[SSC05] BIOCLIMATIC TECHNIQUES TO QUANTIFY MITIGATION MEASURES FOR CLIMATE CHANGE WITH SPECIFIC REFERENCE TO PRETORIA

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Abstract

The purpose of this paper is to research the expected effect of climate change on South African cities, with specific reference to Pretoria. A bioclimatic analysis is used to quantify the most appropriate mitigation techniques for new and existing structures. With increased climate change, it is increasingly important that South African cities and buildings are resilient. Recent research predicts that Southern Africa can expect a temperature increase of between 4 °C and 6 °C in the hot western areas. Significant warming is expected in cities where high temperatures will be exacerbated by the Urban Heat Island (UHI) effect.

In this research weather files were generated for the current climatic conditions of the three main climatic regions of Pretoria. Subsequently synthetic weather files were generated to quantify the effect of climate change up to the year 2100. An A2 climate change scenario of the Special Report on Emission Scenarios (SRES) for the period 1961-2100 was used. An A2 scenario can be described as business as usual. Recent research indicates that this is the most likely scenario for South Africa. Using these weather files a comprehensive bioclimatic analysis was firstly run to quantify the current appropriate passive design measures and secondly to determine changes caused by climate change. This was further analysed in relation to proposed passive design measures.

The results indicate that a significant amount of mitigation is possible if the correct engineered bioclimatic design approaches are used and complimented by other beneficial building and urban techniques such as the use of cool roofs and urban vegetation.

1. Introduction

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 urban heat island effect (UHE). 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, 2016b: 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) is a good method to reduce the UHE due to a combination of shade and evaporative cooling (Stoffberg *et al*., 2010: 9).

2. Methodology

The purpose of this paper is firstly to research the effect of climate change on the South African city, with specific reference to the three main climatic zones of Pretoria (Conradie *et al*., 2016a: 3). A bioclimatic analysis is then used to quantify the most appropriate mitigation techniques for new and existing structures. It is not possible to directly quantify the effect of all mitigation techniques such as urban trees, however the use of bioclimatic techniques in conjunction with other techniques are able to quantify a significant subset of design strategies. Lastly the critical solar angles were calculated to achieve better solar control.

To support both the bioclimatic analysis and the solar angle calculations detailed weather files were generated with the *Meteonorm* software for the current three climatic zones of Pretoria 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 be described as Business As Usual (BAU). Recent 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 *Climate Consultant 6.0* to quantify current appropriate passive design measures and the predicted changes that will be caused with climate change. This was then further analysed in the light of techniques to achieve better solar control.

3. The expected effect of climate change in Pretoria

The City of Tshwane metropolitan municipality range in latitude between 25° 6' 41.86" and 26° 4' 26.00" and in longitude between 27° 53' 34.85" E and 29° 5' 42.25" E (Figure 1). The altitude varies from 975 m in the north to 1 620 m above mean sea level (masl) in the south (Figure 1)

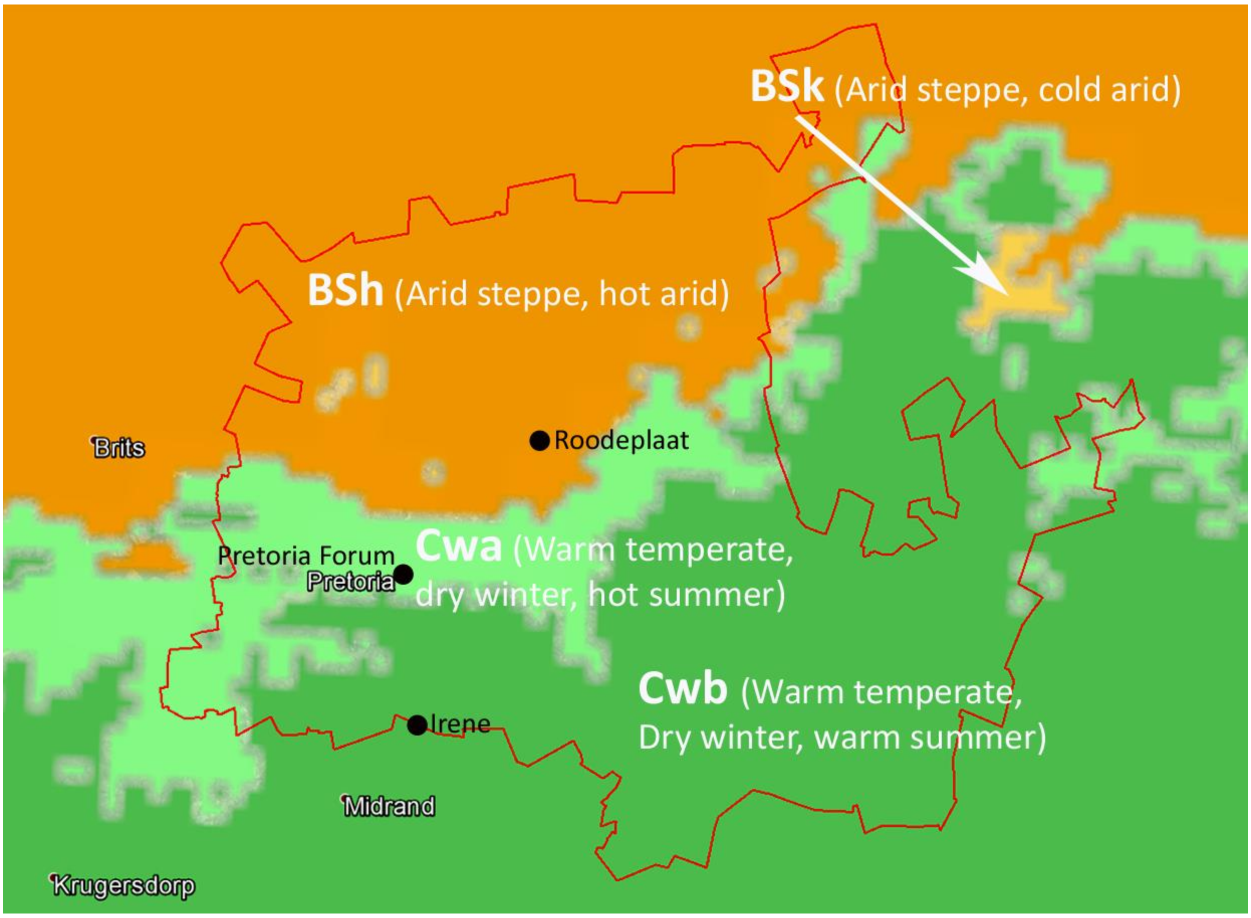


Figure 1 The current Köppen-Geiger climatic zones of the City of Tshwane metropolitan municipality. (Based on Conradie et al., 2012: 195-203) The locations of weather stations used in the calculations are indicated with black dots. Johannesburg is south of Midrand, just off the map.

This large area of 6 296 km² includes cities and towns such as Pretoria, Bronkhorstspruit and Cullinan. Currently it comprises three distinct Köppen-Geiger climatic zones, i.e. BSh, Cwa and Cwb (Conradie *et al.*, 2016a). BSh (Steppe climate, hot steppe/ dessert) occurs in the northern part. Cwa (Temperate, Dry Winter, Hot Summer) occurs in the centre of the area and Cwb (Temperate, Dry Winter, Warm Summer) in the southern parts. The latter forms part of an extensive high lying area of 140 405 km² (12.11% of South Africa's area) locally known as the "Highveld". Johannesburg, that is 53 km to the south of Pretoria/ Tshwane, also falls in this climatic zone.

Climate change means it is increasingly important that the South African city is resilient. Recent research predicts that Southern Africa can expect a temperature increase of between 4 °C and 6 °C in the hot western dessert areas if the global average temperature world increases by 3 °C (Engelbrecht *et al.*, 2016: 258). This significant warming will have a severe impact on cities where the so-called Urban Heat Island (UHI) causes cities to be significantly warmer than surrounding rural areas.

Higher temperatures cause more extreme weather conditions. In December 2015 and once again in January 2016 exceptionally high dry bulb temperatures of 42.5 °C were experienced in the central Pretoria area with a Cwa Köppen-Geiger climatic classification (Temperate, Dry Winter, Hot Summer) as measured by the author's own WH3081 solar wireless weather station made by Fine Offset. The previous summers of December 2014 and January 2015 were also extremely hot. During this heatwave the amount of energy in the atmosphere increased drastically that led to extreme weather conditions. This was evident in an extreme precipitation event of a severe hailstorm that fell on the farm Selderus (Broederstroom west of Pretoria) on Saturday afternoon, 9 January 2016 during a storm that followed the extreme heatwave mentioned above. The diameter of the stones was 50 mm Ø as measured by the author and it was calculated that the terminal velocity when it reached ground level was at least 35.833 m/s. This caused massive damage to infrastructure and vegetation.

In 2008 climate modelling groups from around the world agreed to promote a new set of coordinated climate model experiments. These experiments comprise the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al., 2012: 485). For the CMIP5 four Representative CO_2 Concentration Pathways (RCPs) have been considered (Taylor *et al*., 2012: 489). These Greenhouse Gas (GHG) concentration trajectories, which are all considered as realistic, are used by modellers to generate climate response and change projections. The RCP2.6, RCP4.5, RCP6.0 and RCP8.5 RCPs have been defined according to their contribution to atmospheric radiative forcing in the year 2100, relative to pre-industrial values. For example, the addition to the earth's radiation budget as a result of an increase in GHGs are for RCP2.6 = +2.6 W/m^2, RCP4.5 = +4.5 W/m^2, RCP6.0 = +6.0 W/m^2 and RCP8.5 = +8.5 W/m^2. In this paper a high (RCP8.5) pathway is used that is similar to the IPCC A2 climate change scenario. The RCP8.5 trajectory is associated with a CO_2 concentration of approximately 950 ppm by the year 2100 (Riahi et al., 2011). The RCP8.5, also known as business as usual is projected to increase even further to a CO_2 concentration ceiling of approximately 1200 ppm after the year 2100.

There are different opinions on the effect of climate change on South Africa, because it is a very complex subject due to the complex interaction of the different variables used to describe the various earth systems. Below two recent quantitative climate predictions are discussed that give different perspectives.

In the first study Rubel *et al*. (2010: 135-141) undertook a comprehensive study, in 2010, to map the world climate change. Two global sets of climatic observations were used to determine the Köppen-Geiger climatic regions. Both sets were available in a 0.5 degree latitude/ longitude with a monthly timeline resolution. The first dataset was provided by the Climatic Research Unit (CRU) of the University of East Anglia. This dataset has nine climatological variables of which only temperature was used. This set is known as the CRU TS 2.1 and has worldwide coverage with the exception of Antarctica. The second dataset was provided by the Global Precipitation Climatology Centre (GPCC) of the German weather service. This is known as the GPCC Full Data Reanalysis Version 4 for 1901-2007. This dataset covers all land areas with the exception of Greenland and Antarctica.

Global temperature and rainfall projections for the period 2003-2100 of the Tyndall Centre for Climate Change Research dataset (TYN SC 2.03) were also used. This consists of a total of 20 Global Climate Change simulations, combined with four possible future IPCC Special Report Emissions Scenarios (SRES) (IPCC, 2000: 3-5). The TYN SC 2.03 dataset takes account of the A1FI, A2, B1 and B2 scenarios.

Table 1 Global Climate Change model simulations used in the two climate change simulations

Description	**Rubel et al. (2010: 138)**	**Engelbrecht et al. (2016: 249)**
Hadley Centre Coupled Model Version 3	HadCM3	HadCM3
National Center for Atmospheric Research-Parallel Climate	NCAR-PCM	
Second Generation Coupled Global Climate Model	CGCM2	
Australian Industrial Research Organization – Climate Model	CSIRO2	
Australian Industrial Research Organization – Climate Model		CSIRO3.5
European Centre Model Hamburg Version 4	ECHam4	
National Oceanic and Atmospheric Administration		GFDL-CM2.0
National Oceanic and Atmospheric Administration		GFDL-CM2.1
German Ocean Model		ECHAM5/MPI
Japanese Agency for Marine-Earth Science and Technology		MIROC3.2-medres

The result of these simulations with regards the IPCC A1FI and B1 simulations over the period 1976-2000 up to 2076-2100 was as follows. The most visible climate change was in the northern hemisphere in the 30° - 80° band.

The A1FI and B1 climate change scenarios are the extremes, but illustrate the point quite clearly. In the period 1976-2000 29.14% of the global land area has a Köppen-Geiger of B, followed by 21.62% D climates, 19.42% A climates, 15.15% E climates and 14.67% C climates. In the A1FI scenario for the period 2076-2100 the ensemble average (Table 1) predicts that the A climates will be 22.46%, B climates 31.82%, C climates 15.2%, E climates 11.04% and D climates 19.48%.

The B1 emission scenario indicates much smaller changes. In the B1 scenario for the period 2076-2100 the ensemble average (Table 1) predicts that A climates will be 21.69%, B climates 30.07%, C climates 14.29%, D climates 21.75% and E climates 12.21%. It is evident from the accompanying climatic map of Rubel *et al*. (2010: 135-141) that Pretoria will fall in a much hotter BSh climatic zone (Figure 2).

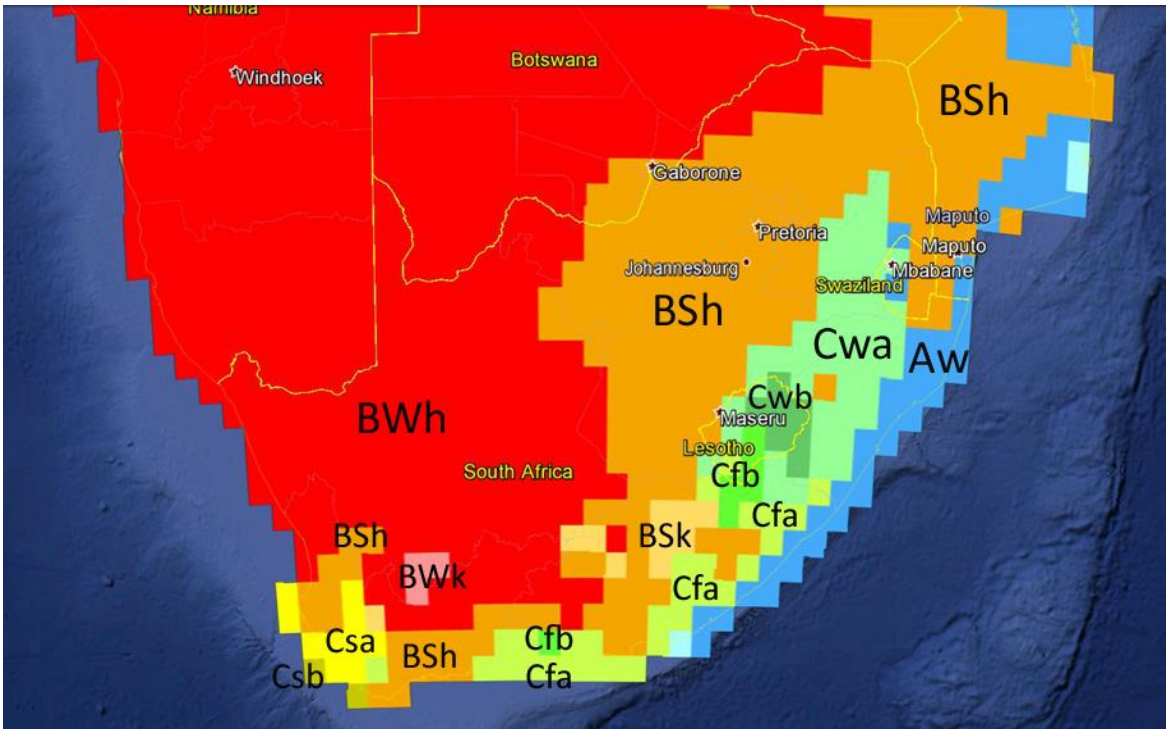


Figure 2 Expected climate change with an A2 scenario by 2076 to 2100 (Rubel et al., 2010)

In the second study Engelbrecht *et al*. (2016: 247-261) used an alternative set of Global Climate Change Models (Table 1). These simulations were specifically done for South Africa and once again Köppen-Geiger maps were used to map the climate change. In all cases the A2 scenario of the IPCC has been used. According to current research by Engelbrecht *et al*. (2016: 247), the A2 scenario is the closest to reality for Southern Africa. A2 is almost as bad from a greenhouse gas emissions point of view as the worst case A1FI climate change scenario. In this study the approach was different than the first study described above. The researchers took 1 to 3 °C as global temperature markers and then calculated the local effect on South Africa that is unfortunately significantly higher than the average global trend. The majority of these simulations indicate that South Africa will in general have a much drier and significantly hotter future. It is clear that the hot western dessert zone (BWh) of South Africa will expand significantly southwards and to a lesser extent eastwards. Simulations also indicate that a drastic local temperature increase of between 4 to 6 °C can be expected locally in the case of the 3 °C global scenario.

The conclusion can be made that the current three climatic zones in Pretoria is very likely to change from the current BSh, Cwa and Cwa to a much expanded BSh Köppen-Geiger classification, both in the case of the 2 and 3 °C global temperature increases. Figure 2 indicates that Johannesburg will also fall in the significantly expanded BSh climatic zone. The latter is a Köppen-Geiger Arid, Steppe, hot climate type. This agrees with the predictions of Rubel *et al*. (2010) as illustrated in Figure 2.

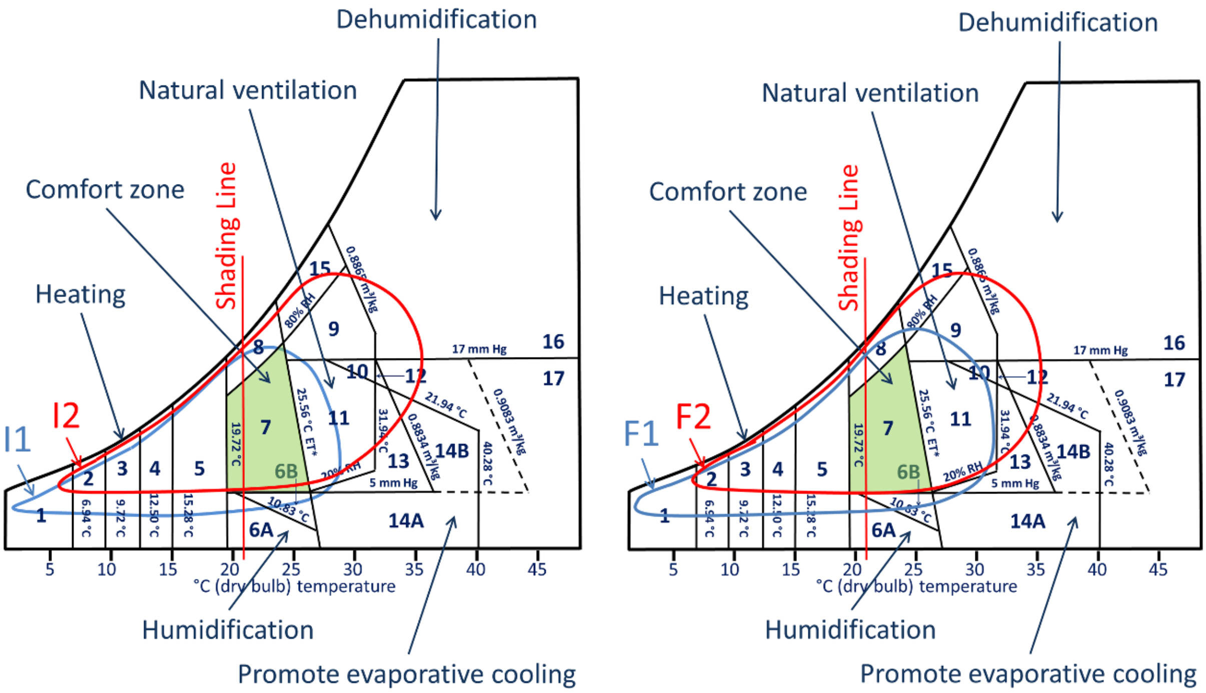
Table 2 The expected year when global temperature will reach 1, 2 and 3 °C above the current baseline for different Global Climate Change Models.

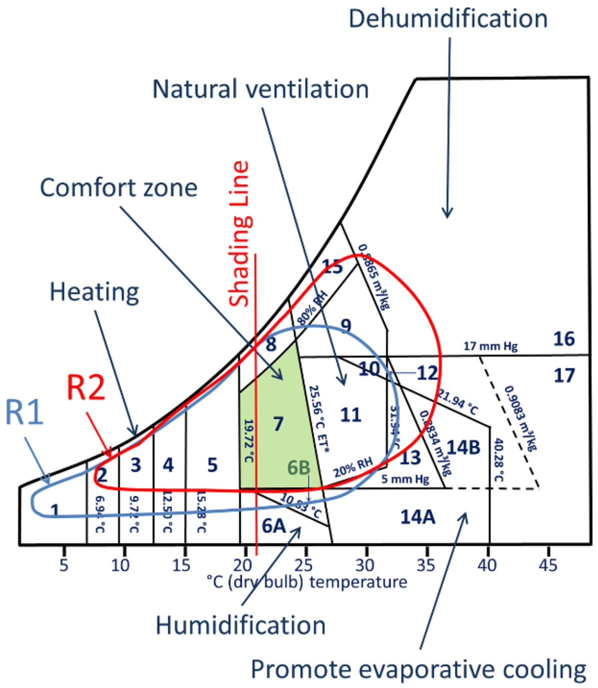
Engelbrecht *et al*. (2016: 249)	**1 °C**	**2 °C**	**3 °C**
HadCM3	2032	2058	2079
CSIRO3.5	2021	2051	2071
GFDL-CM2.0	2029	2058	2078
GFDL-CM2.1	2026	2064	2083
ECHAM5/MPI	2037	2061	2077
MIROC3.2-medres	2019	2054	2070

Table 3 The percentage area of the different Köppen-Geiger climate types in Southern Africa in comparison to the historic basis (1961-1990) (Processed from Engelbrecht et al., 2016: 251 results).

Köppen-Geiger main climate family	**Current basis**	**1 °C**	**2 °C**	**3 °C**
A	1.74	2.16	2.89	3.96
B	77.58	78.93	82.57	82.65
C	20.67	18.91	14.55	13.39

4. Bioclimatic analysis





Identification of climate control strategies on the Building Bioclimatic Chart (adapted after Givoni)

BIOCLIMATIC NEEDS ANALYSIS	
Heating (< 19.72 °C)	1-5
Cooling (> 25.56 ET*)	9-17
Comfort (19.72 °C – 25.56 °C ET*, 5 mm Hg – 80% RH)	7
Dehumidification (> 17 mm Hg or 80% RH)	8-9, 15-16
Humidification (< 5 mm Hg)	6A, 6B (14)
STRATEGIES OF CLIMATE CONTROL	
Restrict conduction	1-5; 9-11, 15-17
Restrict infiltration	1-5; 16-17
Promote solar gain	1-5
Restrict solar gain	6-17
Promote ventilation	9-11
Promote evaporative cooling	6B, 11, 13, 14A, 14B
Promote radiant cooling	10-13
Mechanical cooling	17
Mechanical cooling and dehumidification	15-16

Figure 3 Illustration of the current and climate change applicable design strategies for the three main climatic zones of Pretoria. Top left is Irene station, top right Pretoria Forum and bottom left Roodeplaat. In each case the blue areas are the current situation and the red the change with climate change. (Overlays compiled by author on backgrounds based on Watson & Labs, 1983: 206)

Victor Ogyay (1963), city planner is the father of bioclimatism or bioclimatic architecture. He was professor of the School of Architecture and Urbanism of the University of Princeton until 1970 and a leading researcher in the investigation on the relation between architecture and energy.

Bioclimatic architecture is an alternative method of designing and constructing buildings in which the local climate are considered and diverse passive technologies are used with the aim of improving occupier comfort and energy efficiency (Manzano-Agugliaro *et al*., 2015: 737).

Many research projects in South Africa and particularly at the CSIR (Nice *et al*., 2015: 175-184) have indicated that the use of passive design principles to design thermally comfortable and energy efficient buildings in hot climates such as South Africa using methods such as such as natural ventilation is feasible and in fact highly desirable.

One of the most accessible methods to determine the correct mix of passive building design techniques is the bioclimatic chart that is combined with psychrometric chart as an overlay. Bioclimatic design is nothing new as the concept was already developed and documented by Olgyay (2015: 14-31) in 1963. At the time it was rather difficult to quantify the different design techniques precisely as there were no detailed supporting weather files or appropriate software analysis tools available to achieve this rather complex task. Furthermore the effects of climate change weren't well understood. This technique is as valid today as it was five decades ago and is today supported by good software that facilitates the analysis task. Bioclimatic design is essentially used to determine passive building design strategies that use natural energy sources that significantly reduce energy use that are appropriate for the specific climatic zone. (Visitsak *et al*., 2004: 1-11). Givoni and Milne (1979: 96-113) improved the original Olgyay chart by replacing the square chart with Cartesian axes that containing respectively humidity and dry bulb temperature with a standard psychrometric chart used by mechanical engineers.

As indicated above the current scientific indications are that the A2 climate change scenario as defined by the IPCC (IPCC, 2000: 3-5) will be applicable to South Africa. To quantify the current effect of the climate and to simulate the likely effect of climate change in Pretoria the weather file creation software *Meteonorm* was used to create six weather files. Three weather files represent the current climate. Measured weather data of the weather stations at Irene (25° 54' 36.00" S, 28° 12' 36.00" E), Pretoria Forum (25° 43' 58.8" S, 28° 10' 58.8" E) and Roodeplaat (25° 34' 58.8" S, 28° 21' 0.00" E) were used for this. These stations are representative of the three climatic zones of Pretoria. This set is as close as possible to the current climate with a period of radiation from 1991 to 2010 and the period for temperature 2000 to 2009. Three other weather files were synthetically generated using an A2 climate change scenario for the year 2100 using the same measured locations previously mentioned. The *Meteonorm* climate change calculations, to create future synthetic weather files, use the IPCC report of 2007 (Meehl *et al*., 2007). The averages of all 18 models have been included in the software. Three different scenarios B1 (low), A1B (mid) and A2 (high) are available in *Meteonorm*, but only the A2 instance has been used. The anomalies of temperature, precipitation, global radiation of the periods 2011-2030, 2046-2065, 2080-2099 were used for the calculation of future time periods. The forecast changes of global radiation until 2100 with all scenarios are relatively small compared to temperature changes.

Climate Consultant 6.0 was then used to create the bioclimatic analyses that are illustrated in Figure 3. The climatic overlays have been simplified somewhat to make the current and climate change effect more visible. Only the outlines of the annual 8 760 hourly temperature/ humidity point clouds have been drawn. It is clear that the climate in all three cases will change significantly with the demand for ventilation (strategies 9-11), promote radiant cooling (strategies 10-13) and "Mechanical cooling and dehumidification" (strategies 15-16) increasing significantly. In all three climatic zones a significant shift in the direction of higher dry bulb temperatures combined with higher humidity is observed.

Table 4 below quantifies the actual changes in design strategy for the current climate and with an A2 changed climate by the year 2100. There is a more extensive set of passive strategies available, however the best set has been selected by the software. The best set is defined as the smallest number of passive design strategies that can potentially achieve closest to 100% or 100% comfort. The surprising result is, even with climate change, it is still possible to achieve 100% comfort in all cases, with a large portion totally passive and some mechanical intervention in extremes (hybrid solutions).

Table 4 Design strategies for the Cwb, Cwa and BSh climatic zones for Pretoria, currently and with climate change. The contribution of each strategy is expressed in hours.

Design strategies	**Cwb (Irene)**		**Cwa (Pretoria Forum)**		**BSh (Roodeplaat)**	
	2009	**2100**[1]	**2009**	**2100**[1]	**2009**	**2100**[1]
Comfortable	2074	1985	2337	1991	2299	1858
Sun shading of windows	913	1993	1342	2106	1337	2281
High thermal mass	348	981	637		638	
High thermal mass night flushed				1154		1069
Internal heat gain	3686	2416	3238	2114	3270	1953
Passive solar direct gain high mass	2464	1718	1614	1561	2310	1377
Dehumidification only	553	1470	704	1502	736	1626
Cooling add dehumidification if	35	1217	172	1330	188	1829
Heating add humidification if needed	1057	353	1250	363	834	234

Comfort as used in the *Climate Consultant 6.0* software is clearly defined in the ASHRAE 55-2010 (ASHRAE 55-2010: 5) standard. This standard uses operative temperature. Operative temperature (OT) integrates the effect of air temperature and radiation, but ignores humidity and air movement. It is unsuitable for application above 27 °C (Holm *et al*., 2005). The range of operative temperatures presented is for 80% occupant acceptability. This is based on a 10% dissatisfaction criterion for general (whole body) thermal comfort based on the Predicted Mean Vote/ Percentage Persons Dissatisfied (PMV-PPD) index, plus an additional 10% dissatisfaction that may occur on average from local (partial body) thermal discomfort. (ASHRAE 55-

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

2010, 2010: 5). Two comfort zones are used, one for 0.5 clo of clothing insulation and one for 1.0 clo of insulation. These insulation levels are typical of clothing worn when the outdoor environment is warm (summer) and cool (winter), respectively. The comfort zone described in the ASHRAE 55-2010 (2010) standard differs slightly from the older New Effective Temperature (ET*) delineated comfort definition used by researchers such as Givoni (1969), Watson and Labs (1993) illustrated in Figure 3. New effective temperature (ET*) is described as the DBT of a uniform enclosure producing the same heat exchange by radiation, convection and evaporation as the given environment. It allows for body, clothing and space interaction. ET* lines coincide with DBT values at the 50 % curve of the psychrometric chart (Holm *et al*., 2005). The quantified results in Table 4 were undertaken by *Climate Consultant 6.0 and* used the latest ASHRAE 55-2010 (2010) definitions and dual summer/ winter comfort zones. De Dear (2011: 108-117) contests the current rather rigid views on thermal comfort described above. He coined the term alliesthesia that is used to differentiate thermal pleasure from thermal neutrality and acceptability.

In all cases the benefit of proper "Sun shading of windows" increases significantly with climate change. This is discussed in more detail below, because solar control is very important in a hot country such as South Africa (Table 4). In the case of Pretoria Forum (Cwa) and Roodeplaat (BSh) the design strategy changes from "High thermal mass" to "High thermal mass night flushed". It is evident what the effect of climate change is in the significant reduction of the number of "comfortable" hours due to the significant increase in temperature. Closely related to this is that the amount of "Cooling add dehumidification if needed" increased significantly. The amount of "Heating add humidification if needed" also reduced significantly.

5. Solar control

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.

Table 5 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.

	Cwb (Irene)		**Cwa (Pretoria Forum)**		**BSh (Roodeplaat)**	
Simulation period	**2009**	**2100[2]**	**2009**	**2100[2]**	**2009**	**2100[2]**
Optimal critical northern solar noon elevation[3]	67°	57°	62°	56°	60°	55°
Estimated solar protection date range[4]	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

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

[3] 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.

[4] 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.

Glass is by far the weakest link in building design even if high performance Low-e glass is used (Conradie *et al.*, 2015: 112-121). Glass should therefore be well protected with shading devices during the overheated period. The discussion continues with an analysis of the northern overhang.

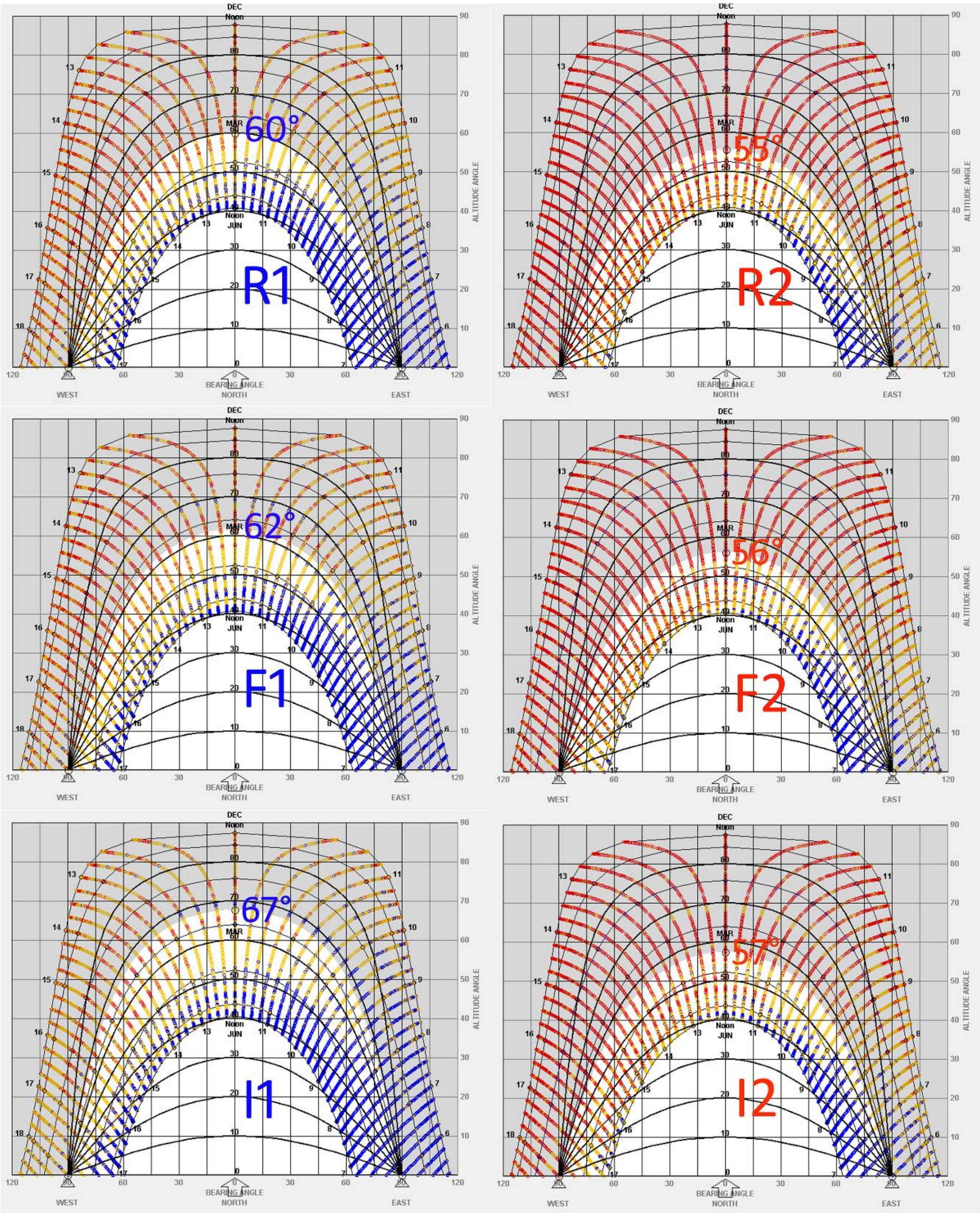


Figure 4 Calculated optimal critical solar noon elevation angles for the current climate (angles written in blue) and with climate change (angles written in red). The top row is for Roodeplaat (R1 and R2) (BSh), the middle row for Pretoria Forum (F1 and F2) (Cwa) and the bottom row Irene (I1 and I2) (Cwb). The optimal solar angle at noon that determines the solar inclusion/ exclusion (depending on season) is indicated in each case.

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 set of weather files described above and used to calculate the shading diagrams in Figure 4. The optimal angle is when there is a balance between the number of hours that is warm/ hot and cool/ cold. Figure 4 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.

Table 5 above quantifies the estimated critical noon solar elevation angles. 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 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.

6. Conclusion and Further Research

The current climate of South Africa is already arid with 70.9% of the surface area in the Köppen-Geiger categories of BSh, BSk, BWh and BWk (Conradie *et al*., 2012: 195-203). The climate change analysis indicates that there is a strong signal that South Africa will experience a significant amount of climate change. It is very likely that Pretoria will change to a BSh climate (Arid steppe, hot arid). This will have a large impact on energy use and comfort in cities and buildings.

Fortunately there is a wide range of passive and other design strategies that can be applied in new designs or retrofitted in existing designs. The detailed bioclimatic analysis quantified the appropriate passive design techniques for Pretoria. It is evident from this that “sun shading of windows” is very important. Due to the importance of solar control in a hot climate such as South Africa, a sun shading chart analysis was done to calculate the critical northern elevation solar angle that determines the angle where solar protection should be applied or allowed into the building depending on the time of year. It is evident that the overhangs would need to be increased significantly with climate change to ensure an energy efficient and a comfortable interior. The corresponding dates when these angles would be reached were calculated by means of a solar angle calculator that the author developed, based on algorithms from NOAA.

Further research can be conducted to determine optimal solar protection angles for all regions in South Africa. A significant amount of research also needs to be undertaken to revisit the old hypothesis of human thermal perception, because that determines to a large extent the definition of the comfort zone as used in bioclimatic design.

It is recommended that local authorities and building design officials take the following actions:

- Make weather files freely available to all professionals to facilitate climate sensitive design.
- Strongly promote correctly engineered bioclimatic and passive design principles.
- Incorporate guidelines for the solar protection measures such as correctly sized overhangs in building regulations and guidelines.
- Building regulations will have to recognize the characteristics and design potential accurately to support engineered passive design principles.

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