and I2) (Cwb). The optimal solar angle at noon that determines the solar inclusion/ exclusion (depending on season) is indicated in each case (Conradie, 2017).

Glass is by far the weakest link in building design even if high performance Low-e glass is used (Conradie *et al.*, 2015b: 112-121). Glass should therefore be well protected with shading devices during the overheated period. For example a PFG 20 mm *Clearvue* insulated Glass Unit with layers of Low-e, 4 mm + 12mm air gap + 4 mm clear glass gives a whole window U-value of 3.05, U-value at the centre of glass of 0.679 and a solar heat gain coefficient (SHGC) of 0.526. The discussion continues with an analysis of the northern overhang.

There are a number of methods that can be used to control solar penetration into buildings. The surfaces around a building or adjoining buildings determine the amount of direct and reflected radiation. In South Africa the northern facades should be protected by correctly sized overhangs. When designing north facing shading devices it is important to remember that the sun is not static. The designer should not design the device to shade only at solar noon. It needs to function during the late morning and early afternoon hours as well. By simply extending the device either side of the window a better degree of shading can be achieved. It is sometimes more economical to group the single windows than to provide individual windows with separate shading devices. Solar penetration into the eastern and western facades should be limited as far as possible by shifting the windows that they either face north or south (saw tooth façade) or use vertical adjustable fins or strategically placed vegetation. Even the southern façade needs protection as it receives a significant amount of solar radiation in summer when the sun rises in a southeasterly and sets in a southwesterly direction. Fins can be used to control this oblique radiation and light as well. The design is a function of the latitude, window size and fin depth/ frequency. Living solar protection such as deciduous trees and trellises with deciduous vines are very good shading devices. They are in phase with the thermal year as they gain and lose leaves in response to temperature changes and will therefore automatically adapt to climate change.

A general rule of thumb is to make the overhang size such that the angle from the centre of the window sill through the edge of the northern overhang of a building the same as the solar noon elevation at the equinoxes for a given latitude. (equinox latitude approach). The SANS 204 (2011: 15-17) standard also describes a basic method to calculate the shading of the northern façade. It states that it should be capable of restricting at least 80% of summer solar radiation and if adjustable is readily operated either manually, mechanically or electronically by the building occupants.

To reduce energy use and to provide a comfortable interior the sun should be excluded during the hot summer months and included during the colder seasons. It is also important to realize that the seasons do not follow the purely geometrical solar positions such as the summer and winter solstices exactly. Although the winter solstice is on 21 June, the coldest period is normally later in July or even August. Similarly the hottest period in summer is not necessarily on summer solstice (21 December), but quite often only in January and February.

It is clear from the above that the hotter the climate gets, with more prevalent heat waves and climate change, the more important adequate shading and correct solar protection measures become to avoid unnecessary heat gains from the roof, that is a very large exposed area, and also the windows. To determine the optimal northern overhang size *Climate Consultant 6.0* was used to calculate the critical noon northern solar elevation angles that can be used to calculate the width of the horizontal overhang for the current climate and then also with climate change using the previously generated set of weather files described above and used to calculate the shading diagrams in Figure 8.

The following method was used to determine the optimal northern overhang. For illustrative purposes only Irene, Pretoria Forum and Roodeplaat were calculated (Table 4). An optimal horizontal northern overhang is assumed to be an overhang where there is a balance between the warm/ hot and cool/ cold periods of the year. In winter, solar radiation should be allowed to heat the interior of the building and in summer during the overheated period it should be excluded or shaded. The *Climate Consultant 6.0* software has a “Sun Shading Chart” that can be used to accurately determine the balanced solar angle for Summer/ Autumn and Winter/ Spring. It has a special slider that the user can drag up and down corresponding to a northerly solar elevation angle of 0 to 90°. An interactive calculator on the top left of the software screen displays the number of warm/hot, comfort and cool/cold hours. By changing the shade angle an ideal angle can be established where there is a balance between the number of hours that shade is needed during the hot period and sun is needed during the cool period.

Angles written in blue and red on Figure 8 illustrates the results of the solar elevation calculations for the period from 21 December to 21 June, i.e. around the autumnal equinox. A similar set can be calculated for the period 21 June to 21 December, i.e. around the vernal equinox.

The next step was to determine from which dates the sun should be allowed and excluded. By means of a special solar angle calculator, that the author developed, based on algorithms from the North American, National Oceanic and Atmospheric Administration (NOAA) the actual autumnal and vernal calendar dates were determined using the critical angles previously calculated. The critical angles are where there is a balance between hot and cold periods. It is evident with climate change that the overhangs must not only be wider, but the period where solar protection will be required will become much longer. In practice it means that South Africa and Pretoria specifically will increasingly have a cooling rather than a heating problem. Table 4 above summarizes the results of abovementioned angle and date calculations.

By using the techniques described above accurate overhangs can be calculated for the other cities and towns as well in a similar way that the angles were calculated for the three illustrative climatic regions of Pretoria.

8.0 Conclusions

Many conclusions can be made from the article and some really interesting discoveries have been made.

The simulations clearly indicate the significant benefit of protecting the various facades of the building against direct solar gain, especially if these facades contain glass in windows or entire facades. It is also far more efficient to keep the direct and indirect solar radiation out of the building by proper ventilated shading devices, rather than trying to rely on expensive glass such as low-e glass that is not nearly as efficient. Modern simulation techniques make it possible design accurately engineered solar protection devices. In all cases the roofs need to be carefully designed as the direct incident radiation on the roof is much larger than any of the other surfaces. The most effective measures to control heat gains from the roof are cool or white roofs or alternatively a ventilated shading device such as the one illustrated in Figure 6 (floating horizontal surface with orange lines).

It is clear that in hot climates during heatwaves or with the expected climate change solar control is becoming increasingly important. It is reasoned and supported by simulation that this will mean increasing the amount of shade by increasing the overhang size on the northern façade. In practice this means keeping the roof as cool as possible and using correctly sized overhangs on the northern façade and appropriate solar protection on the other facades. It is important to realise that there are solar gains from the southern façade as well. For example in Pretoria solar gains from the southern façade cannot be entirely ignored because in summer the sun rises well south of east and sets south of west. The research indicated that the northern overhang size will have to be increased to counter the overheating caused by climate change. The calculations in Table 4 clearly indicate that the shading period must also be increased because the overheated period is gradually increasing. It was beyond the scope of this chapter to calculate this detail for all the other cities and towns. However similar techniques can be used.

The sections of shade and albedo indicate that the solar protection devices need to provide good quality shade. The surrounding surfaces also need to be taken account of otherwise indirect reflections from high albedo surfaces can neutralise the effects of carefully designed solar protection.

Although the article concentrated on solar protection other passive design aspects such as adequate ventilation and use of natural daylight should not be neglected. Improved ventilation will also help to promote evaporative cooling from the skin and in the process increase the general sense of comfort during the overheated period. From personal experience it is clear that the human body can withstand higher temperatures than previously thought if it had enough time to adapt or acclimatize.

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