South Africa's Climatic Zones: Today, Tomorrow

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Abstract

To design energy efficient buildings using an optimal combination of passive design strategies it is necessary to understand the particular climate designed for. To use energy simulation software such as *EnergyPlus*[TM], *Ecotect*[TM] or *DesignBuilder*[TM] to calculate building energy consumption or undertake a predictive thermal simulation of naturally ventilated buildings requires a detailed set of specially structured electronic weather data files such as the epw, tmy and iwec formats widely available in the U.S.A. Unfortunately there is a lack of these in South Africa. On the *EnergyPlus*[TM] website [13] there are only two weather files available for South Africa in contrast to 1 479 for the U.S.A. If the *Meteonorm*[TM] software is acquired a further 34 directly measured meteorological stations (weather files) are available for South Africa. Weather files for in between locations in the software mentioned are created by means of sophisticated interpolation formulas.

Recently the South African SANS 204-2 [1] standard introduced six main climatic zone region map in an attempt to inter alia establish the maximum energy demand and maximum energy consumption in the design of a particular building. This was a first step to introduce a more quantified view of climate regions into the South African National Building Standards. The question is raised whether this approach is adequate to optimally support medium to long term design decisions within the built environment for simulating and quantifying passive design strategies such as natural ventilation, thermal mass and passive solar heating.

As a first stage to address this shortcoming it was decided to create a highly detailed climatic map of South Africa using 20 years of precipitation and temperature data using a Köppen-Geiger climatic classification to provide better general insight than the six-zone model. After this the predicted climate change over the next 100 years expressed as Köppen categories was researched.

Secondly the research team investigated the relationship of available weather files mentioned above, using software such as *Meteonorm*[TM], to the 13 Köppen regions found in South Africa. International [2] and local researchers using sophisticated ensembles of General Circulation Models (GCM) are predicting likely Köppen category shifts using various scenarios. The hypothesis is made that if the

future Köppen category for a particular building or location under consideration is known and a relationship between a detailed weather file to a particular Köppen category is known then the likely future energy performance could be predicted.

1   Introduction

The CSIR is committed to promoting sustainability in the built environment and thus pursues the design of buildings that are responsive to the specific characteristics of the climate in which they are placed. Climate-responsiveness of buildings is key, regardless of the solutions and technologies employed in the design and engineering of building.

Solutions could include passive design technologies (such as solar heating, thermal mass, natural ventilation, or direct and indirect evaporative cooling), mechanically engineered solutions or hybrid strategies. These lead to improved building performance, enhanced energy efficiency and optimised internal environmental conditions.

The climate of an area is the averaging effect of weather conditions that have prevailed there over a long period of time such as 30 years. Due to the fact that earlier climate researchers in the 1900s did not have computers or electronic databases available to research the gradual changes in climate Wladimir Köppen and Rudolf Geiger regarded climate as a constant and used the sparse climatic information available to compile a single static climatic map [2]. The first quantitative hand drawn map of climate classification was published by Köppen in 1900 and the latest version by Geiger in 1961 before Austrian researchers created a modern version in 2005 [3].

The climate of a location is affected by its latitude, terrain and altitude, as well as nearby water bodies and their currents. Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation. The most commonly used classification scheme was originally developed by Wladimir Köppen in 1900. The Thornthwaite system, in use since 1948, incorporates evapotranspiration along with temperature and precipitation information and is used in studying animal species diversity and potential effects of climate changes. The Bergeron and Spatial Synoptic Classification systems focus on the origin of air masses that define the climate of a region. The Holdridge life zones system is a global bioclimatic scheme for the classification of land areas. It was first published by Leslie Holdridge in 1947 and updated in 1967.

To perform a quantified predictive building performance analysis by means of simulation software a detailed set of specially processed raw climatic data is required called a weather file. In South Africa there is currently a minimal set of weather data files (such as the epw, tmy and iwec formats widely available in the U.S.A.) required to support tasks such as the calculation of building energy consumption or to undertake a predictive thermal simulation of naturally ventilated buildings,

CSIR researchers recently focused on the climate map in SANS 204-2 [1], which is currently used to inform South African built environment professionals in design decision making. Two key questions emerged: Is the resolution of the climate information that is reflected adequate to support optimal design in an emerging era of green building practice? What is the likely effect of climate profile change on building performance over a 100-year horizon? The CSIR researchers realised that a classification system that has a bioclimatic basis would be the best to classify climate, because living beings such as plants, animals and humans are sensitive and directly affected by climate. Furthermore plants synthesised the various climatic characteristics into a unique solution for a particular climate.

The CSIR thus created a detailed, new Köppen-Geiger map to quantify the current climatic conditions in South Africa with unique accuracy. Using 20 years of processed raw precipitation and temperature data [6], a Köppen-Geiger climatic classification with the 13 primary climate categories present in South Africa was developed. This is a significant refinement of the six-zone model of SANS 204-2 [1].

2   Climatic classification

2.1   The climatic regions of South Africa

Low [4] recognized seven vegetation biomes in South Africa that is subdivided into 68 vegetation types. These types are mainly determined by climate but sheltering, soil type, occurrence of veld fires, browsers (wild life), elevation and inclination and other minor factors also play a role. The boundaries for these climatic regions were determined by making use of these vegetation types. Combinations of smaller vegetation types into larger regions, which are easier to map and described from a climatic point of view, were made by Kruger [5].
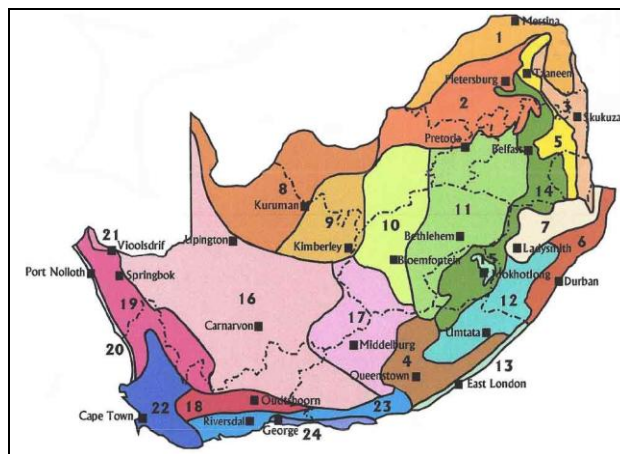

Figure 1 1. Northern Arid bushveld 2. Central Bushveld 3. Lowveld Bushveld 4. South-Eastern Thornveld 5. Lowveld Mountain Bushveld 6. Eastern Coastal Bushveld 7. KwaZulu-Natal Central Bushveld 8. Kalahari Bushveld 9. Kalahari Hardveld Bushveld 10. Dry Highveld Grassland 11. Moist Highveld Grassland 12. Eastern Grassland 13. South-Eastern Cost Grassland 14. Eastern Mountain grassland 15. Alpine Heathland 16. Great and Upper Karoo 17. Eastern Karoo 18. Little karoo 19. Western Karoo 20. West Coast 21. north-Western Desert 22. Southern Cape Forest 23. South Grassland 15. Alpine Healthland 16Great and Upper Karoo 17. Eastern karoo 18. little karoo 19. Western Karoo 20. West Coast 21. North-Western desert 22. Southern Cape forest 23. South Western Cape 24. Southern Cape.

Figure 1 illustrates these climatic regions. Nine Savanna-type climatic regions have been identified, six Grassland-type regions, five Karoo-type regions, two Fynbos-type regions, one Forest-type region and one Desert-type region.

2.2 The South African National Standard (SANS 204-2) [1]

The new SANS 204-2 [1] standard recognizes six main climatic regions in South Africa (Fig. 2). It is an attempt to inter alia establish the maximum energy demand and maximum energy consumption in the design of a particular building into the South African climate into the National Building Standards.
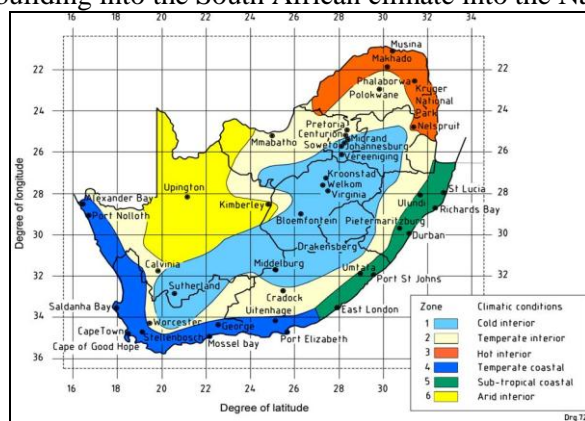

Figure 2: Climatic zone map (SANS 204-2, 2008)

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

If this classification is compared with more detailed research work of that our team at CSIR undertook over the last two years it is clear that much more refinement in the base map would be required and the free availability of weather files to support designers within the built environment.

2.3 Köppen-Geiger classification

There are many different approaches for bioclimatic, empirical climate classification as discussed above. However the Köppen-Geiger classification is still the most widely used worldwide [2]. Köppen was a trained plant physiologist and realised that plants are indicators of many climatic elements. His effective classification was constructed on the basis of the five main vegetation groups determined by the French botanist De Candolle that referred to the original climate zones of the ancient Greeks [1]. The five vegetation groups of the Köppen classification distinguish between plants of the equatorial zone (A), the arid zone (B), the warm temperate zone (C), the snow zone (D) and the polar zone (E). A second letter in the classification considers the precipitation and a third letter the air temperature. The Köppen classification therefore essentially uses combinations of temperature and precipitation.

The CSIR created a detailed new Köppen-Geiger map to quantify the current climatic conditions as accurately as possible in South Africa (Fig. 3). This classification uses a concatenation of a maximum of three alphabetic characters that describe the main climatic category, amount of precipitation and temperature characteristics. A detailed dataset of 20 years of raw processed temperature and precipitation ranging from 1985 to 2005, based on a 1 km x 1 km grid, was obtained from the South African Agricultural Research Council [5] (Agrometeorology staff, 2001). *ArcMap* GIS was used to compile a climatic map using the algorithms (Tables 1 and 2) as described by Kottek [3] (Figure 3).

Table 1 lists the formulas that the research team used to derive the first two letters of the classification. The annual mean temperature is denoted by T_{ann} and the monthly mean temperature of the warmest and coldest months by T_{max} and T_{min} respectively. P_{ann} is the accumulated annual precipitation and P_{min} is the precipitation of the driest month. The values P_{smin}, P_{smax}, P_{wmin} and P_{wmax} are defined as the lowest and highest monthly precipitation values for the summer and winter half-years for the particular hemisphere considered. All temperatures are calculated in °C , the monthly precipitation in mm/ month and the annual precipitation P_{ann} in mm/ year.

In addition to the temperature and precipitation values a dryness threshold P_{th} in mm is introduced for the arid climates (B), which depends on $\{T_{ann}\}$ (formula below), the absolute measure of the annual mean temperature in °C and on the annual cycle of precipitation.

$$
P_{th} = 2\{T_{al}\begin{cases} 2\{T_{ann}\} & \text{if at least 2/3 of the annual precipitation occurs in winter,} \\ & \text{if at least 2/3 of the annual precipitation occurs in summer,} \\ 2\{T_{ann}\} + 14 & \text{in all other cases.} \end{cases}
$$

Table 2 indicates how the additional temperature conditions, i.e. the third letter was determined for arid climates (B) as well as for warm temperate (C) and snow climates (D). In this table T_{mon} is the mean monthly temperature in °C.
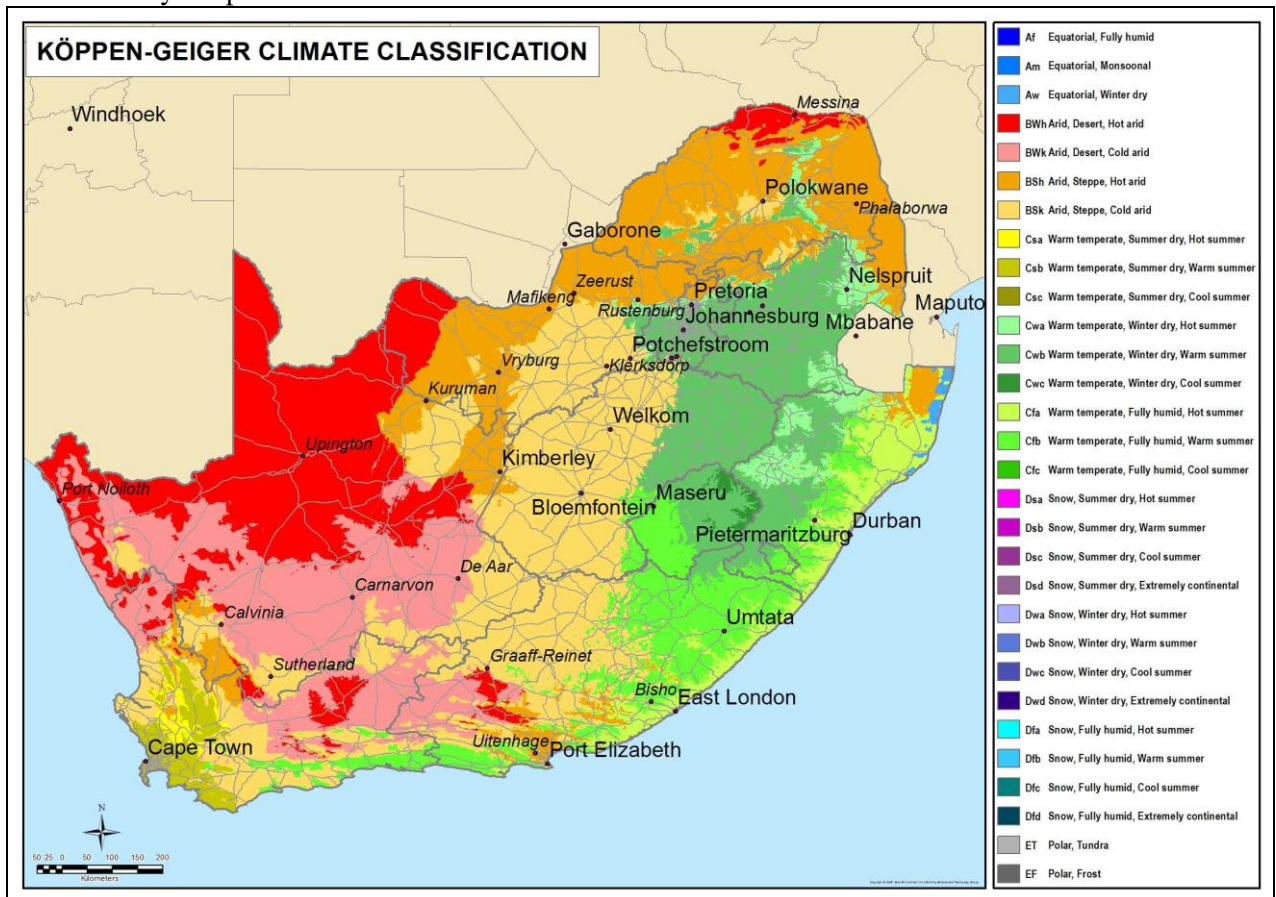

Figure 3: CSIR Köppen-Geiger map based on 1985 to 2005 South African Weather Services data on a very fine 1 km x 1 km grid (Author)

Table 1 Key to calculate the first two letters of Köppen-Geiger climate classification for the main climates.

Type	Description	Criterion
A	**Equatorial climates**	$T_{min} \geq +18$ °C
Af	Equatorial rainforest, fully humid	$P_{min} \geq 60$ mm
Am	Equatorial monsoon	$P_{ann} \geq 25(100-P_{min})$
As	Equatorial savannah with dry summer	$P_{min} < 60$ mm in summer
Aw	Equatorial savannah with dry winter	$P_{min} < 60$ mm in winter
B	**Arid climates**	$P_{ann} < 10\ P_{th}$
BS	Steppe climate	$P_{ann} > 5\ P_{th}$
BW	Desert climate	$P_{ann} \leq 5\ P_{th}$
C	**Warm temperate climates**	-3 °C $< T_{min} < +18$ °C
Cs	Warm temperate climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\ P_{smin}$ and $P_{smin} < 40$ mm
Cw	Warm temperate climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\ P_{wmin}$
Cf	Warm temperate climate, fully humid	Neither Cs nor Cw
D	**Snow climates**	$T_{min} \leq -3$ °C
Ds	Snow climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\ P_{smin}$ and $P_{smin} < 40$ mm
Dw	Snow climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\ P_{wmin}$
Df	Snow climate, fully humid	Neither Ds nor Dw
E	**Polar climates**	$T_{max} < +10$ °C
ET	Tundra climate	0 °C $\leq T_{max} < +10$ °C
EF	Frost climate	$T_{max} < 0$ °C

Table 2 Key to calculate the third letter temperature classification in the Köppen-Geiger classification.

Type	Description	Criteria
h	Hot steppe/ desert	$T_{ann} \geq +18$ °C
k	Cold steppe/ desert	$T_{ann} < +18$ °C
a	Hot summer	$T_{max} \geq +22$ °C
b	Warm summer	not (a) and at least 4 $T_{mon} \geq +10$ °C
c	Cool summer and cold winter	not (b) and $T_{min} > -38$ °C
d	Extremely continental	like (c) but $T_{min} \leq -38$ °C

3 Climate change

In the light of the results of research of the Biometeorology group at the University of Veterinary Medicine in Vienna, the Carinthian Institute for Climate Protection in Klagenfurt [2] and also the MIT Center for Global Change Science [12], the author is of the opinion that South Africa can expect a significant amount of climate change over the next 100 years. This will have a profound impact on the built environment and how buildings should be designed in future. The research team thought that if climate change could be expressed in terms of changes in the Köppen category for a particular location and building performance could be related to a particular Köppen classification it would become feasible to predict the future performance of a building within that particular location. The implication of this ambitious hypothesis is also that if existing weather files are known and connected for a particular Köppen classification it can be reasonably assumed that buildings in other areas that have the same Köppen classification will perform in a very similar way. The team therefore investigated two further aspects, i.e. the thermal performance of two test buildings in different Köppen categories using reliable known weather files. The second investigation was to determine the expected shift in Köppen categories due to climate change.

At the moment many research organizations are working on virtual advanced climate models known as General Circulation Models (GCM) in an attempt to quantify the likely effect. Table 3 illustrates the current percentage distribution of Köppen categories in South Africa calculated from our study. However this is slowly changing. Advanced ocean-atmosphere coupled climate models such as the

Hadley Centre for Climate Prediction and Research's HadCM3 are currently being used in climate change studies [7].

A good example of such a study to calculate future Köppen-Geiger climatic maps is by Rubel [2]. Global temperature and precipitation projections for the period 2003-2100 were taken from the Tyndall Centre for Climate Change Research dataset.

It comprised a total of 20 GCM runs that combines four possible future worlds of emission scenarios with five state-of-the-art climate models. The emission scenarios were developed in the mid-1990s and are based on four different scenarios. Each scenario represents a different view of how the weather will change in future. Scenario A1 is a world with quick economic growth and with a quick launch of new and efficient technologies. A2 is a very heterogeneous world with a focus on family values and local traditions. B1 is a world without materialism and the launch of clean technologies. B2 is a world with a focus on local solutions for economic and ecological sustainability [2]. The main variables in each model include population growth, economic development, energy use, efficiency of energy use and mix of energy technologies [2].

An ensemble of five general GCMs were used to simulate climatic changes, i.e. the Hadley Centre Coupled Model, the National Center for Atmospheric Research-Parallel Climate Model, the second Generation Coupled Global Climate Model, the Industrial Research Organization climate Model Version 2 and the European Centre Model Hamburg Version 4. These analyses predicted the expected climatic changes expressed as Köppen categories for South Africa over the next 100 years.

Table 3 Current % of Köppen categories in South Africa and suggested passive design strategies (Author)

Climatic Characteristics				Passive Design Strategy					
Description	Köppen-Geiger Classification	Area in km²	Percent (%)	Passive Solar Heating	Thermal Mass	Exposed Mass and Night purge Ventilation	Natural Ventilation	Direct Evaporative Cooling	Indirect Evaporative Cooling
Equatorial climates (0.2%)	Aw	2296.00	0.20	■			■		
Arid climates (70.89%)	Bsh	192269.00	16.59	■	■	■	■	■	■
	Bsk	275927.00	23.81						
	Bwh	188784.00	16.29	■	■	■	■	■	■
	Bwk	164629.00	14.20						
Warm temperate climates (28.91%)	Cfa	42918.00	3.70	■			■		
	Cfb	93405.00	8.06	■	■		■		■
	Cfc	84.00	0.01	■	■		■		
	Csa	5120.00	0.44	■	■		■		
	Csb	18395.00	1.59						
	Cwa	31162.00	2.69	■	■	■	■		
	Cwb	140405.00	12.11	■	■		■		
	Cwc	3564.00	0.31	■	■		■		
	Total	1158958.00	100.00						

One of the accessible methods also used in our study to determine the passive design strategies in Table 3 is the bioclimatic chart. Bioclimatic design is used to define potential building design strategies that utilize natural energy resources and minimize energy use [9]. This approach to building design for maintaining indoor comfort conditions was first developed by Olgyay [10]. To address the problems of the original Olgyay chart, Givoni developed a chart for "envelop-dominated buildings"

based on indoor conditions. In 1979, Milne and Givoni combined the different design strategies of the previous study of Givoni [11] on the same chart. The Givoni-Milne bioclimatic chart is currently used by many architects. Software such as *Ecotect™* has a psychometric chart with Givoni-Milne overlays. Table 3 above suggests some passive design strategies using the principles of the Givoni-Milne approach that could be used to improve the comfort of buildings in the context of various different Köppen climatic regions in South Africa.

4   Conclusions

Advanced computational building performance (CBP) software products using weather files make it easier to qualify and quantify the energy and ventilation performance of a particular building design before construction. A good understanding of the basic principles will lead to buildings that use appropriate passive design strategies where possible and environmentally conscious energy efficient architecture. This assumes the availability of accurate weather files to support the process. The creation of a new South African Köppen-Geiger map and the subsequent research provided a good overview of the different climatic regions in South Africa. In ongoing research the team is gradually overcoming the present limited availability of specific weather files. Inter alia the research indicated that 0.2% of the country's area is equatorial, 70.89% arid and 28.91% has a warm temperate climate.

The study indicated that a strong relationship exists between a particular Köppen region and the expected building performance. This was investigated by means of extensive CBP simulations in different climatic regions. On the basis of this a relationship could be established between a particular Köppen region, climatic characteristics and appropriate passive design strategies. When adopting this finding for the prediction of thermal comfort across regions, the impact of regional humidity variations should be factored in separately. Neither the Köppen data nor the *Ecotect™* simulations consider humidity directly and the correlation could not be extrapolated to include this factor.

From other studies and publications it is clear that depending on the climatic region designers can go much further in using thermal mass, insulation, ventilation and solar penetration better. [8] Holm (1996) provides a detailed discussion of the possible measures that should be taken when designing for the different climatic zones in South Africa.

Acknowledgements

Reference

[1] SANS 204-2. *South African National Standard. Energy efficiency in buildings, part 2: The application of the energy efficiency requirements for buildings with natural environmental control*. SABS Standards Division. 2008.

[2] Rubel, F. and Kottek, M. Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger classification. *Meteorologische Zeitschrift*, Vol. 19, (2010), No 2, pp.135-141.

[3] Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel. World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, Vol. 15 (2006), No 3, pp. 259-263.

[4] Low, A.B. and Rebelo, A.G. *Vegetation of South Africa, Lesotho and Swaziland*. Department of environmental Affairs and Tourism, Pretoria, 1996.

[5] Kruger, A.C. *Climate Regions – Climate of South Africa*.

[6] Agrometeorology Staff. *ARC-ISCW Climate Infornation System*. ARC-Institute for soil, Climate and Water, Pretoria (2001).

[7] Wikipedia. *Global Climate Model*. http://en.wikipedia.org/wiki/Global_climate_model. Accessed 20 October 2011.

[8] Holm, D. *Manual for Energy Conscious Design*. Department of Minerals and Energy Directorate Energy for Development. 1996.

[9] Visitsak, S. and Haberl, J.S. An Analysis of Design Strategies for Climate-Controlled Residences in Selected Climates. *Proceedings of Simbuild 2004, IBPSA-USA National Conference*, Boulder, CO, August 4-6, 2004.

[10] Olfyay, V. *Design with Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton University Press, Princeton, NJ: 14-32, 1963.

[11] Givoni, B. Man, Climate and Architecture. Elsevier Publishing Co. Ltd., New York, NY., 1969.

[12] Chen, Y-H. *Estimation of Methane and Carbon Dioxide Surface Fluxes using a 3-D Global Atmospheric Chemical Transport Model*. Center for Global Change Science, Department of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge, MA: 2003.

[13] U.S. Department of Energy. *Weather Data, All Regions: North and Central America WMO Region 4*. http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data2.cfm/region=4_north_and_central_america_wmo_region_4. Accessed 20 July 2012.