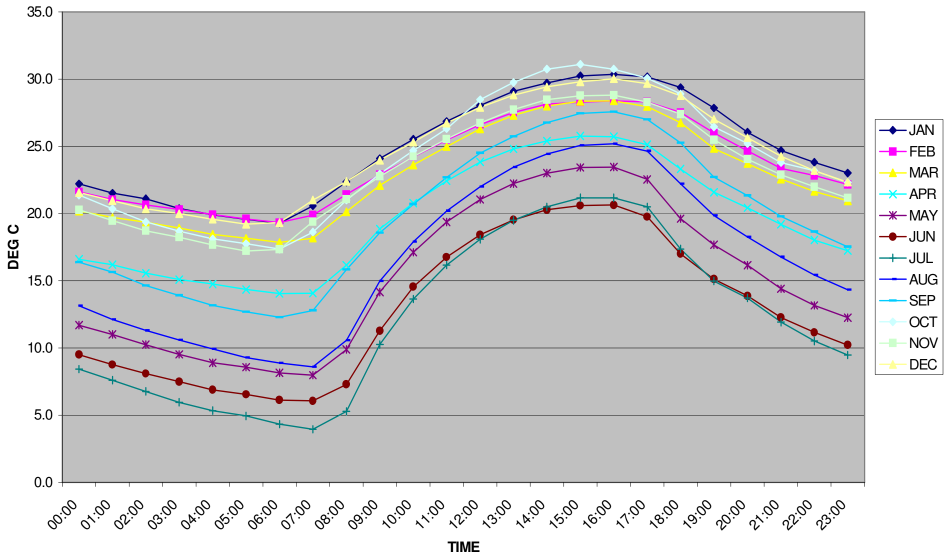
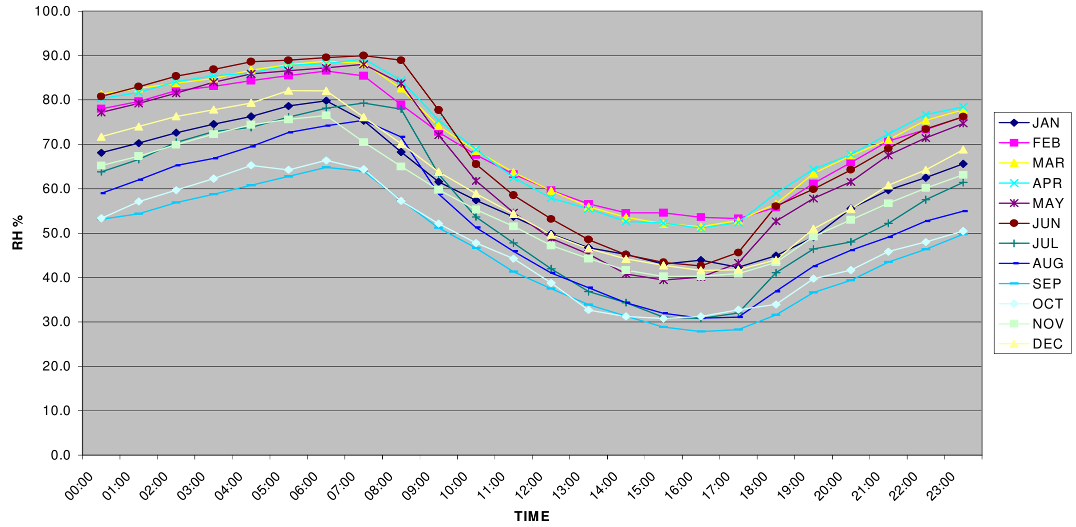
SECTION 3 CLIMATE

HOURLY AVERAGE TEMPS GABORONE 2000-2002



HOURLY AVERAGE RH GABORONE 2000-2002



ENERGY EFFICIENCY BUILDING DESIGN GUIDELINES FOR BOTSWANA

Revision 1 September 2007

ENERGY EFFICIENCY BUILDING DESIGN GUIDELINES FOR BOTSWANA

Sections:

CONTENTS

3. CLIMATE

3.1. Overview

This Section addresses the subject of climate and its impact on building energy performance in Botswana. The topics that will be covered are briefly outlined below.

3.1.1. Climate of Botswana.

The section begins with an overview of the climate of Botswana in a global context. The classification of the climate is considered, and various cycles in the climate are identified.

3.1.2. Elements of climate.

This section includes a general discussion of the principal elements of climate and how they relate to building energy performance. The ways in which data are collected and made available are also considered.

3.1.3. Climatic zones.

The variation in climate with location is considered, with particular reference to the implications for building energy performance. It is recommended that the country be divided into two climatic zones for the purposes of these Guidelines.

3.1.4. Climate patterns.

In addition to the geographical variations in climate, there are also patterns of climate within one locality. In considering the impact of climate on building energy performance, it is important to consider the different patterns that occur, and differentiate these from the average characteristics, which may never be experienced.

3.1.5. Climate and simulation.

Building energy performance may be predicted using software that simulates the interaction of the building with the climate.

Typical meteorological year data has been prepared for Gaborone and Maun, which have been taken as typical of the Northern and Southern climate zones.

This data is available in a format that may be used for computer simulation of building energy performance.

3.2. Climate of Botswana

3.2.1. Classification.

In the Köppen Climate Classification System, the climate of most of Botswana falls in the classification 'BSh: semi-arid steppe, hot'. The exception is the extreme north of the country, which is classified, as 'Aw: tropical wet-dry (low sun dry) – savanna'. Approximately two thirds of the area of the country is within the tropics. The Tropic of Capricorn crosses the Jwaneng - Ghanzi road just north of Kang, runs through the middle of Khutse game reserve, and crosses the Gaborone - Francistown road just north of Dibete.

Generally Botswana experiences a very high proportion of clear, sunny days, with little cloud cover or rain.

The summers are warm to hot in the day and cool at night, particularly in the southwest of the country. Rainfall generally occurs in the time between October and April, which coincides with the summer months.

Winters are warm in the day and cool at night, with minimum temperatures lower in the south, and increasing as one moves further north.

Summer maximum daytime temperatures are closely related to rainfall, rising rapidly in times of drought. In years of reasonable rainfall, the highest average maximum temperature often occurs in October, before the rain begins, after which temperatures drop due to increased cloud cover and evaporative cooling from the moisture in the soil. In years of drought, and in regions that receive less rain the maximum temperatures continue to rise until January or February.

Botswana is completely landlocked, and is located in the centre of the southern African plateau. The country is approximately equidistant from the Atlantic Ocean coast, 1,000km to the west, and the Indian Ocean coast about 960km to the east (measured to the middle of the country). The country is relatively flat, at an average elevation of approximately 1000m above sea level. As a result moist air from the oceans seldom reaches Botswana without having first shed its moisture on the escarpments between. The distance from the ocean together with the relatively high altitude result in low, intermittent and unreliable rainfall. The rain that does occur is a result of localised regions of low pressure that draw in moist air from the coast.

Not only is the average rainfall in Botswana low, it is also very variable, both within a particular year, and from one year to the next. There is a trend for average rainfall to reduce and variability to increase from north to south, and from east to west.

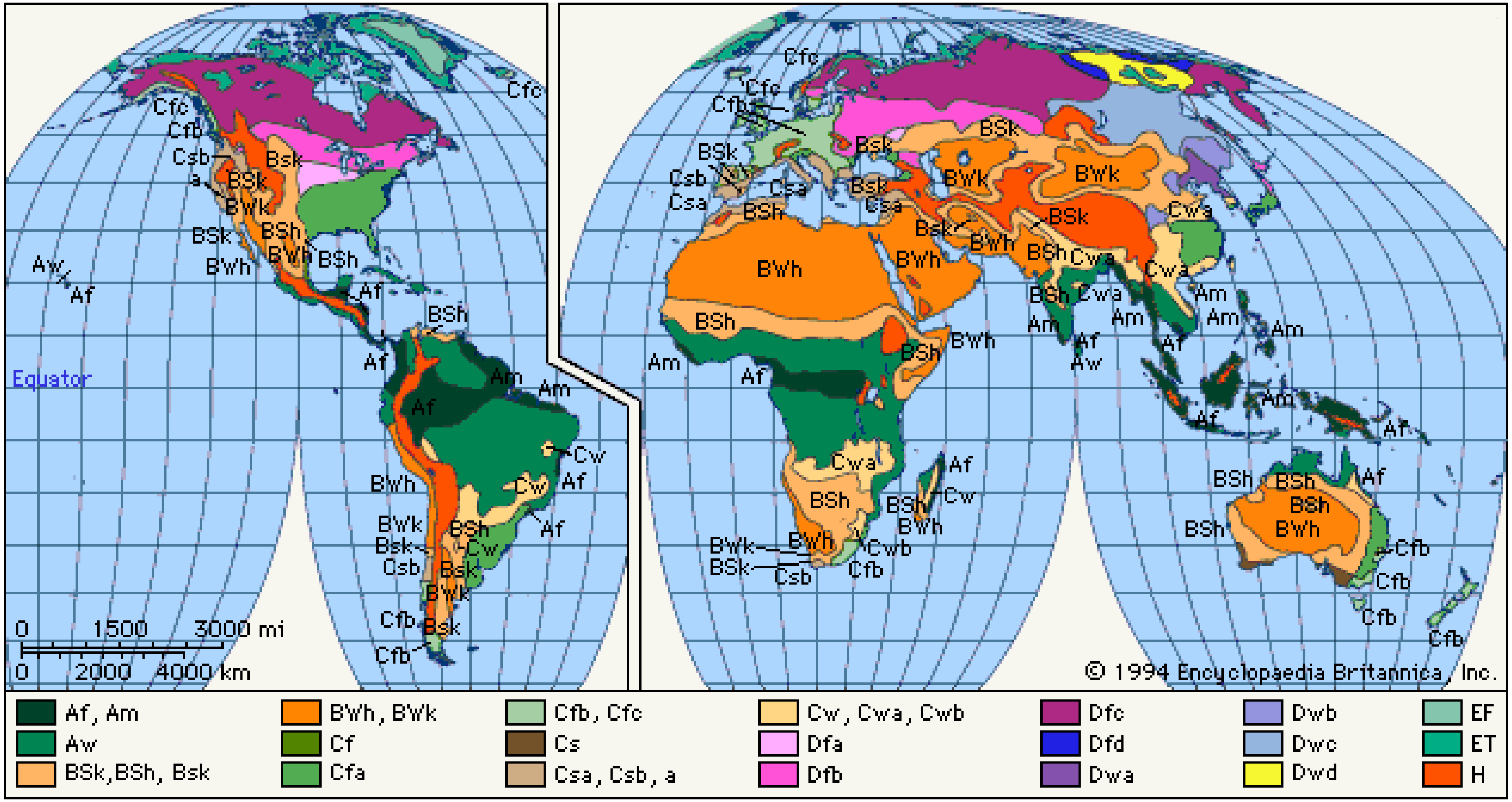


Fig. 3.1 Koppen climate classification.

3.2.2. Cycles of climate and global warming.

A number of different climatic cycles have been observed, including a short-term cycle of about 6-10 years during which a few years of good rain are followed by years of below average rain or drought. This takes place within the framework of a longer cycle spanning several centuries, and another even longer cycle of several thousands of years. Although the Kalahari has generally been a semi-arid area for millions of years, during that time there have been periods of sufficient rainfall to maintain large inland seas and perennial rivers that now remain as fossil river valleys.

Over the past century the natural long-term climatic cycles of the earth have been subject to increasing influences from human activity, particularly the enormous increase in energy consumption from fossil fuels and resulting emissions of carbon dioxide. This has resulted in increased concentrations of greenhouse gasses in the atmosphere. These act as a radiation filter surrounding the earth, which allows solar radiant heat to pass through, but reflects thermal radiant heat back to the earth, as does the glass in a greenhouse. The consensus view of the Intergovernmental Panel on Climate Change (IPCC), the world authority on global warming, is that this could result in an increase in average temperatures over southern Africa of between 2-5°C over the coming century. The following excerpt from an article by Mike Davis in The Science News suggests that this may be a highly optimistic view.

The actual rate of change of climate may not be accurately predictable, but there seems to be little doubt that increases in temperature will be experienced throughout this century, together with increased energy cost, both in economic and environmental terms. This makes it even more urgent that buildings are designed and built to achieve human comfort with minimal energy consumption.

The Science News

Scientific discussions of environmental change and global warming have long been haunted by the specter of nonlinearity. Climate models, like econometric models, are easiest to build and understand when they are simple linear extrapolations of well-quantified past behavior: when causes maintain a consistent proportionality to their effects.

But all the major components of global climate - air, water, ice and vegetation - are actually nonlinear: at certain thresholds they switch from one state of organization to another, with catastrophic consequences for species too finely-tuned to the old norms. Until the early 1990s, however, it was generally believed that these major climate transitions took centuries if not millennia to accomplish. Now, thanks to the decoding of subtle signatures in ice cores and sea-bottom sediments, we know that global temperature and ocean circulation can change abruptly - in a decade or even less.

The paradigmatic example is the so-called 'Younger Dryas' event, 12,800 years ago, when an ice dam collapsed, releasing an immense volume of meltwater from the shrinking Laurentian ice-sheet into the Atlantic Ocean via the instantly-created St. Lawrence River. The freshening of the North Atlantic suppressed the northward conveyance of warm water by the Gulf Current and plunged Europe back into a thousand-year ice age.

Abrupt switching mechanisms in the climate system, like relatively small changes in ocean salinity, are augmented by causal loops that act as amplifiers. Perhaps the most famous example is sea-ice albedo: the white, frozen Arctic Ocean reflects heat back into space, thus providing positive feedback to cooling trends; alternatively, shrinking sea-ice increases heat absorption and accelerates its own melting and planetary warming.

Thresholds, switches, amplifiers, chaos - contemporary geophysics assumes that earth history is inherently revolutionary. This is why many prominent researchers - especially those who study topics like ice sheet stability and North Atlantic circulation - have always had qualms with the consensus projections of the Intergovernmental Panel on Climate Change (IPCC), the world authority on global warming.

by Mike Davis; October 05, 2005

3.3. Elements of Climate

3.3.1. Meteorological data

In Botswana the responsibility for the collection, processing, storage and dissemination of meteorological data rests with the Department of Meteorological Services (DMS) in the Ministry of Environment, Wildlife and Tourism. The DMS maintains synoptic weather stations at the following locations around Botswana:

- Francistown
- Ghanzi
- Jwaneng
- Kasane
- Letlhakane
- Mahalapye
- Maun
- Pandamatenga
- Selebi-Phikwe
- Sir Seretse Khama Airport
- Shakawe
- Sua Pan
- Tshabong
- Tshane

A wide range of variables are measured, including the following:

- Dry Bulb Temperature
- Humidity
- Wind Speed
- Wind Direction
- Rainfall
- Sunshine hours
- Evaporation
- Air pressure
- Soil Temperature

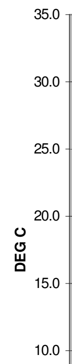
In addition, rainfall and temperature are measured at a large number of other locations by volunteers who regularly submit their data to DMS.

3.3.2. Temperature

Air temperature (Dry Bulb temperature) is the characteristic of climate that most directly affects comfort. It determines the rate of heat transfer by conduction and convection. Assuming that there are no significant sources of radiant heat transfers, DB temperature is the main determinant of human comfort, and therefore the most significant variable to be specified when defining indoor climate requirements. Heating and cooling equipment is generally controlled by thermostats that are set to a particular target temperature or temperature range.

Dry bulb temperatures in Gaborone vary throughout the year, between an average daily maximum temperature of 32°C in October, and an average daily minimum temperature of 4°C in July. [Bauer Consult].

The maximum daily temperature in summer typically occurs at about 3.00pm, and the minimum daily temperature in winter typically occurs at 7.30am.



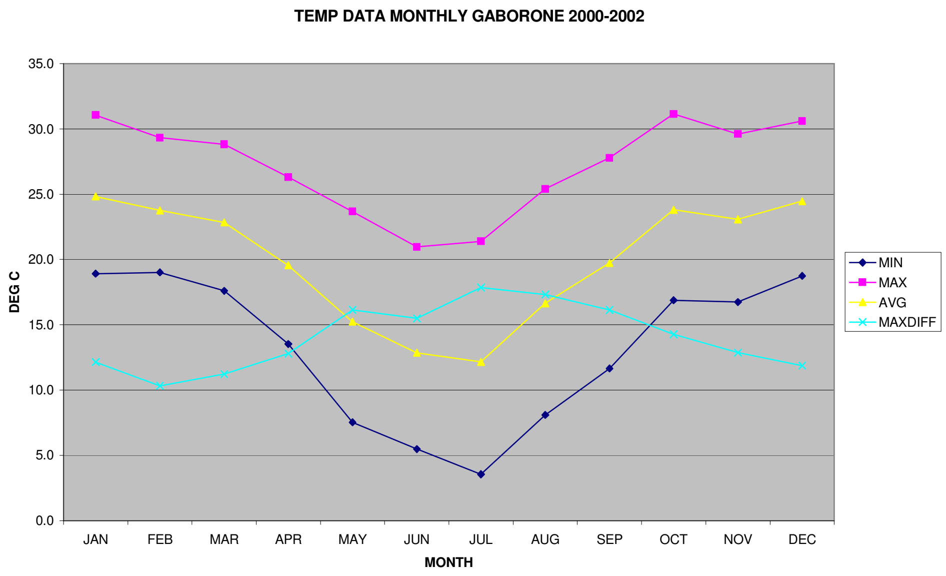


Fig. 3.2 Temperatures in Gaborone, by month.

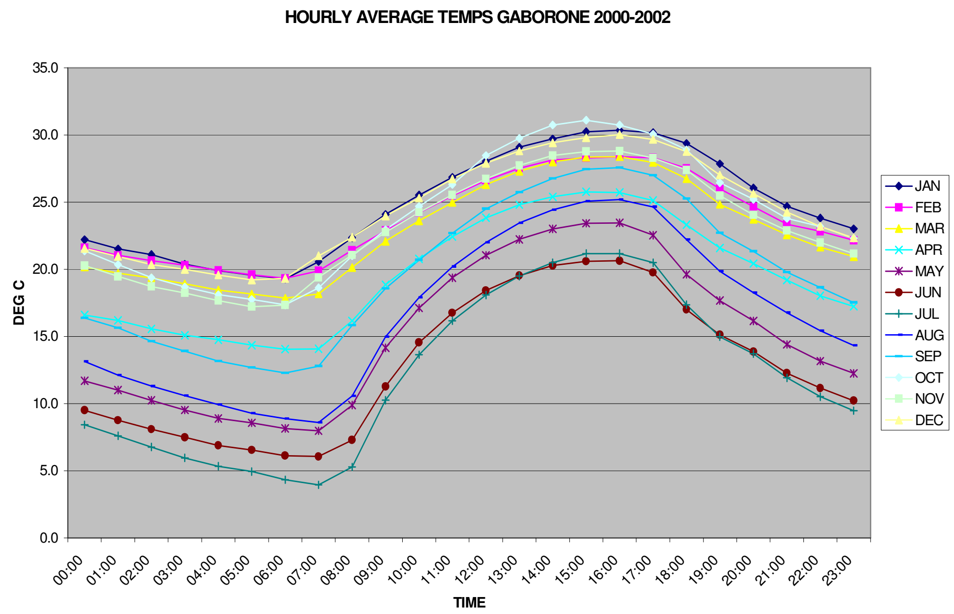


Fig. 3.3 Temperatures in Gaborone, by hour.

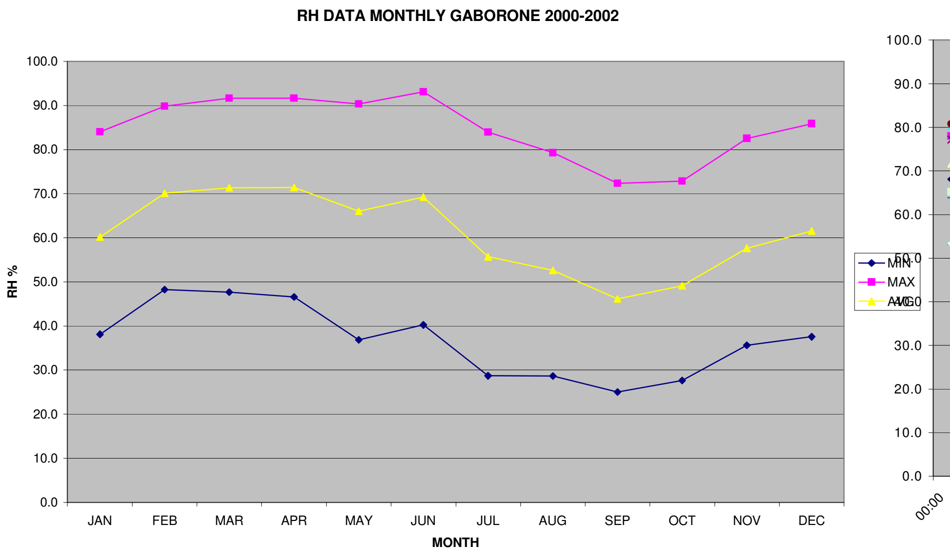


Fig. 3.4 Relative Humidity in Gaborone, by month.

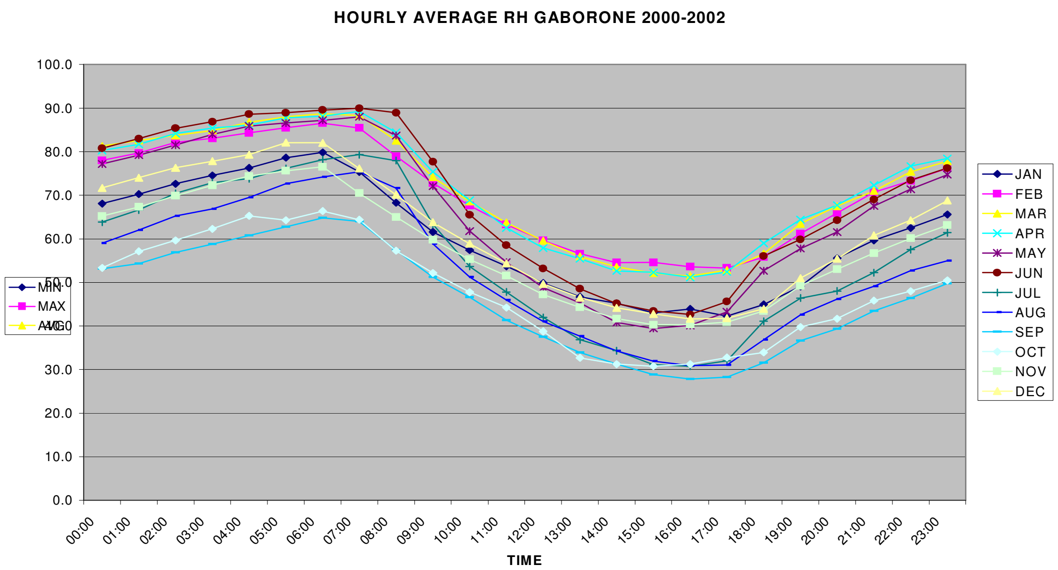


Fig. 3.5 Relative Humidity in Gaborone, by hour.

	dry bulb °C	wet bulb °C	relative humidity
ASHRAE design temperature Gaborone Airport (Jan) based on 0.4% chance of exceedance (derived using IES software)	37.7	19.9	20%
CIBSE A guide (5th Ed) design temperature Maun (October)	39	22	24%
CIBSE A guide (5th Ed) design temperatures Maun (Jan)	37	25	39%
CIBSE A guide (5th Ed) design temperatures Ghanzi (Nov)	38	23	29%
CIBSE A guide (5th Ed) design temperatures Ghanzi (Jan)	37	24	36%
Standard design conditions in common usage (Gaborone)	38	25	36%
More extreme design conditions (Gaborone)	40	27	38%
Based on the Typical Meterological Year (TMY) for Gaborone and Maun generated by Meteonorm:			
Heating Dry Bulb temperature (99% chance of no lower temperature, Gaborone)	2.5		
Cooling Dry Bulb temperature (1% chance of higher temperature, Gaborone)	34.1	25.6	61%
Heating Dry Bulb temperature (99% chance of no lower temperature, Maun)	6.3		
Cooling Dry Bulb temperature (1% chance of higher temperature, Gaborone)	39.1	22.4	45%

Table 3.1 Design Day Conditions for Gaborone, Maun, and Ghanzi

3.3.3. Design Day Conditions

Although it is recommended that buildings are simulated using real weather data (see section @@) some buildings may continue to be designed using “design day” methods. Typical design temperatures for both cooling and heating design are provided in Table 3.1 above.

The choice of design day temperatures is something that the client must sign off, since it involves a choice about how often the building is likely to overheat, versus the risk of oversizing plant. Generally, for an energy efficient building it is desirable to use lower design temperatures and allow the building to overheat occasionally.

One of the reasons that more extreme design conditions are used is to give a design margin and effectively to give the client future flexibility for increased heat loads or for variations/defects in the construction of the building post design stage. However, this should be avoided as it is likely to result in over sizing of plant.

3.3.4. Humidity

Humidity is a measure of the moisture content of the air. It is generally measured as relative humidity, which indicates the percentage saturation of the air.

Relative humidity (RH) is an important characteristic of climate with regard to building design for the following reasons:

- It is a determinant of the comfort zone temperatures.
- It determines the effectiveness of evaporative cooling.

Generally RH varies inversely with temperature through the day. It is higher in the summer months when rain occurs than in the dry months of winter.

For Gaborone the highest hourly average RH is 90% and occursin June. The lowest hourly average RH is 28% and occurs in September. [Bauer Consult]. Maximum RH typically occurs at 7.00am, while minimum RH typically occurs at 5.00pm.

3.3.5. Radiation

Radiation is a critically important characteristic of climate, both at a macro, outdoor level and in relation to indoor climate.

Heat transfer by radiation is proportional to the difference in temperature of the surfaces raised to the fourth power. It is therefore a minor component of total heat flow between surfaces where the temperature difference is small, and rapidly becomes the major component of heat flow when temperature difference increases. It is also affected by other characteristics of the surfaces, including colour and texture, as well as the translucence of the intervening space.

During the day radiant heat transfer between a building and its surroundings is primarily in the form of solar heat gain, and includes direct, diffuse and reflected radiation.

During the night, radiant heat loss to the night sky occurs from any surface in view of the sky.

Total solar radiation received on a horizontal surface has been recorded at Sebele since 1977. For other locations it has been calculated from recorded measurements of bright sunshine duration using the Angstrom formula.
The annual average daily total radiation on a horizontal surface varies between 19.6 MJ/m^2.day in Sebele, to 22.0 MJ/m^2.day in Tsabong. [Bhalotra]

The monthly average daily total radiation on a horizontal surface for Gaborone varies from 14.6 MJ/m^2.day in June, to 26.2 MJ/m^2.day in December. [Bhalotra]

The indoor radiant environment is often underestimated as a factor in determining comfort. A space may feel uncomfortably hot even when the air temperature is several degrees below the minimum comfort level, if there is a hot surface in view (such as the sun, seen through a window, or even a warm wall). Likewise, a space with an air temperature higher than the maximum comfort level may feel cold if there is a view to a cold body such as the night sky. (See **Section 4, Indoor Environment**.)

3.3.6. Wind

Wind is significant in energy efficient building design as a driving force for ventilation, which is of benefit in the following ways:

- Natural ventilation to improve air quality.
- Natural ventilation to provide cooling air movement.
- Wind driven evaporative cooling.

Wind driven infiltration is a problem in the following ways:

- Heat loss through infiltration.
- Heat gain through infiltration.
- Excessive air speeds due to infiltration in high winds.
- Entry of dust or other contaminants due to infiltration.

Wind direction for most of Botswana is predominantly from the East, with a significant component from the south to southwest in the extreme southwest of the country. There are extensive periods of calm, e.g. 37.7% for Gaborone.

It would be important to analyse wind data to determine whether there is a difference between the dominant wind direction for light winds and for strong winds.

3.3.7. Rainfall

Rainfall has limited direct effect on building energy performance, but is important since it is closely linked to other climate variables. For example, in a year of good rainfall, the hottest month of the year is frequently October, which in such years is generally still dry with little cloud cover. Rainfall during the months of December and January helps to reduce temperatures through evaporation and reduced sunshine hours. In years of drought, the reverse is the case, with temperatures in December and January exceeding those of October.

Rainfall must be taken into consideration in designing the landscape around a building. Plants that require much irrigation should be avoided, since water is a scarce resource in Botswana. Opportunities for using greywater should be considered in any building project. The website at www.oasisdesign.net has useful information on practical greywater design solutions.

3.4. Climatic Zones.

Botswana extends from latitude 17°,50’ at Kasane in the north, to latitude 26, 59’ at Bokspits in the south. The western border with Namibia runs along longitude 20, 0’ E, while the confluence of the Limpopo and Shashe rivers in the east is located at longitude 29°, 30’E. The country spans approximately 1,100 km from north to south, and 965km from west to east.

The variations in climate across the country are such that they need to be taken into consideration in building design for comfort and energy efficiency.

Fig. 3.7 shows the monthly mean maximum and minimum temperatures for various locations around Botswana.

Fig.3.6 Map of Botswana (source: US – CIA)

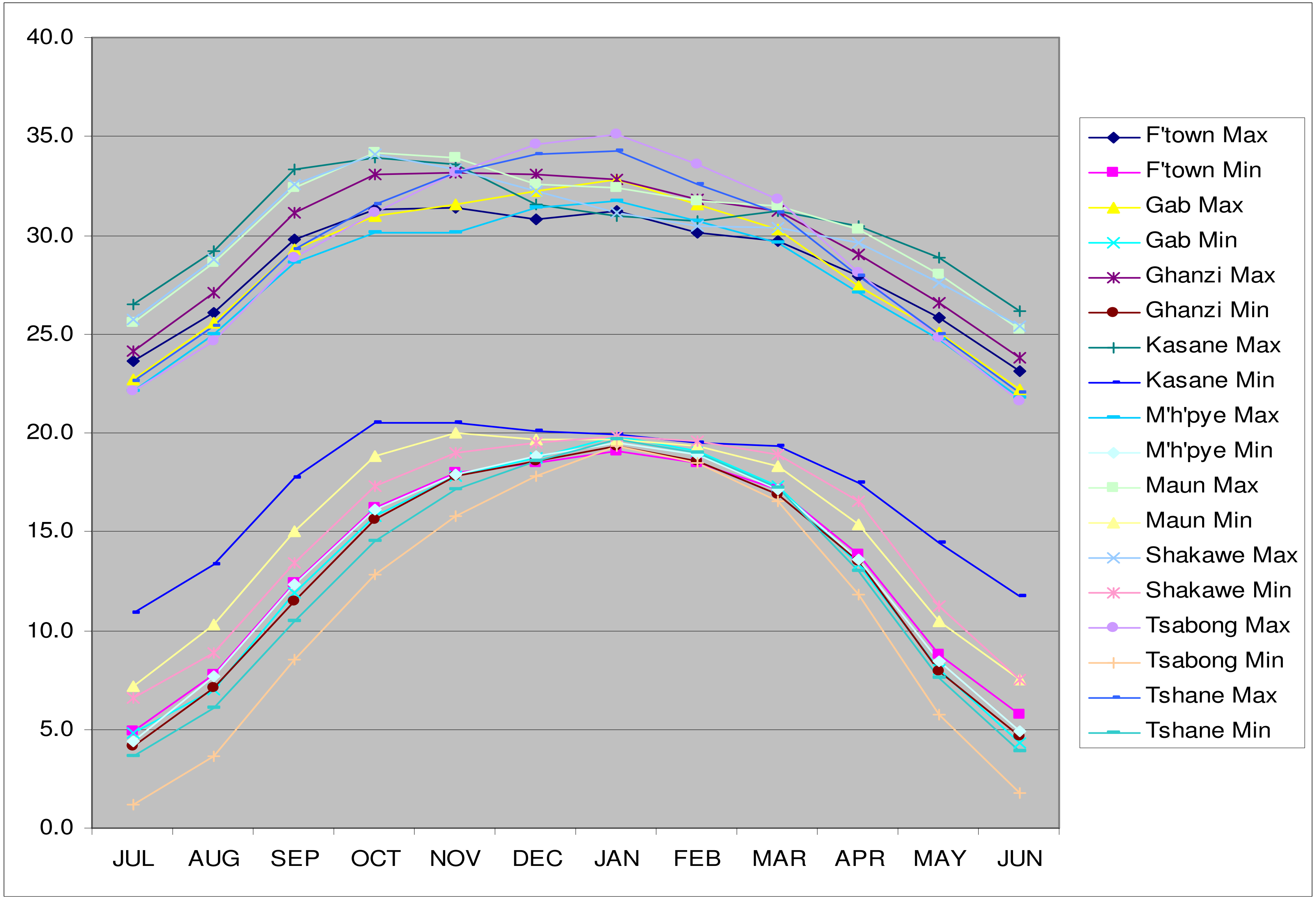


Fig. 3.7 Temperatures in different locations. (1961-1990)

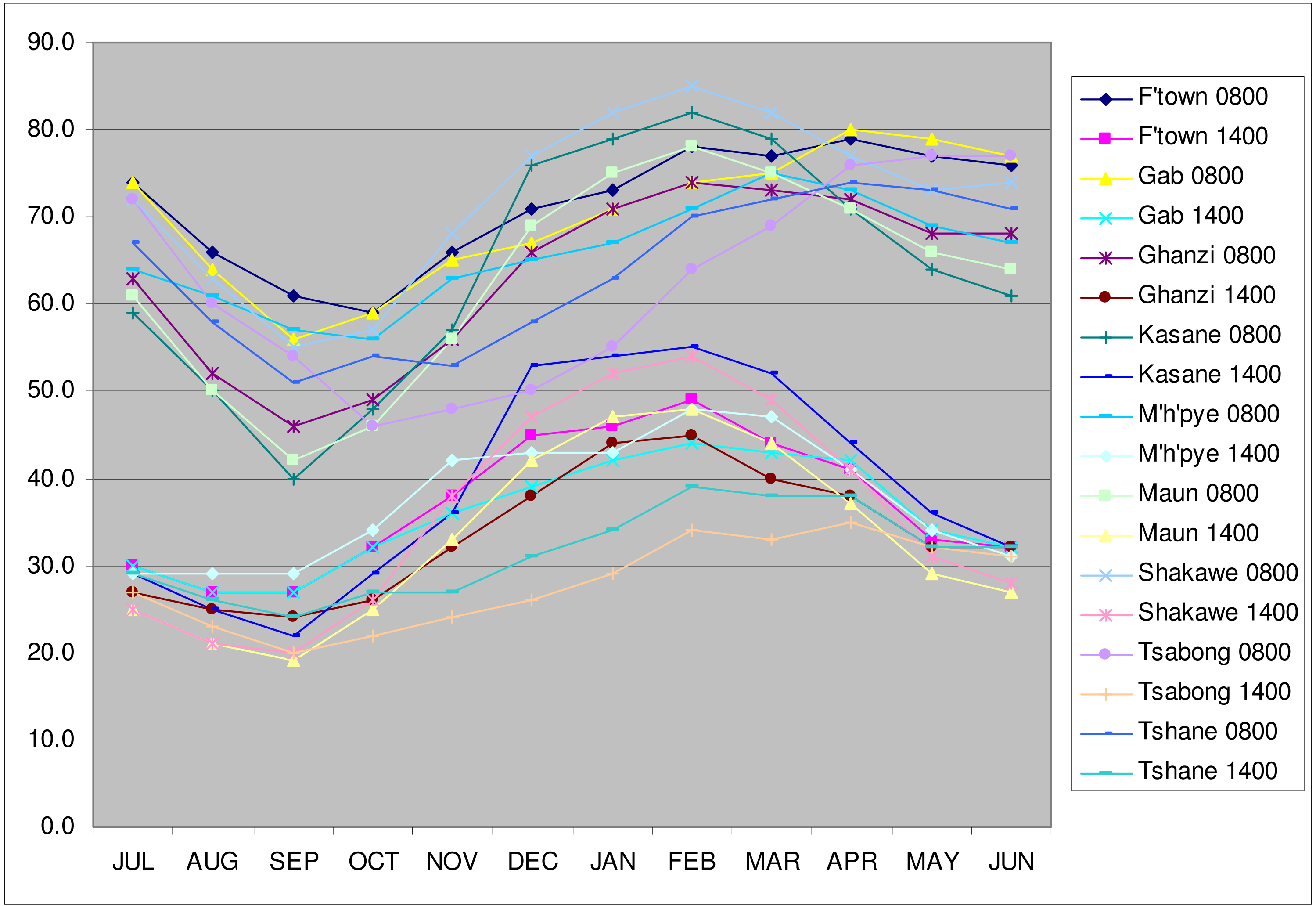


Fig. 3.8 Relative Humidity in different locations. (1961-1990)

There is considerable variation in temperature in different areas of Botswana. Generally winter minimum temperatures are higher the further north you go, with average minimum temperatures in July of 1°C for Tsabong, compared to 11°C in Kasane. Extreme minimum temperatures vary much more, with the coldest monthly mean temperature in Tsabong being –9.5°C compared to 3°C in Kasane.

Maximum summer temperatures show less variation, with the mean maximum temperature for January of 35.1°C in Tsabong, compared to the mean maximum temperature for October in Kasane of 33.9°C. The highest monthly mean temperature in Kasane was 41.5°C compared to 42.1°C in Tsabong.

In the north of the country there is little or no need for winter heating, whereas this is required in the south, and particularly southwest.

It is recommended that for building energy purposes the Ngamiland District and Chobe District which include Maun, Shakawe and Kasane should be regarded as the Northern Climate Zone, and the remainder of the country be regarded as the Southern Climate Zone.

3.5. Climate Patterns.

In addition to the geographical variations in climate, there are also patterns of climate within one locality. In considering the impact of climate on building energy performance, it is important to consider the different patterns that occur, and differentiate these from the average characteristics, which may never actually be experienced.

During the winter there tend to be a succession of cold fronts that move across southern Africa from the south to the north. These are experienced in Botswana as a period of time, ranging from a few days to about two weeks with low temperatures, cold southerly winds, and clear skies. In low lying areas between hills, these are the times when frost is experienced. Typically these cold spells occur in the month of June, or Seetebosigo (don't visit at night).

In between these cold fronts, the winter weather may be relatively warm during the day, when the sun warms the still air, and cool at night with the minimum temperature experienced at dawn when the earth has had a full 9-10 hours of radiation to the clear night sky. The difference may be as much as 8°C in minimum temperature within a week. If the average hourly temperature were to be taken for design purposes, the actual conditions would never be reflected.

In the summer there is perhaps even more variety in climatic patterns, with some years being generally dry years of drought, some years wet, with 'good' rains, and many years falling somewhere in between. During years of good rain, a daily cycle may occur for several weeks at a time, with clear skies until mid afternoon, when thunderclouds roll in from the southwest, breaking into a violent thunderstorm in the late afternoon. When this has exhausted its load of moisture onto the earth, the clouds simply disappear, leaving a clear sky at or just after sunset, and throughout the night. Following a cycle of such daily storms, there may be a period of dry weather with not a cloud to be seen for days or even weeks at a time. Again, the average data for a month that includes both types of weather pattern would provide a weather picture that may never actually occur in reality.

3.6. Resource Material

3.6.1. Books and papers

Anderson, R. 1970. 'Climatic Factors in Botswana'. Botswana Notes and Records Volume 2 pp. 75-78. The Botswana Society.

Bauer Consult. Gaborone climatic data based on hourly data for years 2000-2002, provided by Department of Meteorological Services.

Bhalotra, Y.P.R. 1987. Climate of Botswana Part II: Elements of Climate. Department of Meterorological Services.

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2. Sunshine and Solar Radiation & Evaporation.
3. Temperatures & Humidity of the Air.
4. Surface Winds & Atmospheric Pressure.

Bhalotra, Y.P.R. 1985. Rainfall maps of Botswana. Department of Meterorological Services.

van Deventer, E.N. 1971. "Climatic and other Design Data for Evaluating Heating and Cooling Requirements of Buildings" CSIR Research Report 300. Reprinted as CSIR Report Number: BOU/R9704, June 1997.

Green Building Guidelines: Meeting the Demand for Low-energy Resource-Efficient Homes, 2004. Sustainable Buildings Industry Council.

Hamilton, L.B., et. al. 1984. Passive Solar Design Workbook. BRET. Botswana.

Lechner, N. 1990. Heating, Cooling, Lighting – Design Methods for Architects. USA. John Wiley & Sons.

3.6.2. Web resources

ASHRAE American Society of Heating, Refrigerating and Air-conditioning Engineers.
http://www.ashrae.org/

CIBSE Chartered Institute for Building Services Engineers
http://cibse.org/

Department of Meteorological Services, Botswana Government.
http://www.weather.info.bw/

EDR. Energy Design Resources
http://www.energydesignresources.com/

EERE Building Technologies Program Home Page
http://www.eere.energy.gov/buildings/

Intergovernmental Panel on Climate Change
http://www.ipcc.ch/

Oasis Design
http://www.oasisdesign.net/

SBIC. Sustainable Buildings Industry Council.
http://www.sbicouncil.org/

South African Weather Service
http://www.weathersa.co.za/

SQUARE ONE environmental design, software, architecture, sustainability.
http://www.squ1.com/site.html

U.S. DOE Energy Efficiency and Renewable Energy (EERE) Home Page
http://www.eere.energy.gov/

WBDG - Whole Building Design Guide
http://www.wbdg.org/