# Landscape and architectural devices for energy-efficient South African suburban residential design

by

**Johan Bothma**

Submitted in partial fulfillment of the requirements for the degree

**Master of Landscape Architecture**

in the

Department of Architecture

Faculty of Engineering, Built Environment and Information Technology

University of Pretoria

Study leader: Prof. Gwen Breedlove

August 2004

## Abstract

The study relates international knowledge of climatically responsive and energy-efficient design to work done in South Africa. It also explores the relevance of design devices from international regions to the climates of this country. The research approach explores existing analyses of the main climate regions and the effects of climate factors on human comfort in each, in order to derive appropriate design solutions for the climate of South Africa.

In South Africa obstacles exist in the face of energy efficiency. The cheapness of electricity to the consumer and the virtual non-existence of appropriate legislation appear to be two of the most significant obstacles. Design and subsequent construction of suburban residences is carried out with little regard for climatic context. Water is shown to be a particularly scarce and unevenly distributed commodity, which the affluent have greater access to and consume in greater quantities. However, it is demonstrated that the South African climate is virtually ideal for several climate-responsive energy-efficiency techniques. Especially due to the high solar radiation levels there is potential for various active and passive solar design techniques and technologies.

The impact of atmospheric temperature and humidity, wind, radiation and precipitation on human comfort is investigated. Humidity and wind are demonstrated to be very influential on human comfort, whereas radiation and wind are the most easily manipulated through design. Furthermore, the specific topography and location of a site can influence the microclimate and solar access of an area to a significant degree.

The South African climate is predominantly either hot semi-arid or temperate. Most of the western interior is hot arid whereas the eastern interior and highveld is predominantly temperate, with temperatures increasing to the north and decreasing to the south. The only cool region of the country is found in the highlands of the Drakensberg, with a significant portion of the eastern coast being hot humid.

Methodologies and guidelines for both layout, or macro design, and detailed design of residential suburbs are explored. The manipulation of solar radiation, sunlight and wind, as well as the management of rainwater and used household water is explored. It is shown that designing suburbs to create access to solar radiation forms the basis of solar design, with solar access control, material and surface treatment largely determining the success of individual designs. Wind manipulation is achieved mainly through planting design, influencing mostly heat loss and gain ratios into buildings. Effective household water management can substantially reduce its consumption. Further research is needed in all aspects of climate-responsive design, especially classification of the South African climate and development of design techniques adapted to this context.

## Keywords

Climate, residential, design, energy efficiency, material, construction, site, layout, orientation, topography, hot arid, hot humid, temperate, cool, building, landscape, architecture, solar radiation, ventilation, irrigation

## Opsomming

Hierdie studie bring internasionale kennis oor klimaat-sensitiewe en energiedoeltreffende ontwerp in konteks met soortgelyke werk deur Suid-Afrikaners. Die studie ondersoek ook bestaande ontledings van die hoof-klimaatstreke en die uitwerking van klimaatfaktore op menslike gemak. Sodoende beoog die studie om gepaste ontwerpoplossings vir die klimate van die land voor te stel.

Verskeie struikelblokke bestaan in die pad van energiedoeltreffendheid in Suid-Afrika. Die lae prys van elektrisiteit en afwesigheid van minimum regulasies blyk twee van die belangrikstes te wees. Ontwerp en konstruksie van voorstedelike wonings geskied sonder inagneming van klimatologiese konteks. Water blyk ook 'n besonders skaars hulpbron te wees. Daar is groter toegang daartoe in meer gegoede en word daar in groter hoeveelhede gebruik. Dit word egter getoon dat Suid-Afrika se klimaat hoogs geskik is vir klimaat-sensitiewe ontwerp, veral vanweë die hoë vlakke van son energie, aanwendbaar volgens beide aktiewe en passiewe benaderings.

Die belangrikheid van atmosferiese temperatuur en humiditeit, wind, son energie en neerslag op menslike gemak word ondersoek. Humiditeit en wind blyk die grootste invloed op menslike gemak uit te oefen, terwyl son energie en wind die optimaal deur ontwerp gemanipuleer kan word. Verder speel die spesifieke topografie en ligging 'n belangrike rol in die mikroklimaat van 'n terrein.

Die Suid-Afrikaanse klimaat is oorwegend of warm en semi-aried, of gematig. Meeste van die westelike binneland is warm-aried, terwyl die westelike binneland en hoëveld gematig is, met 'n gemiddelde toename in temperature na die noorde. Die enigste koel streek is te vinde in die Drakensbergse hoogland, en 'n beduidende deel van die Ooskus is warm en vogtig.

Metodologieë en riglyne vir uitleg, grootskaalse ontwerp en detailontwerp van residensiële woonbuurte word ondersoek. Die manipulasie van uitstraling, sonlig en wind, sowel as die bestuur van reënwater en huishoudelike afloop word aangespreek. Daar word gewys dat toegang tot sonlig die basis vorm vir woonbuurte wat vir son energie benutting beplan word, terwyl beheer van sonlig, keuse van materiaal en oppervlakbehandeling die sukses van

individuele ontwerpe bepaal. Windbeheer word hoofsaaklik toegepas deur plantontwerp en strukturele elemente, deur die verlies van hitte en opname deur geboue te beheer. Effektiewe residensiële waterbeheer kan die gebruik daarvan dramaties verminder. Daar word ook getoon dat meer ondersoek na veral die klassifikasie van die Suid-Afrikaanse klimaat, ten opsigte van klimaat-sensitiewe ontwerp, en die ontwikkeling van ontwerpriglyne in daardie konteks nodig is.

## Sleutelwoorde

Klimaat, residensieel, ontwerp, energie doeltreffend, materiaal, konstruksie, terrein, uitleg, oriëntasie, topografie, warm en aried, warm en humied, gematig, koel, gebou, landskap, argitektuur, uitstraling, ventilasie, besproeiïng.

# TABLE OF CONTENTS

## List of figures

## List of tables

## List of abbreviations

ASLA: American Society of Landscape Architects Foundation

BTU: British thermal unit

CSIR: Council for Scientific and Industrial Research

DBSA: Development Bank of Southern Africa

DEAT: Department of Environmental Affairs and Tourism

DI: Discomfort index

DME: Department of Minerals and Energy

DWAF: Department of Water Affairs and Forestry

GWh: Gigawatt hours

IDRC: International Development Research Centre

ISES: International Solar Energy Society

kWh/m$^2$: kilowatt hours per square metre

MW: megawatt

NBRI: National Building Research Institute

RH: Relative humidity

SABS: South African Bureau of Standards

SBAT: Sustainable building assessment tool

SEED: Sustainable Energy for Environment & Development Programme

SHI: Sustainable Homes Initiative

UN: United Nations

WHO: World Health Organisation

W/m$^2$: Watt per square metre

## Glossary of terms

Albedo: The ratio of reflected solar radiation to the total incoming solar radiation where both streams are measured across the complete wavelength range of solar radiation.

Built windbreak: A built structure such as a fence or wall that is designed and placed to reduce the speed of oncoming wind on its downwind or leeward side.

Climate/climatic region: A generic term used in this study to indicate any geographic area with common climatic characteristics.

Discomfort Index: A system used by weather services to determine how uncomfortable certain combinations of temperature and humidity are to humans, determined by the equation $(2 \times T) + (RH/100 \times T) + 24 = DI$ where: T = temperature in °C, RH = relative atmospheric humidity and DI = discomfort index.

Embodied energy: Energy associated with the production, transport and storage of materials in construction that is "hidden" and not directly associated with the building process itself.

Emissivity: The degree to which a real body approaches being a perfect absorber and emitter of radiation.

Energy efficiency: Using energy and the resources used in its production in ways that eliminate unnecessary or avoidable waste.

Life-cycle costs: The comparison of the capital expenditure used to create the system compared with the savings in money that arise from reduced fuel use.

Shelterbelt: A structure that is composed of plants and designed and placed to reduce the speed of oncoming wind on its downwind or leeward side.

Skyspace: The solar access zone or portion of sky north (in the southern hemisphere) of a collector that must remain unobstructed by objects that block solar radiation, in order for a solar collector to function optimally.

Sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Windchill factor: The process through which wind augments the convective heat loss through the skin, resulting in a temperature being perceived as being lower than the ambient atmospheric temperature. This phenomenon is especially pronounced under cold conditions.

Windbreak: A generic term used in this study to indicate both built windbreaks and vegetative windbreaks or shelterbelts.

# 1 CHAPTER I – INTRODUCTION

## 1.1 Background for the study: the problem in context

### 1.1.1 Introduction

> "Achieving sustainable development is no easy task. Significant changes will be needed—in decision-making at the highest levels, and in day-to-day behaviour by producers and consumers—if we are to reach our goal of development that meets the needs of today without sacrificing the ability of future generations to meet their needs…If we are to achieve sustainable development, we will need to display greater responsibility—for the ecosystems on which all life depends, for each other as a single human community, and for the generations that will follow our own, living tomorrow with the consequences of the decisions we take today" Kofi A. Annan 2001. (UN (b), accessed 01-09-2003).

It is with this vision as foundation that this study will investigate energy inefficiency in South African higher income residential suburbs and what can be done to contribute to an energy-efficient and more sustainable South Africa. To this end Section 1.1 will investigate the following problems associated with the ways that we design and maintain our cities:

1) It will explore the energy and resource consumption crisis with which the world and particularly South Africa is faced;

2) It will consider the lack of planning and design aimed at reducing the consumption of these commodities; and

3) It will investigate the results that this situation has had on our cities and landscapes.

### 1.1.2 Energy and resource consumption crisis in South Africa and the world

The energy crisis in 1973/1974 resulted in large amounts of research and development being done in energy efficient designs for residential and commercial applications in America and

Europe. Yet when oil prices fell in the early eighties much of the awareness was forgotten. This meant that little of the comprehensive theoretical solutions to the energy problems were implemented. Unfortunately, as Owens (1987:169) states, the problem did not disappear with the fuel crises and the need for efficiency still remains. The steady increase of energy consumption in all sectors of society has lead to widespread pollution of land, sea and air, reduction and degradation of natural habitats and problems in energy supply. In fact, "…Consideration of Agenda 21 shows that almost every problem area is predominantly an issue of energy supply…" (Scheer 1994:4).

Sustainable energy provision and efficient energy utilisation are topics that are receiving considerable attention worldwide. The United Nations (UN) has set as one of its Millennium Development Goals the ensuring of environmental sustainability, which it aims to achieve by integrating the principles of sustainable development into country policies and programmes, reversing the loss of environmental resources and improving the lives of disadvantaged and underdeveloped populations. The seriousness of this goal is reflected by the fact that all 191 UN member states have pledged to meet the above goals by the year 2015 (UN (c), accessed 01-09-2003). The energy sector itself is the focus of much attention and the UN Development Programme (UN (a), accessed 01-09-2003) has defined four energy priorities that must be addressed if energy efficiency is to be achieved. These are:

1) Strengthening national energy policy frameworks to incorporate sustainable energy considerations.

2) Promoting rural energy services focusing on energy efficient conventional and renewable heating, cooking and electricity provision in rural areas.

3) Promoting clean energy technologies and addressing both global environmental protection and local development needs.

4) Increasing access to financing for energy focusing on support to enhance developing countries' ability to attract investment financing for sustainable energy options.

The industrial and economic sectors are also spending considerable resources in developing and marketing sustainable and efficient solutions for energy provision. A scan of publications dealing with energy issues, such as Refocus (Refocus September 2002-September 2003), the official magazine of the International Solar Energy Society (ISES), shows that photovoltaic and solar, wind turbine, biomass and even ocean tidal utilisation technologies are being developed and implemented throughout the world at an increasing rate. The race to find sustainable energy alternatives has begun.

However, Michels (1979: vii) contends that energy conservation is far more important than solar energy utilisation, as design professionals and the societies that they design for and aim to serve, are trapped by the promise of more efficient technologies in the future. Napier (2000:1.3) shares a similar view, stating that the most elementary and effective way in which positive environmental changes can be brought about through architecture is by saving energy. In other words, not needing large quantities of energy to live our lives is more sustainable than producing that energy from solar, or other renewable sources. The solution is not creating the same amounts of energy more efficiently, or even using the same amounts of energy efficiently, but using less energy and still creating it in a sustainable and efficient manner. Yet residential, industrial and commercial design in South Africa seems to be characterised by energy inefficiency. According to van Horen and Simmonds (1998:895-896) two large obstacles, created by the national utility Eskom, exist in the development and especially implementation of energy efficiency measures in South Africa. The first of these is the fact that coal and subsequently electricity are inexpensive in this country. Whereas the prices of electricity are steadily rising in many industrialised countries the real price of electricity has for various reasons remained low or even decreased in South Africa, eliminating one of the major potential driving forces in energy efficiency. The second problem is that until recently Eskom experienced a state of oversupply of electricity and this is still the situation in many rural areas and smaller towns. The company made massive capital investments in its supply capacity during the early 1980s but the growth of electricity demand since then has been smaller than projected, meaning that for years the company has had a much larger supply capacity than was necessary. This meant that efforts directed towards new energy-efficient production facilities were considerably delayed compared to those of other large utility companies around the world. Gibberd (30-09-2003) is of a like mind, stating that one of the key obstacles hindering energy efficiency in South Africa is the relative cheapness of electricity. In his opinion energy-efficient technologies should be heavily subsidised, and general behavioural patterns changed by creating greater public awareness of their benefits and the need to adopt them.

The importance of both cleaner energy and more efficient energy use is illustrated when one considers the pollution caused by energy production through the burning of fossil fuels. As Ward (2002:16,19) indicates, South African coal is relatively low in sulphur, which is a key contributing factor in the formation of acid rain, but it is high in ash, which causes respiratory health problems. Although the performance of Eskom is well within the regulatory requirements for particulate emissions of ash, as regulated by the Chief Air Pollution Control Officer, and the company has registered a downward trend in the total tons of particulate emitted annually (Eskom (a), accessed 30-07-2003), the associated health risks of the different emissions are substantial. Emissions from the energy sector, which includes the combustion of any raw material to generate energy, is the single largest source of carbon dioxide ($CO_2$) and sulfur dioxide ($SO_2$) emissions in South Africa. The Department of Environmental Affairs and Tourism (DEAT) reports that concentrations of carbon dioxide as measured at Cape Point show an overall increase of approximately 0.6% per year (DEAT (a), accessed 24-08-2003). This is a global phenomenon. Especially in the major urban areas, where the concentrations of sulfur dioxide, nitric oxide, ozone and particles are high, health risks increase, especially in people who are already experiencing respiratory problems. Considering the fact that more sustainable energy production technologies are not predicted to make a significant impact on the energy sector in the foreseeable future and that such applications currently only find implementation in specific and often remote locations (Eskom (b), accessed 30-07-2003) it is of paramount importance that the amounts of emissions are not only kept as low as possible through efficient energy production, but also through efficient energy use.

> "Urban hydrology will have an increasing role to play in the sustainability of human societies. Urban population is growing at an accelerating pace and, simultaneously, sources of water supply decrease or, at the best, remain constant in quantity but decrease in quality" (Niemczynowicz 1999:2).

Access to safe drinking water, a luxury taken for granted in developed countries, does not exist for many across the world. The World Health Organisation (WHO) reports that in the year 2000 1,099 billion people or 18% of the world population had no access to improved water (WHO, accessed 01-09-2003). As the population of the world increases and water resources become more strained due to pollution, waste and uneven distribution, this figure can surely only increase. According to the State of the Environment of South Africa Report (DEAT (b), accessed 24-08-2003), the problem of water availability is particularly severe in this country. South Africa has one of the lowest rainfall conversion rates in the world, as only 8.6% of precipitation is available as surface water. Groundwater reserves are also relatively low compared to international averages. In fact Basson (1997:65) contends that South Africa faces the possibility that its water demand may soon exceed its available resources, unless the efficiency of the different user sectors is drastically and rapidly improved, especially in the rapidly growing domestic and industrial sectors.

### 1.1.3 Energy efficiency as an afterthought in South African urban planning and design

The provision for the use of solar and other climatic resources in the planning phases of an urban area is essential. Failure to do so would mean that the possibility of using these resources could be lost for an extended period of time or permanently. Often it is impossible to rectify mistakes made in the planning and layout phases of urban areas, even with sensitive and skilled design. Altering the existing urban fabric and the structures therein is usually prohibitively costly, consuming time and manpower. Radovic (1988:374) explains that policies to retain the possibility of using such natural resources as solar energy and wind are of great importance, especially in residential sectors. Most first world countries have energy conservation regulations. However, according to the Department of Minerals and Energy (DME), no energy efficiency regulations exist in South Africa (DME (c), accessed 05-08-2003). However Golding (16-01-2004) states that this situation is set to change and although only codes of conduct and standards currently exist, several programmes such as the Draft Energy Efficiency Strategy and the Energy Act are in the process of being developed. The Housing Code of the Department of Housing, which is enforceable through regulatory measures, will also soon include provision for energy efficiency practices.

The South African climate is particularly mild with a relatively short heating season throughout most of the country. Lombard, Mathews & Kleingeld (1999:229) believe that this fact, coupled with the popularity and affordability of small electrical resistance space heaters mean that most homes are built with no regard for climate-responsiveness or thermal response considerations. Currently the potential benefits that the South African climate has to offer are not being realised to any meaningful degree and energy efficient designs are usually only single, isolated developments or projects. Furthermore, where sustainability

**Figure 1.1 Urban sprawl in a Pretoria suburb**

programmes exist in South Africa, they often tend to focus on economic sustainability without paying much attention to environmental matters. According to the Council for Scientific and Industrial Research (CSIR)(accessed 05-03-2004) the Joburg 2030 Vision is a good example of this phenomenon, with especially its housing programmes falling short of achieving meaningful change. The report states that "…It is therefore doubtful whether the housing delivered by the City of Johannesburg will live up to its vision of sustainable housing except in a few showcase projects."

### 1.1.4 Cognitive dissonance in urban design

Thayer and Richman (1984:192,193) explain that periodically throughout history a state of "cognitive dissonance" occurs in design. This is a gaping divergence between what societies know to be the visual reality of their cities and what they hold as the visual ideal of what their cities should look like. Such a period is typically followed by a revolution in planning and design. For instance, Jellicoe and Jellicoe (1995:233) explain how the English Landscape School was a rejection of the highly manicured and geometric patterns of French Baroque, initiating the idea that man and nature are equal and can exist in harmony, as opposed to nature being subservient to and in competition with mankind. Considering the vast amounts of ever-decreasing resources that humans use and rely upon to live, especially in large cities, and the research that is currently being done on ways to use these and other resources in efficient and sustainable ways, it stands to reason that such a state of cognitive dissonance presently exists in many cultures and urban communities. Therefore a revolution in urban design and living is needed, and renewable ways of creating and using energy must form an integral part of this new way of life.

Such a revolution nevertheless cannot simply be a formula that is universally applied to cities everywhere. Cities are a reflection of their people and their cultural, religious and historical backgrounds. Thus methods for reducing energy consumption must be acceptable to the people of a city and integrated with the existing urban fabric. Furthermore, such methods can only be truly effective if they reflect the climatic setting of the city that they are intended for. Serra (1988:7) calls for a regionally specific architecture to replace the "jaded building types of international architecture", that is adapted to its place in the landscape and that responds to the influences of "…sun and shadow, to the wind and moisture, to the day and night and, in brief, to all that is contradiction in the world and in human life."

Hyde (2000:3-4) defines this concept as "climate-responsive architecture" and states the following in this regard:

> "Climate-responsive design is based on the way a building form and structure moderates the climate for human good and well-being. Any cursory exploration of this concept reveals that there is a strong form determinant to the relationship. The pragmatic and physical parameters associated with this aspect of architectural design are constants that transcend time and are regulated by the laws of science, in particular the laws of thermodynamic. Yet the pragmatics are also balanced by a desire to respond to the poetic aspects of climate. Many architects seek to use the building as an implement, not just to moderate climate, but to enhance and expose the senses to the spectrum of thermal and visual delight…Climate-responsive design … requires of the architect both analytical and synthesis skills to optimise the relationship between site, climate and briefing requirements. In addition, those buildings which use climate as a form determinant in both the pragmatic and poetic sense result in climate-responsive architecture."

### 1.1.5 Summary

In Section 1.1 the review of current literature regarding the provision of energy to cities indicates that these activities are associated with many environmental and health problems and our ability to adequately and appropriately address these issues in the future is in jeopardy. Efforts are under way to find new and improved methods to provide this energy, yet one of the key solutions is to use less energy in the first place. In South Africa several obstacles exist in the face of energy efficiency, amongst which the cheapness of electricity to the consumer and the virtual non-existence of appropriate legislation appear to be two of the most important. It was also found that in higher income households, energy efficiency is not a consideration that receives particular attention, mainly due to the lack of structured programmes to promote implementation and the comparatively inexpensive nature of conventional alternatives.

## 1.2 Motivation

### 1.2.1 Introduction

For research and development in any specific field to be justifiable the context of the problem must first be established and then it must be determined if the research can contribute to its solution. It has been established in Section 1.1 that the ways in which energy and resources are utilised and in which our cities are planned and designed must be drastically revised if they are to become energy efficient. The problem has thus been identified. The aim of this study is to determine whether a potential for furthering the sustainability of South African cities exists within the residential sector by increasing their energy use efficiency. To establish whether this is the case several aspects have to be considered and the role of South African suburbs in the consumption of energy and resources determined. Subsequently the following issues will be addressed in Section 1.2:

1) What the potential impacts of residential suburbs in the energy efficiency of cities are;

2) What the potential is for energy-efficient and climatically responsive residential neighbourhoods in South Africa;

3) What the potential contributions of landscape design of higher income residential suburbs towards the energy efficiency of South African cities are;

4) What the role of legislation and governmental involvement might be.

### 1.2.2 Potential contributions of residential suburbs towards energy efficiency

Energy efficiency may for many mean hi-tech solutions to large-scale urban and industrial developments, far removed from the common activities of daily life. Others may view energy efficiency as a goal set by multi-national oil or utility companies. Yet our everyday living environment, our homes and the simple activities that take place there, provide the opportunity for some of the most fundamental advances in energy efficiency.

> "The search for new {energy} alternatives has focused on new resources and/or more efficient exploitation. Instead, modern man should turn to natural systems and processes, which provide a sound basis for design and problem solving. The use of basic 'natural technology' augmented by more technical systems – if needed – can satisfy man's needs." (Yellot and Aiello 1978:73)

South African households are currently responsible for the consumption of about 24 % of the country's energy (DME (a), accessed 15-07-2003). To reduce this figure more efficient ways of using energy in the residential sector must be found. To this end this study will explore ways in which renewable sources like solar energy and wind can be utilised. Designs utilising such sources of energy may contribute to energy efficiency in different ways. For instance, Holm (1996:1) states that the life-cycle and maintenance costs of correctly designed passive solar houses are lower than those of conventional houses. This means that there may be a monetary incentive for owners and developers to design houses with climate and energy efficiency in mind. Ward (2002:57) shows that higher density climatically responsive housing developments are also less costly to build, they are more land and resource efficient, create a greater communal sense of place and human scale and can support more amenities than the standard one-lot-one-house approach. Guthrie (1991:14) points out that further embodied benefits exist by reducing the amount of energy consumed by at resident level. Saving energy at the end of the production-consumption chain results in energy savings throughout the rest of the process.

Yet perhaps some of the most significant household savings may be achieved by simply adapting our lifestyles and especially by changing small, but wasteful habits. In an experiment to test household energy efficient design devices in Pretoria, South Africa, Basson Page-Shipp and Johnson (1986:38) have demonstrated that occupant behaviour can play a greater role than the appropriateness of the design of a building. In this experiment failure by the occupants of the test design house to correctly utilise simple passive solar design devices and other negative habits resulted in the design house faring more poorly on some accounts than the control house, which did not have these devices installed. In other words, energy efficiency can only be achieved in part by design; the rest is up to the users. Some of the most significant savings in the resources of the earth can come from simply changing our habits. Nel (2002:182) explains that simply taking short showers instead of bathing can save up to 10000*l* per household per year.

### 1.2.3 Potential for energy-efficient and climatically responsive suburbs in South Africa

If climate-responsive design is to be used to save energy in the residential sector of South Africa it must be established if the climate of the country provides the potential to do so. In the White Paper on the Energy Policy of the Republic of South Africa (1998) it is stated that the theoretical potential for solar water heating in South Africa is 500 GWh per year and although more than 484000m$^2$ of solar water heater panels have been installed, this constitutes less than 1% of the potential market. Furthermore, the installed capacity of photovoltaic systems in this country is only approximately 5 MW peak, of which 50% is used for telecommunications and non-residential applications (DME (c), accessed 06-08-2003). Eggertson (2002:42-43) explains that solar insulation levels in South Africa are very high, ranging between 4.5 kWh/m$^2$ and 6.4 kWh/m$^2$, compared with 3.6 kWh/m$^2$ for parts of America and 2.5 kWh/m$^2$ for Europe. This means that the amount of solar energy per square area of land that reaches the surface of the earth is much higher for this country than for most other countries. Table 1.1 compares the percentages of sunshine of that which is possible, for some southern African cities, with other international cities, clearly illustrating that sunshine is an abundant resource in this region.

**Table 1.1 Average annual percentage of the possible sunshine for selected cities (Neethling 1978:46)**

| | | | |
|---|---|---|---|
| *Buenos Aires* | 59 | *Paris* | 48 |
| *Hamburg* | 36 | Pretoria | 74 |
| *Honolulu* | 65 | Durban | 54 |
| *London* | 33 | Bloemfontein | 78 |
| *Miami* | 65 | Kimberley | 78 |
| *Sydney* | 49 | Cape Town | 67 |
| *Washington* | 57 | Windhoek | 82 |

In addition to this vast potential for utilising the energy of the sun, the climate of South Africa is generally mild compared to that of many other regions of the world. Although harsh conditions do occur in some isolated areas for brief periods, minimum temperatures in particular are not extreme and the need for heating is secondary to that for cooling in almost all areas. According to Neethling (1978:7), in 1976 only 7% of the total net energy consumption per household in South Africa was for space heating, compared to 63% in America and 82% in Holland. Furthermore, Meyer & Tshimankinda (1998:679) state that South Africa has some of the best conditions for solar water heating in the world but currently the number of higher income residences that are fitted with them is insignificant, mostly due to the high initial cost of solar water units and cheap South African electricity. Yet according to Ward (2002:25) domestic water heating accounts for one third of the domestic power used in South Africa and standard electric geysers account for roughly 60% of the electrical bill of an average middle income household. Solar water heaters could save the country 2000 MW of capacity - the equivalent of a coal-fired power station - and the units also pay for themselves in two to five years in energy savings. One of the most attractive advantages for South Africa, a country in dire need of employment creation and economic stimulation, is the potential job creation benefit inherent in renewable development and retrograding. Holm (2001:43) says that one study found that if solar-passive design was applied to half of the existing and new South African homes, 70 000 direct and 130 000 indirect jobs would be created over the next ten years.

### 1.2.4 The role of landscape design in the energy efficiency of South African higher income suburban residential areas

A scan through the Internet shows that much of the research on energy efficiency in South Africa and especially the subsequent implementation thereof seems to be occurring in lower income housing, both formal and informal. A myriad of different programmes and initiatives operating on every possible scale exist throughout the country. Many cities throughout South Africa have programmes and initiatives aimed at creating sustainable and economically viable housing for underprivileged communities in conjunction with local economic development. Two examples of such programmes are the EcoCity project of the Johannesburg City Council, currently focused on development in the Midrand area (Midrand EcoCity Website, accessed 05-08-2003) and the Durban Self-Help Housing Project, a project under The Australian Agency for International Development, which promotes and develops the use of mud brick house construction through established organisational networks in the area (The Durban Self-Help Housing Project Website, accessed 05-08-2003). National projects like the Urban Sustainable Energy for Environment & Development Programme (SEED) aim to promote sustainable development through the integration of energy and environmental-related issues in the context of the urban environments of South Africa (SEA Website, accessed 05-08-2003). Programmes funded by multiple organisation collaborations such as The Sustainable Homes Initiative, involving Eskom, USAID and the UK Department for International Development, also contribute to furthering training for and networking of efforts to help historically disadvantaged communities build healthy and efficient homes (SHI website, accessed 05-08-2003).

From a human comfort and health perspective, living conditions in disadvantaged settlements usually range from sub-optimal to potentially life-threatening. Understandably the environmental impacts of any climate modification measures taken by the residents to improve their comfort are not considered. Thus redevelopment programmes to improve energy efficiency in lower income townships are usually also largely aimed at improving the quality of life and health of the residents. This adds incentive and political motivation for spending considerable effort and resources on such projects. It is therefore reasonable to infer that these measures, if they are practically and financially feasible and understood by their target audiences, will be quite readily implemented. However, this vital catalyst, namely the improvement in quality of life and health standards of the residents, does not exist in higher income areas. Residents of these areas can afford to "buy" comfort in various forms such as portable resistance heaters, under floor heating, electric blankets, large amounts of hot water, air conditioning and other measures appropriate to the specific climate. A study has found that poor people in Midrand use up to a quarter of their income on energy, 65% of whom earn less than R800 a month. In contrast affluent people in that area spend only 2% of their income on energy (Midrand EcoCity Website, accessed 05-08-2003). It is possible that this is a significant reason why residential energy efficiency has fallen by the wayside in higher income areas. As stated in the White Paper on the Energy Policy of the Republic of South Africa 1998, despite the higher energy consumption rates of affluent households and the near-total reliance on electrical energy of such users, energy policies have placed little emphasis on encouraging energy conservation in such households (DME (c), accessed 06-08-2003).

### 1.2.5 The role of structuralised urban design codes within a socio-political and economic setting

Alp (1988:79) states that designers of the urban environment have the possibility to use natural and climatic elements to create more comfortable and sustainable buildings, and have a moral obligation to do so. However according De La Barra & Rickaby (1987:6) proposals that aim to conserve fuel or any other resource usage only have merit when the same standard of living is offered to occupants as conventional land use policies. Energy efficiency has little chance of becoming a common reality in South Africa, or any country for that matter, unless regulations that make certain standards compulsory are put in place, as this extract from Knowles (2003:15) implies:

> "So far, there has been little incentive for developers to worry about the long-term energy costs of keeping our buildings comfortable and repaired. Pressures are so enormous to build fast and move on quickly to the next project that construction techniques emphasize rapid assembly over the effects of long-term wear and tear. Developers do not pay the bills for heating, cooling and lighting over time and seasons. Consequently they have demanded that architects specify energy-intensive systems rather than make the effort to design with nature. In the simplest ungrammatical terms, we 'grow cheap' and 'maintain expensive'."

Designers and developers can make individual or small aggregations of developments energy efficient and climatically appropriate through correct placement, orientation and appropriate land use density. However, Sheldrick & Cooper (1987:190) contend that measures to make entire areas or regions energy efficient lie beyond the scope of influence of such bodies. Municipalities and governments determine much of what is done on intermediate and regional scales and according to Lam (1986:63) urban energy efficiency and climate-responsiveness can become mandatory, as illustrated by the plan of Peking's Forbidden City in Beijing, China (Figure 1.2). Here laws required that all major buildings be orientated north-south and only service buildings face east-west. The major buildings are also designed with buffer zones on the eastern and western sides and openings to the exterior are reduced for climatic amelioration. Although complete governmental enforcement and control is perhaps too extreme, energy efficiency in the building industry will only be a reality when certain standards become mandatory.

**Figure 1.2 North-facing buildings of the Forbidden City in Beijing, China (ccf-dbs, accessed 18-05-2004)**

To this end it is important that efforts are coordinated and integrated by an overriding policy structure. Lombard *et al* (1999:236) state that a "basket of actions" has to be defined and formalised, through such measures as upgrading and enforcing of building codes, taxing of environmentally unsustainable appliances and temperature regulation methods, and public awareness campaigns and educational programmes to illustrate the importance of energy efficiency and proper associated city zoning. Although this study does in no way aim to address all of these issues it nevertheless intends to form a part of, and aid such programmes and efforts. By providing an information basis for energy efficient design in the South African climatic context this study will consider international trends in climate-responsive design and provide much-needed information.

For suitable and practical building standards to be established, a common "design language" for each climatic region must be created that responds to the requirements of each region. Hawkes, McDonald and Steemers (2002:57-47) define this concept as "typology" in design, or creation of appropriate design solutions through reference to existing successful solutions to similar scenarios. The strength of this methodology is that it does not copy solutions from one example and apply them verbatim to another design scenario but rather creates a conceptual and functional framework within which specific solutions to each scenario can then be generated. In this fashion "existing knowledge" forms the basis from which the problem is solved. This study aims to contribute to the establishment of such typologies, which may in future be used to formulate appropriate design specifications and laws that govern energy efficient residential design.

### 1.2.6 Summary

1) From Section 1.2 it can be seen that the South African residential sector contributes significantly to the amount of energy used in the country.

2) It was demonstrated that the South African climate is virtually ideal for several climate-responsive energy efficiency devices and techniques and that indeed the implementation of these could prove to be favourable for the building industry and users alike.

3) It was found that especially in the higher income section of the residential sector the implementation of these measures has not occurred to a meaningful degree and that most awareness and implementation programmes are aimed at disadvantaged communities.

4) Lastly it was found that the implementation of most of these techniques in more affluent areas on any meaningful scale is unlikely if they are not included in building codes and required at least to a minimum specification by legislation.

## 1.3 Problem statement, hypotheses and research methodology

### 1.3.1 The problem statement

The aim of this study is to identify and describe landscape and architectural devices that will bring about energy efficiency in South African suburban residential design based on the climate regions of the country.

The research approach will be to explore and understand existing analyses of the main climate regions and the effects of climate factors on human comfort in each, in order to derive appropriate design solutions for the climate of South Africa. Because the scope of the different design devices and the geographical region of the study area are vast, a design device can yield different results when applied in different locations, even if they are in the same climate region. Subsequently the study will be a qualitative investigation of the different climates and the design devices that may be used in these climates. Mouton (2001:161) describes qualitative research as being based on descriptive and evaluative questions and defines it as "…evaluation approaches [involving] the use of predominantly qualitative research methods to describe and evaluate the performance of programmes in their natural settings, focusing on the process of implementation rather than on (quantifiable) outcomes."

Thus the research will describe the general attributes of different climates and design solutions and set basic parameters for their definition and implementation. The structure of the research process, based on the three sub-problems, follows.

### 1.3.2 Hypothesis one: The climate factors that influence human comfort can be identified and described

**Sub-problem one**

The first sub-problem is to identify the climatic factors that are of specific importance to human comfort. The factors that will be considered are those that can be manipulated or influenced to aid climatically responsive design. The effects that these factors have on human comfort in different climate regions must also be understood. The effects of combinations of climatic factors, resulting in phenomena such as wind chill and human discomfort index must also be understood.

From the preliminary literature overview these factors have been identified as air temperature, humidity, wind, solar radiation and precipitation. These climate factors will be studied from a human comfort perspective. This will be done to determine the relative importance of the factors in different climates and to what degree they can be utilised in climate-responsive design. The different physiological effects of these elements on humans will also be explored. For this purpose sources dealing with climate-responsive design and human physiology will be consulted.

### 1.3.3 Hypothesis two: The climatic character of the landscape can be identified and described

**Sub-problem two**

The description of the basic climate regions must be based on weather phenomena, climate-responsive design considerations and human comfort rather than purely geographical considerations. The climatic conditions that define each climate region must be defined and parameters set for the identification of the different climate regions. Lastly this sub-problem must illustrate what influences the specifics of the location of a site will have on its solar access and radiation energy concentrations. This must be done in terms of the site-specific factors of latitude, altitude, slope and topography.

From the preliminary literature overview the basic climates have been identified as hot humid, hot arid, temperate and cool. Several other climate regions such as Mediterranean and composite climates have also been encountered, yet from a human comfort perspective these regions seem to fall into the four major types. Thus these four climate types will be described. These descriptions must facilitate climate-responsive design that aids human comfort and cannot be purely geographical. Therefore sources with geographical and design perspectives on climate will be considered.

The next step involves determining what the climatic regions of South Africa are. To this end climatic classifications of South Africa from a geo-climatic and design perspective will be considered. A geo-climatic classification of the country by Schulze (1965) and a more design-orientated classification by Napier (2000) will be used to determine the climatic context of South Africa.

Secondly, the effects of characteristics such as slope, solar aspect and latitude on the amount and concentration of solar radiation that a site receives will be investigated. The specific influences of these factors on microclimate will also be examined. For this purpose sources dealing with solar design and climatology will be consulted.

### 1.3.4 Hypothesis three: Climate design devices for the climate regions, that enable energy efficiency, can be identified and described

**Sub-problem three**

The third sub-problem will assess strategies for achieving energy efficiency in suburban residential design. Design techniques will be investigated that utilise and respond to climate conditions that are comparable to the climate regions of South Africa. The application of the devices in climatic contexts and their potential outcomes or expected effects will also be explored.

To this end design solutions to climatic challenges from across the world but compatible or adaptable to the local context will be considered and evaluated. Due to the various scales and levels of design involved in suburban development, solutions dealing both with neighbourhood and individual property scale must be included in the study. Solutions dealing with solar access through orientation and placement of buildings on site and landscape design, different building shapes and layouts, passive heating and cooling of buildings and associated building materials, windbreaks and the manipulation of wind, as well as water harvesting, conservation and recycling techniques will be investigated.

## 1.4 Delimitations and boundaries of the study

1) The intended application of the study will be limited to the geographical area of South Africa.

2) The design devices explored in this study will be aimed at affluent suburban residences.

3) The design devices established in this study will seek to advance energy efficient and climatically appropriate design by responding to the climatic regions of South Africa.

4) Weather elements and processes of site and regional scale, solar radiation, sunlight and available water that together constitute the climate of a specific location or region will be investigated. These elements and factors are to some extent a given, whether modified by humans or undisturbed, to all sites and locations and thus represent the most accessible and available resources for use by the designer.

5) The descriptions of climate regions and the parameters set for their definition will be based specifically on human comfort and climate-responsive design.

6) Considerations regarding the embodied energy of building material will not be considered and mention thereof in the text will only be to illustrate secondary benefits of a given design technique or device.

7) The effects of the production and transport of building material on the environment and associated considerations such as fuel consumption for transport will not be considered.

8) The expected lifecycle of building materials are not investigated in this study.

9) The financial implications of the guidelines in this study are not taken into consideration unless mention is made in the text to illustrate or clarify a point.

10) The design guidelines contained in this study will be aimed at suburban residences of the following descriptions:

- Detached, free-standing single houses
- Semi-detached townhouses in a complex-type development
- Row-house developments of one or two stories high
- Small cluster-type developments of one or two stories high, with shared/communal gardens.

11) The scope of this study will be limited to the following spectrum of landscape and architectural design considerations:

- Suburban layout covering a scale spectrum from individual lot orientation to street block layout and orientation.

- Landscape architectural design considerations of site-specific scale addressing planting, surface coverage and spatial relationships of design elements to aid in climate modification, solar radiation utilisation and water use efficiency.

- Architectural energy efficiency design considerations that are closely associated with and dependent on climatic processes and associated landscape modification. Such guidelines will be of a general nature only and will exclude detailed architectural and engineering aspects.

- Interior architectural design will not be addressed in this study.

- Urban density considerations will be based on climate-responsiveness requirements and will not incorporate other energy-related components such as transportation.

12) The techniques in this study will be aimed at new developments and buildings. Retrofit of existing buildings will not be specifically addressed.

13) This study will investigate design considerations and techniques toward energy efficiency with the intent that they be developed and researched to be included in building codes and legislation. However no attempt will be made to define or describe such codes and legislation and the potential worth of such codes for urban energy efficiency will merely be considered.

## 1.5 Present state of information

### 1.5.1 Preliminary literature overview, locally and abroad

For the purposes of this study preliminary literature research will be done from both local and international sources to create an extensive resource foundation. This will help to establish the extent of research that has already been completed in, and applied to South African conditions. It will also be established if research done abroad can be related or adapted to local conditions. The following sources were consulted for the preliminary literature overview:

**Local:**

*The atmosphere and weather of Southern Africa* by Preston-Whyte and Tyson (1995) is a geographical analysis of the different climatic elements that together determine the weather patterns of the country. Important regional and local weather systems and phenomena are investigated and the relationships between these and other factors such as site topography, ocean currents and global weather conditions illustrated.

*The weather and climate of Southern Africa* by Tyson and Preston-Whyte (2000) is a revision and expansion of their first publication listed here and explores several climatic processes in more detail.

*The energy book for urban development in South Africa* by Ward (2002) illustrates the energy scenario in South Africa and highlights both the problems that exist and solutions to mitigate and prevent them. Although the focus of this publication is on the low-income household energy sector, a broad set of issues are addressed and the South African situation as a whole is addressed.

Holm (1983) investigates methods of climatic amelioration and energy conservation in building design in *Energy conservation in hot climates*. This publication explores the various climates of Southern Africa and focuses on design and energy issues that relate to the context of this part of the continent. Emphasis is placed on the implementation of simple, inexpensive solutions to these problems by relating local and international examples to this predominantly hot region.

Another publication by Holm (1996), called *Manual for energy conscious design*, addresses the need for simple yet effective and comprehensive measures to create buildings that use solar energy for optimal thermal and energy performance. It explores human comfort, urban layout and building design considerations to this end and relates these considerations to different climate regions of the country.

*Enviro-friendly methods in small building design for South Africa* by Napier (2000) is a collection of design guidelines for small buildings and addresses issues such as passive heating and cooling, daylighting, ventilation control and placement of buildings on site to enable energy efficiency. Other measures to ensure environmental sustainability are also explored. The guidelines in this publication are done with the South African climatic context in mind and a synopsis of the different climate regions is also given.

**Abroad:**

*Energy efficient site design* by Robinette (1983(a)) is a collection of observations and experimental findings on climate design from numerous international sources, commenting on the different devices and techniques and relating them to different applications. A vast spectrum and scale of applications is covered and a wealth of numerical and statistic data provided.

*Landscape planning for energy conservation,* also by Robinette (1983(b)) is similar in nature to the previous publication but deals specifically with the American context and provides information focussing mainly on site selection and large-scale urban layout considerations.

*Energy-conserving site design,* edited by McPherson (1984), is a collection of works that address energy-efficient landscape design and focuses on climate modification. The design process from the initial site analysis and planning phases to detail design is discussed. Landscape design topics addressed include planting design for solar and wind control, and water conservation through landscape design.

*The passive solar energy book* by Mazria (1979) is a comprehensive yet uncomplicated investigation of design techniques aimed at using solar energy for climatic amelioration, daylighting and other measures to houses and other buildings climate-responsive.

The *Solar access in New South Wales: technical report* by the Total Environment Centre (1982) relates much of the work done in the Northern Hemisphere to the context of the Southern Hemisphere. This document focuses on suburban layout in terms of street and lot orientation, and development density to achieve optimum solar access for all the units in a development.

The publication by Erley and Jaffe (1979) entitled *Site planning for solar access: a guide for residential developers and site planners* deals with site selection, building design and urban layout considerations to maximise solar access and explores how this can be achieved in the different climate regions of the USA.

*Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988*, edited by Fernandes and Yannas

(1988), is a collection of papers that address an extensive scope of topics relating to climate-responsive and energy efficient design, focussing on the semi-arid Mediterranean region.

Various articles from ScienceDirect Online Publications were also consulted to gain a better understanding of various climate amelioration methods and passive solar design techniques.

From the preliminary literature overview it was gathered that an extensive body of information concerning energy-efficient and climate-responsive design exists and that significant work has already been done in this field in South Africa. However, much of the available information from other countries, especially methods from other semi-arid and temperate regions, will also be applicable to the South African context.

### 1.5.2 Computer programs and database resources available to urban designers

Many methods and tools exists abroad that aid designers and developers in maintaining standards of living while reducing resource depletion and environmental damage caused by the building and operating of buildings. According to Murakami (accessed 05-11-2003) examples of these are BREEAM (Building Research Establishment Environmental Assessment Method) from the UK, LEED (Leadership in Energy and Environment Design) from the USA and the GB (Green Building) Tool from Canada. A nationally authorised system in Japan, called the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), constitutes the next step in urban sustainability and includes these and other assessments as well as a new concept labelled BEE (Building Environmental Efficiency).

Similar systems relevant to the local context also exist. Gibberd (accessed 12-09-2003) describes the Sustainable Building Assessment Tool (SBAT) as a computer-based program that facilitates more sustainable practices in the building and construction industry in developing countries, particularly South Africa. The tool prioritises the needs of developing countries by placing strong emphasis on social and economic considerations as well as issues that relate to environmental and resource sustainability. The aim of the tool is to create a greater overall awareness and realisation of sustainability in the building sectors, among designers, owners and users alike.

The DME has developed a computer program called SunCalculator which considers the solar altitude, solar azimuth, vertical shadow angles, building overhangs and building distances for the provinces of Gauteng, Mpumalanga, North-West, and Limpopo as well as Swaziland (DME 2000:17). This useful program calculates the minimum north-south distances between buildings so that the southern building has winter sunshine. It also allows for deviations from the geographical north orientations to be calculated and optimal shading overhangs is calculated. This simple tool, if expanded and made available to designers of the urban environment throughout South Africa, can be a powerful asset to help ensure energy efficiency in this country.

# 2 CHAPTER II – ESTABLISHING THE CLIMATIC FACTORS THAT INFLUENCE HUMAN COMFORT

## 2.1 Climatic factors that dictate energy efficient climatic landscape design

### 2.1.1 Introduction

To investigate the first hypothesis it is necessary to establish clear descriptions of the various factors that together determine and comprise the different climate regions of South Africa and influence human comfort. The climatic factors identified during the initial literature overview that will be investigated are:

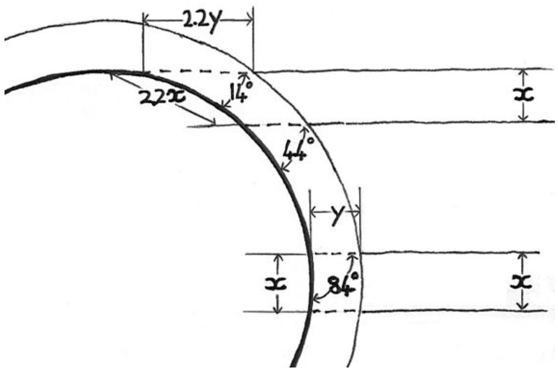
1) Temperature
2) Humidity
3) Wind
4) Radiation
5) Precipitation
6) Latitude.

Each factor will be understood and explored according to its causes and spatial occurrences in the natural world and their importance to human comfort illustrated.

### 2.1.2 Temperature

Although air temperature is one of the first factors that comes to mind when considering human comfort it is in itself not the most important nor is it an easy element to manipulate or control when considering outdoor environments. Brown and Gillespie (1995:65) illustrate this by showing that an outside air temperature of 20°C can be conceived as being anything from uncomfortably warm if the humidity is high with no wind, to quite cool if it is a cloudy, windy day. According to Hobbs (1980:62) temperature in conjunction with the relative humidity of the air, the amount of air movement, perceived as wind, and radiation quantities determine human comfort and together constitute the most important elements of climate-responsive design. Temperature is nevertheless one of the main climatic characteristics of any geographic region, and must therefore be understood.

Barry (1981:17) explains that as one moves further away from the equator the angle of the incoming rays of the sun becomes sharper relative to the surface of the earth, due to the curvature of its surface. This means that the rays nearer to the poles have to penetrate a larger amount of atmosphere before reaching the earth's surface than at the equator, resulting in a decrease of net and solar radiation and an overall drop in temperature (Figure 2.1).




Note to Figure: values are approximate only.

**Figure 2.1 An increase in latitude causes a decrease in the incidence angle and concentration of solar radiation**

According to Byers (1974:57) the influences of altitude are rather more complex but generally a site at a higher altitude is colder than one at the same latitude but a lower altitude. The average environmental lapse rate, described by Barry (1981:40) as the rate at which temperature decreases with an increase in altitude, is roughly 6°C/km in the free atmosphere. A reversal of the environmental lapse rate, called temperature inversion, can occur at night mainly due to two reasons. Geiger (1969:121-122) explains that an increase in temperature with an increase in altitude can occur due to nocturnal radiative cooling at the earth's surface creating a layer of cooler air near the surface and a relatively warmer, more stable layer of air called a thermal belt above that. Temperature inversion also occurs in deep valleys or depressions by cold air forcing warmer, lighter air upwards as it sinks into the lower areas.

Herrington (1984:62) describes how heat is transferred by one of three methods. The first way is conduction, when sensible heat is transferred through the vibration of the molecules of gases, liquids and especially solids. Secondly, sensible heat is transferred through the movement of mass known as convection. Convection only occurs in gases and liquids. Thirdly latent heat, unfelt heat associated with changes in the state of a material, is transferred through evaporation, which also requires the movement of mass. A common example is the evaporation of water that needs rising air to carry it upwards. Temperature control in the landscape is achieved by controlling the transfer of heat. The easiest way of achieving this is through the control and manipulation of shade and sun patterns. Simply put this means providing shade when it is too hot and allowing in sunlight when it is too cold. This is true for both outdoor and indoor environments although it is more effective to manipulate indoor temperatures in this fashion. Nevertheless the human body will radiate heat to any surface or body that is cooler or be heated by anything that is warmer than it. Egan (1975:5) therefore contends that the temperatures of building surfaces are crucial for achieving thermal comfort and that external control of the amount of sunlight that reaches a building is influential in climatically responsive design.

### 2.1.3 Humidity

The humidity of the air is dependent on the amount of water vapour that is present in the atmosphere through evaporation. To that end four factors are important, according to Henderson-Sellers and Robinson (1986:94-95):

1) The presence of water bodies greatly affects the humidity of the air in any given area. Significant amounts of available liquid water means that through evaporation the humidity of the air near that water body can be higher than that of areas that are far from open water.

2) The available amount of energy determines the rate at which evaporation occurs. Thus if there is ample available energy, the rate of evaporation increases.

3) The humidity gradient away from the surface also greatly influences how much vapour is present in a parcel of air. When the flow of water molecules away from the water body into the atmosphere is greater than the flow of molecules to the water body from the atmosphere, humidity increases.

4) Wind directly above the water surface increases the rate of evaporation as the moving air carries away some of the vapour-laden air.

The most significant effect of humidity on human comfort is that it changes the perceived temperature of the air. An increase in atmospheric humidity will cause a person to experience a rise in the perceived temperature. Table 2.1 gives the relationship between actual air temperatures and humidity and the apparent temperature as a function of relative humidity; however, it does not take the influence of wind into consideration.

**Table 2.1 Apparent temperature as a function of relative humidity (Henderson-Sellers and Robinson 1986:332)**

| Air temp (°C) | Apparent air temperature in °C | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | 28 | 29 | 29 | 30 | 31 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 41 | 43 | 45 | 47 | 50 | | |
| 29 | 26 | 26 | 27 | 27 | 28 | 28 | 29 | 29 | 30 | 31 | 31 | 32 | 32 | 33 | 34 | 35 | 36 | 37 | 39 | 41 | 42 |
| 27 | 23 | 23 | 24 | 24 | 25 | 25 | 26 | 26 | 26 | 27 | 27 | 27 | 28 | 28 | 29 | 30 | 31 | 31 | 32 | 32 | 33 |
| 24 | 21 | 21 | 21 | 22 | 22 | 22 | 23 | 23 | 23 | 23 | 24 | 24 | 24 | 24 | 25 | 25 | 26 | 26 | 26 | 26 | 27 |
| 21 | 18 | 18 | 18 | 18 | 19 | 19 | 19 | 19 | 20 | 20 | 21 | 21 | 21 | 21 | 21 | 21 | 22 | 22 | 22 | 22 | 22 |
| Relative hum. % | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |

The importance of humidity to human comfort is further illustrated when viewed in terms of the discomfort index used by the Weather Bureau (1987:3-7). Table 2.2 illustrates this index, used to determine how uncomfortable certain combinations of temperature and humidity are to humans. For example, a combination of 36°C and 10% humidity would have an index of 100, as would 27°C and 80% humidity. In this fashion an index of 80-90 is moderately uncomfortable, 90-100 is very uncomfortable, 100-110 is extremely uncomfortable and above that is hazardous to human health. The index is determined by the equation

$$(2 \times T) + (RH/100 \times T) + 24 = DI$$

where: T = temperature in °C, RH = relative atmospheric humidity and DI = discomfort index

**Table 2.2 The human discomfort index (Weather Bureau 1987:10)**

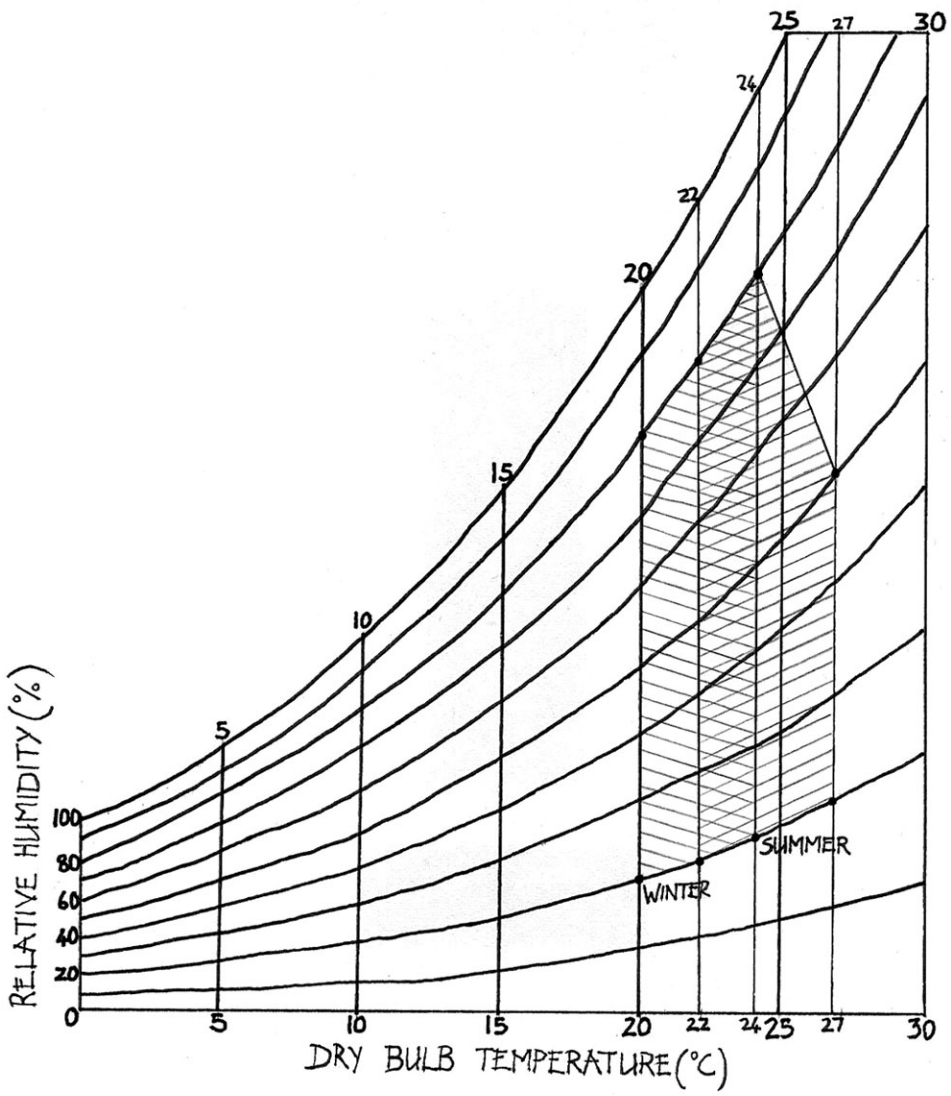
| | Relative humidity | | | | |
|---|---|---|---|---|---|
| Air temp | 10% | 20% | 40% | 60% | 80% |
| 20°C | 66 | 68 | 72 | 76 | 80 |
| 25°C | 77 | 79 | 84 | 89 | 94 |
| 30°C | 87 | 90 | 96 | 102 | 108 |
| 35°C | 98 | 101 | 108 | 115 | 122 |

Thus the combination of atmospheric temperature and humidity is the main determining factor with regards to human comfort, both in the outside environment and indoors. Although all people do not experience the same combinations of temperature and climate to be pleasant there is a certain core range of temperature-humidity relations that is acceptable to most people, as illustrated by Figure 2.2. This graph is called a psychrometric chart, described by Holm (1996:2) as dealing with the properties of the atmosphere in terms of the behaviour of the mixture of dry air and water vapour and illustrates human comfort response under different conditions.

## 2.1.4 Wind

Wind is a complex environmental element that is caused and influenced by many factors. Nevertheless it is one of the most useful microclimatic design elements and greatly affects human comfort levels. Brown and Gillespie (1995:123) are of the opinion that wind is of great importance to human comfort as it can be manipulated to a significant extent to promote energy-efficient design.

Wind is a significant factor as it affects human comfort levels in different manners in different climates. Even relatively gentle breezes can make an otherwise uncomfortably hot location seem more bearable. Flach (1981:113) explains that evaporation of perspiration from the skin effectively cools a person as heat is used to change the phase of the moisture from liquid to a vapour gas. According to Sohar (1979:480) one litre of perspiration that completely evaporates dissipates approximately 600 calories, but this becomes increasingly difficult as the humidity of the atmosphere increases. In humid areas wind is especially important for human comfort, as it mixes the more humid air around the body with less humid air to aid in evaporation.




Note to Figure: These conditions are relevant for persons doing light work (1 met) and wearing light clothing (0.6 clo) in still air (0,1m/s). The core represents conditions that 80% of the population will find comfortable and the periphery where 70% will be comfortable

**Figure 2.2 The human comfort zone represented on the psychrometric chart (Holm 1983:19)**

However, the effects of wind become much greater in cool regions. Barry (1981:279) describes the process through which wind augments the convective heat loss through the skin, called the windchill factor. Table 2.3 illustrates the empirical relationship to calculate perceived temperature due to the effect of wind chill.

**Table 2.3 Wind chill equivalent temperatures (Weather Bureau, 1987:12)**

| Air temperature (˚C) | Wind speed (m/s) | | |
|---|---|---|---|
| | 2 m/s | 6m/s | 10m/s |
| 5 | 4 | -4 | -8 |
| 0 | -1 | -10 | -15 |
| -5 | -6 | -17 | -22 |
| -10 | -11 | -23 | -30 |

From Table 2.3 it can be seen that temperatures that are still bearable can become dangerous when strong winds blow and that the effect becomes increasingly severe as the temperature drops. Although few locations are likely to experience temperatures below -10˚C for long it becomes clear that the wind plays a dominant role in human comfort in cooler climates.

### 2.1.5 Radiation

The radiation that reaches the earth from the sun provides the energy for all atmospheric systems and processes on earth and is therefore also one of the most important factors to consider when investigating climatic conditions of any area. According to Brown and Gillespie (1995:46) solar radiation is one of the climatic elements that we can most effectively manage and utilise. This is because the path of the sun through the sky and related shading can be accurately predicted, using a variety of tools and methods described by Erley and Jaffe (1979:33-35), Markus and Morris (1980:172-182), Richards (1981), McPherson (1984a:285-286), and Grabovac and Dragovic (1988:638-641) amongst others. These predictions are done using sun angles and azimuth angles for specific latitudes.

The solar energy that reaches the surface of the earth follows one of three possible paths as described by Mazria (1979:15-16). It is absorbed by the surface of the material, transmitted through the object or reflected back into the atmosphere as long-wave radiation. When sunlight strikes an object it heats up and the object reflects both short-wave light giving it the colour and hue of the surface and long-wave energy, felt as heat, to cooler surfaces, objects or the atmosphere. In this way the amount of radiation that reaches the earth’s surface plays an important part in both macro- and microclimatic conditions. The nature of the reflection can either be specular, as from a polished surface, or diffused as from matt surfaces (Figure 2.3).

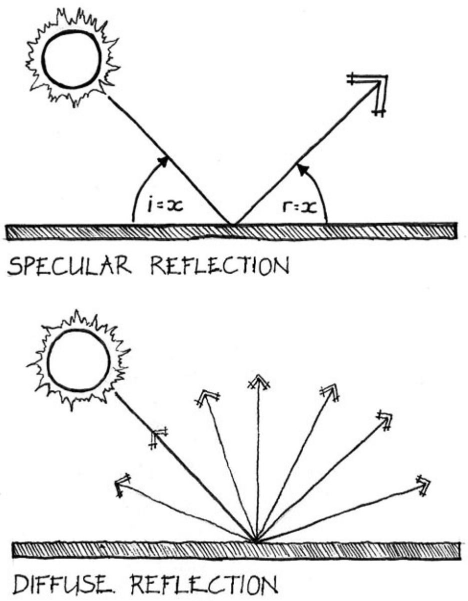



**Figure 2.3 Specular and diffused reflections (Mazria 1979:16)**

### 2.1.6 Precipitation

The importance of the roles that precipitation and air temperature play in defining the climate of a region can be illustrated by considering popular conceptions of the general climate types of the world. Tropical climates are considered to be places with high temperatures and ample rainfall; deserts have high temperatures with little rainfall; cold regions have low temperatures with snow and rain and temperate regions lie somewhere in the middle. Although this is a deceptively simple way of explaining climate and does not accurately describe the conditions in any of the regions, it does illustrate the fact that precipitation is an integral part of any climate and is thus of great importance when establishing climatic zones for any region.

The relationship between the amounts of precipitation that a given location receives and what happens to it once it has fallen, is as important to the climate of a region as the nature of the precipitation. This relationship is called the water balance of that region. Goudie (1984:107) defines it as the relationship between the input of water through precipitation and the losses arising through evaporation, transpiration and changes in its storage, for instance soil moisture and groundwater content. This relationship indicates the relative wetness or dryness of a location and varies drastically for different climates. Very humid climates have a highly positive balance, which means that the input of moisture is far greater than the losses. Conversely arid regions have negative water balances, meaning that the amount of evapotranspiration in such an area exceeds the average amount of precipitation for that region. Schulze (1997:172) illustrates that South Africa can indeed be considered an arid country as the mean annual evaporation exceeds annual precipitation in almost all regions of the country.

### 2.1.7 Summary

1) Section 2.1 illustrated the individual effects of temperature, humidity, wind, radiation and precipitation on both climatic conditions and perceived human comfort within these conditions.

2) The specific importance of humidity and wind in relation to the other climatic factors has also been illustrated. Decreasing, increasing or manipulating these factors in controlled ways can be of great value to modifying microclimatic conditions to achieve greater human comfort in extreme conditions.

3) Furthermore it has become obvious that the specific topography and location of a site can influence the microclimate of an area and that this aspect should be further investigated.

## 2.2 Influence of latitude and physical site character on solar access

### 2.2.1 Introduction

Section 2.2 focuses on the influences that the physical character of the landscape has on the microclimate of a site location. The effects of the following considerations that may alter the local climatic conditions of a site from the general climatic conditions in the area will subsequently be examined:

1) Specific sun angles caused by the latitude of a site location.

2) The aspect of the site in relation to the position of the sun.

3) Site slope and topography.

### 2.2.2 Site latitude, sun and azimuth angles

When the effects of latitude, aspect and slope gradient are integrated, a complex set of considerations arise that must be considered as a whole in order to effectively design for solar access. However, for the purposes of this investigation these elements will be discussed in isolation, in order to create a clearer picture of the roles that each plays in climate-responsive design. The significance of these elements is that they will determine the specifics of the solar access zone and the solar collectors that will operate within this zone. Zanetto (1984:99) describes solar collectors as any object, surface or space that uses the energy of the sun through direct gain to reduce the amounts of energy that are imported and used in a building. According to Erley and Jaffe (1979:33) the solar access zone or skyspace is the portion of sky north of a collector that must remain unobstructed by objects that block solar radiation, in order for a solar collector to function optimally (Figure 2.4).

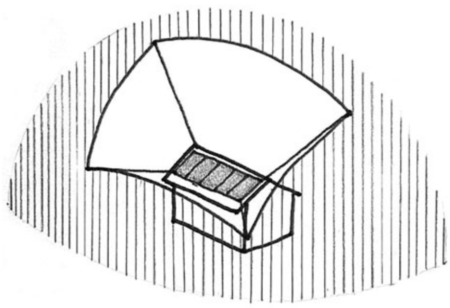


**Figure 2.4 The skyspace of a solar collector (Zanetto 1984:99)**

Site latitude refers to the global position of a site in relation to the east to west orientated latitudinal degree lines that circle the earth. The equator is represented by the 0° latitude line and the north and south poles by 90° north and south latitude respectively. The equator is characterised by smaller variations in seasonal weather phenomena, because the incoming solar radiation reaches the earth at angles close to perpendicular throughout the year and thus the amount of atmosphere that it passes through remains relatively constant. The amount of atmosphere that radiation passes through also influences how much energy is lost in the process. An increase in the depth of atmosphere that radiation passes through results in larger energy losses due to absorption and reflection. This means that the amount of radiation that reaches the surface of the earth at the equator varies comparatively little annually. At higher latitudes the angle of incidence and length of atmosphere that the radiation must pass through varies considerably both daily and annually due to the axial tilt of the planet, resulting in pronounced seasonal weather phenomena and varying day lengths (Figure 2.5). When the sunlight impinges on the surface of the earth the slope of the site will also determine the concentration of solar radiation. Smaller incidence angles will result in decreased concentrations of solar energy (Figure 2.6).

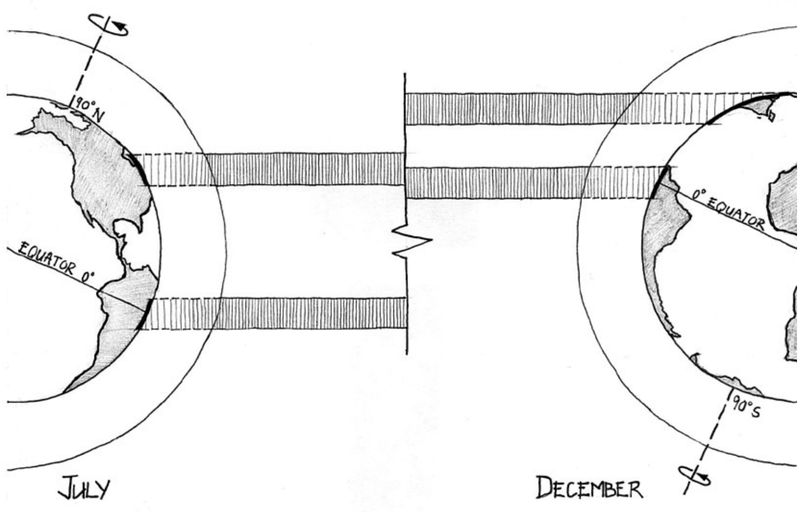
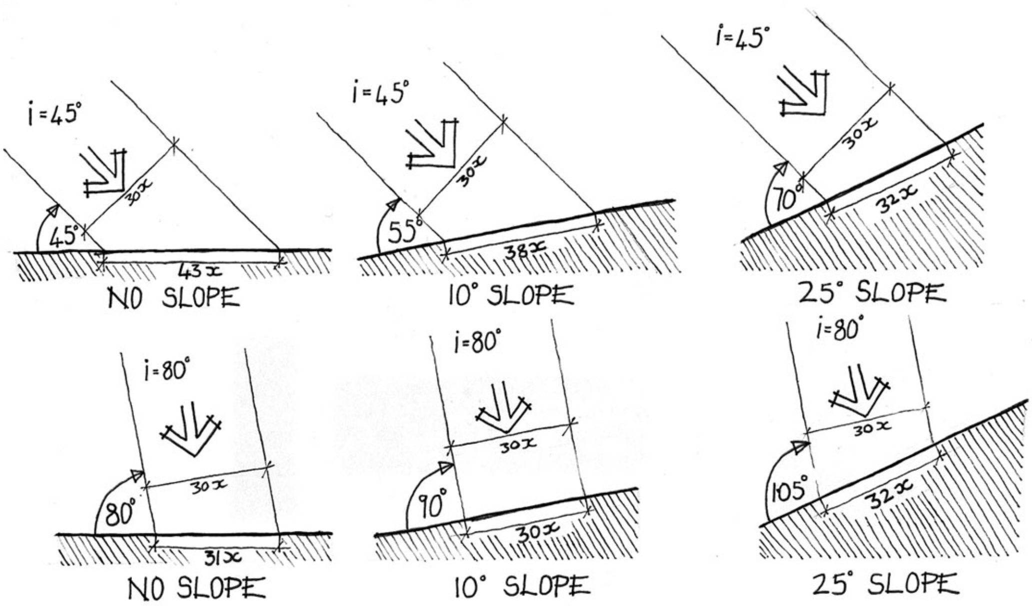



**Figure 2.5 Annual variation of solar radiation with latitude**




Note to Figure: values are approximate only.

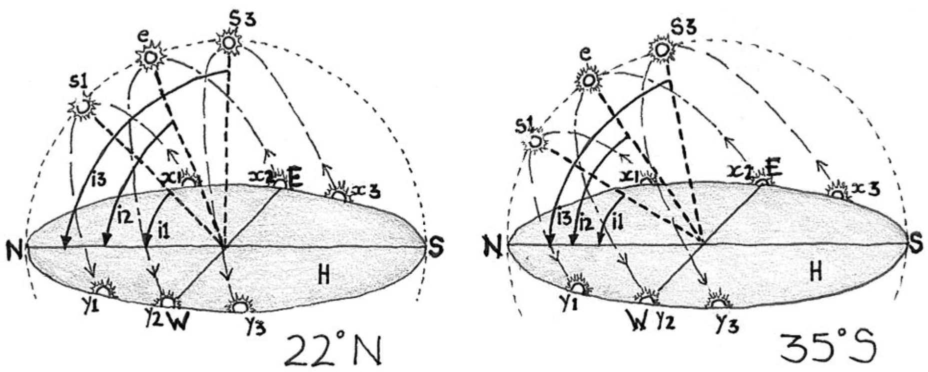
**Figure 2.6 Concentration of solar radiation is determined by the angle of incidence and the angle of the slope**

At lower latitudes these angles are greater, putting the sun higher in the sky in relation to the horizon. Furthermore latitude determines the positions where the sun rises and sets on the horizon and how large the difference in position is between summer and winter. This difference is larger and the positions further south and north during the summer and winter respectively, at higher latitudes. Figure 2.7 illustrates the path of the sun for a low and high latitude position at June and December solstices and during equinox. To terrestrial observers the earth appears flat and the sun and other heavenly bodies to be travelling along a hemispheric dome and thus are represented as such. The positions of the sun at noon during summer and winter solstices and its equinox are determined by the following formulas provided by Oliver (1973:228-229):

*Winter solstice: Solar altitude angle = 90° - (latitude + 23½°)*

*Summer solstice: Solar altitude angle = 90° - (latitude - 23½°)*

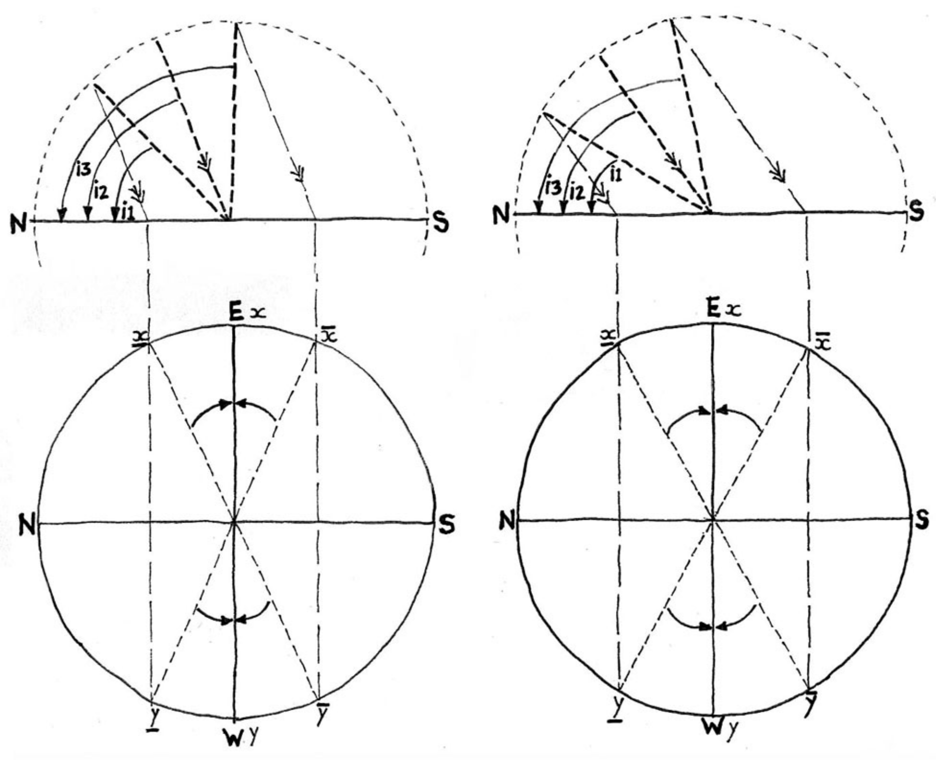
*Equinox: Solar altitude angle = 90° - latitude*




Legend: x1, x2, x3=winter solstice, equinox and summer solstice sunrises respectively. y1, y2, y3=winter solstice, equinox and summer solstice sunsets respectively. s1, e, s3=winter solstice, equinox and summer solstice midday sun positions respectively. i1, i2, i3=minimum, mean/solstice and maximum solar incidence angles respectively. H=imaginary horizontal plane from site position

**Figure 2.7 The apparent path of the sun through the sky for a low and high latitude position (adapted from Strahler 1969 as shown in Oliver 1973:229)**

A method to determine the position where the sun will rise and set during the equinox and solstices, based on Figure 2.7 is illustrated in Figure 2.8. For this procedure the horizontal plane is redrawn edge on from the west in elevation and the positions of the sun plotted using the appropriate formulas. The position of the sun during equinox is connected with the middle of the east-west axis and parallel lines drawn from the solstice positions, to intercept the east-west axis. A plan view of the same plain is drawn beneath the elevation. By vertically extending the points where the lines from the solstice positions cross the east-west axis on the elevation to the plan below, the points where the sun rises and sets are indicated where these vertical lines intercept the plain, seen in plan. At equinox the sun rises due east and west. The angles can now be measured to see what the bearings of the positions of sunrise at the solstices are. These positions indicate the furthest north and south that the sun will rise and set.




Legend: i1, i2, i3=minimum, mean/solstice and maximum solar incidence angles respectively

**Figure 2.8 A method to determine the position of the sunrise and sunset position for any given latitude during the equinoxes and solstices**

### 2.2.3 Aspect and site physical location

Aspect refers to the orientation of a slope relative to the sun’s path through the sky, in other words whether the slope is on the sunny or shadow side of a topographical landform. The gradient of the slope of the site location, which is discussed separately in Section 2.2.4, has significant influences of its own. However, the basic factors of importance concerning aspect are discussed here. Robinette (1983a:12) states that site aspect is important for solar heat gain in almost all climates and where heat is not particularly welcome aspect becomes important to shading and radiation control. In the southern hemisphere sites facing north are exposed to the incoming rays of the sun and shadows are cast to the south.

The influence of the sun changes both daily and seasonally and these influences are different for all slopes. Figure 2.9 illustrates these considerations. It is possible for both north and south facing slopes to receive direct sunlight if the slope is gentle enough and the sun climbs high enough in the sky (1). This is typical of lower latitudes throughout the year and during summer in higher latitudes. South-facing slopes can also receive some sunlight during the morning or afternoon when the sun is shining from nearer to the east and west, although the intensity of the rays is reduced due to the low angle of the sun (2). However, if the sun sinks low enough or if the slope is steep enough only northern slopes receive sunlight. This occurs when the angle of the incoming rays is less than that of the south slope (3). This phenomenon becomes more pronounced with an increase in latitude and is of special importance in cold areas, where the lack of sunlight can cause temperatures to be significantly lower than on the northern slope.

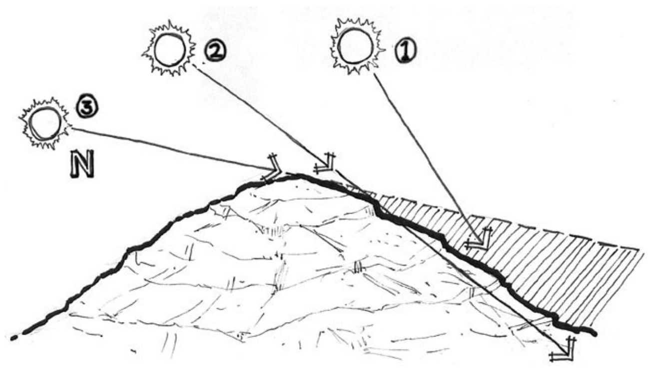



**Figure 2.9 Aspect in relation to sun angles**

Another consideration of aspect is that shadows are much longer on south-facing slopes than on north facing ones. This occurs because the angle between the shadow line and the ground plane is larger on north slopes and thus intercept each other over a shorter distance (Figure 2.10).

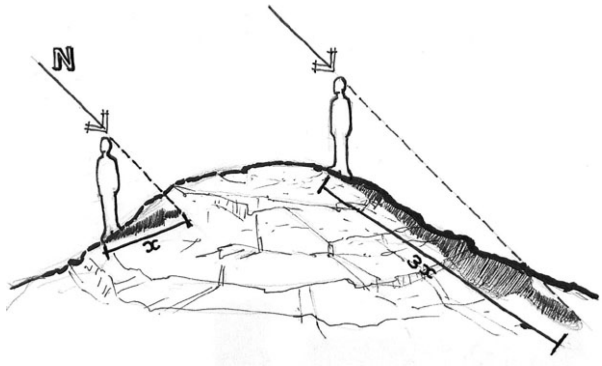



**Figure 2.10 Different shade lengths on north and south slopes**

East- and west-facing slopes are orientated in the general direction of the rising and setting sun respectively and therefore they receive most of their sunlight in the early morning and late afternoon respectively. The incidence angle of the incoming solar radiation at these times is smaller and the energy is less concentrated meaning that these slope heat up less rapidly than north-facing slopes. According to Geiger (1969:117), there is a difference between easterly and westerly slopes in that westerly slopes tend to be drier and warmer than easterly ones. This is because the ground is usually more humid in the mornings and much of the radiation energy is used during evaporation, thus easterly slopes are only moderately warmed in the mornings. In contrast when the sun shines on westerly slopes during the afternoon the ground is much drier due to short-wave radiation and rising temperature. Direct heating of the ground and air above it is much more effective, amplified by the fact that ambient temperatures are also higher than in the early morning. The result is that the highest ground temperatures are found on northwestern slopes, especially during summer.

### 2.2.4 Site slope

The slope gradient or gradient of a site further influences the effects that the aspect and latitude has on the length of shadows that are cast on it. If the gradient of the slope is increased shadows are slightly shorter on northern slopes and considerably longer on southern slopes (Figure 2.11). The gradient of the northern slope also influences the concentration of solar radiation on that slope. In most cases a steeper slope causes the incidence angle of the sunlight to increase, resulting in higher concentrations of radiation. Steeper southern slopes are more likely to be in shadow and for a longer period of the day.

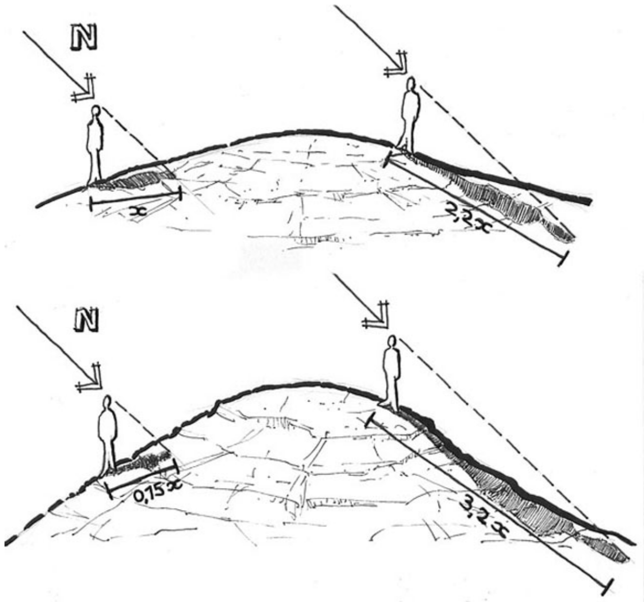



**Figure 2.11 Shadows decrease on northern slopes and increase on southern slopes when site slope increases**

## 2.2.5 Summary

From these considerations several different elements that influence microclimate and specifically relate to the site itself arise:

1) The vertical incidence angles of the sunlight throughout the day.

2) Horizontal azimuth angles of the sun throughout the day.

3) Positions where the sun rises and sets.

4) Slope gradient of the site.

5) Aspect of the site.

These elements together are illustrated by Figure 2.12 and together determine the specifics of the solar access of any location.

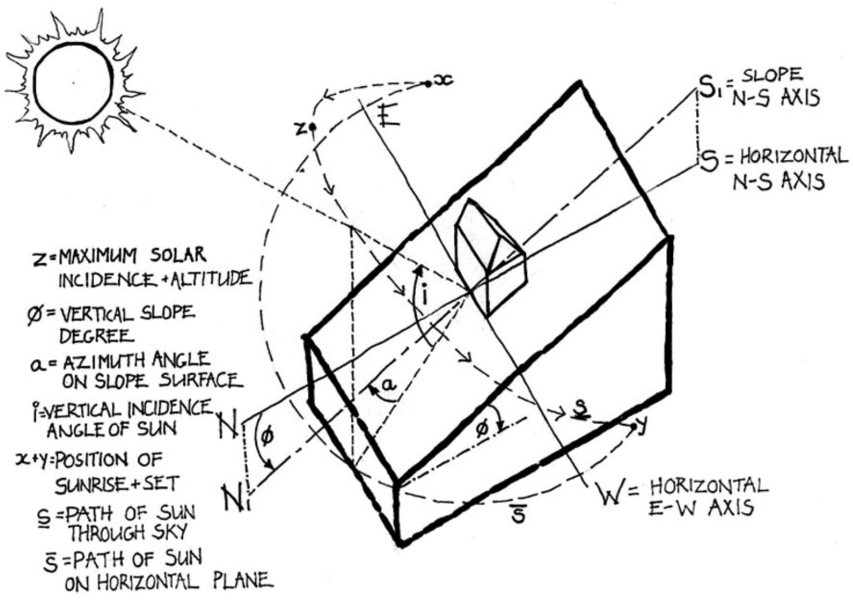



**Figure 2.12 The elements of site slope and aspect that influence passive solar design (based on Erley and Jaffe 1979:16, Markus & Morris 1980:172)**

# 3 CHAPTER III – THE CLIMATIC DESIGN REGIONS

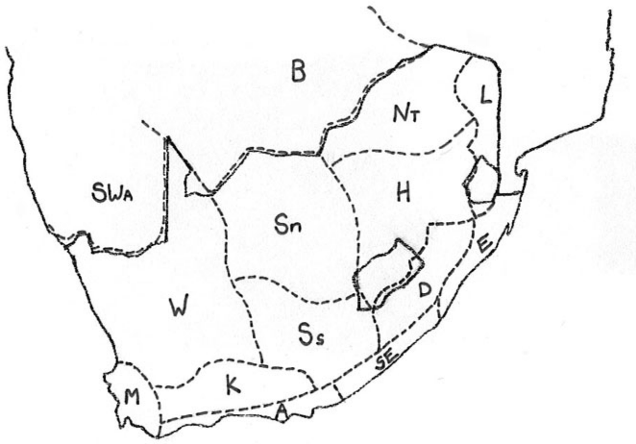
## 3.1 The South African context

### 3.1.1 Introduction

The aim of the study is to establish the basic climates of South Africa for the purpose of energy efficient climate-responsive urban design, specifically for higher income suburban detached and semi-detached residences. These classifications will serve to better relate internationally developed and used climatic design techniques to local conditions. Two climatic classifications of South Africa will be used for this purpose. The first is a widely used geo-climatic classification by Schulze (1965) while the second is a recent re-classification of the country by Kruger (2003) which incorporates more detailed information on plant type distributions. This classification is as yet unpublished and communicated by the author via e-mail. The third is a climatic classification aimed at aiding environmentally sensitive design in small buildings, by Napier (2000).

### 3.1.2 Geo-climatic classification of the country by Schulze (1965)

In order to determine the climatic contexts in which climate-responsive energy efficient design in South Africa must take place several climatic classifications of the country will be examined. The detailed geo-climatic classification of Southern Africa by Schulze (1965:313-322) is illustrated by Figure 3.1 and summarised in Appendix A. Urban design guidelines for each zone of this classification by Holm (1996:14-78) is also summarised in Appendix C. The map creates a good impression of the varying climatic conditions experienced as one moves from east to west and the descriptions provide useful information for each region.

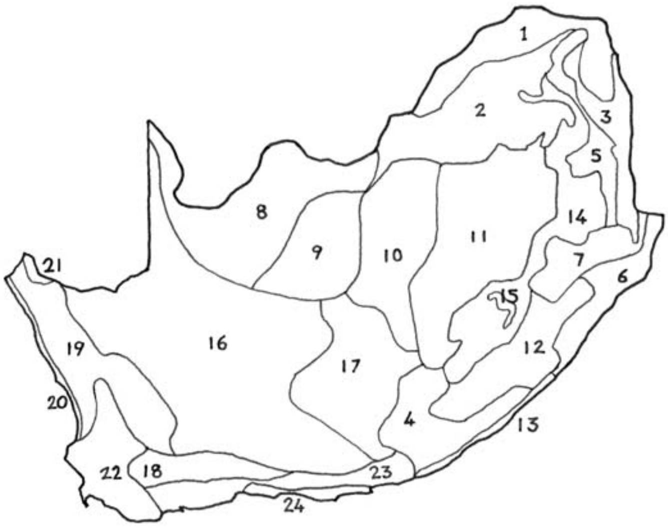



Legend: M=Mediterranean region, A=Garden route, K Little and Great Karoo, W=Desert steppe, SWa=Poor steppe, Ss=Southern steppe, Sn=Northern steppe, SE=South eastern coastal region, E=warm to hot and humid subtropical region, D=Drakensberg/Natal Highlands region, L=Transvaal Lowveld, H=Highveld, NT=Northern Transvaal, B=region B/Namibia

**Figure 3.1 The geo-climatic zones of South Africa according to Schulze (1965:313)**

### 3.1.3 Phyto-geographical climatic analysis according to Kruger (2003)

Kruger's climatic classification is based on similar criteria as that of Schulze but incorporates more detailed information on plant type distribution, resulting in a complex map of the country. Some zones are almost entirely distinguished from each other by their plant populations, with little variance in actual climatic conditions. However, it does create a detailed picture of the somewhat subtle variance in conditions that exists between certain regions. A summary of each zone is presented in Appendix D.

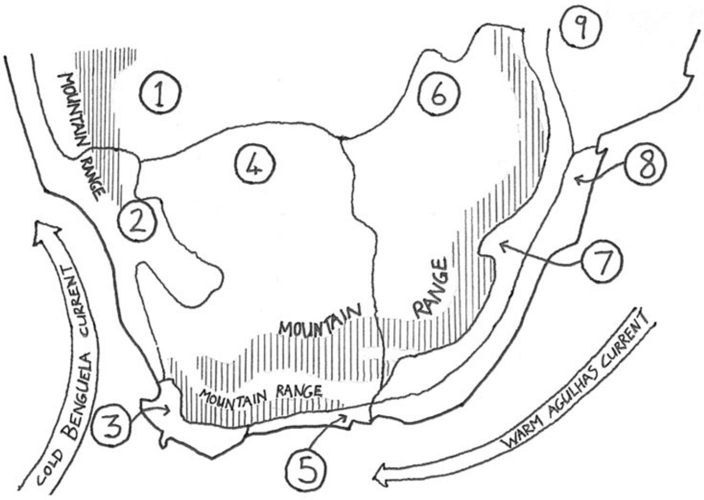



Legend: 1=Northern Arid Bushveld, 2=Central Bushveld, 3=Lowveld Bushveld, 4=Southeastern Thornveld, 5=Lowveld Mountain Bushveld, 6=Eastern Coastal Bushveld, 7=KwaZulu-Natal Central Bushveld, 8=Kalahari Bushveld, 9=Kalahari Hardveld Bushveld, 10=Dry Highveld Grassland, 11=Moist Highveld Grassland, 12=Eastern Grassland, 13=Southeastern Coast 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=Northwestern Desert, 22=Southern Cape Forest, 23=Southwestern Cape, 24=Southern Cape.

**Figure 3.2 Phyto-geographical climatic analysis of South Africa according to Kruger (13-09-2003)**

### 3.1.4 Climatic classification of the country by Napier (2000)

Napier's design-orientated climate classification of South Africa is based on rainfall quantities, temperatures, general wind patterns, relative humidity, hours of sunshine and general weather and habitat phenomena to divide the country into nine zones as illustrated by Figure 3.3. His classification is aimed at aiding environmentally sensitive and climate-responsive design of small buildings, including residential dwellings. The parameters used to establish the different zones and their descriptions can be found in Appendix B. Although somewhat simplistic this classification reflects both phyto-geographical and comfort-related climate considerations and the zone descriptions give a good indication of the general conditions that can be expected in each climate region.




Legend: 1=Sub-tropical plateau, 2=Desert, 3=Mediterranean, 4=Semi-arid plateau, 5=Temperate coast, 6=Temperate eastern plateau, 7=Plateau slopes, 8=Sub-tropical coast, 9=Sub-tropical lowveld

**Figure 3.3 The climatic zones of South Africa according to Napier (2000:9.3.1)**

## 3.2 Describing the four main climate regions

### 3.2.1 Introduction

The hypothesis seeks to define basic climate regions in a manner that applies specifically to urban design purposes in terms of human comfort. Four basic climate regions will be discussed and described, with reference to the climate factors discussed in Chapter II. These classifications were chosen after the initial literature overview revealed that they are the most commonly used and best defined. They are also the most generic and can be adapted to the specific conditions of different regions if needed. Previously published definitions and descriptions of different climate regions will be reviewed from a variety of local and international sources to establish as wide an understanding of each zone as possible. The climate regions chosen for this study are:

1) Hot humid

2) Hot arid

3) Temperate

4) Cool climates.

### 3.2.2 Hot humid climate

Hot humid regions are described by Robinette (1983b:106) as areas that typically have warm climates with relatively small yearly temperature variations and high average annual humidity levels due to precipitation, the effects of nearby oceans and the effects of under-drained lowland evaporation. Temperatures rarely fall outside 18°C to 29°C and rainfall is high and occurs for a large portion of or throughout the year. Holm (1983:15) describes sub-tropical humid climates as having diurnal and annual temperature ranges that are almost equal at around 9°C. The humidity of such places is up to 70% to 80% in the wet season and 40% to 70% in the dry season. At coastal examples land and sea breezes are predominant whilst inland fohn (or berg) winds are predominant.

Because hot humid regions tend to be relatively close to the equator the incoming rays of the sun strike the earth at angles close to perpendicular. This means that the minimum amount of energy is lost to the atmosphere before reaching the surface and the ground is rapidly heated.

Gresswell (1979:50-52) states that the most obvious examples of hot humid regions are the equatorial forests, where seasons are largely indistinguishable from each other. However, not all areas within the equatorial belt can be described as hot and humid. Parts of many of the world's driest and hottest deserts, like the Sahara, Namib and Atacama, occur within the two tropics. Furthermore there are areas that fall within the description of hot humid zones that lie outside of the tropics, although usually not by much. These areas usually occur only in narrow strips along coastlines between the ocean and high mountain ranges, with warm sea currents along them as described by Gresswell (1979:61).

### 3.2.3 Hot arid climate

Robinette (1983b:119) defines hot arid regions as places that have extended periods of overheating, large diurnal temperature ranges, low humidity and precipitation and winds that vary diurnally. The sunlight probability is 0.75 and 0.55 of the possible for the summer and winter respectively. According to Holm (1983:7) hot arid climates have a diurnal temperature range of at least 17°C, which is greater than the annual temperature range of around 14°C. Ground temperature is warmer than air temperature and the annual relative humidity is 10% to 55%. Winds in these regions have local diurnal cycles following the sun's path.

Aridity is defined by the deficit in the water balance of an area. This deficit in any region of the world is the product of a combination of four major factors, as summarised from Goudie (1984:109-110) and Slaymaker and Spencer (1998:178).

1) Firstly dry regions are often found deep in the interior of a continental landmass far from the moisture-providing oceans.

2) Secondly almost all dry areas occur between 20º and 40º latitude, which is the core region of the subtropical high-pressure cells. The trade winds that blow across these zones evaporate moisture because they warm up as they move from higher to lower altitudes. This does not mean that the dry regions are continuous around this belt as monsoon incursions or other factors do cause heavy rain in some regions within this belt.

3) Thirdly some dry regions are found in the rain shadow of a mountain range or escarpment.

4) Fourthly aridity is often accentuated by winds blowing over areas of sea with cold currents, usually along the Western shores of continents. These winds, cooled by the cold seawater, have low moisture bearing capacity and become stable as they heat over the landmasses, preventing precipitation.

Hillel (1978:161) is of the opinion that hot arid zones will be one of the most important areas for the future expansion of human civilisation. As more temperate regions get crowded and resources strained humanity is likely to start looking to the drier parts of the world for expansion. Arid regions have vast expanses of open space and untapped reserves of energy and mineral deposits that still need to be developed and utilised. The importance of arid areas is further illustrated when one considers how much of the surface of the earth is dry. More than a third of the total land surface of the planet (Figure 3.4) is arid or semi-arid. Yet perhaps the most important aspect of deserts may not be the available space but the superabundance of solar energy available to designers and developers alike. Of all the resources that the desert has to offer it is the least utilised and could be a major factor in future settlements in these regions. Finding ways to live in these areas may therefore well be one of the most significant developments of the twenty-first century.

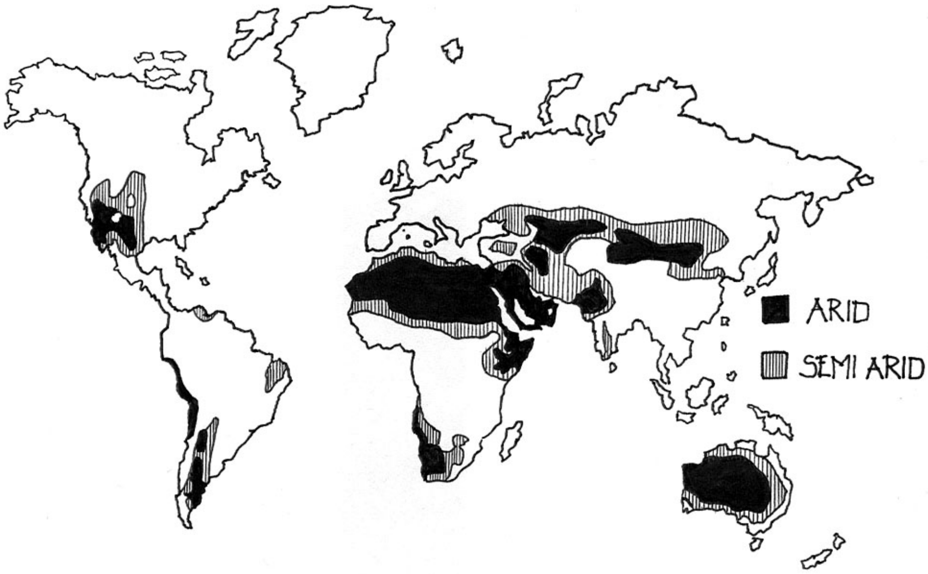



**Figure 3.4 A third of the surface of the earth is arid or semi-arid (Askin 1986, accessed 05-11-2003)**

Several characteristics of dry climate regions identified by Landsberg (1978:24-25) are of importance when considering human comfort and climatically responsive design.

1) Due to the influences of sea currents, air pressure patterns and topography, certain regions experience very high temperatures up to 40°C and higher. Where these temperatures occur for extended periods accompanied by lack of moisture, arid or semi-arid conditions occur. Low night temperatures can also occur when surfaces quickly lose heat to the clear night sky.

2) Minimal rainfall is definitive of all arid regions. Eckbo (1983:319) describes arid regions as having an average annual rainfall of 250mm or less and semi-arid regions receive up to 500mm. Associated with the minimal rainfall are low levels of relative air humidity. As the atmosphere heats up in the mornings the little moisture that is present is quickly burnt away and atmospheric humidity drops dramatically. Precipitation in desert or semi-desert regions is usually also variable and unpredictable, consisting of only a few downpours and usually only during a few months of an otherwise dry year and the amount of precipitation can vary greatly.

Some regions are characterised by a few years of comparatively good rainfall followed by an exceptionally dry period.

3) Dry regions tend to be clear and sunny, with a high percentage of the sunshine that is possible. Being largely covered with sand and rock, such regions have high average albedos. Sandy soil reflects up to 35% of the light falling on it and dunes up to 75% (Brown and Gillespie 1995:49). Thus solar energy is poorly absorbed by these surfaces and due to the high number of sunny days deserts are quite bright, reflecting a lot of light.

4) A final characteristic of dry regions, caused by the climate, is infertile soil. Plant life is minimal which means that little organic matter is present in the soil to begin with. Erosion caused by the periodic flash floods removes most of it and leaching of organic compounds occurs due to rapid water infiltration and evaporation. These factors result in soils that are mineral-laden and brackish.

### 3.2.4 Temperate climate

The temperate climatic design zone is perhaps the hardest to define, as its characteristics seem to be the most general of the four. According to Olgyay (1963:161) temperate zones are areas that require the maintenance of the seasonal balance of heat production, radiation and convection for human comfort. Robinette (1983b:95) states that summer cooling and winter heating are both important factors and wind patterns may differ seasonally. McPherson (1984b:163) states that temperate zones experience almost even overheated and underheated periods, with summers that are relatively humid and warm to hot; and winters that can be cool or sometimes cold. Especially winter conditions are not as severe as in the cool regions. According to Robinette (1983b:99) these regions have between 53% and 68% of the possible number of sunny days. There are four main types of temperate climates throughout the world distinguished mainly by their annual climatic cycles and characteristics, as shown by Gresswell (1979:69-85). The last three climates in Table 3.1 differ mainly due to their proximity to the oceans and the ameliorating effects of sea breezes. The continental temperate climates have a greater temperature range than the maritime climate. The temperate grasslands have a temperature range comparable to that of the continental temperate climate but are drier due to greater remoteness from the oceans, forming a transition area with arid or semi-arid regions.

**Table 3.1 The temperate climates and generalised typical characteristics (Gresswell 1979:84)**

| | Mediterranean | Marine | Continental | Grassland |
|---|---|---|---|---|
| Mean annual temperature | 15˚C | 10˚C | 7˚C | 7˚C |
| Annual range | 10˚C | 10˚C | 25˚C | 25˚C |
| Annual precipitation | 500mm | 750mm | 600mm | 500mm |
| Wet quarter contains* | One half (winter) | One quarter (late summer) | Two fifths (late summer) | One half (early summer) |
| Dry quarter contains* | One twentieth (late summer) | One quarter (varies) | One eighth (winter) | One eighth (winter) |
| *of the annual precipitation | | | | |

Goudie (1984:87-89) differentiates between two main types of temperate regions - the cool temperate climates consisting of the cool temperate oceanic climate and cool temperate continental climate, and the warm temperate climates consisting of the warm temperate western margin (Mediterranean) and warm temperate eastern margin. The main difference between these two groups is that the cool temperate climates have a true cold season that retards plant growth whereas the warm temperate climates do not. However the western and eastern warm temperate margins also differ from each other, mainly in humidity and rainfall patterns. The western temperate climates have a distinct winter rainfall element, relatively dry, hot summers and mild winters. These areas typically also have high amounts of sunshine. The eastern temperate margins also have hot summers and milder winters but these areas are characterised by more prominent summer precipitation and higher humidity.

### 3.2.5 Cool climate

Cool regions have varying characteristics and it is not easy to formulate a specific description of what such a region is. For instance some cool regions are quite arid, like Montana in the United States, whereas other parts with low annual temperatures get lots of rain, like Iceland. However according to Olgyay (1963:155) in cool regions winter response in design is three times as important as summer response. As the name implies cool regions are characterised by low temperatures for a significant period of time. Defining what “cold” means is somewhat conjectural as people have differing climatic tolerances to both hot and cold extremes. A valid description of the word cold, for the purposes of design considerations and human response, could perhaps read "temperatures that cause a person to change their external environment or clothing, or take other measures to warm their body, due to discomfort caused by these temperatures."

Latitude and altitude are two of the most determining reasons why certain regions or locations are predominantly cool although other factors such as sea currents and topographical features also have marked influences. The importance of latitude is further discussed in Section 2.2 and the effects of altitude are discussed in Section 2.1.2. For the purpose of definition, it is important to note that many of the cool regions of the world are closer to the poles, which means that they have long winter periods and that the sun is relatively low in the sky, even during the summer and at noon. As Byers (1974:57) states, the rate of temperature change with altitude is around 1000 times greater than that of latitude; so cool regions are often also at high altitudes. This is not to say that it never gets warm in cool regions. Although extreme locations like northern Canada probably never experience conditions that can be described as hot, McPherson (1984b:162) illustrates that Minneapolis in Minnesota, USA, still gets bitterly cold in the winter but can be uncomfortably warm in the summer. This is due to high summer temperatures combined with high humidity. Therefore another consideration in cool regions is the potentially large annual temperature range.

Another factor to consider in cool regions is the wind. Brown and Gillespie (1995:123) state that wind strongly affects human thermal comfort and energy use in buildings and in areas where temperatures are already low for extended periods its importance is magnified due to the influence of wind chill. Prolonged exposure to temperatures below 0˚C can already be dangerous, but at -30˚C the threat is significant and below -60˚C exposed flesh can freeze in 30 seconds, as Dorward (1990:68) points out. Even though few regions of the earth ever experience -30˚C, Table 2.3 shows that the experienced temperature of 0˚C in winds of 10m/s is -12˚C. Consideration of the temperature measurements of South Africa done by the National Weather Bureau over the years reveals that such conditions are not uncommon during winter in some parts of the country, especially in the Highveld region and mountainous parts of Kwazulu-Natal and Lesotho.

A last aspect of cool regions is that snowfall may occur and that in some places it is a dominant factor. The incidence of snow is greatly affected by relief and altitude, and as

Gresswell (1979:79) points out areas that are much higher than their surroundings are much more likely to receive snow or frost conditions. That is why the summit of Kilimandjaro is permanently covered with frost and snow while the surrounding plains, more than 4000m lower, are tropical savannah. Where snow does occur regularly it is a major environmental factor that has several significant impacts on climate and site alike. Apart from the physical problems posed by large amounts of snow two factors that are of great significance, namely the albedo and temperature influences of snow, must also be considered. Snow has a comparatively high albedo, reflecting from 40% to as much as 95% of the light falling on it as pointed out by Dorward (1990:72) and Robinette (1983b:16), depending on the wetness of the snow and the angle of the sun falling on it. Most of the energy from the sun is reflected and little radiative heating of the atmosphere above the snow occurs. This means that the diurnal temperature variation in snow-covered areas is also less pronounced but that radiative heating of the air above snow-covered surfaces is limited and that especially low-lying areas will be very cold even during the day.

### 3.2.6 Summary

In summation of Section 3.1 the following can be said about the most likely climate regions in Southern Africa:

1) Hot humid regions are characterised by relatively high average annual temperatures during both day and night, combined with high atmospheric humidity levels, especially during the summer. Due to the close proximity to the equator of most hot humid regions, solar radiation is concentrated, and rainfall is high caused mostly by local warm air convection. Where warm ocean currents exist, usually along eastern shorelines, orographic rainfall is also high if large topographical features are found there. From these descriptions hot humid conditions can be expected to occur along the northeastern coastline of South Africa.

2) Hot arid climates are characterised by high daytime temperatures, especially during the summer, along with large diurnal temperature ranges. The relative atmospheric humidity levels are low, precipitation is also limited and usually occurs in sporadic events and solar radiation levels are intensely high. Hot arid regions occur deep in the interior of continental landmasses between 20° and 40° latitude, often also in the rain shadow of mountain ranges. Winds blowing over cold sea currents along

western shorelines frequently contribute to the aridity of a region. These descriptions describe much of the interior and west of South Africa. Consequently much of the country can be expected to be hot arid.

3) Descriptions of temperate regions cover a wide range of conditions and especially temperatures vary greatly. Summer conditions are more severe than those experienced during the winter, with high temperatures and humidity. Sunshine levels are moderately high and distinction is made between maritime and continental temperate climates. Maritime temperate climates experience smaller temperature ranges and especially in Mediterranean regions winter rainfall is prominent whereas continental temperate regions are characterised by larger annual temperature ranges and more prominent summer rainfall. This tendency also increases as one moves further east. These descriptions would suggest that especially the southwestern and southern Cape region would be temperate in nature as well as less arid parts of the eastern interior.

4) Cool regions are characterised by cold temperatures during winters and cool to warm summer temperatures, depending largely on the latitude of the location. Globally temperatures decrease as one moves away from the equator although this phenomenon is only detectable over considerable distances. High altitudes generally experience lower average temperatures than locations at the same latitude but lower altitude. Where sufficiently low temperatures occur, usually during the winter, frost and snow may occur. From the above descriptions it can be deduced that South Africa is unlikely to have large cool zones and such areas will probably not be characterised by extreme conditions associated with truly cold zones as described above. The main reasons for this are that South Africa, at between 22° and 35° South, lies entirely within the tropical and sub-tropical latitudes; and with the exception mainly of the escarpment most of the country is relatively low above sea level. Nevertheless there are isolated locations that do get very cold during the winter and climate-responsive design can be applied to create more comfortable conditions and reduce energy consumption in these areas.

# 5 CHAPTER V – LANDSCAPE DESIGN DEVICES FOR ENERGY EFFICIENCY IN THE CONTEXT OF THE SUBURBAN RESIDENCE

## 5.1 Introduction

The third sub-problem seeks to assess strategies for creating climate-responsiveness suburban residential design in South Africa in order to achieve greater energy efficiency. To this end design solutions applicable to the relevant climatic contexts will be considered and evaluated in Chapter 5. The guidelines will focus on various aspects related to climate-responsiveness, namely:

1) Suburban fabric character and development density considerations to ensure adequate solar access to individual units.

2) Solar water heating and passive heating of buildings.

3) Windbreaks and manipulation of airflow and humidity for heating and cooling purposes.

4) Thermal mass and passive cooling methods.

5) Optimal building shapes, orientations and surface treatments for solar access control and daylighting purposes.

6) Effective residential water management strategies.

Due to the often interacting and interdependent nature of these design aspects they will be discussed separately only as far as is practical.

## 5.2 Suburban structure and layout

### 5.2.1 Initial considerations

According to Guthrie (1991:23) an effective way of analysing the "needs" of the climate-responsive building is to see it as a living being with the same needs and wants as its occupants. If the occupants want shade, so does it, if the occupants want sun, so does it. The more the needs of this hypothetical being are met, the more energy is saved. Thus suburban residential layout and design have to respond to the specifics of climate and site to achieve energy efficiency. For this to be possible on a meaningful scale these resources must be available to designers, developers and residents alike. Radovic (1988:373) contends that securing the use of beneficial climatic factors in future town and city development can be achieved by detailed town development plans. These plans should define all the parameters and guidelines for the effective use of climatic factors for energy efficiency, in respect of specific areas or locations. This can be done for any number of climatic factors and components, although the most effective ones to include will probably be parameters and specifications for solar access and utilisation regulating the following:

1) Lot orientation and layout density;

2) Minimum design requirements for solar gain;

3) Minimum material and construction specifications for insulation purposes; and

4) Water recycling or re-use systems and associated design.

Consequently the application of passive solar design, as well as more efficient water management practices, will become possible on a suburban scale, instead of just being applied in isolated projects.

Grabovac & Dragovic (1988:638) have identified three conceptual design conditions that must be satisfied in order to successfully apply passive solar design in any urban or suburban setting:

1) Optimum orientation of the building with respect to the specific local climate and site characteristics must be ensured.

2) Minimal shading of the building by structures, features or elements on the site or adjacent sites is necessary.

3) Optimum dimensions and proportions of buildings for specific climatic conditions must be respected and incorporated in the design.

When these minimum requirements are satisfied it is possible to design buildings and plan residential suburbs in ways that harness the environmental and climatic potential offered by any site.

### 5.2.2 Street and lot orientations

Designing suburbs to create access to solar radiation forms the basis of solar design. According to Erley and Jaffe (1979:11) the value of site design for solar access is that in most cases the same design elements as for conventional development are used - they are only arranged differently. There are also no real differences in initial cost, only in planning. Of these decisions street and lot orientation are some of the first and most important ones to be made, because to ensure that buildings are optimally orientated for solar design the streets and individual lots have to be set out in a fashion that facilitates correct building orientation. Carter & De Villiers (1987:6) state that optimised lot orientation and allocation can provide solar access for all units in a given area, whereas standard conventional subdivision often greatly reduces the possibility for passive solar design. Figure 5.1 compares a typical conventional suburban layout with more favourable alternatives for solar design.

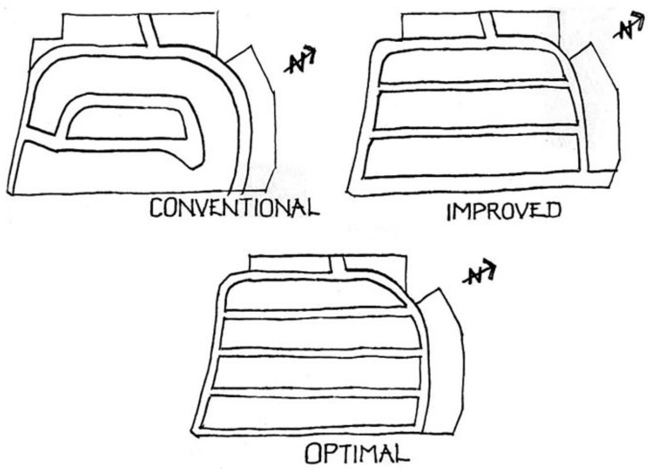
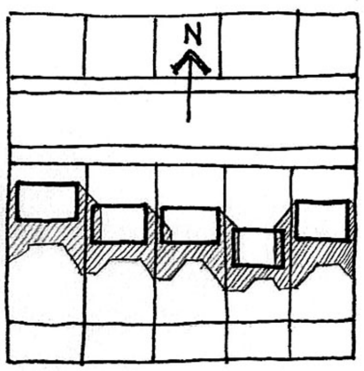
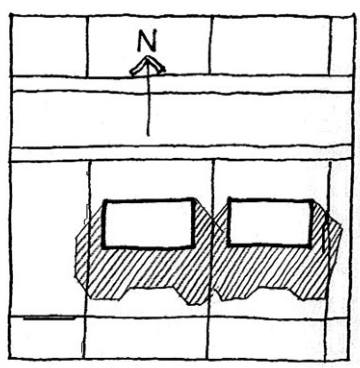
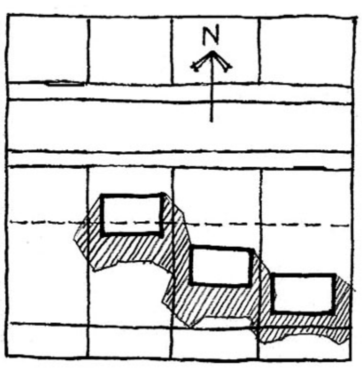
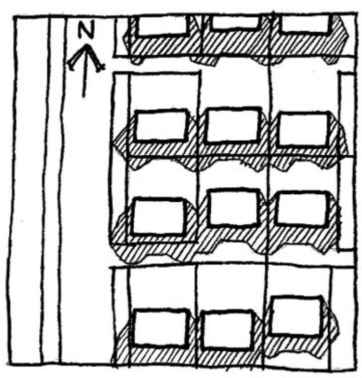



**Figure 5.1 Site and road layout determines passive solar utilisation potential (Carter and de Villiers 1987:5-6)**

Shashua-Bar and Hoffman (2003:63) state that generally speaking a north-south orientated street allows for more direct solar radiation onto the walls of any surface facing that street, receiving the radiation symmetrically along its central axis. Where streets are aligned east-west the north-facing walls predominantly receive the direct radiation. Only in the tropics does the sun alternate between shining on northern and southern facades, due to the fact that it shines on different sides of the equator at different times of the year. Figure 5.2 illustrates different street and lot layout configurations to optimise the solar access zones of each lot, for different situations. The shaded areas on the figures indicate the entire area that is shaded by the structure during the course of the day.

| | |
|---|---|
|   |   |
| Smaller lots allow greater development density but cause more overshadowing | Larger lots allow larger units and less overshadowing but reduced development density |
|   |   |
| Adjustable setback and staggered building line reduce overshadowing | Battleaxe lot layouts allow northern sun access, increased density and reduced street lengths in north-south orientated streets. Some overshadowing may occur |

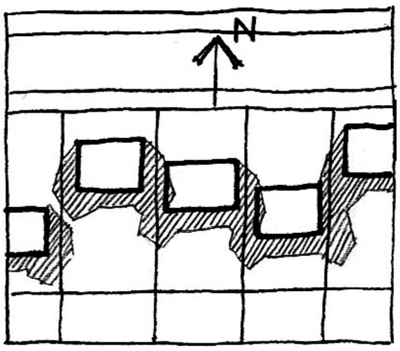
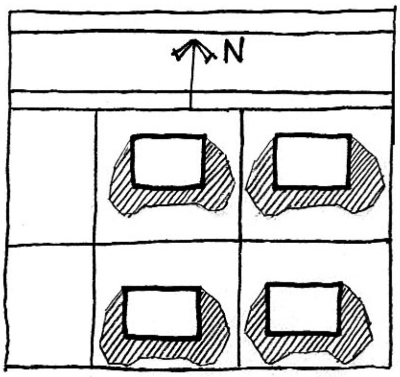
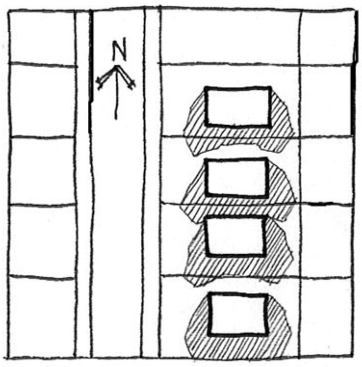
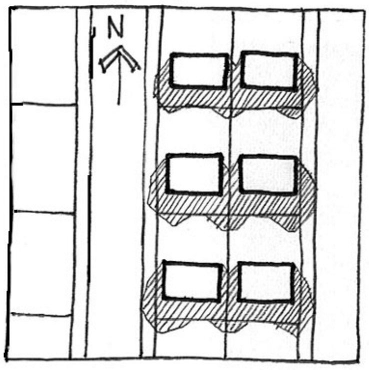
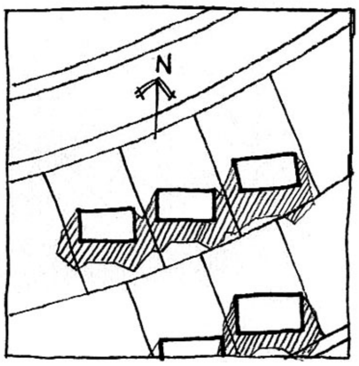
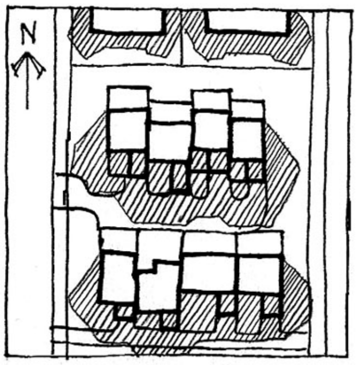
| | |
|---|---|
|  |  |
| Rectangular lots orientated perpendicularly with the street reduce street frontage and solar access and cause some overshadowing but also reduce street length and surface | More square lots with the same area as rectangular ones allow less overshadowing but increase street length and lot frontage to street |
|  |  |
| Narrow street fronts perpendicular to sun cause much overshadowing in north-south orientated streets | Increased street frontage perpendicular to sun reduces overshadowing but increases street length in north-south orientated streets |
|  |  |
| Correct placement can ensure solar access in sub-optimal street layouts | North-facing private gardens and south entry to garage increases density and solar access. This arrangement is suited to double storey double unit arrangements |

**Figure 5.2 Different street- and lot layout configurations to optimise the solar access zones of each lot, for different situations (Total Environment Centre 1982:10-13)**

From these considerations some deductions can also be made concerning street tree planting. In areas where good solar access is a necessity for climate-responsive design, especially colder parts, poor street tree placement can limit or interfere with the climate-responsive potential of a design. Subsequently different tree placement, sizes and spacing will be needed in different situations (Figure 5.3).

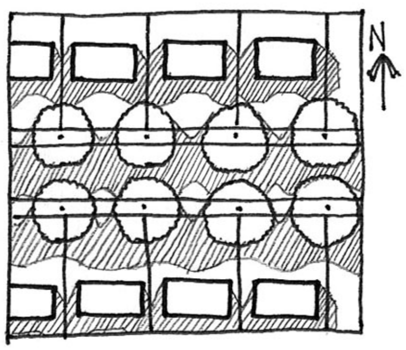
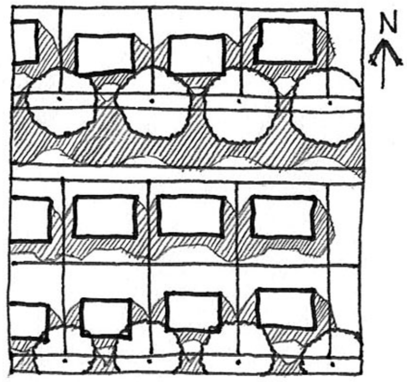
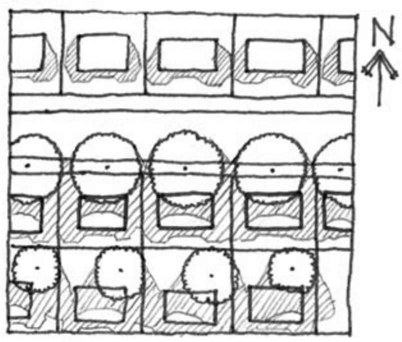
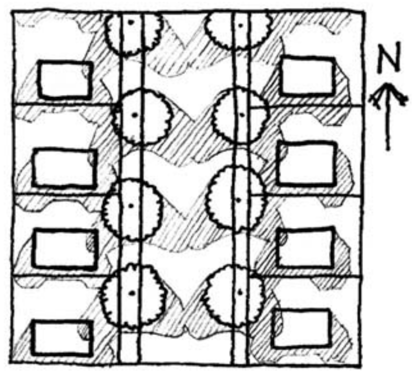
| | |
|---|---|
|   |   |
| Larger lots allow street trees on both sides without overshadowing buildings if building line is set back far enough | Where overshadowing is unwanted smaller lots and narrower streets should only accommodate trees on north side of street |
|   |   |
| Where shading is beneficial in the summer street trees placed on the South side of the street may shade units if they are close enough to the road | Staggering trees relative to units can prevent shading of units in densely developed North-south orientated streets and can substantially shade road surfaces |

**Figure 5.3 Street tree placement to ensure solar access to different lot sizes and street widths**

These simple measures can already contribute significantly to reducing household energy consumption. According to Procos (1988:121) emphasis has been placed on correct street orientation for solar access in Canada, where detached single residences are strongly favoured over attached townhouses or apartment buildings. This has led to noticeable thermal improvement in ordinarily designed and constructed houses. Legislation has been passed in some areas that require compliance with minimum orientation specifications. Given the precedence of single-standing houses or semi-attached town house units in affluent suburbs of South Africa, correct street and lot orientation should play a significant part in their energy efficiency.

### 5.2.3 Streetscapes and planting

Municipal streetscapes can have significant influences on the thermal performance of buildings and can either aid in or inhibit climatically responsive design. The ambient temperatures of a location can be favourably affected through sensitive streetscape planting design and surface treatment. Favourable climate changes will be brought about through the correct application of different elements in the landscape. Depending on the climatic conditions of an area, the aim may either be to lower or increase ambient temperatures.

As pointed out by Alp (1988:76), and Akbari (2002:120), trees in particular can moderate the climate of the urban environment in various ways if they are chosen and placed correctly. Aside from directly blocking solar radiation from a surface or allowing it to penetrate onto it, the shade from trees also reduces glare and diffused light from other surfaces and cools through evapo-transpiration. At night trees can retard the heat flow from buildings to the outside environment and reduce the air exchange rate between interior and exterior, by slowing wind speeds around buildings. Lower wind speeds also reduce the rate at which heat is lost from sunlit surfaces, which means that the building shell can heat up more, which in turn results in increased heat transmission into the building.

Streetscape trees are especially valuable in reducing ambient temperatures in urban areas that are often characterised by the heat island effect. According to Shashua-Bar and Hoffman (2003:61) a study in Tel Aviv done on 11 wooded urban sites has found that 80% of the cooling effect at these sites is attributable to the trees planted there. This city is situated at 32° north, the same latitude as many South African towns (Cradock, Graaff-Reinet, Beaufort-Wes and Clanwilliam), and among others has a comparable hot semi-arid climate. Thus wooded urban sites can have a similar cooling effect on the microclimatic conditions of these South African towns, highlighting the importance of garden and street trees in arid areas. Carter and De Villiers (1987:5) state that by decreasing the amounts of tar road surface in hot areas, the amount of heat absorbed by streets can also be significantly reduced. Thus planting enough trees in strategic places to shade reduced road surfaces during summer can significantly reduce cooling loads in hot regions.

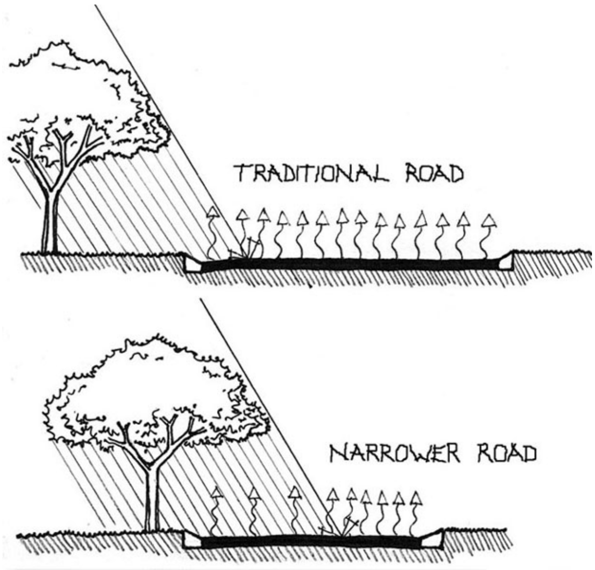



**Figure 5.4 Strategically placed street trees to shade reduced road surfaces during summer**

A potential benefit of street trees in cooler areas, as illustrated in Figure 5.5, is that they help to reduce wind speed in built-up areas. In fact the overall wind speeds above and near the surface of built-up suburban areas are lower than over flat undisturbed country, mainly due to the resistance created by the more irregular surface that such a landscape provides. This

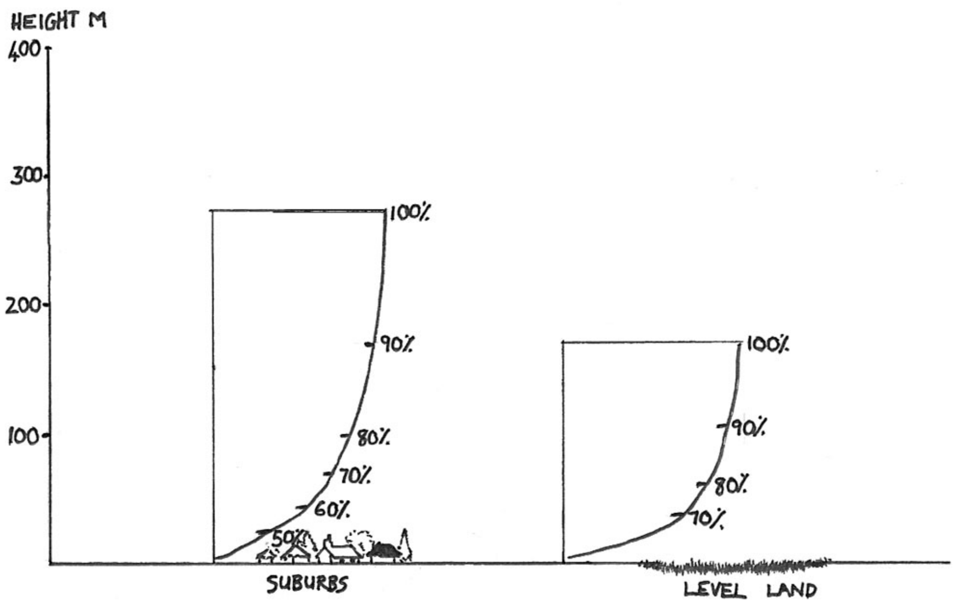



**Figure 5.5 Wind speed profiles over flat open country and urban areas or large farmsteads (Clark 1999:105)**

may be a favourable effect in cool regions where wind can lower the experienced ambient temperatures of that area and cause heat loss from buildings. However the nature of the topography of a region will also have some influence on the prevailing wind patterns. It is important to note that rolling landscapes tend to disturb the flow of air less than more pronounced topographical features, causing less turbulence, as Figure 5.6 shows.

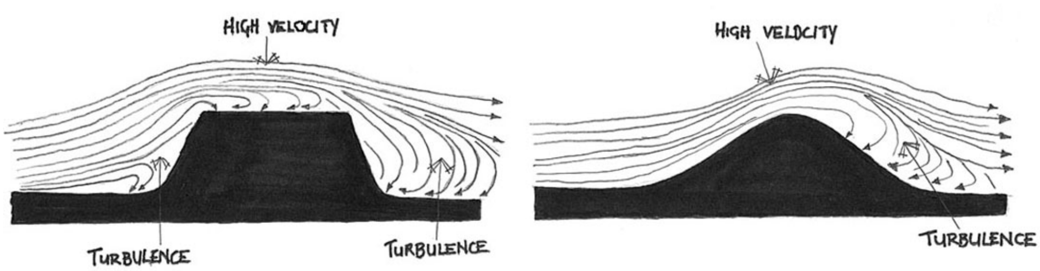
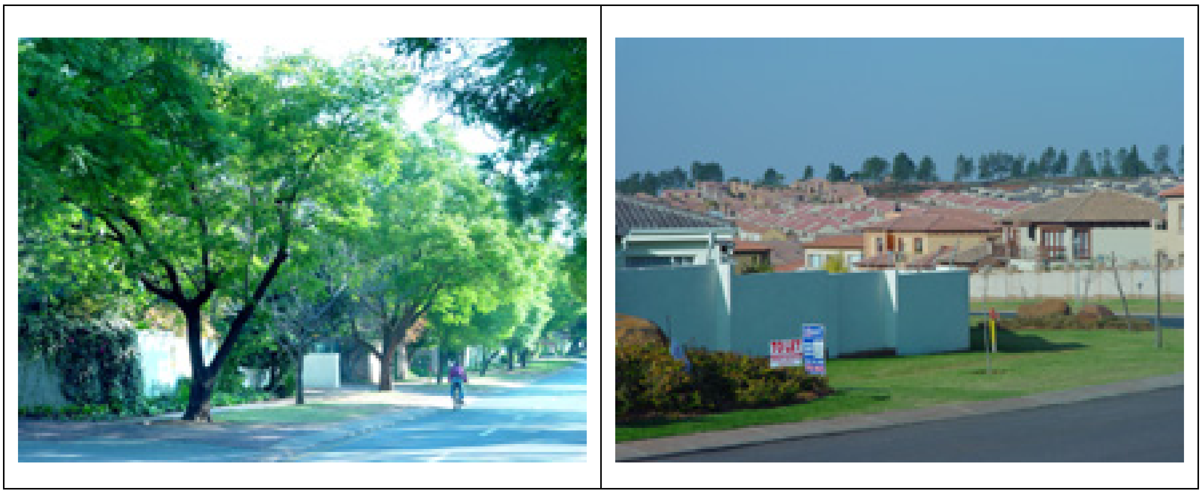



**Figure 5.6 The influence of pronounced vertical and rolling topographical landforms on wind speed and airflow (Clark 1999:106)**

Observing new higher density cluster housing and security village developments reveals that many have few trees, especially in situations where vehicular streets are enclosed by the boundary wall of the estate or development. In such instances street trees are often left out of the design, or are fewer in number than in older neighbourhoods as Figure 5.7 illustrates.



Note to Figure: a=Dense vegetative cover in older lower density neighborhood and b=Sparse vegetation in typical cluster housing development.

**Figure 5.7 Photos illustrating the amount of vegetative cover found in two typical eastern Pretoria neighbourhoods**

This can be problematic for the urban climate from a comfort and energy conservation perspective as there are several microclimatic effects associated with the removal of trees from any type of landscape. Pokorný states that more solar energy is converted to heat in areas where trees are removed, increasing ambient temperatures. The landscape loses water as the rate of evaporation is increased due to the increased solar radiation, and small-scale atmospheric pressure differences due to localised heating of surfaces give rise to higher wind speeds (Pokorný 2001:644). All of these effects can be detrimental to comfort if they occur in the wrong circumstances, which results in more energy being spent to correct the situation through airconditioning or heating devices.

### 5.2.4 Topographical and development density considerations

There are five possible levels of solar access that can be incorporated in urban areas, with the highest levels of access at ground level creating the greatest potential for conflict with higher levels of development (Total Environment Centre 1982:7). These levels are:

1) Rooftop access which allows for active systems placed on rooftops, such as solar photo-voltaic and heater systems, as well as skylights.

2) North wall access which allows additional access for all passive systems on this façade.

3) North lot protection which includes levels 1 and 2 but which also allows for attached greenhouses and the use of reflectors to increase the efficiency of passive and active systems.

4) Whole lot protection where sunlight that naturally reaches a plot can potentially be used as in 1 to 3 and for various additional quality of life purposes; and

5) Detached collector protection where additional freestanding or accessory building structures can also use sunlight.

Given the general low density of suburban development in most of South Africa, level 3 could be available to all suburban residences in the country and in many instances level 4 or 5 may be achievable.

Topography significantly influences the availability of sunlight on a site and will play a major part in the layout of suburbs that are planned to make use of solar radiation for energy efficiency. The difference in shade length on north- and south-facing slopes means that greater development density is possible on north-facing slopes than south-facing ones (Total Environment Centre 1982:9). Erley and Jaffe (1979:20) concur that, within the constraints of economic and practical considerations, developments that aim to maximise the potential benefits of solar radiation are most feasible on moderate north-facing slopes. Solar developments are therefore much more feasible and less complicated on north slopes and greater care in the site layout phase has to be taken to make southern slopes feasible for solar design. Solar development density should be decreased, or may even be unfeasible on southern slopes. As Zanetto (1984:100) points out the most important consideration regarding solar radiation is that solar collectors are most effective when solar radiation strikes them perpendicularly, thus it is necessary to consider the influences that latitude and site topography have on the solar radiation that reaches the site.

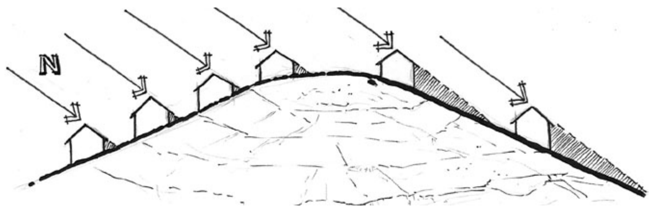



**Figure 5.8 Greater development density is possible on north-facing slopes than on south-facing ones**

However according to Cook (1988:39), studies in Yugoslavia have shown that solar architecture need not have significant negative impacts on the density of development. Similarly, studies in Greece have shown that retrofitting of existing buildings that are regionally appropriate, to make use of solar energy, need not be unreasonably expensive and can have a relatively short investment payback period. It is therefore possible that suburbs that are planned for the use of solar and other climatic resources from the start, and designed accordingly, can be both affordable and easily integrated with existing urban fabric.

Apart from solar access there are several other considerations that will determine the density of a residential development. Different densities will have advantages and disadvantages and the optimum density for individual developments should be determined by comparing the consequences of different scenarios. Where lower densities allow better access to climate elements for microclimatic amelioration they result in increased travel distances and infrastructure costs. Higher density developments may support mixed use and decreased travel distances but renewable energy utilisation may be limited. Table 5.1 illustrates the various considerations that must be taken into account when establishing the building density of a residential development.

**Table 5.1 Implications of density for sustainable housing – comparison of three paradigms (Edwards 2000:132)**

| Type | Houses/hectare | Advantages | Disadvantages |
|---|---|---|---|
| Low density | 10 | 1) Renewable energy can readily be exploited<br>2) Rainwater and greywater systems can be employed<br>3) Food production in gardens<br>4) High biodiversity<br>5) High tranquillity | 1) Poor land utilisation<br>2) Infrastructure costs high<br>3) High transport energy costs<br>4) High building energy costs unless renewables used |
| Medium density | 30 | 1) Renewable energy can be exploited<br>2) Some local food and energy crops can be grown in gardens<br>3) Movement by bicycle viable<br>4) Community greywater systems possible | 1) Public transport will need large subsidy<br>2) Careful design needed to exploit renewable energy<br>3) Neighbour disputes can arise over waste or recycling initiatives<br>4) Poor urban form |
| High density | 60 | 1) Compact forms are energy efficient<br>2) Supports mixed use development<br>3) Most journeys on foot, bicycle or public transport<br>4) Good urban design<br>5) Good microclimate | 1) Crime and vandalism can be a problem<br>2) Anti-social behaviour undermines community spirit<br>3) Low tranquillity<br>4) Good design essential<br>5) Costs can be high per unit |

### 5.2.5 Suburban layout in different climatic contexts

Due to the widely varying conditions of different climate regions, applying the same layout principles to each would be a mistake and may impede climate-responsive design. Different climatic settings have different implications for the layout and fabric of suburbs. Ward (2002:71) explains that in hot humid regions low-density developments allow breezes to penetrate more freely through the urban fabric, making provision for good airflow and circulation. She continues by mentioning that trees with high canopies and ground clearance further aid air circulation, which helps to cool hot humid regions by removing humid air and allowing drier, cooler air to replace it. Along the eastern coast of South Africa sites exposed to north-easterly and south-westerly breezes are preferable. Holm (1996:49) contends that a narrow plan form with a single row of rooms allow for the most effective ventilation, with the north-south sides being the longest. Although other factors also come into play when laying out suburban areas hot humid regions are in a sense the simplest to plan. Low urban density allows for both ample solar skyspace that can be managed through planting and the like, and good air movement for cooling. However, according to Erley and Jaffe (1979:29), site location is important in such climates and suburban development should preferably be located on breezy ridge tops, southern slopes or gentle northern slopes. Eastern, western and steep sites should be avoided, as well as locations where landforms create wind-still conditions.

Hot arid regions are more complex to set out if adequate solar exposure and ventilation is to be ensured. Olgyay (1963:173-177) gives several guidelines for areas where overheating tends to be a regular problem. Residential developments should preferably be located on slopes that are cooler all year round. Especially western slopes tend to be too hot as they receive sunshine late in the afternoon and if atmospheric conditions are already hot this can lead to overheating of the buildings. However, in very hot climates eastern slopes can also be uncomfortably hot early in the morning and in such instances either northern or even southern slopes are recommended for residential development. Ward (2002:71) recommends that for the desert steppe and lowveld regions, both of which fall predominantly within the hot arid zone, massive and thermally inert constructions and compact layouts be used. For the highveld region, which is predominantly temperate and in places transitional hot arid, north and east slopes are preferable and heavyweight construction with a relatively compact layout and shared walls between units is recommended. Mutual shading by buildings is especially important in hot arid regions. Ward also recommends that for the winter rainfall region of South Africa a dense, compact layout be used. Protection against the southeast winds in the summer and northwest winds in the winter is recommended, especially with evergreen planting. The winter rainfall or Mediterranean region of South Africa falls within the boundaries of the western hot arid and temperate regions described in Section 3.2.6.

Robinette (1983a:97) gives further guidance for choosing sites that are most suited for design in temperate climates. The most suited sites for climate-responsive development here are ones that are located on the middle or upper downwind sides of slopes, as they receive the most radiation in the winter and less radiation during the summer than slopes at the foot or crest of the slope. Especially the crests of slopes should be avoided as these receive the strongest winds. Robinette (1983a:84-85) also suggests that in cool regions the highest development should occur on the northeastern slopes, to take full advantage of optimal solar orientation with sparser development on the southern slopes, due to the low incidence angle of the sun. Extensive buffering is required in cooler areas to reduce heat loss and air infiltration. Medium-density clustering to create sun pockets is advisable on northern slopes, especially with multi-storey buildings. Table 5.2 gives more detailed orientation guidelines for the four main climate types.

**Table 5.2 Site orientation guidelines for the four main climate regions of the world (Keplinger 1978 as shown in Owens 1986:45)**

| | Cool regions | Temperate regions | Hot humid regions | Hot arid regions |
|---|---|---|---|---|
| Adaptations | Maximise warming effects of solar radiation, reduce impact of winter wind, avoid local climatic cold pockets | Maximise warming effect of sun in winter, maximise shade in summer, reduce impact of winter wind but allow air circulation in summer | Maximise shade, maximise wind | Maximise shade late morning and all afternoon, maximise humidity, maximise air movement in summer |
| Position on slope | Low for wind shelter | Middle-upper for solar radiation exposure | High for wind | Low for cool air flow |
| Orientation on slope | North to Northeast | North to northeast | North | East to northeast for afternoon shade |
| Relation to water | Near large body of water | Close to water but avoid coastal fog | Near any water | On lee side of water |
| Clustering | Around sun pockets | Around a common sunny terrace | Open to wind | Along east-west axis, for shade and wind |
| Building orientation | Northeast | North to northeast | North towards prevailing wind | North |

| | Cool regions | Temperate regions | Hot humid regions | Hot arid regions |
|---|---|---|---|---|
| Tree forms | Deciduous trees near buildings, evergreens for windbreaks | Deciduous trees nearby on west, no evergreens near on north | High canopy trees, deciduous trees near buildings | Trees overhanging roof if possible |
| Road orientation | Perpendicular to winter wind | Perpendicular to winter wind | Broad channel, east-west axis | Narrow, east-west axis |
| Materials coloration | Medium to dark | Medium | Light, especially for roof | Light on exposed surfaces, dark to avoid reflection |

Note to Table: North and South have been switched around to relate Table to Southern Hemisphere conditions.

## 5.3 Passive solar design

### 5.3.1 Passive versus active solar design

Passive solar design uses and integrates various architectural features and materials to create thermal comfort for the occupants. McFadden and Andrejko (1989:9) describe passive heating as relying on the processes of heat transfer through convection, radiation and conduction to manage the energy from the sun and normally using no external power to operate. Sheinkopf (1989:11) defines passive cooling as relying on construction methods and design that incorporate heat avoidance techniques and natural cooling methods to reduce energy consumption and increase thermal comfort levels for occupants. Passive cooling methods include natural ventilation, night cooling, earth contact cooling, evaporative cooling and radiative cooling. These systems usually use the same materials and design elements as conventional buildings and operate without mechanical assistance or external power supply.

Although according to Lebens (1980:3,118) passive solar systems are usually less spectacular and graphic than active systems they produce better results in terms of energy conservation and life-cycle costs. Passive systems also have a shorter payback period on the invested capital and are less maintenance and repair-intensive than active systems. This makes passive solar systems ideal for South Africa, a country that has high levels of sunshine in comparison with the rest of the world. In fact, Ward (2002:54) argues that passive solar heating of homes is the most cost effective method available in the South African context provided that sound design and effective insulation is used.

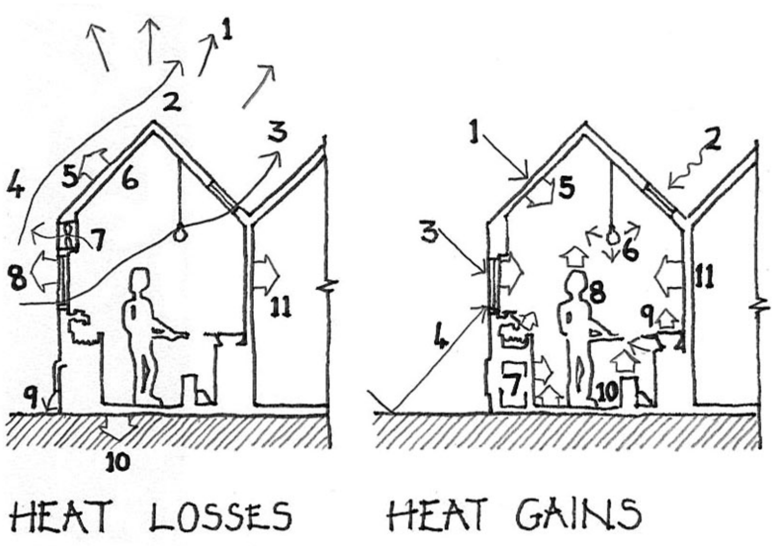
Passive solar design devices are usually conceptually quite simple and because they do not rely on complex machinery and electronics to operate they should present an attractive alternative to both conventional heating and active solar heating devices. When the climate of South Africa is considered the value of these systems becomes even clearer. A study done by the National Building Research Institute (NBRI) of the CSIR found that only five to ten percent of the electric energy used in Pretoria was for space heating (Basson *et al* 1986:2). Although this figure can be expected to be higher in cooler regions, the climate of the country is such that the little energy used for space heating can be greatly reduced through climate-responsive design. As the degree of heating that is needed in most parts is also generally quite low, passive solar heating is an effective option.

Jaffe and Erley (1980:19-21) distinguish between three types of passive solar gain systems. Direct gain passive systems allow sunlight directly into a building, usually through windows, causing it to be converted to heat when it strikes the interior of the building. Heat is stored in the building materials of the floor and walls and released at the appropriate time into the building. Indirect gain systems also allow sunlight into a building to heat a storage mass behind. During the winter this space is vented to allow the heated air into the buildings behind whilst in the summer it is vented to the outside. Isolated gain systems like greenhouses operate separately and outside the building and heated air is vented into the building when needed. Direct gain systems only incorporate building elements that are found in conventional buildings, albeit to different specifications and in different relationships to each other. This means that they imply the least drastic alterations to a conventional building design to make it more climatically responsive, whereas indirect gain systems require more operation and maintenance and additional design elements.

### 5.3.2 Passive solar design and temperature regulation – the flywheel effect

In areas where the need to warm buildings is great, merely correctly placing and orientating a building will not be enough to ensure that the interior is sufficiently warm to keep the occupants comfortable, especially during the winter. The need for heating may also be increased due to incorrect design. To remedy the heat requirement electrical devices such as resistance heaters and underfloor heating are used, but in most parts of the country such measures are only required for relatively short intervals of the year. If houses are designed so that they are naturally heated when necessary the money invested in heating equipment can be put to other uses.

Consideration of the temperatures in cool and hot arid areas reveal that both actually require buildings to be heated for at least a portion of the day, during certain times of the year. In cool regions it may well be necessary to ensure heated building interiors for several winter months during the days and nights, whereas in hot arid regions the need for heating only exists during nights, especially during the winter. For the rest of the time buildings have to be kept cool. Nevertheless the basic thermal influences of the sun on a building remain the same for all climate conditions, as illustrated in Figure 5.9.

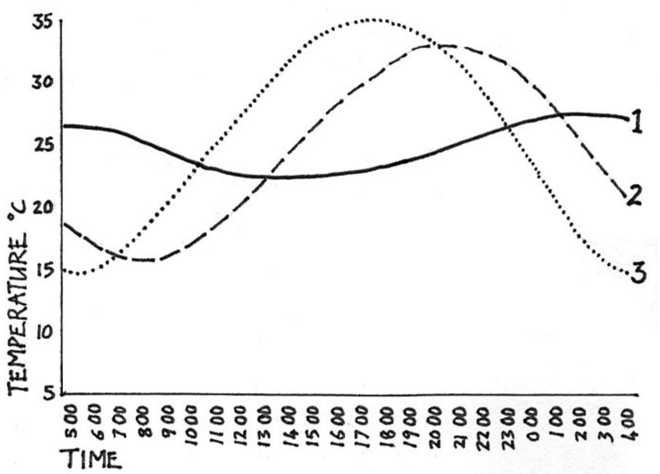



| | |
|---|---|
| Legend: 1=Radiation to sky and surrounding objects, 2=Convection, 3=Infiltration/ventilation, 4=Wind assistance, 5=Conductive fabric loss, 6=Fabric absorption, 7=Forced ventilation, 8=Conductive glazing loss, 9=Hot water rejection, 10=Conduction to ground, 11=Conduction to other spaces | Legend: 1=Direct solar radiation absorption, 2=Diffuse solar radiation, 3=Solar gain through glazing, 4=Reflected solar radiation, 5=Re-radiation, 6=Lights, 7=Water heating, 8=People, 9=Cooking, 10=Appliances, 11=Conduction from other spaces |

**Figure 5.9 Thermal influences operating on spaces within buildings (Matthews 1987:30)**

Nahar, Sharma and Purohit (2003:109) explain that in deserts such as the Thar Desert in India vernacular measures to achieve passive temperature amelioration often relied on thick, thermally inert walls made of baked mud bricks. The walls would heat slowly enough for the heat to only reach the interior of the building at night, when heating is actually wanted. In this way passive cooling by day and passive heating by night is achieved. Alp (1988:69) also points out that massive walls effectively regulate the temperature in areas where days are disturbingly hot and nights cool or even cold. 300 mm of baked brick wall successfully replaces adobe walls in such climates.

Napier (2000:3.6.1-3.6.2) explains this phenomenon, called the flywheel effect. During summer days, the cool structural mass of the building draws heat from the interior of the building, cooling it. The thermal mass also slows solar radiation from reaching the interior. Combined with appropriate shading and window shuttering this keeps temperatures down during the day. At night, stored heat is radiated into the structure, and opened windows can allow ventilation to cool the structural mass and regulate the interior temperature. During winters, more heat can be allowed into the building through windows while the structure of the building heats. During the night drawn curtains and closed windows allows the heat to radiate to the interior of the building, warming it. Figure 5.10 illustrates the thermal performance of a lightweight and mass construction box in hot arid conditions.




Legend: 1=Heavyweight box, 2=Lightweight box, 3=Outside temperature

**Figure 5.10 Internal temperature moderation through heavyweight construction (Hyde 2000:189)**

## 5.3.3 Passive solar design and materials

From this description of the flywheel effect it becomes clear that in hot arid regions it is necessary that during the day the heat should move slowly from the outside of the building to the inside, which will allow for the building interior to only heat at night. Subsequently in such climates materials with a long heat flow time lag period are needed for passive thermal control. Table 5.3 shows how long it takes for heat to pass through several materials and widths. It is illustrated that thick brick or stone walls are most suited for this purpose, followed by solid concrete in situ or block walls. Due to the fact that a large percentage of the radiation that a building receives impinges on the roof, especially in arid climates where the sun is high in the sky for large parts of the day, it is important that heavyweight roofs are also used. Shariah, Shalabi, Rousan and Tashtoush (1998:273,283) elaborate on this point by stating that solar radiation significantly affects indoor temperatures of buildings by entering through windows and other openings; and through absorption by the walls and roof. The roof in particular absorbs a lot of solar energy and significant reductions in heat gain can further be achieved by applying light-coloured or reflective coatings to roof surfaces. Cavity walls are also effective passive temperature regulation devices. According to Ward (2002:71) heavyweight cavity walls are best for the winter rainfall regions of South Africa. This form of wall construction has a long heat flow time lag period and the cavity prevents rising damp from entering the building.

**Table 5.3 Time lag of heat flow through various construction materials (Strock and Koral 1965 as shown in Mazria 1979:345)**

| **Building element** | **Width or description** | **Time lag of heat flow in hours** |
|---|---|---|
| **Walls** | | |
| Brick wall | 101,6 mm | 2.3 |
| | 203,2 mm | 5.5 |
| | 304,8 mm | 8.0 |
| Concrete, solid or block | 50,8 mm | 1.0 |
| | 101,6 mm | 2.6 |
| | 152,4 mm | 3.8 |
| | 203,2 mm | 5.1 |
| | 254 mm | 6.4 |
| | 304,8 mm | 7.6 |
| Glass | Window | 0.0 |
| | Block | 2.0 |

| Building element (cont.) | Width or description (cont.) | Time lag of heat flow in hours (cont.) |
|---|---|---|
| Stone | 203,2 mm | 5.4 |
| | 304,8 mm | 8.0 |
| Frame | Wood, plaster - no insulation | 0.8 |
| | Wood, plaster and insulation | 3.0 |
| | Brick veneer, plaster - no insulation | 3.0 |
| | Brick veneer, plaster and insulation | 5.5 |
| **Roofs** | | |
| Light construction | | 0.7-1.3 |
| Medium construction | | 1.4-2.4 |
| Heavy construction | | 2.5-5.0 |
| Note to Table: units have been converted from inches to mm using 1 inch = 25.4mm. | | |

Water is another substance that has considerable potential as a thermal insulator. Table 5.4 shows that the thermal admittance of water is high, which means that it has the capacity to store a substantial amount of energy. This in turn means that it can effectively be used to lessen the diurnal temperature range in buildings. The skytherm system as described by Raeissi and Taheri (2000:529-530, 541-542) consists of bags made of a thin plastic that are filled with water and placed directly onto the roof of a building. Moveable insulation panels mean that the water bags can be closed during summer days to prevent heat gain and opened at night to facilitate radiant heat loss to the night sky. The process is reversed during the winter so that the water is heated during the day to release energy into the building at night. This system has several implications for the roof construction but favourable performance has been found for both winter and summer. In cooler regions, the same principle can be used to keep building interior temperatures higher, provided that the water does not freeze.

Garde, Mara, Lauret, Boyer and Celaire (2001:112) explain that in humid tropical climates the main source of interior discomfort is caused due to the lack of adequate solar protection, which can be achieved to a substantial degree through shading. Garde *et al* further state that roofs can account for up to 60% of the total envelope heat gains of a building, whilst walls contribute 20% to 30%. Hyde (2000:57) is of the opinion that the main climate design methods in hot humid regions are to minimise heat gain, maximise ventilation and maximise shading, and that the response strategies to achieve this include crossventilation of high ceilings, window shading all year round and shaded verandas. In such conditions, where heat gains are to be avoided, thermally massive construction is not wanted and will indeed be detrimental to the thermal performance of a building. Table 5.3 illustrates that a wooden frame wall, plastered and with no insulation, offers little time resistance for heat transfer into a building interior and the same is true for a light roof construction. Thus, although the air inside the building will soon begin to heat up during the day, little energy will be stored in the building material itself. Heat build-up in the building interior can be avoided with adequate ventilation and the light construction materials will not result in heat being radiated into the interior at night.

A study done by Onmura, Matsumoto & Hokoi (2001:653-666) tested the effects of a lawn roof garden on the exterior concrete roof slab and indoor temperatures in a building in Osaka, Japan, during the summer, when temperatures and humidity are very high. Figure 5.11 shows a schematic representation of its construction and Figure 5.12 their findings for two separate days when skies were clear and overcast respectively. A significant decrease of heat

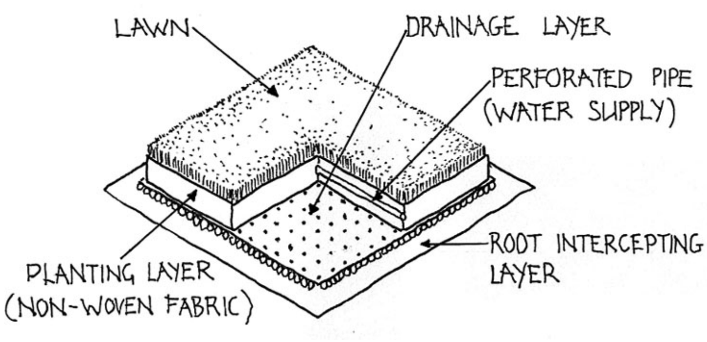
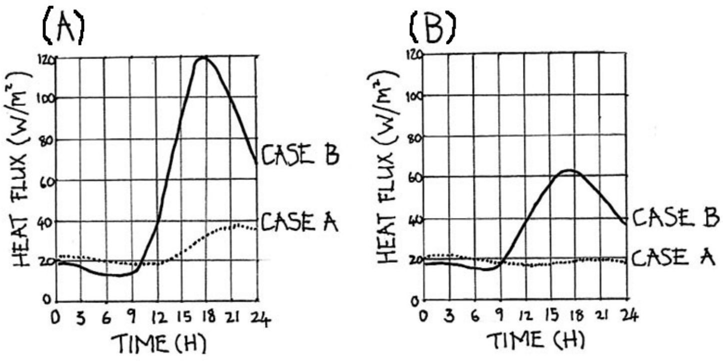



**Figure 5.11 Schematic diagram of roof lawn sample (Onmura *et al* 2001:654)**

flux into the building was achieved in both cases, which implies a decrease in the maximum interior room temperature. A further advantage of the non-woven fabric planting layer is that it only weighed around 60kg/m² when wet, compared to 400 and 160 kg/m² of conventionally used soil and artificial soil, respectively. This means that the amount of structural adaptation of the roof to support the roof lawn is greatly reduced.

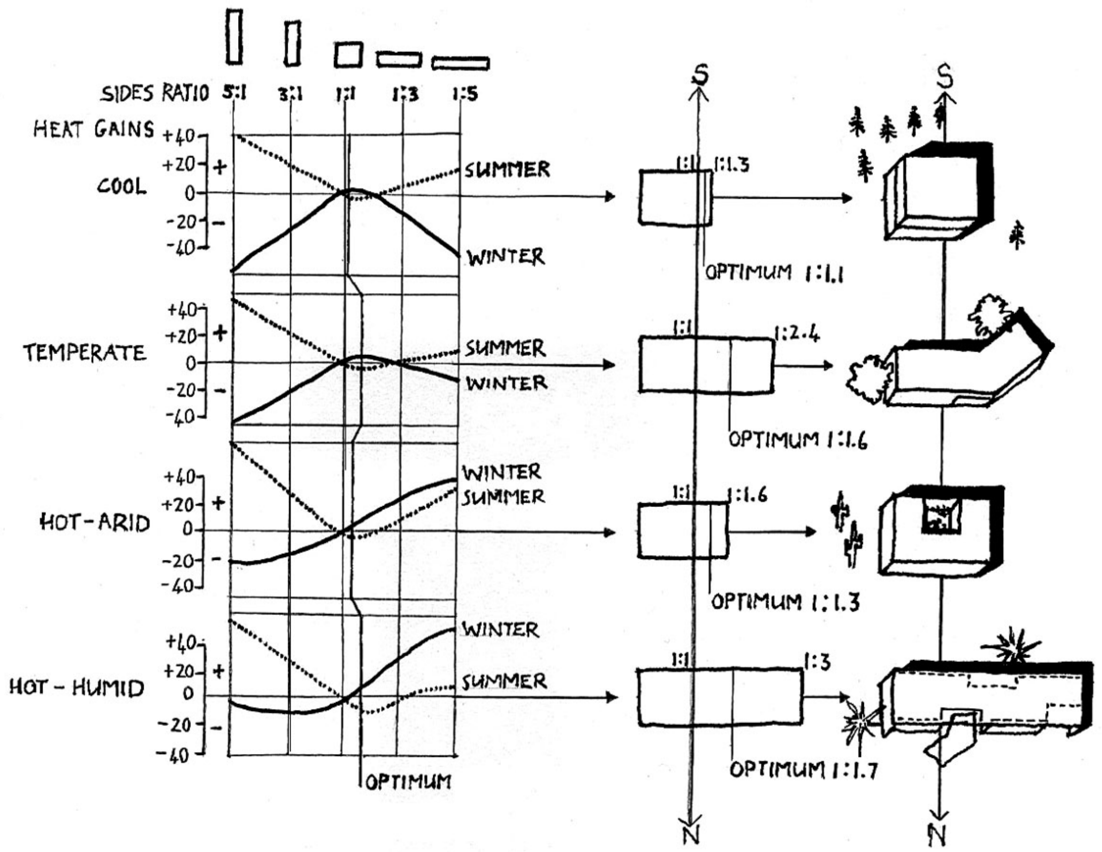



Note to Figure: Case A = house with roof lawn garden, Case B = control unit without roof lawn garden. (A) = clear day, (B) = cloudy day

**Figure 5.12 Decrease of heat flux into a building from the roof due to lawn roof garden (Onmura *et al* 2001:657)**

## 5.3.4 Passive solar design and building shape and orientation

The shape and proportions of a building will also influence its thermal performance by determining how much solar radiation is absorbed and how well absorbed heat is retained. It is for this reason that the correct ratio of the side lengths of a building for different climate regions must be used. Figure 5.13 illustrates the heat gains in ten thousands of BTUs per day of different building shape configurations and translates this information to the optimum building proportions for the different climates. As can be seen a near-cube form is best suited for cold climates where heat retention and even heat distribution is important, whereas temperate and hot humid regions require more oblong building shapes. A compact courtyard shape is suggested for hot arid conditions.




Note to Figure: North and South have been switched around to relate the Figure to Southern Hemisphere conditions.

**Figure 5.13 Taxonomy of environmentally determined building forms (Hawkes *et al* 2002:6 after Olgyay 1963)**

Hinrichs (1988:56-57) illustrates how courtyard-type houses that are built side by side present the smallest surface area to volume ratio through which heat is both lost and gained, resulting in smaller internal temperature fluctuations (Figure 5.14). A stand-alone courtyard building has the maximum surface to volume exposure, which is appropriate for small buildings, such as single residences, in hot humid climates. However to be appropriate for hot arid or composite climates the ratio of thermal mass to fenestration must be balanced. When used in conjunction with thermally massive construction methods courtyard buildings are ideally suited to hot arid conditions. Minimising the surface to volume ratio is further achieved by packing the units together. Cluster and semi-attached developments done in this fashion can subsequently be beneficial from a thermal point of view and is not incompatible with current trends or existing urban developments.

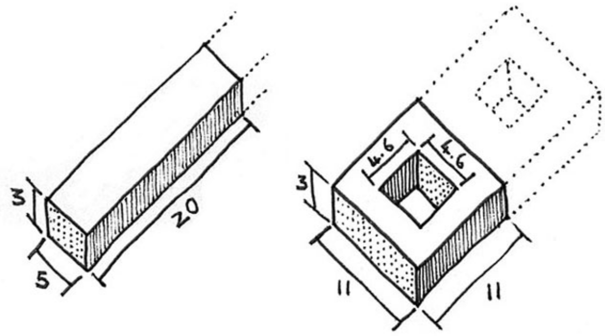



**Figure 5.14 Proportions of rectangular versus courtyard form (Hinrichs 1988:57)**

The shape of a building can also aid in removing unwanted heat from the interior of the building. Alp (1988:74-75) describes how a curved roof has a larger convection heat-transfer surface than a flat one. Once heated, air will rise inside the interior of a building and if a domed roof is provided this air will accumulate inside it, drawing it away from the occupants. The inclusion of an air vent at the top of the roof increases its effectiveness. Wind blowing over the apex of a spherical roof accelerates and decreases the pressure, forcing air inside the dome to be sucked out. The air inside the domed section of the room is normally the hottest and in this manner an effective heat exhaust is formed. Closure panels can prevent overcooling at night.

Mazria (1979:86-88) explains how shaping or locating a building in such a way that the south wall has as small a surface area as possible reduces the amount of heat lost from that side of the building. This is especially true in cool regions where the difference between the interior and outside ambient temperatures can be substantial. Reducing the surface area of the south wall can be achieved by either sloping the roof of the building to the north so that that side of the house is comparatively larger, which also increases the effective area for solar collection, or by digging the southern façade into the earth or raising the ground level around it so that the increased earth contact creates better insulation for the walls. Another advantage of this technique is that it reduces the area south of the building that is shielded from direct solar radiation. This further decreases the amount of heat lost through radiation from the building, as a smaller shaded area south of the building results in a smaller temperature difference between the building interior and exterior. Furthermore in cold climates there are benefits to sharing building exterior walls in order to minimise the amount of exposed exterior wall surface of each living unit. Figure 5.15 shows how different options can influence the amount of heating that is required for each living unit.

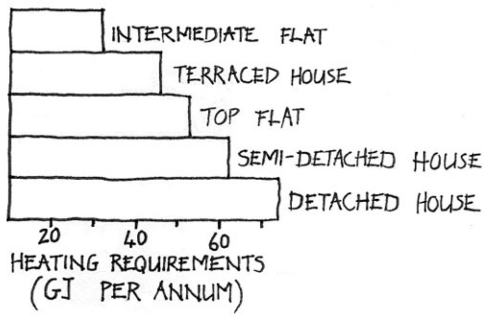



**Figure 5.15 Influence of built form on heating requirements (Owens 1986:42 after BRE 1975)**

As was seen in Section 2.1.4 in cold climates wind can lower perceived temperatures considerably. If the cold air infiltrates a building it can have seriously detrimental effects to the thermal comfort inside and undo much of the positive effects of otherwise sound passive solar design. Robinette (1983a:92) explains that blank, windowless walls, storage rooms and garages should be placed on the side of the building that receives prevailing cold winds during the winter, to create a buffer zone. This is particularly true for cool regions. According to Michels (1979:10) a simple and efficient method of reducing air infiltration into buildings from the outside is to arrange the plan in such a manner that entries are buffered. This is achieved by arranging the plan form in such a manner that closed but infrequently used rooms like garages, entry vestibules (Figure 5.16) or sun porches (Figure 5.17) are placed between doors, especially frequently used ones. The buffer rooms usually have a temperature that is lower than that of the heated interior of the house and higher than the outside temperature, reducing the heat loss from the living spaces through air change when opening the door. If this strategy is to be implemented successfully, however there are design considerations that have to be addressed. Reduction of the air exchange rate is only needed in areas where low temperatures pose a problem and in such regions other considerations that will impact on the plan form are also important. The placement of buffer rooms must not interfere with solar access where it is needed as the gains in reduced air exchange gained from these buffer rooms can be at the cost of other valuable opportunities such as passive heating and day lighting. Placement of such functions on east or west facades or designing them in such a way that they do not shade the north façade is paramount.

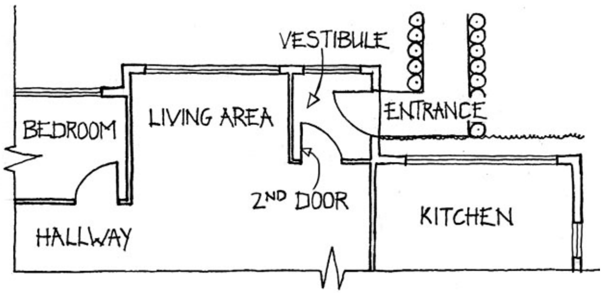
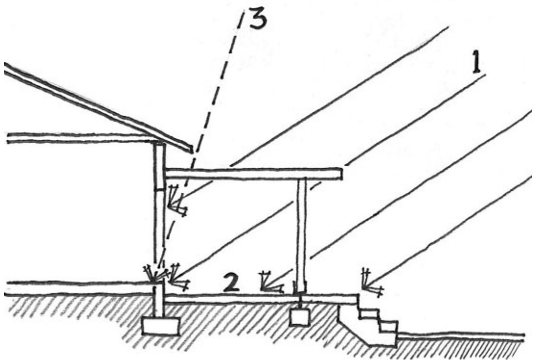



**Figure 5.16 Entrance vestibule used to create interior temperature buffer room**




Legend: 1=Low angle winter sun penetrates into sun porch and building interior, 2=Thermal mass of paving stores and re-radiates heat throughout day and afternoon, 3=High angle summer sun shaded by deciduous vine-covered structure or roof overhang

**Figure 5.17 Sun porch used to create exterior temperature buffer zone**

## 5.4 Wind breaks

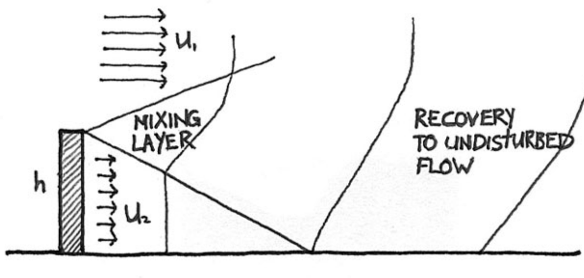
### 5.4.1 Vegetative and built windbreaks

Note to Section 5.4: All arrows in Figures representing wind are meant only to illustrate the general resultant wind direction/s and not actual air movement patterns, which are highly complex and variable. Windbreaks can be defined as any type of barrier that is purposely erected to offer protection from wind and can be categorised into two main groups, namely vegetative windbreaks and built structures. Built structures can be further subdivided into two groups, namely impermeable or solid structures and permeable or porous ones. Windbreaks will be discussed according to this subdivision. Vegetative windbreaks will be referred to as shelterbelts in this document.

Due to the partially permeable nature of shelterbelts they display a number of important characteristics that may greatly affect their application in different circumstances. Olgyay (1963:78), and Robinette (1983b:30) describe how shelterbelts allow a certain amount of laminar or jet air movement through them but at a velocity lower than that of the oncoming, undisturbed wind, which reduces the amount of turbulence or eddying behind such a windbreak. Furthermore Olgyay (1963:68) states that shelterbelts also produce wind reduction over a longer distance behind the barrier than do other forms, partially due to the semi-penetrable nature of the barrier. However, the amount of reduction in wind velocity is usually less than that provided by solid barriers.

Built windbreaks differ from shelterbelts in that they do not change over time, while shelterbelts grow, increase in height and change in density and structure. Thus in a sense built windbreaks are easier to integrate into a design considering a long-term view of a project, both from a functional and visual perspective. Furthermore upon completion of their construction they immediately provide the maximum amount of protection whilst vegetative barriers usually have to grow for a period before they perform optimally. However there are several factors that may favour shelterbelts over built windbreaks. For one, shelterbelts tend to provide a reduction in wind velocity over a longer distance than built structures. For another, one might argue that shelterbelts can be visually more pleasing than built ones and may have ecological value if indigenous species are used correctly. They may also allow greater visual penetration into the surrounding landscape. Due to the design programme requirements or aesthetic considerations there are instances when built windbreaks such as walls, fences and berms would be needed, and careful consideration may be needed to choose the correct option.

In all cases, though, the choice between a built windbreak or shelterbelt structure, of whatever nature, will from a functional point of view be determined by the horizontal extent and degree of wind reduction required. Whether or not a windbreak is permeable greatly influences the percentage and physical spatial extent of the wind speed reduction. The effects of permeable and non-permeable windbreaks on the flow of air can diagrammatically be illustrated in Figure 5.18 and Figure 5.19 respectively.




Legend: U1=Undisturbed wind velocity, U2=Disturbed wind velocity due to bleed flow

**Figure 5.18 Schematic diagram of wind flow behind a porous barrier (Nelmes, Belcher & Wood 2001:305)**

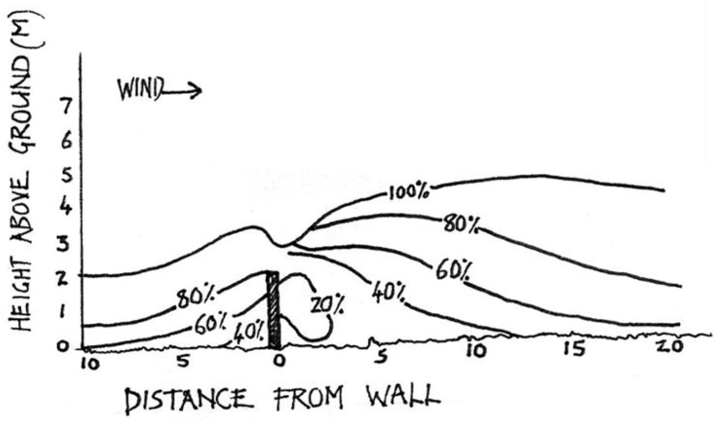



**Figure 5.19 Schematic diagram of wind behind solid windbreak relative to free stream velocity at 2 m above the ground (Brown & Gillespie 1995:129 after Geiger 1965)**

The angle with which the wind strikes a windbreak is a significant factor in its performance. For windbreaks to perform optimally the wind has to reach the structure perpendicularly. According to Heisler (1984:170) a marked reduction in the area of protection occurs when the wind's direction of approach to the barrier deviates from 90°. For instance, the distance over which a 20% or more reduction in wind velocity will be offered downwind of the windbreak, against winds approaching at a 60° deviation from perpendicular, will only be half of that offered from winds approaching perpendicularly.

## 5.4.2 Shelterbelt structure

Shelterbelts are logistically more complex to plan and integrate into a design than built windbreaks, due to the temporally variable nature of the structure of the shelterbelt itself. Especially the choice of plant species will greatly affect the performance of the shelterbelt and several aspects should be taken into consideration. The International Development Research Centre (IDRC) states that plant species selected should be dense with low wind permeability, or visual porosity, and capable of withstanding prolonged exposure to wind. In addition plants that are chosen for coastal or arid areas must be able to tolerate salinity and exposure to airborne sand and be drought-resistant to suit the specific conditions of such locations. For the shelterbelt to function adequately throughout its lifetime plants should be chosen that do not shed their lower limbs or thin with age, have strong root systems and a relatively long lifespan. Resistance to disease and pests is also advantageous (IDRC, accessed 12-05-2003). The extent and degree of protection that the shelterbelt can potentially offer will normally increase as the windbreak itself grows, provided that it is planned and implemented correctly. For this reason it is advantageous to use plants that grow relatively fast and have predictable or easily managed growth forms. Preference should in any case be given to local rather than exotic species as they may have additional ecological benefits such as providing habitat and food for small animals and using less water than exotic species.

The overall physical shape and structure of a shelterbelt will determine the effects that it will have on oncoming wind, but the qualitative nature of the protection is relatively similar for most shelterbelts. The most protected area of a shelterbelt is usually almost directly behind the structure, with a small area of protection on the windward side, especially in the case of dense shelterbelts, as described by Robinette (1983a:35,66). Different vertical sectional profiles will have various effects on the airflow patterns associated with a shelterbelt. Vegetative barriers often have an increased density or decreased porosity as one moves up vertically along their structure, due to the larger amount of foliage and branching higher up, which could seriously impede the effectiveness of the shelterbelt. A windbreak consisting only of trees and that has an open understory, as would be the case with trees that branch relatively high or that are very old, will allow significant air movement under the canopy and subsequently reduce the effectiveness of the shelterbelt. Therefore care must be taken that air is not allowed to stream unchecked through the base of the structure, to the detriment of the sheltering effect that the shelterbelt could offer.

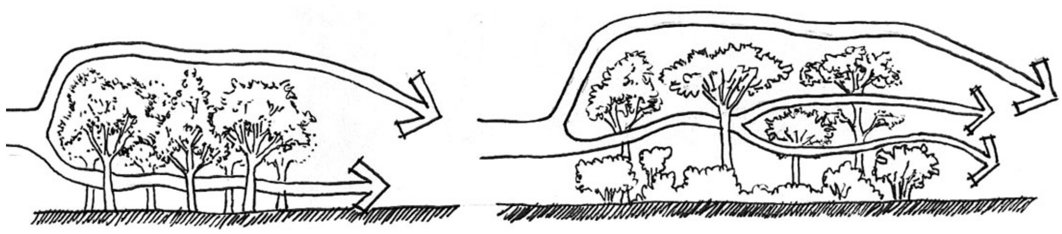


**Figure 5.20 Poor vertical layering of a shelterbelt will cause air movement underneath or through the windbreak**

Shelterbelts that have a pitched section, especially towards their windward side are less effective than those that present a more vertical surface to the wind. However very uniform configurations may produce eddying on the downwind side of the shelterbelt, and therefore irregular profiles are preferable.

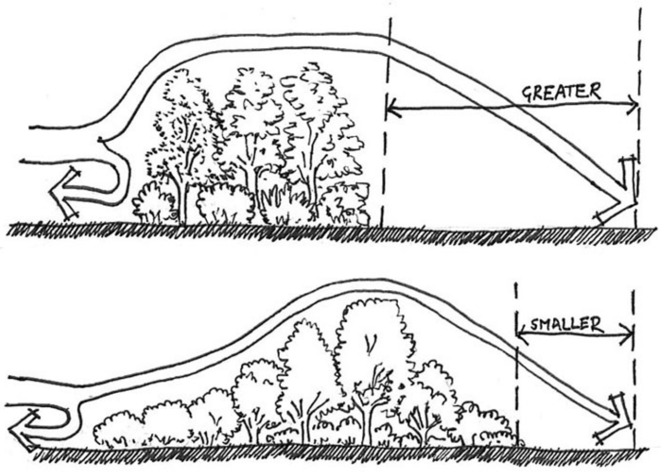



**Figure 5.21 Sloped shelterbelt profiles and uniform configurations are less effective at reducing wind speed than vertical, irregularly composed ones**

The upper surface of a shelterbelt also influences the movement of air over the structure. Shelterbelts that have a uniform and relatively smooth upper surface are less effective than those that have an irregular or "rough" surface, as would be produced by a mixture of species, sizes and textures (ASLA 1977:35).

The width of a shelterbelt also plays a significant part in its effectiveness. The effective density of a shelterbelt increases as the width of the structure is increased; thus a shelterbelt created from two rows of the same plant species will be denser than a shelterbelt consisting of

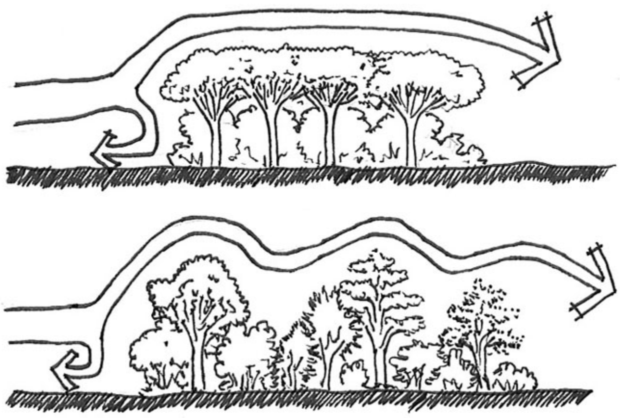


**Figure 5.22 Shelterbelts with smooth upper surfaces are less effective at reducing wind speed than ones with irregular upper surfaces**

only one row of the same species. Experiments carried out by Boldes, Colman and Marañón Di Leo (2001:682-683,685) have shown that double row shelterbelts are more efficient at extracting momentum from oncoming wind and that the bleed flow through the shelterbelt seems to persist over a longer distance downwind of the structure, creating a longer horizontal area of protection downwind of the structure. The double row shelterbelt displayed a better overall average wind and turbulence intensity reduction than the single-row shelterbelt. However, increasing the width of a shelterbelt will not continue to improve its performance indefinitely. Figure 5.23 illustrates how very wide shelterbelts tend to have a reduced protected area downwind of them when compared to a windbreak of the same height and composition but with a reduced width.

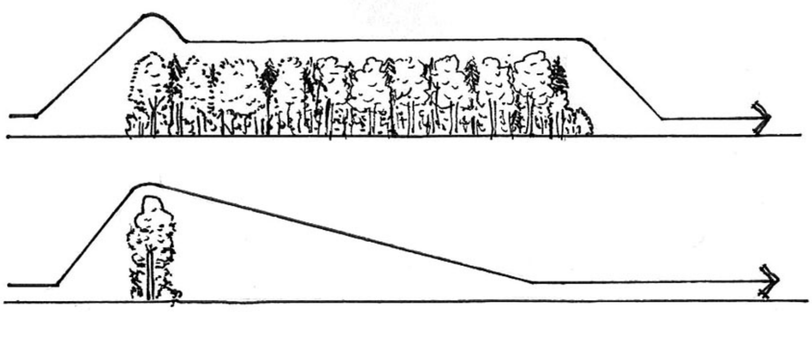
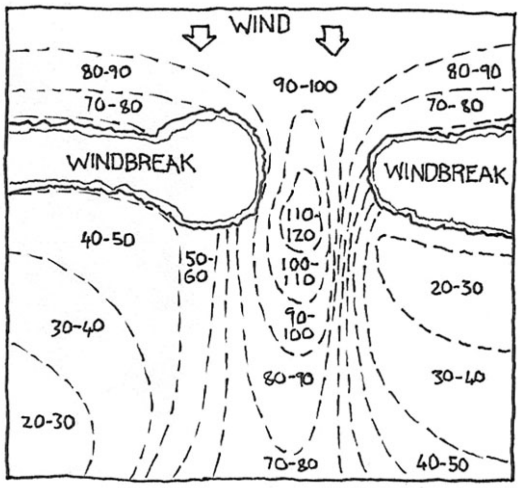


**Figure 5.23 Wide shelterbelts have a shorter downwind area of protection than do narrower windbreaks of a similar height and composition (Panfilov 1940 as shown in Robinette 1983b:35)**

Continuity of the shelterbelt structure is needed if effective wind reduction is to be achieved. According to Heisler (1984:170) when wind flows through a constricted space it accelerates. In this fashion a gap in a windbreak, be it vegetative or built, will force the wind through it, causing an area of increased wind velocity downwind of the windbreak (Figure 5.24). In cool climates this phenomenon would be detrimental to the effective functioning of the windbreak were it to occur near a building or area that needed sheltering. However in hot climates this form of forced ventilation could be employed to aid ventilation and cooling, provided that the building is orientated that the air stream is intercepted and circulated through the building.




Note to Figure: Numbers indicate percentage of open wind

**Figure 5.24 Wind is accelerated through a gap in a windbreak (Caborn 1957 as shown in Heisler 1984:170)**

### 5.4.3 Shelterbelt density and visual porosity

The type and density of planting used will have a significant influence on airflow patterns windward and downwind of the shelterbelt. Figure 5.25 illustrates how different windbreak densities can affect wind velocity. Very dense windbreaks tend to have a greater reduction in velocity close to the belt but this effect decreases over a shorter distance than is the case with belts with a looser structure.

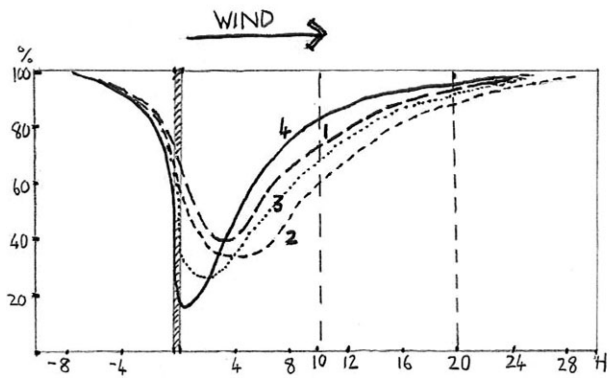



**Figure 5.25 The influence of different density shelterbelts on the velocity of the wind, measured at a height of 1.4 metres from the surface (van der Linde 1962, as shown in Robinette 1983b:22)**

The visual porosity of a windbreak is determined by creating a silhouette of the structure. The percentage of the structure that is open to the flow of air, represented by the white of the silhouette, determines the visual porosity of the structure and the solid percentage of the structure, the black of the silhouette, represents the barrier elements that alter the flow of wind through the structure. Experiments on model windbreaks by Schwartz, Fryrear, Harris, Bilbro and Juo (1995:20-21) have shown that decreasing the porosity of a windbreak below 20% does not result in any significant sheltering benefits. According to their findings the optimum visual porosities for built windbreak fences and shelterbelts are 30% and 20% respectively, provided that the structure is of uniform porosity distribution.

## 5.4.4 Shelterbelts and oblique winds

It is necessary to consider the effects of shelterbelts and windbreaks on oblique winds as it stands to reason that in most locations the wind does not blow from one direction only and will approach a shelterbelt at different incidence angles over time. Incidence angle is defined as the angle formed between the direction of the approaching wind and the windbreak itself. Thus, an incidence angle of 90° indicates wind approaching the barrier perpendicularly. According to Wang and Takle (1996:99,101) a decrease in the incidence angle of the approaching wind results in a reduction of the horizontal ranges and magnitude of the zones of wind reduction both windward and leeward of the shelterbelt. However, the height, or vertical range of wind reduction, increases when the incidence angle decreases.

The width of a shelterbelt plays a significant role in the distribution and amount of wind speed reduction leeward of the shelterbelt, especially as the incidence angle of the wind increases. Wang and Takle (1996:105) report that with small incidence angles, wider shelterbelts produce a smaller zone of wind speed reduction leeward of the shelterbelt, but produce greater wind speed reductions due to the greater amount of friction produced by the greater amount of vegetative material and longer bleed flow path of wind through the barrier. Because the qualitative properties of the effects of shelterbelts on wind speed is the same for oblique and perpendicular incidence angles this fact is also true for wind that approaches a vegetative barrier head-on.

Visual porosity also has significant influences on wind speed for oblique wind conditions. According to Schwartz *et al* (1995:12,20) the optimum visual porosity of a shelterbelt is around 20%, which produces the best overall wind speed reduction both in terms of the size of the zone of reduction, and the amount of reduction. The porosity of a shelterbelt also influences how that shelterbelt will affect wind reduction in oblique wind conditions. Wang and Takle (1996:101-103) explain that as the incidence angle of the wind increases the minimum wind speed is decreased for lower density, or more porous, shelterbelts whereas the minimum wind speed is increased for denser, or less porous, shelterbelts. When the wind

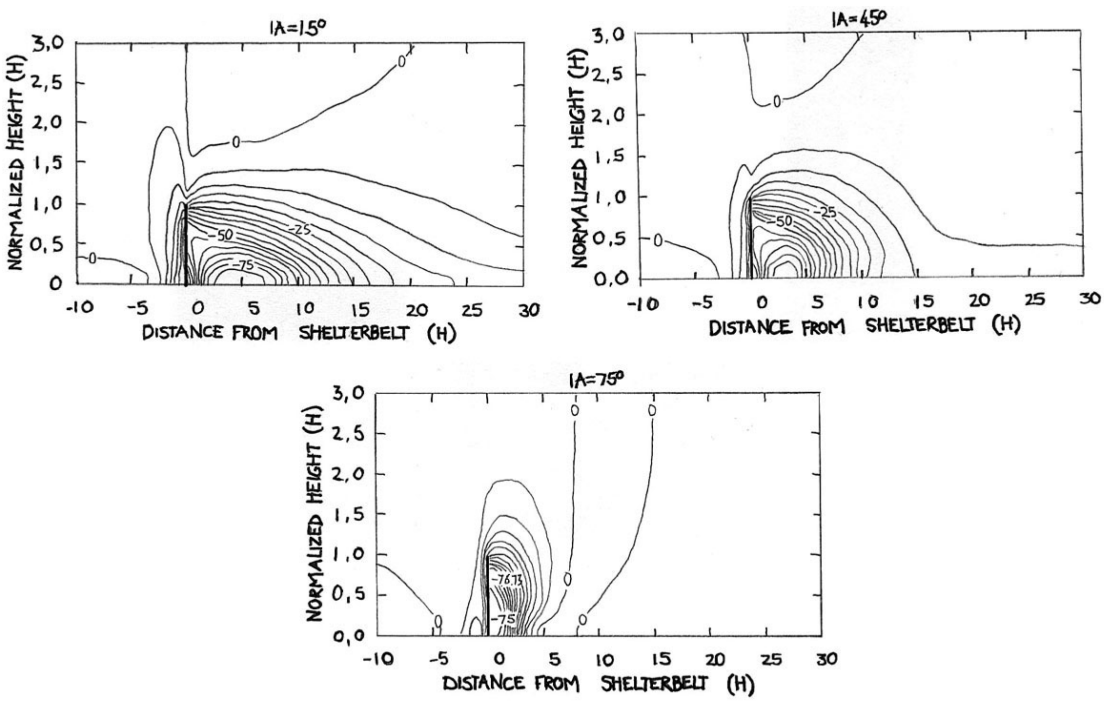



**Figure 5.26 Wind speed reduction graphs in oblique wind conditions for shelterbelts with width=0.5 height for incidence angles of 15°, 45° and 75° (Wang & Takle 1996:98-99)**

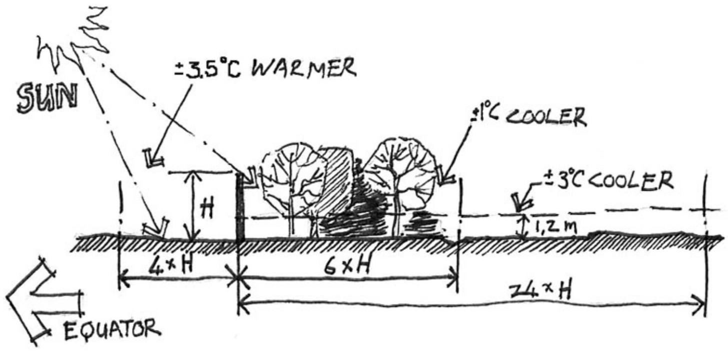
incidence angle is large (70° to 80°) the effects of successive rows of shelterbelts can actually be detrimental as a region of about 2 to 9 times the height of the structure on the leeward side of the shelterbelt experiences an increase in the wind speed, much like the channelling effect of a valley. This effect is also more pronounced in more dense windbreaks.

### 5.4.5 Other effects of shelterbelts on microclimate

Well-conceived shelterbelts can have various other advantageous effects on microclimatic conditions, effects that can be used by the designer for climatic amelioration and control. Read (1964:4,5) conducted experiments in Kansas and the Great Plains, USA to establish what influences shelterbelts have on air temperature and humidity. His findings were a reduction of about 3°C on the downwind side of the structure, mainly due to shading of direct sunlight, and about 3.5°C increase in air temperature on the exposed side of the windbreak as illustrated by Figure 5.27. He also found that air humidity was between two and four percent higher on the downwind side of the windbreak than that of the ambient, and that evaporation from open bodies of water was reduced for a distance of up to 24 times that of the height of the windbreak on the downwind side. Shelterbelts are usually created to reduce wind speed, but De Wrachien and Chisci (1999:207) explain that they may provide several further benefits such as lower evapotranspiration from plants downwind of the structure, higher soil temperatures in winter and lower temperatures in summer, and a higher average soil moisture content on the downwind side of the structure.

Experimental observations and modelling by Wang and Klaassen (1995:205) have shown that a stagnant layer of air develops between successive shelterbelts during calm or stable atmospheric conditions, implying that the surface layer flow over an area with successive shelterbelts changes from wake-interference flow to skimming flow. In other words the flow of air above a series of shelterbelts interferes less with the sheltered area behind each successive structure and actually skims over the tops of the structures, provided that the spacing between each shelterbelt is not too great. The result is that a landscape dominated by shelterbelts would probably be characterised by more moderate diurnal temperature fluctuations, and that especially in colder regions, temperatures may be more tolerable.

However, it would seem that the direction of the sun plays an important part in the influences of the shelterbelt on temperatures downwind of the structure. As Wang and Klaassen (1995:207) explain, shelterbelts decrease cooling at night and increase heating during the day mainly due to increased surface heating between windbreaks during the day, which allows the less turbulent air pockets between windbreaks to reach higher temperatures. Night-time temperatures are also higher as more heat is stored in the soil and released at night. It would therefore seem that if the downwind side of a shelterbelt receives sunshine for a significant period of the day, especially between successive parallel shelterbelts, the calmer air heats to higher temperatures, whereas prolonged periods of shading downwind of the shelterbelt creates lower temperatures than the ambient, due to blockage of the solar radiation.

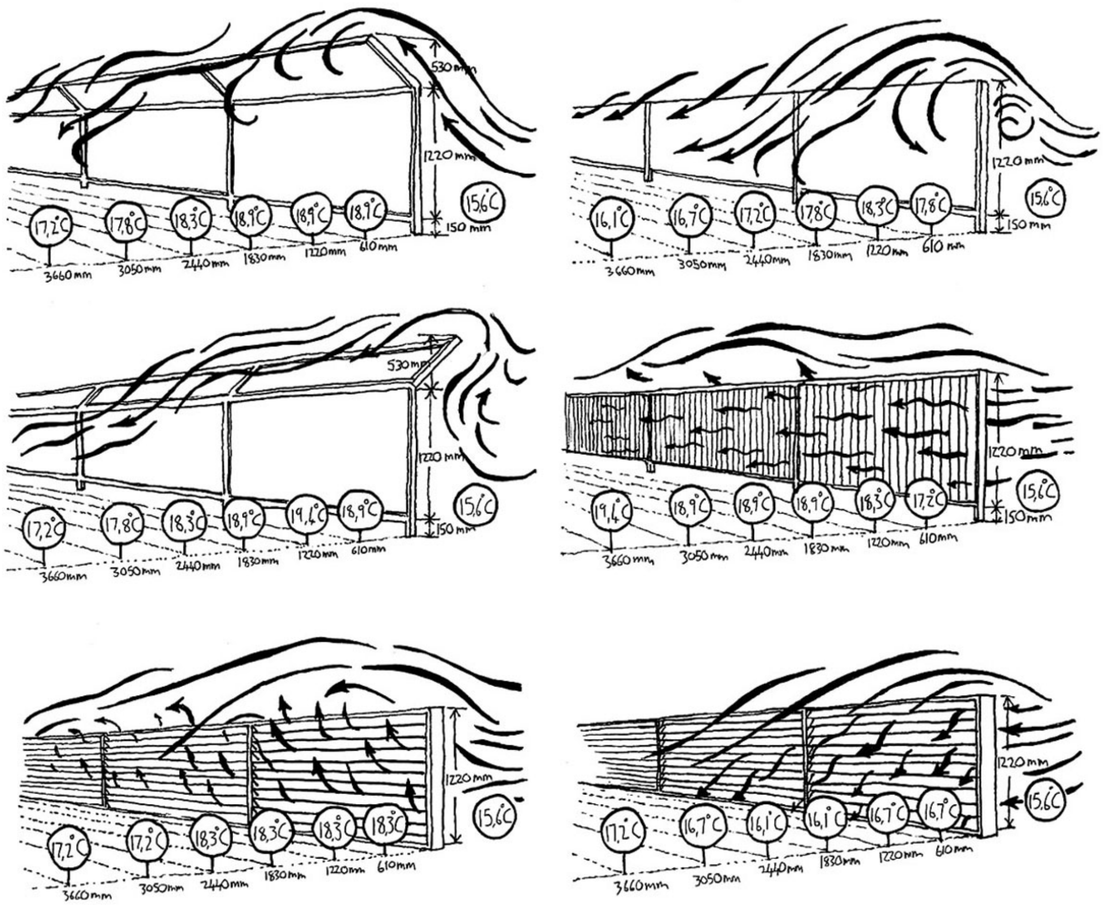



Note to Figure: temperatures have been converted from Fahrenheit to Celsius.

**Figure 5.27 Influences of shelterbelts on air temperatures (Robinette 1983a:36)**

## 5.4.6 Built windbreaks

Solid or impermeable built windbreaks provide the greatest reduction in wind velocity on the downwind side of the structure, usually directly behind the structure itself. However this creates the problem of eddying airstreams behind the structure, which can be both uncomfortable and reduce the effectiveness of the barrier for applications that require an extended area of protection. For this reason built windbreaks should be partially permeable to allow a degree of laminar jet or bleed flow through the structure, which will reduce the amount of eddying behind the structure and increase the horizontal distance of protection downwind of the structure. Then again, porosity configuration seems to have a grater effect on the extent and distribution of wind reduction and temperature change than the porosity percentage alone, as Figure 5.28 illustrates.




Note to Figure: temperatures have been converted from Fahrenheit to Celsius.

**Figure 5.28 The effects of different porosity configurations and built windbreak structures on air flow and temperatures (Robinette 1983a:68-70)**

As can be seen from Figure 5.28 vertical slats create higher temperatures over the greatest distance downwind of the structure although the temperature increase is less directly behind the structure than around three times its height downwind of it. The solid structure with the additional diagonal protrusion pointing into the oncoming wind creates the highest temperatures directly downwind of the structure but this effect dissipates rather rapidly further downwind, presumably due to the influence of wake interference form above. A similar pattern is true for the solid structure with the downwind-pointing protrusion. The amount of wind reduction provided by any windbreak will vary greatly according to various factors and thus “rule of thumb” values for different windbreaks cannot be assumed. The specific climatic and topographical conditions of every site will determine the exact effects of any windbreak and only very general orders of magnitude at best can be assumed for different conditions and windbreak structures.

### 5.4.7 Windbreaks and wind management in different climatic contexts

Hot humid and cool regions are arguably the two contexts in which effective wind control and manipulation is most important to human comfort. However, the ways in which wind should be managed in these climates is fundamentally different. In hot humid regions the aim is to get as much air movement around structures, so that moisture-laden air can be removed and replaced with cooler air. In cool regions, however, the design of the landscape should direct wind movement away from buildings or slow it down considerably, to minimise heat loss caused by increased air infiltration. In either case this may be relatively simple to achieve when a building stands alone in the landscape, but in the context of a suburban development, where many living units are placed in close proximity to each other in the landscape, this becomes less simple.

Robinette (1983a:85,86,112-113) explains how cluster developments can be adapted to the differing requirements of these climatic settings. When buildings are clustered in hot humid regions, the wind should pass through the entire space, which is achieved by placing the openings in such a way that a change of direction occurs between the entrance and exit points of the wind (Figure 5.29). Placing clusters or groups of buildings askew to the direction of the approaching wind and locating openings on opposite sides of the groupings will achieve maximum ventilation for all the individual units (Figure 5.30). In cooler locations unit clusters can also be used to buffer each other at the same height to distance ratios. The addition of solid fences south of the units can further decrease air infiltration. The preferred wind orientation for attached living units in cool regions is to have the long axis of the building cluster parallel to the direction of the winter wind, which results in the reduction of air infiltration and heat loss. This arrangement also presents the smallest amount of surface area to the oncoming wind and makes sheltering easier (Figure 5.31). When forced to position building clusters perpendicular to the direction of the approaching wind an effective shelterbelt can be created by placing a shelterbelt one and a half to two times the height of the units to the upwind side of the clusters, in combination with a fenced space in front of the building (Figure 5.32).

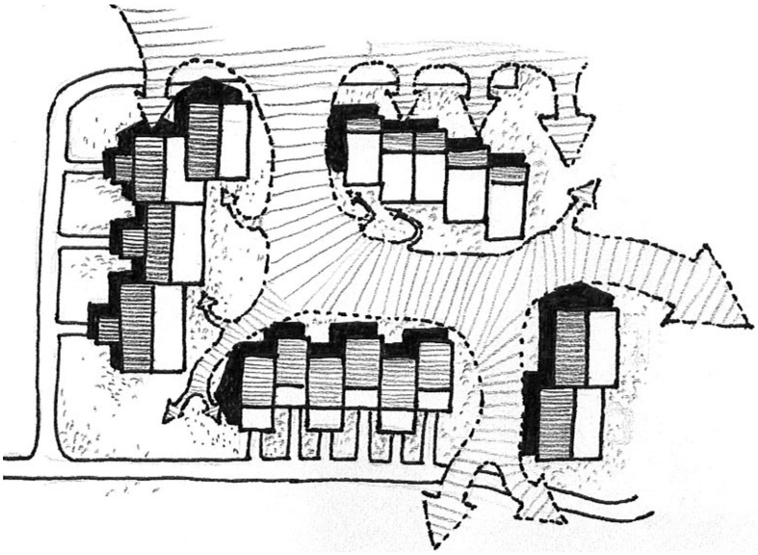


**Figure 5.29 Placing entrance and exit openings for airflow at right angles eliminates dead air pockets and improves ventilation (adapted from Robinette 1983a:115)**

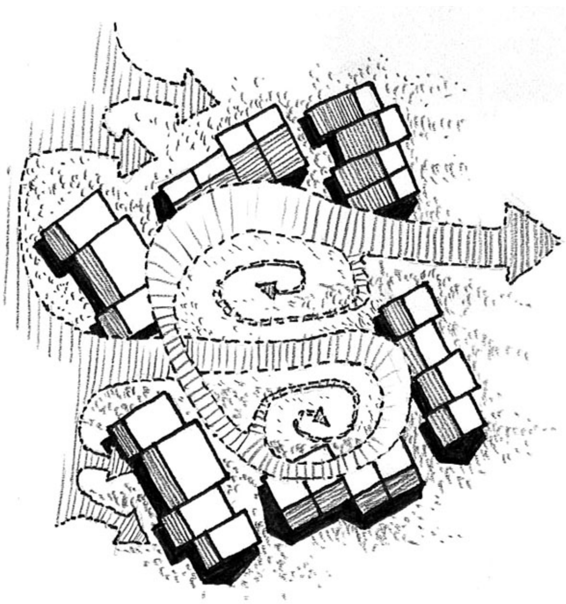


**Figure 5.30 Placement of building clusters at an angle diagonal to that of the approaching wind increases overall ventilation (Robinette 1983a:114)**

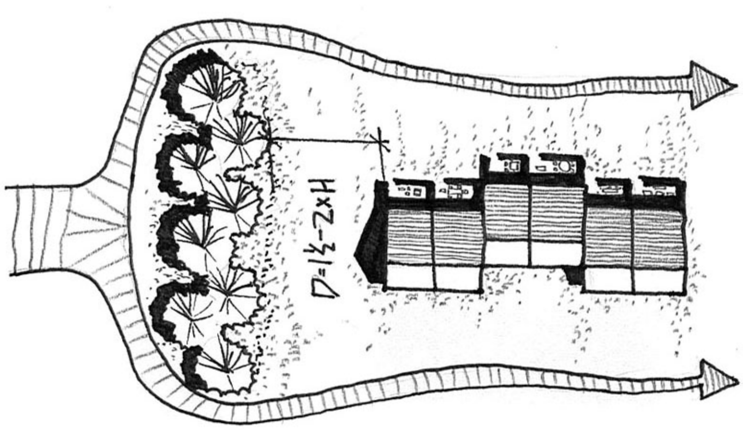


**Figure 5.31 In cool regions a shelterbelt placed one and a half to two times the height of a building upwind of that building combined with fenced enclosures on the south side will greatly reduce air infiltration and heat loss (Robinette 1983a:86)**

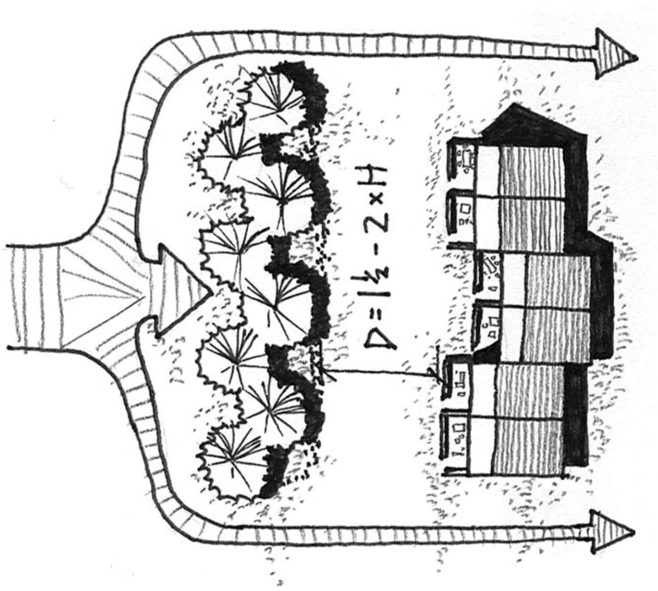


**Figure 5.32 When forced to locate building clusters perpendicular with the direction of the wind in cool regions, shelterbelts in combination with built windbreaks can significantly reduce air infiltration and heat loss (Robinette 1983a:89)**

## 5.5 Solar access control

### 5.5.1 Building shape and orientation

The orientation of a building in relation to the position of the sun in the sky is of great influence in determining how much and when a building receives solar radiation. For this reason careful design is needed if the sun is to be used to create comfortable and energy-efficient buildings. Both the physical dimensions and shapes of the building plan and the orientation of the plan will influence the availability of sunlight and these factors must therefore be examined. Solar demand will be determined by the climate and season of the site location. In South Africa most regions will have a greater demand for minimising the amount of sunlight that reaches a building.

One of the simplest methods of creating indoor comfort is through correct building orientation. Van Wamelen, Higgs & Page-Shipp (1986:8) report that experiments by the NBRI compared the comfort levels of several test houses orientated north-south with that of one orientated east-west. Even though the west-facing house had a more even overall temperature distribution during the winter than the other houses, thermally the west-facing house performed much poorer than those facing north, overheating during the summer and experiencing noticeably colder temperatures during the winter. These findings clearly illustrate that correct solar orientation has thermal, and subsequently energy-conserving, benefits over houses that are not orientated to take advantage of the sun. Therefore it is necessary to determine what the correct solar orientation is, if the sun is to be used successfully in suburban design.

For useful solar access to be possible a building must be orientated in such a way that its solar skyspace receives sunlight during the right times and allows that sunlight onto the correct sides of the building. According to Kachadorian (1999:76-77) little solar benefit is lost if a house is orientated within 20° or so of facing the equator. At 22.5° deviation 92% solar benefit is still possible, whereas at 45° from true north/south 70% is available and at 67.5° only 36%, illustrating the importance of correct building orientation in order to achieve successful solar design. However, Ward (2002:71) stipulates that directly north is not the optimal solar orientation for all the climatic regions of South Africa. Buildings in the hot humid east coast of the country should face 5° east of north, whereas buildings in the temperate region should be orientated north to northeast and in the southwest Mediterranean regions of the Cape an orientation of north to 17° east of north is most advantageous.

The plan shape of a building will significantly influence where, when and how much sunlight the interior of the building will receive. Furthermore the plan form will determine the size and location of outdoor living spaces and extensions of the interior, such as patios, balconies and courtyards. Napier (2000:7.2.1-7.2.7) illustrates how different plan shapes will offer different possibilities and have limitations in terms of solar and wind exposure (Figure 5.33).

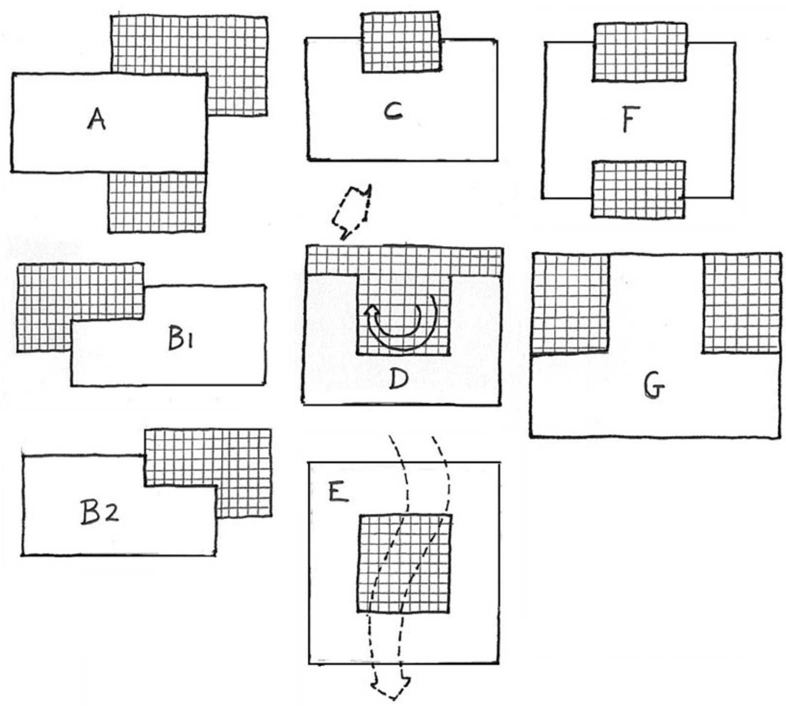



**Figure 5.33 Different plan shapes afford different solar access possibilities for different climates (Napier 2000:7.2.1-7.2.7)**

A building with a rectangular shape (A) can have a patio on the north and east sides of the building for utilising the morning sun, yet be exposed to southerly winds along the eastern side, making it a good choice for warmer weather. An additional outdoor space on the south side of the building can be shaded for summer use. A corner rebate (B1 and B2) can offer protection against or exposure to wind and exposure to morning or afternoon sun, depending on the particulars of the site. Placing windbreaks or screens can further manipulate the flow of air to aid cooling or heating as desired. Recesses, like shapes C and D, can provide heat pockets in front of the building, making them ideal for cool regions. Directing wind into the recess with screening, as shown in D, can make this shape more suited for summer applications, provided that the courtyard is covered with a deciduous vine-covered pergola. An enclosed courtyard (E) works well for dry climates, provided the courtyard is well shaded. In humid climates air movement through the space is vital, and generous airflow through the building itself is also needed. Recessed patios on both sides of a building (F) offer outdoor living spaces for all seasons; and effective control of airflow through the building from one side to the other can create either cool or warmer building interior temperatures. Thus if the building needs cooling, opening windows on the south side and allowing for ventilation through small openings on the north or east will draw the cool air on the south of the building to the interior. Shape G allows pleasant conditions for mornings and afternoons, and the heating of the east and west facades in the morning and afternoon respectively make this a good choice for cool regions. Shading the patios during the summer can widen the range of applications to warmer climates.

In developments where semi-attached or attached cluster housing is favoured, provision of solar access becomes more complicated. The shape of the individual units and the manner in which they are attached becomes more influential in the amount of sunlight afforded each unit. Figure 5.34 illustrates that units with a square plan form sharing their east and west walls will both have good solar access although the unit on the east side will receive more sun during the morning whereas the unit on the west side will receive more afternoon sun (A). Oblong units placed north and south of each other will result in the northern unit receiving daylight throughout the day at the expense of the Southern one (B). Oblong units placed east and west of each other along a north-south axis will result in reduced sunlight for both units throughout the day and possible overheating for the western unit in the afternoon in hot climates.

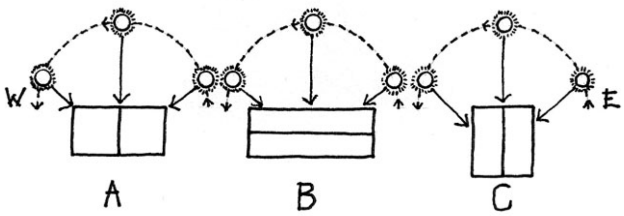



**Figure 5.34 Different duplex plan shapes and orientations for solar access (adapted from Erley and Jaffe 1979:57)**

## 5.5.2 Sun and shade control and daylighting

Planting is an extensively used method of solar access control and can be employed to filter or shade direct sunlight. Correct placement of the planting in relation to the building or structure that is to be shaded is essential for this technique to be successful. Furthermore the shape and growth habits of the plants are also important, as these characteristics will influence the placement of the plants. In principle, trees and shrubs should be planted so that they shade critical parts of a building or outdoor space when sunlight is unwanted and allow it through when it is needed. Several methods exist to determine the shadow patterns of planting and selecting appropriate plant species and locations for different applications, as described by Erley and Jaffe (1979:136-140), Thayer (1984:123-136), McPherson (1984b:153-160, 281-290) and others, but detailed discussion of these is not warranted here. From these sources it becomes clear that in order to successfully utilise the patterns of shade and sun, designing for solar access has to be done both on plan and in section. Sectional design can be used to establish basic planting distances from buildings, using solar incidence angles for critical dates and sun positions. This form of design is also useful to aid in the placement of solar collectors. Figure 5.35 shows how correct tree placement and foliage characteristics can be advantageously applied in a temperate climate with warm to hot summers and cool winters. During the summer the deciduous tree can shade a significant part of the roof and northern façade of the house, keeping it cooler, whilst allowing the solar water heater to function. During the winter sunlight is allowed into the house and on the roof for passive heating, whilst still allowing the solar water heater to function. Designing for solar access on plan is more complicated, as a shadow template or other means of representing the shadow path of the tree through the day and for different times of the year has to be used. These are created with calculations using the latitude and slope of the site, as well as a series of shadow length ratio tables for various slope orientations and angles. Figure 5.36 illustrates a tree shadow template for a tree during summer, showing how it is used to place the tree so that it shades the western façade of a building from hot afternoon sun without shading the solar water heater.

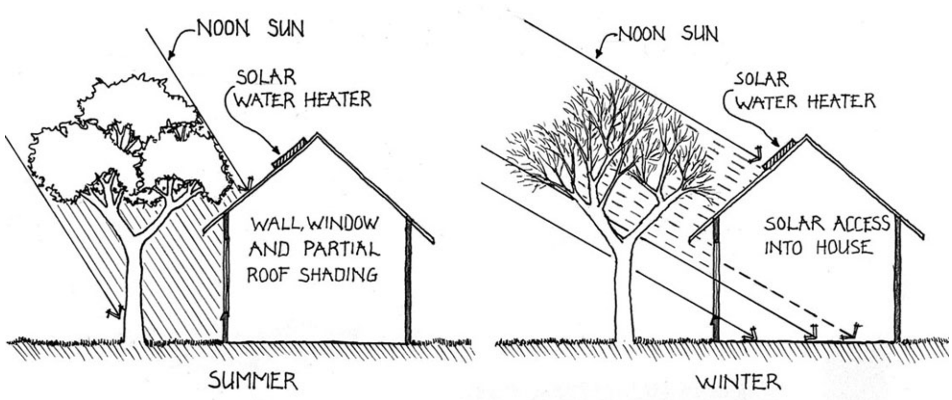



**Figure 5.35 Planting design in section for optimal solar access control**

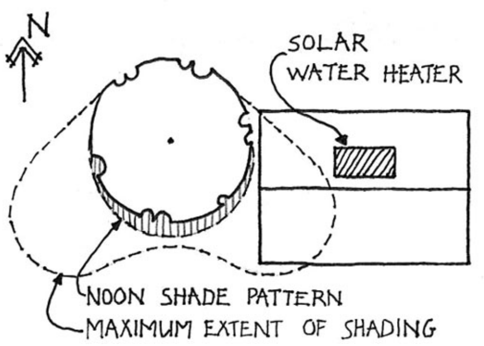



**Figure 5.36 Tree shadow template for a tree in winter and summer, used to determine optimum placement for solar access control**

Daylighting, described by Bryan (1989:14), involves the deliberate use of natural sunlight through design techniques and material choice for the daytime lighting needs inside a building. Although daytime artificial lighting needs are usually much less or even non-existent in houses than at night, correct design can still eliminate electrical lighting altogether and improve ambient lighting conditions. Subsequently the following initial design considerations, from Holm (1996:7) can be implemented to utilise solar light for day lighting purposes:

1) The orientation of a building should be such that unwanted solar gain in the afternoons does not occur, as daylighting is not about admitting as much light as possible but rather admitting the required light levels at the right places naturally.

2) Careful space organisation will ensure that the most frequently used rooms will receive light at the required times. South lighting, due to its more diffuse nature is often also desirable.

3) Deeper buildings require larger windows for light to penetrate to the back of the room, in which case skylights can be useful.

4) Window locations can also be used to control at what time light penetrates a building and to what distance. If the same window is situated higher in a wall it will allow light to penetrate more deeply into a room, but will also cast a shadow in the front of the room. Similarly vertically longer windows allow greater penetration of light than horizontally longer ones.

The quality and quantity of light that is permitted to enter a building is crucial to the success of daylighting strategies. Evans (1981:52-54) explains that direct sunlight and skylight, for the purposes of residential illumination, should be avoided. This is especially true in very warm climates, where the problem of glare frequently occurs. In such climates light coloured building surfaces are preferable as they reflect more light, decreasing the heat gains of the building through its exposed surfaces. However in such climates this strategy can lead to ambient light levels becoming very high. Excessive amounts of direct light causes great visual contrast between illuminated and shaded areas, which in turn leads to visual discomfort and reduced visibility. Several strategies that involve filtering, diffusing or softening light before or while it enters the building exist to counter this problem (Figure 5.37).

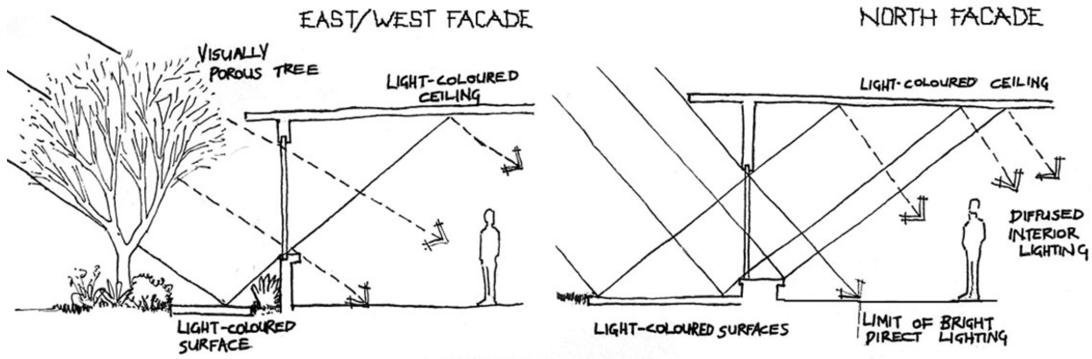



**Figure 5.37 Allowing sunlight to be filtered by plant material, or reflected from another surface before entering a building, increases lighting quality and reduces glare**

Evans (1981:52) explains that allowing sunlight to enter a building from high up, through the roof or the top of walls, is advantageous as it allows for deeper and more even penetration into a building creating more uniform illumination inside. Unwanted and very sharp sources of light at eye level, such as windows opening to a northerly view, can be shaded without detrimental effects to the quality and levels of lighting inside the building. Lam (1986:68, 69) states that allowing light into a building from the roof or high up against the walls is especially beneficial in areas where high development density is advantageous, like very hot and arid climates. In densely built-up areas, such as hot arid climates, courtyards can be used to provide light into buildings especially if the surfaces of the courtyard are painted with a light colour. The incoming light can be redirected towards facades that are in shade in order to aid daylighting of the building.

Several architectural methods exist for allowing sunlight into buildings in such a way that it is more evenly distributed and less sharp than direct light, as seen in Figure 5.38. Reflected light from surrounding surfaces allowed into buildings can be controlled in various ways. Lam (1986:144,148) illustrates that reflected light that enters the building at a lower level, will penetrate more deeply into the building (A) whereas the reverse is true for light entering higher up (B). Light can also be allowed into the building through skylights and "light scoops". Skylights can be used to illuminate walls and thus provide softer lighting to the interior of a building (C) or reflective surfaces nearer to the surface (D), the latter being effective for courtyard applications. A light scoop is a transparent surface that its turned away from the sun and which allows reflected and ambient light into a building (E). According to Lam, light scoops or skylights aimed away from the sun are particularly effective in warm climates (both arid and humid) when lighting is needed but potential heat gain through the transparent material would be detrimental to thermal comfort. Sloping skylights so that they receive direct radiation during the solstice periods (F) produces the best overall summer/winter performance.

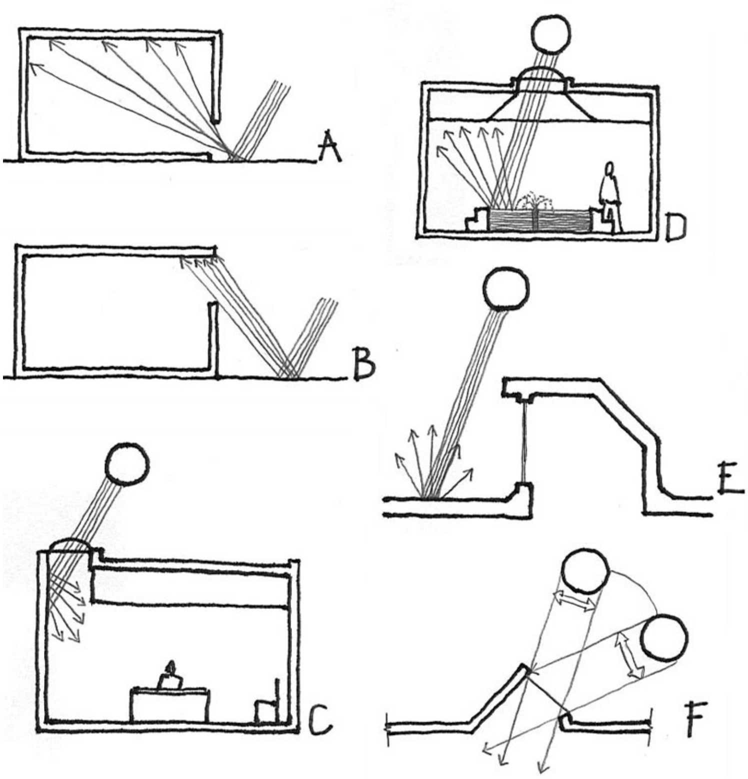
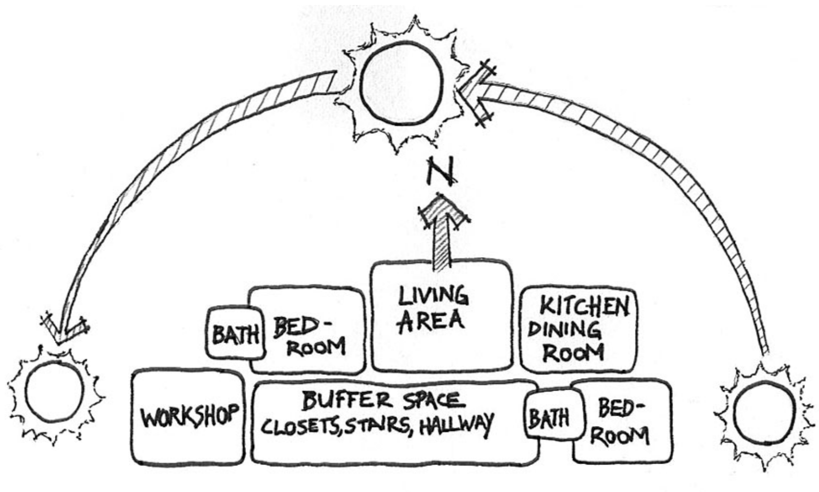



**Figure 5.38 Different strategies to allow reflected and overhead sunlight into buildings (Lam 1986:76,144,148).**

Robinette (1983a: 102,124) gives advice for utilising sunlight in buildings. Infrequently used rooms should be located on the south side of buildings, as they require both less light and heat. Exterior living spaces on the north-northeast side of a building will receive morning sun exposure heating them for comfortable outdoor living. Outdoor living and working areas should be arranged according to the time of day during which they will be used so that they receive shade or sunlight at the required times. Garages, tool sheds or similar storage buildings and blank walls should be located on the west of the building to prevent overheating during the afternoon. These facades can also be shaded during the summer for greater effect. Figure 5.39 further illustrates how a building can be designed and its interior spaces arranged so that the full potential of the available sunlight is utilised.




Note to Figure: North and south have been switched to relate to Southern Hemisphere conditions.

**Figure 5.39 Suggested spatial arrangement of interiors of a solar home for optimum efficiency in sunlight use (Mazria 1979:91)**

In some instances it is difficult or unpractical to orientate a building to the north. For instance the most attractive views may be to the south of the building, or the lot may be oblong and orientated north-south. In such instances creative ways have to be found to allow sufficient sunlight to enter the building whilst satisfying other requirements, such as visual access to views. Napier (2000:8.11.3, 8.12.1) offers some simple solutions to these problems, as shown in Figure 5.40. When most of the windows of a building are on the south side of a building to maximise on view, placement of windows and room arrangement on the north side of the building should allow light to penetrate as far into the building as possible. Corner windows, as in the left-hand figure, allow light from the northeast to enter deeper into the building, whereas the arrangement of the dining room, living room and entrance in the right-hand figure allow light from the north to penetrate deep into the building.

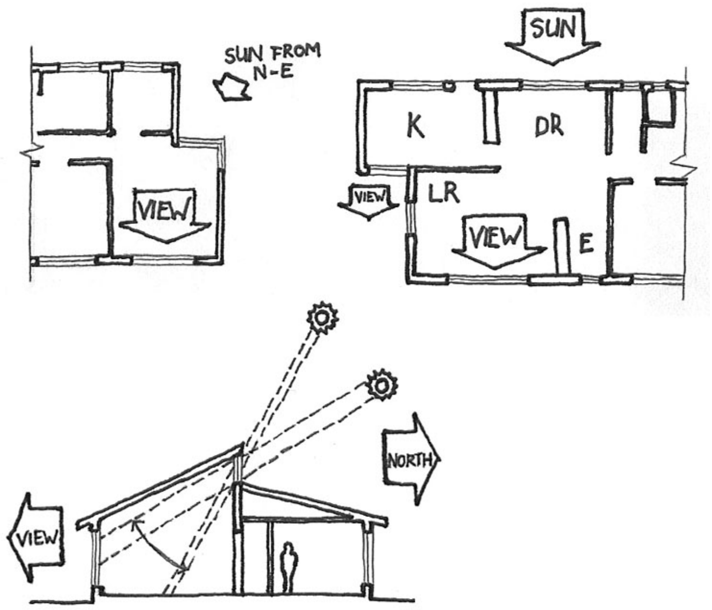



**Figure 5.40 Daylighting solutions when the view and sun are in opposite directions (Napier 2000:8.11.3, 8.12.1)**

Windows themselves are another very important element to consider in solar access control in buildings, both in terms of their size and placement. Table 5.3 shows that glass offers no heat flow time lag and subsequently otherwise sound passive designs can be rendered ineffective if the window to floor surface area is not determined correctly. Failure to do so can result in overheating of buildings during the day in hot climates or massive heat loss at night in cold climates. In this regard Al-Sallal (1998:365) states that windows are particularly important in connecting the outdoor environment with the indoor environment and that this connection becomes all the more important when buildings are designed to be efficient in their use of energy through passive solar means. Furthermore, in colder parts the use of double and even triple glazing is sometimes necessary to prevent uncomfortably low interior building temperatures at night.

Holm (1996:11,16,20,26,31,36,41,46,50,55,61,66,71,75) suggests different equatorial glazing percentages of the floor area of a building for the climatic regions identified by Schulze (1965), which can be found in Appendix C. From these several conclusions can be made regarding optimal glazing for the four basic climate regions established in this study. For the hot arid parts of the country a fairly large range of glazing percentages are suggested (17% to 22%), with an overall decrease in glazing percentage as one moves away from the equator. This is presumably due to the fact that the decrease in solar incidence angles further from the equator results in more sunlight striking the equatorial façade. Under such conditions in hot arid regions a decrease in glazed area would be needed to prevent excessive solar penetration into the building and subsequent overheating. In all hot arid areas however Holm states that windows should be properly shut or shaded during the day to prevent overheating and opened during warm nights for ventilation. For most hot humid areas along the east coast only 16% glazing is recommended along with extensive shading during the summer; and even less towards the southeast coast (10.6%) due to moderate temperatures, high humidity and lower sun angles there. Shading during the summer is also recommended. For the more temperate conditions of the Garden Route and Cape Town area equatorial glazing can be higher (18% to 21%) although summer shading is still necessary. For the cooler Natal highlands 20% equatorial glazing is recommended, for sufficient solar gain during the winter. However this should be combined with high thermal efficiency levels to prevent heat loss at night and summer shading of windows is still necessary. The rest of the eastern interior requires equatorial glazing between 19.2% and 21.2%, with an increase in glazing area towards the equator.

### 5.5.3 Surface treatments and colour

In Section 2.1.5 it was explained that the solar radiation that reaches a surface is absorbed, transmitted or reflected back into the atmosphere. According to Mazria (1979:655) this reflectivity, or the percentage of solar radiation that is reflected by a surface, is called its albedo. Table 5.4 shows the albedo, emissivity and thermal admittance of several building materials and surfaces common in suburban settings.

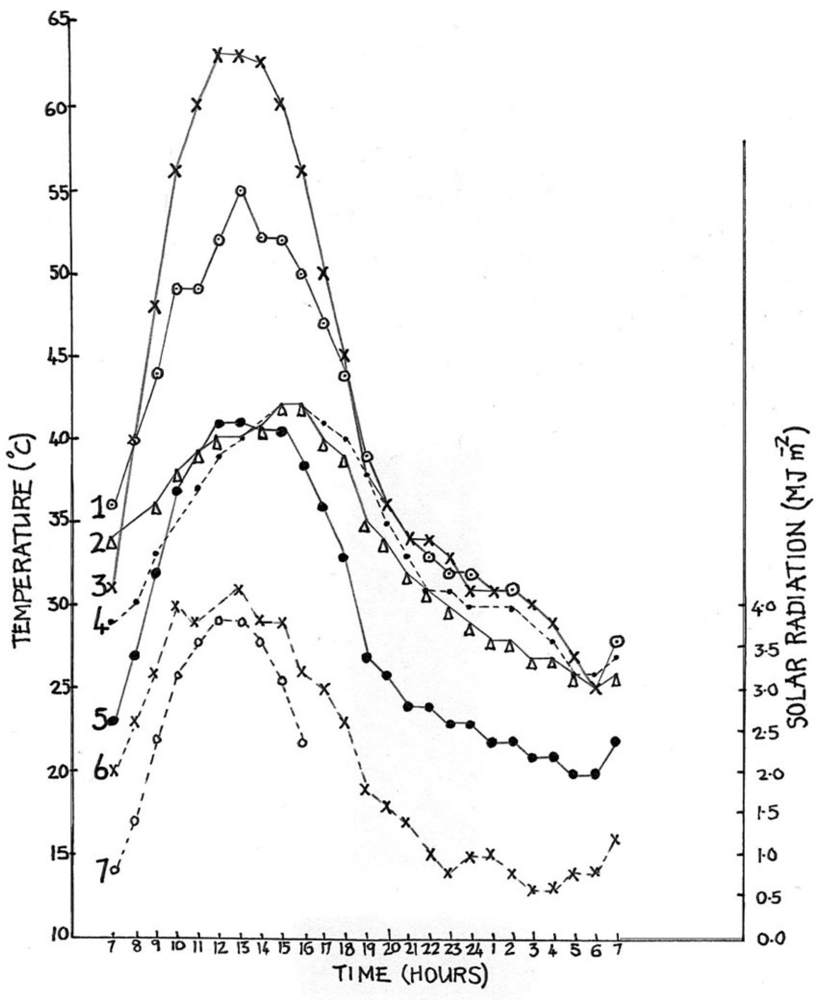
**Table 5.4 Albedos, emissivities and thermal conductiveness of common elements in the landscape (Brown & Gillespie: 1995:49)**

| | Albedo (%) | Emissivity (%) | Thermal admittance ($J/m^2s^{½}K$) |
|---|---|---|---|
| **Soils:** | Range: 5-75 | 90-98 | |
| Moist dark cultivated | 5-15 | | |
| Moist grey | 10-20 | | |
| Dry sandy | 25-35 | 84-91 | |
| Wet sandy | 20-30 | | |
| Dry soil | | | 600 |
| Wet soil | | | 2500 |

| | Albedo (%) | Emissivity (%) | Thermal admittance (J/m²s½K) |
|---|---|---|---|
| **Vegetation:** | Range: 3-30 | 90-99 | |
| Grass | 20-30 | 90-95 | |
| Green fields | 3-15 | | |
| Meadows | 10-30 | | |
| Brown grassland | 25-30 | | |
| Deciduous forest | 10-20 | | |
| Coniferous forest | 5-16 | 97-98 | |
| **Water:** | Range: 5-95 | 92-97 | 1500 |
| Water (high sun angle) | 5 | 92-97 | |
| Water (low sun angle) | 95 | 92-97 | |
| Snow (fresh) | 70-95 | 99 | 130 |
| Snow (old) | 40-70 | 82 | 600 |
| **Urban surfaces:** | | | |
| Asphalt | 5-15 | 95 | |
| Concrete | 10-50 | 71-90 | |
| Brick | 20-50 | 90-92 | 950 |
| Stone | 20-35 | 85-95 | |
| Tar and gravel roof | 8-18 | 92 | |
| Tile roof | 10-35 | 90 | |
| Slate roof | 10 | 90 | |
| Thatch roof | 15-20 | | |
| Corrugated iron | 10-16 | 13-28 | |
| White paint | 50-90 | 85-95 | |
| Red, brown, green paint | 20-35 | 85-95 | |
| Black paint | 2-15 | 90-98 | |
| **Air:** | | | |
| Still | | | 5 |
| Turbulent | | | 400 |

The albedo of a surface can have significant implications for climate-responsive design, as this aspect will partially determine how much energy a building will transmit into a building. In this fashion energy that is reflected back into the atmosphere cannot heat the interior of a building, meaning that reflective surfaces are advantageous in hot climates if used correctly. For example experiments carried out by Nahar, Sharma and Purohit (1999:89-95) compared different treatments of the roof surfaces of a series of test structures to determine which treatments reduced indoor temperatures the most in hot arid environments. Figure 5.41

illustrates their findings, showing that evaporative cooling was the most effective, followed by a white painted roof.

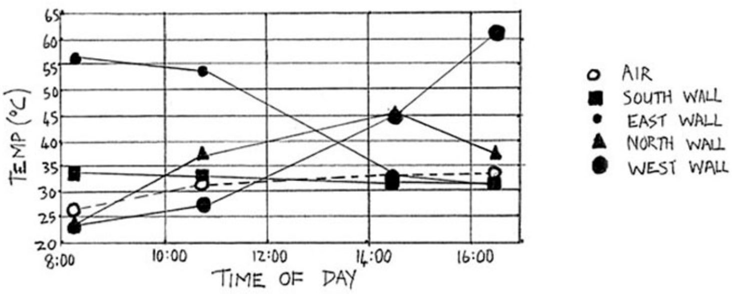



Legend: 1=Thermal insulation under roof, 2=Water tank with movable thermal insulation, 3=Control shed, 4=Ambient air temperature, 5=White paint over roof, 6=Evaporative cooling, 7=Solar radiation

**Figure 5.41 Diurnal variations in roof temperatures inside test structures (Nahar *et al* 1999:92)**

Further experiments carried out by Nahar *et al* (2003:112,114) in the Thar Desert in Rajasthan, India, compared the impacts of several roof surface treatments on the temperatures inside a series of test structures. The results showed that broken white glazed tiles applied to the outside roof surface performed better than all the other methods tested, except for evaporation of water from organic material linings on top of the roof surface. However, considering the cost-effectiveness of the tile method and the scarcity of water in arid regions the white glossy tiles were considered to be the most effective passive cooling method in this series of experiments. From Table 5.4 it can be seen that dark-surfaced roofing materials, like slate tiles, tar or gravel roof covering and black paint all have low albedos and thus absorb large amounts of thermal energy. Combined with adequate thermal mass such surfaces can be put to good use in cool areas to effectively heat buildings, storing the heat in the structure of the building and releasing it during the night when the building needs heating.

Another important consideration regarding solar access control is planting. As was seen in Section 5.2.3 plants, especially trees, are effective means of controlling solar radiation. However, according to Raeissi and Taheri (1999:569), at middle latitudes shade from trees has a much greater effect on east and west building facades than on the roof of the building. These sides of a building receive low angle sunlight during the morning and late afternoon, whereas the roof intercepts most of the radiation when the sun is overhead during midday. Consequently the amount of direct sunlight that can be blocked by trees at midday is greatly reduced and trees are most effective when planted where they can shade the low-level sun. Although the concentration of radiation from low-level sun is much lower than that of direct overhead radiation, shading of low-level sun on east and especially west facades may still be necessary and even critical in climates where overheating is a problem. Figure 5.42 demonstrates how the temperatures of these sides of a building can be very high, especially in hot climates. Trees can be planted a respectable distance away from the structure and still shade these sides of a building, whereas other structures such as pergolas, roof overhangs and retractable shade devices should be used for the north façade.




Note to Figure: North and south have been switched around to relate the Figure to Southern Hemisphere conditions.

**Figure 5.42 Surface temperatures of different building façades (Bonan 2000:106)**

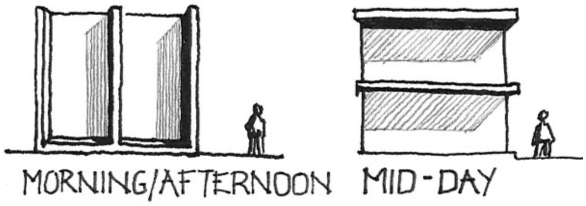



**Figure 5.43 The use of vertical and horizontal built shade devices for different times of the day (Lam 1986:84-85)**

Where fixed built shading structures are used, vertical elements are most effective for shading morning and afternoon low-level sun, whereas horizontal structures provide better shade at noon when the sun is highest (Figure 5.43). The use of planting to shade building roofs effectively throughout the day becomes possible with the use of roof gardens. This technique greatly reduces the amount of solar radiation absorbed by a building through its roof, a benefit that is not possible, or at least much reduced, when attempted by shading with trees and plants planted next to the building as in normal gardens. Wong, Cheong, Yan, Soh, Ong and Sia (2003:354) explain that the plants used in roof gardens absorb large amounts of solar radiation, increasing the effective amount of insulation. They are of the opinion that the most significant influences of roof gardens on the microclimate of an urban environment are qualitative, such as the retention of storm water and mitigation of the heat island effect that characterises many urban environments. Figure 5.44 illustrates that, due to the combined effects of solar radiation blockage, evaporative cooling and high solar emissivity, roof gardens greatly reduce the surface temperature of a roof and subsequently the amount of heat that a building will absorb.

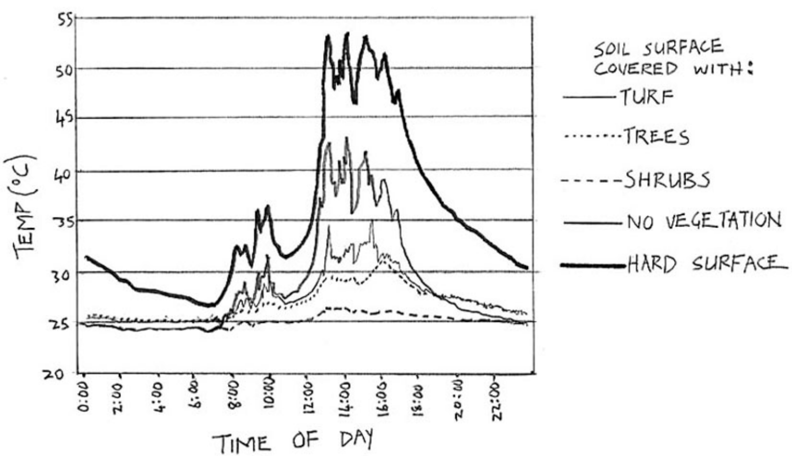



**Figure 5.44 Surface temperatures of soils covered with different materials (Wong *et al* 2003:358)**

Thompson and Sorvig (2000:112-114) note that the practice of creating sod roofs is an age-old tradition in Scandinavia and elsewhere that requires far less structural modification to a building than conventional roof gardens. This is because pedestrian movement is generally not facilitated on this type of roof and both the planting medium and plants are relatively light (Figure 5.45) and existing roofs can potentially be retrofitted. Furthermore sod roofs can be created on much steeper inclines than conventional roof gardens, which require a very small gradient, meaning that less limitation is placed on the design possibilities of the building. If properly constructed sod roofs have several advantages. This form of construction greatly improves the thermal insulation of a building, produces oxygen and stores carbon, thereby alleviating air pollution, it absorbs and stores rainwater which reduces runoff, and it creates wildlife habitat. It is, however, important to note that sufficient structural support, waterproofing and drainage must be provided.

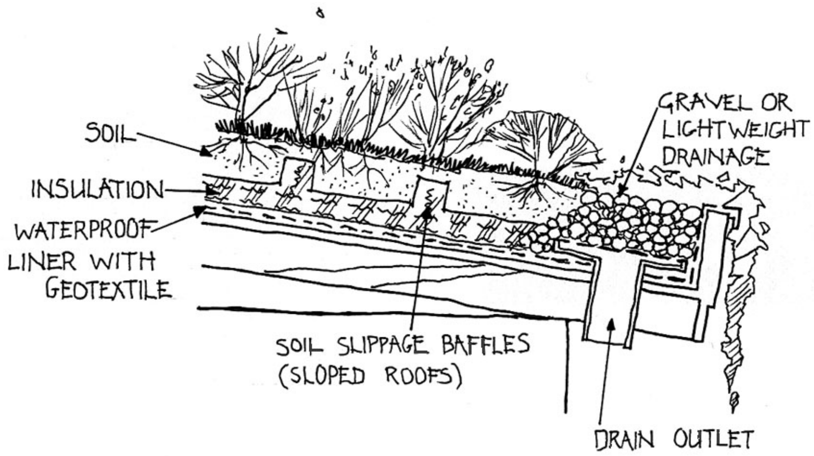



**Figure 5.45 Section of contemporary sod roof construction (Thompson and Sorvig 2000:112)**

Not only the surface treatments of buildings are of importance to climate-responsive design. Figure 5.46 (A) & (B) shows how different landscape surface treatments can drastically affect the temperatures of a surface and subsequently the air temperatures directly above the surface. Using the correct surface materials can lower or increase the ambient temperatures of an area, significantly affecting comfort levels. Robinette (1983a:103) states that lawns should be located near structures, as they tend to reduce the diurnal temperature fluctuations and lower summer high temperatures. This is especially relevant for locations with high temperatures. Egg crate type shade devices, or any other semi-transparent shade structure, can also be placed on the east and west facades of the building, to block unwanted morning and afternoon sun. This may be more necessary in the summer than in the winter and adjustable or moveable or otherwise deciduous shading may be necessary.

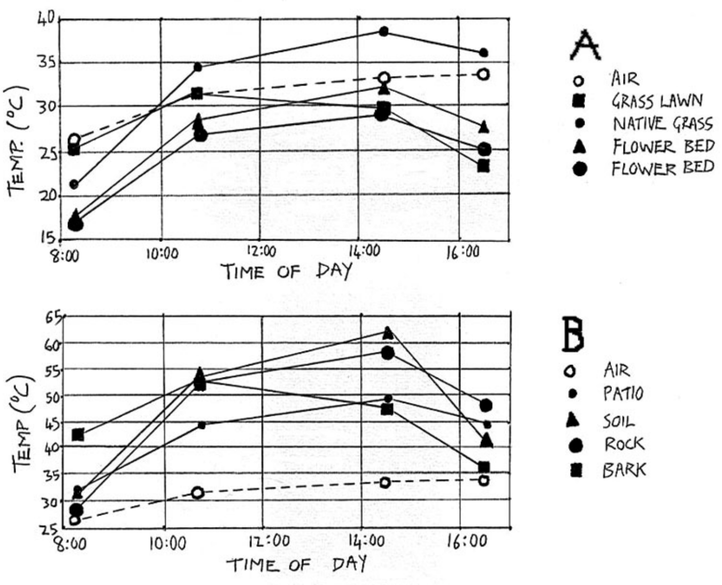


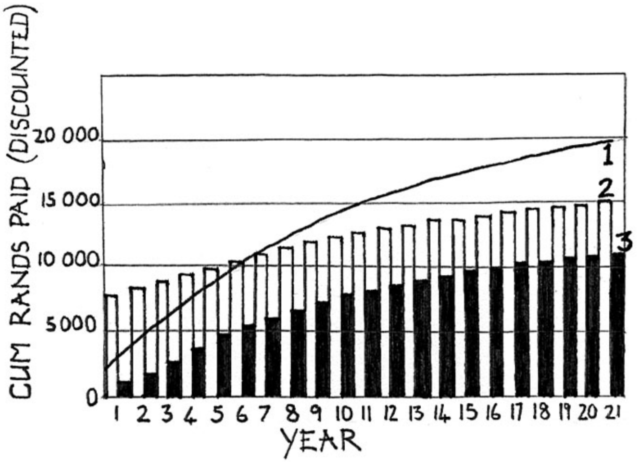

**Figure 5.46 Temperatures of various surfaces of a Colorado, USA suburban neighbourhood measured on 17 July 1997 (Bonan 2000:106)**

## 5.5.4 Solar water heating

Meyer and Tshimankinda (1998:679) have shown that because of the very mild climate of South Africa the largest user of electric energy in the domestic sector is not through space heating, as with many colder climates, but through hot water consumption. They have also found that people occupying expensive low-density townhouses in Johannesburg use up to 44% more hot water than residents of high-density townhouses and that the amount of hot water used increases by 70% during the winter (Meyer & Tshimankinda 1998:681). Another survey done in Johannesburg by Meyer (accessed 22-09-2003) has revealed that more affluent people occupying low-density houses use as much as 3.6 times more hot water than those living in high-density houses. These figures illustrate that the affluent sector of a suburb contributes heavily to both energy and water consumption which implies that some of the greatest reductions may be achieved if a viable energy efficient means of heating or pre-heating water is widely implemented in higher-income South African suburban residences. In this context Gibberd (30-09-2003) believes that some of the greatest potential for energy-efficient South African societies lies in more efficient ways of domestic water heating. Ward (2002:34) suggests that if finance, safety and health factors are taken into consideration solar water heating is preferable to electric and gas as methods for heating water. Thus an increase in the use of solar water heating could result in significant financial and energy savings especially if incorporated in higher income residences.

The DME reports that two of the largest obstacles facing the solar water heating industry in South Africa, are the excessive prices of equipment in South Africa and outdated standards of the South African Bureau of Standards (SABS). These problems are compounded by the fact that the demand for solar water heating equipment is small in South Africa and proper testing of equipment is lacking (DME (b), accessed 15-07-2003) which has so far resulted in very limited growth of the industry. The domestic solar water heating capacity installed in South African domestic residences in 2001 was only 2 220 000 m² with 227 000 m² of solar swimming pool heating installed (South African Consulate General in New York, accessed 24-09-2003). However, a joint study by ISES and the Development Bank of Southern Africa (DBSA) (ISES/DBSA, accessed 24-09-2003) has shown that the potential growth of this industry in the region is great. It is the renewable energy technology with the greatest amount of regional trade, with local manufacturing capacity in South Africa and Botswana amongst other countries, with imports from Australia and Europe making up the rest. The two greatest obstacles identified by the study have to be overcome if this industry is to come to full fruition. These were the fact that imported units are usually not suited to the high radiation levels of South Africa and prohibitively expensive, and the low cost of grid electricity and conventional electric appliances.

Sherman is of the opinion that a combination of financially subsidising equipment and enforcing installation will spearhead the solution. He states that the energy savings and environmental benefits that the widespread introduction of solar water heating in the residential sector alone would have, warrant appropriate legislation to insure implementation, as is the case in Israel. He also means that funding should be made available by multinational, developed-country organisations to make such a program more feasible (Sherman, accessed 24-09-2003).




Legend: 1=Electric geyser, 2=Solar water heater purchased cash, 3=Solar water heater financed

**Figure 5.47 Solar water heater cost comparison (Ward 2002:54)**

## 5.6 Water and runoff management

### 5.6.1 The need for water conservation

One of the greatest challenges that mankind faces and will increasingly be forced to deal with in the future is water scarcity. In the year 2000 1,099 billion people or 18% of the world population had no access to improved water (WHO, accessed 01-09-2003). As the world population continues to grow this problem can only increase. Yet the problem of water scarcity is often not related to inadequate quantities of water, but the pollution or ineffective utilisation of available water sources. Nel (2002:182) is of the opinion that one of the main problems that water efficiency efforts in South Africa face is that this scarce resource is too cheap in this country. However, increasing the price will not solve the problem and will in fact create new ones. Poor people that use much less water than affluent ones will be hard hit by such a measure. Subsequently those who are already using little water will be forced to use even less, further decreasing their quality of life whereas those who can afford more expensive water will probably continue to waste it. The Department of Water Affairs and Forestry (DWAF) (accessed 5-08-2003) states that the detrimental impact of domestic and municipal users on the quality of water resources and the amounts used by this sector is also growing rapidly due to service expansion, and local governments and their domestic users that they serve will need to seriously consider the ways water is used and often wasted.

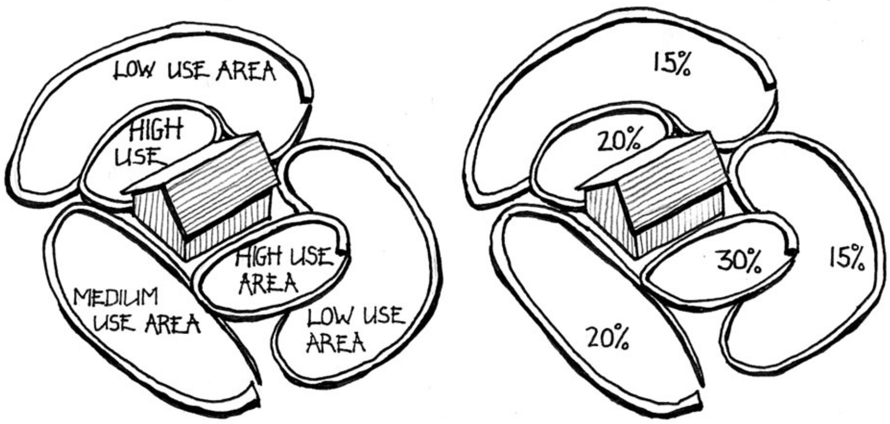
Mollison (1990:35) contends that since the rise of landscape planning and design as a profession, the emphasis seems to have shifted from functionality and utilitarianism to almost purely cosmetic. According to Robinette (1984:94) aesthetic fads seem to dominate the decision process of modern residences and the associated landscaping and a tendency that is becoming increasingly evident in the design and installation of landscapes is the use of plants that are not suited to the environment or location that they are used in. Where a region does not have a specific established historical or cultural visual character, aesthetic ideas that are appropriate or justified in another region are imported without any thought being given to the appropriateness of these ideas to their new setting. In this way plants are often used in landscaping where they cannot under normal circumstances survive and subsequently require unjustifiable amounts of extra water simply to stay alive. It should be obvious for instance that in drier parts of the world more water is required to keep the same garden looking green and lush than in a temperate or humid climate. The logic behind this argument is simple yet a realisation of the implications that it should have on landscape planning and design seems to be non-existent.

Where an abundance of rainfall is present throughout the year such considerations for residential gardens may not exist at all but given the predominantly sporadic annual frequency and distribution and low amounts of rainfall in South Africa as explained in Section 2.1.6 and illustrated in Section 3.2.6 this is not likely to be the case, except perhaps for a few locations along the East and South Coast. Therefore strategies to reduce the amounts of water used for residential garden irrigation, to effectively utilise on-site rainfall, to prevent evaporation of water especially in drier parts and to recycle household water where possible are potentially effective ways of reducing water usage in suburban areas.

### 5.6.2 Xeriscaping

According to Robinette (1984:125) an effective method to conserve water in the landscape is to plan developments around different irrigation zones. Small, highly used zones and areas that are required to be highly aesthetic can be fully irrigated and planted with species that may require more water such as ornamental exotics or preferably indigenous display plants that originate from areas with higher rainfall. The other larger zones of the garden that are not frequently used are designed for minimal irrigation and maintenance. Such areas can serve as a backdrop, shelterbelt or other functional structure and should be planted with species that are adapted to the natural water availability of the region. Furthermore these sections of the garden can also serve as detention areas for rainwater (Figure 5.48 and Figure 5.49).

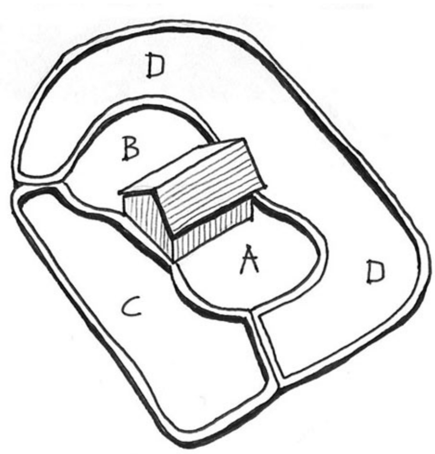
Plants that are indigenous to the area of application are naturally adapted to the amount of water available in their habitats and will require less additional irrigation, or if carefully chosen, almost none at all. Tarjuelo and De Juan (1999:391) explain how plants from areas that experience regular drought conditions show physiological and morphological adaptations that limit transpiration losses of water and increased tolerance of lowered water potential, in order to use water more efficiency. Usually such plants show a decrease in leaf size and an increase in stem volume due to nutrient storage in these parts. Plants that respond in this way to high annual temperatures and the poor seasonal availability and quantity of water are ideal to use in the low irrigation zones.




Note to Figure: Percentage figure indicates percentage of total irrigation water allocated to each irrigation zone

**Figure 5.48 Different irrigation zones to minimise unnecessary and ineffective residential garden water use (adapted from Robinette 1984:125,196)**

Mart'in de Santa Ollala, Fabeiro Cort'es, Brasa Ramos and Legorburo Serra (1999:289) describe controlled-deficit irrigation, a water saving strategy that is used in commercial crop production based on controlled reduced watering during those periods of a plant's life-cycle in which such action does not significantly affect the production and quality of the crop involved. This technique is applied to annual croplands and orchards and is done in such a manner that crop requirements are still satisfied during the remainder of the crop cycle. Utilising this tactic in residential applications such as lawns, shelterbelts and visual screen planting could potentially lower water use in gardens without causing significant reduction in the visual and functional quality of the planted areas.




Legend: A=Display garden and planting focal features, B=Lawn and play area with border flowers, C=Mixed use lawn, vegetables, climate amelioration planting, water catchment landscaping, screening planting etc, D=Climate amelioration planting, screening planting

**Figure 5.49 Conceptual garden layout based on different irrigation zones (adapted from Robinette 1984:125)**

This technique can effectively be incorporated with irrigation zoning. Plants chosen for their ability to withstand decreased watering during periods of water shortage should be used in the low irrigation zones. Thus if a period of below average rainfall or a particularly long dry season occurs irrigation can be focused on the high irrigation zones, further reducing the amount of water used by the bulk of the garden. Again the plant species most suited for this purpose will probably be indigenous to the specific areas of application.

Innovative solutions can further reduce the amount of water that is used to irrigate residential gardens and also make use of runoff. Rand Water (accessed 12-09-2003) explains simple and easy to implement methods for use in residential settings. Paving should be used in high traffic areas instead of lawn and where possible impervious paving should be replaced with permeable surfaces such as gravel, stepping stones or grass blocks. Driveways should be made from semi-permeable paving units and curbs should have inlets into planted areas or be removed entirely. Lawns should be shaped into shallow hollows where runoff can accumulate and slowly seep into the ground. Furthermore lawns should be given the lowest irrigation priority in a landscape as they are slower to die than most other plant types, recovers easily from drought and are easier and less expensive to replace than other plant types. In fact lawn areas should be reduced in favour of hardy ground covers, ornamental indigenous grasses or mulch surfaces. The area of lawn should only be large enough to accommodate the various activities that may occur there.

Through the implementation of such strategies the landscape will begin to reflect efficient and appropriate water use and in the process help to establish a specific regional character for different suburbs. The argument that xeriscaping is detrimental to the visual aesthetic of the landscape need not be true as there are many truly beautiful plants indigenous to every climate region of South Africa and even the driest parts sport spectacular species that are used throughout the rest of the country in a variety of landscaping applications. In any event such a change in landscaping aesthetic is needed if public awareness of water efficient urban landscaping solutions is to be created. Thayer and Richman (1984:194) explain this argument: "Without a physical, imageable manifestation in the landscape, water conservation has little chance of helping to influence public opinion and alter resource-wasting habits."

### 5.6.3 Evaporation prevention

In areas were the water balance is highly negative, merely catching and judiciously applying rainwater to different uses may not be enough to ensure that the water is actually effectively managed. Evaporation from the ground and lawn surfaces can be responsible for considerable water losses greatly reducing the savings achieved from an otherwise effective design. Subsequently in such areas measures have to be taken to prevent evaporation and the most effective way of doing this is to prevent direct solar radiation from reaching the water. Figure 5.50 illustrates the various ways by which water enters onto and leaves residential properties. By maximising the water holding capacity of the landscape and minimising the amounts of water lost from it, especially through evaporation, transpiration and runoff, more effective water management can be realised.

Mulching, described by Tarjuelo and De Juan (1999:412-413) is used widely in agricultural farming and crop production and constitutes covering the soil surface with green and/or dry plant material, such as grass clippings or crop residues like residual leaves and stems. This reduces the evaporation rate of water from the surface and upper soil horizons because the residue shades the soil surface, reducing the surface temperature and aiding deep percolation, and increases organic matter content in soil.

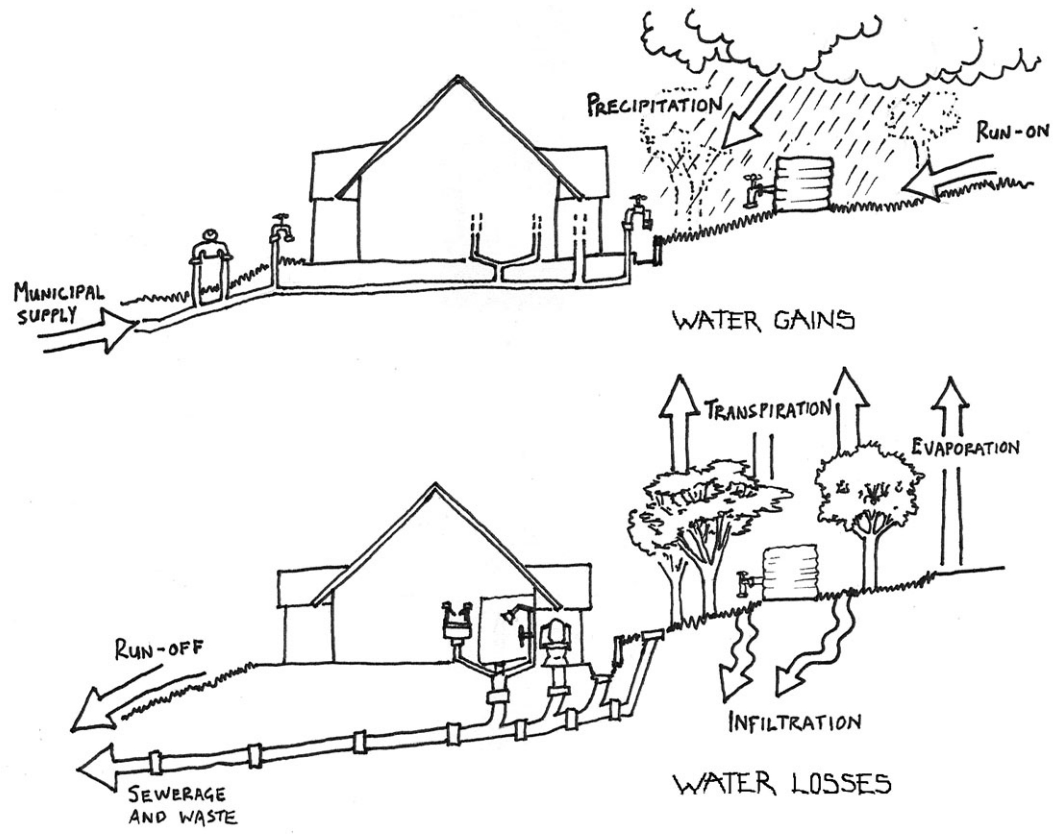



**Figure 5.50 Ways by which water enters onto and leave residential properties (adapted from Morrow 1993:40)**

Earthworms and other soil fauna are encouraged to inhabit such soil, which provides channels for more effective water infiltration. Mulching also protects the soil against raindrop impact, which causes the soil surface to seal and the velocity of the runoff to increase. De Wrachien and Chisci (1999:204) explains that mulch simulates the effects of plant cover and is often used as a substitute for a cover crop, especially in dry areas. Subsequently in hot arid regions attractive mulching materials such as bark chips, pebbles and gravel can be used to replace irrigation-intensive ground cover plants in areas where they are not often seen.

Mulching is most effective when used where large amounts of water accumulate in the landscape, such as planting beds for large trees. Waterfall (accessed 11-09-2003) shows how creating basins in the landscape around trees or other planting areas that require large amounts of water will cause runoff to accumulate there, which will increase the amount of water available to the plants there. This is especially true for sloped surfaces where most of the water would otherwise have run off the site and not have been available to plants for absorption. The trees can shade the accumulated runoff for parts of the day especially at noon, but adequate mulching would greatly increase the effectiveness of this technique by reducing evaporation and thus increasing runoff infiltration.

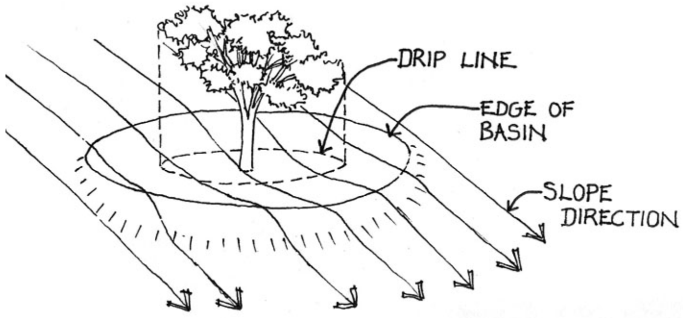



**Figure 5.51 Depressions in the landscape used to collect surface runoff (adapted from Waterfall, accessed 11-09-2003)**

## 5.6.4 Runoff utilisation

Niemczynowicz (1999:3) argues that the highly concentrated nature of modern urban areas and the associated transformation of the landscape have significantly changed the hydrological cycle. The increased area of impervious surfaces results in higher peak flow rates, increased runoff volume and transport and deposition of sediments and pollutants that affect ecological systems both within the city and downstream. Urbanisation not only influences the amounts of surface water available for use by a city, it also impacts on the quantity and quality of groundwater underneath a city and its surroundings. Foster (2001:186) states that these influences are caused mainly by the changes in the patterns and rates of water infiltration into the soil and changes in quality of that recharge water. Urban transport, particularly in the form of motor vehicles, can be blamed for a large percentage of the impervious surface of modern cities, in the form of roads and parking surfaces. Associated stormwater sewers channel water, greatly increasing its velocity and depositing pollution into waterways. The large amounts of impervious areas should instead be made to work for us as they can be used as water collection devices, if planned and designed to perform these functions.

According to Brooker (1998:23) it is important that stormwater runoff remain on the surface for as long as possible. Pipes are hydraulically very efficient and remove water from site at a rapid rate. However, this decreases the period during which a catchment is drained of runoff and increases the peak flow rates of its waterways. Therefore roofs, driveways, parking areas and patios can all be used to collect, detain and channel water so that it can be used on-site for irrigation and other purposes. In fact, Hillel (1978:165) describes how many ancient cities in arid regions relied on a system of local, instead of central water supply for domestic use, collecting natural runoff from roofs in gutters and storing it in cisterns. If such a system were applied in suburban residences today it would have the advantage of reducing installation and supply costs of municipal systems. The stored water could provide a reserve in case of emergencies or exceptional demand and can significantly reduce the amount of municipal water used, especially for uses that do not require potable water, such as toilet flushing, irrigation and evaporative cooling.

Thus, for runoff to be used in the residential context it must be effectively collected, or harvested, from the landscape. Phillips (2003:44) explains the principle of water harvesting in the landscape by using the analogy of a cupcake pan. Traditional landscape architecture can be illustrated by turning the pan upside down. Mounds, medians and other structures from which water runs off or away from characterise most landscaped properties. When one turns the pan around, however, a series of depressions that collect water is formed. This is how landscaped areas that aim to collect water should function. In this context Robinette (1984:83) states that there are several principles that are of importance with regard to effective management of water that falls on a site.

1) Water must be slowed down when it falls on site so that it can be absorbed into the soil.

2) The flow of falling water intended for specific use should be focused and directed, in such a way that safety is not negated.

3) Water should be moved to where it is needed on the site and allowed to infiltrate.

4) Water that is not used immediately should be stored on site so that it can be used at a later stage.

Subsequently Waterfall (accessed 11-09-2003) describes a simple water harvesting system as consisting of a catchment area and a means of distribution. A catchment is any area from which water can be collected and used, the most effective surfaces being hard and smooth. In some instances a holding facility such as a tank or pond can store water for later use. The water is moved via the distribution system to the areas of application. The distribution system can be simple swales, concave paving areas and gentle berm structures, or complicated pipe and channel systems. Often a series of temporary holding areas can also be introduced in the distribution system to further slow the flow of water. Upon first consideration such a system may appear to be a disruptive imposition on the landscape that may interfere with other activities and functions. However, this need not be the case. Earthworks and structures to collect and store water in the landscape can together perform multiple tasks. Phillips (2003:44) describes how these elements can form part of an energy efficiency system:

> "Water harvested in earthworks can be used to help grow plants that buffer noise, produce food, entice visitors, cool buildings, and deflect wind. Water harvesting structures themselves can stop erosion, define site usage areas, and act as physical barriers. Harvested water in tanks can be used to supply cooling towers, provide emergency drinking water, grow gardens, wash vehicles, and water plants. And tank structures can moderate microclimates, provide trellis structures for plants, and act as fire barriers."

When one considers the roof of a building it becomes clear that it potentially presents a large surface that can be used to harvest rainwater. Most roofs have relatively smooth surfaces and in any case the pitch of the roof controls the direction of runoff, meaning that the runoff can easily be collected. Even though collecting rainwater from the roof of a house will have some design implications the choice to do so need not limit the design possibilities of the house itself. Waterfall (accessed 11-09-2003) illustrates how the choice of a pitched or level roof surface does not significantly influence the amount of water that can be harvested from the building, as the effective collection surface for both roofs is the same. Thus the ability to collect rainwater from the roof of a residence need not limit the architectural possibilities available to the designer, although together with other considerations such as solar access and passive heating it may do so.

Coombes, Argue and Kuczera (1999:338) explain the components of a basic rainwater harvesting system, applicable to single residences and water-wise community developments, implemented at Figtree Place in New South Wales, Australia. Water collected from the roof surface passes through a "first flush" pit which removes the first 2 mm of rain, then enters the main storage tank(s) from an inlet. The "first flush" pit also serves as an access point to

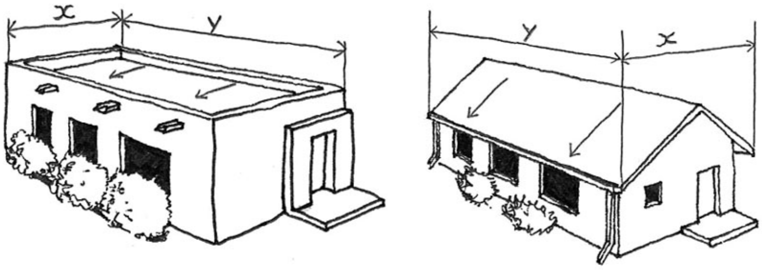
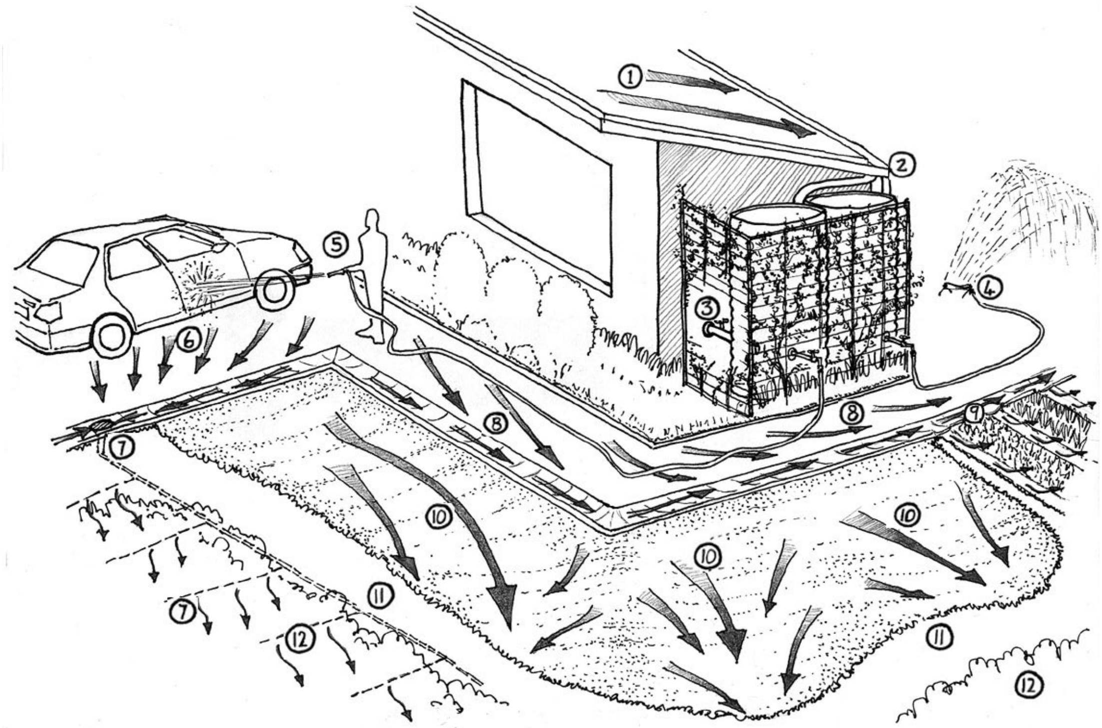



**Figure 5.52 The choice between a flat and pitched roof does not influence the amount of surface available for rainwater harvesting (Waterfall, accessed 11-09-2003)**




Legend:

1=Roof slope used to collect rain runoff, 2=Roof gutter collection of water and storage in tanks, 3=Connection to house for emergency use or toilet flushing (if water is adequately purified), 4=Garden and lawn irrigation with stored water, 5=Car washing and pool filling with stored water, 6,7=Collection of runoff from paving for drip irrigation, 8=Collection of runoff from paving for (9) open channel irrigation and on-site detention, 10=Lawn areas act as detention/infiltration areas and runoff diverters, 11=Decorative planting areas receive higher irrigation priority and runoff utilisation, 12=Hardier edge, screening and windbreak planting

**Figure 5.53 Combination of water harvesting and runoff utilisation techniques for a single residence**

remove debris and sediment. From the rain tanks an outlet is provided for residential use and a pipe conveys overflow water to a groundwater recharge trench. The latter consists of an underground gravel trench 0f 750mm deep by 1000mm wide enclosed by geofabric and a perforated pipe for distributing the water. The system at Figtree Place also includes a detention basin, a depressed lawn area covering a 750 mm deep layer of gravel enclosed in geofabric, from which additional irrigation water can be drawn via pressure-activated submerged pumps placed within the basin.

### 5.6.5 Water re-use

Basson (1997:10) has determined that water use in South Africa is dominated by commercial crop irrigation, 54% of the country's water is used in crop production. Although significantly less, domestic and general urban water consumption accounts for 11% of the country's total water use, which is more than that of the mining and forestry sectors, both at 8%. These figures, although compiled from various reports and only indicative of the state of the country's water use and not authoritative, show that urban water use constitutes a significant percentage and that greater efficiency in this sector, as with all others, could free up some of this essential resource for productive use.

According to Niemczynowicz (1999:4) a major detrimental factor to sustainable urban water use is the way the problem is perceived. Often our cities are not troubled by a water quantity problem but by a water quality problem. Especially in developing countries the entire amount of water that reaches a household is purified, due to the fact that there is only one supply network, but is viewed as waste once it leaves the building and is contaminated by the relatively small percentage that really is wastewater, which means that the whole quantity of water that leaves that building has to be treated again. Such a system results in very large quantities of water being unavailable for use, while in circulation in the system. If water were treated to the required quality of its intended use only and delivered through separate systems, substantial efficiency could be achieved. However, the major drawbacks of such a system is that it would be complicated to design and very costly to implement and maintain. In the absence of such public municipal facilities and supply systems, local water recycling and re-use could partially fulfil such a function.

As many residential water uses do not require water of a potable quality it is possible to utilise both stored rainwater and filtered grey water for such purposes. In this way water is

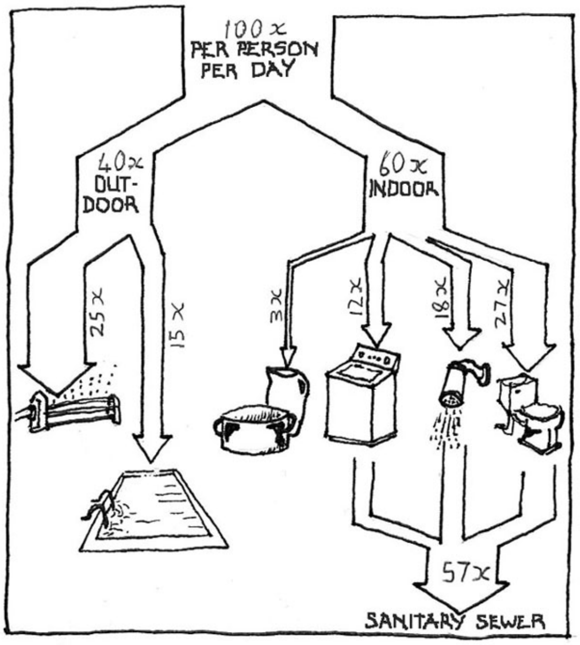



**Figure 5.54 Hypothetical water use of conventional household (Robinette 1984:165)**

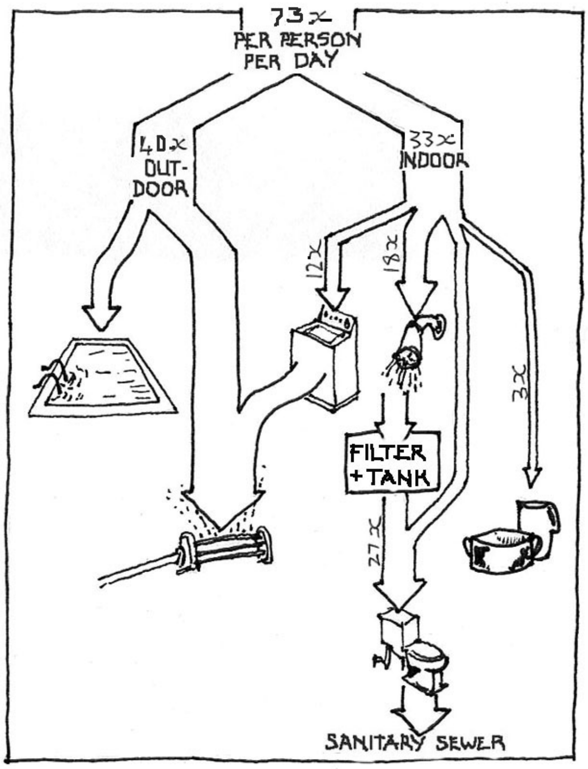



**Figure 5.55 Reduced water use through partial re-use (Robinette 1984:166)**

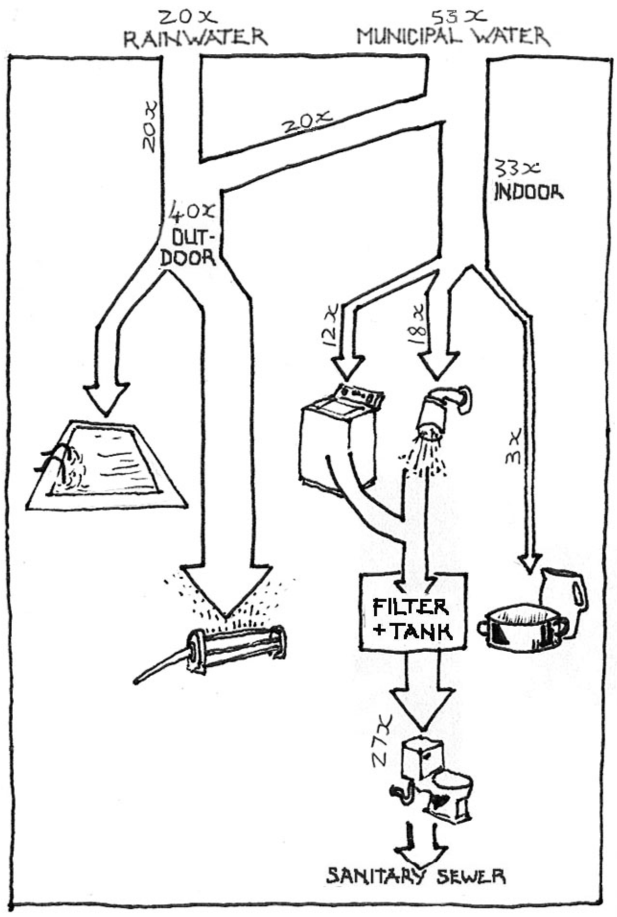



**Figure 5.56 Further reduction in water use through utilisation of collected rainfall**

used for as many purposes as is safe and practical before discharging it, either to the sewer system or into the landscape. Figure 5.54 to Figure 5.56 illustrate how this might be achieved, using a hypothetical quantity of 100x litres of water per person per day. Figure 5.54 illustrates how this quantity might conventionally be utilised, leading to more than half of the water ending up in the sanitary sewer system. If water is successively used for different applications before being disposed, it becomes possible to reduce the amount of municipal water used (Figure 5.55). Furthermore the quantity of water that is disposed of in the sewer system is more than halved. Collected rainwater can be utilised to further increase the efficiency of this system (Figure 5.56). If a quantity of 20x water is used for outdoor and garden purposes, the initial amount of municipal water (100x) used in this household is now almost halved.

Al-Jayyousi (2003:184-185) explains the technology involved in two-stage residential gray water re-use systems, common in Britain and elsewhere (Figure 5.57). The system is comprised of a coarse filtration metal strainer and disinfection stage using chlorine or bromine. The basic two-stage system was designed to meet the less stringent reuse standards akin to those for bathing water, limiting the range of uses of the water produced. However, this fact need not negatively impact on the appeal and feasibility of residential gray water recycling. Jeppesen (1996:312-313) contends that the safest way to re-use household greywater is in applications that do not require human contact, most notably sub-surface irrigation at 200mm to 300mm below the ground level, and toilet flushing. Accordingly Australian households are reported to be able to achieve savings of up to 50% of their total water usage, if all gray water is re-used. According to Jeppesen (1996:313) especially irrigation is an effective method of water re-use as other uses usually require more expensive systems and equipment and are less likely to be used where reticulated water is available.

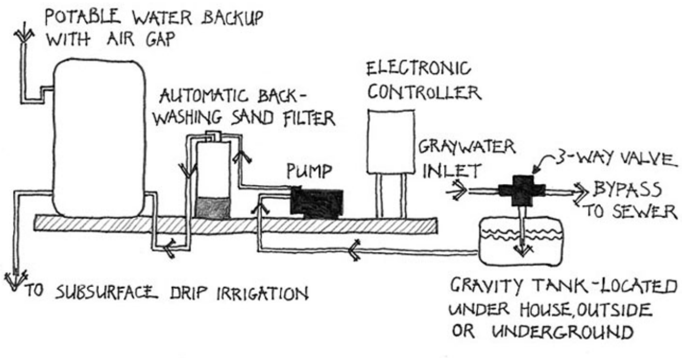



**Figure 5.57 Basic components of residential two-stage gray water purification system (Al-Jayyousi 2003:189)**

## 5.6.6 Evaporative cooling

Evaporative cooling of buildings is one of the many uses for water harvested in the landscape or recycled from other uses. This method of cooling is specifically suited to arid conditions as Flach (1981:113) explains that the evaporation of water to vapour uses up considerable energy, in this case heat. For evaporative cooling to be effective in such conditions it is preferable to locate the water source in such a way that the air passing over it has already been cooled somewhat before reaching the water. Locating it in a shaded area will help to cool the air before it passes into the building. Furthermore the rate of airflow must be sufficient to allow enough ventilation, around two to three metres per second so that the humidity of the air inside the building does not increase, as this will be detrimental to thermal comfort. In situations where the increased humidity may cause discomfort it is not wise to employ evaporative cooling. According to Nel (28-11-2003) this is only really a serious problem where air movement is limited and the water evaporates from hot surfaces. If the humid air is trapped in a confined space that receives plentiful radiation, conditions may become uncomfortable. In such instances the provision of shade, planting and increased ventilation will help to create the desired effect.

Alp (1988:70-73) describes how fountains, in combination with courtyards or wind towers, can form the basis of an evaporative cooling system, a common method of temperature amelioration in many middle-eastern regions. A courtyard stores the cool night air and releases it during the warmest part of the following day. The walls are as high as the courtyard is wide, for the cool air to remain undisturbed and the use of plants to shield them from direct sunlight enhances the effectiveness of the technique. Surrounding rooms draw daylight and coolness from the courtyard and perimeter arcades provide shade in the warmest hours when the midday sun is overhead. Running water inside the courtyard, such as provided by a fountain, is crucial for evaporative cooling (Figure 5.58). Wind towers can be used to “catch” the prevailing summer breezes and cool them down before distributing the cool air through a building. They are useful in high-density arid region settlements, where the flow of prevailing winds may have been disturbed by the structures of the buildings. By lifting the intake point above the general building height level less disturbed airflow may be available for cooling. Access panels are used to control the flow of air through ducts. The addition of running water, or fine water sprays in the tunnel cools the air by partially evaporating the liquid. A small fountain at the point where the tower opens into the structure will further enhance the effect if vents or openings are provided to create an airflow stream.

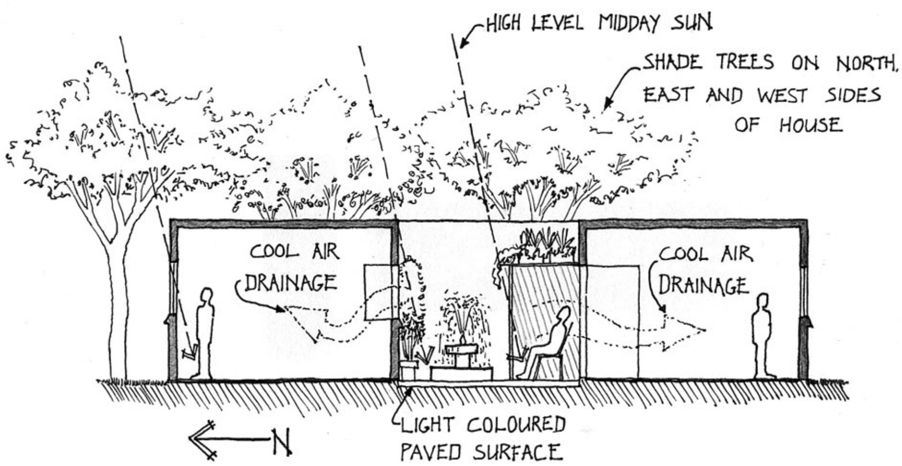



**Figure 5.58 Section through residence illustrating courtyard and fountain combination to create cooler conditions in hot arid regions**

# 6 CHAPTER VI - CONCLUSIONS, SHORTCOMINGS AND FURTHER RESEARCH

## 6.1 Conclusions

### 6.1.1 Introduction

> "We have worshipped at the altar of growth. Partly, this is the consequence of a need to house continuing migrations of people being drawn from traditional to cosmopolitan settings. Partly, it is the result of a swelling world economy that rewards ever-expanding markets over constancy, development over a steady state, novelty over tradition. Our predilection in favour of growth over maintenance has raised doubts about a sustainable future." Knowles (2003:15)

This study has revealed that globally and in South Africa there is a need for improved energy efficiency and more sustainable energy production methods. Although the situation is not yet desperate, it is most certainly very urgent and globally efforts to realise these goals are under way. Climatically responsive urban design is a solution to one of the many facets of the problem and has indeed been implemented for millennia in different parts of the world and in different climatic contexts, to achieve human comfort and optimise the use of scarce natural resources. South Africa offers good potential for energy-efficient urban design, but many changes are needed if this is to happen. More extensive research is needed in al aspects of this situation, legislative steps have to be taken and greater awareness of the problems must be created in both professional and public sectors.

### 6.1.2 The problem of residential energy inefficiency in South Africa and the potential for change

1) Our ability to transform the world to meet our demands has had profound impacts on all of its eco-systemic processes and resource bases. Although not all have been bad, the global situation is such that humanity cannot continue to live the way that it recently has. Many of the methods by which we generate and use energy pollute the

environment, are detrimental to human health and deplete essential yet dwindling natural resources. Renewable and sustainable energy technologies present several options. Another important solution is the improved consumption efficiency of available energy resources.

2) In South Africa several obstacles exist in the way towards greater urban energy efficiency, amongst which two of the most significant are the relative affordability of electricity to the consumer and lacking or insufficient legislation and enforcement of energy efficient measures and technologies. Measures to improve energy efficiency seem especially lacking in higher-income households as much of the programmes and funding efforts that exist in this country are directed at historically disadvantaged communities.

3) Water is a particularly scarce commodity that is being put under increasing strain due to urban expansion and increased development in the agricultural and industrial sectors. Furthermore it is an unevenly distributed resource that the affluent have greater access to and squander in much greater quantities.

4) The climate of South Africa is particularly mild and energy expenditures on climate modification are relatively small, compared to that of many American and European cities. Nevertheless the South African climate, especially the high levels of solar radiation, presents many opportunities for climate-responsive design aimed at creating energy efficiency.

### 6.1.3 Climatic factors and the influences of site

1) In terms of human comfort and response, the climate of a region is mostly determined by its air temperature and humidity, wind conditions, radiation levels and amounts and nature of precipitation. Of these, combinations of humidity, wind and radiation levels are of particular importance to human comfort and subsequently climatic design. Atmospheric humidity can greatly influence the perceived comfort of a given temperature and especially high temperatures can be anything from relatively pleasant under low humidity conditions to intolerable under very high atmospheric humidity. Under such conditions wind plays an important part in improving comfort by removing moisture and increasing evaporation. In cold

climates windchill can significantly lower perceived temperatures to the point where they can become detrimental to thermal comfort and even dangerous to human health. The amount of energy that a surface absorbs and subsequently the rate at which it and surrounding temperature heat up can also be influenced by controlling the amount of solar radiation that it receives.

2) The specific topography and location of a site can influence the microclimate of an area and will have significant implications for climatic design. There are several site-related characteristics that influence microclimate, mainly due to the influences that these factors have on the concentrations and times of solar radiation exposure. These factors are the vertical incidence angles of the sunlight throughout the day, the horizontal azimuth angles of the sun throughout the day, the positions where the sun rises and sets due to the latitude of the site, the slope gradient of the site, and its aspect or orientation in terms of the cardinal points.

### 6.1.4 The climate of South Africa

1) It was found that most of the South African climate is relatively mild, having neither very high nor very low temperature extremes and only moderate humidity levels. Thus less energy is used for climatic amelioration than in many European and American locations. Due to the high solar radiation levels there is potential for various active and passive solar design techniques and technologies.

2) The South African climate is predominantly either hot semi-arid or temperate. Most of the western interior is hot arid with the most extreme conditions occurring in the northwestern parts of the country. The eastern interior and highveld is predominantly temperate, with temperatures increasing to the north and decreasing to the south. The only cool region of the country is found in the highlands of the Drakensberg, with a significant portion of the eastern coast being hot humid. A small region of composite climate is found in the most northeastern part of the country that has both hot humid and hot arid characteristics.

### 6.1.5 Considerations regarding energy efficiency in South Africa

1) If climatic resources are to be utilised to improve energy consumption efficiency in suburban residences, provision has to be made for their use from the start. Climatic

forces, solar radiation and water are elements of the outdoors environment and have to either somehow be let into a building to be used or kept out if they have negative effects on the occupants and energy consumption. Therefore effective suburban layout and structuring of the landscape and areas surrounding buildings is of crucial importance in this regard. It is here that landscape planning and design to aid and ensure residential energy efficiency should come into play. However, unless current practices change, which seems unlikely in the present situation, this will not happen.

2) The changes that are needed to make energy efficiency, climate-responsiveness and sustainable resource management a reality may well completely alter the face of our cities in the future. Gibberd (30-09-2003) is of the opinion that urban design guidelines governing land use and urban development densities, rainwater harvesting and drainage requirements, transportation and other considerations could render typical conventional suburban residences obsolete and even unallowable.

3) Often the problems of resource and energy inefficiency are not just design-related, but originate from our everyday activities and habits. Water recycling, runoff storage and evaporation preventing design will be of little effect if we leave taps running while we brush our teeth, neglect to repair leaky taps and irrigate our gardens during the heat of the day. Energy efficient design and sustainable energy production need to go hand in hand with everyday resource-consciousness and environmentally sensitive lifestyles.

### 6.1.6 Climate-responsive design in the suburban context

1) Designing suburbs to create access to solar radiation forms the basis of solar design. Optimum orientation of the building with respect to the specific local climate and site characteristics must be ensured. Correct solar orientation has thermal, and consequently energy-conserving, benefits over houses that are not orientated to take advantage of the sun. Generally a north-south orientation was found to be adequate for most climates although slight variations for optimal performance were identified in some instances.

2) Controlled shading of buildings is necessary to effectively utilise sunlight and solar radiation as heat source. Both planting design and built features can be employed for

this purpose, although planting design was found to be more successful for low level light, whereas architectural roof and other structural devices are more suited to midday sun. Light surface treatments can be utilised to reflect diffuse light into buildings and to lower the rate of energy absorption of a building through its roof. Windows play an important part in solar access control and generally smaller windows should be employed in hot arid climates. In cooler climates triple glazing and methods to prevent heat loss through the window must be utilised and in hot humid climates windows should be shaded as much as possible.

3) Optimum dimensions and proportions of buildings for specific climatic conditions must be respected and incorporated in the design. In cold climates shapes that have a low surface area to volume ratio are most suited for efficient heat retention, whereas oblong structures exposed to wind are more suited to hot humid climates. In hot arid conditions courtyards and shared exterior wall surfaces minimise heat gain and maximise shading. Solid, thermally inert construction is most suited for such conditions, whereas light, easily ventilated structures should be employed in hot humid conditions.

4) Manipulation of wind can occur through either built or vegetative structures. Vegetative structures provide a much larger area of wind protection downwind of the structure but the degree of protection is relatively low compared to that of built windbreaks, which offer a much shorter area of downwind protection. In both cases the degree of protection is largest when the wind approaches the structure perpendicularly. Both types of windbreak can also cause a rise in temperature downwind of the structure, depending on solar orientation.

5) Designing gardens around priority irrigation zones can ensure significant water savings while retaining aesthetic appeal and character. Using locally indigenous plant species can increase the ecological function of these environments. Several effective methods of runoff collection and detention for irrigation purposes exist, especially from the building roof and large paved surfaces. Household gray water can be purified for various purposes but the process is expensive and use for irrigation is the most cost-effective. Significant savings are also possible if water is used for successive purposes before disposed of in the municipal sewer system.

### 6.1.7 Current shortcomings in the field

Several shortcomings in the field of energy-efficient, climatically responsive urban design in South Africa have been identified, and to varying degrees described, in this investigation. Although by no means the only shortcomings that currently exist in this field, it is felt that the following points stand out:

1) A lack of adequate, comprehensive descriptions of the South African landscape in terms of energy-efficient urban design and human comfort exists.

2) A shortage of landscape climate design devices that aim to facilitate energy efficiency exists, originating from or adapted to the South African context, or there is insufficient documentation of existing devices.

3) There is insufficient integration of such landscape and architectural design strategies, in theoretical approaches and actual implementations on both macro-design or layout and detail design scales.

4) There is a lack of clear, detailed and specific laws and standards governing energy efficient design and construction, especially in terms of the use of climatic energy sources.

## 6.2 Recommendations for further research

### 6.2.1 Introduction

Considering the conclusions and especially the identified shortcomings discussed in Section 6.1.7, the need for further research in several aspects of energy efficient design is indicated. Although some of the issues listed and discussed below have not been dealt with directly in this study, they are integral to achieving this aim.

### 6.2.2 Climatic design-orientated assessments of the climate of South Africa

It has been established that South Africa offers the potential for various climate-responsive urban design options and that few locations have truly challenging conditions. Nevertheless various climatic contexts exist in this country. Although extensive documentation and classification thereof have been done, little has been from a purely design-orientated perspective, especially from a human comfort point of view. Therefore it is recommended that further assessments of the various design climates should be carried out and a method of classifying and mapping these should be established.

### 6.2.3 Climate-responsive design techniques in the South African context

This study has identified and described numerous design devices developed both locally and abroad that are of potential use in the South African context. However, it appears that much research and testing is still needed in this regard and that more efforts to relate the various techniques to specific locations and regions are necessary. Combining such research with detailed geographic assessments of the climate of South Africa may be of great value to the field.

### 6.2.4 Energy-efficient building codes and legal requirements

A very important area for further research is the possibility of making energy efficiency mandatory. The goal of this study was to establish basic energy-efficient design guidelines for the different climate regions of South Africa, with the aim of establishing a basis from which such building codes and laws may eventually be established. However, much work will still be needed before appropriate laws governing different aspects of energy efficiency in different climates can be compiled and it is suggested that extensive further studies be carried out to realise such codes and laws.

### 6.2.5 Embodied energy and financial considerations

Two aspects regarding the design techniques assessed in this study that have not been addressed and that warrant further investigation are their embodied energy content and financial implications. These considerations are key aspects of energy efficiency and sustainability in their own right and in specific instances otherwise sound techniques may be rendered inappropriate. For instance, the gains achieved through the reduction of energy use may be eliminated by the installation or running cost of the energy efficiency design device. Alternatively, the very energy-intensive production methods used to produce the building materials used in the design may be more than the gains of the finished product.

Subsequently it is recommended that further study be carried out to establish ways in which to achieve the guidelines set out in this study, with as small an embodied energy content as possible. The financial implications of the guidelines contained in this study should also be investigated to determine their general financial feasibility in the South African context. Ways to make these techniques as cheap and easy to achieve as possible should also be devised in order to effect greater implementation.

### 6.2.6 Urban density and transport considerations

South African suburbs are generally characterised by low population density patterns and one of the problems associated with this type of urban fabric is increased commuting distances to various destinations. Although this study has addressed appropriate development densities to facilitate climatic design the relationship to transport has not been investigated. Further studies to determine ways of achieving greater urban density levels whilst satisfying climatic design considerations is therefore necessary.

### 6.2.7 Retrofit of existing buildings for energy efficiency and climate-responsiveness

It has been established in this study that energy efficiency does not feature in most existing residences in South Africa, especially in higher income communities. Although future developments aimed at addressing this problem will no doubt contribute to ensuring energy efficiency, efforts at making existing buildings more energy efficient, through climate-responsive devices amongst others, should in the future play an important part to this end. Research and development of cost-effective devices, building retrofits and improvements to achieve this are therefore needed.

### 6.2.8 Design of communally integrated energy efficiency measures

One of the key findings of this study has been that in South Africa many community projects aimed at improving energy efficiency exist in historically disadvantaged and poor areas. However, few if any such projects are currently active in more affluent suburbs. This is hindering the application of such techniques and technologies on significant scales in these areas. Further studies to establish ways of creating small-scale community integration of the design methods established in this study should be carried out. This may help to create and foster a sense of shared sustainability in our societies. Especially residential estates and townhouse communities may offer promising scope for such efforts. Ultimately sustainability will only be achieved if it is based on a many-to-many, holistic approach.

# REFERENCES


1. AKBARI, H. 2002. Shade trees reduce building energy use and $CO_2$ emissions from power plants. *Environmental Pollution*, 116:119-126.

2. AL-JAYYOUSI, O. R. 2003. Greywater reuse: towards sustainable water management. *Desalination*, 156:181-192.

3. ALP, A. V. 1988. Vernacular climate control in desert architecture, in *Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988.* Edited by E. de O. Fernandes & S. Yannas, Oxford: Pergamon Press: p67-79.

4. AL-SALLAL, K. A. 1998. Sizing windows to achieve passive cooling, passive heating, and daylighting in hot arid regions. *Renewable Energy*, 14(1-4):365-371.

5. AMERICAN SOCIETY OF LANDSCAPE ARCHITECTS FOUNDATION (ASLA). 1977. *Landscape planning for energy conservation.* Virginia: Environmental design Press.

6. ASKIN, S. 1986. To them that have, in *New internationalist issue 165 November 1986.* [Online] Available: http://www.newint.org/issue165/update.htm. (Accessed 5 November 2003).

7. BARRY, R. G. 1981. *Mountain weather and climate.* New York: Methuen & Co.

8. BASSON, J. A., Page-Shipp, R. P. & Johnson, M. 1986. *The Garsfontein low-energy experimental housing project: Final report.* Pretoria: National Building Research Institute (NBRI), Council for Scientific and Industrial Research (CSIR).

9. BASSON, M. S. 1997. *Overview of water resources availability and utilization in South Africa.* Pretoria: Department of Water Affairs and Forestry.

10. BOLDES, U., Colman, J. & Marañón Di Leo, J. 2001. Field study of the flow behind single and double row herbaceous windbreaks. *Journal of Wind Engineering and Industrial Aerodynamics*, 89:665-687.

11. BONAN, G. B. 2000. The microclimates of a suburban Colorado (USA) landscape and implications for planning and design. *Landscape and Urban Planning,* 49(3-4):97-114.

12. BROOKER, C. 1998. Environmentally sensitive stormwater management. *Urban Green File,* 3(3):22-23.

13. BROWN, R. D. & Gillespie, T. J. 1995. *Microclimatic landscape design: creating thermal comfort and energy efficiency.* New York: John Wiley & Sons.

14. BRYAN, H. J. 1989. Daylighting, in *Assessment of solar energy technologies.* Edited by D. A. Andrejko, Boulder, Colorado: American Solar Energy Society: 14-16.

15. BYERS, H. R. 1974. *General meteorology.* Fourth edition. New York: McGraw-Hill.

16. CARTER, C. & De Villiers, J. 1987. *Principles of Passive solar building design with microcomputer programs.* New York: Pergamon Press.

17. : CCF-DBS. The Third International Symposium on Cooperative Database Systems for Advanced Applications April 23-24, 2001, Beijing, China. [Online] Available: http://www.ccf-dbs.org.cn/codas01/aboutbeijing.htm. (Accessed 18 May 2004).

18. CLARK, R. N. 1999. Wind energy, in *CIGR handbook of agricultural engineering; Volume 5: Energy and biomass engineering.* Edited by O. Kitani. USA: American Society of Agricultural Engineers (ASAE): P100-123.

19. COOK, J. 1988. Climate making architecture, in *Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988.* Edited by E. de O. Fernandes & S. Yannas, Oxford: Pergamon Press: 35-43

20. COOMBES, P. J. Argue, J. R., & Kuczera, G. 1999. Figtree Place: a case study in water sensitive urban development. *Urban Water,* 1:335-343.

21. CSIR. Sustainability analysis of human settlements in South Africa. [Online] Available: www.csir.co.za/akani/print/2002/nov/print09.html. (Accessed 5 March 2004).

22. DE LA BARRA, T., & Rickaby, P. 1987. A hierarchical land use and transport model for energy evaluation, in *Energy and urban built form.* Edited by D. Hawkes… [*et al*], London: Butterworths: 5-28.

23. DE WRACHIEN, D. & Chisci, G. 1999. Soil conservation: erosion control, in *CIGR handbook of agricultural engineering; Volume 1: land and water engineering.* Edited by H. N. Van Lier. USA: American Society of Agricultural Engineers: P184-212.

24. DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM (a). State of the environment South Africa: Climatic and atmospheric change. Updated November 2000. [Online] Available: http://www.environment.gov.za/. (Accessed 24 August 2003).

25. DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM (b). State of the Environment report of South Africa: Freshwater systems and resources overview. Updated October 1999. [Online] Available: http://www.environment.gov.za/soer/nsoer/issues/water/index.htm. (Accessed 24 August 2003).

26. DEPARTMENT OF MINERALS AND ENERGY (a). Energy efficiency in different sectors. Updated Nov 2002. [Online] Available: http://www.dme.gov.za/home.asp?menu=energy/liquid_fuels.htm. (Accessed 15 July 2003).

27. DEPARTMENT OF MINERALS AND ENERGY (b). Solar water heating. Updated November 2002. [Online] Available: http://www.dme.gov.za/energy/solar_water_heating.htm. (Accessed 15 July 2003).

28. DEPARTMENT OF MINERALS AND ENERGY (c). White Paper on the Energy Policy of the Republic of South Africa 1998. [Online] Available: http://www.gov.za/whitepaper/1998/energywp98.htm. (Accessed 6 August 2003).

29. DEPARTMENT OF MINERALS AND ENERGY. 2000. *Quick reference guide for energy conscious design (report nr. EO9410).* Pretoria.

30. DEPARTMENT OF WATER AFFAIRS AND FORESTRY. White Paper on the Water Policy of South Africa 1997. [Online] Available: http://www.polity.org.za/html/govdocs/white_papers/water.html. (Accessed 5 August 2003).

31. DORWARD, S. 1990. *Design for mountain communities: a landscape and architectural guide.* New York: Van Nostrand Reinhold.

32. ECKBO, G. 1983. Directions for arid-zone urban planning, in *North America, in Design for arid regions.* Edited by G. S. Golany, New York: Van Nostrand Reinhold: 319-327.

33. EDWARDS, B. 2000. Design guidelines for sustainable housing, in *Sustainable housing principles and practice.* Edited by B. Edwards & D. Turrent, New York: E & FN Spon. 124-141.

34. EGAN, M. D. 1975. *Concepts in thermal comfort.* New Jersey: Prentice-Hall.

35. EGGERTSON, B. 2002. Clear intensions? South Africa's transition towards renewable energy. *Refocus,* September/October 2002:42-44.

36. ERLEY, D. & Jaffe, M. 1979. *Site planning for solar access: a guide for residential developers and site planners.* Chicago: American Planning Association.

37. ESKOM (a). Environmental performance: Annual report 2002. [Online] Available: http://www.eskom.co.za/about/Annual Report 2002/Enviro info/Eskom_Final/index.htm. (Accessed 30 July 2003).

38. ESKOM (b). Frequently asked questions. [Online] Available: http://www.eskom.co. za/tools/faq.asp. (Accessed 30 July 2003).

39. EVANS, B. H. 1981. *Daylight in architecture.* New York: McGraw-Hill.

40. FLACH, E. 1981. Human bioclimatology, in *World survey of climatology volume 3: general climatology, 3.* Edited by H. E. Landsberg, Amsterdam: Elsevier: 1-177.

41. FOSTER, S. S. D. 2001. The interdependence of groundwater and urbanisation in rapidly developing cities. *Urban Water,* 3(3):185-192.

42. GARDE, F., Mara, T., Lauret, A. P., Boyer, H., & Celaire, R. 2001. Bringing simulation to implementation: presentation of a global approach in the design of passive solar buildings under humid tropical climates. *Solar Energy,* 71(2):109-120.

43. GEIGER, R. 1969. Topoclimates, in *World survey of climatology volume 2: general climatology, 2.* Edited by H. Flohn, Amsterdam: Elsevier: 105-138.

44. GIBBERD, J. (jgibberd@csir.co.za) 2003. Aspects of urban energy efficiency. E-mail to Bothma, J. (johanbothma@xtracker.co.za) 30 September.

45. GIBBERD, J. 2002. Sustainable Building Assessment Tool: assessing how buildings can support sustainability in developing countries. [Online] Available: http//:www.csir.co.za/akani/2002/nov/gibberd_sandton.pdf. (Accessed 12 September 2003).

46. GOLDING, T. (tony@mepta.pwv.gov.za) 2004. Reply: query on the status of laws governing energy efficiency in South Africa. E-mail to Bothma, J. (johanbothma@xtracker.co.za) 16 January.

47. GOUDIE, A. 1984. *The nature of the environment: an advanced physical geography.* Oxford: Basil Blackwell.

48. GRABOVAC, J. & Dragovic, M. 1988. The influence of planning and architectural design on the efficient exploitation of energy in housing, in *Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988.* Edited by E. de O. Fernandes & S. Yannas, Oxford: Pergamon Press: 637-644.

49. GRESSWELL, R. K. 1979. *Physical geography. Second edition.* London: Longman Group.

50. GUTHRIE, P. 1991. *Desert architecture: climate-responsive design as a means to energy efficient homes and buildings.* Arizona: John Pat Guthrie, Architect.

51. HAWKES, D., McDonald, J. & Steemers, K. 2002. *The selective environment: an approach to environmentally responsive architecture.* New York: Spon Press.

52. HEISLER, G. M. 1984. Planting design for wind control, in *Energy-conserving site design.* Edited by E. G. McPherson, Washington D.C.: American Society of Landscape Architects (ASLA): 165-184.

53. HENDERSON-SELLERS, A. & Robinson, P. J. 1986. *Contemporary climatology.* Essex: Longman Scientific and Technical. Co-published in the USA with John Wiley & Sons.

54. HERRINGTON, L. P. 1984. Climatic variables, in *Energy-conserving site design.* Edited by E. G. McPherson, Washington D.C.: American Society of Landscape Architects (ASLA): 59-78.

55. HILLEL, D. 1978. Water supply systems for an arid-zone city, in *Urban planning for arid zones: American experiences and directions.* Edited by G. Golany, New York: John Wiley and Sons: 161-166.

56. HINRICHS, C. L. 1988. The courtyard housing form as a traditional dwelling in the Mediterranean region, in *Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988.* Edited by E. de O. Fernandes & S. Yannas, Oxford: Pergamon Press: 53-59.

57. HOBBS, J. E. 1980. *Applied climatology.* Kent, Colorado: Dawson Westview Press.

58. HOLM, D. 1983. *Energy conservation in hot climates.* London: Architectural Press.

59. HOLM, D. 1996. *Manual for energy conscious design.* Department of Minerals and Energy; Directorate Energy for Development.

60. HOLM, D. 2001. Renewable energy in Africa. *ESI Africa,* 8(3):42-44.

61. HYDE, R. 2000. *Climate-responsive design.* New York: E & FN Spon.

62. INTERNATIONAL DEVELOPMENT RESEARCH CENTRE (IDRC). Proceedings of a Workshop on Taxonomy and Seed Handling of Australian Tree Species. Qualities required of species for agroforestry and fuelwood. Updated Nov 1998. [Online] Available: http://www.idrc.ca/library/document/074940/chap1_e.html. (Accessed 12 May 2003).

63. INTERNATIONAL SOLAR ENERGY SOCIETY (ISES) /Development Bank of Southern Africa (DBSA). 1999. Renewable energy technologies in Southern Africa: a guide to investors. [Online] Available: http://www.ises.org/ISES.nsf/0/1dc00fec2e880ea8c1256b3a005308b3/PageContent/M3/Investment%252BGuide%252BMAPS.pdf?OpenElement. (Accessed 24 September 2003).

64. JAFFE, M. & Erley, D. 1980. *Residential solar design review: a manual on community architectural controls and solar energy use.* Chicago: American Planning Association.

65. JELLICOE, G. & Jellicoe, S. 1995. *The landscape of man.* London: Thames and Hudson.

66. JEPPESEN, B. 1996. Domestic greywater re-use: Australia's challenge for the future. *Desalination,* 106:311-315.

67. KACHADORIAN, J. 1999. The passive solar concept, in *Ecological design handbook*, Edited by F. A. Stitt, New York: McGraw-Hill: 75-82.

68. KNOWLES, R. L. 2003. The solar envelope: its meaning for energy and buildings. *Energy and Buildings*, 35(1):15-25.

69. KRUGER, A. 2003. (andries@weathersa.co.za) 2003. Reply: Klimaatklassifikasie. E-mail to Bothma, J. (johanbothma@xtracker.co.za) 13 November.

70. LAM, W. M. C. 1986. *Sunlighting as formgiver for architecture.* New York: Van Nostrand Reinhold.

71. LANDSBERG, H. E. 1978. Planning for the climatic realities of arid regions, in *Urban planning for arid zones: American experiences and directions.* Edited by G. Golany, New York: John Wiley and Sons: 23-37.

72. LEBENS, R. M. 1980. *Passive solar heating design.* London: Applied Science Publishers.

73. LOMBARD, C., Mathews, E. H. & Kleingeld, M. 1999. Demand-side management through thermal efficiency in South African houses. *Energy and Buildings*, 29:229-239.

74. MARKUS, T. A. & Morris, E. N. 1980. *Buildings, climate and energy.* London: Pitman Publishing.

75. MART'IN DE SANTA OLLALA, F., Fabeiro Cort'es, C., Brasa Ramos, A. & Legorburo Serra, A. 1999. Irrigation scheduling techniques, in *CIGR handbook of agricultural engineering; Volume 1: land and water engineering.* Edited by H. N. Van Lier. USA: American Society of Agricultural Engineers: P284-297.

76. MATTHEWS, L. 1987. A method for determining energy flows in urban built form, in *Energy and urban built form.* Edited by D. Hawkes… [*et al*], London: Butterworths: 29-42.

77. MAZRIA, E. 1979. *The passive solar energy book.* Expanded professional edition. Emmaus: Rodale Press.

78. McFADDEN, P. & Andrejko, D. A. 1989. Passive heating, in *Assessment of solar energy technologies.* Edited by D. A. Andrejko, Boulder: American Solar Energy Society (ASES): 9-11.

79. MCPHERSON, E. G. 1984a. Precision planting for solar control and solar access (Appendix C), in *Energy-conserving site design.* Edited by E. G. McPherson, Washington D.C.: American Society of Landscape Architects (ASLA): 281-290.

80. MCPHERSON, E. G. 1984b. Solar control planting design, in *Energy-conserving site design.* Edited by E. G. McPherson, Washington D.C.: American Society of Landscape Architects (ASLA): 141-164.

81. MEYER, J. P. & Tshimankinda, M. 1998. Domestic hot water consumption in South African townhouses. *Energy Conversion & Management*, 39(7):679-684.

82. MEYER, J. P. [S.a.] Domestic hot-water consumption in different types of dwellings in Johannesburg for developed and developing communities. [Online] Available: http://www.ctech.ac.za/conf/due/SOURCE/Web/Meyer/meyer.htm. (Accessed 22 September 2003).

83. MICHELS, T. 1979. *Solar energy utilization.* New York: Van Nostrand Reinhold.

84. MIDRAND ECOCITY WEBSITE. [Online] Available: http://www.ecocity.org.za/. (Accessed 5 August 2003).

85. MOLLISON, B. & Holmgren, D. 1990. *Permaculture one: a perennial agriculture for human settlements.* Tyalgum, New South Wales: Tagari Publications.

86. MORROW, R. 1993. *Earth user's guide to permaculture.* Kenthurst, New South Wales: Kangaroo Press.

87. MOUTON, J. 2001. *How to succeed in your Master's & Doctoral studies.* Pretoria: Van Schaik Publishers.

88. MURAKAMI, S. 2002. CASBEE: Comprehensive Assessment System for Building Environmental Efficiency [Online] Available: http://www.iijnet.or.jp/ibec/CASBEE/CASBEE_Ever1/. (Accessed 05 November 2003).

89. NAHAR, N. M., Sharma, P. & Purohit, M. M. 1999. Studies on solar passive cooling techniques for arid areas. *Energy Conversion & Management*, 40:89-95.

90. NAHAR, N. M., Sharma, P. & Purohit, M. M. 2003. Performance of different passive techniques for cooling of buildings in arid regions. *Building and Environment,* 38:109-116.

91. NAPIER, A. 2000. *Enviro-friendly methods in small building design for South Africa.* First edition. Durban.

92. NEETHLING, A. J. 1978. *Sonenergie en Suid-Afrika: 'n verslag vir 'n hulpkomitee van die Energiebeleidskomitee.* Pretoria: Departement van Beplanning en die Omgewing.

93. NEL, M. 2002. Tackling water demand management, conservation and development, in Business & sustainable development: Johannesburg World Summit on Sustainable Development special edition: *Sustainable Development International/Urban Green File*: 181-183.

94. NEL, P. 2003. Private conversation on 28 November 2003, Pretoria, about climate amelioration techniques in the South African suburban context. ####

95. NELMES, S., Belcher, R. E. & Wood, C. J. 2001. A method for routine characterization of shelterbelts. *Agricultural and Forest Meteorology*, 106:303-315.

96. NIEMCZYNOWICZ, J. 1999. Urban hydrology and water management - present and future challenges. *Urban Water*, 1:1-14.

97. OLGYAY, V. 1963. *Design with climate.* New Jersey: Princeton University Press.

98. OLIVER, J. E. 1973. *Climate and man's environment: an introduction to applied climatology.* New York: John Wiley and Sons.

99. ONMURA, S., Matsumoto, M. & Hokoi, S. 2001. Study on evaporative cooling effect of roof lawn gardens. *Energy and Buildings,* 33:653-666.

100.OWENS, S. 1986. *Energy, planning and urban form.* London: Pion Limited.

101.OWENS, S. 1987. The urban future: does energy really matter?, in *Energy and urban built form.* Edited by D. Hawkes… [*et al*], London: Butterworths: 169-186.

102.PHILLIPS, A. 2003. A good soaking: an introduction to water harvesting in the Southwest. *Landscape architecture,* 93(8):44-53,98.

103.POKORNÝ, J. 2001. Dissipation of solar energy in landscape – controlled by management of water and vegetation. *Renewable Energy*, 24(3-4):641-645.

104.PRESTON-WHYTE, R. A. & Tyson, P.D. 1995. *The atmosphere and weather of Southern Africa.* Cape Town: Oxford University Press.

105.PROCOS, D. 1988. Does street orientation have an effect on passive solar heating?, in *Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988.* Edited by E. de O. Fernandes & S. Yannas, Oxford: Pergamon Press: 121-125.

106.RADOVIC, D. 1988. Energy conservation in urban planning, in *Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988.* Edited by E. de O. Fernandes & S. Yannas, Oxford: Pergamon Press: 371-374.

107.RAEISSI, S. & Taheri, M. 1999. Energy saving by proper tree plantation. *Building and Environment*, 34:565-570.

108.RAEISSI, S. & Taheri, M. 2000. Skytherm: an approach to year-round thermal energy sufficient houses. *Renewable Energy*, 19:527-543.

109.RAND WATER. Water wise gardening. [Online] Available: http://www.randwater .co.za/Home_and_Garden/Water_Wise_Gardening.asp. (Accessed 12 September 2003).

110.READ, R. A. 1964. Tree windbreaks for the central plains. *U.S. Forest Service Agriculture Handbook,* No. 250.

111.RICHARDS, S. J. 1981. *Solar charts for the design of sunlight and shade for buildings in South Africa.* Pretoria: NBRI, CSIR.

112.ROBINETTE, G. O. 1983a. *Energy efficient site design.* New York: Van Nostrand Reinhold.

113.ROBINETTE, G. O. 1983b. *Landscape planning for energy conservation.* New York: Van Nostrand Reinhold.

114.ROBINETTE, G. O. 1984. *Water conservation in landscape design and management.* New York: Van Nostrand Reinhold.

115.SCHEER, H. 1994. *A solar manifesto.* English edition. London: James & James Science Publishers.

116.SCHULZE, B. R. 1965. *Climate of South Africa: part 8: general survey, WB28.* Pretoria: Government Printer.

117.SCHULZE, R. E. 1997. *South African atlas of agrohydrology and-climatology.* Water Research Commission, Pretoria, report tt82/96.

118.SCHWARTZ, R. C., Fryrear, D. W., Harris, B. L., Bilbro, J. D. & Juo, A. S. R. 1995. Mean flow and shear stress distributions as influenced by shelterbelt structure. *Agricultural and Forest Meteorology,* 75:1-22.

119.SERRA, R. 1988. Climate and complexity in architecture, in *Energy and buildings for temperate climates: a Mediterranean approach. Proceedings of the sixth international PLEA conference Porto, Portugal, 27-31 July 1988.* Edited by E. de O. Fernandes & S. Yannas, Oxford: Pergamon Press: 3-7.

120.SHARIAH, A., Shalabi, B., Rousan, A. & Tashtoush, B. 1998. Effects of absorbtance of external surfaces on heating and cooling loads of residential buildings in Jordan. *Energy Conversion & Management,* 39(3-4):273-284.

121.SHASHUA-BAR, L. & Hoffman, M. E. 2003. Geometry and orientation aspects in passive cooling of canyon streets with trees. *Energy and Buildings,* 35:61-68.

122.SHEINKOPF, K. G. 1989. Passive cooling, in *Assessment of solar energy technologies.* Edited by D. A. Andrejko, Boulder, Colorado: American Solar Energy Society: 11-14.

123.SHELDRICK, B., & Cooper, I. 1987. Intermediate scale energy initiatives in Britain: Exemplary projects, not strategic planning, in *Energy and urban built form.* Edited by D. Hawkes… [et al], London: Butterworths: 187-218.

124.SHERMAN, R. 2001. Strategy for renewable energy in South Africa (consensus draft). [Online] Available: http://www.sessa.org.za/restrategy2203200.pdf. (Accessed 24 September 2003).

125.SLAYMAKER, O. & Spencer, T. 1998. *Physical geography and global environmental change.* New York: Addison Wesley Longman.

126.SOHAR, E. 1979. Man in the desert, in *Arid zone settlement planning-the Israeli experience.* Edited by G. S. Golany, New York: Pergamon Press: 477-518.

127.SOUTH AFRICAN CONSULATE GENERAL IN NEW YORK. 2001. Mining, Minerals and Energy. [Online] Available: http://www.southafrica-newyork.net/consulate/ mining.htm. (Accessed 24 September 2003).

128.SUTAINABLE ENERGY AFRICA (SEA) WEBSITE. What is urban SEED? Updated June 2003. [Online] Available: http://www.sustainable.org.za/Whatisseed.htm. (Accessed 5 August 2003).

129.TARJUELO, J. M. & De Juan, J. A. 1999. Crop water management, in *CIGR handbook of agricultural engineering; Volume 1: land and water engineering.* Edited by H. N. Van Lier. USA: American Society of Agricultural Engineers: P380-429.

130.THAYER JR., R. L. & Richman, T. 1984. Water-conserving landscape design, in *Energy conserving site design.* Edited by E. G. McPherson, Washington D.C.: American Society of Landscape Architects (ASLA): 185-214.

131.THAYER JR., R. L. 1984. Planting for solar access, in *Energy conserving site design.* Edited by E. G. McPherson, Washington D.C.: American Society of Landscape Architects (ASLA): 115-139.

132. THE DURBAN SELF-HELP HOUSING PROJECT WEBSITE. [Online] Available: http://www.selfhelphousing.org.za/. (Accessed 5 August 2003).

133. THE SUSTAINABLE HOMES INITIATIVE WEBSITE. [Online] Available: http://www.sustainablehomes.org/. (Accessed 5 August 2003).

134. THOMPSON, J. W. & Sorvig, K. 2000. *Sustainable landscape construction.* Washington, D.C: Island Press.

135. TOTAL ENVIRONMENT CENTRE. 1982. *Solar access in New South Wales: technical report*. Sydney.

136. TYSON, P. D. & Preston-Whyte, R. A. 2000. *The weather and climate of Southern Africa.* Second edition. Cape town: Oxford University Press South Africa.

137. UNITED NATIONS (a) Development Programme. Energy Priorities. [Online] Available: http://www.undp.org/seed/eap/html/priorities.htm. (Accessed 1 September 2003).

138. UNITIED NATIONS (b) Johannesburg Summit 2002 Brochure. [Online] Available: http://www.johannesburgsummit.org/html/basic_info/basicinfo.html (Accessed 1 September 2003).

139. UNITED NATIONS (c) Millennium Development Goals. [Online] Available: http://www.un.org/millenniumgoals/index.html. (Accessed 1 September 2003).

140. VAN HOREN, C. & Simmonds, G. 1998. Energy efficiency and social equity in South Africa: seeking convergence. *Energy Policy*, 26(11):893-903.

141. VAN WAMELEN, J., Higgs, F. S. & Page-Shipp, R. J. 1986. *Passive solar energy research – the South African scene. Paper presented at the International Symposium: Passive solar techniques for energy conservation in buildings.* Pretoria: National Building Research Institute (NBRI), Council for Scientific and Industrial Research (CSIR).

142. WANG, H. & Klaassen, W. 1995. The surface layer above a landscape with a rectangular windbreak pattern. *Agricultural and Forest Meteorology*, 72:195-211.

143. WANG, H. & Takle, E. S. 1996. On shelter efficiency of shelterbelts in oblique wind. *Agricultural and Forest Meteorology,* 81:95-117.

144. WARD, S. 2002. *The energy book for urban development in South Africa.* Noordhoek: Sustainable Energy Africa (SEA).

145. WATERFALL, P. H. [S.a.] Harvesting rainwater for landscape use [Online] Available: http://www.ag.arizona.edu/pubs/water/az1052/harvest.html. (Accessed 11 September 2003).

146. WEATHER BUREAU, DEPARTMENT OF ENVIRONMENTAL AFFAIRS. 1987. *Meteorological observations and instruments.* Pretoria: Government Printer.

147. WONG, N. H., Cheong, D. K. W., Yan, H., Soh, J., Ong, C. L. & Sia, A. 2003. The effects of rooftop garden on energy consumption of a commercial building in Singapore. *Energy and Buildings,* 35(4):353-364.

148. WORLD HEALTH ORGANISATION. Domestic water quantity, service level and health. [Online] Available: http://www.who.int/water_sanitation_health/diseases/wsh0302/en/. (Accessed 1 September 2003).

149. YELLOT, J. I. & Aiello, D.1978. The arid West and human responses to it, in *Urban planning for arid zones: American experiences and directions.* Edited by G. Golany, New York: John Wiley and Sons: 68-74.

150. ZANETTO, J. 1984. Master planning, in *Energy conserving site design.* Edited by E. G. McPherson, Washington D.C.: American Society of Landscape Architects (ASLA): 87-114.

# SUGGESTED READING

1. BROWN, R. D. & Gillespie, T. J. 1995. *Microclimatic landscape design: creating thermal comfort and energy efficiency.* New York: John Wiley & Sons.

2. ERLEY, D. & Jaffe, M. 1979. *Site planning for solar access: a guide for residential developers and site planners.* Chicago: American Planning Association.

3. EVANS, B. H. 1981. *Daylight in architecture.* New York: McGraw-Hill.

4. HOLM, D. 1983. *Energy conservation in hot climates.* London: Architectural Press.

5. HOLM, D. 1996. *Manual for energy conscious design.* Department of Minerals and Energy; Directorate Energy for Development.

6. MAZRIA, E. 1979. *The passive solar energy book.* Expanded professional edition. Emmaus: Rodale Press.

7. McPHERSON, E. G. (Editor). 1984. *Energy-conserving site design.* Washington, D. C.: American Society of Landscape Architects (ASLA).

8. MOLLISON, B. & Holmgren, D. 1990. *Permaculture one: a perennial agriculture for human settlements.* Tyalgum, New South Wales: Tagari Publications.

9. MORROW, R. 1993. *Earth user's guide to permaculture.* Kenthurst, New South Wales: Kangaroo Press.

10. NAPIER, A. 2000. *Enviro-friendly methods in small building design for South Africa.* First edition. Durban.

11. OLGYAY, V. 1963. *Design with climate.* New Jersey: Princeton University Press.

12. PRESTON-WHYTE, R. A. & Tyson, P.D. 1995. *The atmosphere and weather of Southern Africa.* Cape Town: Oxford University Press.

13. ROBINETTE, G. O. 1983a. *Energy efficient site design.* New York: Van Nostrand Reinhold.

14. ROBINETTE, G. O. 1983b. *Landscape planning for energy conservation.* New York: Van Nostrand Reinhold.

15. ROBINETTE, G. O. 1984. *Water conservation in landscape design and management.* New York: Van Nostrand Reinhold.

16. TYSON, P. D. & Preston-Whyte, R. A. 2000. *The weather and climate of Southern Africa.* Second edition. Cape town: Oxford University Press South Africa.

17. WARD, S. 2002. *The energy book for urban development in South Africa.* Noordhoek: Sustainable Energy Africa (SEA).

# APPENDIX A: GEO-CLIMATIC CLASSIFICATION OF SOUTHERN AFRICA, SUMMARISED FROM SCHULZE 1965:313-322

**Region M or Mediterranean**

Rainfall: Mainly during May to September. Orographic and cyclonic in nature. Influenced by orographic features. 250mm in Breede River valley, 400-500mm on Cape Flats, 3000mm in some mountain kloofs.

Temperatures: Average maximums January 28°C, July 17°C; average minimum January 15°C, July 6°C.

Humidity: Average monthly humidity is 54% and is partly above the comfort zone in the winter and to a lesser degree in the summer.

Frost/snow: Average five occasions per year, usually in winter and early spring.

Winds: Summer winds mostly from southeast. Winter winds from northwest and bring rain. Winds are often strong to gale force.

Sunshine: 70% of possible in January, 60% of possible in July.

Notes: Climate similar to Mediterranean regions.

**Region A or Garden Route**

Rainfall: Receives rain throughout the year, although slightly more in autumn and spring. Orographic and cyclonic in nature. Thunderstorms and hail are infrequent. 1100mm at some coastal locations, 400mm on plains south of Riversdale.

Temperatures: Average maximums January 26°C, July 19°C; average minimums January 15°C, July 7°C.

Humidity: The average monthly humidity is high at 72%. Winter humidity is partly above comfortable but summer excess humidity is significant.

Frost/snow: Frost rare, snow on one to two occasions per year in the Langeberg and Outeniqua Mountains.

Winds: Can be strong along the coast in the spring, and in the interior berg/fohn winds blow one to three times per month in the summer increasing temperatures to around 38°C.

Sunshine: Average of 50% of the possible throughout the year.

Notes: Many prominent topographical features, beaches and great variety of plant types.

**Region K or the Little and Great Karoo**

Rainfall: Fairly evenly distributed throughout the year but with a double maximum common in March and November. Rain is almost always due to thunderstorms. Hail is infrequent. 250mm throughout most of reaches except some mountain areas receive up to 750mm.

Temperatures: Very large diurnal and annual variations in temperature are characteristic. Average maximums January 32°C, July 18°C; average minimums January 15°C, July 5°C. Temperatures of up to 44°C are not uncommon in the summer, and are caused by hot winds that blow off the high plateau.

Humidity: The average monthly humidity is around 68% and is usually within the comfort zone.

Frost/snow: Frost occurs from June to August but this period can be longer in extreme years. Snow occurs on the higher mountain reaches on about five occasions a year.

Winds: Winds are not strong but can cause temperatures to rise dramatically in the summer.

Sunshine: Around 70% of the possible.

Notes: Diurnal temperatures can range with 28°C or more, and despite the high summer temperatures winter nights can be chilly to cold.

**Region W and SWAs or desert and poor steppe**

Rainfall: Rainfall is unreliable and amounts to 250mm in the interior and decreases towards the west coast to 50mm or less. In the interior precipitation is in the summer and mainly in the form of conventional showers. Near the coast the rainfall is in the winter, sometimes the annual total falls in one heavy shower. Hail is uncommon in this region.

Temperatures: Temperatures are subject to great diurnal and seasonal variations. Average maximums January 35°C, July 18°C; average minimums January 17°C, July 3°C.

Humidity: Humidity is very low and usually below comfort index.

Frost/snow: Snow occurs around five times a year in the south near Sutherland but rapidly decreases to the north and west.

Winds: Dust storms similar to the "haboob" of Sudan sometimes occur in the Kalahari and hot easterly winds blow along the coastal belt during winter.

Sunshine: 80% or more of the possible throughout the year.

Notes: The west coast is often foggy due to the influence of the cold Benguela current. The highest temperatures in the country have been recorded in this region, with summer maxima of 46. Yet some of the coldest minimum temperatures in the country have also been recorded in this region near Sutherland.

**Region Ss and Sn or southern and northern steppe**

Rainfall: This region is on average semi-arid and receives from 250mm in the west to 500mm in the eastern reaches. Rain is in showers from October to March, the peak of which being near the end. Sometimes hail occurs in the early summer on a localised scale.

Temperatures: Average maximums January 30-33°C, July 17°C; average minimums January 15, °C July 0°C. Temperature ranges are slightly larger in the southern steppe region.

Humidity: The humidity of the southern steppe is around 55%, which is fair and within human comfort throughout the year. The northern steppe is only slightly dryer at 53%.

Frost/snow: Frost can be expected from May to September. Snow falls on around 5 occasions in the mountains of the southern region, notably the Snow, Winter- and Stormberg mountains.

Winds: They are usually north westerly with maximum speeds in the afternoon. During thunderstorms gusty south westerly winds are common. Dust storms also occur, although they are infrequent.

Sunshine: 70-80% of the possible, throughout the year.

Notes: Minimums of –11°C are possible in higher parts of the region.

**Region SE or the south eastern coastal region**

Rainfall: This region has a definite summer rainy season, which is at a maximum in March. Rain is usually of a showery nature and thunderstorms are relatively frequent. Hail is more frequent in the interior. The minimum rain fails in June. Rainfall varies from 500mm in the Fish River valley to 1250mm or more at Port St. Johns.

Temperatures: Average maximums January 28°C, July 21°C; average minimums January 17°C, July 8°C.

Humidity: Average humidity is 70% and is high throughout the year but due to the temperature range this is usually not problematic.

Frost/snow: The frost period is only about one and a half months long, during July and August.

Winds: The winds are usually parallel to the coast, northeasterly and southwesterly. The former brings cloudless hazy skies and the latter is associated with cloudy weather and rain. Occasional gale force winds occur and on occasion during the late winter berg winds do occur.

Sunshine: During the winter the skies are clear about 70% of the time and in the summer around 50% of the time.

**Region E or warm to hot and humid subtropical climate**

Rainfall: The rainy period is usually in the summer from October to March with 120 to 140 rain days per year. The rain is usually due to instability showers with thunder on 40 to 50 occasions a year. The average varies from around 760mm in the northern interior to 1250mm on parts of the coast and the interior mountains.

Temperatures: Average maximums January 28°C, July 22°C; average minimums January 19°C, July 9°C.

Humidity: The average monthly humidity is 70% and in this region are problematic during the summer due to the high temperatures.

Frost/snow: frost only rarely occurs in some mountain valleys.

Winds: Northeasterly winds in the summer and southwesterly winds in the winter blow in equal proportions. The former is responsible for severely hot conditions and on rare occasions hot westerly winds blowing down from the mountains increase the temperature to around 38.

Sunshine: Summer cloudiness reduces the amount of sunshine to around 45% but during the winter it is around 70%.

Notes: This region has the smallest annual and diurnal temperature fluctuations and is one of the most humid in the country.

**Region D or Drakensberg region**

Rainfall: Most rain falls in the summer from November to March. Rainfall is mostly due to intense thunderstorms (60 to 90 a year) but mist and drizzle are common in the higher areas. The average annual amount varies from 680mm in the Tugela basin to 1900mm on some of the slopes of the mountains. Hail occurs around 6 times a year.

Temperatures: Average maximums January 27°C, July 19°C; average minimums January 15°C, July 3°C.

Humidity: The average humidity is seldom below 50%, and can be above comfort levels.

Frost/snow: The frost period is largely determined by the topography and can be from April to September. Snow is more frequent in the mountains than anywhere else in the country, around eight occasions a year.

Winds: Winds are southerly to northerly and northwesterly, the latter often being very strong.

Sunshine: This aspect varies from 50 to 60% in the summer and 70 to 80% in the winter.

Notes: This region has a climate similar to S and Se except that temperatures fluctuate more. It is the highest region in southern Africa.

**Region L or Transvaal Lowveld**

Rainfall: The rainy season lasts from November to March with a peak in January. Heavy thunderstorms and showers are most common. Against the mountains orographic rain and mist is more frequent. Amounts vary from 500mm to 700mm from north to south, but with a rapid increase along the escarpment to up to 2000mm a year. Hail only occurs about two times a year.

Temperatures: Average maximums January 30°C, July 23°C; average minimums January 18°C, July 8°C.

Humidity: The average monthly humidity is 47%, but summer humidity is high and sometimes uncomfortable, and below comfort in the winter.

Frost/snow: Frost is seldom experienced, usually in low-lying areas.

Winds: Winds are mainly from the south-southeast or north-northwest and sometimes reaches gale force along the mountains.

Sunshine: During the winter sunshine persists for around 75% of the possible time and in summer 50%.

Notes: The high temperatures and high general humidity can make this region oppressive at times, non the less it is one of the most popular tourist destinations in the country. Up to 300mm of rain in one day have been recorded in some parts of the region.

**Region NT or the Northern Transvaal**

Rainfall: Thunderstorms account for most of the rainfall, which varies from 380mm in the north to 700mm on parts of the Waterberg. The rainy season lasts from November to March. Rain is unreliable in this region and hail infrequent.

Temperatures: The climate is semi-arid and hot in the Limpopo valley but somewhat cooler and more humid in the mountainous areas. Average maximums January 32°C, July 22°C; average minimums January 18°C, July 4°C.

Humidity: The average monthly humidity is 59% and is not considered problematic throughout the year.

Frost/snow: Frost normally occurs from around June to August.

Winds: These are usually light to moderate and blow from the northeast except during weather changes or thunderstorms when they blow from the south.

Sunshine: This varies from 80% in the winter to 60% in the summer.

Notes: Summer days can be oppressive and some winter nights are decidedly chilly.

**Region SWAn and B**

Rainfall: rainfall is almost exclusively due to thunderstorms but hail is infrequent. Averages vary from 250mm to 600mm in the north. The rainy season is from around November to March.

Temperatures: Average maximums January 33°C, July 22°C; average minimums January 18°C, July 5°C. Low minimum temperatures of around –9°C can occur in the lower lying south of the region.

Humidity: The average humidity for this region is low, around 38%, and is below comfort for large periods of the year.

Frost/snow: The frost period is usually during June to August but decreases northward.

Winds: Winds are mainly light to moderate and from the northeastern sector.

Sunshine: Winter skies are almost cloudless with 90% of he possible sunshine and summers vary from 65 to 80%, cloudier conditions more common to the north.

Notes: The climate of the region is a composite of that of the three adjoining ones with an increase in humidity to the north.

**Region H or the Highveld**

Rainfall: Most of the rain is due to heavy thunderstorms that are accompanied by fierce lightning. Hail occurs around four to seven times a year. Amounts vary from 900mm in the east to 650mm in the west.

Temperatures: Average maximums January 27°C, July 17°C; average minimums January 13°C, July 0°C.

Humidity: The average monthly humidity is 56% and can be quite low during the winter.

Frost/snow: Frost can be expected from May to September in the northern parts of the region and for even longer periods in Lesotho.

Winds: On average winds are light but quite variable from location to location.

Sunshine: Sunshine is about 60% of the possible in summer and 80% in the winter.

Notes: Hail is most frequent in this zone, occasionally reaching the size of chicken eggs or tennis balls. They cause severe damage, as do the very rare tornadoes if they reach populated regions.

# APPENDIX B: CLIMATIC CLASSIFICATION OF SOUTH AFRICA ACCORDING TO NAPIER (2000:9.1-9.11)

**Sub-tropical plateau**

Summer rainfall: 62mm in the west of the region to 375mm in the east.

Winter rainfall: Less than 62mm in the west to 125mm in the east.

Summer temperatures: 15ºC in the west of the region to 27ºC in the east.

Winter temperatures: 7ºC in the west to 12ºC in the east.

Prevailing winds: South in the summer and northeast in the winter.

Relative humidity: Less than 30%

Hours sunshine: More than 80%

General comment: Vegetation is sparse, with desert grasses and shrubs growing on sandy and stony surfaces. Conditions are very hot in summer, and in winter, cold at night especially at higher altitudes. Comparatively dry all year round, with greater precipitation in summer.

**Desert**

Summer rainfall: Less than 62mm.

Winter rainfall: Less than 62mm in the north to 250mm in the south.

January temperatures: 15ºC at the coast to 25ºC in the east.

July temperatures: Less than 7ºC to 10ºC.

Prevailing winds: South in the summer and north in the winter.

Relative humidity: Less than 30% inland to more than 70% at the coast.

Hours sunshine: 70-80%

General comment: With a cold sea current land adjacent is affected in temperature and humidity, with dramatic changes at high altitudes. Desert to semi-desert generates very high summer temperatures and in winter, cold night time readings. The high humidity at the cost is not uncomfortable because of lower temperatures from the sea. Fog patches are frequent.

**Mediterranean**

Summer rainfall: 62mm to 250mm in the south.

Winter rainfall: 250mm to more than 750mm at the Peninsula.

January temperatures: 20ºC to 23ºC.

July temperatures: 7ºC to 10ºC.

Prevailing winds: South to southeast in the summer and west to northwest in the winter.

Relative humidity: 50% inland to more than 70% at the coast.

Hours sunshine: Less than 60%in south to 80% in the north.

General comment: This zone is noted for its variety of fynbos and evergreen shrub. Winter rainfall gives the name "Mediterranean" and winds, especially from the southeast can be very strong, commonly reaching gale force. Prolonged cold wet spells mark the winter while hot persistent sun dominates the summer months.

**Semi-arid plateau**

Summer rainfall: 62mm in the East to 500mm in the west.

Winter rainfall: Less than 62mm in (East?) to 250mm in the west.

January temperatures: 20ºC in South to 27ºC in north.

July temperatures: Less than 7ºC in the central plateau to 12ºC in south and north.

Prevailing winds: North and south in the summer and northwest in the winter.

Relative humidity: Less than 30% in north to 50% in the south.

Hours sunshine: 60% in south to more than 80% in the north.

General comment: This region envelops most of the Little and Great Karroo and the sparse vegetation is mostly scrub and grass. Rainfall is low, with the greater proportion falling in the summer. Summer temperatures climb high during the days, and in the winter, nights are cold to very cold. Summer windstorms drive dust, being lifted by whirlwinds.

**Temperate coast**

Summer rainfall: 250mm to 500mm.

Winter rainfall: 250mm to 750mm at the coast.

January temperatures: 20ºC to 23ºC.

July temperatures: 12ºC to 17ºC.

Prevailing winds: south to west in the summer and west and east in the winter.

Relative humidity: 60% to more than 70%.

Hours sunshine: 60-80% inland.

General comment: This narrow strip is distinctive in having a year round rainfall. Vegetation is therefore profuse, with dense indigenous forest under preservation. The area is in close proximity to the Karoo and the climates are in strong contrast because of the dividing mountain ranges as related to wind directions. While relative humidity is high, temperatures are moderate (because of latitude and a moderating ocean) and comfort standards are not unpleasant.

**Temperate eastern plateau**

Summer rainfall: 125mm to 375mm.

Winter rainfall: 62mm to 250mm.

January temperatures: 20ºC to 25ºC.

July temperatures: 10ºC to 15ºC.

Prevailing winds: Northeasterly in the summer and northeasterly to northwesterly in the winter.

Relative humidity: 30-50% in the east.

Hours sunshine: 60-80% in west.

General comment: The Highveld is predominantly grassland with scattered trees in the wetter parts. Summers are warm to hot, with fairly dry air, relieved by thunderstorms generated from thermal air movement. Hail is not uncommon. Winter days are pleasantly sunny with clear cold to very cold nights. The Eastern portion of this region comprises the Drakensberg, which generate their own climatic patterns dependant upon the topography of the particular location. Differences from the rest of the region are mainly colder winter temperatures bringing occasional snow, hail and more pronounced thunderstorms.

**Plateau slopes**

Summer rainfall: 750mm to more than 1000mm.

Winter rainfall: 250mm to 375mm.

January temperatures: 20ºC to 25ºC.

July temperatures: 7ºC to 12ºC at lower altitudes.

Prevailing winds: South-Easterly in summer and South-West in the winter.

Relative humidity: 50% to 60%.

Hours sunshine: Less than 60%.

General comment: The foothills of the Drakensberg benefit from generous orographic rain brought from the warm Indian Ocean, resulting in rich grassland with trees in isolated patches. High rainfall gives longer protection from sun, but summer days are often warm to hot, relieved by thunderstorms as well as more prolonged rain spells, the former bringing hail periodically. Winter days are pleasant with nights cold to very cold.

**Subtropical coast**

Summer rainfall: 750mm to more than 1000mm.

Winter rainfall: 375mm to 750mm.

January temperatures: 20ºC to 25ºC.

July temperatures: 15ºC to 20ºC.

Prevailing winds: South to southwest and northeast.

Relative humidity: More than 70%.

Hours sunshine: Less than 60%.

General comment: This coastal strip is noted for its combination of medium to high summer temperatures with high relative humidity, resulting in very uncomfortable conditions. The Southern part of the region is relieved, with more frequent winds and lower temperatures. Winters are pleasantly warm, with nights cool but seldom cold. Summer nights are warm and humid, and the days, a challenge to architectural designers. Vegetation is mainly grass with subtropical bush land in patches, resulting from high rainfall. The nature of rain for the earlier part of the season is three or four consecutive days of moderate to mild precipitation, and the latter part, thunderstorms.

**Subtropical low veld.**

Summer rainfall: 750mm to 1000mm.

Winter rainfall: 500mm to more than 750mm.

January temperatures: 25ºC to 27ºC.

July temperatures: 15ºC to 20ºC in the north.

Prevailing winds: Easterly.

Relative humidity: More than 70%.

Hours sunshine: Less than 60%.

General comment: the description for this region is as that above, with more exaggerated temperatures and humidity but lower rainfall. Without mountains creating a boundary (as in the previous region), a large sector of low-lying land has lush vegetation, but with high humidity, shade provides little respite.

# APPENDIX C: URBAN AND BUILDING RESPONSES TO GEO-CLIMATIC ZONES OF SOUTHERN AFRICA AS CLASSIFIED BY SCHULZE (1965), SUMMARISED FROM HOLM 1996:14-78

**Mediterranean zone**

Compact urban planning is useful for protection against strong prevailing winds (p14). Buildings should be orientated with longest side facing north/south creating an oblong plan form and should shield against summer living areas from southeasterly wind. Inhabited rooms should face north. Thermal mass is effective for approximately half the winter and is advantageous in summer, and should be concentrated in walls and floors. Cavity walls enhance thermal mass and provide damp protection (15). Summer sun should be screened and winter sun should penetrate. Single glazed equatorial windows should be 21% of the rooms serviced, reduced to 14% for double glazing. Natural ventilation is efficient for cooling (16), and direct evaporative cooling is sufficient for additional cooling where necessary (17).

**Garden route**

Compact urban planning with protection of outdoor living areas from winds from southeast and southwest. Oblong north-south building plan is preferred and inhabited rooms facing north (19). Thermal mass is effective for approximately half the winter and advantageous in the summer, concentrated in the walls and floor. Ample roof overhang and medium internal thermal mass is required. Summer sun should be screened and winter sun should penetrate, with equatorial windows 18% of floor area of rooms serviced (20). Natural breezes and ventilation should be sufficient to prevent overheating and may be aided by indirect evaporative cooling (21).

**Semi-arid Karoo**

Urban planning should be densely packed with mutual shading of buildings during summer. Streets to the shaded side of buildings should have deciduous trees. Evaporative cooling is important. Building plan should be as compact as possible with minimal exposed areas (24). Plan form should be such that living spaces are on the north, to take advantage of winter solar gain, with shading in summer. Buffer spaces such as storage or garages should be placed on the east and west of the building. Large amounts of internal thermal mass are required to reduce diurnal temperature swings and massive external insulation should be provided. Dense concrete, brick and water are ideal insulation materials. Summer sun should be screened and winter sun should penetrate (25). 17% equatorial window to floor size is sufficient (26).

**Desert steppe**

Same as previous urban layout (compact etc) with large spreading trees. Typical plans are centred around a courtyard with small openings in exterior walls. External dimensions should be reduced with larger dimensions facing north and south (29). Inhabited rooms should face the courtyard with buffer rooms on the outside. Large thermal mass for interior and exterior surfaces is needed which alleviates half of the winter heating load and most of summer cooling load if combined with night ventilation. All surfaces should be lightly coloured, summer sun screened and winter sun allowed to penetrate (30). Shading of all exterior areas in summer is advised, with materials that have low thermal capacity. Equatorial glazing of 22% of floor area is sufficient for entire underheated period. Night ventilation is essential but ventilation during the day will have no positive effect! Openings should be closed during day in summer (31) and direct evaporative cooling is effective for half of overheated period. Indirect evaporative cooling is effective for entire period, and courtyard can be used for this purpose.

**Northern steppe**

Urban planning is of medium density with many shade trees in open spaces (34). Relatively compact plan forms are successful, with a well-insulated envelope and ground contact. External spaces should provide shade; deep verandas and pergolas are effective. Thermal mass in the form of massive floors and roofs and internal partitions can achieve this. Exterior surfaces should be light coloured (35). 21% of equatorial surfaces should be glazed, orientated towards the winter sun and shaded in the summer. Shade devices should have low thermal capacity. Night ventilation is effective throughout the over heated period if combined with thermal mass. Stack ventilation or wind is effective for summer daytime cooling (36) and direct and indirect evaporative cooling is effective.

**Southern steppe**

Difficult to determine planning densities, due to contradictory requirements. Winter demands require a compact plan form with a well-insulated envelope and solar gain (39). External spaces should provide shade in summer for outdoor activities. Massive floors and internal partitions can aid in the reduction of diurnal temperature fluctuations. Exterior vegetation cover of deciduous plants is advised (40). Windows should be exposed for the winter sun and shaded during the summer and equatorial windows can provide most of the heat needed in the winter (41). Direct evaporative cooling is effective throughout the summer (42).

**Southeastern coast**

A loosely knit urban structure, that allows breezes to permeate is required, similarly the building plan form should include breezeways, combined with verandas (44). Buffer rooms should be placed on west of building, and thermal mass alleviates most of the underheated period cold. Lightweight roof insulation is needed if the roof is not massive. Winter sun should penetrate but summer sun should be shaded (45). Equatorial windows should amount to 10,6% of the floor space of these rooms. Evaporative cooling is ineffective, but ventilation can be used to assist the thermal mass effect during the overheated period (46).

**Subtropical**

Buildings should be free-standing and planned to assist air movement. Vegetation should not impede the movement of air. A narrow plan form with a single row of rooms allow for the most effective ventilation, with the north-south sides being the longest. Uninhabited rooms can be used as a buffer on the west side of the building with other rooms running the entire depth of the plan to facilitate cross ventilation (49). Lightweight construction is most appropriate for this climate, with thermal mass and ground contact being ineffective. However building on slopes allows good ventilation. Insulation on walls and roof is not necessary if they are totally shaded, with planting or a double roof construction. Light-coloured external surfaces ensure effective reflection and minimised heat gain. An equatorial window area of 16% is effective for the entire underheated period, but walls and openings should be totally shaded. Deep verandas and broad eaves are also recommended (50). Adequate ventilation is necessary to remove excess heat and humidity. East- and west-facing walls should not have windows but the other facades must allow for the maximum penetration of wind. Wind should not pass over heated surfaces before passing through the building. Reflective (but not shiny) roofs and ventilated roof spaces are also effective.

**Natal highlands**

Open urban design required for summer conditions with covered sidewalks. Plan form should be oblong with an east-west footprint (54). High building mass will address above a third of the summer overheating problem but interior ventilation is required. Massive building materials for passive effects are required. Equatorial windows should be 20% of the floor area and is effective for the entire under heated period (55). Evaporative cooling is not effective and design that aids ventilation is needed (56).

**Lowveld**

Compact urban layout is needed to prevent against overheating during the summer, and row houses with internal courtyards are the most successful plan forms (59). The plan should allow for rooms that overheat quickly (like kitchen) or that are occupied often to ventilate to outside. Bedrooms may be lightweight to cool off faster. Thermal mass is only partially effective during summer and winter, whilst light-coloured exteriors and interiors are needed (60). Equatorial glazing of 19.4% is effective and daytime ventilation is effective to reduce overheating. Openings should be shaded during the day. Only indirect evaporative cooling is advised, as direct evaporative cooling will increase the high humidity (61).

**Highveld**

Relatively compact urban layout with protection against the high radiation levels is needed (64). Winter and summer requirements differ and therefore the plan form, and solar gain in the winter and adequate insulation is important. External shade spaces for summer activities are necessary, and a compact plan form is advisable. Thermal mass is also important, provided by correct materials, massive floors and walls and internal partitioning. Lightweight insulated roofs are also feasible. Light coloured reflective (but not shiny) materials to minimise solar gain is also important (65). Equatorial glazing should be 19,2% and should be so orientated that winter sun is allowed to penetrate (especially early mornings

- own note) but screened in the summer. Ventilation can alleviate overheating but may be unnecessary if thermal mass is employed. Summer night ventilation may compensate for insufficient mass (66). Direct evaporative cooling is effective throughout the summer and may be used to aid insufficient thermal mass (67).

**Northern Transvaal**

Canopies, arcades and trees are important and south facades should also be shaded in the summer due to high solar angle. Relatively compact plans and urban layout are also desirable as well as solar gain for the winter (69). External living spaces with shade should be provided. Buffer zones should be included on the west and south. Thermal massing is effective for half of the underheated and the whole overheated period. Massive floors, walls, roofs and partitions can provide this, although ceilings can be lightweight. External surfaces should be light in colour (70). Equatorial glazing should be 21,2% of the floor area and ventilation is effective during the summer. Night ventilation can compensate for insufficient mass during the summer. Direct evaporative ventilation is effective for the entire overheated period (71).

**Namibia**

Public fountains, trees, other vegetation and minimised paving improve climate. Large verandas and balconies create intermediate living areas. South facades are exposed to radiation during sunrise and sunset therefore living areas are best placed on the north (74). High mass, light colour and insulation required. 18,4% of equatorial floor area glazed. Night ventilation is useful (75). Evaporative cooling during summer and air movement can compensate for insufficient thermal mass (76).

# APPENDIX D: CLIMATIC CLASSIFICATION OF SOUTH AFRICA ACCORDING TO KRUGER (13-11-2003)

Table III. Savanna-type Climatic Regions

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 1. Northern Arid Bushveld | Lower than average (300–500 mm p.a.) and somewhat erratic precipitation for the Savanna type regions, with semi-arid and hot conditions in the Limpopo and Olifants River basins. Rainy season lasts from about Nov to Mar, with the peak falling in Jan. Winds are light to moderate and blow mostly from the northeastern sector. Almost frost free. | Northern and northwestern parts of the Northern Province. | Dominated by stunted shrubby growth with mostly dense Mopane *Colophospermum mopane*, with e.g. Acacia *Acacia nigrescens* and Boabab *Adansonia digitata*, White Seringa *Kirkia acuminata*, Stem Fruit *Englerophytum magalismontanum*. Grasslayer includes Redgrass *Themeda triandra*, Common Nine-awn grass *Enneapogon cenchroides*, Guinea Grass *Panicum maximum* and Tassel Three-awn *Aristida congesta*. | Ecotourism, cattle and game farming, subtropical fruit and vegetables (mainly through irrigation). |
| 2. Central Bushveld | Similar to region 1 but decidedly wetter (500–750 mm p.a.) and somewhat cooler. Frost occurs more often. | Parts of Gauteng, North-West and Northern Province. | Tree species include African Beechwood *Faurea saligna*, *Acacia*, Buffalo Thorn *Ziziphus mucronata*. Shrublayer is moderately developed with e.g. Sandpaper Raisin *Grewia flavescens*, Peeling Plane *Ochna pulchra* and Blue Guarri *Euclea crispa*. Grasslayer well developed with e.g. Wire Grass *Elionurus muticus*, Turf Grass *Ischaemum afrum*, Fingergrass *Digitaria eriantha* and Common Russet Grass *Loudetia simplex*. | Ecotourism, cattle and game farming, wheat, maize, sunflowers. |
| 3. Lowveld Bushveld | Moderate summer precipitation (500–700 mm p.a.) with maximum in Jan, with warm to hot temperatures. Humidity is fairly high, with summer days uncomfortable. The region is virtually frost-free. Sunshine duration during summer is below average for the Savanna climates. | Parts of Eastern Mpumalanga and Northern Province, extending into KwaZulu-Natal. | Tree species mainly Lebombo Ironwood *Androstachys johnsonii*, Red Bushwillow *Combretum apiculatum*, *Acacia*, Marula *Sclerocarya birrea*. Grasslayer moderately developed with e.g. Redgrass *Themeda triandra*, Annual Redtop *Brachiaria xantholeuca* and Common Nine-awn grass *Enneapogon cenchroides*. Dense bush on the uplands, where shrub- and grass layers are poorly developed. | Game, cattle and goat farming, subtropical fruit and vegetables (through irrigation), sugarcane, ecotourism. |

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 4. Southeastern Thornveld | Late summer precipitation (450–700 mm p.a. but can be much higher in isolated areas due to topography) with maximum in Mar. Below average temperatures while occasional snow can occur over the mountainous areas. The period which frost can be expected lasts from about May to Sep. Winds are usually northwesterly, although cold snaps during winter are accompanied by unpleasant cold southerly to south-westerly winds. | Central area of Eastern Cape Province. | Mainly bushveld with *Acacia*, but more grassland further inland with e.g. Redgrass *Themeda triandra*. | Cattle, sheep and goats. |
| 5. Lowveld Mountain Bushveld | Due to its locality on the slopes of the Drakensberg, rainfall (with max in Jan) is high due to orography and can reach figures of 2000 mm in isolated areas. Patches of forest are therefore also present in this region. Although the incidence of fog is about 23 days per annum, it varies substantially from one area to another. Sunshine duration during summer is about 50% of the possible. | Eastern slopes of Drakensberg from Northern Province, through Mpumalanga into Swaziland. | Open tree savanna with e.g. Silver Clusterleaf *Terminalia sericea*, Bushwillow *Combretum collinum* and *Acacia*. Shrubs e.g. Sickle Bush *Dichrostachys cinerea*. Grass is tall and dense with e.g. Yellow Thatching Grass *Hyperthelia dissoluta*. | Cattle and game farming, subtropical fruit, forestry, ecotourism |
| 6. Eastern Coastal Bushveld | Wet and humid, with the avg. annual precipitation reaching about 1400 mm at the coast, peaking in Jan or Feb. Winds are mainly north-easterly or south-westerly, especially close to the coast. Sunshine during the summer is below average with about 45% of the possible. | East coast westwards to the lower slopes of the Drakensberg in KwaZulu-Natal. | Forest patches at the coast with e.g. Forest Iron Plum *Drypetes gerrardii*, Uzimbeet *Millettia grandis* and White Ironwood *Vepris lanceolata*. Closer to seashore evergreen thicket occurs. Grasses include Ngongoni Bristlegrass *Aristida junciformis*. In swampy locations palms are prominent. Inland *Acacia* and Nogongoni Bristlegrass *Aristida junciformus* dominate. In valleys valley thicket occurs, forests in the more sheltered valleys and slopes. | Sugar and timber, cattle grazing. |
| 7. KwaZulu-Natal Central Bushveld | Similar to region 6, although the precipitation is lower (700–900 mm p.a.) and the temperatures fluctuate more due to altitude and distance from the coast. Depending on topography, the period of possible frost can last from 90 - 150 days from Apr to Sep. Winds are mainly southerly and northerly to north-westerly, the latter often very strong in autumn. Sunshine duration varies from 50 - 60% of the possible in summer. | Northern KwaZulu-Natal. | Open savannah with *Acacia*. Variable grass layer with Common Thatchgrass *Hyparrhenia hirta* and Hairy Tridentgrass *Tristachya leucothrix* dominating. Northwards a mix of scrub and savanna, with trees e.g. *Acacia* and Red Bushwillow *Combretum apiculatum*. Also grass species like Redgrass *Themeda triandra* and Spreading Pricklegrass *Aristida congesta*. | Cattle and game farming, sugarcane, subtropical fruit, forestry |

Table III. Savanna-type Climatic Regions (continued)

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 8. Kalahari Bushveld | Rainfall varies from about 200 mm in the west to a maximum of about 450 mm p. a. at its eastern border. The rainfall season has its maximum during Jan and Feb in the central and eastern parts but Mar in the west, where it is very erratic. Temperatures are very extreme with about 3 months during summer with average max temperatures above 30 and one month during the year where the minimum drops below freezing. Sunshine duration is about 80% of the maximum, even during the rainy season in summer. Winds are usually north-westerly. Occasional cold snaps are accompanied by southerly winds that can last for a day or two. | Northern parts of the Northern Cape and northwestern part of North-West. | Sparsely scattered trees of the *Acacia* type as well as e.g. Sheperd's Tree *Boscia albitrunca*. Shrub- and grass layers poor to moderately developed depending on rainfall. Species include e.g. Honeythorn *Lycium bosciifolium*, Kalahari Currant *Rhus tenuinervis*, Sour Bushmangrass *Schmidtia kalihariensis* and Kalahari Coach *Stipagrostis amabilis*. Further south trees give way to a well-developed grass layer, but in the east a typical bushveld character exists. | Livestock and game farming, ecotourism |
| 9.Kalahari Hardveld Bushveld | This region is similar to region 8, but because of the somewhat higher elevation, the rainfall is higher and less erratic and ranges from 350–500 mm. Hail is also possible. Northerly winds tend to dominate. | Northeast Northern Cape, southwestern part of North-West and small part of Western Free State. | Tree layer poorly developed with e.g. Wild Olive *Olea europaea* and Black Thorn *Acacia mellifera*. Shrubs e.g. Camphor Tree *Tarchonanthus camphoratus* and Kunibush *Rhus undulata*. Grass layer moderately developed with e.g. Broadleaf Bluestem *Diheteropogon amplectens* and Copperwire *Aristida diffusa*. Eastward trees become more abundant e.g. *Acacia* types; tall grass species e.g. Redgrass *Themeda triandra* are abundant. | Livestock and game farming |

Table IV. Grassland Type Climatic Regions

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 10.Dry Highveld Grassland | Precipitation ranges from about 450 mm in the west to about 700 mm at its northern border. The rainy season reaches its maximum during Dec and Jan in the north, but Feb to Mar in the west and south. Over the high lying areas snow is possible during the winter months. Winds are highly variable but tend to be more from the north to north-east. | Parts of eastern North-West southwards into central and western Free State. | Vegetation consists of mainly grassland with some trees along watercourses. Grass species include Giant Speargrass *Trachypogon spicatus*, Broadleaf Bluestem *Diheteropogon amplectens*, Caterpillar Grass *Harpochloa falx*, White Buffalograss *Panicum coloratum*, Weeping Lovegrass *Eragrostis curvula*, Redgrass *Themeda triandra*. Woody vegetation such as *Acacia* and Mountain Karee *Rhus leptodictya* also occur. West of Bloemfontein, Karoo elements are present, but this should not necessarily be considered as encroachment. | Maize production, cattle and sheep. |
| 11. Moist Highveld Grassland | Similar to region 10, but cooler and wetter due to higher elevation and position relative to rain-bearing systems. Precipitation, which ranges from 600-800 mm p.a., has its maximum during Dec and Jan, but Feb in the south. Frost occurs regularly during the winter months and ranges, from available data, from about 30 days in the Mpumalanga area to about 70 days in the southern Free State. Winds are highly variable but easterly and westerly winds are more prevalent. Closer to the mountain ranges the incidence of frost is probably even higher. Over the higher lying areas snow is not an unusual event. | Parts of Gauteng and Mpumalamga southwards into eastern and southeastern Free State. | Grass species include Redgrass *Themeda triandra*, Three-awn Rolling Grass *Aristida bipartita*, Fan Lovegrass *Eragrostis plana*, Broom Needlegrass *Triraphis andropogonoides*, Bushveld Turpentinegrass *Cymbopogon plurinodis*. Forbs include Fishbean *Tephrosia semiglabra*, Wild Petunia *Ipomoea obscura*, and Bladderweed *Hibiscus trionum*. Invasion of Karoo bushes e.g. Bitterkaroo *Pentzia globosa* may occur in some areas. Some dense woody thickets e.g. Oldwood *Leucosidea sericea* occur in places in the north. | Maize, Cattle and sheep, crop production, dairy farming, ecotourism. |
| 12. Eastern Grassland | A more moderate climate than region 11, with less frost during winter due to its lower elevation. Rainfall is high and ranges from 650 mm to more than 1000 mm closer to the Drakensberg. Winds tend to be from the northeastern or southwestern sector. A total of 100–150 rainy days are experienced. Intense thunderstorms occur frequently, but less so closer to the coast. Snow is possible over the higher lying areas. | Southern KwaZulu-Natal and eastern Eastern Cape interiors. | Grasspescies include Redgrass *Themeda triandra*, Speargrass *Heteropogon contortus*, Wire Grass *Elionurus*. Forbs e.g. Spiky Cucumber *Cucumis zeyheri*. Trees and shrubs e.g. Common Spikethorn *Maytenus heterophylla* occur in sheltered sites. | Grazing, crop production, forestry, ecotourism. |

Table IV. Grassland Type Climatic Regions (continued)

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 13. South-east Coast Grassland | A wet climate (1000 to more than 1250 mm but somewhat drier in the south) with moderate temperatures. The rainfall season peak during the early rain months from Oct to Dec. Winds, that tend to be from the northeastern or southwestern sectors, are sometimes very high. | Eastern coastal strip of the Eastern Cape. | Grasspecies include Redgrass *Themeda triandra* and Hairy Tridentgrass *Tristachya leucothrix.* Although the vegetation consists of mainly grass, Fynbos patches are common as well as shrubs e.g. Blombos *Metalasia muricata* and Gonnabos *Passerina rigida.* | Grazing, tourism. |
| 14. Eastern Mountain Grassland | Rainfall varies a lot over short distances due to topography (500 mm in the valleys and lee sides of the mountains and some places exceeding 2000 mm p.a. on the eastern slopes), and occurs mainly during summer, peaking between Dec – Feb. Temperatures tend to be cool, especially in the south. Also due to the topography, the directions of winds tend to vary substantially from one area to another. The climate is extreme with frost and fog occurring frequently, while snow is also possible in most parts. | High-altitude mountainous area (mainly the Drakensberg Range) stretching from the Northern Province southwards into the Eastern Cape. | Grasses include Common Russetgrass *Loudetia simplex*, Giant Speargrass *Trachypogon spicatus*, Wiregrass *Elionurus muticus*, Common Thatchgrass *Hyparrhenia hirta*, Drakensberg Danthonia *Merxmuellera drakensbergensis*, Goat Fescue *Festuca caprina*. Forest-related bush clumps with woody species e.g. Bastard Lemonwood *Psychotria capensis* and Broadleaf Waxberry *Myrica pilulifera* occur in places, especially in the north. Lilies (Lilaceae), Irises (Iridaceae), Daisies (Asteraceae), Mints (Lamiaceae) and Orchids (Orchidaceae) occur. Many forest patches occur. Dwarf shrubs e.g. Ghombos *Felicia filifolia* and Anchorkaroo *Pentzia incana* may occur in drier or overgrazed patches. | Forestry, grazing, ecotourism, and most importantly a water catchment area. |
| 15. Alpine Heathland | Similar to region 14, but decidedly colder and drier due to height above sea level. | High altitude area of the Drakensberg range with altitude above 2800 – 3000 m | Similar to region 14 but species that can withstand altitudinal drought become more common. These include the abundant shrub *Helichrysum trilineatum* and the more localized *Erica dominans. Merxmuellera macowanii* grass tends to be prominent in this area. *Chysocoma ciliata* shrubs are also common, especially in disturbed areas. | Grazing, tourism, and water catchment. |

Table V. Karoo Type Climatic Regions

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 16. Great and Upper Karoo | A dry (less than 100 mm in the northwest – 300 mm in the east), extreme climate with high temperatures during summer but very cold in the winter. Autumn rainfall, peaking in March, tends to be highly unpredictable and occurs in patches. This tends to be in the form of isolated thunderstorms but rainfall of a cyclonic nature can also occur in the southwest. During summer winds from the southwest are more prevalent compared to winter when winds from the north tend to dominate. | Central Northern Cape. | Annuals e.g. Brakspekbos *Zygophyllum simplex* and non-succulent shrubs e.g. Thorny Kapokbush *Eriocephalus spinescens*, Silverkaroo *Plinthus karooicus* and Perdekaroo *Rosenia humilis*. After good rains perennial grasses become more visible e.g. Tassel Bristlegrass *Aristida congesta* and Lehman's Lovegrass *Eragrostis lehmanniana*. Among the steep slopes of the Orange River Quiver Tree *Aloe dichotoma*, Bushman Poison Tree *Euphorbia avasmontana* and Aggenys Milkbush *Euphorbia gregaria* occur. Trees include *Acacia*, Threethorn *Rhigozum trichotomum* and Sheperd's Tree *Boscia albitrunca*. | Small-stock farming e.g. sheep and goats. Irrigation crops along Orange River e.g. cotton, lucerne and grapes. |
| 17. Eastern Karoo | Similar to region 15, but decidedly wetter (300-500 mm p.a.). The late-summer to autumn rainfall season peaks from Feb – Mar. | Parts of western Free State, Northern Cape And Eastern Cape. | A complex mix of grass and shrubs depending on seasonal rainfall events. Shrubs include Bitterkaroo *Pentzia incana* and Kapokbush *Eriocephalus ericoides*. Grasses e.g. Redgrass *Themeda triandra* occur extensively after good rains. *Acacia* trees are common along dry river beds. | Small-stock farming e.g. sheep and goats. Irrigation along Orange River. |
| 18. Little Karoo | Low rainfall (less than 200–300 mm p.a. but patches with higher rainfall exist due to topography), mainly in winter, of a cyclonic nature. It becomes more evenly distributed in the east. | Parts of the Western Cape interior. | Succulent species e.g. Thorn Vygie *Ruschia intricata*. Non-succelent shrubs e.g. Hairbush *Hirpicium integrifolium* and Bankruptbush *Pteronia pallens*. Low Trees e.g. Jacketplum *Pappea capensis* and Common Guarri *Euclea undulata*. Grasses are scarce. | Irrigation e.g. grapes, wheat, lucerne. Ostriches, small stock and cattle. |
| 19. Western Karoo | Very dry (less than 100–200 mm p.a.) with extreme temperatures, which can become very cold during winter. Rainfall can be isolated thunderstorms or of a cyclonic nature. Winds are similar to region 20. | Western Northern Cape and parts of the Western Cape. | Low shrubs and small trees, e.g. the Quiver Tree *Aloe dichotoma* which dominates in the west, while plants in the Vygie family (Mesembryanthemaceae) are the dominant dwarf shrubs. Most plants depend on the cyclonic winter rains for moisture. | Small stock farming, tourism, irrigation e.g. wheat, oats and barley. |

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 20. West Coast | Very dry almost desert-like climate (especially in the north) with a high frequency of fog due to the cold Benguela ocean current. Rainfall period exclusive to Jun and Jul. Winds are mainly from the south, but quite variable during the winter months. | A strip along the west coast. | Low shrubs to medium-tall shrubs in the south occur e.g. Sage *Salvia lanceolata* and Tortoisebush *Zygophyllum morgsana*. This vegetation is called the Strandveld. | Minerals, tourism, fish. |

Table VI. Desert Type Climatic Regions

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 21. Northwestern Desert | Annual rainfall is 50 mm or less. It receives more rain in the form of thunderstorms than cyclonic winter rain. The above, as well as the infrequent fog it receives from the sea, results in a true desert similar to the Namib in adjacent Namibia. | Extreme northwestern Northern Cape. | Mainly annual species as well as perennial types in the drainage channels and washes. The grass *Aristida parvula* is a good example of an annual species in this area. | Tourism. |

Table VII. Fynbos Type Climatic Regions

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 22. Southwestern Cape | Winter rainfall with very dry summers. The climate varies a lot from pace to place due to the mountainous nature of the area. The climate can thus not really be considered homogeneous, except for the rainfall season and to a lesser extent the temperatures; which tend to be moderate, but can become high during summer. E.g. the rainfall varies from 250 mm at the west coast to 1400 mm on the slopes of Table Mountain. Winds from the north to north-west as well as from the south tend to dominate, but due to topography more inland this can also become more variable. | Southwestern Western Cape. | Numerous fynbos species in the more mountaineuos areas. Also Conebush *Leucadendron elimense*, Blombos *Metalasia muricata*, Elim Gonna *Passerina galpinii* lower down. On limestone Limestone Sugarbush *Protea obtusifolia* and Limestone Conebush *Leucadendron meridianum* and members of the Buchu Family (Rutaceae). On the sandy plains Ninepin Heath *Erica mammosa*, Starface *Phylica cephalantha* and Sandveld Thatching Reed *Thamnochortus punctatus* dominate. Renosterbushes include Renosterbos *Elytropappus rhinocerotis*, Gumbush *Relhania genistifolia, Acasia*, Bitter Aloe *Aloe ferox*, Common Guarri *Euclea undulata*, Ashbush *Pteronia incana*, Wild Rosemary *Eriocephalus africanus*, Dune Teabush *Leysera gnaphalodes*. Grasses include Redgrass *Themeda triandra* and Cape Terpentinegrass *Cymbopogon marginatus*. Geophytres include Irises (Iridaceae) and Lilies (Liliaceae). Bush clumps occur with e.g. Wild Olive *Olea europaea* and Dune Taaibos *Rhus laevigata*. Wind-created cloud on the higher mountains in summer is important for many fynbos species. | Water catchment, sheep farming, wheat, vegetables, fruit, flowers, recreation, ecotourism. |
| 23. Southern Cape | A moderate, all-year rainfall climate, with maxima in autumn and spring. Winds tend to blow from the northwestern and southeastern sectors in the west, from the west and east in the center of the area, and from the southwestern and northeastern sectors in the east (the directions coincide with the orientation of the coastline). | Southern Western Cape and Eastern Cape. | More or less the same as above but a high proportion of grasses exists, especially in the east, mainly Redgrass *Themeda triandra*, Velvet Signalgrass *Brachiaria serrata* and Ratstail Dropseed *Sporobolus africanus*. | The same as above, but including forestry |

Table VIII. Forest Type Climatic Regions

| Region | Climatic properties | Locality | Vegetation | Economic Uses |
|---|---|---|---|---|
| 24. Southern Cape Forest | A moist area with high rainfall (800 to more than 1000 mm p.a.), having two maxima during the year, but peaking in October. Three to four months of rainy days are experienced. Temperatures are mild and frost is almost non-existent. The topography and its closeness to the coast, make the part of this region closer to the mountains prone to fog. George and Saasveld experience fog about 29 days p.a. Winds are mainly westerly or easterly. | Southern parts of Western Cape and Eastern Cape, between the sea and the Cape Fold Belt Mountains. | Although forests occur at several places in the east and south of South Africa, this is the only region where it forms a sizeable area for climatological purposes, solely occupied by it. Were it not for fires, forests would have occupied a larger area, but in this region it is protected by the sea and the Cape Fold Belt mountains. Trees dominate with e.g. Outeniqua Yellowwood *Podocarpus falcatus* and White Witchhazel *Trichocladus ellipticus*. Shrubs and climbers are common e.g. Common Spikethorn *Maytenus heterophylla* and Cat-thorn *Scutia myrtina*. Grasses, herbs and ferns occur in the undergrowth. As a consequence of substrate and soil moisture differences a significant part of the area is not covered with forest but with fynbos. | Tourism, forestry, firewood and water catchment. |