EFFECTS OF SOLAR RADIATION ON BUILDINGS AND THERMAL COMFORT

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NOMENCLATURE

CHAPTER ONE		
Symbols and Acronyms	**Description**	**Unit**
MYER	Malawi Yearly Economic Report	
GDP	Gross Domestic Product	
COMESUN	Commission for the Establishment of a University in the North	
MOEM	Ministry Of Energy and Mining	
FRIM	Forestry Research Institute of Malawi	
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers	
PMV	Predicted Mean Vote	
ISO	International Standards Organisation	
CHAPTER TWO		
Q	Quantity of heat in body	Joules
λ	Wave length	m
C_1	Constant dimensionless	
C	Constant	W^{-2}
C_2	Constant	m K
T	Absolute temperature	°K
S	Entropy	Joules
η	Mechanical efficiency	%
CIBSE	Chartered Institute of Building Services Engineers	
ET	Effective Temperature	
CET	Corrected Standard Temperature	
SET	Standard Effective Temperature	
BRS	Building Research Station	
I	Heat Stress Index	
ITS	Index of Thermal Stress	
t_{tc}	Thermal Comfort Temperature	°C
t_a	Air Temperature	°C
t_w	Wet bulb temperature	°C
V	Air Velocity	ms^{-1}
t_n	Neutral Temperature	°C
R_m	Mean responses from voters	°C
t_{rm}	Room Temperature	°C
Clo	Unit of Clothes thermal insulation	
f	Frequency Distribution	

t_{ef}	Effective Temperature equation format	°C
t_{eq}	Equivalent Temperature	°C
A_b	Body Surface Area	m^2
W_b	Body Weight	kg
H_b	Body Height	m
t_r	Radiant Temperature	°C
t_{ar}	Ambient Temperature	°C
t_s	Skin Temperature	°C
t_b	Body Temperature	°C
p_s	Water vapour pressure	Nm^{-2}
S_k	Vote Count	
AMV	Actual Mean Vote	
PPD	Predicted Percentage Dissatisfied	
ATCM	Adaptive Thermal Comfort Models	
CHAPTER THREE		
a_z	Angle between the local the zenith and the sun	°
a	Solar altitude angle	°
a_i	Angle of incidence of solar radiation	°
I_λ	Incident Terrestrial Solar Radiation at a defined wavelength	Wm^{-2}
$I_{o\lambda}$	Extraterrestrial Solar Radiation	Wm^{-2}
τ_λ	Optical thickness	m
z	Height of reference	m
β	Atmospheric Attenuating Factor at height z	
β_s	Scattering Factor	
β_a	Absorbing Factor	
A_1	Constant that indicates the clearness of the atmosphere and varies with time of the year due to distance of the earth from the sun.	kWm^{-2}
A_2	A coefficient of the direct radiation reaching a surface from the ground	
B	A coefficient complementary to A_1that affects the clearness of the atmosphere and varies with time of the year	
C_s	A constant that varies through the year and is dimensionless	
ϱ	Ground reflectivity	
F_s	Surface coefficient between sky and surface	

F_g	Surface coefficient between ground and surface	
a	Regression constant for cloud cover to sunshine hours	
b	Regression constant for cloud cover to sunshine hours	
s	Cloud cover hours	h Day^{-1}
S	Sun shine hours	h Day^{-1}
I_t	Terrestrial Solar Irradiation reaching a horizontal surface per Day	MJ $m^{-2}Day^{-1}$
I_o	Extraterrestrial Direct Solar Irradiation reaching a horizontal surface per Day	MJ $m^{-2}Day^{-1}$
M_b	Metabolic rate	W
E_b	Energy lost from the body by evaporation	W
R_b	Energy lost from the body by radiation	W
C_b	Energy lost from the body by convection	W
S_b	Rate at which energy is being stored in the body	W
p_s	Water vapour pressure in the ambient air	Nm^{-2}
P_w	Body water vapour pressure	Nm^{-2}
E_v	Rate of evaporation	$m^3\ s^{-1}$
V	Wind speed	$m\ s^{-1}$
Q	Rate of heat gain	$Wm^{-2}\ deg^{-1}C$
A	Surface area	m^2
F	Energy extraction factor dependent on the structure characteristics	
τ	Weighted average absorptivity	
I	Global Irradiance (corrected for inclined and vertical surfaces)	$W\ m^{-2}$
U_L	Weighted transmittance value of all surfaces in contact with the external environment	$Wm^{-2}\ deg^{-1}C$
t_{ei}	Indoor temperature	°C
t_{cl}	Lower limit Thermal Comfort Temperature	°C
t_{mw}	Mean temperature of the inside walls	°C
t_a	Air temperature	°C
κ	Number of air changes	
σ	Constant relating indoor air changes and external wind speed	
β	Wind speed coefficient	
V_u	Wind speed measured at 10 mitres	$m\ s^{-1}$
C	Convective heat exchange	W
ϕ	Factor of heat exchange and is dependent on type of clothes	
V	Indoor wind speed	$m\ s^{-1}$
t_a	Air temperature	°C
C_s	Cooling sensation	m^3s^{-3}
k	Proportion of the metabolic heat dispatched by means	$Wm^{-2}\ deg^{-1}C$

	other than evaporation	
t_c	Area weighted mean outer surface temperature of clothes	
h_c	Coefficient of heat transfer by convection	Wm^{-2} $deg^{-1}C$
h_r	Coefficient of heat transfer by radiation	Wm^{-2} $deg^{-1}C$
S_r	The required Sweat rate	Wm^{-2}
R	Radiant heat exchange	Wm^{-2}
f_s	Cooling efficiency factor of seating dimensionless	
W	Metabolic energy transformed into useful mechanical work	W
I	Heat Stress Index	
R_m	Mean radiant temperature energy incidence	Wm^{-2}
p_a	Atmospheric vapour pressure	Nm^{-2}
CHAPTER FOUR		
I_{tG}	Global Irradiation as read on a Gunn-Bellan Spherical Pyranometer	Cal cm^{-2} Day^{-1}
K	A conversion factor (Cals to joules)dimensionless	
I_{tS}	Global Irradiation as read on a Camp-Bell Stokes Sunshine Recorder.	Cal cm^{-2} Day^{-1}
D.d	Degree-Day	Deg C Day
A_L	Altitude of a location	m
f_d	Factor relating assessed Degree Days to Actual Degree days above the reference temperature of 27°C dimensionless	
t_{ref}	Reference Temperature	°C
t_{min}	Minimum temperature acceptable by occupants	°C
p	The period over which the temperature above 27°C is being considered	Days
PBWT	Preferred Bath Water Temperature	
t_a	Air Temperature	°C
HMMT	Hourly Mean Maximum Temperature	°C
MMMT	Monthly Mean Maximum Temperature	°C
$t_{a-h1400}$	AIR temperature at 1400 Hours	°C
t_{a-mm}	Mean Monthly Maximum Temperature	°C
t_a	Preferred Bath Temperature	°C
t_{ab}	Air Temperature in the Bathroom	°C
ISO	International Standards Organisation	

CHAPTER SIX

N	Number of samples	
HW	House Width	mm
RAP	Roof Apex	mm
HL	House Length	mm
P_r	Solar Power	W
W_s	Air Mass 1 or 2	
λ	Wave length	m
R	Directional Reflectance of Irradiance dimensionless	
a	Solar Angle	
κ	Absorptance	
d	Solar declination	
L	Latitude of a location	
h	Hour angle	
a_1, a_2	Critical Solar Angle	
τ_1, τ_2	Solar Wall Azimuth Angle	
I_t	Global Irradiation	Wm^{-2}
I_d	Diffuse Irradiation	Wm^{-2}
I_r	Reflected Irradiation	Wm^{-2}
R_1	Height to, underside of the roof at the door position	mm
R_2	Height to level where a horizontal plane perpendicular to plane of height just clears the edge of the eaves.	mm
R_3	$R_1 - R_2$	mm
E_w	Width of Eaves	mm
E_d	Width of Verandah	mm
H_v	Height of Eaves to verandah plinth	mm
H_e	Height of Eaves to natural ground	mm
H_k	Height of Verandah above the natural ground	mm
θ	Roof slope angle	
M	Mass	kg
F_1	Force acting on the grass on roof down slope	Nm^{-2}
F_2	Force acting on the grass opposing F_1	Nm^{-2}
g	Gravitational acceleration	ms^{-2}
μ	Coefficient of friction dimensionless	
H_m	Humidity	%
I_t	Global Irradiation	MJm^{-2} Day^{-1}
R_f	Rainfall	mm
L	Latitude of a location	^0S or ^0N
t_a	Air temperature	°C
V	Wind speed	ms^{-1}

ABSTRACT

This work was undertaken to investigate the perceived problem of Thermal Discomfort in Malawi. One observable effect of thermal discomfort was the amount of foreign exchange that was spent to import air conditioning devices. The purpose of the work was to find out, and quantify the problem of thermal discomfort and outline its effects to the people and country.

In order to investigate the problem of thermal discomfort in depth in a place where the necessary data hardly existed a lot of work had to be done. The work has been outlined in four stages of research, analysis and documentation and these are as follows

1 Literature Review

The subject of Thermal Comfort appears to be location specific, but the general principles are universal. In that context it was necessary to read widely on both historical and contemporary current work. The problem of thermal comfort in general was being discussed as early as 1758 and still remains a big area of research and discussion today. A considerable number of literature that specifically relate to the problem of thermal comfort in the tropics has been reviewed. The problem of scales for thermal comfort measurement has been discussed in detail. It is still not possible to quote a scale that is satisfactory. However, the recent approach of Adaptive Thermal Comfort Model seems to be closer to the answer than the others

2 Analysing Existing Relevant Information And Data In Malawi

In the course of this work it was found out that quite a large amount of useful data existed in Malawi. However, this data was not standardised. Most of this data had to be cleaned and updated. Some of the old formulae are quoted in their original formats in order not to confuse the referencing. The data that exists in Malawi has been recorded on three types of instruments; namely the Gunn Bellum Spherical Pyranometer, the Camp Bell Stoke Sunshine Recorder and the Eppley Pyranometer. Most of the data was recorded using the Camp Bell Stokes Sunshine Recorder. The

data recorded on the Gunn Bellum Spherical Pyranometer had to be related to that from the Camp Bell Stokes Sunshine Recorder. The former gave data that was more accurate as was found out when a comparison was made with data recorded on an Eppley Pyranometer. A paper on this subject was accepted for publication in the *Renewable Energy Journal* of WREN. Wind speeds, air temperatures, and humidity have been analysed to investigate the severity of thermal discomfort relative to locations in Malawi. This has resulted in the identification of three climatic zones. A tool for testing Thermal Discomfort severity of a location by calculating number Degree Days (***D.d***) if the altitude (A_L) has been developed; as

$$\mathbf{D.d} = -575.994 \ln A_L + 4226.6$$

3 Field Measurements

In order to investigate some of the issues that came out of this work, it was felt simpler to conduct field measurements. For example it would have been possible to build typical experimental houses, and extract performance data on Thermal Comfort from these buildings. However, this approach would have been very expensive. On the other hand it was felt that it was possible to find in the field that were representative of typical buildings and could be prepared and tested to extract performance data for use in the work. The latter approach was adopted and has proved to be more realistic than the former.

4 Field Surveys

There were certain areas where the only way to find information was not to conduct experiments but to conduct field conduct surveys. This was done once to find the Preferred Bath Water Temperature (PBWT) and deduce the Neutral Temperature Range for Malawi. This yielded very useful results. The first published paper on this work was in this area (copy of this publication is attached). The second area of field survey was to survey traditional buildings in seven selected districts stretching from latitude 9°S to 17°S; covering a terrestrial distance of over 1000 km; over altitudes from 52 to over 1600 metres above mean sea level (m.a.m.s.l). This again yielded very useful environmental data that explained why traditional buildings have certain structural elements as functions of the environment and the need to achieve Thermal

Comfort. A number of useful equations have been developed. From that sub routine of this research of PBWT survey an equation was developed that related the bath temperature (t_b) to the air temperature (t_{ab}) as; $t_b = 0.3772\ t_{ab} + 36.4401$. Part of this work was also published separately in 2001.

From this equation the Thermal Comfort Temperature Range for Malawi was deduced as 22-27°C. From the survey of the traditional buildings, a number of structural elements were that are functions of Thermal Comfort were identified as derivatives of the desire to have Thermal Comfort in the buildings. A regression equation that can give values of irradiation of the locality in $MJm^{-1}\ Day^{-1}$ was developed.

Lastly the results have been extracted as recommendations directed at policy makers, and both Architects and Engineers to use this data and the results in their design work. It is also further recommended that the national buildings regulations could be updated and revised to incorporate some of the findings. It is strongly believed that some of the findings will be incorporated to update the two main Laws that regulate Public Health in Malawi. These are the *Public Health Act; Cap. 34.01,* and the *Health and Safety at Work Act, 1977;* of the Malawi Laws.

All data that has been cleaned up or measured specifically for this work has been organised and tabulated into ready-to-use tables and are included.

CHAPTER 1

1.0 INTRODUCTION

1.1 THE PROBLEM OF THERMAL COMFORT IN MALAWI

Solar radiation warms up building structures and if the structures are not designed to allow for natural ventilation or air conditioning the resultant ambient thermal energy causes thermal discomfort. The problem of thermal discomfort in both the living and working environments and its effects on people are not understood. In many instances the discomfort is accepted as natural without understanding or appreciating the physiological stress this thermal discomfort can cause. Sometimes the solutions undertaken to induce thermal comfort require expenditure that involves foreign exchange. If buildings are designed with thermal comfort using passive techniques, this expenditure may not be necessary.

In Malawi there are areas that are too hot for comfortable living. Thermal discomfort has a number of harmful physiological effects. The human mind can only command the body's physiological processes effectively within a certain range of temperature. Beyond this range the mental faculties are affected. Intellectual output and work performance can be reduced. Low productivity both mentally and physically can further contribute to external dependence for material wealth of a nation.

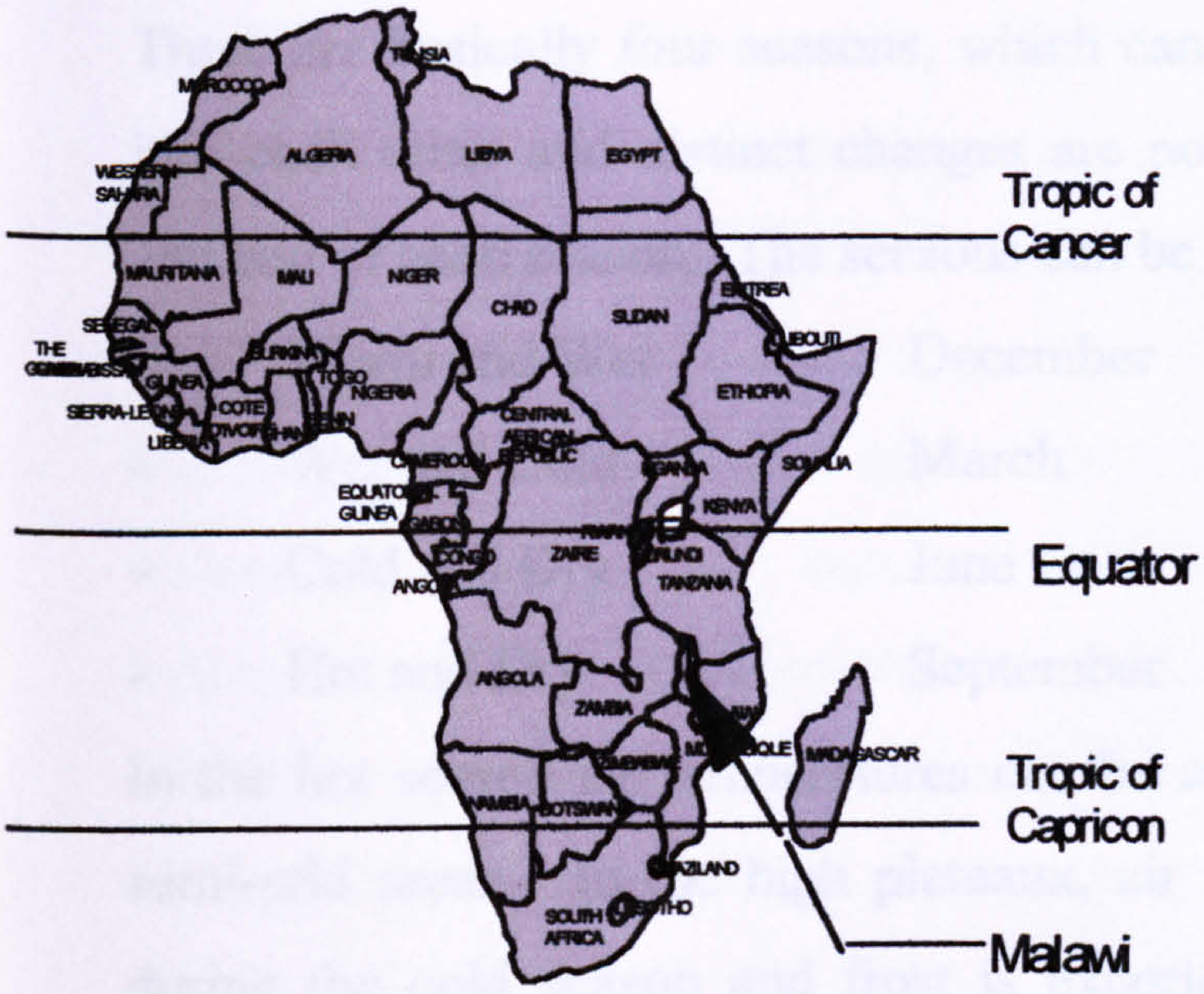
In this investigation it is intended to outline and explain the effects of thermal discomfort to peoples' health and how thermal comfort is achieved in traditional buildings. It is probably common knowledge that economic growth of a nation slows down if the level of trade deficit it has, with its trading partner countries increases. If the country imports more than it can export, the obvious result is economic drain of its natural resources and loss of wealth. When people experience thermal discomfort in the living environment, they take positive action to reduce the discomfort by acquiring cooling devices. For Malawi these devices have to be imported from other countries. As imported items they are only affordable by a few people. This is the current situation in Malawi. What is not known is how much thermal discomfort is experienced. The problem of thermal discomfort may be acknowledged but its severity is not officially appreciated. Thermal discomfort can cause physiological inefficiency while the use of air conditioning equipment to restore comfort requires the use of foreign exchange to procure these devices from abroad. There is need to investigate and find some solutions that can be applied that are effective and affordable to induce thermal. To do this, the geographical, topographical, environmental and other conditions need to be understood by carrying out detailed analyses of the factors that affect thermal discomfort. The purpose of this study is to understand the dimensions of this problem in Malawi and its distribution over the country.

The concept of thermal comfort has not been researched in Malawi. There is no information on what are the temperature limits tolerable by the people. The standard limit of 19-24°C that is in current in use is adopted from other countries such as the United State of America and the United Kingdom. In this work it is also intended o show that the limits of thermal comfort do vary from country to country and are dependent on several factors including the countries location, the people, and their culture and many other factors.

Although it is acknowledged that there is very little or no information on this subject in Malawi, it would be a tremendous contribution to knowledge to start working in this area. Of course there must be some information in some countries that are located in a similar geographical location like Malawi. However, this would on be a starting point and the final usable knowledge must be that derived from the environment in Malawi.

1.2. GEOGRAPHICAL LOCATION OF MALAWI.

Malawi is a land locked country south of equator in Africa. It has common borders with Tanzania in the North, Zambia in the West, and Mozambique in the East and South.



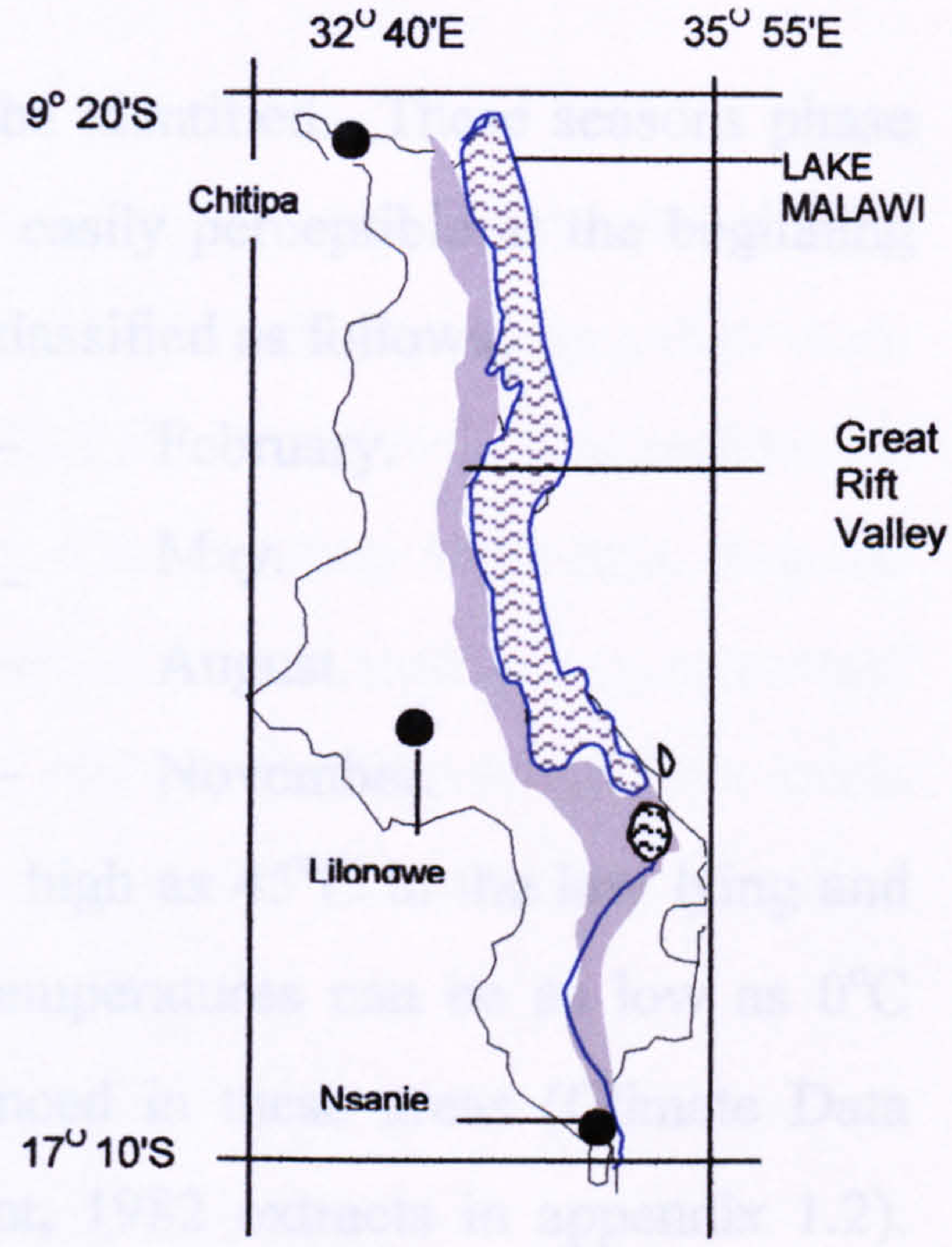


Figure 1.1 Map of Africa

Figure 1.2 Map of Malawi

The country stretches from 9° 20'S to 17° 10'S and 32° 40'E to 35° 55'E. The land mass area is 94,276 sq. km while the total area covered by lakes is 24,208 sq. km; about a third of the land mass; see Appendix 1.1.

1.3 GEOGRAPHICAL FEATURES.

The country lies partly in the Great Rift Valley that starts from the Red Sea in North Africa. The rift valley continues through into part of Kenya, Tanzania and Malawi. The largest water body is Lake Malawi. This lake has an outlet that flows into Zambezi River draining into the Indian Ocean. The lake catchments area extends into Tanzania and Mozambique (Pike; 1968). The country has very diverse vegetation ranging from typical tropical forests in the river valleys to savannah and semi arid land. The lowest habitable area is 48 *meters above mean sea level* (m.a.m.s.l) Nsanje in the South, while the highest habitable area is over 1600 meters a.m s.l, Dedza in the centre and Livingstonia in the North.

1.4. SEASONAL CHANGES.

There are basically four seasons, which can be identified. These seasons phase into each other and distinct changes are not easily perceptible at the beginning and end of each season. The seasons can be classified as follows;

- Warm and Wet December – February.
- Wet and Cold March – May.
- Cold and Dry June – August.
- Hot and Dry September – November.

In the hot season air temperatures can be as high as 45°C in the low lying and semi-arid areas. In the high plateaux, air temperatures can be as low as 0°C during the cold season and frost is experienced in these areas (Climate Data tables of Malawi, Meteorological Department, 1982 extracts in appendix 1.2). The climate falls between the Warm Humid and Warm Dry as classified by Van Straaten et al (1969). Some areas fit the Hot Dry desert climate and Tropical Upland Climate templates as classified by Atkinson; (1953). These temperature profiles necessitate heating (in the cold season; June to August) and cooling (in the hot season; September to December) of habitable areas.

1.5 THE PEOPLE, POPULATION, AND ECONOMIC POTENTIAL

The indigenous Malawian people have descended from a very old ethnic group in Central Africa (Pachai; 1967, Rangely; 1964). It has been reported in the 1998 census that Malawi has a population of 9.8 million (Malawi Government Census; 1998). Over 85% of these people live in rural areas. However, the rate of migration towards the urban areas is increasing due to the unfavourable economic pressures in the rural areas. It is further reported that over 87% of the rural population are engaged in agricultural work. The economic growth is 3.1% (MYER; 1999), and the largest contributor to the GDP is agriculture at 37%, followed by distribution services at 24.2%, manufacturing at 13.4%, and government services at 9.5%. Certainly the economy of the country does not depend on industrial production.

The overall literacy rate of the country is 26% and it is estimated that 3.5 million are economically active. Sixty four percent of the females are engaged in work compared to 67% of the male population (COMESUN; 1996). The problem is that most of the work is done by hand and therefore productivity is low. Imports exceed exports by 37%. Some of these items are in hi-technology areas and include air conditioning equipment for offices and homes. Some of these items could be proved unnecessary if buildings were constructed properly; incorporating the principles of passive design.

1.6 ENERGY SOURCES AND COST

The extremes of temperature cited in section 1.4; are outside the normal limits of thermal comfort for humans. Thermal Comfort studies conducted in Zambia; which is a neighbouring country to Malawi and a country of similar anthropological origin (Malama; 1998, Harris; 1974), have concluded that the Thermal Comfort range in Zambia is 23.5 to 28.5°C in the warm season. Although similar studies are yet to be done in Malawi; these ranges are likely to be similar to those in Zambia. This assumption then conveys the fact that there is a definite need for heating and cooling in the homes in the two seasons. This energy demand is met by biomass, which provides 93% of the national energy demand; where 87% is from wood fuel and 6% is from Charcoal. The balance of 5% comes from petroleum; 1% from coal and 1% from electricity (Kettle; 1991). The people who use air conditioning devices to cool their homes or offices use some of this electricity. Again if a building is well designed this component of expenditure is not necessary.

The country has 164 MW of installed hydro electricity but the penetration is only 4%. A unit of electricity (I kWh) on Domestic Tariff sells at US$ 0.02. Considering the per capita income of US$140, electricity is not affordable to most of the people. The pattern of energy consumption published by the Electricity Supply Corporation of Malawi (ESCOM Reports, 1997, 1998) show an increase in electricity consumption between May and August which is the cold season. This must obviously be caused by the need to heat homes water. This part is perhaps necessary however, during the warm moths people use air conditioning devices to cool the liveable environments. This latter part is not necessary and both the energy and the cost of the equipment could be saved.

Dodd reports that wood fuel consumption in Malawi is 4.05 m^3 per family of five persons (Dodd; 1978). An official government document compiled in 1993 reports that the average per capita consumption had increased to 1.31 m^3 by that year (MOEM; 1993). The most common firewood trees are the *Brachystegia, Eucalyptus* and *Pinus* species which have calorific values of 20.26 MJ/Kg, 19.39 MJ/kg and 17.75 MJ/kg respectively. *Brachystegia* species are a typical hardwood with a low growth rate. Oppenshaw reports (Oppenshaw; 1981) that when wood fuel is used in homes, 35% of the energy is used for water heating. Kettle reports (Kettle; 1991) that 87% of the charcoal sold in the urban areas in Malawi, is used for space and water heating. Most of the financially less able people in the urban areas use charcoal and firewood to heat water and warm the homes in the cold season. Recent reports have stated that an urban dweller consumes over twice the mount of wood fuel than the rural dweller. Most of the charcoal is made from the indigenous trees because of the high calorific values. The Brachystegia species have some of the highest calorific values approaching

20.26 MJ/kg (FRIM; 1979). Calorific value in wood is a function of density of the wood and is directly proportional to that density.

Mkaonja reports that wood generation rate of indigenous trees in Malawi are 0.2-3.1m^3/hectare year (Mkaonja 1979). This explains the extensive deforestation being experienced in Malawi now. This means that the regeneration of wood per year of the indigenous species cannot support a family in a year at the current rate of fuel wood consumption. In the urban areas, offices are supplied with fans and electric heaters, or fitted with air conditioners. Middle and upper income groups have air-conditioned houses; whenever this is possible. Since the penetration of the electricity grid in Malawi is only four percent, the rest of the people have no access to electricity. It is acknowledged that domestic energy consumption; mainly for heating and cooling forms the biggest portion of the energy used in the home.

In Malawi houses require heating or cooling at the appropriate times of the year to restore the fluctuating thermal balance. A number of homes use oil for heating and the oil is imported. For cooling, almost all financially able homes use mechanical cooling devices. These are that all imported. Both these requirements use considerable amounts of foreign exchange. The notion of spending energy at a considerable cost to cool or heat homes has to be questioned and alternatives must be explored.

A subtle point to appreciate here is that, while discomfort due to low temperatures can be resolved by simple methods such as clothing and heating, the problem of high temperatures has no simple solution apart from the removal of the clothing or applying air cooling devices. The inability to resolve the thermal discomfort in Malawi may have negative economic consequences that are not yet being taken seriously.

1.7 BUILDING STYLES AND THERMAL COMFORT

Construction in Malawi has developed along the lines of a tradition that was introduced by the British in 1898 (Phiri, 1988, Clark 1996). From that date, generally to date; the popular building styles in urban areas are foreign. Majority of residential buildings in the peri urban areas and the countryside are constructed using indigenous technology that has developed over five hundred years; (Cole; 1954). While the British influenced architecture has developed in urban areas and local centres, the vernacular architecture still thrives in the countryside.

The principal function of a house is to provide shelter but in the long term the house must be comfortable. One of the most important physiological criteria for comfort in a house is Thermal Comfort. Thermal Comfort is a function of solar irradiance as the main generator of ambient thermal energy. The solar energy induces a number of effects in the environment thus creating different climates as modified by local geographical features. This climate, in turn, influences human thermal comfort in the environment.

In this work Thermal Comfort will be defined as "that condition of mind which expresses satisfaction with the thermal environment"; according to ASHRAE (Taki et al 1999).

Electricity consumption pattern shows increased energy demand between the months of May and August when air temperatures are low. This is simple evidence that thermal comfort is achieved by adding energy to the environment. Fluctuation of room temperatures in homes could be minimized by careful design of the buildings. In contrast, the experience by those who have lived in both traditional and modern types of houses is that the former type of house is thermally comfortable. It is also a fact that the traditional house costs less to construct and maintain than the modern house. Holm, (1995) reports that in his observation, modern and high cost housing in Southern Africa do not necessarily induce thermal comfort

It is argued in this presentation; that with careful design based on knowledge of passive design, resources that are spent to achieve thermal comfort in liveable areas can be reduced. Passive design, techniques could be adopted from the vernacular buildings and then use these in modern buildings wherever it is possible. Energy saved from "domestic energy budget" can be directed to other sectors of development. A country's development is directly related to its per capita energy consumption (Saif-Ul-Rehman; 1991).

1.8 OBJECTIVES OF CURRENT RESEARCH

The objectives in this research work are to investigate in building parameters and structural elements that moderate the effects of solar radiation on buildings and consequently to promote thermal comfort. The specific objectives of this work are as follows:

1.8.1 To review literature and study some important parameters on thermal comfort and the condition that is associated with its causes and effects. This has been described in Chapter 2;

1.8.2 To review theories in this area, identify important areas, and compile parameters that govern thermal comfort as specifically applied to the conditions in Malawi. This has been done by reviewing the Thermal Comfort limits and conducting field surveys on hot bath/shower temperatures. These have been analysed and treated as dependants of air temperatures, to establish a Preferred Bath Water Temperature for Malawi. The preferred PBWT has been compared to the thermal comfort temperatures as given by the Predicted Mean Vote (PMV) as published in ISO 7730. This has been done in Chapter 3;

1.8.3 To undertake a detailed analysis of meteorological data from all weather monitoring stations, filtering this data and confirm its reliability, analysing the pattern and distribution of solar radiation in Malawi and identify characteristic geographical zones and requirements for thermal comfort. This has been done in Chapter 4;

1.8.4 To undertake field studies of traditional houses in order to investigate the comparative thermal performance of common building types to establish relative thermal performance under typical solar radiation. This has been done in Chapter 5;

1.8.5 To undertake a detailed house survey to investigate the function of some design features in traditional buildings that contribute to thermal comfort. This has been done in Chapter 6.

1.8.6 To propose a design procedure that can be used by those persons in Malawi who are responsible for the designing the liveable environments and who can design buildings using the approach to improve thermal comfort. This has been presented in Chapter 7.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 THE HUMAN BODY THERMAL BALANCE

The Thermal Comfort Criteria are considered here as a function of the sum of the intrinsic body thermal energy and thermal energy gained from the environment. The body energy is generated by chemical processes in cells that break down ingested food and release energy forms that are required by the body muscles, growth and replacement of body tissue. From a consideration of the First Law of thermodynamics namely that energy is always conserved irrespective of form. A simple thermal energy balance paradigm is presented in fig. 2.1.

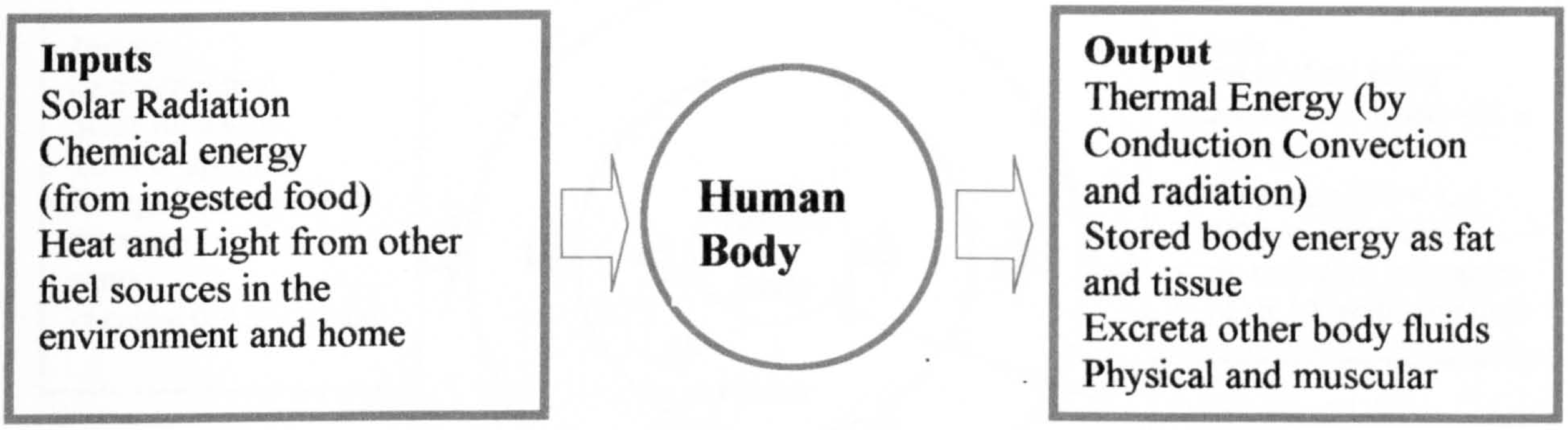


Figure 2.1 Thermal Energy Balance in the Body.

Figure 2.1 shows how the law of conservation of energy is upheld outline that; a energy audit of the body should show that the energy input into the body must balance with the sum of energy stored and extracted from the body. In reference to the thermal energy; this energy balance infers that the entropy of the body must not be altered.

The first law of thermodynamics in this particular case can be outlined in a very simplified format as;

$$Q_b = \sum_{i=1}^{n\to\infty}(Q_{I..} .. Q_N) \qquad (2.1)$$

Q_n is the n^{th} energy component in the body as heat, fat, tissue and all the heat in the body fluids and excreta.

A comfortable house must maintain a thermal balance; namely that the house must moderate and maintain a thermal balance required by the body to prevent the body from losing or gaining thermal energy and alter the balance. The most important measurable environmental parameters that cause this change are solar radiation, temperature, humidity, wind and precipitation (Givoni; 1969, Barrington 1962 and 1967). In liveable environments the thermal balance must be maintained. To maintain this state of balance, (Coveney, 1992) thermal energy must be extracted out of the building or added to the building. Or the design of the building structure must be such that the natural thermal energy storage and exchange between the structure and the environment matches those rates that promote the thermal balance in the body.

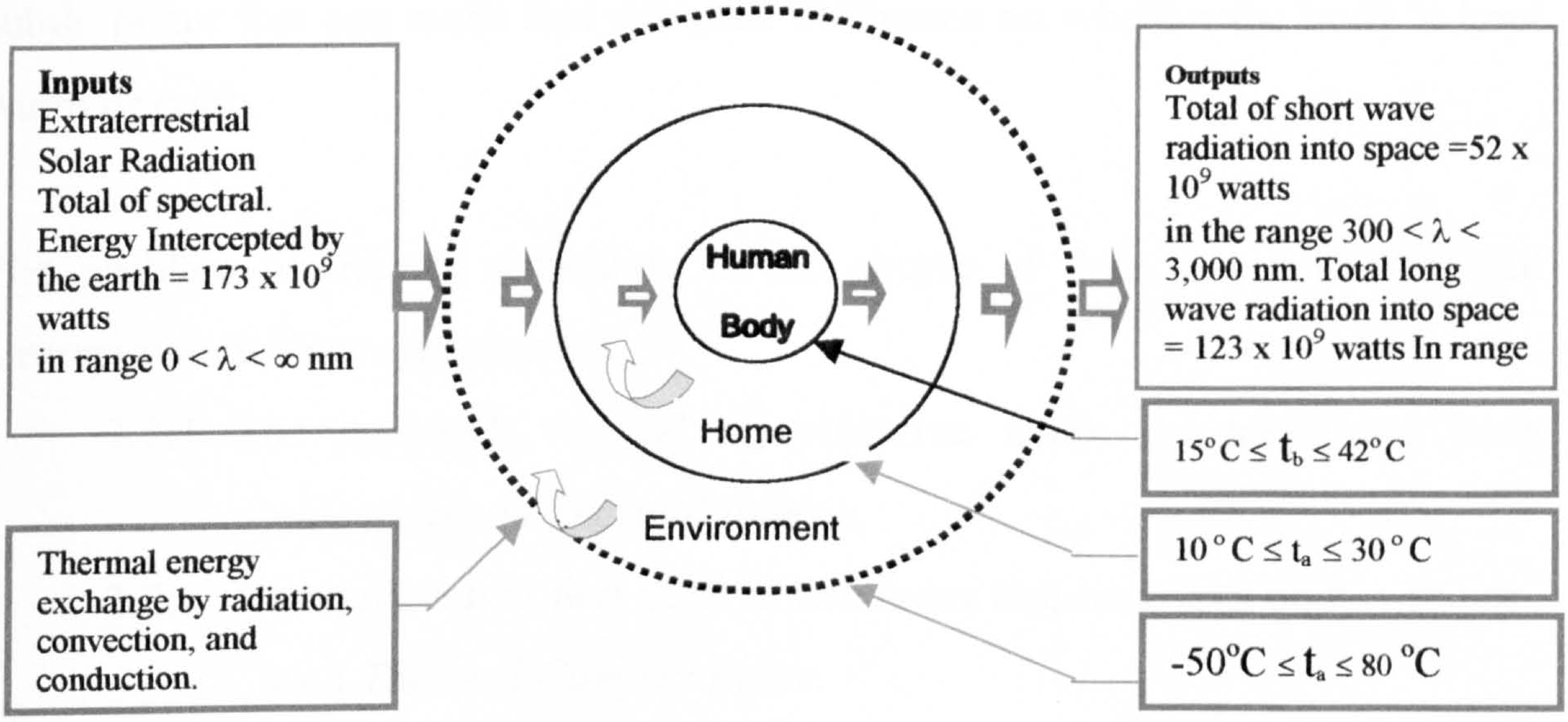


Figure 2.2 The Thermal Balance System that Interacts with the Body

(t_b, t_a t_e represent body, air, and environment temperatures respectively. Energy figures adapted from Hill et al, (1995) some extreme parts of the body can be at 5°C e.g. toe, cheek and ear when the internal organs are still at 37°C)

Figure 2.2 presents an extended paradigm that shows the overall thermal balance in the three domains; namely body, house, and environment. Of the three domains, the home has the smallest tolerance range.

2.2 THE MEASUREMENT OF BODY THERMAL COMFORT

The subjective sensation of heat in the body is a common phenomenon. However, an objective method to establish cause and effect quantitatively has taken a long time to be understood scientifically and to be resolved. Literature shows that as early as 400 B.C; Hypocrites described the effects of climate on thermal comfort (Webb; 1959). McPherson reports; (1962) that Galileo in 1593, attempted to determine temperature as an index of thermal sensation and that Benjamin Franklin in 1729, demonstrated rates of absorption of solar radiation by clothes of different colours. Franklin is probably; the first to demonstrate that thermal comfort is also a function of the type and colour of clothes; a rather subtle factor that can make that marginal difference on whether the body is kept warm or cold.

The problem of thermal sensation, in the course of time, has been resolved through two distinct approaches.

2.2.1 The approach to find an objective index for measuring body temperature is *Thermal Index.*

2.2.2. The approach to find a subjective index that measures body warmth as a *Thermal Comfort Index.*

2.3 OBJECTIVE MEASUREMENT OF TEMPERATURE AS INDEX FOR THERMAL COMFORT

In the history of science, the problems of thermometry, calorimetry, and thermodynamics have been key areas for the advances in science in general, but also in the furtherance of the deep understanding of dynamics of body thermal energy in particular.

Relevant to the study of thermal energy in the human body, are the familiar Kirchoff, Kelvin, Plank, and Wiens laws of thermal transfers as reported by Hill (Hill et al; 1995) Emissive power from a black body

When power from a black is plotted as a function of wavelength, a characteristic curve is, and the sun emits power as black, a relationship is obtained where Wiens Displacement Law can be illustrated. Wiens Law states:

$$\lambda_{max} T = \text{Constant} \qquad (2.2)$$

$$= 2898 \times 10^{-16} W^{-2}$$

The change of entropy of a body can be defined as;

$$\delta S = \left(\delta Q \frac{1}{T} \right) \qquad (2.3)$$

Thermal changes in the body can be assessed through monitoring the temperatures. Givoni (1969) reports that body temperatures measured in the mouth and rectum can accurately represent the temperature of the core organs of the body. The normal body temperature is 36.7^0C while rectal temperature is 37^0C, skin temperature is constantly at 35^0C being the interface between the body and the environment.

From this discussion it has been outlined that the normal inner body temperature is 37°C. In the review that follows in this work, numerous measurements and surveys have shown that generally, the common limits of *Thermal Comfort* vary between 18°C and 28°C.

From these facts, and if the body can be likened, theoretically, to a Carnot engine, practical pieces of information emerge as follows:

2.3.1 The maximum wavelength (λ_{max}) of radiation emitted by the body at 35^{0}C is 9410 nm; directly from the equation (2.2)

2.3.2 The theoretical efficiency (η_K) of the body (from the second first law) can be evaluated as follows:

$$\eta_{301}\ ^oK = 6.13\% \qquad (2.4)$$

$$\eta_{291}\ ^oK = 2.40\% \qquad (2.5)$$

$$\eta_{310}\ ^oK = 0\% \qquad (2.6)$$

where the subscripts represent the absolute temperature in question.

As far as the objective measurements of temperature are concerned, and purely from a mechanical point of view at zero efficiency, the chemical processing mechanisms that constitute life should cease to work. Jones; (1973) reports that sweating ceases at 40.5°C, while death occurs at 43.5°C. This report directly supports the thermodynamic deduction that sweating as a mechanism to cool the body sets in at 25°C but the risk of death starts at 35°C (BRS 66).

The Agreément Board of Republic of South Africa reported later in section 2.8 has recommended 30°C as the absolute maximum temperature for habitable areas (Wentzel et al, 1981). All these facts confirm the fact that the body can only function normally within a specific temperature range with minor adjustment to culture and geographical location of the subject.

2.4 THE PROBLEMS OF THERMAL COMFORT

In section 2.2, it has been shown that objective measurement can indicate upper temperature limits where the body ceases to function from a mechanical point of view. However, life as is known is reactive and humans survive, although for short periods; in temperatures higher than 70°C which is equivalent to 100°C radiant temperature (Budd et al, 1974 and Jones, 1973). As a demonstration of subjective experience on the inadequacy of temperature measurement to indicate thermal "feeling", Ellis as reported by McPherson, (1962) wrote in 1758;

> *"The same thermometer I have had in equatorial parts of Africa at Jamaica and West India Islands and on examination of my journals I did not find that quick silver ever rose above the 87 and to that seldom. And yet I think I have felt those degrees with moist air more disagreeable than what I feel*

This excerpt indicates the need for other methods for measuring the thermal "feeling" in the human body that cannot be detected by the dry bulb thermometer.

2.5 **Thermal Indices and Measuring Devices.**

The main temperature scales in common use are the Fahrenheit and Centigrade Scales. There are not less than nineteen thermal indices that have been developed in the course of time. It is important here to classify and briefly comment on their uses.

The main classifications can be listed as follows:

2.5.1 Those that measure the physical parameters in the environment.

2.5.2 Those that are based on the measurement of the physical strain caused by the environment.

2.5.3 Those that are based on the resultant interaction of the body/environment interface.

Tables 2.1 and 2.2 show summaries of thermal indices and their basic working principles. The author has observed that the measurement of the physical factors can only be done as accurately as the instruments can allow. However, the measurement of the factors in table 2.3, have the intrinsic problem of interpretation, lack of standardisation and vague limits of sensation.

Macpherson reports that work by Baurine de Saussure, as early as 1873; led to the perfection of an instrument to measure humidity. This work; Macpherson further reports, was later complemented by Lislie who devised the anemometer (Macpherson, 1962). Humidity and air movement are now known to be very important factors in thermal comfort assessment. The two inventions added a new dimension towards resolving the problem of quantifying thermal comfort.

2.6 Measurement of Subjective Warmth.

A number of factors that determine physiological thermal comfort have been reported, correspondingly there are a number of interventions that have been devised to moderate different problems. For purposes of detailed discussion it is necessary to classify these factors as;

2.6.1. Environmental factors;
2.6.2. Physiological factors;
2.6.3. Sociological factors.

Table 2.3 summarises specific effects of these factors and lists the selected references of previous work. Most of the detailed work on thermal comfort has been done in the temperate climate areas as reported by Winslow et al; (1937), and Humphreys; (1975). This study draws some principles from these works but attempts to concentrate on literature that reports research work from the tropical areas where climatic conditions are similar to those experiences in Malawi.

Table 2.1. Thermal Index Devices

	Instrument/Index	Deviser and Year	Use	Comments on Limitations
2.1.1	Dry Bulb Temperature	Fahrenheit;	Measures Temperature	Useful for objective and quantitative indication of heat.
2.1.2	Wet Bulb Temperature	Halden; 1905;	Measures humidity and air temperature	Useful for objective thermal index measurements but does not give information radiant temperature and air velocity. Implicitly indicates the partial water pressure in the atmosphere.
2.1.3	Kata Thermometer	Hill; 1914	Measures Cooling power of air	Gives objective measurements and can also be used for measuring air velocity but only provides partial information
2.1.4	Globe Thermometer	Vernon;930	Measures Radiant Temperature	Can measure indirect effect of temperature i.e radiant heat. Ignores the effect of air speed.

Table 2.2 Type of Thermal Indices

2.2.1	**Indices Measuring Physical Factors**	Author	Year Published
2.2.1.1	Dry Bulb Temperature	Fahrenheit;	1714
2.2.1.2	Wet Bulb Temperature	Haldane;	1905
2.2.1.3	Cooling Power	Siple and Passel;	1945
2.2.1.4	Equivalent Temperature	Dufton;	1932
2.2.2	**Indices Based on Physiological Strain**		
2.2.2.1	Effective Temperature Scale	Houghten Yaglou;	1923
2.2.2.2	Corrected Effective Temperature Scale	Bedford;	1946
2.2.2.3	Equivalent Effective Temperature Corrected for Radiation	Yaglou et al;	1950
2.2.2.4	The Equatorial Comfort Index	Webb	1959
2.2.2.5	The Index of Physiological Effect	Robinson et al;	1945
2.2.2.6	The Predicted Four – Hour Sweat Index	Mc Ardle et al;	1947
2.2.2.7	The Thermal Stress Index	Lee;	1956
2.2.2.8	The WBGT (Combine result of Wet Bulb, dry bulb and Global Temperatures	Yaglou and Minard	1957
2.2.3	**Indices Based on Calculation of Heat Exchange**		
2.2.3.1	Thermal Acceptance Ratio	Ionide et al;	1954
2.2.3.2	Index for Evaluating Heat Stress	Belding and Hatch;	1955
2.2.3.3	Operative Temperature	Gagge;	1937
2.2.3.4	Standard Operating Temperature	Gagge;	1941

Table 2.3 Factors that Determine Thermal Comfort

	General Factors		Brief Discussion Notes		References	Year Published.
2.3.1	Environmental					
2.3.1.2	Air Temperature		Air temperature reduces ambient radiant temperature. as long as the air temperature is lower than the radiant temperature		Houghten et al; Robinson et al; Hindmarsh and Macpherson; Humphreys. Adarve et al; Van Straaten et al; Givoni; Marko et al; Van Wamelon et al Webb; Bedford	1923 1944 1962 1975 1991 ;1969 1969 1994 1986 1959 1946
2.3.1.3	Air Velocity		Affects the rates of thermal energy transfer by creating thermal gradient and dilutes concentrations of injurious gases in enclosures or localities. Gusts of air		Auliciems; Szokolay; Swartman; Bansal et al;	1981 1976 1978 1988

			at frequencies of 0.2-0.5Hz have been found to be most effective. The cooling mechanism in the process of removing the sweat from the skin.		Webb; Marko et al;. Bedford; Vernon; Yaglou and Drinker;. Ansley and Thain	1959 1994 1936 1930 1929 2002
2.3.1.4	Humidity		Induces evaporative cooling by causing a moisture gradient between the air and the skin surface although the skin temperature is independent of humidity. The body can tolerate a wide range of humidity Variation; 30 – 85%.		Houghten et al; Robinson et al. McPherson; Givoni; Wentzel et al; Woodlard; Swartman; Bowen; Ambler; Bedford;	1923 1944 1962 1969 1981 1981 1978 1978 1955 1946
2.3.1.5	Geographical Location		Geographical locations can increase or decrease wind speed, screen off surfaces from extreme radiation and moderate humidity		Webb; McPherson;. Page;	1959 1962 1979

	General Factors		Discussion Notes		References	Year Published.
2.3.2	Physiological					
2.2.3.4	Metabolic Rate		Metabolic rates determine the heat output these rates are higher in males than in females at any defined activity levels.		Humphrey' Du bois and Du bois; Givoni;	1970 1916 1969
2.3.3.1	Sociological					
2.3.3.2	Expectation		This is a strange phenomenon but it has been reported in literature; that for the same set of thermal conditions the thermal tolerances differ from morning to afternoon and from winter to summer.		Ambler Ambler; Koch et al; Hindmarsh and Macpherson; De Dear and Auliciems; Saini;. Szokolay Yaglou and Drinker. Ahmed,	1966 1955 1960 1962 1988 1978 1976 1929 1974
2.3.3.3	Acclimatization		It has been reported that subjects born in temperate climate and move to warmer climate eventually get used to the new climate. This process is different from that		De Dear and Auliciems;. CIBSE Guide; Bedford; Hindmarsh and Macpherson;	1988 1988 1936 1962

			in 2.3.3.2 above. It has also been observed that people from hot countries to cold countries initially enjoy the cold weather and can tolerate lower thermal comfort limits. This phenomenon is associated with "novelty"		Humphreys and Nicol; Ambler; Sayigh; Ahmed ,	1970 1966 1998 1974
2.3.3.4	Clothing		The type of clothes can add to insulation value of on the body. This factor offers an opportunity for choice. However, certain clothing regimes are not convenient in certain working activity and conditions. Heavy clothing on the body reduces the body agility to make free movements.		Yaglou and Drinker; Humphreys Swartman; McPherson; Givoni; Wentzel et al, Humphrey's; Humphrey's Marko et al.. Andersen; CIBSE Guide, Koch et al; Ahmed,	1929 1970 1978 1962 1969. 1981. 1975. 1973. 1994. 1970. 1988. 1996. 1974

2.7 THE SUBJECTIVE SCALES OF THERMAL COMFORT

The subjective scale of Thermal Comfort was developed to accurately represent the human thermal sensation. There are two distinct lines of investigations. One line of investigation is the laboratory based as performed by Blagden (McPherson; 1962), Houghten et al; (1923), Givoni; (1969), Bedford; (1936), The other line of investigation is the field survey method; as performed by McPherson; (1962), Ambler; (1966), and Webb; (1959), Hind marsh and McPherson; (1962), Budd et al; (1974), and Humphrey's; (1975).

Humphrey's (1975) has critically examined the techniques used to derive parameters of thermal comfort. His report indicates that data collection and analysis, of the results can be grouped into two types of scales. The two groups are; the symmetrical as in the Bedford and the ASHRAE scales, and the asymmetrical scales as in the Ambler, Grooms, and the Sharma scales. Typical scales are presented in table 2.3 including their numerical designations.

The large number of indices used in assessing thermal comfort; now exceeding nineteen, demonstrates the immense difficulty that exists in standardising subjective scales. Even for the same scaling format the ASHRAE, CIBSE, and the ISO 7730 do not agree Humphrey's (1975) rates Air Temperature; (AT) as the simplest index to use when the differences between air temperature and radiant temperature are less than 2°C and air speed < 0.2 ms^{-1}. Given; (1969), rates Effective Temperature (ET) (Yaglou; 1947) which is the temperature derived after taking into account the effect of humidity and air velocity, as one of the least reliable in predicting the expected physiological and sensory response. Wentzel et al; (1981), reports that the Corrected Standard Effective

Temperature (CET) and the Standard Effective Temperature (SET) are more useful in evaluating thermal environments.

Humphrey's has conducted a detailed comfort scales correlation analysis of fifteen indices and reports that it was not possible to compare the performance of each index relative to the other. The study excluded CET and SET scales. The results the analysis showed that while the Air Temperature correlation with thermal comfort was 0.52, the Equatorial Comfort Index (described below) had a correlation of 0.48. This suggests that either of the indices would give satisfactory results for purposes of analysing a tropical environment. A similar conclusion is reached by Woodlard who has conducted a multi-regression analysis of five of these indices, namely; Air temperature, Globe temperature, Heat Stress Index, Index of Thermal Stress and Corrected Effective Temperature (Woodlard; 1981). However, it is appreciated here that each one of the indices has been developed to indicate specific information in a given situation. And all indices and scales attempt to evaluate the physiological conditions and sensory response of a person on thermal comfort in the areas of temperature sensation, thermal discomfort and thermal effects on health.

2.8 TOOLS IN USE FOR PREDICTING THERMAL COMFORT

The depth of the problem and intricacy of the arguments to accurately determine Thermal Comfort are evidenced in the variety of assessment tools that have been developed. These are as follows:

2.8.1 Predictive Equations. In this group are numerous equations such as those developed by Vincent (1890), Du Bois and Du Bois; (1916), Ambler (1955) Webb (1959); Givoni; (1969) Humphrey's; (1975), and Wentzel et al; (1981).

2.8.2 Charts and Monograms. In this group commonly known as bio climatic charts, are included those developed by Houghton et al; (1923), Aglow (1947), Misheard as reported by Givoni, (1969), Olglay, (1963) and *the Equatorial Comfort Index* (BRS 66). The charts use the environmental factors, namely dry bulb, wet bulb, radiant temperature, and air velocity. Other calculated and observed conditions include metabolic rates and levels of clothing

2.8.3 Vote Count Distribution. These include the Bedford scale, (1936) the Ambler scale; (1955), and the Humphrey's; (1975) scale based on neutral zone, and as adopted by the CIBSE and also as accepted by the ISO, as ISO 7730.

The vote count scales are based on subjects' responses to questions put to them on how comfortable they feel in given thermal environments. By plotting the votes through a range of temperatures from low to high relative to body temperature, a neutral zone is determined where 80-100% of the subjects feel comfortable. Although the vote scales are the closest method to describe the subjective feeling, the problems of lack of thresholds still do exist. Some of these scales match subjects' feelings but even then, specific feelings or sensations are not the same for different people.

The units of these scales are not absolute and are only relative. The Webb scale (1959) has nine points and is classified as symmetrical. The Ambler Scale (1955) has seven points and is classified as asymmetrical. The Goromosov scale has four points only and is asymmetrical (Humphreys; 1975). The Bedford scale (1936); when rearranged to make level vote count four as a neutral point, are symmetrical

Koch et al (1960) report on a six point linear scale that describes perspiration but do not describe how this scale could be equated or compared to similar scales that measure body heat stress such as the H.S.I and the Index of ITS. Other scales shown in Table 2.3. Generally these scales describe the feeling but are not in themselves quantitative.

Table 2.4 **Symmetrical And Asymmetrical Thermal Comfort Scales**

(The convention is zero as neutral as adopted from Humphrey; 1975)

SYMMETRICAL SCALES	Numerical	Descriptive	ASSYMETRICALSCALES	Numerical	Descriptive
Bedford scale (1936)	3	Much too warm	**Ambler Scale**(1955)	-2	Uncomfortably cold
	2	Too warm		-1	Cool
	1	Comfortable warm		0	Just right
	0	Comfortable		1	Warm, sweating slightly
	-1	Comfortably cool		2	Sweating considerably
	-2	Too cool		3	Very heavy sweating, uncomfortable
	-3	Much too cool		4	Very uncomfortable indeed
Ambler scale (1959)	-4	Excessive cold	**Mookerjee and Sharma Scale (1953)**	-2	Feeling cold
	-3	Cold		-1	Cool
	-2	Cool		0	Comfortable and pleasant
	-1	Comfortable cool		1	Comfortable
	0	Comfortable and neither cool or warm		2	Warm
	1	Comfortably warm		3	Hot
	2	Warm		4	Very hot or extremely hot
	3	Hot			
	4	Excessively hot			

Hindmarsh and Macpherson Scale (1962)	-3	Much too cold	**Goromosov Scale (1965)**	-1	Cool
	-2	Too cold		1	warm
	-1	Cool		2	Hot
	0	Comfortable			
	1	Warm			
	2	Too warm			
	3	Much too warm			
Givoni (1969)	-4	Unbearable cold			
	-3	Very cold			
	-2	Cold			
	-1	Cool			
	0	Comfortable			
	1	Slightly warm			
	2	Warm			
	3	Hot			
	4	Very hot			
	5	Unbearable hot			

It is noted that Koch et al ;(1960) have introduced yet another term. This term is *Pleasantness*. The author classifies this as a tertiary scale after the scales measured by instruments and the neutral temperature ranges deduced from vote counts. The scale of Pleasantness brings in the psychological state of mind superimposed on the physiological state. The experience may be subjectively easy to describe but it would not be easy to share the experience of each description. If culture is considered as an influential factor then the problem becomes more complicated. Ahamed working with his colleagues states that, "culture and sensation affect people's description of sensation and not sensation itself."

In 1949-1950; Webb collected a lot of data while in Singapore and derived an equation that predicts Thermal Comfort Temperature (t_{tc}) approximated to

$$t_{tc} = \frac{1}{2}\left(t_a - t_w\right) - \frac{1}{4}V^{\frac{1}{2}} \tag{2.7}$$

Equation (2.8) was developed through using male subjects, from that, Webb developed the Singapore Index. It is not very sensitive to thermal sensory perception and has a very narrow range. From this Singapore index the Equatorial Comfort Index monogram was developed and published as BRS No.66.

This monogram takes into account the climatic conditions of typical tropical country climates such as that of Malawi. This scale is useful for assessing buildings in the tropical countries in order to determine how to achieve thermal comfort.

Using the concepts of neutral zone as adopted by the CIBSE ;(1988) and the ISO 7730; (1994) recommends the comfort vote distribution diagram as a basis for assessing thermal comfort. The ISO standard recommends thermal comfort ranges of 20-24°C and 23.0–26°C for winter and summer respectively. Humphrey's; (1975), after a rigorous analysis of a large number of thermal comfort temperature ranges, suggested the following equation:

$$t_n = 2.56 + 0.831t_m \qquad (2.8)$$

Considering that, in all the neutral zone scales analysed, the common temperature range for adults was 4 deg C, equation (2.9) is modified to;

$$R_m = 0.64 + 0.25\,t_n - 0.208\,t_m \qquad (2.9)$$

This form of the equation is convenient for immediate practical use since it is possible to vary at will, during the building design process. Using this equation in conjunction with others can lead to accurate predictions of indoor temperatures of a building at the design stage.

2.9 THERMAL COMFORT IN WORKING CONDITIONS THAT INVOLVE STRENUOUS PHYSICAL WORK

Equations 2.9 and 2.10 are all assuming sedentary subjects where the metabolic rate M <100 watts. In order to cover working environments the Agreément Board of South Africa (Wentzel et al; 1981) have recommended the use of SET in warm environment. The Council for Scientific and Industrial Research (CSIR) of South Africa defines neutral temperature as;

> *"The temperature of a sea level isotherm environment at 50 per cent relative humidity, air movement 0.1 – 0.15 ms^{-1}, in which a sedentary occupant at a metabolic rate of 1.1 met (64 Wm^{-2}) wearing clothing of an insulation value of 0.6 Clo,) would exchange the same amount of heat at the same mean skin temperature and skin-wetness as observed in the actual environment and actual clothing under consideration".*

The SET just like the ITS evaluated by Givoni; (1969) takes into account of radiation. However, the parameters used in SET and ITS are not easily measurable but the indices are useful for factory type of work where it is necessary to monitor physiological stress.

2.10 THERMAL COMFORT AND RISK TO HEALTH

Thermal balance equations are based on the fact that the body thermal balance must be maintained at all times if the body is to function normally. Andersen; (1968) reports that mental deterioration of acclimatised persons start at 30°C while a temperature of 27°C was found to cause impairment in learning in school pupils. Human efficiency (thinking and finger dexterity) is maximised within the thermal comfort zone. It is therefore very important to note that these tools for assessing thermal comfort have made it possible for environments to be reviewed and predictions made whether an environment would promote efficiency in human physiological activities or would put health at risk. Andersen also reports and admits that, a low temperature limit at which harmful and irreversible physiological changes would occur is yet to be agreed by researchers in this field.

2.11 EVALUATION OF THE DATA REPORTED IN THIRTY SIX REFERENCES

Temperature data published in thirty-six references on the subject of thermal comfort were analysed. These data included medians and ranges of thermal comfort temperatures. Most of the data quoted in literature is from either temperate or humid climate countries. Nonetheless it was felt that a detailed analysis of these data could reveal some very useful information that can support this work. The data has been statistically analysed to show the distribution of the frequency (f) occurrence of the preferred comfortable temperatures. As shown on the table, each temperature was entered separately as a frequency occurrence. Fractions of a degree are rounded off to the nearest whole number.

In all there were 262 temperatures points entered. The results of the analysis from figure 2.3 that are worthy noting are as follows.

Mean Temperature	*21.7°C*
Standard deviation	*7*
Median	*22°C*
Minimum Temperature	*11°C and*
Maximum Temperature	*33°C*

The minimum and maximum temperatures reported were11°C and 33°C. These are included in the analysis. From figure 2.3, the highest frequency of 26 occurs at 23-24 °C. If in general the width of the comfort zone is deg°C difference, as observed by Humphreys; (1975), and a temperature mean of 22°C are adopted then, the neutral zone across these countries is 20°C - 24°C. These temperatures are within the limits as proposed by the ISO 7730 and the limits reported by Malama; (1998).

This temperature range agrees with the observations made by Andersen (1968) where some countries in Europe have made it mandatory that the thermal comfort limits must be $18^{\circ}C \leq t_{\alpha} + \Delta \text{ temp} \leq 22^{\circ}C$. In this case the term Δ temp represents the incremental temperature difference between the air temperature and the upper limit of the thermal comfort. The literature survey includes countries in temperate climate, humid climate, and warm climates. Andersen emphasises that for interhuman and intrahuman reactions on static and dynamic conditions, the acceptable medic-hygienic limits must be 20-22°C

Table 2.5 Thermal Comfort Ranges As reported By Various Authors

Temperature	°C		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	REMARKS	AUTHORS
												▨	▨	▨	▨	▨	▨	▨	▨										Chamber experiments	Houghten and Yagloglou 1923
																		▨	▨	▨	▨								Summer	Ballinger et al 1993
					▨	▨	▨	▨	▨	▨	▨	▨																	Winter	Ballinger et al 1993
												▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		UK	Humphrey 1975
															▨	▨	▨	▨											Optimum range for pupils	Humphrey 1974
												▨	▨	▨	▨	▨	▨	▨	▨											Humphrey and Nocol 1970
														▨	▨	▨	▨	▨	▨	▨	▨	▨								Szokolay 1976
												▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								CANADA	Swartman 1978
												▨	▨	▨	▨	▨	▨	▨	▨	▨										Jones 1973
												▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								Bowen 1978
												▨	▨				▨	▨	▨										Evening India Experience	Ambler 1966
														▨	▨	▨	▨	▨	▨										Morning Nigeria Experience	Ambler 1963
																	▨	▨	▨	▨									Summer	Fanger 1987
														▨	▨	▨	▨	▨											Winter	Fanger 1987
														▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				Koch et al 1960
																							▨							Wamelon et al
													▨	▨	▨	▨	▨	▨											UK	CIBSE 1988
																▨	▨	▨											Summer	ISO 7730 1994
																	▨	▨	▨	▨									Winter	ISO 7730 1994
																▨	▨	▨	▨	▨	▨	▨							Summer	Malama 1998
																	▨	▨	▨	▨	▨	▨	▨						Winter	Malama 1998
																▨	▨	▨	▨	▨	▨	▨	▨							Webb 1958
																			▨	▨	▨	▨	▨	▨						Woodland 1958
														▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						Australia	Auliciems 1981
															▨	▨	▨	▨	▨	▨	▨	▨	▨						USA	Bedford 1936
					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨													London	Reid 1844
													▨	▨	▨	▨	▨	▨											Washington	Billings 1923
											▨	▨	▨	▨															Two subjects only	Fishnden and Willingress 1925
										▨	▨	▨	▨	▨	▨	▨													Average for winter and summer	Patridge and McLean 1935
						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨											USA	Vernon and Bedford 1926
												▨	▨	▨	▨	▨	▨	▨	▨	▨									USA	Yaglou and Drinker 1928
											▨																		Reported by Bedford	Silovester 1835
												▨	▨																USA	Hambly and Bedford 1921
														▨	▨	▨	▨												New Guinea	Hindmarsh and MacPherson 1962
																						▨	▨	▨	▨	▨			Libya	Taki et al 1999
										▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨							Algeria	Belyat et al 2002
Frequency					2	3	3	3	3	5	7	15	16	20	21	24	26	26	21	17	13	12	9	4	3	3	1			

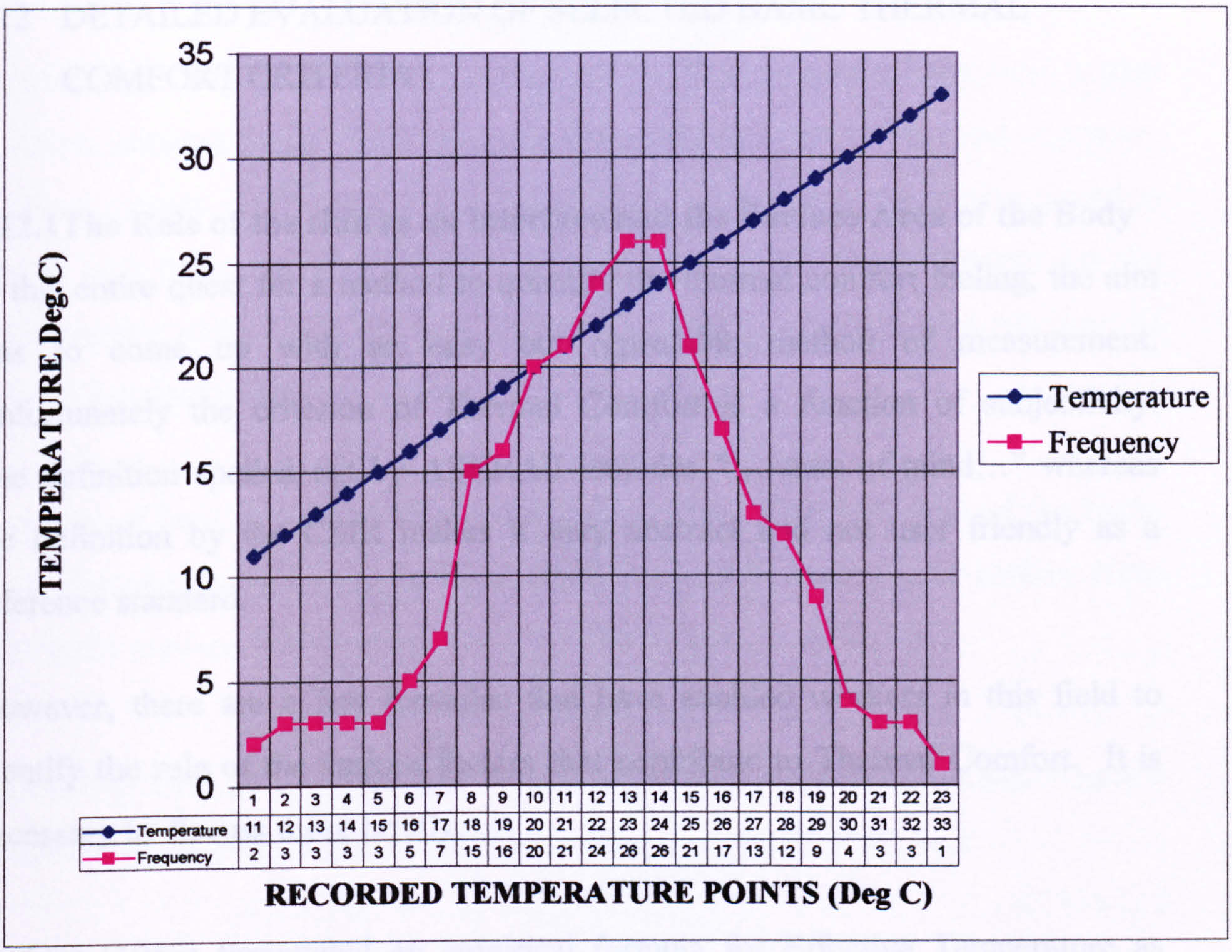


Figure 2.3 A graph of Calculated Frequency Distribution of the Comfort Temperatures as Abstracted from Table 2.4.

Malama conducted his vote count of thermal comfort work in Zambia; a country which shares a common border with Malawi and lies almost within the same latitudes. The people of the two countries have the same ancestral origin. This eliminates the factors of differences in geographical, climatic and cultural differences. The conclusion in Malama's work is perhaps a result that would be closest and suitable for application in Malawi, if the vote count exercise and an analysis were to be carried out to compare the results.

2.12 DETAILED EVALUATION OF SELECTED BASIC THERMAL COMFORT CRITERIA

2.12.1The Role of the skin as an interface and the Surface Area of the Body

In this entire quest for a method to quantify the thermal comfort feeling, the aim was to come up with an easy but repeatable method of measurement. Unfortunately the criterion of Thermal Comfort is a function of subjectivity. The definition spelled out by ASHRAE includes "....state of mind..." whereas the definition by the CSIR makes it very abstract and not user friendly as a reference standard.

However, there are a few formulae that have enabled workers in this field to identify the role of the various factors that contribute to Thermal Comfort. It is necessary to discuss these briefly.

Ambler (1955) formulated an empirical formula for Effective Temperature as follows;

$$t_{ef} = t_w + \left(\frac{t_a - t_w}{3}\right) + A_X \qquad (2.10)$$

In this formula and as suggested by Houghten and Yagloglou (1923) the factor of atmospheric water pressure is taken into account indirectly by the use of t_w . However, in this equation, radiant heat from the surroundings is completely ignored.

The ambler equation was later modified to take into account of radiant heat. This is the Equivalent Temperature t_{eq}. An empirical equation is reported as follows: $t_{eq} = 0.522t_a + 0.478t_w - 0.1474\sqrt{A_Y}(100 - t_a)$ (2.11)

Ambler reports that the neutral temperature is different during sleep and is also different amongst races. This brings in the aspect of body surface and exposure. Bedford reports (1936) that the metabolism is high at low temperatures and is low at high temperatures. This observation agrees with that of Ambler but the commonality might lie in the need to consider size of a person, and whether the body is exposed or not.

The idea of heat loss implicitly brings in the effect of surface area of the body. Both Humphrey (1970) and Bedford quote the Dubois Equation of surface areas where if a persons body surface are *(*A_b*)* can be calculated from;

$$A_b = W_b^{0.423} \times H_b^{0.732}\, 0.2024 \qquad (2.12)$$

Bedford (1936) also reports the Vincent Equation (1890); that considered the actual temperature of the skin and formulated an equation as follows

$$t_s = 26.5 + 0.3t_a + 0.t_r - 1.2\, A_Z \qquad (2.13)$$

The equation is one of the most earliest and comprehensive. Although this equation was not popular the missing factor that led to the correction of the Effective Temperature to Equivalent Effective temperature had already been taken into account. However, the Vincent formula ignored the partial water pressure in the atmosphere.

The problem in this search for an index for thermal comfort lay on the relationship of the measurable air, body and radiant temperatures, and wind speed to the subjective feeling. Bedford (1936) extended his analysis and derived two simple regression equations as follows;

$$t_b = 0.399t_a + 29.22 \qquad (2.14)$$

$$t_b = 0.399t_a + 0.363t_w + 25.76 \qquad (2.15)$$

These can be viewed as purely mechanical and would perhaps not be very useful in assessing thermal comfort over the range of a living subject since they do not show any limiting factors. At high temperatures there would be not any body temperatures worthy talking about. The subject would have since died of the heat! However the two equations can be combined and the body temperature can be given in terms of t_w only.

2.12.2 Simplicity of Scales.

A great deal of rationalisation and simplification of the scales of thermal comfort can be attributed to work by Bedford (1936), McPherson (1962) and Humphrey (1975). Bedford was the first to propose the seven point subjective scale that is in use by the ASHRAE. He also derived an equation that relates the subjective scale (S) to the air temperature, mean surrounding temperature, and air speed. His original equation is as follows;

$$S_k = 11.16 - 0.0556t_a - 0.0538t_w - 0.372p + 0.00144\sqrt{A_r}(100 - t_a) \qquad (2.16)$$

The subjective scale assess the severity of discomfort reported by persons as count votes under negative or positive thermal stress. In this context the zero point is regarded as a neutral temperature where 80-100% persons would report that they are comfortable. On each end of the scale the extreme (cold or hot) is represented by a value of 3. Both Bedford (1936) and Humphrey (1975) have carried out correlation exercises comparing the popular temperature indices against the vote count scale. In each case the Equivalent Temperature was found to be the best with a correlation of 0.52. Although the equation incorporates all of the important parameters that are reputed to be factors of thermal comfort the close fit on a scale of −1 to +1 is still only 0.52 of the causal relationship; in this case between the vote count and the Equivalent Temperature are not completely satisfactory.

2.12.3 Extended use of the Vote Count Scale

The Vote Count approach has been accepted by both ASHRAE and CIBSE. However, taking a vote count for design purposes would be tedious. These scale, the Predicted Mean Vote (PMV) and the Predicted Percentage Dissatisfied (PPD) have been developed as design tools. Recent work (Hessian et al; 2002) has shown that using the relevant parameter levels that relate to the various PMV points, as a rational assessment of the thermal comfort conditions in an experiment can successfully be undertaken. For example it has been shown that window orientations of a building model can to give best ventilation or high PMV; on a scale of 1-7, when the windows are wind facing.

In another assessment (Taki et al 2002) the PMV, the assessment method was renamed as Actual Mean Vote (AMV) and was used to assess the thermal comfort in new and old buildings in Libya. In this most recent work the following equations make an interesting result.

$$AMV = 0.6t_a - 14.97 \qquad (2.17)$$

for old buildings and

$$AMV = 0.22t_a - 4.23 \qquad (2.18)$$

for new buildings

These formulae show that people felt comfortable in old buildings at higher temperatures while the same conditions were achievable at lower temperatures in new buildings. The new buildings in this particular were air-conditioned. These observations agree with those of De Dear and Auliciems (1988) and as shown on table 3.3; that in air-conditioned rooms people's neutral temperatures shift to the lower temperatures. This can mean a higher cost due to the large amount of thermal energy that has to be extracted in order to bring the temperatures down to the required temperatures.

2.12.4 The Adaptive Thermal Comfort Approach

The adaptive Thermal Comfort Model is a relatively new approach. In the authors view, it represents level 4 of search for Thermal Comfort Index. Briefly the progress in Thermal Comfort Indexing can be categorised as follows;

Level 1	Instrumentation such as thermometers and hygrometer etc.
Level 2	Analytical charts, monograms and regression equations. In this group are the bio climatic charts, including the widely used Psychometric chart.
Level 3	the PMV and PPD scaling methods.
Level 4	The Adaptive Thermal Comfort Models (ATCM).

Humphrey cites the **Adaptive Principle** as;

> "*If a change occurs that produces discomfort, people will tend to act to restore their comfort.*"

This approach appears to overcome the problems that have been exhibited in the correlation scales. The correlations of the ATCM with subjects comfort of course appears to be better than all the others discussed in levels 1 to 3.

There may be still a few problems with the ATCM. For example if a specific place is uncomfortable rather than do something to the cause, the subject moves to a location where the effect of that cause is absent. However, since this approach is based on the subject's own reactions then the approach is practical and is useful.

It has been observed that the neutral temperature zone changes with time of the day (Ambler, 1966), season (Hindmarsh and McPherson; 1962), and even with the weather of the day (Ambler, 1955). From this body of information, it would seem that charting a comfort zone as constant throughout the year as is the case by Koenigsberger et al; (1974), could be misleading. It is more accurate to state that the comfort range temperatures are lower (cooler) in winter and at night than in summer and during the day. Therefore the neutral temperature would tend to vary with the subjects anticipation for better and balanced thermal conditions in the environment. This observation is supported by computation (Ahmed et al, 1990) where data from Dakhar in Bangaladesh; which is a tropical country, was used. It may be said that there is no such a thing as "Optimum Thermal Comfort Temperature";(Humphrey and Nicol 1970). The terms that will be used in the current studies are Neutral Zone of 4 deg °C differences and the Thermal Comfort Range as the general range between the minimum and maximum reported Comfortable Temperature Ranges namely 11-33 °C. Thus the Neutral Zone is taken as 4 deg °C and the Comfortable Temperature Ranges is 22 deg C.

CHAPTER THREE

3.0 THEORETICAL CONSIDERATIONS

3.1. SOLAR RADIATION, ITS TERRESTRIAL DISTRIBUTION, AND PATTERN.

Almost all the thermal energy on earth except nuclear and chemical energy originates from the sun. The sun located on one of the arms of the Milkyway galaxy at a distance of 1.496×10^8 Km holds the key to life as we know it on earth. It is a star classified as type dG2 on the astronomical scale and is 4.5 billion years old (Calder; 1969, Halacy; 1980) and radiates energy in the form of waves; radio, infra-red rays, ultra-violet rays, X-rays and gamma-rays and matter; primary cosmic rays, and neutrinos. The sun radiates the energy with a typical profile of a black body at 6000°K, as deduced from Abbots work, (Chandrasekhar; 1994, Coulson; 1975), peaking at the visible range of 350nm – 850nm (Sayigh; 1979), with an energy intensity of 2.6 Wcm^{-2} nm^{-1}. Out of $3.8x10^{23}$ kW of energy radiated out by the sun, the earth intercepts $1.7x10^{14}$kW only. This is the energy that generates life on earth but also causes thermal discomfort wherever the ambient temperature is higher than the body temperature. Naturally ventilated and comfortable buildings are only those that incorporate structural features that are specifically designed; either intuitively or through simulation and laboratory work to mitigate the effects of this radiation.

3.2 THE IRRADIANCE ON THE EARTH'S SURFACE

The earth's thermal balance is maintained due to its axial rotation and its inclination at 66½° to the plane of its solar orbit. The solar constant is 1353 Wm^{-2} (Kondratyev; 1972, Sayigh; 1979) but attenuated by atmospheric constituents including the length of the optical path or air mass (Coulson; 1975), aerosols (Elhadid and Shaahid; 1994), solar zenith, atmospheric turbidity; (Moseley et al 1999), cloud cover (Udo and Aro; 1999),and terrestrial conditions, (Samimi; 1994, Ertekin and Yaldtz; 1999).

These factors can be grouped into three areas namely:

3.2.1 Astronomical factors; which include solar distance inclination and zenith;

3.2.2 Atmospheric factors; which include air mass, water vapour, dust, particles and aerosols; and

3.2.3 Terrestrial factors that include altitude and ground albedo.

Generally the extraterrestrial solar intensity is reduced to 70 per cent by the time it reaches the earth's surface (Jones; 1973). The intensity characteristics follow the Bouguer - Lambert Law which for a plane parallel and horizontal atmosphere can be written as;

$$I_\lambda = I_{o\lambda} \exp(-\tau_\lambda \sec \alpha_z) \tag{3.1}$$

If the optical thickness of the atmosphere is defined from any height Z, equation 3.1 can be modified to read

$$\tau(\lambda, Z) = \int_z^\infty \beta(\lambda, Z) \delta Z \tag{3.2}$$

Where $\beta(\lambda Z)$ is an attenuation coefficient which is a function of both λ and Z.

Considering that the attenuation is true absorption and scattering (Mier and Raleigh Scatters; Coulson; 1975), the attenuation can be summed as;

$$\beta = \beta_s + \beta_\alpha \tag{3.3}$$

where the subscripts ***s*** and ***a*** represent scattering and absorption.

The degree of attenuation depends on the optical path length as defined by the angle of solar incidence (α_z), and the type and density of the aerosols, gases and water vapour present, in the atmosphere.

3.3 INCIDENT SOLAR RADIATION, ITS COMPONENTS, AND MEASUREMENT

There are a number of standard equations used for calculating solar irradiance. One of these which is recommended by the ASHRAE is given as

$$I_t = A / \exp(B / \sin\alpha) \qquad (3.4)$$

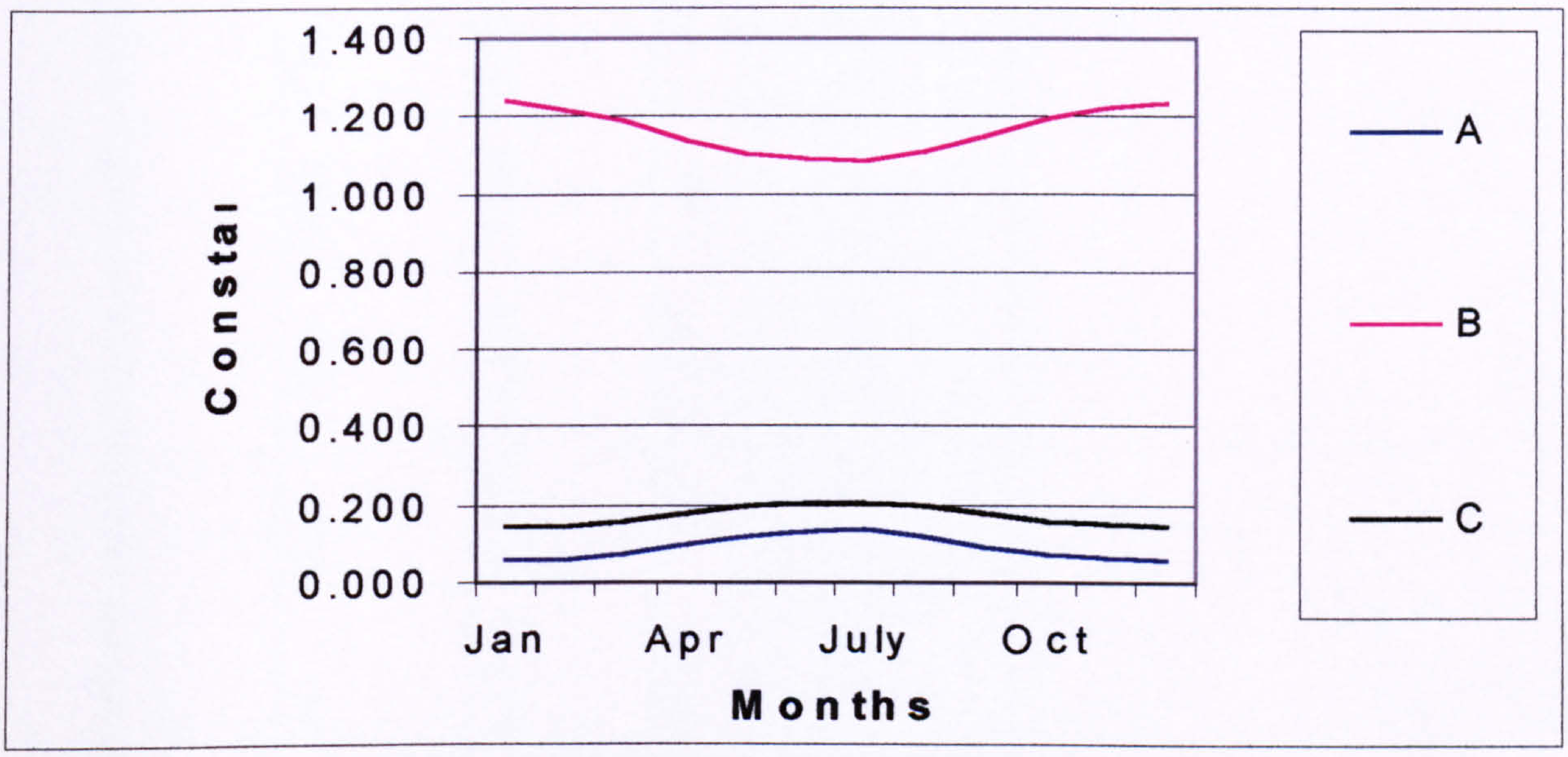


Fig.3.1**The Constants Used to Evaluate Solar Radiation (from Jones; 1963)**

The total radiation (I_t) reaching earth's surface can also be estimated by

$$I_t = I \cos\alpha + I_d + I_r \qquad (3.5)$$

The A.S.H.R.H.E. Guide evaluates I_d and I_r as

$$I_d + I_r = C I F_s + \rho I (C + \sin\alpha) F_g \qquad (3.6)$$

Where **C** varies throughout the year as in figure 3.1

Usually $F_g = 0.5 (I \cos\psi)$ (3.7)

Where ψ is the angle of tilt to the horizontal surface;

and $F_s = 1 - F_g$ when the surface in question is directly exposed to the radiation from the ground.

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Table 2.6 **Constants for Determining the values of direct and scattered radiation at sea level, used in Equations (3.4 and.(3.6)**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Units
C	0.058	0.060	0.071	0.097	0.121	0.134	0.136	0.122	0.092	0.073	0.063	0.057	–
A_1	1.230	1.213	1.186	1.135	1.104	1.088	1.085	1.107	1.152	1.192	1.220	1.233	kWm^{-2}
B	0.142	0.144	0.156	0.180	0.196	0.205	0.207	0.201	0.177	0.160	0.149	0.142	–

The reflected radiation is mainly long wave radiation of $\lambda \geq 3000\text{nm}$; (Sayigh; 1979) and this long wave radiation. For thermal comfort under a shade where; $I\cos\alpha \approx 0$ the sum of $I_d + I_r$ should not exceed the metabolic rate if the body has to remain at a state where it will be emitting the excess heat. In other words the body has to continue to emit radiation to maintain the comfort balance by getting rid of waste thermal energy. The wavelength of the radiation from the surrounding environment must then be $\lambda \geq 9410\text{nm}$ as predictable by equation 2.3. This would be a condition where a breeze in the shade restores the body to thermal equilibrium. This happens the in the tropics.

3.3.1 The Direct Beam, Diffuse and Reflected Radiation

The solar radiation has three components namely *direct* beam, *diffuse* and the *reflected* components. These are related to each other as follows.

$$I_t = I_d + I_f + I_r \qquad (3.8)$$

It is relatively easy to measure the global solar radiation using a number of instruments. The global radiation in Malawi has been evaluated from data recorded on Gunn Bellman Spherical pyranometer and the Campbell Stokes Sunshine Recorders. However, in practice the direct beam can also be determined by subtraction using the relationship in equation 3.7; and the reflected component is less than 10% and in most instances this component is so small that it can be ignored. In lowland areas in Malawi and in the dry season, the reflected component can be high. This would be due to the ground albedo that increases, as the ground gets bare of vegetation. Consequently the long wave contribution increases.

3.3.2 Diffuse Component

The diffuse radiation is not directional. Valko conducted a number of measurements of the diffuse radiation at different horizontal angles of mounted solarimeters and established a relationship between diffuse radiation and global radiation (Valko;1968). The relationship is presented as follows;

$$I_c = \cos^2 \alpha_i / 2 \, I_f + \sin^2 \alpha_i / 2 \, A_2 I_t \qquad (3.9)$$

A_2 is equal to 0.2; and

The diffuse radiation is predominantly short wave in the bandwidth $115<\lambda<3000$nm. (Sayigh; 1979). Van Deventer and Dold (1964) report that vertical surfaces receive short wave radiation that includes the ground reflected radiation. It is therefore important to note that the ground reflection can contribute to high temperatures in the shade of a building. This confirms the general observation that during a strong sunny day, a bare ground in front of a verandah "feels" hot.

Measurement of the diffuse component of the solar radiation is not easy. However, work by (Liu and Jordan, 1960) established formulae that are useful for calculating the solar radiation on a horizontal surface, the magnitude of the diffuse component, and the clearness index of the sky. Further work by others; (Mason 1966, Reindl *et al;* 1980, Gopinathan; 1990,1992, Chen *et al*; 1993, Ideriah *et al*, 1989, Chandrasekaran and Kumar; 1994, Kudish and Ianet; 1993, Karapantsios et al;1999, Maduekwe and Garba *et al*; 1999, Soler *et al;* 1999, Feuillard *et al*; 1989, Camps and Soler 1992 and Ashjaee *et al*; 1993), show that these formats of formulae can be used for evaluating the diffuse component including clearness indices. Hinrichsen; (1994), has shown that in equation (3.9) discussed below, the constant a is actually the ratio of the diffuse component to the global radiation while the b(s/S) is the ratio of the direct component to the global radiation. A table of a, b, and (a + b) to indicating how these constants vary in different countries is shown in table 3.1.

Table 3.1 Constants Obtained From Angstrom Type Of Equation By Different Authors In Different Locations

Country	a	b	a+b	Remarks	Author
Stockholm	0.25	075	1	-	Abdel Wahab; 1993
Zimbabwe	0.32	0.47	0.79	-	Barker; 1959
Zimbabwe	0.301	0.52	0.82	Using Malawi, mid country latitude of 14 degrees Celsius	Vernon; 1960
Malawi	0.28	0.52	0.80	Formula in current use	Met. Dept. Malawi
Malawi (1978 data)	0.24	0.42	0.66	Data recorded by Geography Department; University of Malawi..	Zingano; 1986
Malawi (1979 data)	0.28	0.41	0.69	Data recorded by Geography Department; University of Malawi.	Ibid
Abu Dhabi	0.307	0.31	0.62		Lewis; (1989)
Athens (Greece)	0.230)	0.46	0.69		Ibid
Cairo (Egypt)	0.140	0.61	0.75		"
New Delhi (India)	0.341	0.45	0.787		"
Italy	0.077	0.69	0.769	Data from 3 locations	"
Alabama USA	0.210	0.56	0.77	Data from two location	"
Jamaica	0.240	0.51	0.753	Data from 8 location	"
Dhahram (Saudi Arabia)	0.175	0.55	0.727	-	"
4 locations (Nigeria)	0.245	0.46	0.701	-	"

Table 3.1 Contn'd.

25 Locations *	0.300	0.400	0.7	Covering the 22 degrees North to 20 degrees South Tropical belt	
Nairobi	0.25	0.58	0.83		J.K. Page
Leopoldville	0.22	0.54	0.76		Ibid
Dakar	0.10	0.72	0.82		"
Tananarive	0.31	0.50	0.81		"
Windhoek	0.24	0.57	0.81		"
Pretoria	0.28	0.47	0.75		"
Bloomfontein	0.26	0.52	0.78		"
Durban	0.34	0.36	0.70		"
Capetown	0.21	0.61	0.82		"
Stanleyville	0.29	0.41	0.70		"
Trinidad	0.28	0.51	0.79		"
Dry Creek	0.31	0.52	0.83		"
Mount Stromlo	0.26	0.56	0.82		"
Versailles	0.24	0.52	0.76		"
Gemboux	0.16	0.56	0.72		"
Kew	0.15	0.68	0.83		"
Rothamsted	0.16	0.57	0.73		"

* Note that all the constants reported for Malawi are within this range as reported by Lewis (1989)

While these empirical relationships can give a fairly accurate level of diffuse radiation if it is required, they can also be used to indicate the clearness of the local sky.

$$I_t/I_o = \alpha \qquad (3.10)$$

$$I_d/I_o = b(s/S) \qquad (3.11)$$

In this statement the reflected radiation is ignored. Most authors treat the diffuse component as isotropic. Others still treat it as anisotropic. In either case the results do not show big differences.

Moseley et al; (1993) report that; although cloud cover can reduce global radiation by 15 per cent, it increases the diffuse component by 30 per cent. Diffuse radiation as short-wave radiation, is very prone to scatter by the Raleigh and Mier scatters (Coulson; (1975). However, in the shade of a house, the verandah, short wave radiation from the sky seen from the verandah and as a component of the total, can cause the discomfort if the total irradiance value of diffuse and reflected components exceeds that emitted by the body through its metabolic rate.

3.3.3 The Reflected Component

Long wave radiation is defined as $\lambda \geq 3000$nm and is non directional. Where a surface, can 'see' another surface, long wave radiation is exchanged until equilibrium in thermal energy level is established (Duffie and Beckman; 1974).

Udo and Aro; (1999) report that long wave radiation can contribute to the global value by 9.9% in summer and up to 7% in winter. This agrees with the observation recorded in section 3.3 above. It has been discussed in section 2.2.4; that short wave radiation influences the air temperature in the shade of a house. If the sum of the diffuse radiation and the reflected radiation exceeds the metabolic rate, then the body would gain heat due to the absence of a cold sink. This results in body thermal discomfort. This is a typical case where it would be best to use global temperature as an index to evaluate the prevalent comfort conditions.

3.4.ASSESSMENT AND MEASUREMENT OF SOLAR RADIATION IN MALAWI

3.4.1 Global Radiation

The solar measuring instruments in Malawi were originally set up on Agricultural Research Stations. Out of the nineteen stations, one station has data taken for six years, three stations have data taken for nine years and the rest of the stations have data taken from more than ten years.

Baker; (1959) analysed three years solar radiation data recorded in Central Africa using the Ångström formula. This formula is of the general form;

$$I_t/I_o = a + b\ (s/S) \tag{3.9}$$

Vernon; (1965), reports results of a detailed study of solar radiation that included eleven stations in Malawi. The results of the two studies established a precursor of the formula that is now being used by Meteorological Department

Barker Eqn., (1959) $I_t = I_0 0.32 + 0.47(s/S)$ Cal cm^{-2} day^{-1} (3.10)

Vernon Eqn., (1963) $I_t = I_o 0.316 \cos L + 0.52(s/S)$ Cal cm^{-2} day^{-1} (3.11)

It has been reported in recent literature that the form of the Ångström formula is too simplistic. A number of workers have generated different versions of this formula to explicitly indicate its usefulness (Feuillard *et al,* Coppoline; 1989, Gueymard et al 1992, Garrison and Adler 1992, Hinirichen; 1994, Abdel Wahab; (1993), Lewis; 1989, Haluan et al 1993, Frangi et al; 1992 and Yeboah et al ; 1990). Many researchers have examined differed regimes of solar radiation (Hans et al, Kambezidis et al,; 1994,Anguir et al 1992, Ertchin and Yaldtz; 1999, Molineaux and Inecichen;1996). In the author's view these other versions may be of academic interest but they do not give results with better accuracy than the original Angstrom formula.

Radiation data calculated using the Ångström formula; as adopted by the Meteorological Department in Malawi, was compared with data recorded on an Eppley Pyranometer from the same station (Zingano; 1986). The results were within 10% difference. However, there were slight variations in the values of constants **a** and **b**. These constants have already been referred to, in table 3.1. The table contrasts the Malawi constants with those from other countries. These constants are not exactly constant throughout the year. However, the long-term averages have been found to give reliable results. Some of the limitations to accuracy stem from the fact that the sunshine recorders themselves require minimum irradiance threshold of 50-Watts m^{-2} to burn the sensitive paper that is used to record the intensity of the radiation (Samimi; 1994).

The Meteorological Department in Malawi has now installed modern Kipp Zonen solarameters in some of the stations. However, due to the proven accuracy of the data derived from the Angstrom formula, it has become acceptable to use data from both sources as equivalent. In this work it will not be necessary to identify the method that was used to record the data on each location.

3.5 EFFECTS OF SOLAR RADIATION ON THERMAL COMFORT.

The effect of solar radiation on a building is discernible by the increase of the fabric temperature (Gupter; 1985), Ashley and Reynolds 1994, Bansal *et al* 1993, Garge and Gupta, 1986). The reradiated energy from the fabric affects the occupants. However, for human thermal comfort and efficiency at work in the absence of any localised thermal radiation (McIntyre; 1977) the resulting temperature must be within the range 22 – 26°C as deduced from the analysis in section 2.9

A number of natural phenomena can be exploited to optimise indoor air velocities in order to achieve thermal comfort and it is the air velocity that lowers radiant temperature. These include proper orientation, usage of wind towers/catchers, and channelling of incoming air over water, (Bansal et al; 1988), ventilating the underside of the house (building on platform) (Garg and Oreszcezyn; 1994). Air velocity cools an environment by creating a thermal gradient as long as the air temperature is lower than the skin temperature. This process removes the energy from the skin and therefore allowing more energy from the inner body to come to the skin zone thereby creating the cooling effect. These techniques promote evaporation and convection and thereby cooling the body to its normal temperature. Since the body produces its own heat, and if it has to dissipate this heat, there has to be cold sink. These natural phenomena create that sink.

3.5.1 Processes of Energy Loss From the Body

The human body loses thermal energy in three ways (Du Bois and Du Bois Bedford; 1936 CIBSE; 1998).Yaglou and Drinker;1929, Jones; 1973) as follows:

Radiation 45%

Convection - 30%

Evaporation - 25%

Thermal balance in the body is given as

$$M - W = E + R + C + S \qquad (3.12)$$

The cooling on the body is a result of evaporation of sweat. For a transverse flow, the rate of evaporation E_v is given as

$$E_V = (0.0187 + 0.1614\,V)(p_w - p_s)\,W\,m^{-2} \qquad (3.13)$$

This equation is very illustrative. Thus the higher the air velocity the higher is the cooling effect. It is quite clear that the higher the difference between p_w and p_s, the larger is the cooling effect. This is one phenomenon that can be exploited when locating a building and deciding where to put the window openings.

Evaporation of water from the body is not dependent on the air temperature but on the air vapour pressure (Givoni; 1969). Givoni has derived practical equations that illustrate this fact clearly;

$$R_b = 22(t_w - t_s) \quad (3.14)$$

$$C_b = 2V^{0.5}(t_a - t_s) \quad (3.15)$$

and

$$E_{b\max} = 10V^{0.4}(p_S - p_a) \quad (3.16)$$

The effect of wind on thermal comfort is considerable. Wind velocity has the effect of lowering the radiant temperature in the immediate environment. Adarve et al; 1988 report that in natural ventilation 40-50% of the external wind speed can be achieved indoor with the right window openings that allow laminar air flows. These openings would have to be such that as when the open area ≥ 0.33 of the area of the enclosing side. To achieve the same effect, mechanical devices can be used to condition the air in the immediate environment. However, the latter method is very unsustainable and not accessible to everybody in Malawi.

Air conditioning involves lowering the temperature of incoming air and reducing its moisture content so that the air has a high capacity to extract heat from the enclosure or environment (Hoogendoorn and Afgan; 1978). This function can be performed mechanically but it has the problems of high cost and has negative psychological impact on occupants. A number of reports have called this effect of air conditioned buildings on people as the 'sick building syndrome' Hounam;(1980), De Dear and Aulcieums; (1986).

3.6 BUILDING STRUCTURES AND ENVIRONMENTAL THERMAL CONDITIONS

Mechanical devices can maintain thermal comfort temperature in a building but the running cost can be high. It is reported that air conditioning can cost up to 30% of the building cost (Szokolay; 1976, Turner and Szokolay; 1985) and up to 40% of the annual running cost (Anson and Spencer; 1973, Ballinger *et al*; 1993,Twidell and Johnstone 1994). Recent research has shown that the neutral zone in air-conditioned rooms is lower than in naturally ventilated rooms. The implication of this finding is that air conditioning is actually more expensive than originally thought because ventilation engineers for a given design unnecessarily prescribe low temperatures. An alternative approach to maintain the required temperatures in a building is to "design with nature". There are several of these passive design approaches. (Kreith and Kreider; 1978, Kreith; 1973, Carter;1994, Sick and Leppänen; 1994). This is the passive design approach. It would be useful to explore to explore how the passive designs are achieved specially in the tropical regions such as Malawi.

In passive design the effects of radiation can either be utilised to warm environment directly or indirectly. The principle of thermal mass in heat storage can be used to store the thermal energy when it is available and release it when it is required to warm the liveable environment. Thus if a building is constructed using dense materials that are also bad thermal conductors such as stone and brick, the building retains heat longer than if the same building were built with light materials that are good thermal conductors.

There are two typical natural heating cycles in a building. The first is the long periodic variation of summer and winter temperatures and the other is the short night and day cycle. (Humphreys; 1975, Ambler; 1966, Hindmarsh and Macpherson;1962) have observed that people can easily adjust for the former but find difficulties to adjust for the latter which can cause discomfort.

3.7 CHOICE AND NON-CHOICE MATRIX OF THERMAL COMFORT

It is convenient to group the thermal comfort factors into four sectors namely; *objective-non-choice, objective choice, subjective non-choice* and *subjective choice.* A qualitative evaluation table is suggested and is shown in table 3.2 below. In the current work categories 1A and 2A are not considered critical since these are not choices and there is very little that can be done about them. Categories 1B and 2B are areas where action can be taken to minimise extreme effects of the environmental factors if thermal comfort conditions to be maintained. Factors in 1B are functions of time that can be formulated by analysing empirical data and modelling (Klein; 1987).

Table 3.2 Choice and non choice of Thermal Comfort Parameters

↑ **Remoteness of Choice**

	Category	**Non Choices** **A**	**Choices** **B**
1	Objective	Solar Radiation	Vapour pressure Humidity Air velocity Temperature
2	Subjective	Age Sex Metabolic rate Health	Physical location Culture Clothes
		Independent Variable **Cases of non-choice**	**Dependent Variable** **Cases of choice**

Table 3.3 shows a list of conditions that have been cited by various authors and the respective associated shift of Neutral Zone Temperatures. The factors vary from objective conditions to subjective. Although this table is similar to table 3.2 it adds a dimension of association. It explains why the Thermal Comfort Temperatures are different in different countries and races in different seasons. Recent observations by Rajah and Mito; (2002) indicate that the ambient environment generates physical and emotional effect on man. If the physical and emotional reactions are positive then work is enjoyed and the efficiency can be high.

A long-term observation and careful analysis of traditional structures can reveal areas where the building design details of these structures have exploited the natural phenomena that promote thermal comfort.

Table 3.3. Observable Factors That Are Associated With Stress

Associated with Low Neutral Zone Temperatures	**Associated with High Neutral Zone Temperature**
Low Temperature	High temperature
Low vapour pressure	High vapour pressure
Low wind speed	High wind speed
Low humidity	High humidity
Darkness	Day light Adult hood
Female	Male
Childhood	Adult hood
Ill Health	Good health
Light skin	Dark skin
High metabolic rate	Low metabolic rate
Light clothing	Heavy clothing
Unpleasant surrounding	Pleasant surrounding
Stale atmosphere	Fresh atmosphere
Non acclimatisation	Acclimatisation

3.8 REDUCTION OF INDOOR TEMPERATURE THROUGH THE WALL AND CEILING.

In a typical building structure the thermal comfort depends on its thermal capacity and, natural ventilation surrounding it Croome;(19810, Szokolay and Ruston; (1985), Turner and Szokolay; (1980), Jones; (19730, and Iqzquierdo *et al;* (1994). In steady state conditions , it can be shown, in a simplified form that the rate at which a building gains total thermal energy through radiation, conduction, and convection in excess of the comfort limit can be approximated to

$$Q = I_t AF - AF\, U_L (t_{eit} - t_d) \tag{3.17}$$

The CIBSE recommends that the value of (t_{ei}) should be evaluated as follows;

$$t_{ei} = 1/2\, t_{ai} + 2/3\, t_m \tag{3.18}$$

The solar energy is mostly absorbed by the building structure. However, if the building is made of light materials, the building stabilises at the ambient temperature very quickly and then radiates out the excess heat. If equation (3.17) is intergrated over a period it would give the quantity of heat gained if the mass of the building was known. Szokolay and Riston (1985), report that mean radiant temperature can also be used instead of the mean surface temperature. By choice, walls can be designed in such a way as to reject the incoming radiation (Kraus *et al* 1993, Ozkan; 1991, Lotz and Richards 1964, Hodgson and Lotz 1965. These can include the use of reflective materials on the roof or completely obstructing the direct radiation by overhang structures to protect the walls of the building (Sutton and McGregor; 1986, Clarke; 1985, Tarrassdi; 1975, Van Ettinger; 1960) and a careful orientation of the building to avoid the direct radiation.

The thermal capacity of a building can moderate the temperature inside the building. A large thermal capacity has the effect of increasing the time lag between the peak of solar irradiance and the indoor temperature. Van Straaten *et* *al*; (1969) report that out of eight experimental walls and roof types where the floor was made of same material (concrete), the most effective combination to lower the indoor temperature in a house with its roof and white walls. The next best result was obtained from a house with brick walls and insulated roof space. The latter achieved a maximum temperature of 2.6 deg. C; below maximum outdoor temperature. Lotz; and Richards (1964) report that a roof space with a reflective insulation metal foil as is the practice in South Africa; loses reflectivity as soon as dust settles on it and this, reduces the insulation effect of the foil. However, he also observes that this type of insulation can reduce peak indoor air temperature by 2.9 deg C. Wooley; (1983), reports experimental results in which he uses twelve types of walls. A hollow concrete block wall with 100mm thick polystyrene is found to be the most stable wall in maintaining the temperature within the thermal comfort zone. However, when the polystyrene insulation is removed and adjustable louvers fixed to the walls, the performance of the wall is still lower but is better than all the other eleven types

Reduction of indoor temperature requires not only barriers to cut off radiation but the incorporation of materials that have low conductivity values or can reflect radiation to slow down the immigration of thermal energy into the liveable area.

It is reported in most recent work (Zakaria and Woods 2002) that for a roof to contribute effectively to Thermal Comfort it must be a roof, with an optimum space of 100mm, insulation of 50mm and the material must be of a light colour.

3.9 REDUCTION OF INDOOR TEMPERATURE BY INCREASING AIR SPEED

Mitchel and Biggs (1964) report that the wind velocity (measured at 10m height) can be related to indoor air changes (κ) as follows;

$$\kappa = \sigma + \beta V \qquad (3.19)$$

In this case the numbers of air changes to any room are useful in ventilating the room. This equation then relates the number of air changes to the outside air speed and can be a useful guide in designing rooms if the wind speed of the location is known

This report confirms that wind speed as read from Wind Rose diagrams can be used to estimate the indoor air Speed design a thermally comfortable building at the design stage. The indoor air speed influences the thermal comfort by increasing the convective heat exchange. For a full dressed person (Givoni, 1969) the body heat exchange factor is related to the indoor wing speed as follows.

$$C = \varphi V^{0.3}(t_a - 35) \tag{3.20}$$

The CIBSE Guide recommends a minimum air velocity of 0.1 ms^{-1} in liveable environments. Adarve et al; (1988) report that in a well ventilated building, a minimum value of 40% of the outdoor air speed can be achieved indoors. However, when the ambient air temperature reaches 35°C; which is the skin temperature, any further increase in air speed does not have a cooling effect on the body (Givoni; 1969). De Dear and Auliciems (1988) confirm the psychological phenomenon that high temperatures and low air speeds are easily acceptable during the day when the same conditions are not acceptable in the night. This has been discussed in the earlier sections.

Wright and Hollands; (1989) report that in a typical roof of a house where corrugated iron sheets are used, convective air currents can be induced in the corrugations of the sheets and they have a cooling effect in the enclosed spaces. However, this effect is small compared to the heat that is radiated from the metal surface, and as a result the indoor temperature can be high in the house and this can result in uncomfortable conditions. In Malawi these corrugated iron roofed buildings are very common and during the hot months of the year many people must feel this effects.

Recent work in this area (Ansley and Thain; 2002) has shown that cooling sensation on the skin can be evaluated using the following equation.

$$C_S = 3.67(V - 0.2) - (V - 2)^2 \tag{3.21}$$

One of the reported work by Ansley and Thain was that air gusts at frequencies of 0.3-0.5Hz give better cooling effect than an air flow at constant speed. This particular effect is attributed to the peak response of the human cold cuteneous thermo receptors located just under the skin. These have an optimum response at this frequency range. Ceiling fans easily create air gusts. Ceiling fans of 1.2-1.5 metres diameter at speed of 315 rpm are being recommended as alternatives to air conditioning units in a room. The power consumption of a fan of this size at this speed would be 160 watts. The speed of this fan at the tips of the blades would be 25 ms^{-1} and would influence 452 m^3. This is one of the devices that are used for cooling environments. Although the power consumption of a ceiling fan as reported is as low as this, the question of use of electricity is in cases not necessary.

3.10 EFFECT OF LEVELS OF HUMIDITY ON AIR TEMPERATURE

The CIBSE Guide (A1-a) indicates that thermal comfort conditions are achievable with humidity levels in the range of 40 - 70%. However humidity levels below 40% in carpeted rooms are likely to cause shocks due to electrostatics. Koch et al; (1960), carried out investigations on the levels of comfort relative to humidity while the temperature was monitored. Their findings confirm that a change of humidity from 30% to 85% only induces a corresponding change in temperature of 0.61 degrees Celsius. Yoglu also reports that a humidity change of 20-80% caused a corresponding temperature change of 1.67 deg C. This seems to suggest that humidity is not a very important variable for thermal comfort.

3.11 EFFECT OF CLOTHING ON THERMAL COMFORT

The effect of clothing on thermal comfort is quite considerable. The rate of flow of thermal energy from the clothing surface to the surrounding can be expressed as;

$$kM=(t_c-t_a)h_c+(t_c-t_m)h_r \qquad (3.22)$$

Humphreys (1970) has shown that equation can be rearranged such that

$$kM\left(\frac{1}{h_c+hr}\right)=t_c-\left(\frac{h_c t_a+h_r}{h_c+h_r}\right) \qquad (3.23)$$

In this case the temperature $\left(\frac{h_c t_a+h_r}{h_c+h_r}\right)$ is a weighted mean between t_a and t_s.

This weighted mean is dependent on the type of clothing. A unit for the insulation value of clothing is a **Clo**. One **Clo** unit is equivalent to 0.155 $W^{-1}m^{-2}$ deg. C. Work by Fanger; (1967), and Woolard; (1981) and others (Forte and Holliers;1970) confirm that the **Clo** unit correlates very well with actual subjective experiences. The values vary from 0- **Clo** for a naked person, to full *arctic winter* clothing at 3 **Clo.** The coldest conditions in Malawi would require a clothing value of 1.5 **Clo**; using Fanger's visual scale of clothing classification.

3.12. EFFECT OF VAPOUR PRESSURE ON AIR TEMPERATURE

Vapour pressure is a complex function of air velocity and humidity. However, it promotes the evaporation of sweat from the skin. Vapour pressure is crucial in assessing the Index of Thermal Stress (ITS) that has been mentioned in section 2.8.and gives the following sweat rate:

$$S_r = [(M - W) + C + R](1/f_s) \tag{3.24}$$

In this formula, the effect of vapour pressure is not immediately discernible. The effect of vapour pressure is in fact included in the assessment of the sweat rate. Givoni (1969) has assessed this equation and found that it overestimates the warming effect of humidity. A better method for assessing the effect of vapour pressure is given by the Heat Stress Index (HSI) developed by Belding and Hatch (1955). This index is defined as;

$$HSI = \frac{\text{Evaporation cooling required}}{\text{Max evaporative cooling possible}} \tag{3.25}$$

This expression was later modified and presented as a Relative Strain (RS) and given by

$$RSI = \frac{M(I_{cw} + I_n) + 5155(t_a - 35) + R\,I_n}{7.5(44 - p_a)} \tag{3.26}$$

Hounam;(1968) *reports that in normal indoor situations ;* M *=115* $W m^{-2}$ *; in this case* I_{cw}*= 0.4 Clo,* I_n *=0.4 and* R=0 *equal air-wall temperature.*

After substituting these in 3.26 simplifies the equation to;

$$RSI = \frac{10.7 + 0.74(t_a - 53)}{44 - P_a} \qquad (3.27)$$

This is a very useful format of the equation. Corresponding useful significant effects of average man are listed in table 3.4

Table 3.4 Effects of Relative Strain of an Average Man

Relative Strain (RS)	Status	Significant effects for standard man
0.1 to 0.2	Zone	All comfortable until near upper limit
0.1 - 0.2	Boundary	85 per cent comfortable
		10 - 15 per cent too warm
0.25		50 per cent comfortable
0.2 - 0.3	Boundary	None comfortable, some signs of distress
0.3 to 0.4	Zone	50 per cent too hot
0.3 to 0.4	Boundary	75 per cent show distress, some failure
0.4 to 0.5	Zone	All too hot, all show signs of distress
Above 0.5		Too hot to endure, action required to alleviate distress

CHAPTER FOUR

4.0 ANALYSIS OF PATTERN OF SOLAR RADIATION DISTRIBUTION AND FACTORS THAT AFFECT THERMAL COMFORT IN MALAWI

4.1 FILTERING OF RECORDED SOLAR RADIATION DATA TO ESTABLISH ITS CREDIBILITY

Most of the agricultural stations in Malawi monitor meteorological data. Almost all the data used in this work has been recorded over a period of ten years or more. In some cases these data has been recorded for the past fifty years, Appendix 4.2 shows details of these stations. The data are recorded using two different instruments, the Gunn-Bellan Spherical Pyranometer and the Camp-Bell Stokes Sunshine Recorder. As part of this work a full report has been submitted for publication separately (Zingano *et al*; 2001). However, the main argument and conclusions of that work are illustrated herein below.

From 1973 to 1977; one weather station; Salima had captured data from both of these instruments. These data have been used to derive a relationship between one set to the other. All this data was recorded in Carls cm^{-2} Day^{-1}. The results and the differences between the data recorded on the two instruments are shown in figures 4.1 and 4.2.

As reported above, most of the meteorological data recorded in Malawi has been captured on the two rather inaccurate but useful instruments; The Gunn-Bellan Spherical Pyranometer and the Camp-Bell Stokes Sunshine Recorder. This presented another hurdle but a challenge. In order to be confident about the data that was to be used, a separate detailed study had to be undertaken to establish the nature and credibility of the data. It was felt that it was important that the relative accuracy of these data be established. To confirm the degree of accuracy, data from one weather station where both instruments were used are analysed in table 4.1. The corresponding Scatter Gram is shown in figure 4.3. The data used in this analysis is shown in Appendices 4.5 and 4.5

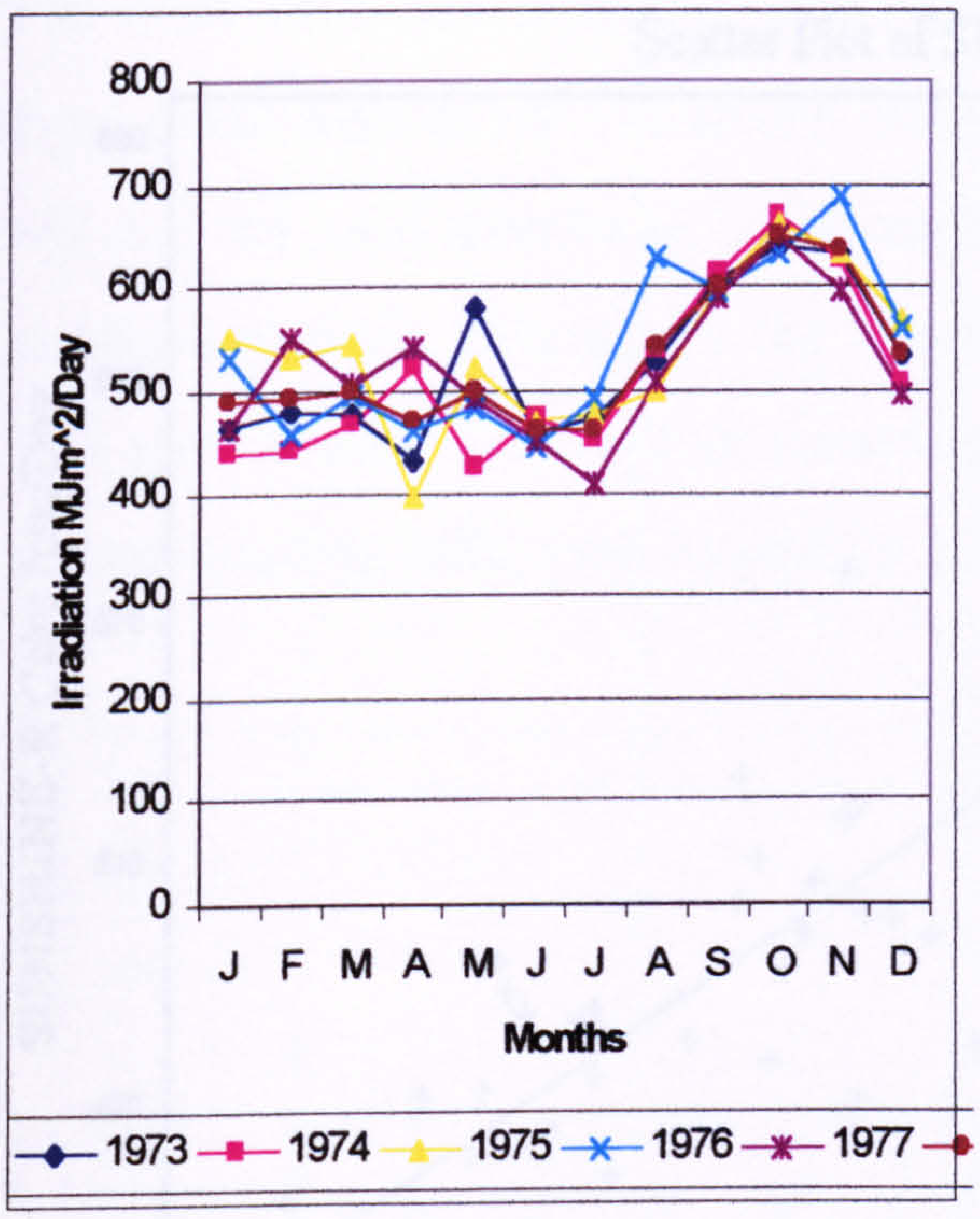

Fig.4 1. Gunn-Bellan Data.

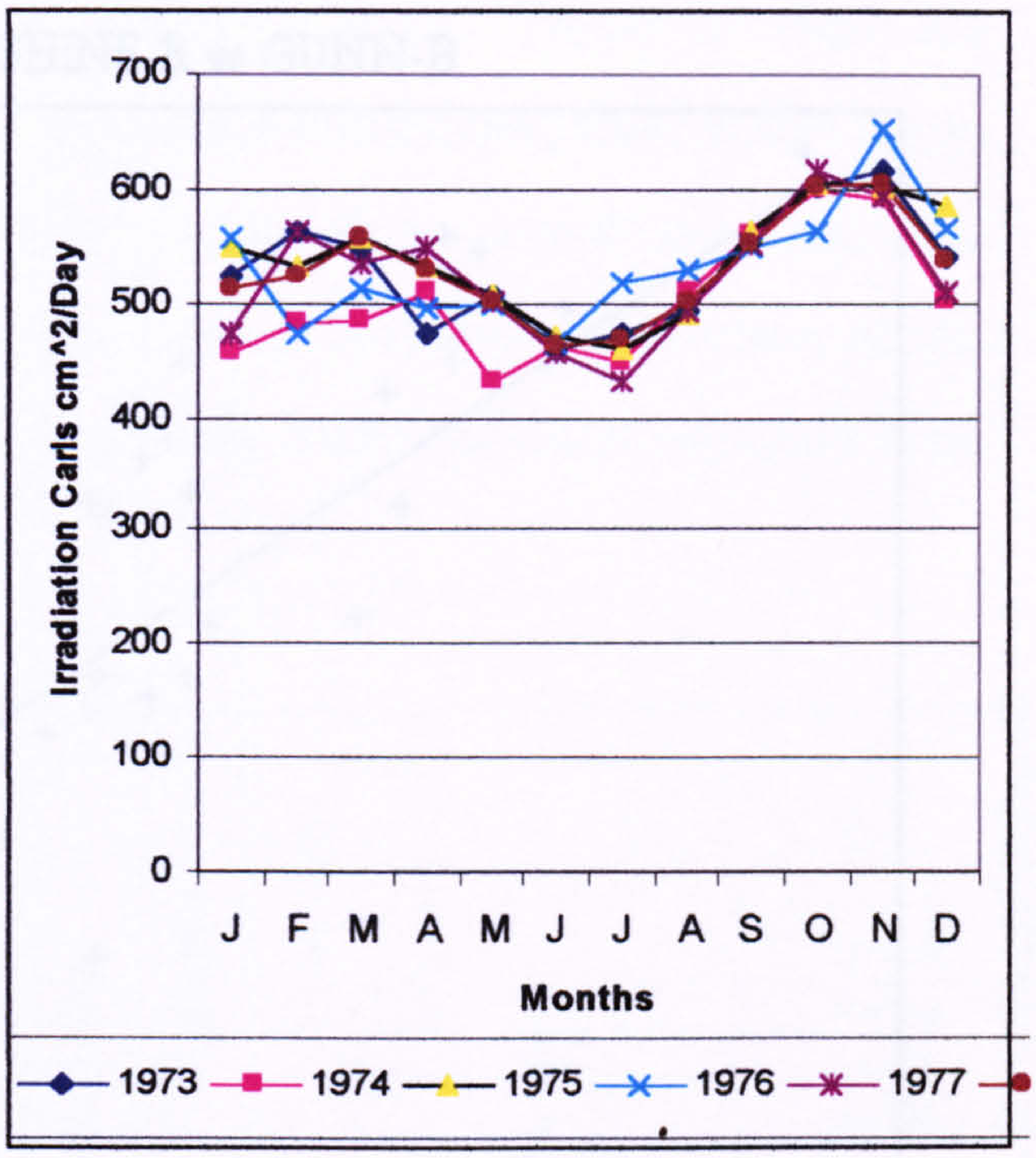

Fig.4 2. Sunshine Recorder Data.

(In both cases Mean of the Monthly Mean values for 5-years is superimposed to illustrate the general shape of the pattern)

Table 4.1.Statistical Parameters Showing The Simple Relationship Between Data Recorded On A Gunn-Bellan Pyranometer And That Calculated From Data On A Camp-Bell Stokes Sunshine Recorder (N=60).

Predictor variable	Coefficient	Standard error	Student's T	P
Constant	215.709	25.5414	8.45	0.0000
Sunshine-R	0.58790	0.04800	12.25	0.0000
r^2	0.7211	Residual. mean square (MSE)		752.178
r^2 adjusted	0.7163	Standard Deviation		27.4259

From this analysis a simple relationship between the data from the two different sources can be represented as follows:

$$I_{tG} = K(0.5879)I_{tS} + 215.709 \ \text{MJ m}^{-2}\,\text{Day}^{-1} \qquad (4.1)$$

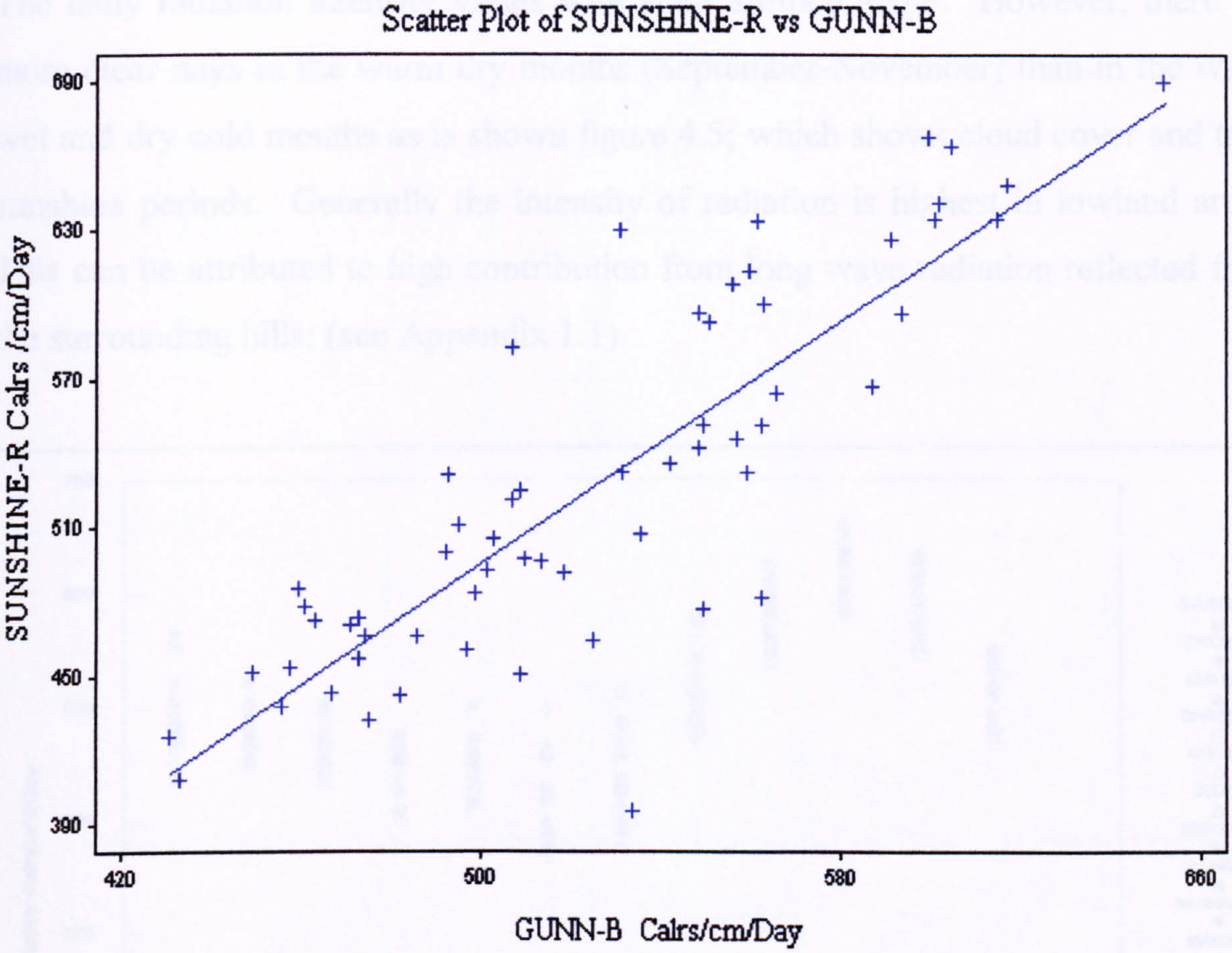

Fig.4 3; Scatter Gram of Data recorded on a Camp- Bell Stokes Sunshine Recorder Vs that from a Gunn-Bellan Spherical Pyranometer.

4.2 LEVELS OF SOLAR RADIATION

The global solar irradiance intensity in Malawi can be as high as 940 Wm^{-2} on a clear October sky and as low as 65 Wm^{-2} when the rain cumulus clouds are low in the rainy season (Zingano, 1986). The annual variations show peaks in September and March (Equinox periods). However, the March peak is lower than the September peak. The former is during the rainy season and it is suggested that this is due to the humidity levels that are constantly high and cloud covers common. These attenuate the radiation and lower the peak values. Figure 4.4 shows solar radiation levels of all locations where solar radiation data is recorded. The altitude and radiation levels as recorded at all the meteorological stations under study are shown in Appendix 4.3. Details of radiation levels are shown in Appendix 4.4.

The daily radiation intensity varies with solar altitude angle. However, there are more clear days in the warm dry months (September-November) than in the warm wet and dry cold months as is shown figure 4.5; which shows cloud cover and total sunshine periods. Generally the intensity of radiation is highest in lowland areas. This can be attributed to high contribution from long wave radiation reflected from the surrounding hills; (see Appendix 1.1)

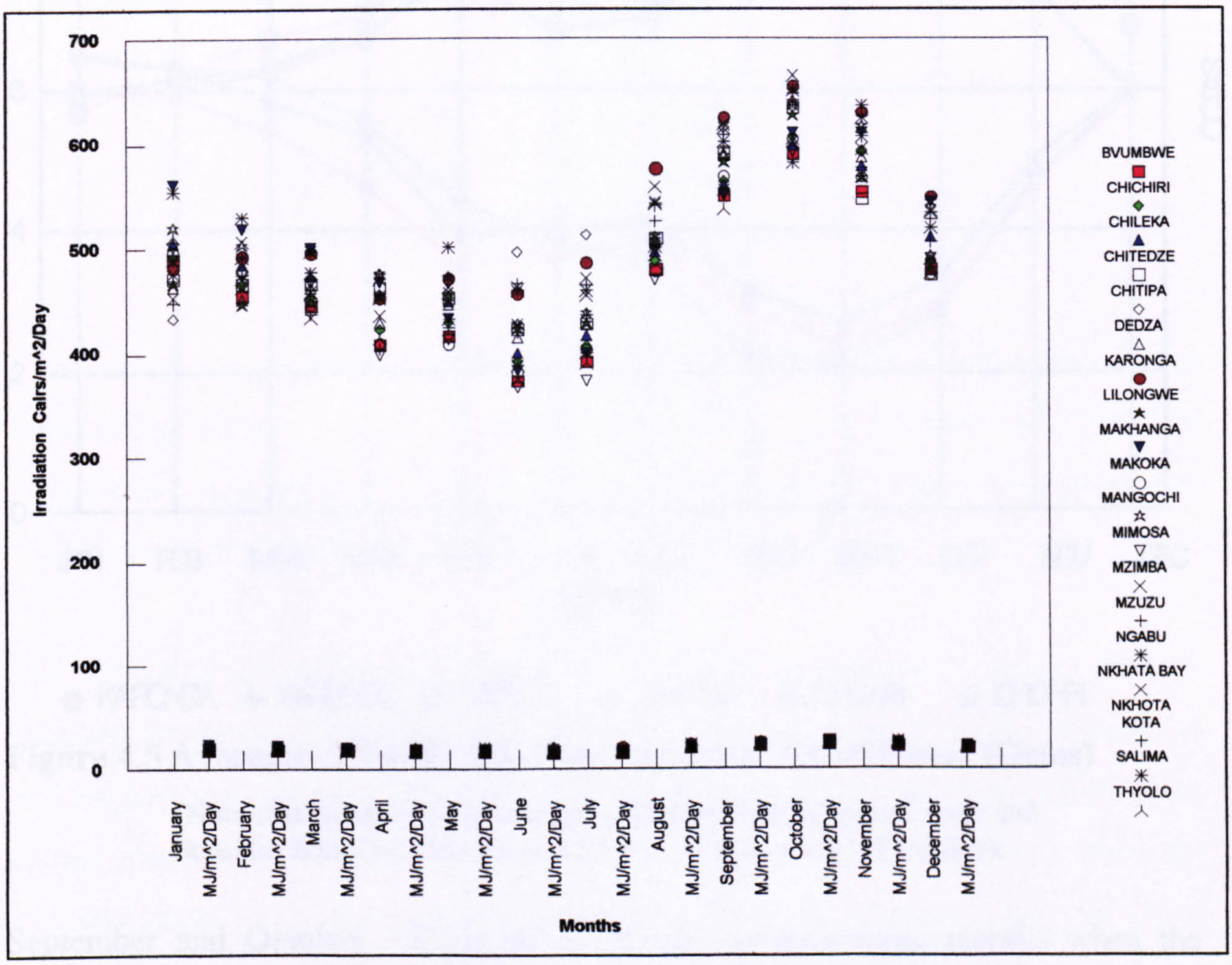

Figure 4.4 Level Of Radiation From All Meteorology Stations
(Note the equivalent values in MJ m^{-1} Day^{-1})

In order to identify areas of extreme temperatures an analysis of cloud cover has been carried out as shown in figure 4.5. This figure confirms that there is less cloud cover in the months of September and October. This explains the radiation data in figure 4.4. Otherwise the levels of radiation should be the same in February to March as in

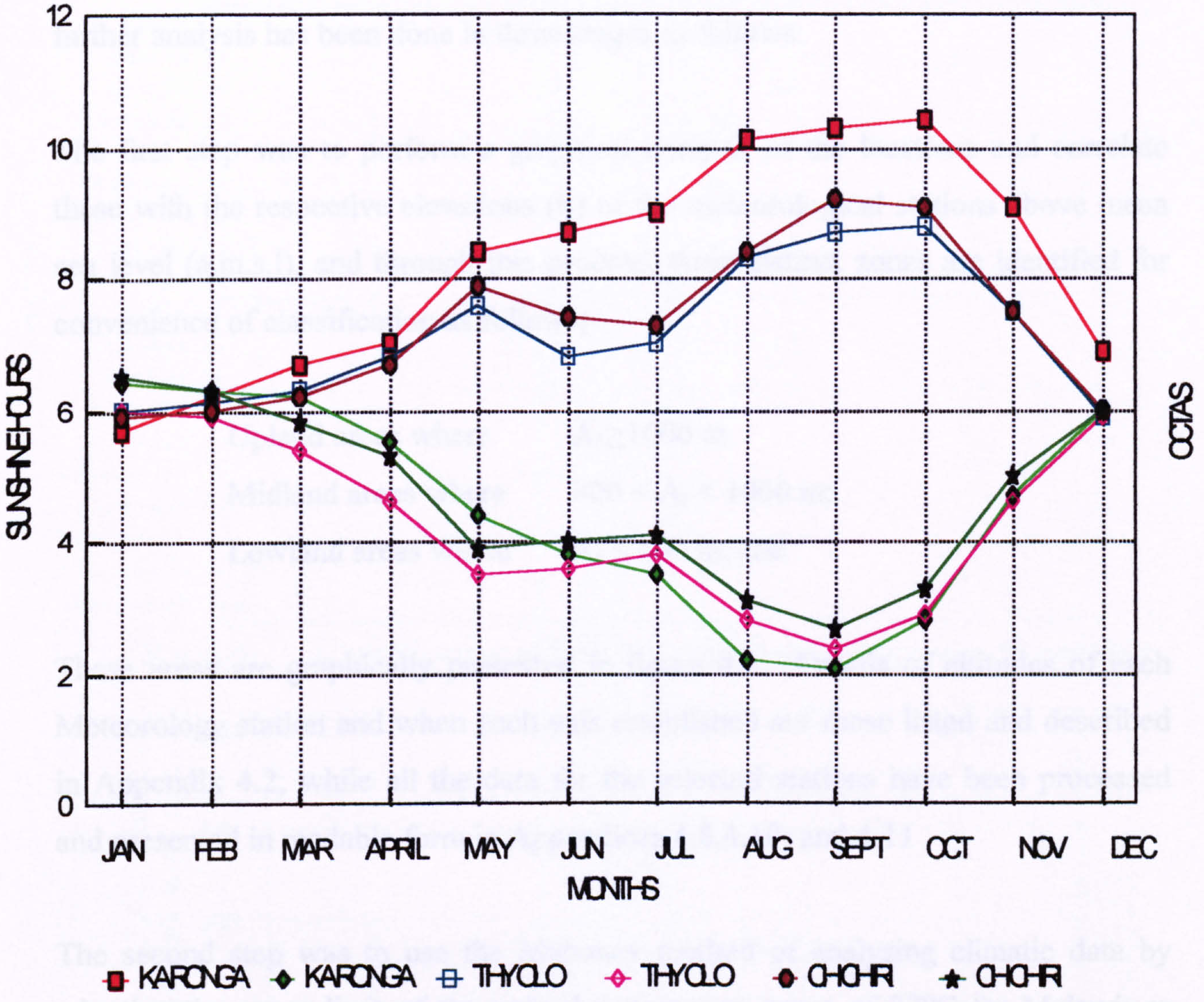

Figure 4.5 Averaged Monthly Sunshine Hours and Cloud Cover (Octas)

(Note that Sunshine is a consequential reciprocal of cloud cover and Sunshine hours in Malawi cloud cover hardly goes beyond 6 hours).

September and October. These would be the corresponding months when the Solar angles would be high in Malawi. In other words since the sun is overhead twice a year over Malawi, there should also be two similar radiation peaks.

4.3 ANALYSIS OF GEOGRAPHICAL ZONES

4.3.1 Variation of Temperature With Altitude

Air temperature is the commonest index that is useful for measuring thermal comfort. In order to identify variation and distribution of air temperature areas a further analysis has been done in three stages as follows:

The first step was to perform a graphical analysis of the locations and correlate these with the respective elevations (**h**) of the meteorological stations above mean sea level (a.m.s.l), and through this process, three distinct zones are identified for convenience of classification as follows;

Upland areas where	$A_l \geq 1000$ m
Midland areas where	$800 < A_l < 1000$ m;
Lowland areas where	$A_l \leq 800$ m; and

These areas are graphically presented in figure 4.6. Details of altitudes of each Meteorology station and when each was established are those listed and described in Appendix 4.2, while all the data for the selected stations have been processed and presented in readable form in Appendices 4.8,4.10; and 4.11

The second step was to use the Mahoney method of analysing climatic data by adopting the upper limit of the neutral temperature range of 27°C for Malawi; as will be justified in the conclusion section of this work, as a datum to calculate the excess temperatures. In this case the Mean Maximum Temperatures from the meteorological data were used rather than the Mean Temperatures to avoid underestimation of the excess temperatures. However, the frequency and duration of the Mean Maximum Temperatures are not available from the recorded data. The frequency and duration would give a more accurate picture of the severity. In this case the intention is to detect where in the country and over which months would the thermal discomfort conditions likely to occur. Figure 4.7 is a plot of cumulative degree-days against the locations. The details of data for this evaluation see appendix 4.9. This is a preliminary attempt to quantify the degree of discomfort levels in each month.

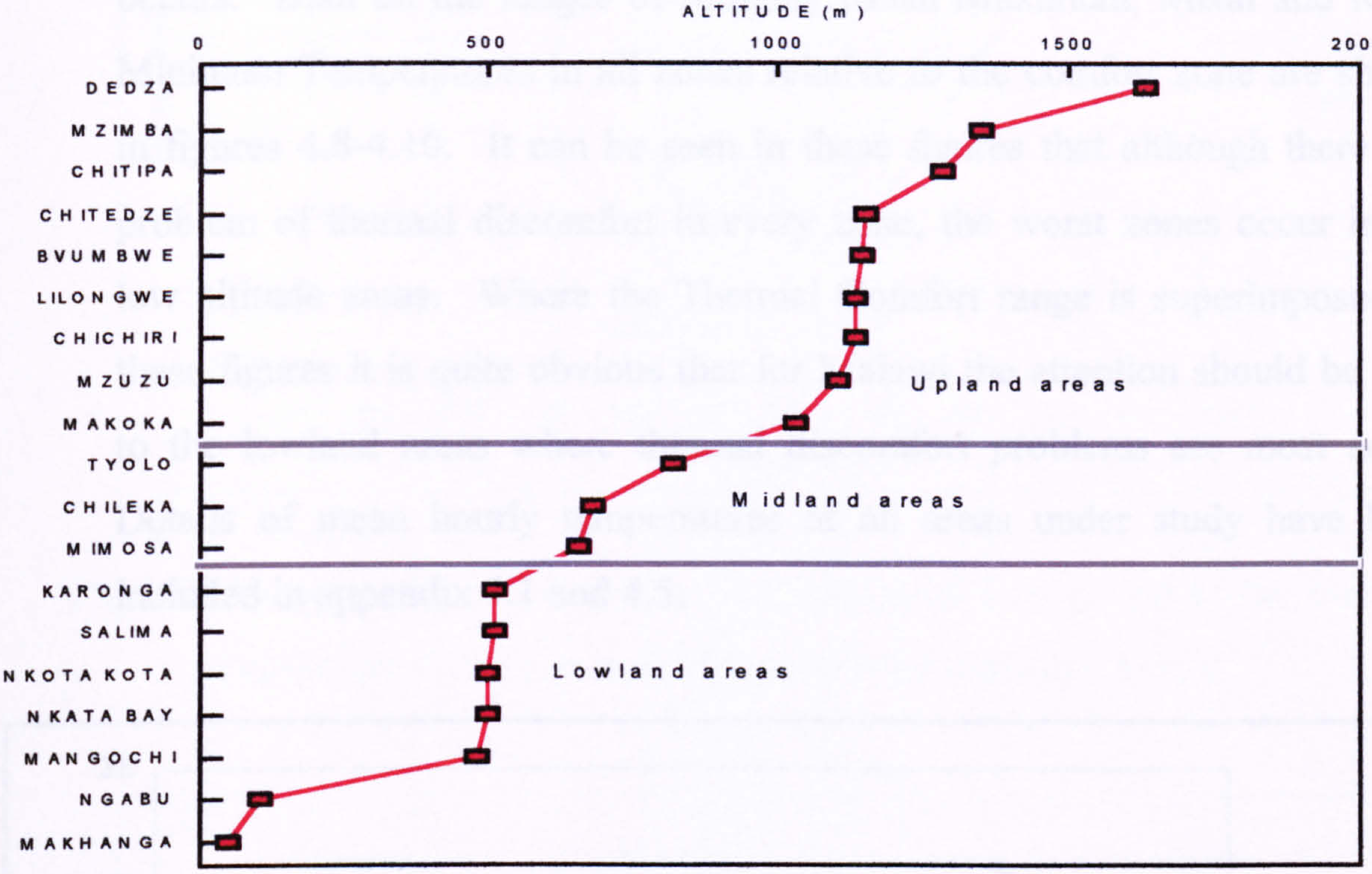

Fig. 4.6; Classification of Climatic Zones with Reference to Altitude

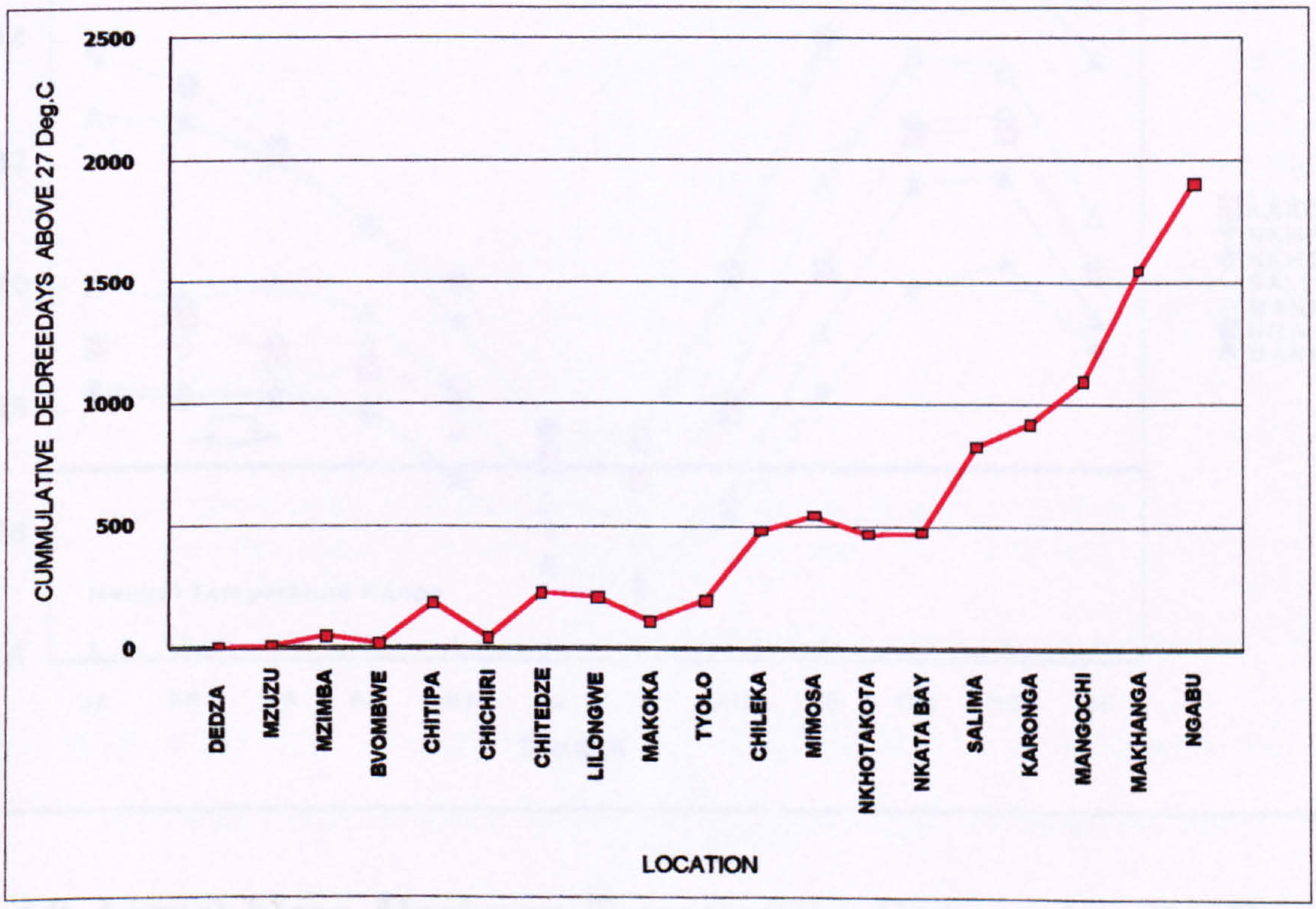

Figure 4.7 Cumulative Degree Days Above 27°C As The Upper Limit Of The Neutral Comfort Zone.

The monthly cumulative degree-days (D.d) are abstracted from appendix 4.8. The degree -day is a product of excess temperature above the upper limit of the comfort zone and the number of days during which that excess occurs. Data on the ranges of Monthly Mean Maximum, Mean and Mean Minimum Temperatures in all zones relative to the comfort zone are shown in figures 4.8-4.10. It can be seen in these figures that although there is a problem of thermal discomfort in every zone, the worst zones occur in the low altitude areas. Where the Thermal Comfort range is superimposed on these figures it is quite obvious that for Malawi the attention should be paid to the lowland areas where thermal discomfort problems are most acute. Details of mean hourly temperatures at all areas under study have been included in appendix 4.1 and 4.5.

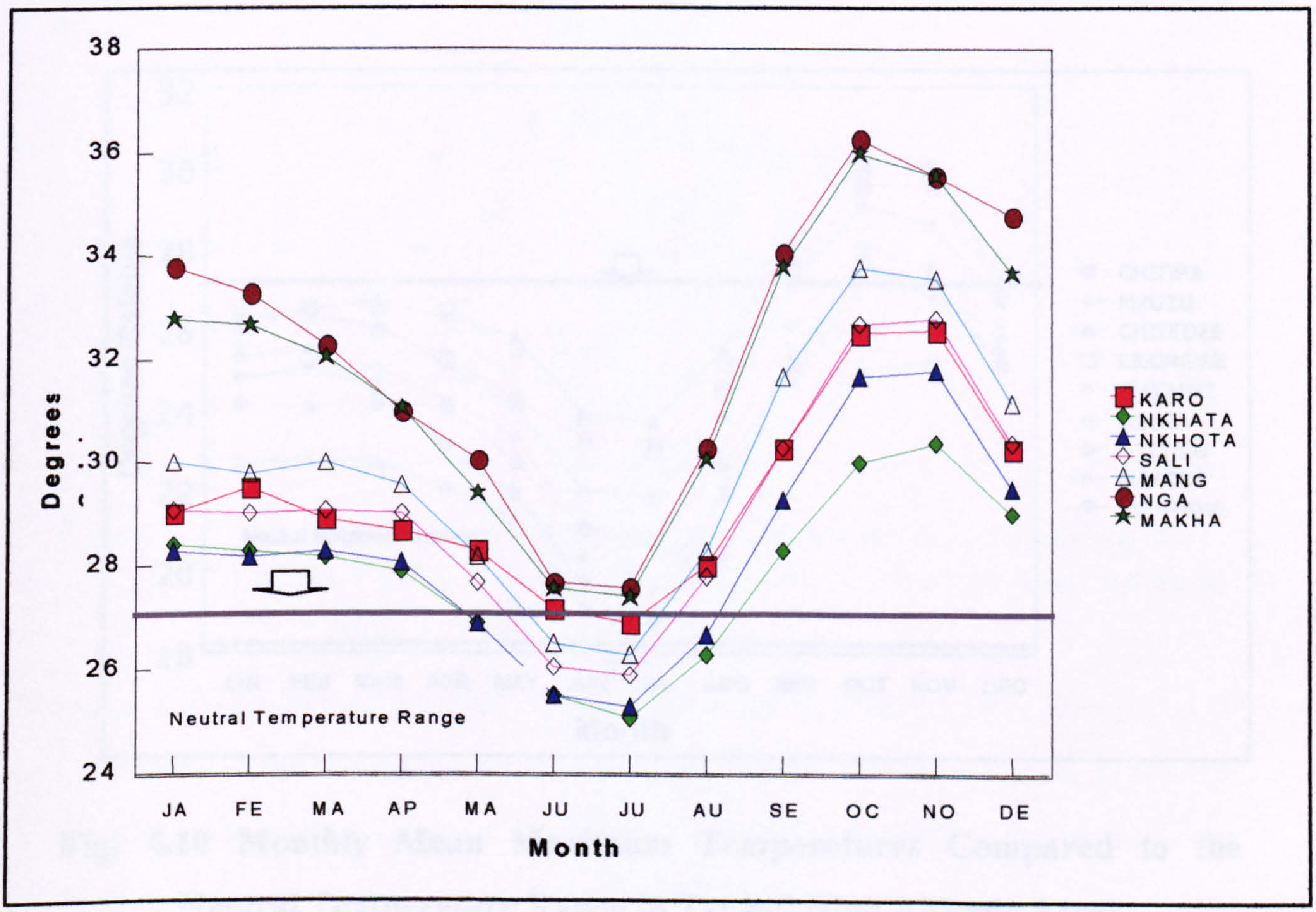

Fig. 4.8 Annual Mean Maximum Temperatures Compared to the Neutral Temperature Range in the Typical Lowland Areas.

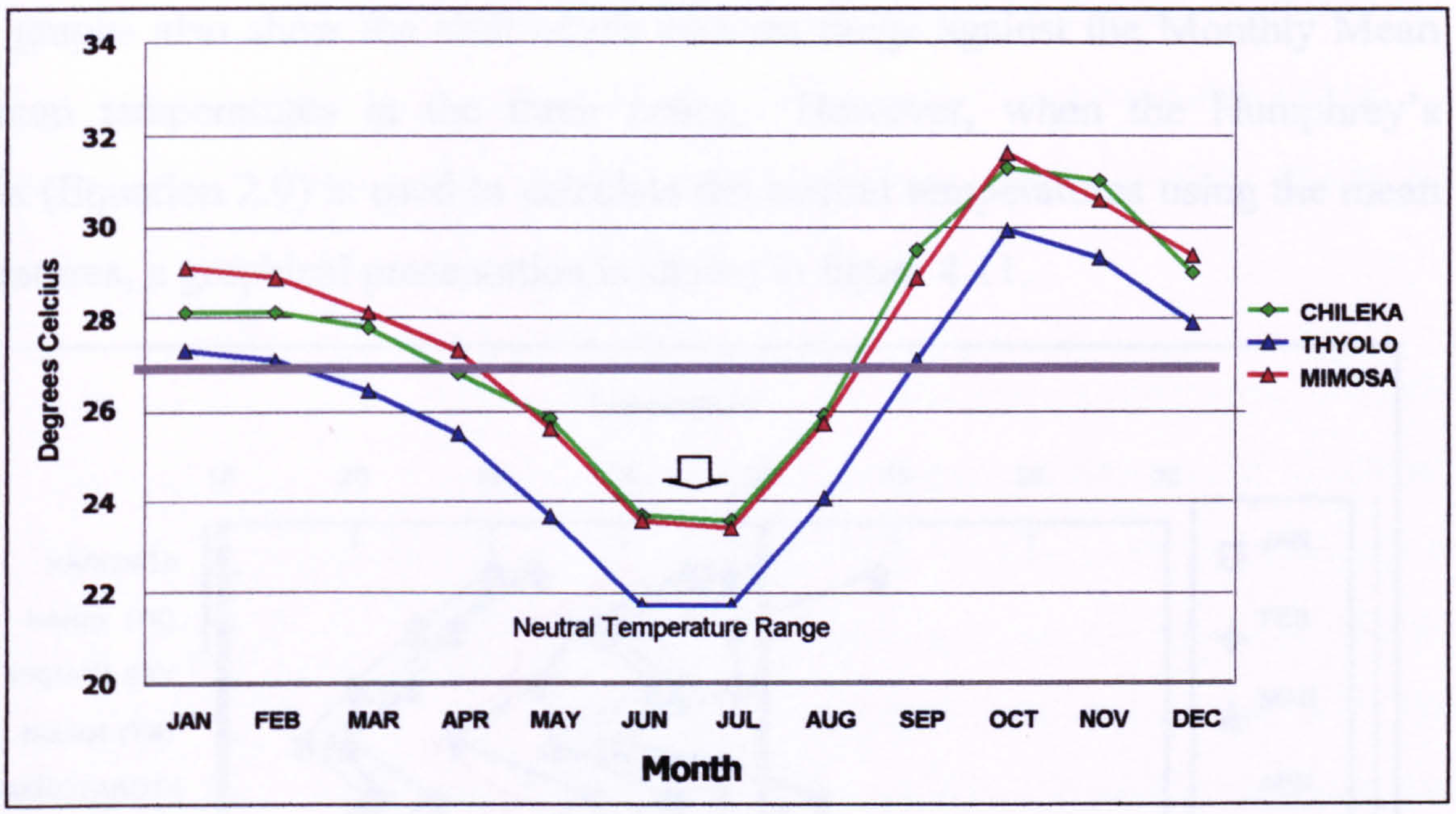

Fig. 4.9 Annual Mean Maximum Temperatures Compared to the Neutral Temperature Range in the Typical Mid Altitude Areas.

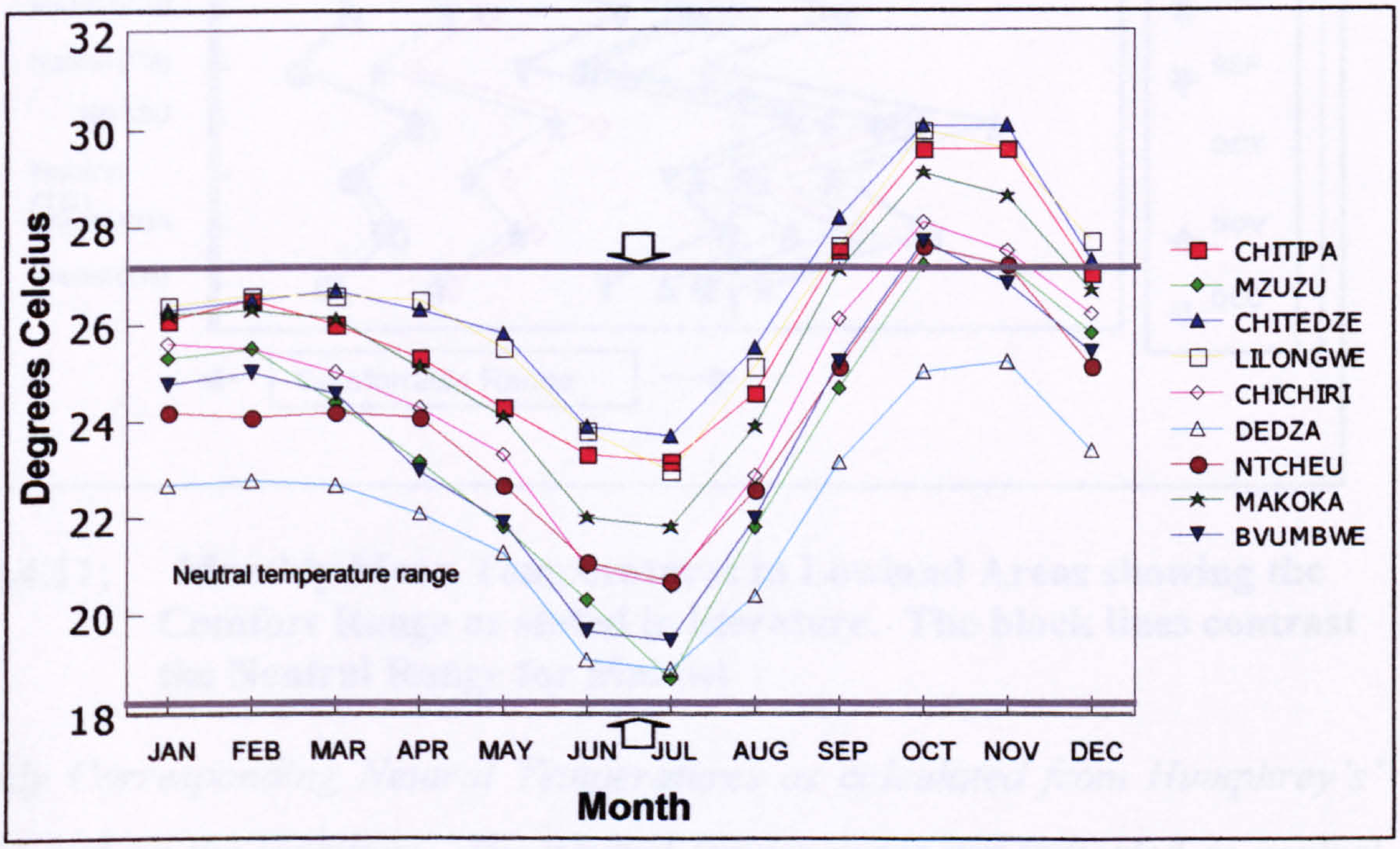

Fig. 4.10 Monthly Mean Maximum Temperatures Compared to the Neutral Temperature Range in Typical High Altitude Areas.

These graphs also show the shift of the comfort range against the Monthly Mean Maximum temperatures in the three zones. However, when the Humphrey's formula (Equation 2.9) is used to calculate the neutral temperatures using the mean temperatures, a graphical presentation is shown in figure 4.11.

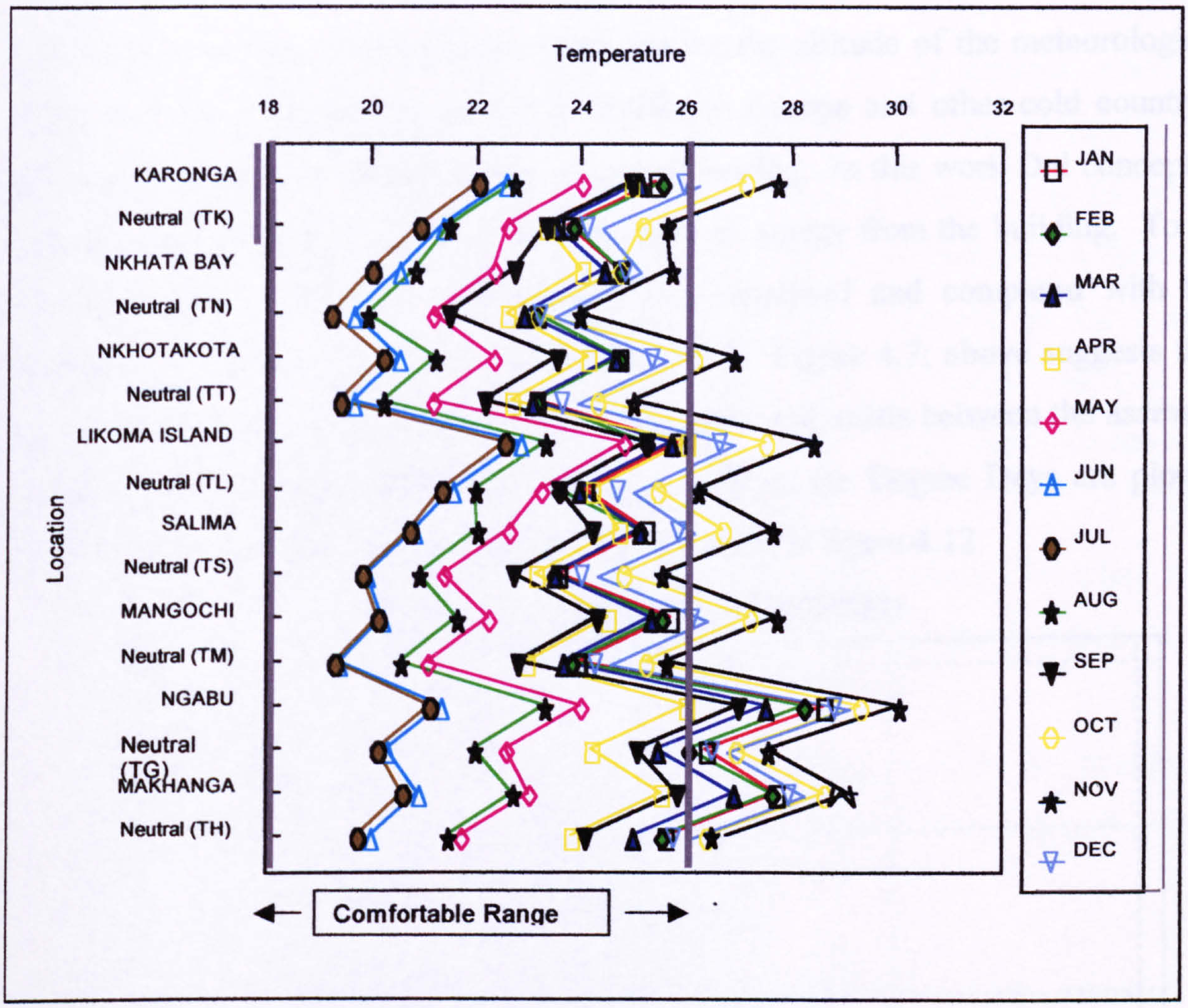

Fig.4.11; **Monthly Mean Temperatures in Lowland Areas showing the Comfort Range as stated in literature. The black lines contrast the Neutral Range for Malawi**

(Monthly Corresponding Neutral Temperatures as calculated from Humphrey's' formula and on the locations. The neutral temperatures are indicated as neutral (T ') where the second letter in the bracket (') is representing the name of the location.

In figure 4.11, almost all the locations (except Nkhata-Bay), in January, October, November and December, have mean temperatures above the comfortable range. From figure 4.8; it can be seen that these lowland areas require cooling almost all the year round.

The third step was to plot Degree-Days against the altitude of the meteorological stations. The degree day concept is familiar in Europe and other cold countries where it is used to estimate the cost of central heating. In this work D.d concept is being used in reverse to indicate the extraction of energy from the building. To do this the Mean Maximum Temperatures were analysed and compared with the altitudes. A scatter gram is shown in figure 4.12. Figure 4.7; above suggests that there is a definite relationship that can be deduced and exists between the assessed Degree Days and the Altitude of a location. When the Degree Days are plotted against the natural logarithm of the altitude the result is figure 4.12

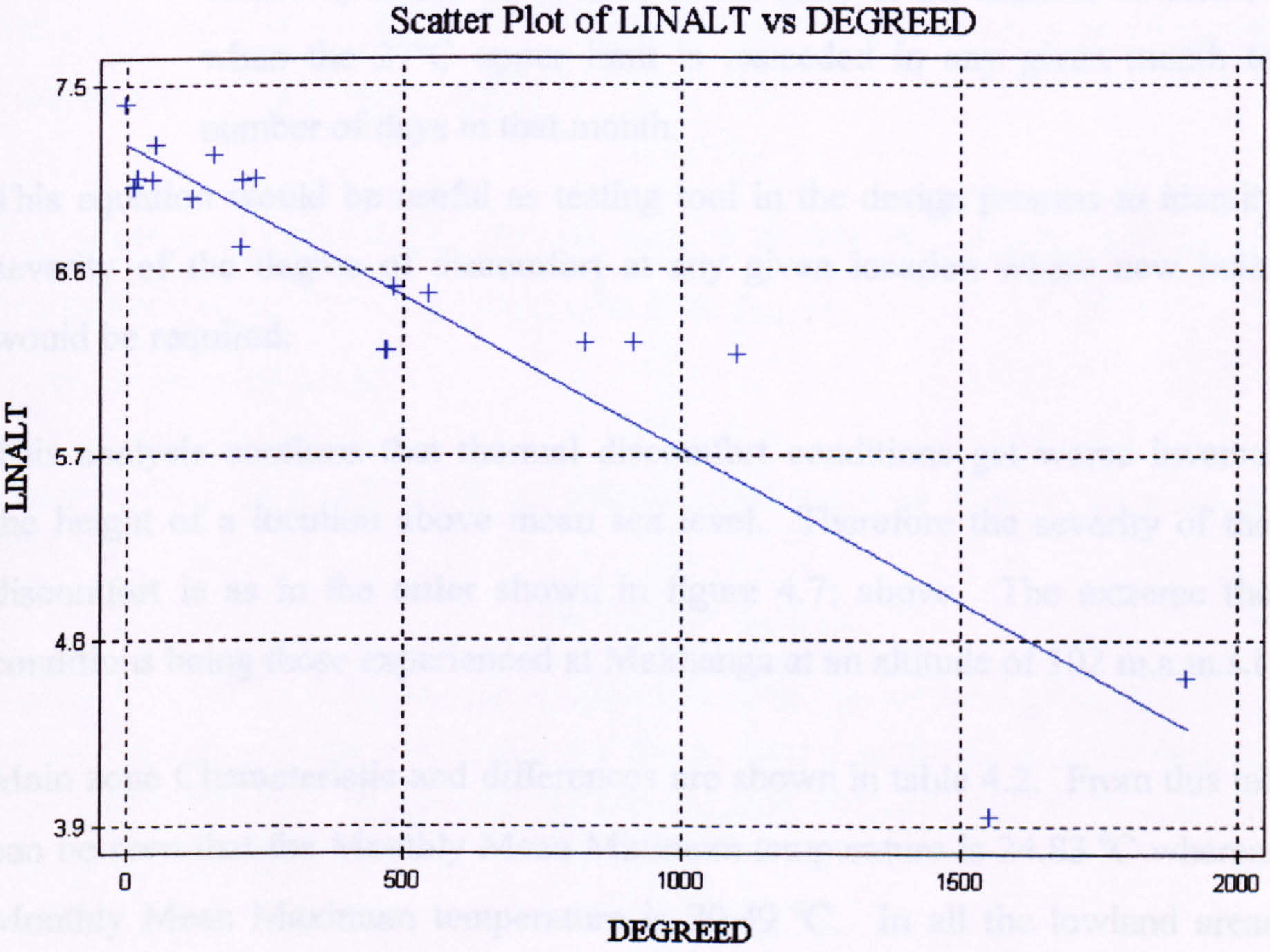

Fig. 4.12 Plot of Degree Days Versus Location, Altitude Data

Figure 4.12 yields a regression equation as follows;

$$D.d = -575.994 \ln A_L + 4226. \qquad (4.2)$$

This equation has a $p<0.045$ and an $r=0.9252$. The likely problem in this result might lie in the fact that the Degree Day value is calculated from the Monthly Mean Maximum temperatures that are recorded at the metrological stations; Appendix 4.8. These data do not show the frequency and the duration when the 27°C upper limit is exceeded in the month. However, the assessment that has led to the deduction of equation 4.2 assumes that the excess occurs over the entire month. Nevertheless this problem can be taken care of by including a factor in equation (4.2) that would take into account the exact duration of the excess temperatures in each month as a ratio of the days when the upper limit was not exceeded at each location. Equation (4.2) can be modified by a factor f_d to read;

$$D.d = f_d(-575.94 \ln A_L + 4226) \qquad (4.3)$$

> Where f_d would be defined as the ratio of the number of actual days when the 27°C upper limit is exceeded in any given month to the number of days in that month.

This equation would be useful as testing tool in the design process to identify the severity of the degree of discomfort at any given location where new buildings would be required.

This analysis confirms that thermal discomfort conditions get worse inversely to the height of a location above mean sea level. Therefore the severity of thermal discomfort is as in the order shown in figure 4.7; above. The extreme thermal conditions being those experienced at Makhanga at an altitude of 102 m.a.m.s.l. .

Main zone Characteristic and differences are shown in table 4.2. From this table it can be seen that the Monthly Mean Minimum temperature is 24.83 °C whereas the Monthly Mean Maximum temperature is 29.49 °C. In all the lowland areas the Monthly Mean Maximum temperatures exceed 27°C.

An inspection of the data from the meteorological stations shows that the monthly Absolute Minimum Temperature can be as low as 0 °C as is the case for Mzuzu and as high as 44.4 °C as is the case for Makhanga.

While the above is sufficient to identify the problem areas there is need for a more detailed programme for recording data for solving equation (4.3). This concept is also relatively new in the cold countries where a new thinking is being undertaken to re-examine this area (Kaplanis et al; 2000). To evaluate the number of Degree Days the following equation has been proposed.

$$D.d = \int_{t_{min}}^{t_{ref}} \left(t_{ref} - t_a\right) p\left(t\right) dt \qquad (4.4)$$

In point of fact whereas the reference temperature t_{ref} would be a function of time, it would be stochastic from day to day. However, the effect of the excess thermal energy above the reference temperature is what has to be estimated and pumped out (in the case of tropical countries) as thermal energy, in order to effect thermal comfort for a healthy environment.

The concept in equation 4.4 can be used in reverse by inserting a negative sign before the integral sign or changing the term $\left(t_{ref} - t_a\right)$ to $\left(t_a - t_{ref}\right)$ where $t_{ref} < t_a$ in a typical Tropical climate .

The excessive Degree Days in the tropical climate can be assessed as a function of time as;

$$D.d = \sum_{i=1}^{n=j} \left[t_a - t_{ref}\left(h_i ; n_j\right)\right] \Delta t \qquad (4.5)$$

Where n *represents the number of days where the upper limit of thermal comfort t is exceeded as average temperature of the* h_i *hour and the* n_j *day at intervals* Δt *These concepts may be general but the detailed analysis have to be specific to a country; in this work to Malawi.*

Table 4.2 Table of Main Characteristic Differences Between High and Low Altitude Areas

High Altitude Areas	Chitipa	Mzuzu	Lilongwe	Chitedze	Chichiri	Bvumbwe	Dedza	Mzimba	Mean
Mean Max. Temp.	26.10	24.00	26.60	26.60	24.60	23.70	22.20	25.00	24.83
Mean. Temp.	21.00	17.80	19.60	20.10	19.90	19.30	17.70	19.70	19.34
Annual Range	5.10	6.20	7.80	6.50	4.70	4.40	4.50	5.30	5.60
Mean Min. Temp.	15.90	11.70	12.80	13.60	15.20	14.80	15.20	14.40	14.17
Diurnal Range	10.20	12.30	13.80	13.00	9.40	8.90	7.20	10.60	10.69
Relative Humidity	71.00	83.00	70.00	69.00	74.00	77.00	71.00	72.00	73.57
Wind Velocity (m)	6.30	4.50	4.90	3.80	5.00	4.20	4.50	6.30	4.74
Rainfall (mm)	1038.80	1238.00	847.50	919.10	1122.10	1158.90	905.00	864.30	1032.77
Sunshine Hours	7.60	7.20	7.40	7.50	7.30	6.80	7.30	7.60	7.30
Cloud Cover	4.30	5.20	4.60	4.30	4.80	4.70	4.50	4.60	4.63
Pressure (Hpa)	NA	NA	889.70	NA	891.10	NA	NA	867.70	890.40
Solar Radiation (MJ/M^2/Day)	21.66	20.91	20.82	20.97	20.41	19.70	20.64	21.35	20.73
Thunder Days	120.00	98.00	96.00	91.00	88.00	96.00	89.00	84.00	96.86
Low Altitude Areas									
	Karonga	Mangochi	Nkata Bay	Nkhota Kota	Salima	Chileka	Makhanga	Ngabu	Mean
Mean Max. Temp.	29.30	29.90	27.80	28.30	29.10	27.50	31.80	32.20	29.49
Mean Temp.	24.80	24.20	23.30	23.70	24.20	22.40	25.50	26.30	24.30
Annual Range	4.50	5.70	3.50	4.60	4.90	5.10	6.30	4.90	4.94
Mean Min. Temp.	20.20	18.60	18.80	19.10	19.30	17.30	19.20	20.20	19.09
Diurnal Range	9.10	11.30	9.00	9.20	9.80	10.20	2.60	12.00	9.15
Mean Relative Humidity	72.00	66.00	78.00	71.00	66.00	66.00	68.00	69.00	69.50
Wind Velocity (m)	3.80	3.80	3.00	5.00	3.80	6.80	3.30	3.50	4.13
Rainfall (mm)	1164.80	823.60	1694.80	1630.80	823.60	857.50	764.50	811.40	1071.38
Sunshine Hours	8.20	7.40	7.70	8.20	8.30	7.40	8.00	8.00	7.90
Cloud Cover	4.50	4.50	4.30	4.00	3.80	4.50	4.10	4.50	4.28
Pressure (Hpa)	NA	NA	NA	NA	NA	857.50	NA	NA	862.60
Solar Radiation (MJ/M^2/Day)	22.23	26.08	21.59	22.17	22.35	20.57	21.36	21.26	22.20
Thunder Days	120.00	98.00	106.00	106.00	109.00	95.00	78.00	68.00	97.50

4.3.2 Variation Of Mean Maximum Air Temperature As An Index Of Thermal Discomfort

In the preceding discussions it was shown that air temperature is one of the most important indicators of thermal discomfort. There are several formats that have been devised to express the temperature as an index. However, the most common format is the Centigrade scale and is used in meteorological stations. One of the objectives of this work is to find practical tools that can be used by architects and engineers in the field at the design stage of any liveable buildings to check whether the criteria for thermal comfort are being met. These tools can be in form of predictive formulae, graphs, and charts.

The information that is easy to find on any survey map of Malawi are altitude; and latitudes and longitudes. In addition and for Malawi; there is a meteorological station in every one of the twenty-four districts. Agricultural stations are also evenly distributed over the country and these stations keep records of air temperature, rainfall, and humidity and sunshine hours. Simple tools that practitioners can use to predict the environmental thermal conditions can be developed from these parameters.

One other important parameter that would be useful in assessing the severity of thermal discomfort is the Mean Maximum Temperature of a location. From the analysis of the Hourly Mean Maximum Temperatures (HMMT) of different locations it is useful to use the obvious relationship between the HMMT at 1400 hours and the Monthly Mean Maximum Temperature (MMMT); see Appendix 4.5. From the meteorological data at each station, it is observed that the maximum air temperatures occur at 1400 hours. It can be inferred that at that hour the ambient solar thermal energy distribution in the environment reaches a steady state. To establish the relationship between the two parameters all the data from the meteorological stations were analysed. To summarise these results figures 4.13-4.18 show scatter grams for five typical stations

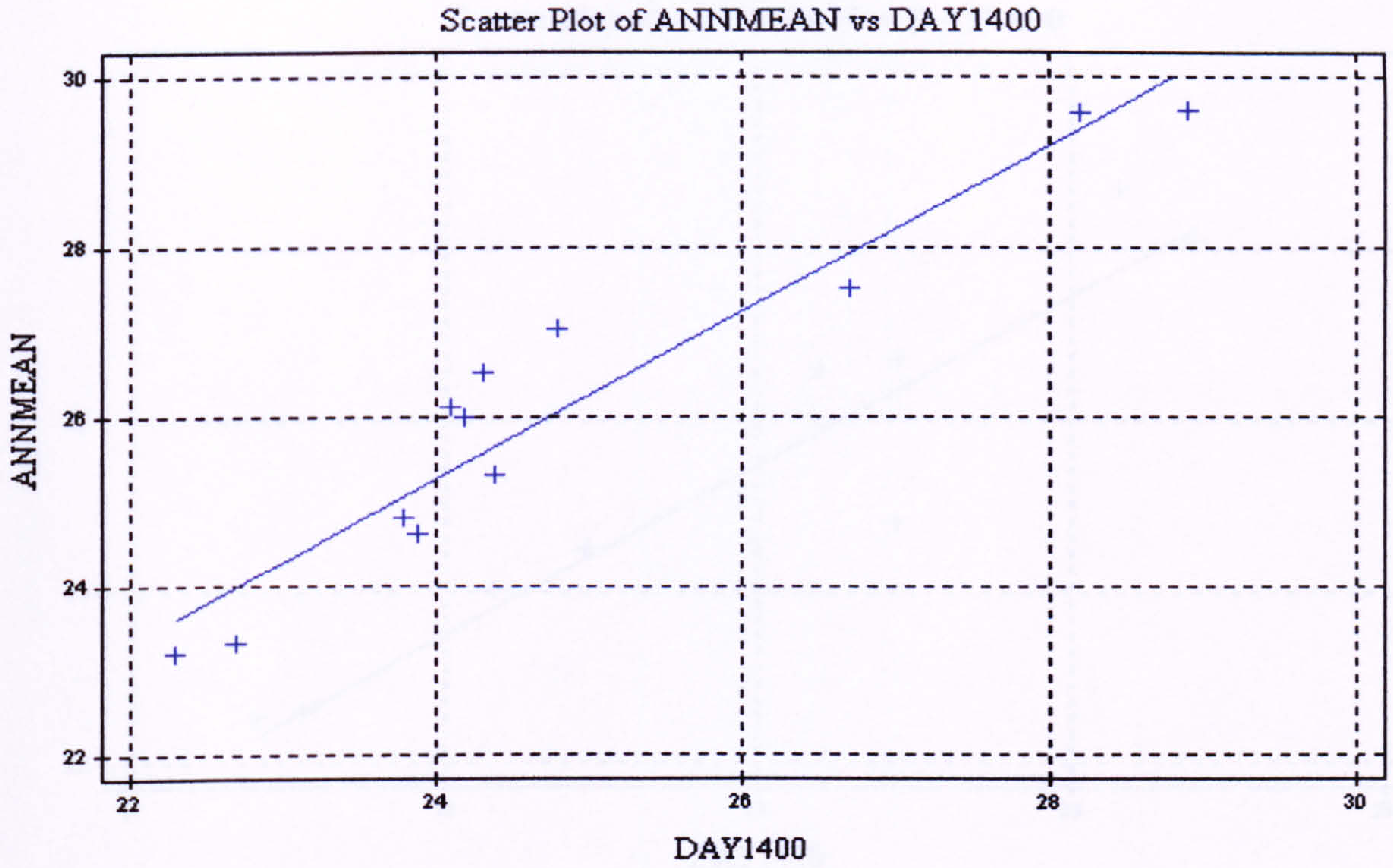

Fig.4.13 Scatter Gram for Chitipa District; Latitude is 9° 42' S Altitude is 1285m

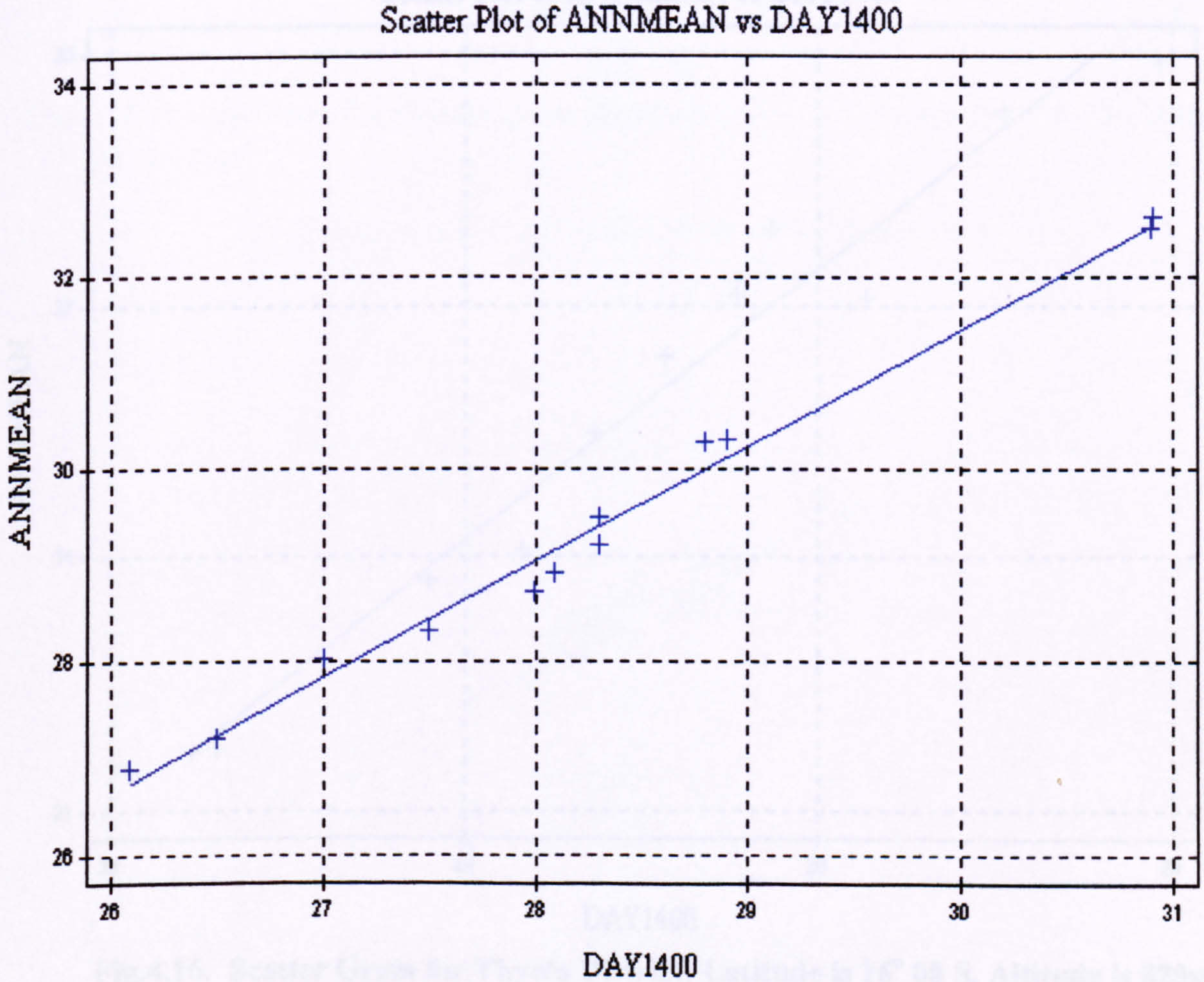

Fig.4.14. Scatter Gram for Karonga District; Latitude is 9° 56'S. Altitude is 529m

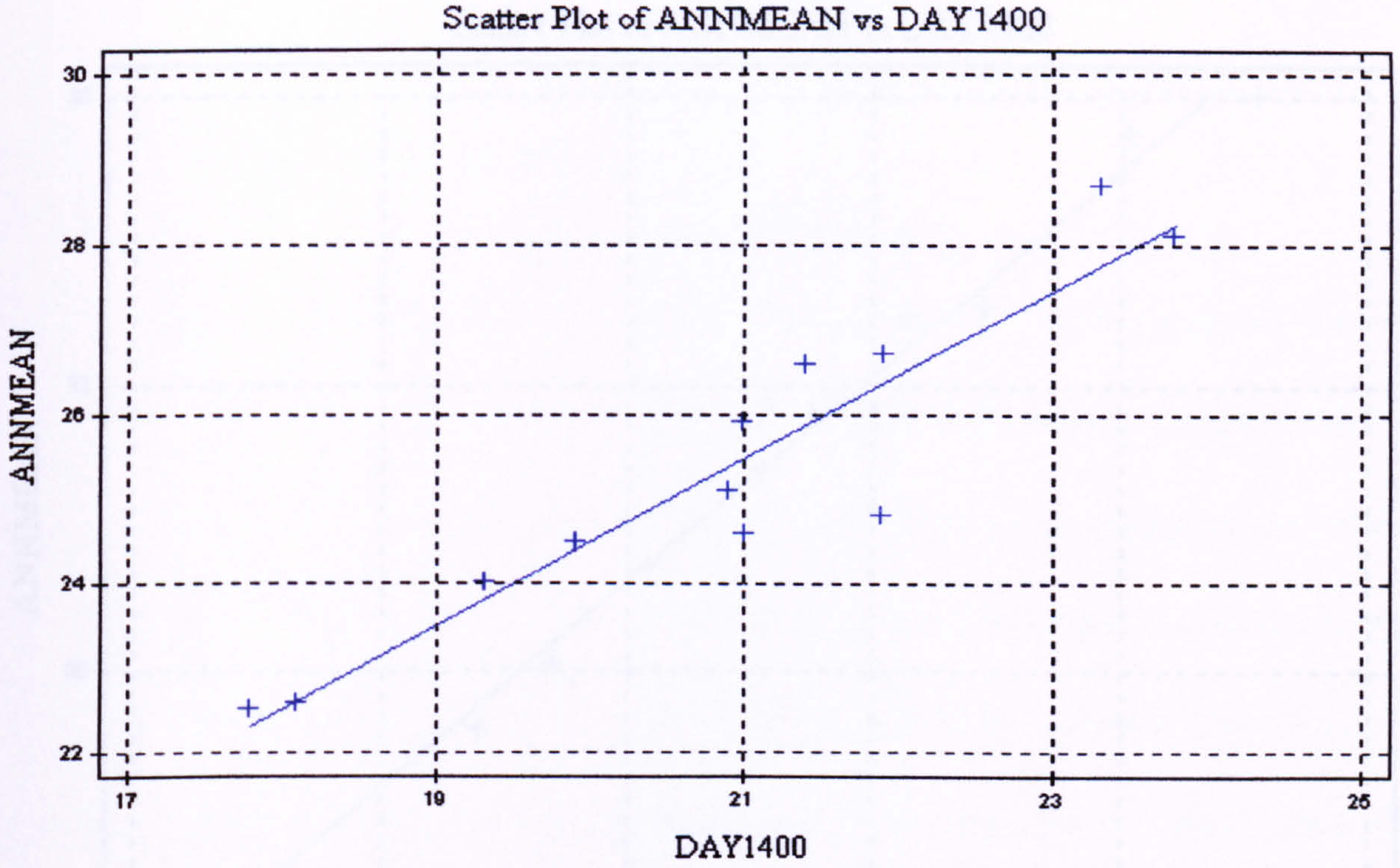

Fig.4.15. Scatter Gram for Dedza District; Latitude is 14° 19 S'. Altitude is 1632m

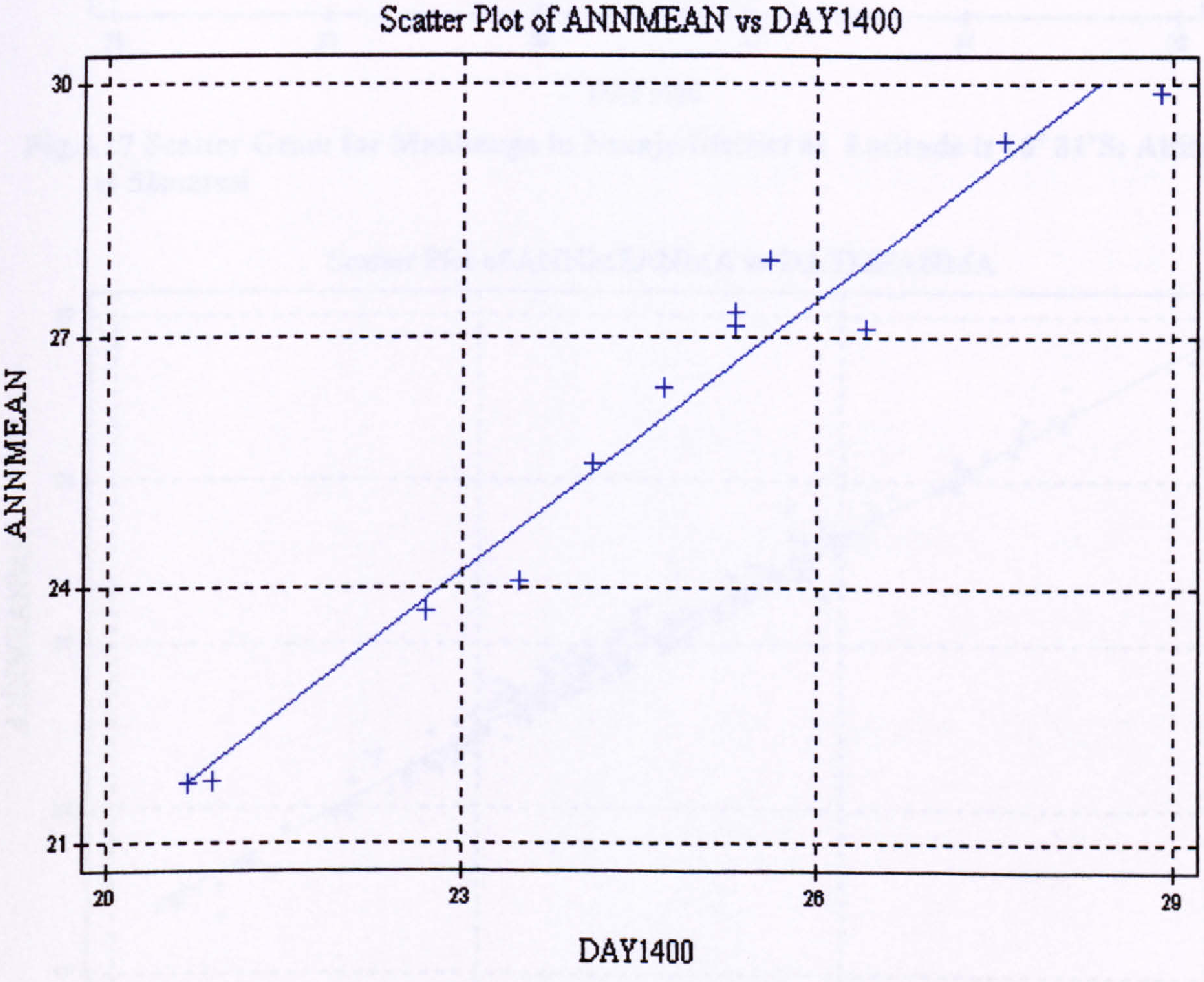

Fig.4.16. Scatter Gram for Thyolo District; Latitude is 16° 08 S. Altitude is 820m

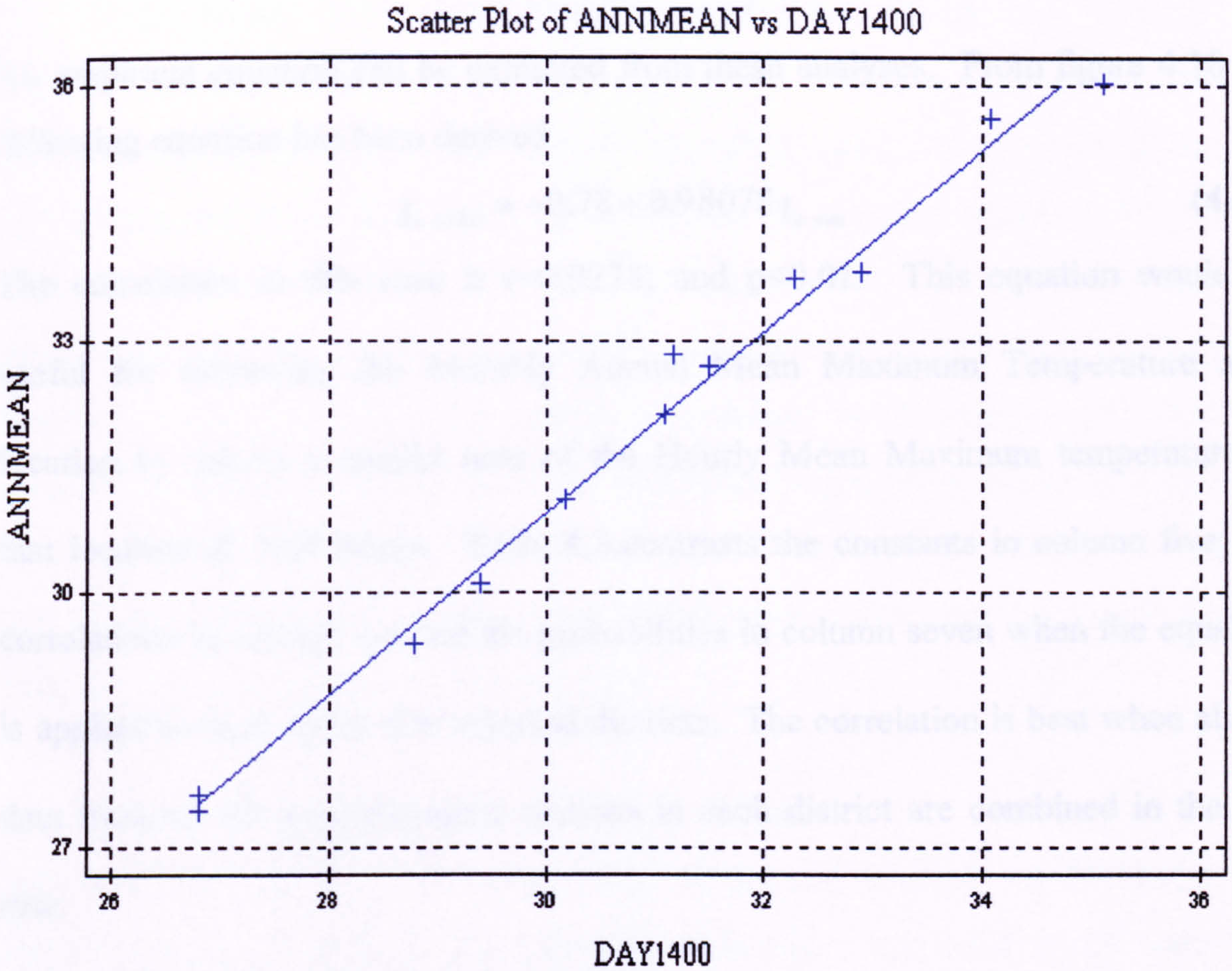

Fig.4.17 Scatter Gram for Makhanga in Nsanje District at Latitude is 16° 31'S; Altitude is 52mamsl

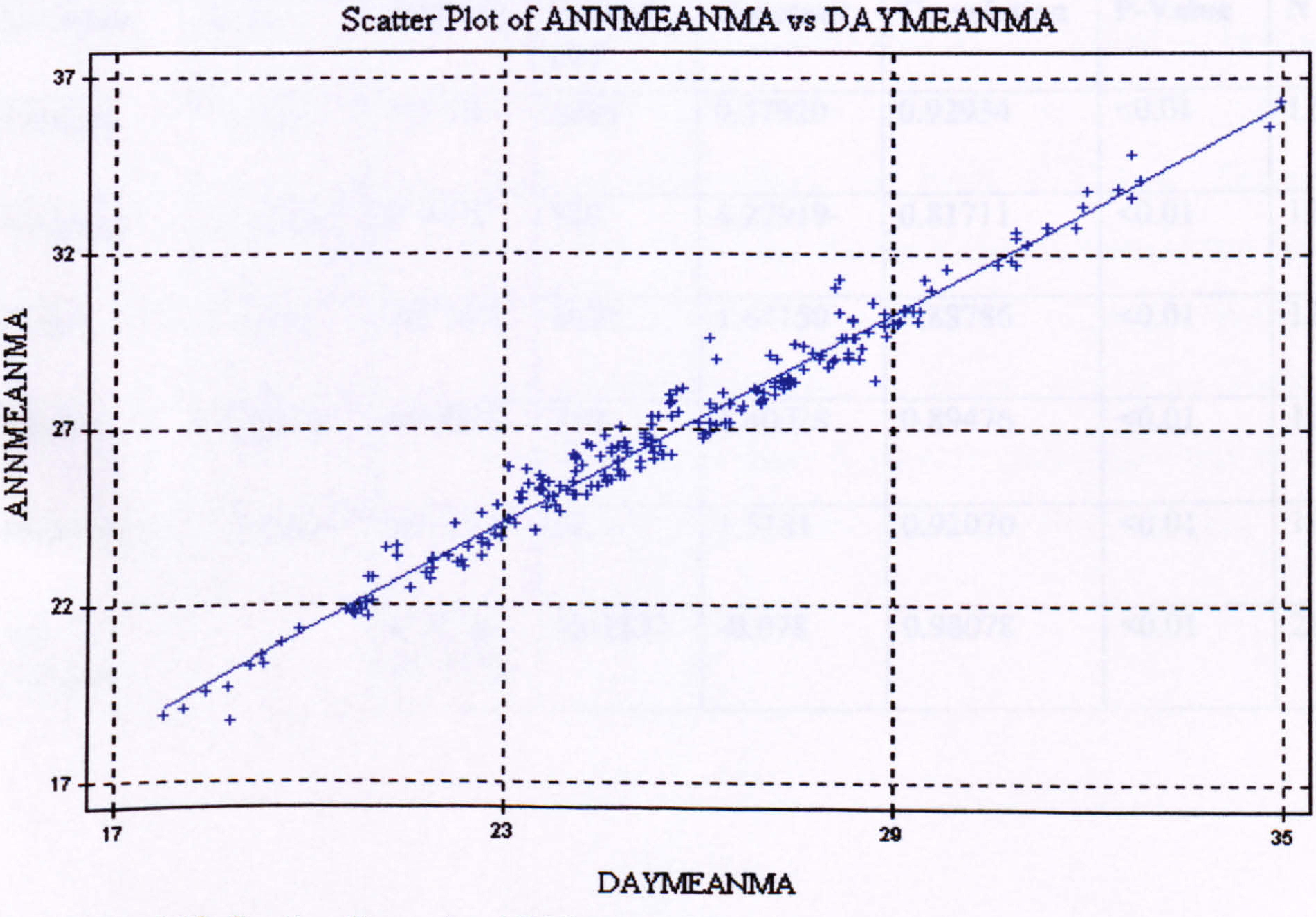

Fig.4.18. Scatter Gram for All Nineteen Meteorology Stations Under Study

An empirical equation can be extracted from these analyses. From figure 4.18 the following equation has been derived

$$t_{a-h1400} = -0.78 + 0.98078\, t_{a-mm} \qquad (4.6)$$

The correlation in this case is r=0.9278; and p<0.01. This equation would be useful for estimating the Monthly Annual Mean Maximum Temperature at a location by taking a careful note of the Hourly Mean Maximum temperature of that location at 1400 hours. Table 4.3.contrasts the constants in column five, the correlations in column six and the probabilities in column seven when the equation is applied to each of the five selected districts. The correlation is best when all the data from all the meteorological stations in each district are combined in the last row.

Table 4.3. Comparative Table Of Selected Statistics Of The Test Representative Stations

Location	Zone	Latitude	Altitude (m)	Constant	Correlation	P-Value	N
Chitipa	Upland	9° 42'S	1285	0.57920	0.92934	<0.01	120
Karonga	Lowland	9° 56'S	529	4.27919-	0.81711	<0.01	120
Dedza	Upland	14° 19'S	1632	1.64150	0.88786	<0.01	120
Thyolo	Midland	16° 08'S	920	1.40028	0.89476	<0.01	120
Makhanga	Lowland	16° 31'S	52	1.5181	0.92070	<0.01	120
All Stations		9° 42'S-16° 31'S	52-1632	-0.078	0.98078	<0.01	2180

4.4 THE NEED FOR REFERENCE TEMPERATURES AS LIMITS OF THERMAL COMFORT) IN MALAWI

In the preceding discussions air temperature, wind speed and humidity (Houghten and Yagloglou; 1923) have been reported to be the principal variables for thermal comfort in the controlled environment. It has also been discussed that amongst other variables the neutral temperature depends on culture and geographical location. It is a fact that the neutral temperature in Malawi has hitherto been assumed as those quoted in standard ventilation engineering books and manuals such as the ASHRAE and CIBSE documents. There is no literature that suggests that the indoor temperatures requirements that are in current use have been derived from local tests and research in Malawi.

For the assessment of severity of thermal discomfort it is necessary to have a reference temperature as an upper limit of thermal comfort for Malawi. The author proposed that if the two variables of humidity and wind speed were kept constant then the neutral temperature could be assessed with respect to the air temperature. One way to do this cheaply was to use the Preferred Bath Water Temperature (PBWT). The PBWT would be a temperature that would represent a thermal balance in an individual who is taking a bath or a shower. A full paper on the methodology and procedure of the method has been published (Zingano; 2001). The deduction draws its relevance on the fact that although the body temperature is 36.5°C, the skin temperature is always at 35°C (Givoni; 1969). If this skin temperature is taken as a reference point that constitutes an interface of body and air, then any environmental temperature higher or lower than this would either induce a thermal gradient into the body or outwards away from the skin.

4.4.1 Deduction of Mid Point of Thermal Comfort Zone From a Preferred Bath Water Temperature (PBWT).

In order to investigate the view questioned by Koch *et al,* (1960) that there is very little contribution on thermal comfort from the humidity, the author sought to investigate this problem in local context and at low cost. Preferred Bath Water Temperature (PBWT) is different for different persons. The air in a bathroom or shower is definitely saturated. The author sought to find a relationship between the bath water and the ambient temperatures in the bath/shower room where humidity would be at constant level. What was required was to conduct a survey of PBWTs in several locations within the country and analyse these data. Standard temperature measuring techniques and methods were used Gagge, (1937).

Twenty mercury-in-glass thermometers were distributed to selected persons who had access to hot water baths and showers in three cities, including lecturers at the University of Malawi. The three cities were Lilongwe in the central region, Blantyre and Zomba in the southern region. The data sheet had clear instructions on how to take the ambient temperature in the bathroom.

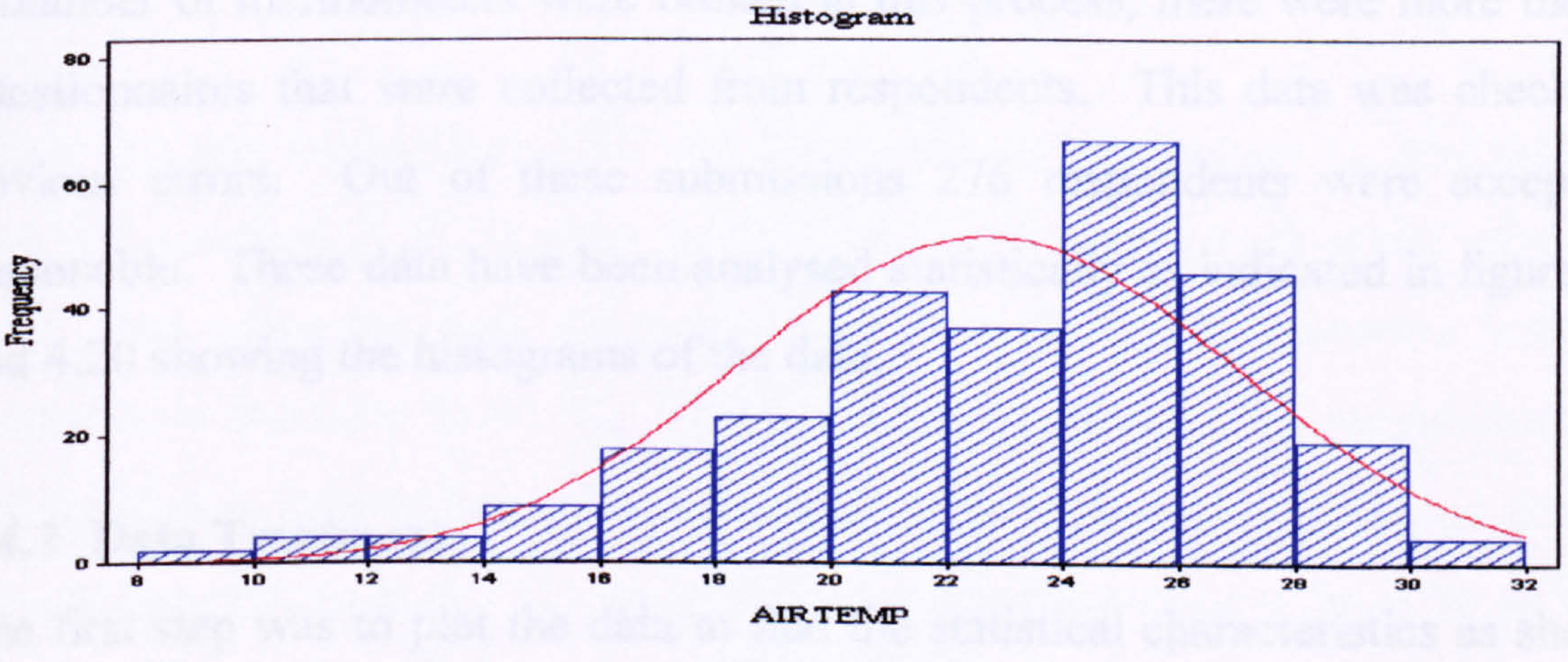

Fig 4.19 Frequency Distribution Of Air Temperature In A Bathroom

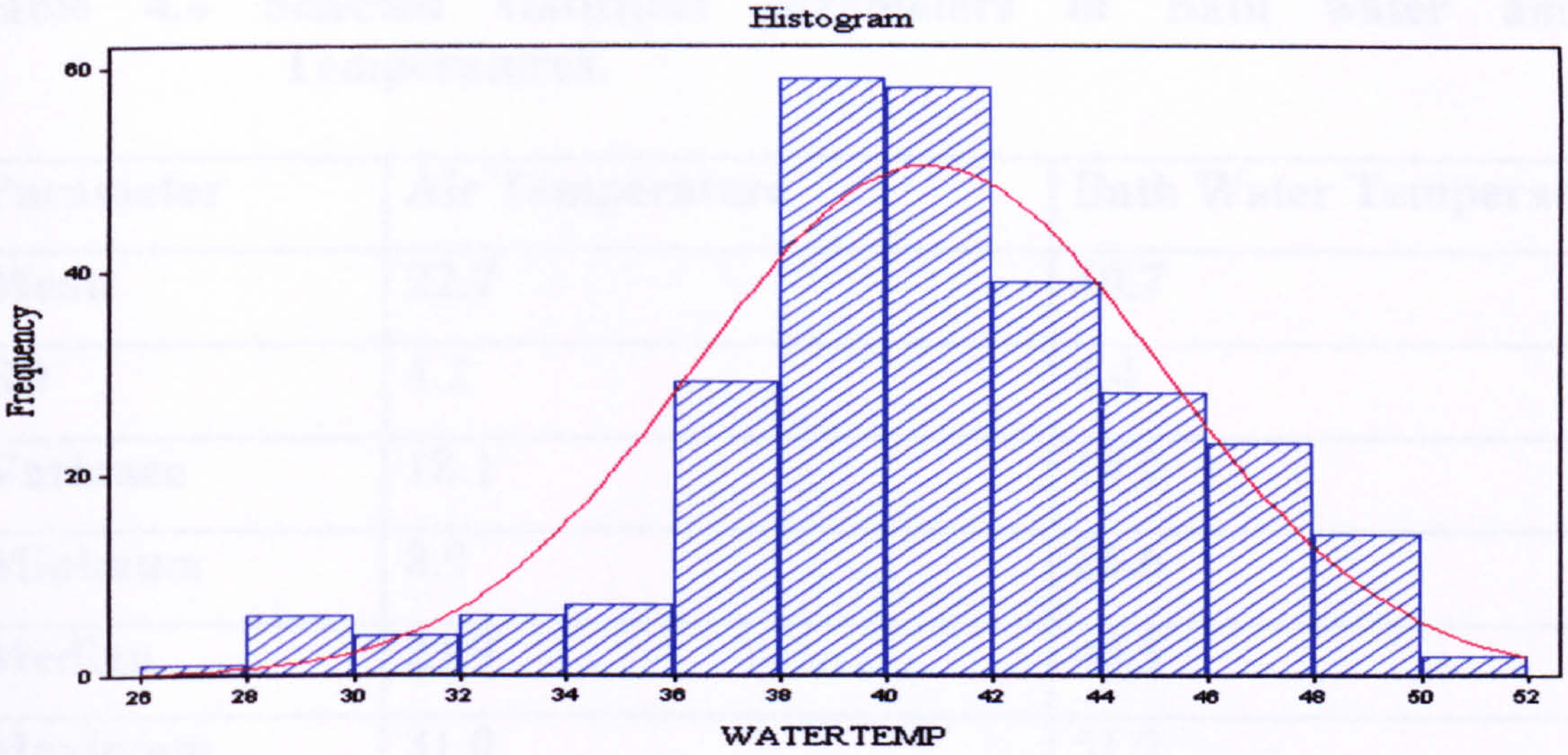

Fig 4.20 Frequency Distribution Of Preferred Bath Water Temperature

The instructions issued to all the respondents were that the air temperature in the bath/shower room should be recorded before the hot water was turned on and then the temperature of the water recorded when the bath/shower was mixed to the preferred temperature. The survey was conducted from April to August through the coldest season (May - July). The process involved travelling to each city to collect the data and distribute the thermometers to another set of persons Although a number of thermometers were broken in this process, there were more than 400 questionnaires that were collected from respondents. This data was checked for obvious errors. Out of these submissions 276 respondents were accepted as reasonable. These data have been analysed statistically as indicated in figures 4.19 and 4.20 showing the histograms of the data.

4.4.2 Data Treatment

The first step was to plot the data to find the statistical characteristics as shown in Table 4.4. This table shows that the data consistent and accurate and can be used to extract reliable information.

Table 4.4 Selected statistical parameters of Bath water and Air Temperatures.

Parameter	Air Temperature	Bath Water Temperature
Mean	22.7	40.7
SD	4.2	4.4
Variance	18.1	19.0
Minimum	8.9	26.6
Median	23.9	40.5
Maximum	31.0	51.2

A test for correlation, using Pearson's correlation, shows that the two sets of data are correlated by $r = -0.3418$ and giving $p \leq 0.045$. A scatter plot of the data gives a constant of 36.44 and a coefficient of -0.34; again, giving a probability of $p \leq 0.045$ which is taken as the acceptable confidence level. The other statistical parameters of interest are; $r^2 = 0.1203$, and the sample population n as 276. The Scatter Gram is shown in figure 4.21. An equation of the form $y = ax + c$ is constructed as follows:

$$t_b = -0.334\, t_{ab} + 36.44 \qquad (4.7)$$

When the skin temperature 35^{0}C is taken as the air temperature t_{ab}; and substituted into the equation (4.7), it gives 24.8 ^{0}C as the preferred bath water temperature (t_b). And when the bath air temperature is at 0 ^{0}C, the preferred bath water temperature becomes 36.44 ^{0}C. This is almost the normal body temperature. This relationship is informative in the sense that it predicts what is expected that when the air temperature is at 0 ^{0}C, the bath water temperature has to be at 36.44^{0}C for a comfortable bath. It can be inferred without contradiction that the mean comfortable temperature for people in Malawi is 24.8 ^{0}C

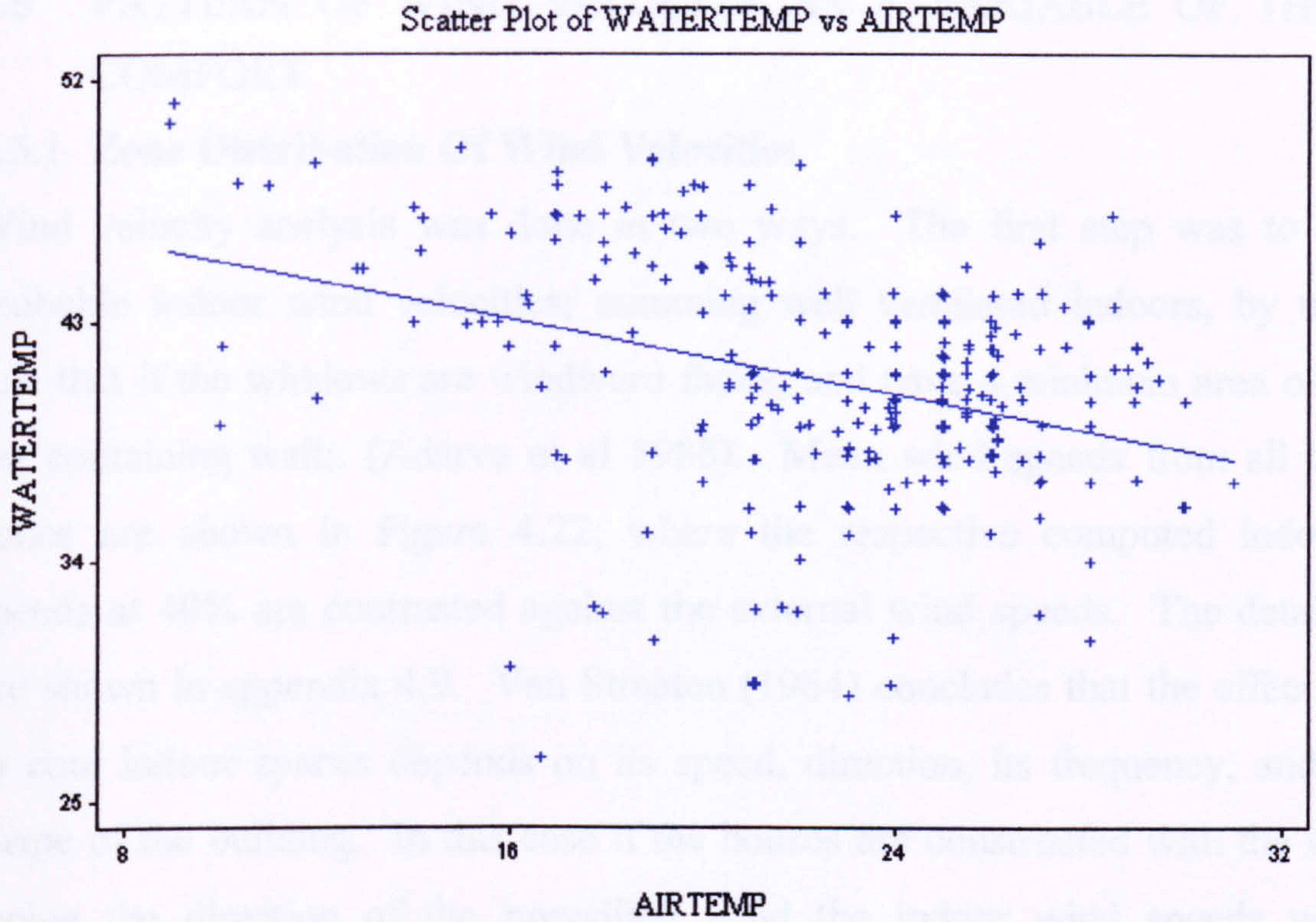

Fig 4.21 A Scatter gram of PBWT against the Air Temperature

Although figure 4.21 would seem to be an unacceptable result as far as a normal regression analysis is concerned the author has chosen to present the results as produced on the 'Statistix' statistical package that was used. These are the results as analysed and applying the least square method of analysis gives the results presented here.

Although a survey of neutral temperatures has not been done in Malawi, it can safely be inferred that 24.6°C would be the middle point of the thermal comfort zone. The observed figure (24.6°C) compares very well with the temperature ranges of 23.5 – 28.5°C and 22 – 24°C reported by Malama (1998) and ISO 7730 respectively. Malama's survey was done in Zambia that has a common border with Malawi and the people in the two countries are of the same ethnic origin. The logical extension of the argument in this case is that preferred temperatures of the two people would not be very different as discussed before in section 2.10.

Until such a time that a thermal comfort survey is done, it is proposed that Malawi should adopt 24.6°C as the mid point of the comfortable temperature zone.

4.5 PATTERN OF WIND VELOCITY AS A VARIABLE OF THERMAL COMFORT

4.5.1 Zone Distribution Of Wind Velocities

Wind velocity analysis was done in two ways. The first step was to estimate probable indoor wind velocities; assuming well ventilated indoors, by using the rule that if the windows are windward facing and have a minimum area of 33% of the containing wall;. (Adarve et al 1988). Mean wind speeds from all the three zones are shown in Figure 4.22; where the respective computed indoor wind speeds at 40% are contrasted against the external wind speeds. The detailed data are shown in appendix 4.9. Van Straaten (1964) concludes that the effect of wind to cool indoor spaces depends on its speed, direction, its frequency, and general shape of the building. In this case if the houses are constructed with the windows facing the direction of the prevailing wind the indoor wind speeds would be acceptable for the thermal comfort.

The next step was to illustrate the data on radar graphs of the wind velocities to indicate the magnitudes of these velocities over the months. These are shown in figures 4.23–4.25;. Wind rose diagrams are constructed and shown in figure 4.26. These wind roses confirm that the dominant prevailing wind direction over the country is from the South-East. This is a very useful fact in the design process if buildings have to take advantage of natural ventilation.

The wind average velocities in the uplands as shown in figure 4.22 are quite adequate to compensate for any high temperatures that might be outside the comfort range if the principles of cross ventilation are applied at the design stage of any building. Generally the high wind speeds occur in the hot dry months. This is an advantage because it would be easier to achieve natural ventilation given a well-analysed design.

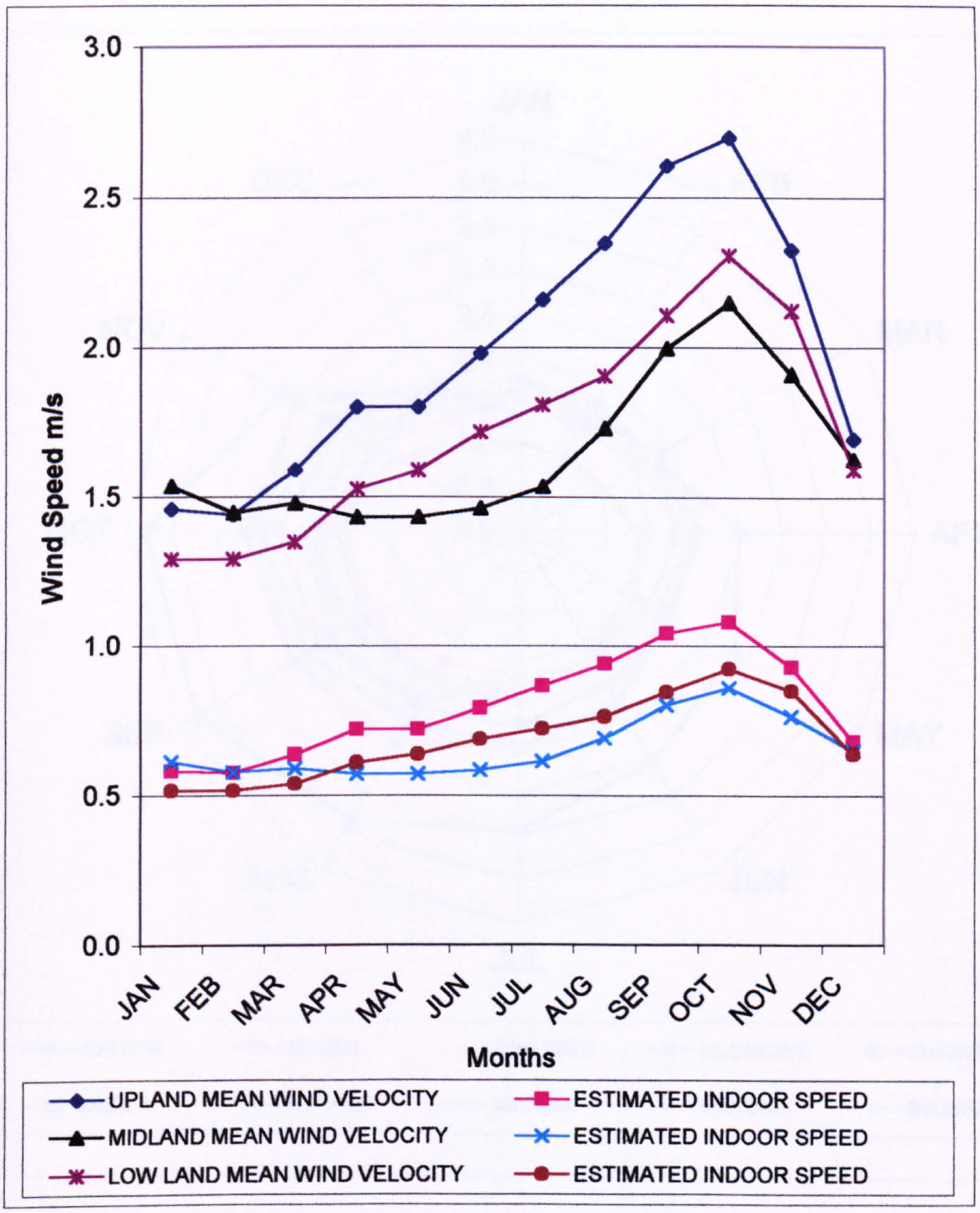

Fig.4.22. Averaged Outdoor Air Velocities Contrasted With Estimated Indoor Air Velocities; Using Darve's Method.

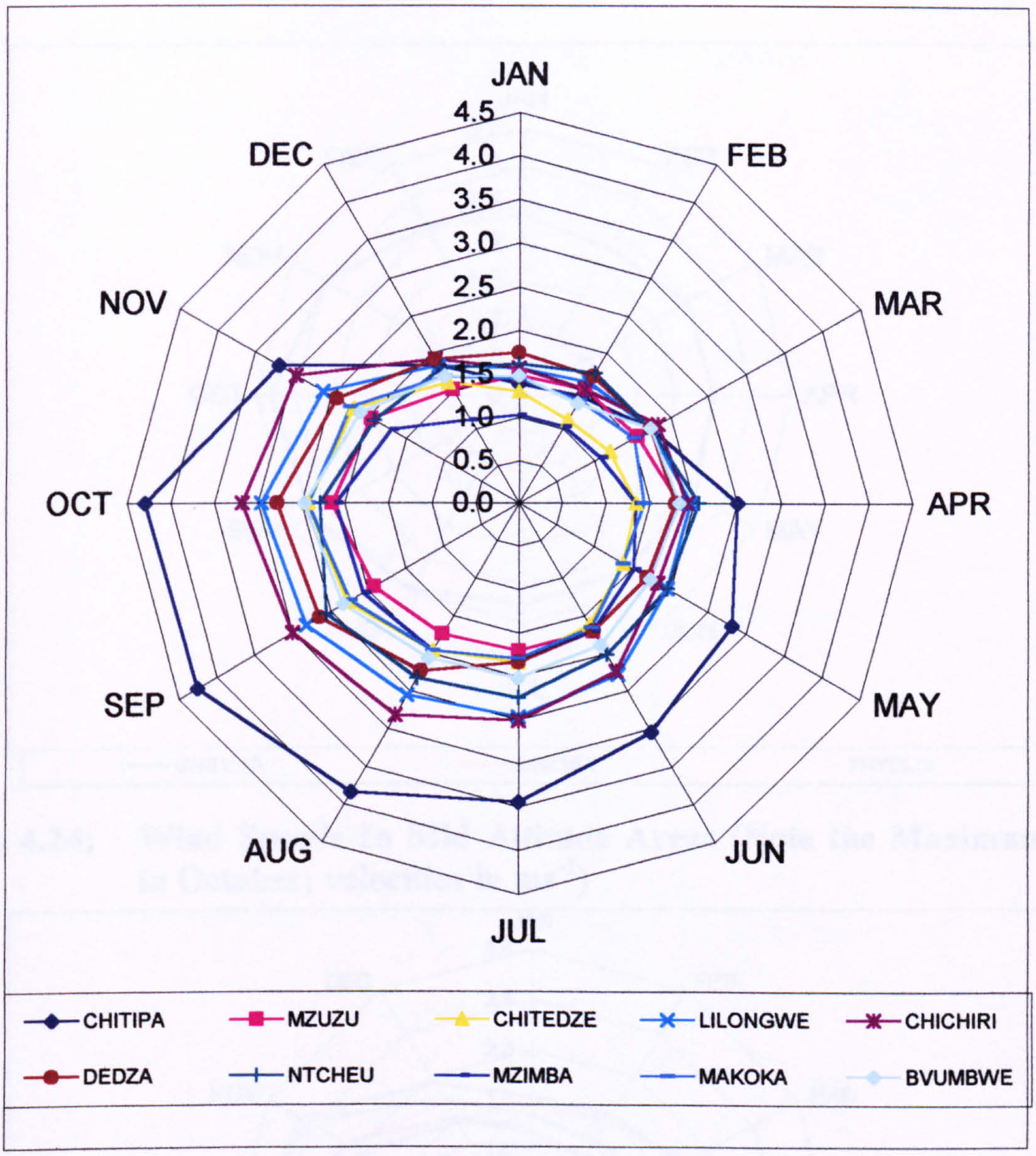

Fig 4.23 Wind Speeds In High Altitude Areas (Note the Maximum speeds in October; speeds in ms^{-1})

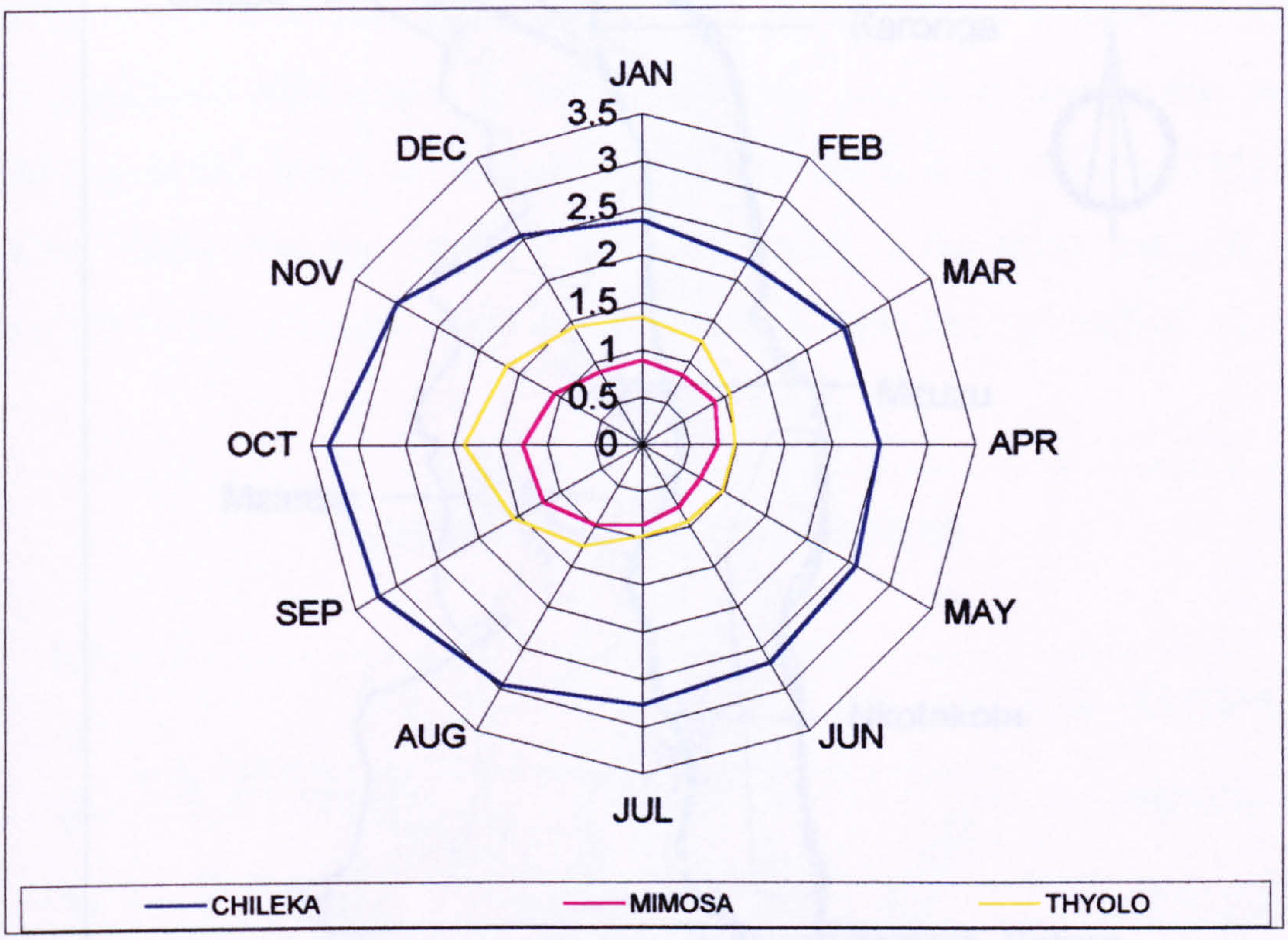

Fig. 4.24; **Wind Speeds In Mid Altitude Areas (Note the Maximum speeds in October; velocities in ms^{-1})**

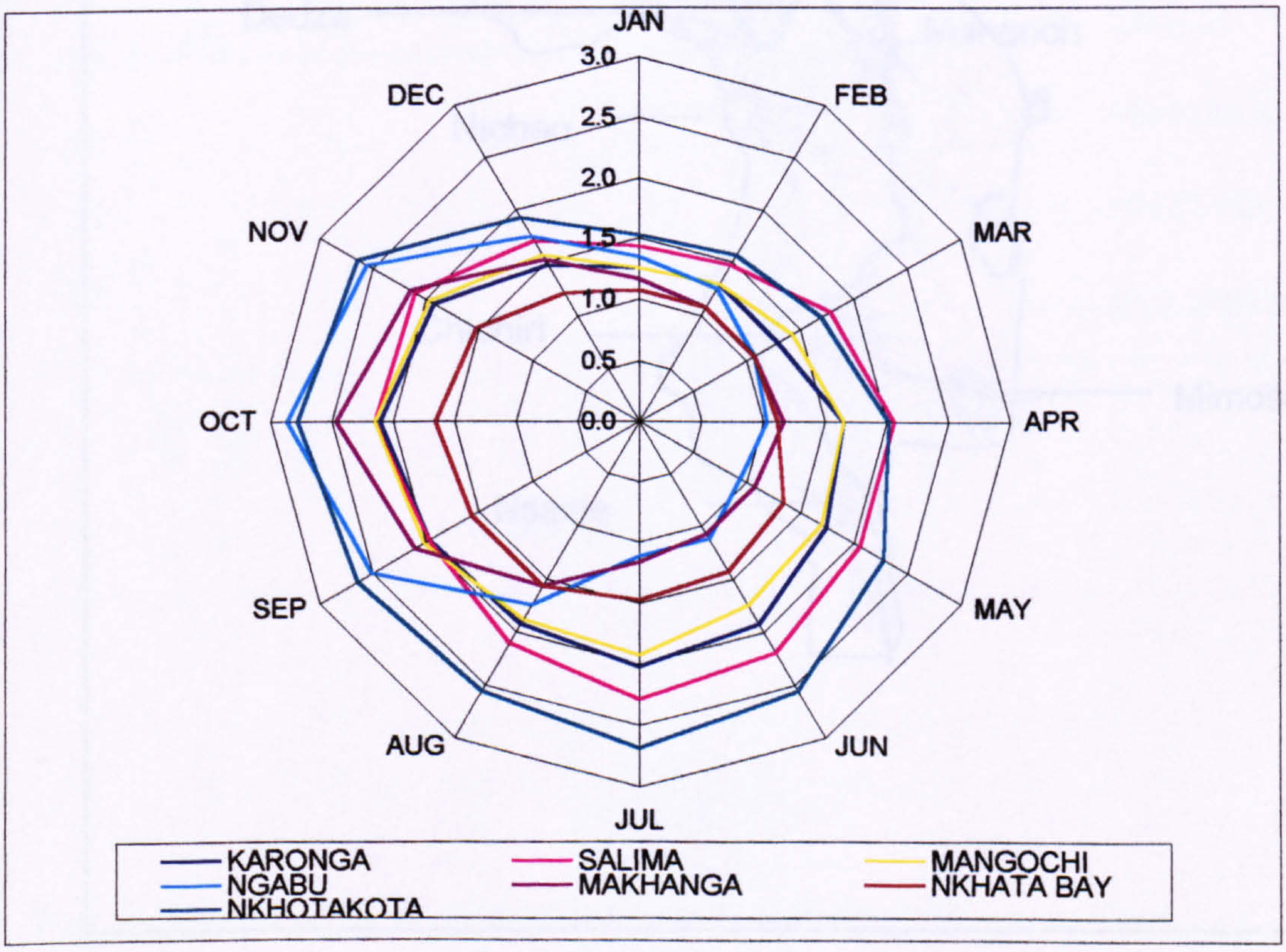

Fig.4.25; Wind Velocities In Low Altitude Areas (Note the Maximum rates in October; velocities in ms^{-1})

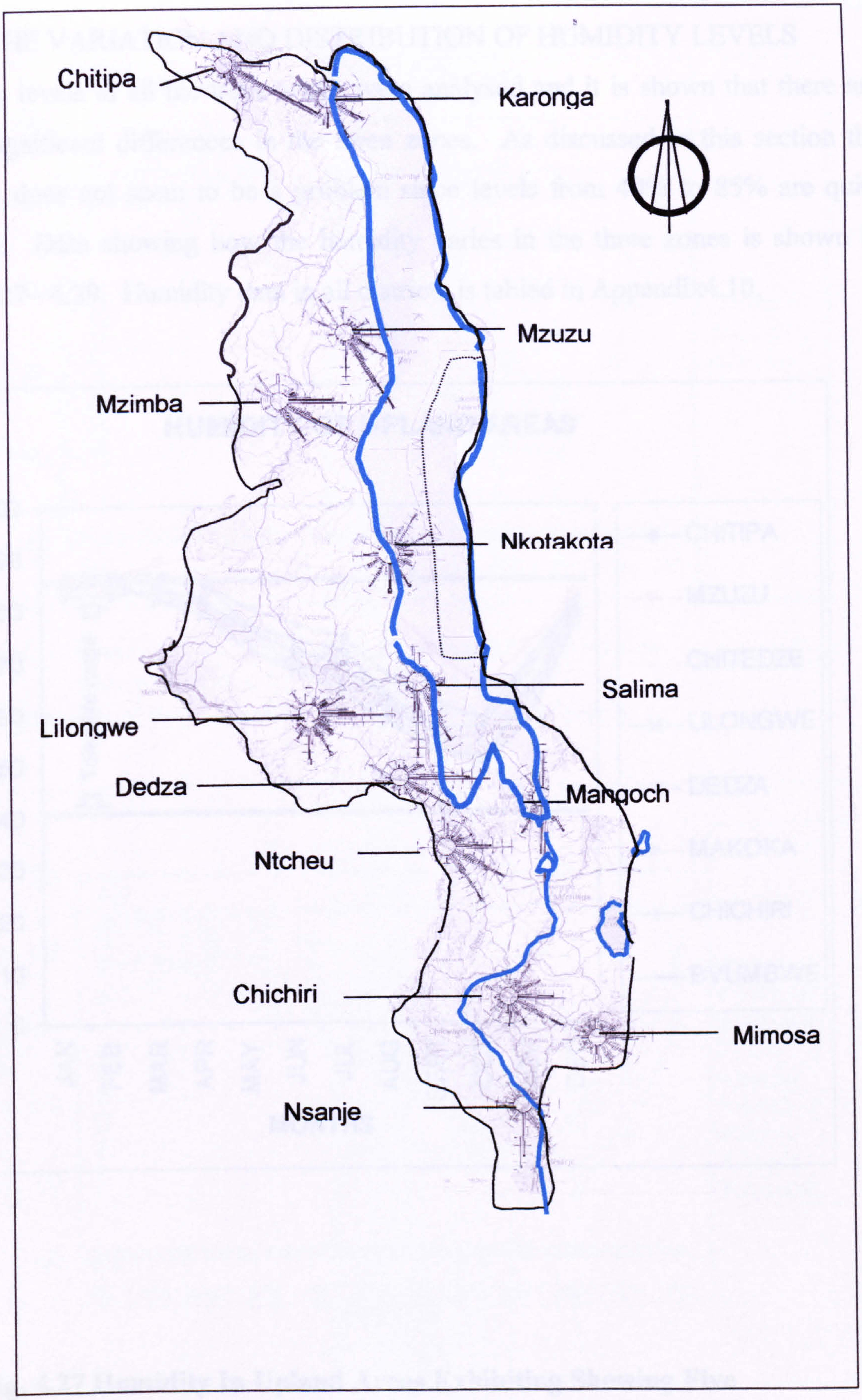

Fig.4.26 **Constructed Wind Rose Map of Malawi Showing the Dominant South-Easterly Prevailing Wind Direction.**

4.6 THE VARIATION AND DISTRIBUTION OF HUMIDITY LEVELS

Humidity levels in all the three zones were analysed and it is shown that there are hardly significant differences in the three zones. As discussed in this section the humidity does not seem to be a problem since levels from 40% to 85% are quite tolerable. Data showing how the humidity varies in the three zones is shown in figure 4.27– 4.29. Humidity data in all districts is tabled in Appendix4.10.

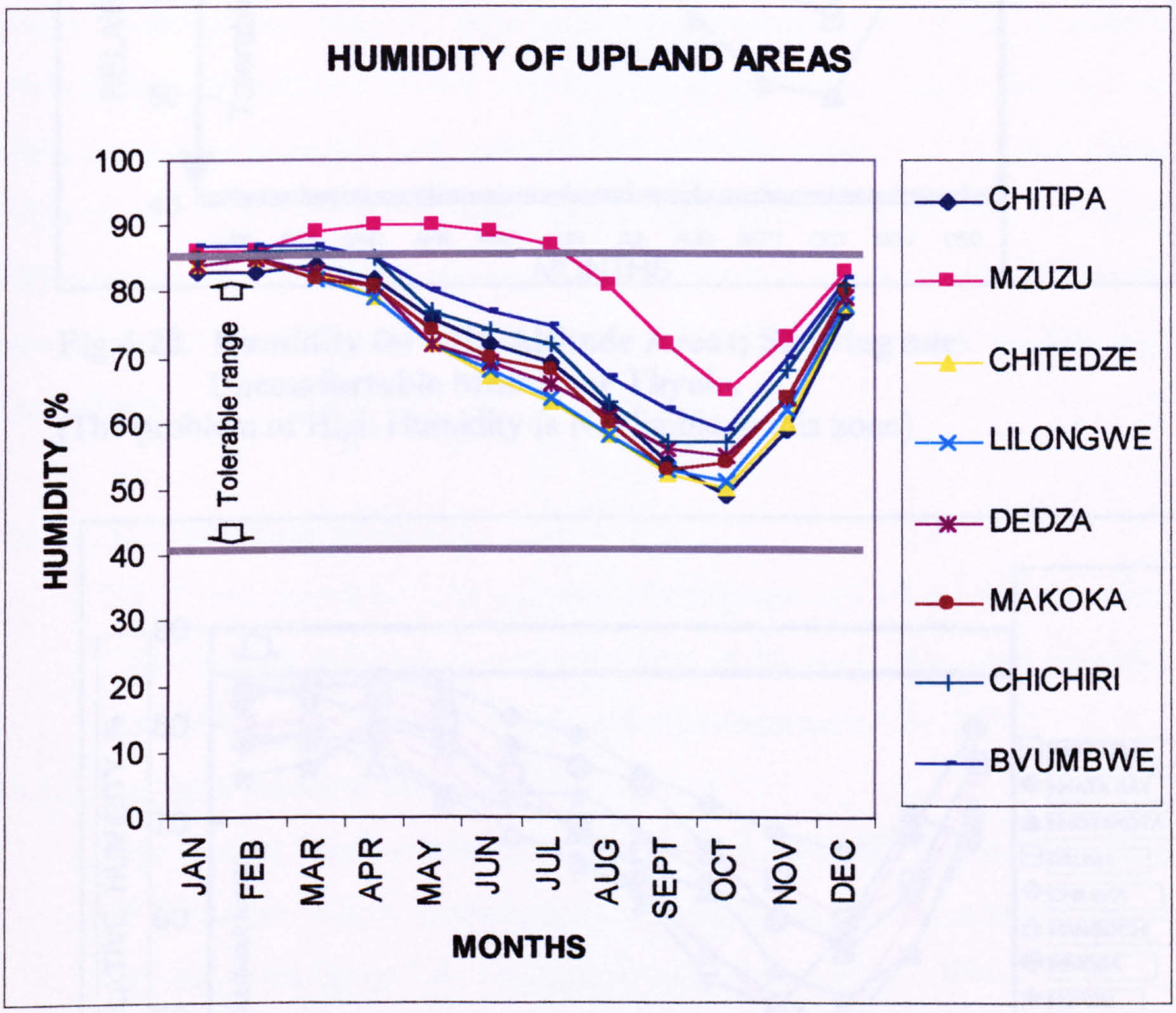

Fig. 4.27 Humidity In Upland Areas Exhibiting Showing Five Months Of Uncomfortable Humidity Levels For Mzuzu.

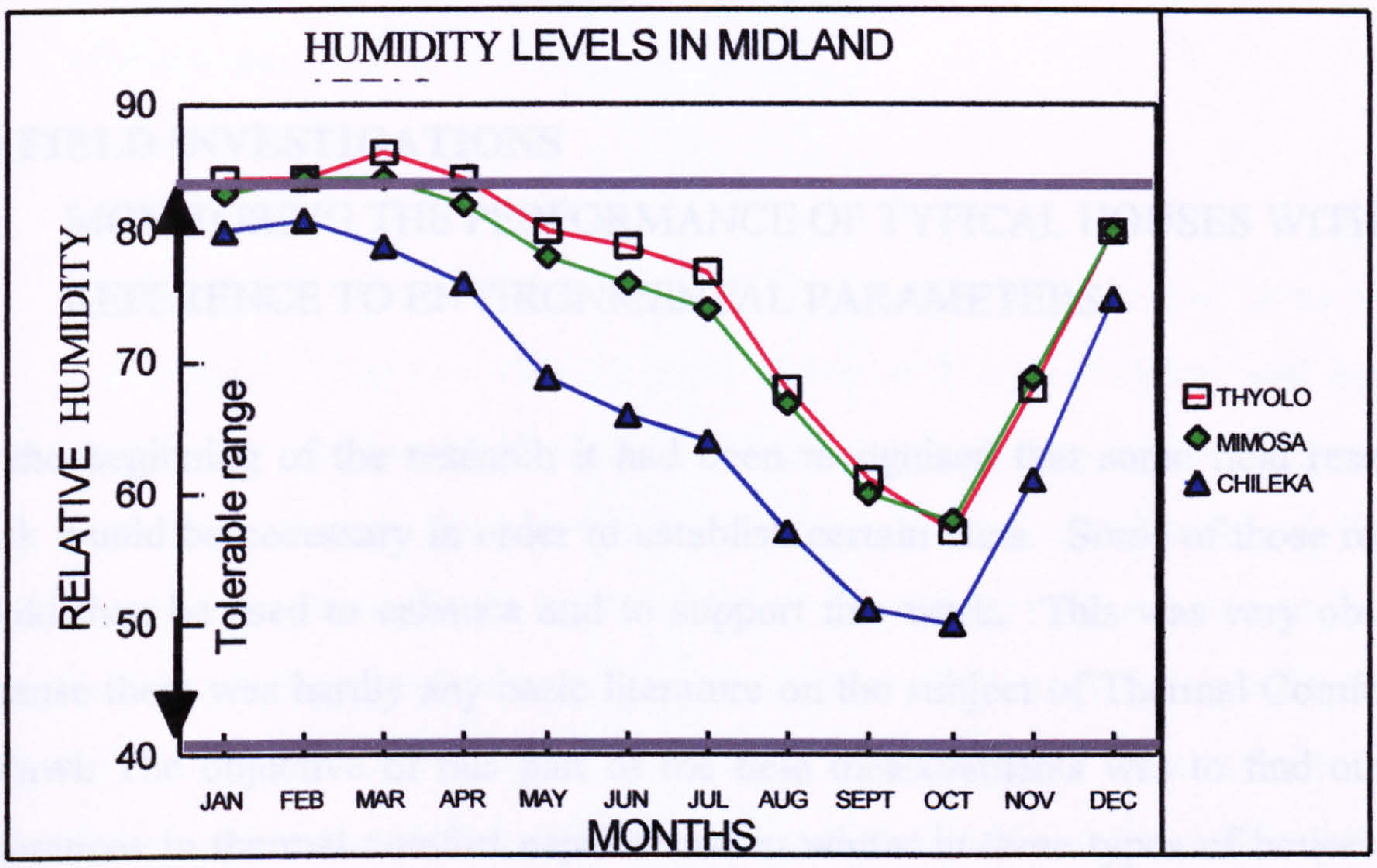

Fig 4.28. Humidity for Mid-Altitude Areas; Showing one Uncomfortable Month for Thyolo.
(The problem of High Humidity Is Negligible in this zone)

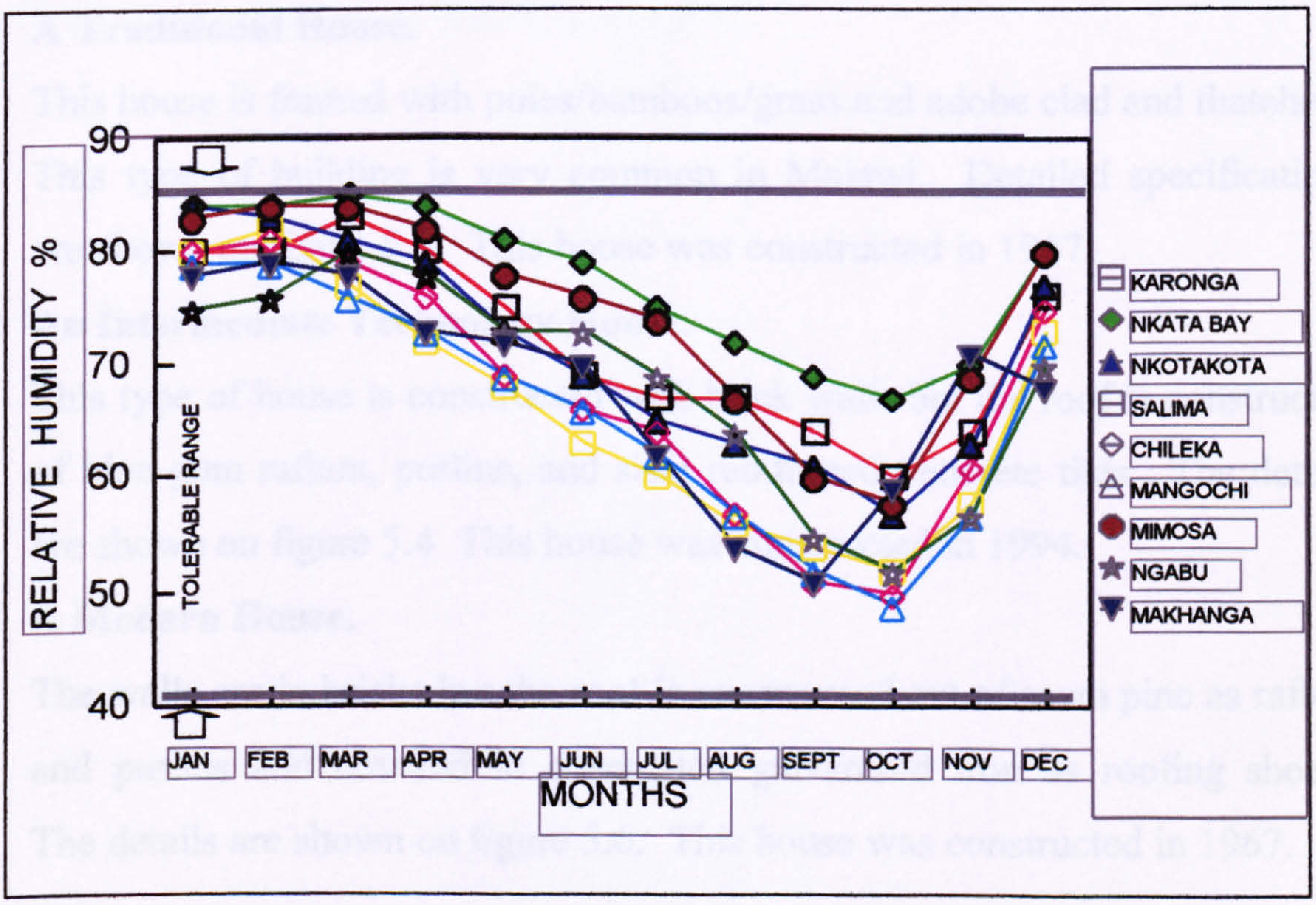

Fig. 4.29 Humidity For Low Altitude Areas;
(The Problem Of Intolerable Humidity does not exist In This Zone.)

CHAPTER FIVE

5.0 FIELD INVESTIGATIONS

5.1 MONITORING THE PERFORMANCE OF TYPICAL HOUSES WITH REFERENCE TO ENVIRONMENTAL PARAMETERS

At the beginning of the research it had been recognised that some field research work would be necessary in order to establish certain facts. Some of those results would then be used to enhance and to support this work. This was very obvious because there was hardly any basic literature on the subject of Thermal Comfort in Malawi. The objective of this part of the field measurements was to find out the differences in thermal comfort experienced in winter in three types of houses that are typical of most houses in Malawi. The characteristics of the building types are as follows;

5.1.1 A Traditional House.

This house is framed with poles/bamboos/grass and adobe clad and thatched. This type of building is very common in Malawi. Detailed specifications are shown on figure 5.2. This house was constructed in 1967.

5.1.2 An Intermediate Technology House.

This type of house is constructed with brick walls but the roof is constructed of blue gum rafters, purlins, and sisal reinforced concrete tiles. The details are shown on figure 5.4 This house was constructed in 1994.

5.1.3 A Modern House.

The walls are in bricks but the roof is constructed out of sawn pine as rafters and purlins and covered in corrugated galvanised iron as roofing sheets. The details are shown on figure 5.6. This house was constructed in 1967.

All measurements were taken at 900mm height from the floor/ground level both indoors and outdoors.

The pyranometers were mounted at 2400mm height in order to clear the obstructions from the surrounding bushes.

5.2 LOCATION

It was difficult to identify three different houses within close proximity to each other in a suitable climatic zone. It was further considered vital that the three house types should be monitored simultaneously in order to ensure that they were all responding to the same environmental conditions and stimuli. Special houses could not be constructed for this experiment due to lack of funding. A fairly extensive search was done to identify three such houses within reasonable distance of each other. Three typical houses were found within 50 metres of each other at Ekwendeni in Mzuzu; the headquarters of the Northern Region of the country. Ekwendeni is a small township that was initially developed by Church of Scotland Missionaries who settled here in 1910. A sketch showing the relative positions of these houses and the pyranometer station are shown in figure 5.1

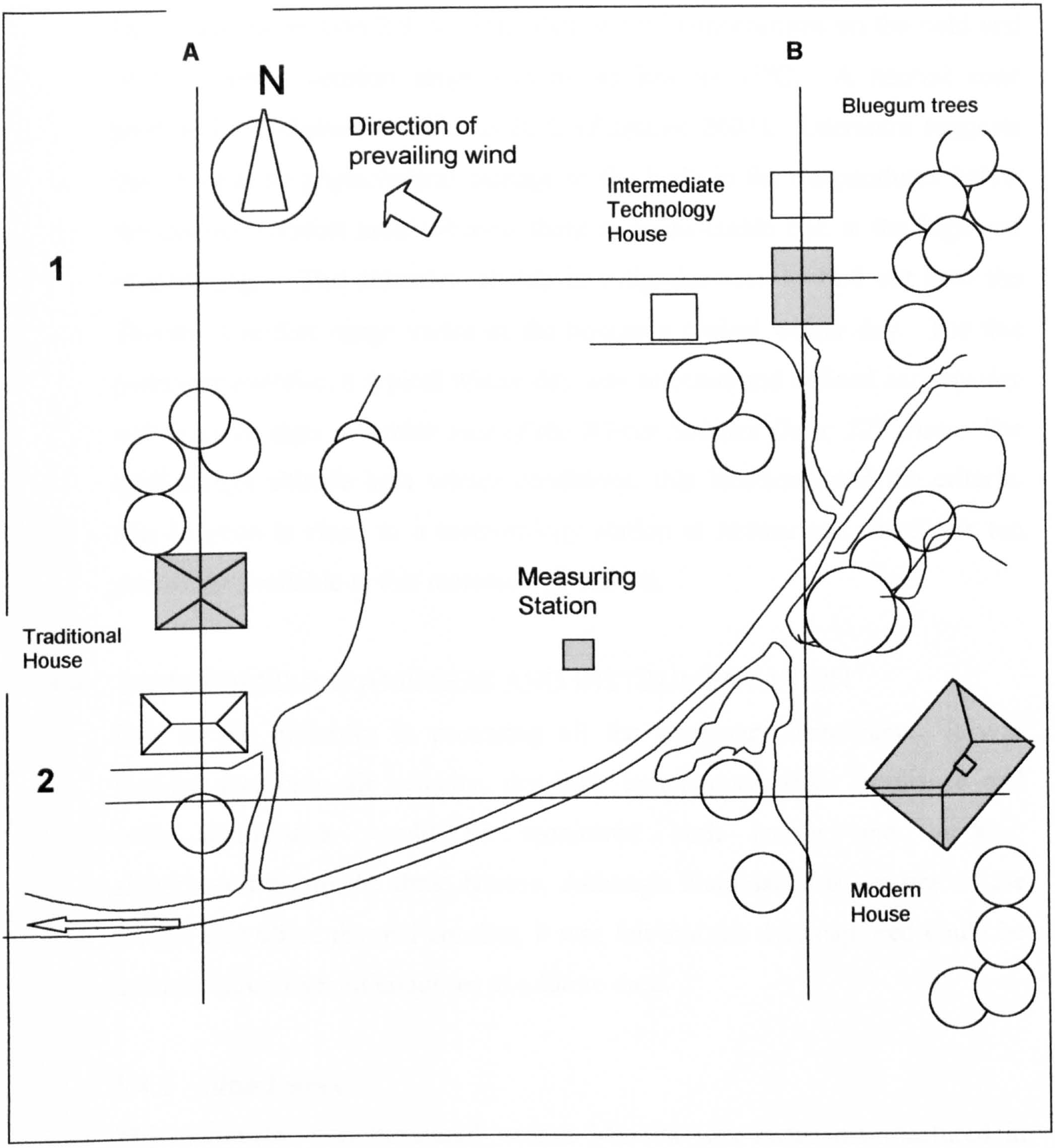

Fig. 5.1 Sketch Of Locality For The Measurements At Ekwendeni

:(Grid at Approxm.100m)

5.3 FIELD INVESTIGATION

Discussion in Section 2.9 confirms that neutral temperatures on the cold end of the thermal comfort range can be as low as 11°C. A neutral zone proposed for Malawi is 22°C to 26°C (Zingano; 2001). Literature suggests that there is no physiological damage to the body in the temperatures below the thermal comfort zone whereas there is considerable risk at the high end of this range. The objective of this investigation was to find out how the Thermal Comfort range varies in the houses a typical winter day. For this particular exercise, a typical winter day was selected and defined as; *Any day within seven days on either side of the Winter Solstice Date; 22nd June.* For typical high altitude area winter conditions, this location fitted the criteria. The location is close to a meteorology station at Mzuzu and there was ten years data available at this meteorology station.

5.4 MONITORED PARAMETERS AND INSTRUMENTATION

Due to the difficulty in procuring all the necessary instruments, it was decided that only air velocity, dry bulb temperature, solar irradiance and solar illuminance would be monitored both indoor and outdoor, simultaneously, on the three houses. Although illuminance is not one of the factors that affect thermal comfort, it was felt that the data captured could be used for other lines of enquiries at a future date.

5.4.1 **Illuminance**

This parameter was measured with a Minolta Lux metre manufactured in Japan, which had a range of 0 – 9,999 Lux. The scale for this parameter is relatively large compared to the others. The data has been compressed by factors in order to fit on the same graph. The data is presented as lux x 10^3 for outdoor illuminance and lux x 10^2 for indoor illuminance.

5.4.2 Air Temperature

This was measured on a Marks Variable Electric meter, powered by batteries and manufactured in Germany. The instrument works on the principle of a hot wire anemometer using Newton's law of cooling. The sensitive part is mounted on a metre long tractable antenna. The scale was readable to a tenth of a degree and this was quite easy to read since the meter pointer was mounted on a mirror background using non parallax imaging principle. Temperature was measured on Celsius scale.

5.4.3 Air Velocity

The same instrument in 5.4.2 could be switched to a different scale to measure air velocity. It was a very convenient instrument in the sense that it could be inserted into a room and the temperature read out without the interference of the reader entering the room. These data were measured in ms^{-1} but were converted to cms^{-1} in order to fit the scale.

5.4.4 Solar Irradiance

Solar irradiance was measured on a Kipp and Zonen Solar Integrator CC 12 on two channels connected to two CM 11 pyranometers whose apertures were as follows:

Short wave cut off : $\lambda \leq 280$ nm
Long wave cut off : $\lambda \geq 3000$ nm

The sensitivities of these pyranometers were 5.04×10^{-6} v/Wm^{-2} and the data were readable on both an LCD screen and a print-out. In order to fit this on the same graph the data were compressed by a factor of 100 and this data is shown as watts $m^{-2} \times 100$.

Plate 5.1 **Kipp Zonnen Integrator C11 with Irradiance Sensors C12. Aperture of Sensors $280<\lambda<3000$ nm.**

5.4.5 **Measurement**

The measurements were taken on 26th June 1997 after getting all the necessary permissions from government, local chiefs, and the owners of the houses. Preliminary measurement trials were made on 25th June 1997 to determine the minimum reading cycle. All occupants of these houses were informed not to change their living habits on the day when the measurements would be taken. Care was taken by the data reading team not to disrupt any occupants' activities. Data were taken every hour in all the houses. A complete data recording session lasted for 15 minutes for all the three houses. . Measurement started at 0700 hours and readings were taken every hour up to 1700 hours, when the sun disappeared behind a hill nearby, in the West. The photographic record of the actual houses that were measured is shown in Appendix 5.1.

5.4.6 Results

5.4.6.1 ***Ventilation***: The prevailing wind on this particular site was predominantly South Easterly and that was evidenced by the growth structure of the local blue gum trees (*Eucalyptus Arborea).* These were leaning toward the North West. All the houses had fairly open areas at the wall plate levels where the air was continuous from the outside to the inside. Indoor velocities in the modern house were slightly higher than in the other two houses. The house in figure 5.6 was better ventilated and had more and bigger windows than the other two houses in figures.5.2 and 5.4. In this presentation it has been decided to present both the data and the graphical form of the data so that the specific subtle differences in performance can be appreciated

Data to all the measurements on the three houses is presented in tables 5.1, 5.2 and 5.3. These data were converted to convenient units to make the graphical presentation fit the scale.

Construction Details	Year Of Construction	Type Of Foundation Used	Type Of Wall	Type Of Window	Type Of Roof	Site/Aspect Details	Other Observations
	1967	Earth walls built using moisturized earth and compacted by hand.	225 mm thick in earth mortar, pointed in sand cement mortar externally and plastered internally. wall height 2400.	Wooden casement window not glazed.	Grass thatch and renewed periodically to replace damages by termites	House faces south, on a site that is relatively exposed and gently slopes eastwards. south-easterly prevailing winds	Roof has been renewed three times since 1967. The grass is 300 mm thick at the head but tapers off to 10mm at eaves. Plastic paper of 90micron thick paper was added during the last grass renewal. No termite damage observed. Underside of roof inside the house was heavily stained with suit from open lighting fire.

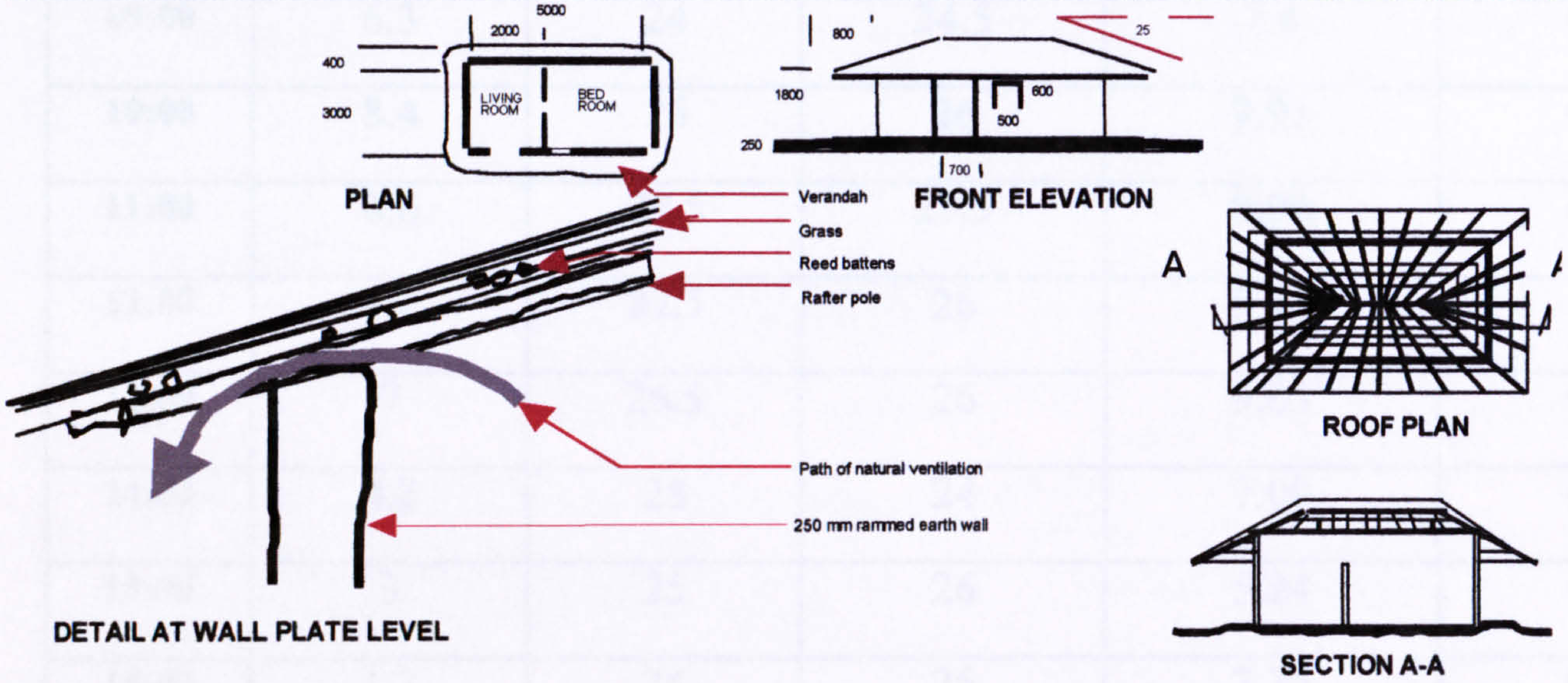

Fig 5.2 Detailed Description Of Construction A Traditional House Including Plan, Front Elevation A Typical Section Through Wall Of House.

Table 5.1 Data As Measured On The Traditional Building.

Local Time	Global Iran ($I_{tr}10^2$) W m^{-2}	Outdoor Temperature (t_o)°C	Indoor Temperature (t_{ic})°C	Outdoor Illuminance (L_O)10^3 Lux	Indoor Illuminance. (L_i)10^2 Lux	Outdoor Air Vel (v_o)10 ms^{-2}	Indoor Air Vel. (v_i)10 ms^{-2}
07:00	2.5	15	15	0.45	1.5	0	0
08:00	4.5	23	22	6.63	0.4	1	0
09:00	6.3	24	24.5	7.4	0.23	1	0
10:00	8.4	26	26	9.95	0.25	1	0
11:00	8.6	27.5	27.5	9.96	0.38	1	0
12:00	8.2	27.5	26	9.11	0.4	4	0
13:00	7	26.5	26	9.05	0.19	5	0
14:00	4.2	25	24	7.09	0.22	10	0
15:00	3	25	26	5.24	0.13	10	0
16:00	1.3	24	25	2.35	0.14	1	0
17:00	0.6	21	22.5	0.3	0.1	5	0

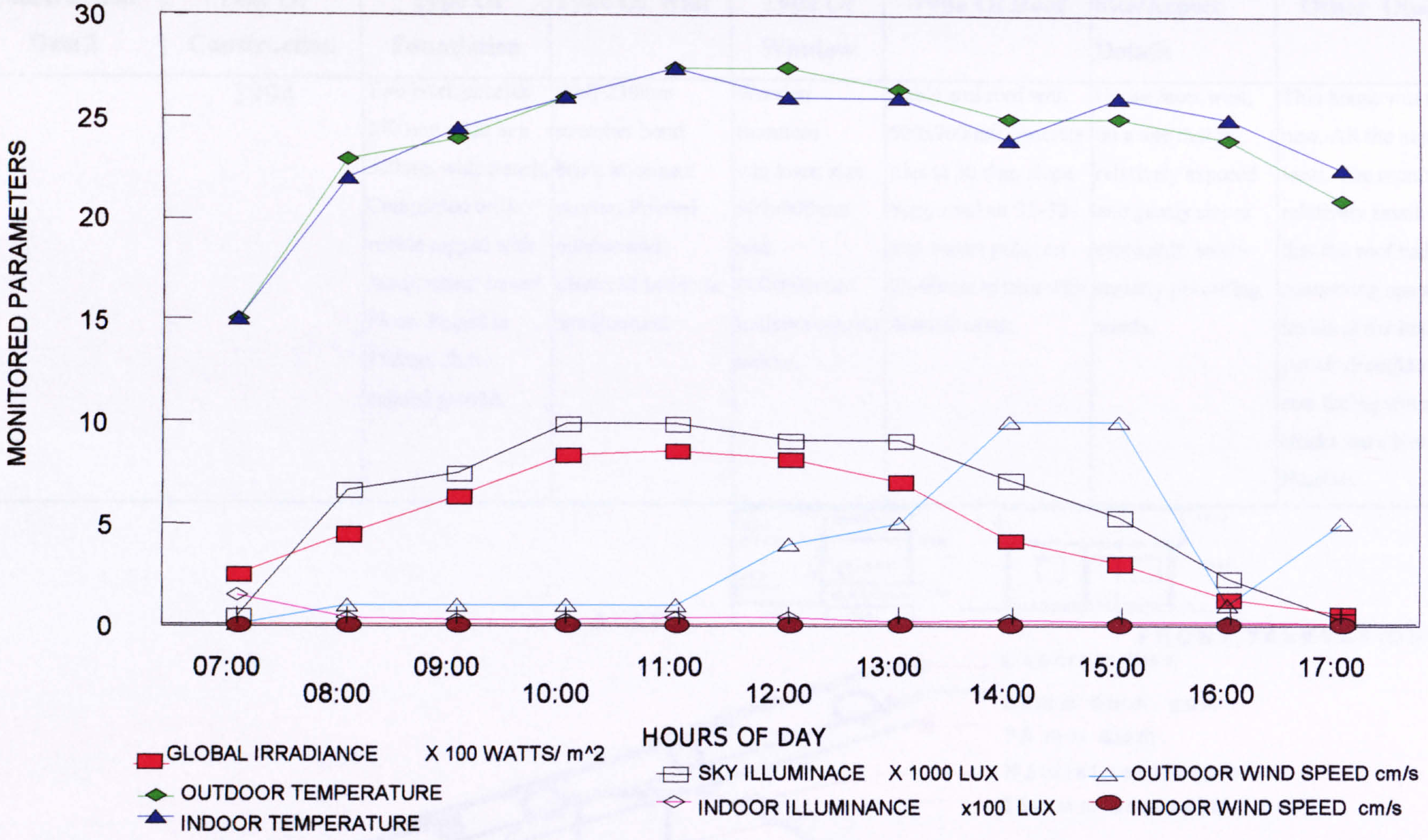

Fig 5.3 **A Plot Of The Parameters Simultaneously Measured Onsite For A Traditional House**

Construction Detail	Year Of Construction	Type Of Foundation	Type Of Wall	Type Of Window	Type Of Roof	Site/Aspect Details	Other Observations
	1994	Two brick courses 340 mm wide in a 300mm wide trench. Compacted brick rubble topped with sand/cement screed. Floor. Raised to 150mm above natural ground.	Wall 230mm stretcher bond brick in cement mortar. Pointed outside and plastered inside in sand/cement	Wooden casement windows; size 900x900mm and 600x600mm hollow concrete blocks.	Gable end roof with 600x900mm concrete tiles at 30 deg. slope Supported on 32-50-mm batten poles on 75-90mm rafters with 400mm eaves.	House faces west, on a site that is relatively exposed and gently slopes eastwards. south-easterly prevailing winds.	This house was relatively new. All the materials were local. The rooms were relatively small. It was noted that the roof had a lot of connecting spaces to the inside of the house. To cut out air droughts and wind, the east facing window hollow blocks were blocked with Hessian.

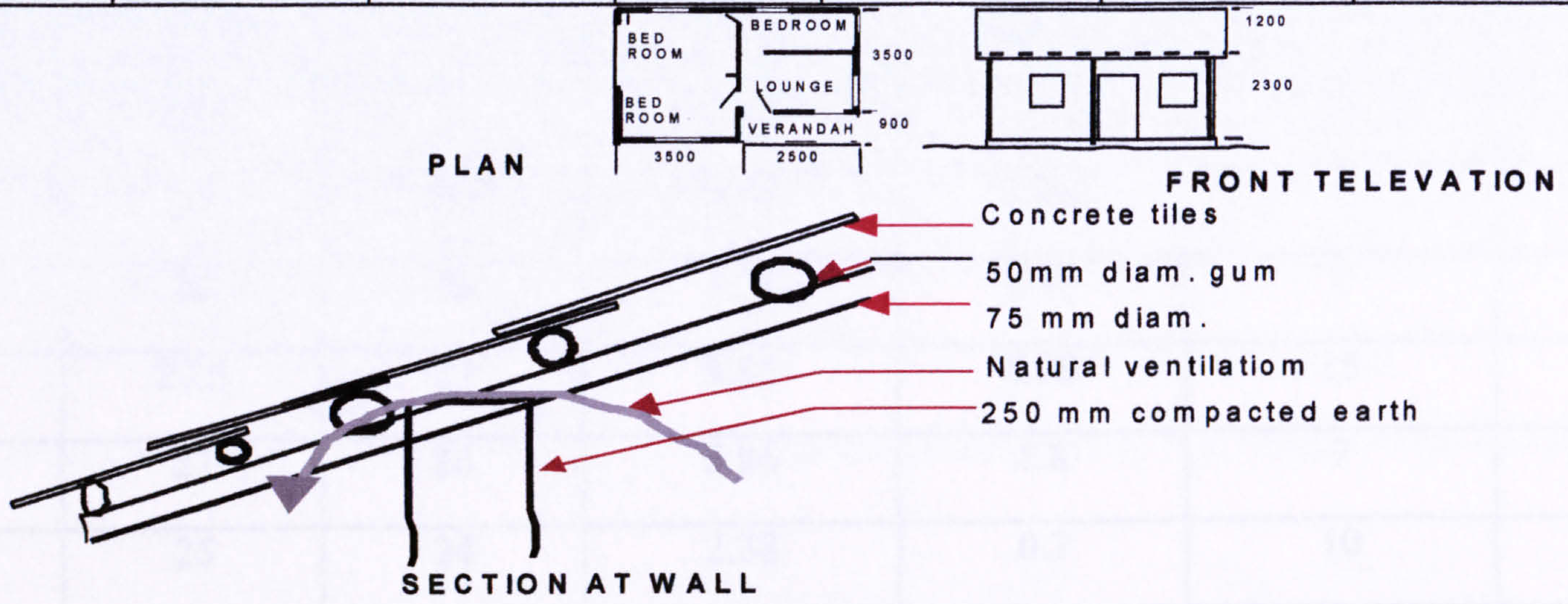

Fig 5.4 **Detailed Description Of Construction An Intermediate Technology House Including Plan, Front Elevation A Typical Section Through Wall; House Type 5.1.2.**

Table 5.2 Data As Measured On The Intermediate Technology Building

Local Time	Global Irrad. ($I_{tr}10^2$) W m^{-2}	Outdoor Temperature $(t_{ao})^{O}C$	Indoor Temperature $(t_{ai})^{O}C$	Outdoor Illuminance $(L_O)10^3$ Lux	Indoor Illuminance. $(L_i)10^2$ Lux	Outdoor Air Vel $(v_o)10$ ms^{-2}	Indoor Air Vel. $(v_i)10$ ms^{-2}
07:00	2.5	15	15	0.25	3.7	0.0	0
08:00	4.5	17.5	18	6.63	3.6	0	0
09:00	6.3	22	22	6.42	0.4	2	0
10:00	8.4	25	25	8.39	0.29	1	0
11:00	8.5	25	25	10.8	0.5	4	0
12:00	8.6	27	26.5	9.57	1.06	7	0
13:00	8.2	28	28	9.58	0.48	1	0
14:00	7	27.5	27	8.05	0.39	15	0
15:00	4.2	27	26	5.86	1.8	7	0
16:00	3	25	24	2.38	0.7	10	0
17:00	0.6	22	20.5	0.5	0.26	7	0

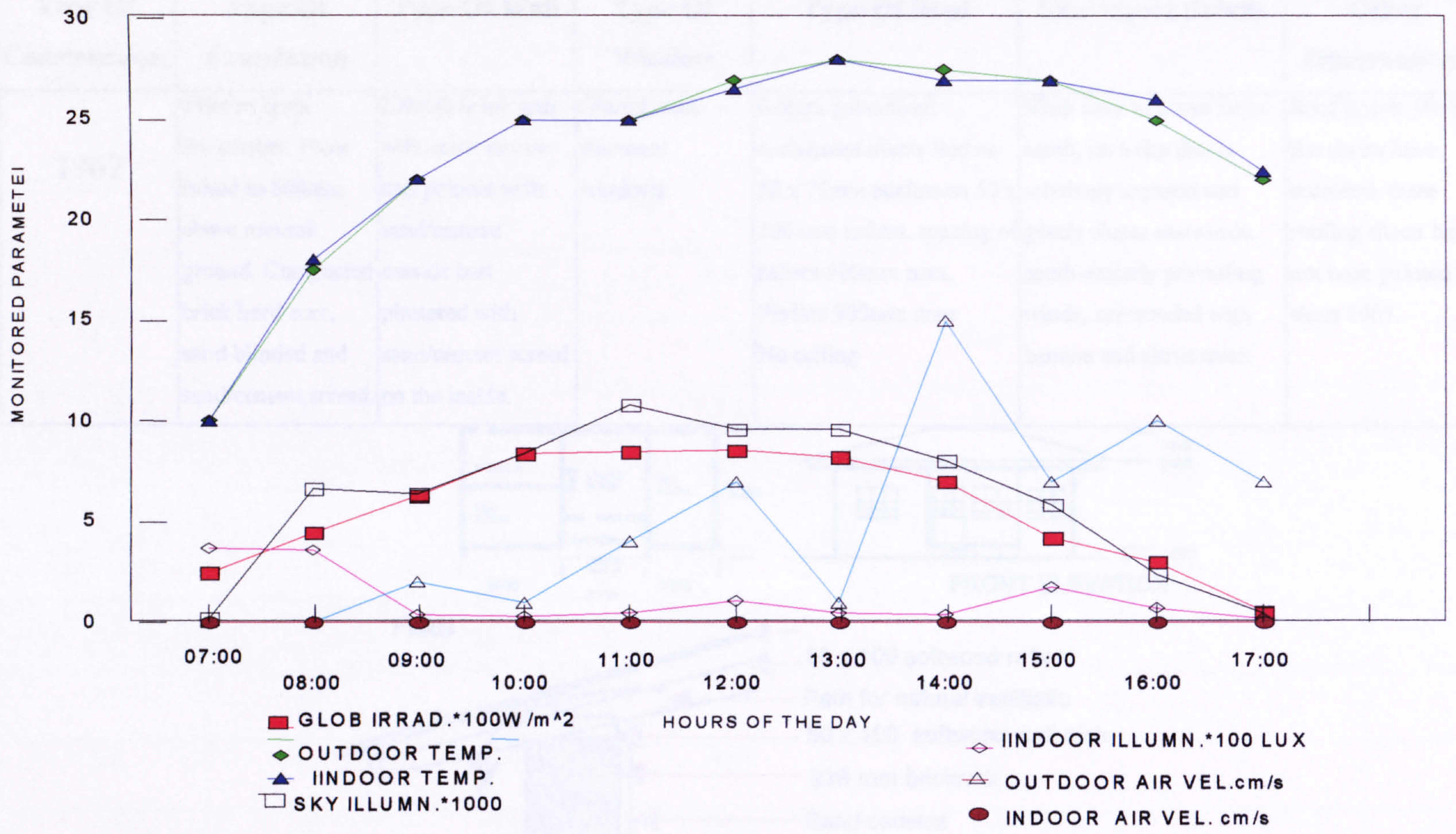

Fig 5.5 **A Plot Of The Parameters Simultaneously Measured Onsite For The Intermediate Technology House; House.**

Construction Details	Year Of Construction.	Type Of Foundation	Type Of Wall	Type Of Window	Type Of Roof	Site/Aspect Details	Other Observations
	1967	340mm brick foundation. Floor raised to 600mm above natural ground. Compacted brick hard core, sand blinded and sand/cement screed.	230mm brick wall with earth mortar and pointed with sand/cement outside butt plastered with sand/cement screed on the inside.	Glazed steel casement windows	0.6mm galvanized corrugated sheets laid on 50 x 75mm purlins on 50 x 100 mm rafters. spacing of rafters 900mm max. Purlins 900mm max No ceiling	Main door to house faces south, on a site that is relatively exposed and gently slopes eastwards. south-easterly prevailing winds, surrounded with banana and citrus trees.	Roof laid in 1967. the sheets have corroded. these roofing sheets had not been painted since 1967.

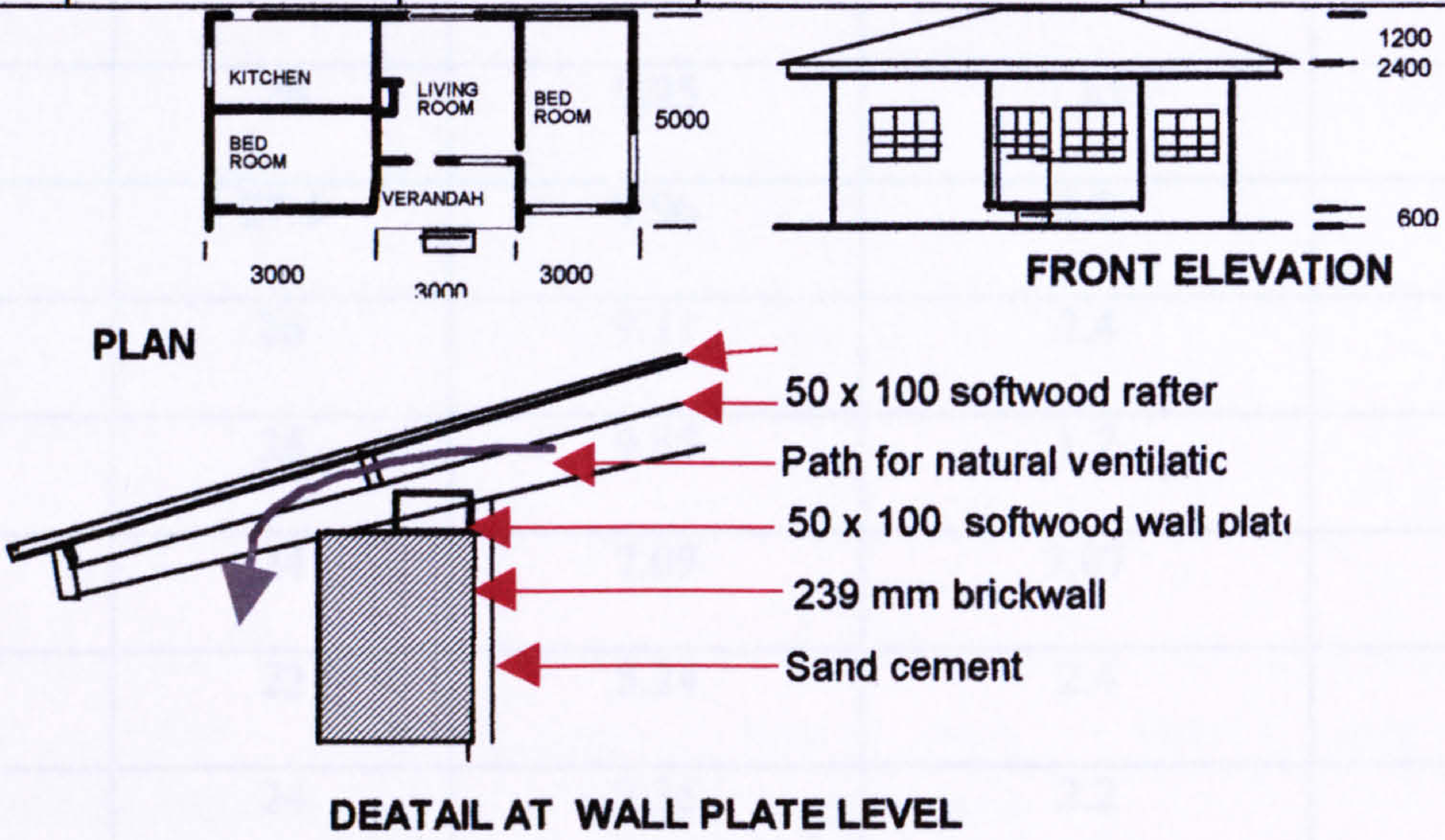

Fig 5.6 Detailed Description Of Construction A Modern House Including Plan, Front Elevation And A Typical Section Through Wall Of House.

Table 5.3 Data As Measured On The Modern Building

Local Time	Global Irrad ($I_{tr}10^2$) W m^{-2}	Outdoor Temperature (t_{ao})^{O}C	Indoor Temperature (t_{ai})^{O}C	Outdoor Illuminance (L_O)10^3 Lux	Indoor Illuminance. (L_i)10^2 Lux	Outdoor Air Vel (v_o)10 ms^{-2}	Indoor Air Vel. (v_i)10 ms^{-2}
07:00	2.5	15	15	0.45	1.5	0	0
08:00	4.5	23	22	6.63	3.66	0.5	0
09:00	6.3	24	24.5	7.4	1.2	0.1	0
10:00	8.4	26	26	9.95	1.55	5	0.1
11:00	8.6	27.5	27.5	9.96	2.7	2	0
12:00	8.2	27.5	26	9.11	2.4	3	0
13:00	7	26.5	26	9.05	1.7	5	0
14:00	4.2	25	24	7.09	3.07	2	0
15:00	3	25	22	5.24	2.4	5	0
16:00	1.3	24	24	2.35	2.2	5	0
17:00	0.6	21	18.5	0.3	0.62	1	0

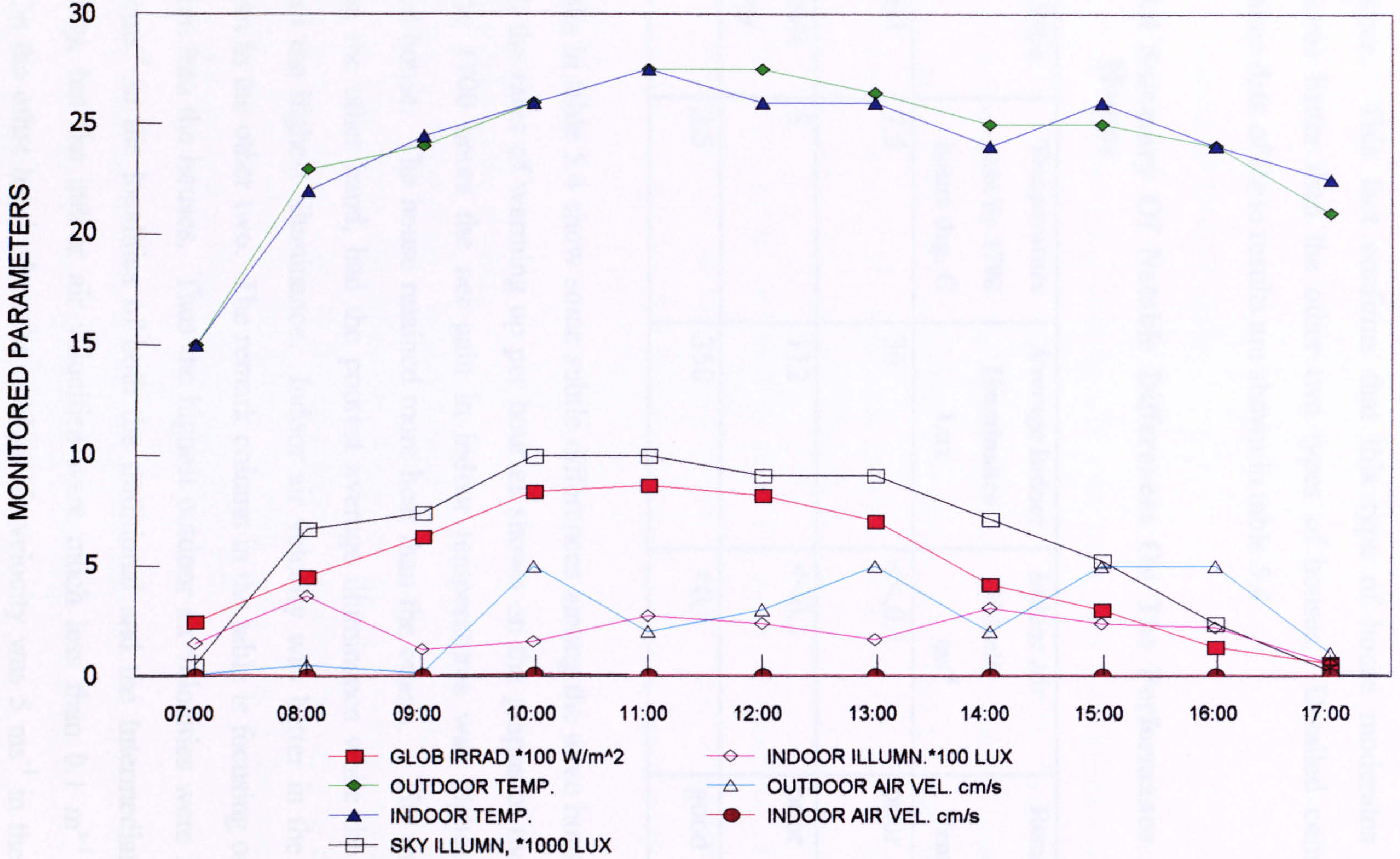

Fig 5.7 **A Plot Of The Parameters Simultaneously Measured Onsite For A Modern House**

The results show that the modern house in figure 5.7 had the best illuminance level. This is attributed to the level of fenestration in this house type. This house had the highest window/floor area ratio. When these figures are examined in detail, it is observed that the traditional house was cooling slowest of the three house types. This fact confirms that this type of house moderates extreme temperatures better than the other two types of houses. Detailed comparative performance data of these results are shown in table 5.4

Table 5.4 Summary Of Notable Differences On The Performance Of The Houses

House Type	Temperature gain by 1700 hours deg. C	Average Indoor Illuminance Lux	Indoor Air Velocity ms^{-1}	Remarks on Air Ventilation
Traditional	7.5	36	<<,0.1	poor
Intermediate Technology	5	112	<<0.1	poor
Modern	3.5	350	≈0.1	good

The results in table 5.4 show some subtle differences among the three house types. Although the rates of warming up per hour as shown on the graphs of the houses appear by 1700 hours the net gain in indoor temperatures was highest in the traditional house. The house retained more heat than the others. The traditional house, on the other hand, had the poorest average illuminance while the modern house had the highest illuminance. Indoor air velocity was better in the modern house than in the other two. The remark column in the table is focusing on the air penetration into the houses. Thus the highest outdoor air velocities were 10 cms^{-1} and 15 cms^{-1} in the localities of both the traditional and the Intermediate house respectively, but the indoor air velocities were much less than 0.1 m^{s-1} in both cases. On the other hand when the outdoor air velocity was 5 ms^{-1} in the locality of the modern house the indoor air velocity was only 0.1 ms^{-1} . This particular result does not agree with Adarve's prediction that the indoor wind velocity should be 40% of the outdoor velocity. The specific condition laid down by Adarve *et al* (1991) is that the ratio of the window area to that of the containing wall must not less than 1:3. All the three houses did not meet this condition. The limitation of the sensitivity of the anemometer is also a limitation here. However, the recorded indoor wind velocity of $0.1ms^{-1}$ is the minimum acceptable indoor wind velocity.

5.4.7 General Observations

It was to observed that even at 15°C in the early hours of the morning, on this winter day, the people in the area including the occupants were dressed in clothes with insulation values of not higher than 0.5 **Clo** using the Fanger's Visual Classification;(Fanger; 1988). The author was not able to establish whether the people were just not able to afford clothes of higher rating than 0.5 **Clo**. However, it was observed that while the irradiance intensity was lower than 400 Wm^{-1}, the people preferred to sit in the sun while at higher irradiance levels definitely higher than 600 Wm^{-2}, the people preferred to sit in the shade of verandas. It can be concluded here that solar irradiance of 600 Wm^{-2} is the upper limit when people cannot tolerate the exposure for the mere reason of absorbing a body thermal energy deficit.

5.4.8 Remarks on the Results

Although the air temperatures ranged from 15°C - 27.5°C on this day, the people did not seem desperately uncomfortable. However, this is a unique situation where the people had a choice either to put on clothes of higher **Clo** value or move to a warmer place, they opted for the latter. In other words this is the true practical example of the *Adaptation* Principle (Humphrey; 2002).

In a working situation such as is the case in schools, this freedom is limited and movements would simply be too disruptive. Although these measurements were done on one day only, the results confirm that at an air temperature as low as 15°C the people were not desperately uncomfortable. This seems to suggest that in

Malawi, it would not make economic sense to worry about low temperatures. Priority should be directed to cooling rather than heating. Certainly, literature in Chapter 2 confirms that there are no known physiological risks at temperatures lower than the comfortable limits. However, there is evidence that at temperatures higher than the upper limit, mental activity starts to be disrupted. This leads to low productivity in whatever task is to be performed. At still higher temperatures then there is the risk of heat stroke. In terms of the world wide recorded Thermal Comfort Range, this temperature is still within the range but definitely outside the established Neutral *Zone* of thermal comfort.

It is probable that the variations observed on the graphs on wind velocities around each house are due to the effect of the local shrubs and trees surrounding each house. However, the instrument that was used was not sensitive enough to detect indoor air velocities lower than 0.1 m s^{-1} although it was possible to record and interpolate to speeds of $0.05m^{s-1}$. On the other hand, the traditional house had the poorest indoor day lighting. This perhaps reveals the fact that life in this society is generally outside and about in the Verandah. And in the traditional setting, there are perhaps very few tasks performed indoors that require illuminance levels as high as the recommended range of 50 - 300 lux in the various rooms in the home (Tut and Adler;1997).

Although these houses were different in size, construction and had minor orientation differences these differences did not affect the overall response of each one of them. Since these buildings are basic models of houses in Malawi these results can be can be taken as basic information to be refined in future.

CHAPTER SIX.

6.0 INVESTIGATION THERMAL COMFORT PRINCIPLES IN TRADITIONAL BUILDINGCONSTRUCTION

6.1 SCIENTIFIC KNOWLEDGE IN BUILDING CONSTRUCTION

In this section the intention is to investigate how the structural features of the traditional house are related to the concepts of thermal comfort. It is further intended to investigate how these relationships vary with factors that are known to influence thermal comfort in a given locality namely; altitude, latitude, air temperature, solar radiation, wind velocity, precipitation, and humidity. A direct method to do this is to conduct a detailed survey of the structural features and compare their contribution to thermal comfort. In other words it is possible to find out what adaptive techniques have been devised by the people in the course of time.

A tradition in construction is the preservation of a set of techniques that have proved to work in a given cultural / environmental interface. Perhaps this process alone cannot be classified as a science. However, the principles upon which the traditional construction rules are based may be similar to those that can be deduced through scientific analysis. Chapters 1, 2 and 3 contain much evidence that has been deduced through scientific analysis. The end result is the identification of parameters that promote thermal comfort in the built environment. However, it is known that man has always dared to tame the environment. The methods used to term the environment in vernacular architecture may not be as efficient as those techniques used in modern buildings. Although the techniques in the latter may be construed to be more efficient than those in the former, the intentions in both may be the same. The fact that there are traditional solutions that have been derived to solve problems of thermal discomfort in the environment would seem to suggest that those solutions might be based on experience. Hernandez and Rivera (1979) report that a principle upheld by knowledge can coincide with that which can be derived through scientific analysis.

Ahmed (1974) reports that internal dimensions of a building have a bearing on the internal mean radiant temperatures that influence thermal comfort in the room. However, his findings show that an increase in ceiling height does not have a linear relationship to a decrease in the mean radiant temperature although the radiant temperature of the room is directly related to the temperature of the ceiling. Rapport, (1985) has observed that vernacular architecture necessarily relates to the environment for its form and function. It can be inferred that the principles of passive design intrinsic in traditional buildings reflect the knowledge to live in a thermally comfortable environment as best as is possible. This may include the consideration of cost that is involved.

Hypothesis. *One of the factors that has influenced the structure, roof shape, and dimensions of a traditional building is the need to achieve thermal comfort.*

In order to prove this hypothesis, it is necessary to undertake a detailed survey and conduct a statistical analysis of the data collected in the survey.

6.2 PRELIMINARY SURVEY OF TRADITIONAL HOUSES IN FOUR DISTRICTS.

A preliminary survey of traditional houses in four districts, as part of this research has shown that despite the fact that there are no manuals for constructing traditional houses, there are definitely certain technical procedures and constants that can be interpreted as "traditional technical rules". Some of the results of this survey conducted by the author in Chitipa, Karonga, Mzimba and Mchinji are shown in figures 6.1-6.4 and table 6.1 below. The buildings surveyed are few in number because the survey was directed at selecting buildings that would represent heterogeneous samples. This preliminary result certainly confirms that there must be certain simple structural relationships within the structural elements of the traditional house that can be attributed to the search for Thermal Comfort. Bearing in mind that measuring instruments are not used in designing these structures except knowledge, how much does that simple relationship integrate and reflect the effects of environmental factors?

These preliminary results do indicate that although there are no written rules in the traditional building construction, there are apparently, salient norms and regulations that subsist in the construction practice. Do some of these rules directly relate to the local levels of incident solar radiation and it is possible that there may be some direct relationships.

Table 6.1 Preliminary Statistical Data on Surveyed Sample Traditional Buildings

District	Number Of Houses Surveyed (N)	Regression Constant	Correlation Of Roof Height (Apex) To Width Of House (HW)	Mean House Roof Height At Entrance (RAP mm)	Mean Of House Lengths (HL) mm	Mean Of House Width Lengths (HW) mm
Chitipa	48	0.8471	0.8173	3061	6167	3831
Karonga	31	0.5290	0.7042	2789	5505	3435
Mzimba	21	0.6878	0.6622	2680	5780	4633
Mchinji	8	0.4190	0.8688	2877	5793	3937

Further questions that must be asked are what are the principles for passive design that have been used in this traditional construction practice? To what extent can they be incorporated in modern buildings to enhance thermal comfort and save the country's foreign exchange and increase productivity of the people by increasing their physiological and mental output? Is it possible that there may be some elements in the traditional practices that are based on sound scientific principles in passive design? Is it possible that there may be some elements in the traditional practices that can be scientifically deducible?

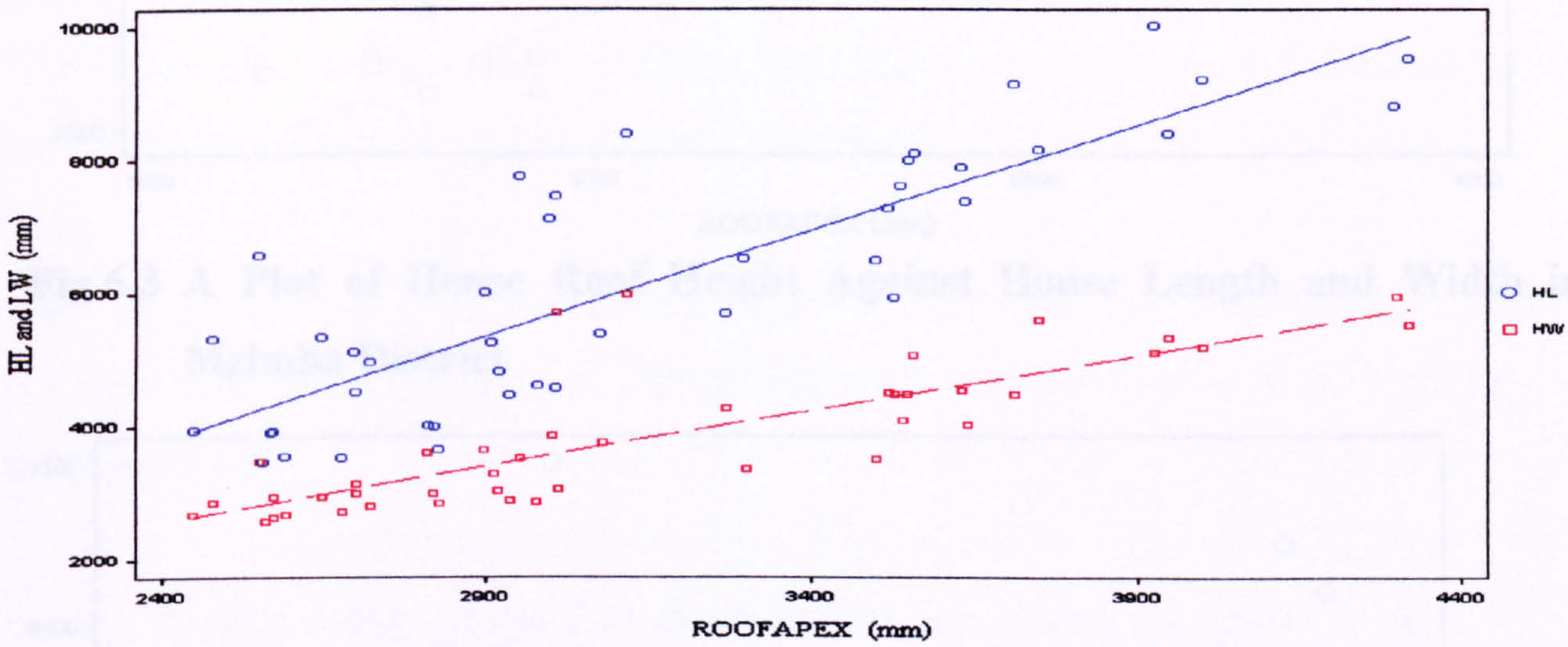

Fig 6.1 A Plot of House Roof Height Against House Length and Width in Chitipa District on Plan

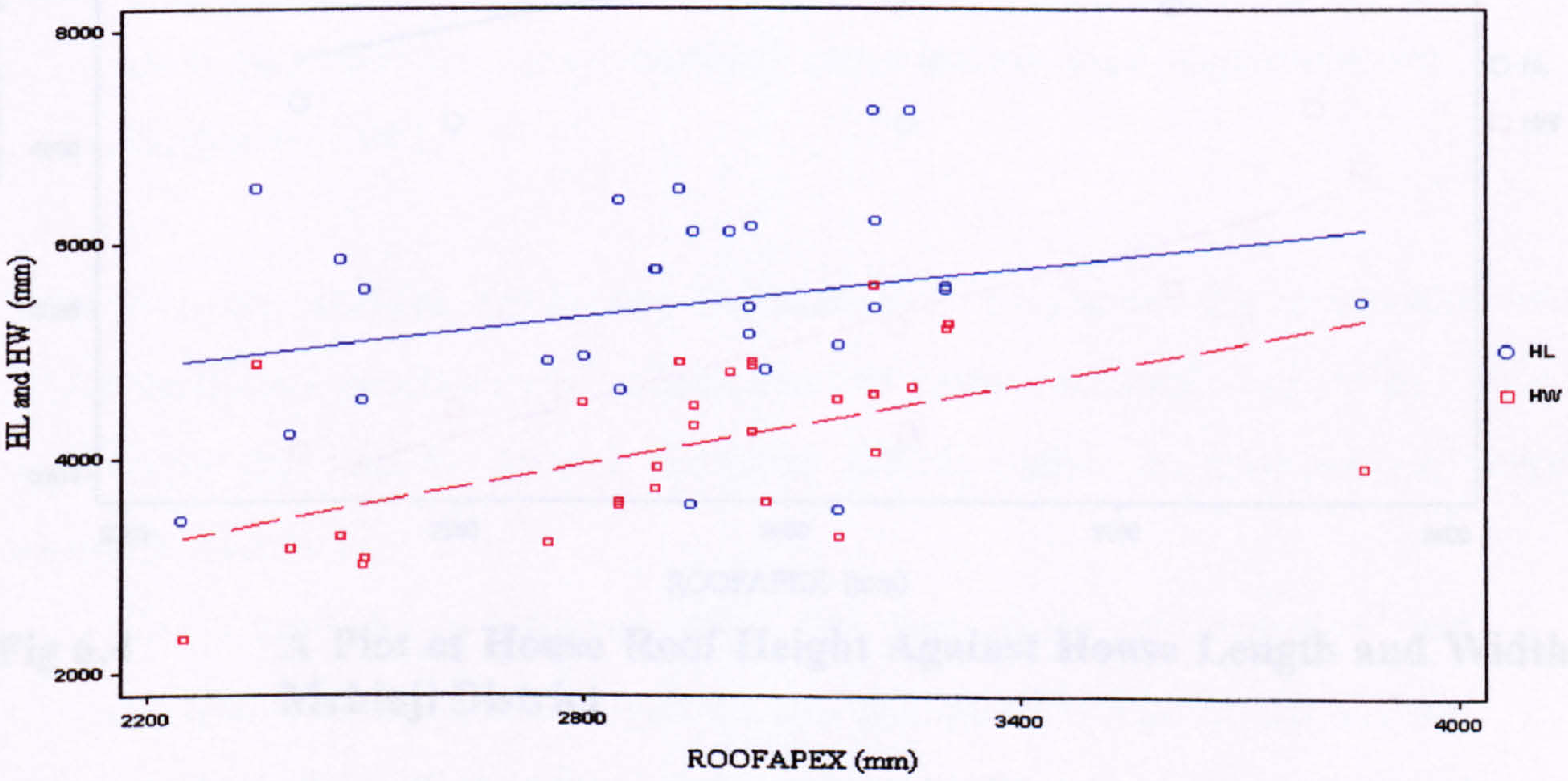

Fig 6.2 A Plot of House Roof Height Against House Length and Width in Karonga District

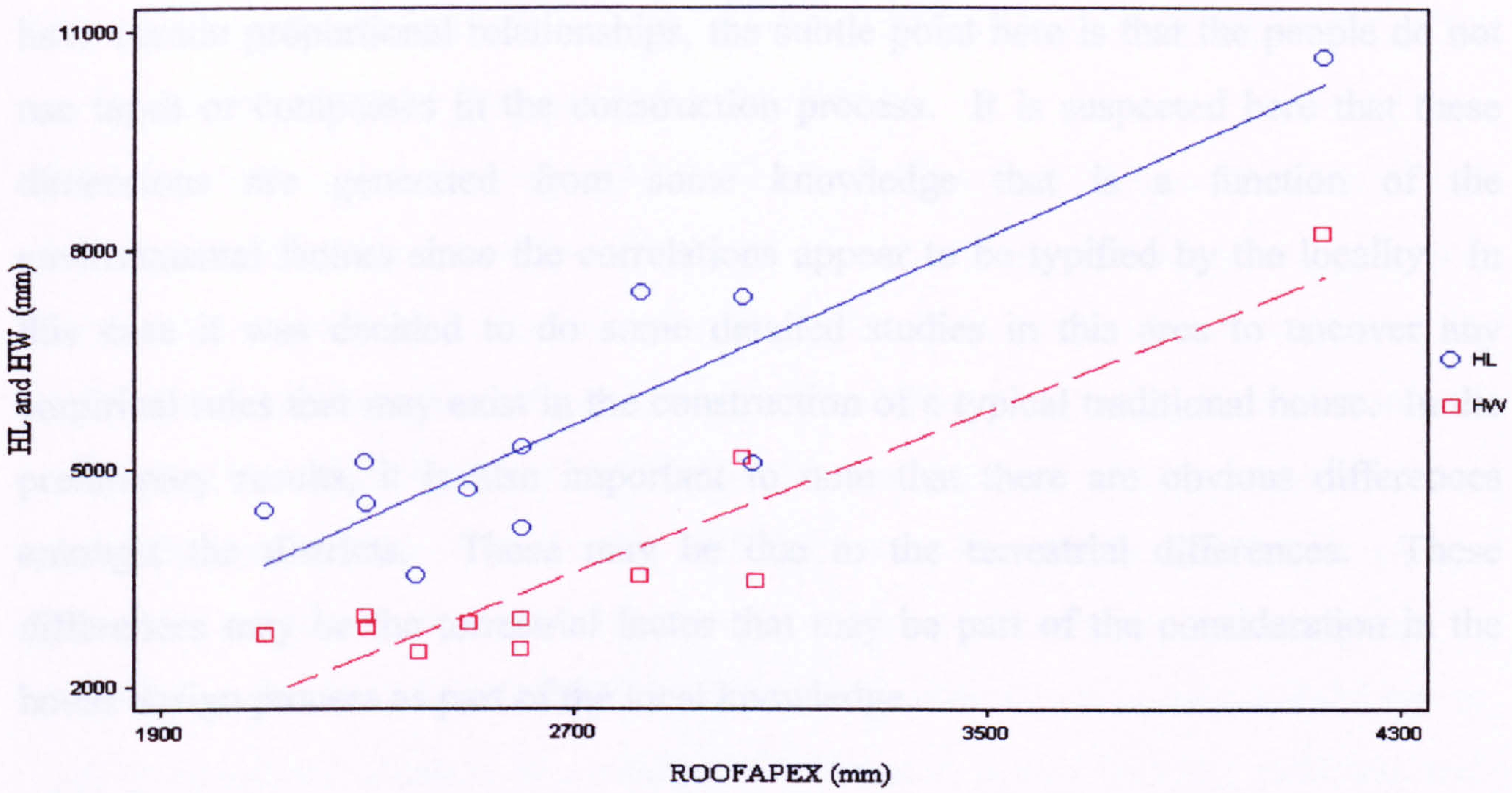

Fig 6.3 A Plot of House Roof Height Against House Length and Width in Mzimba District

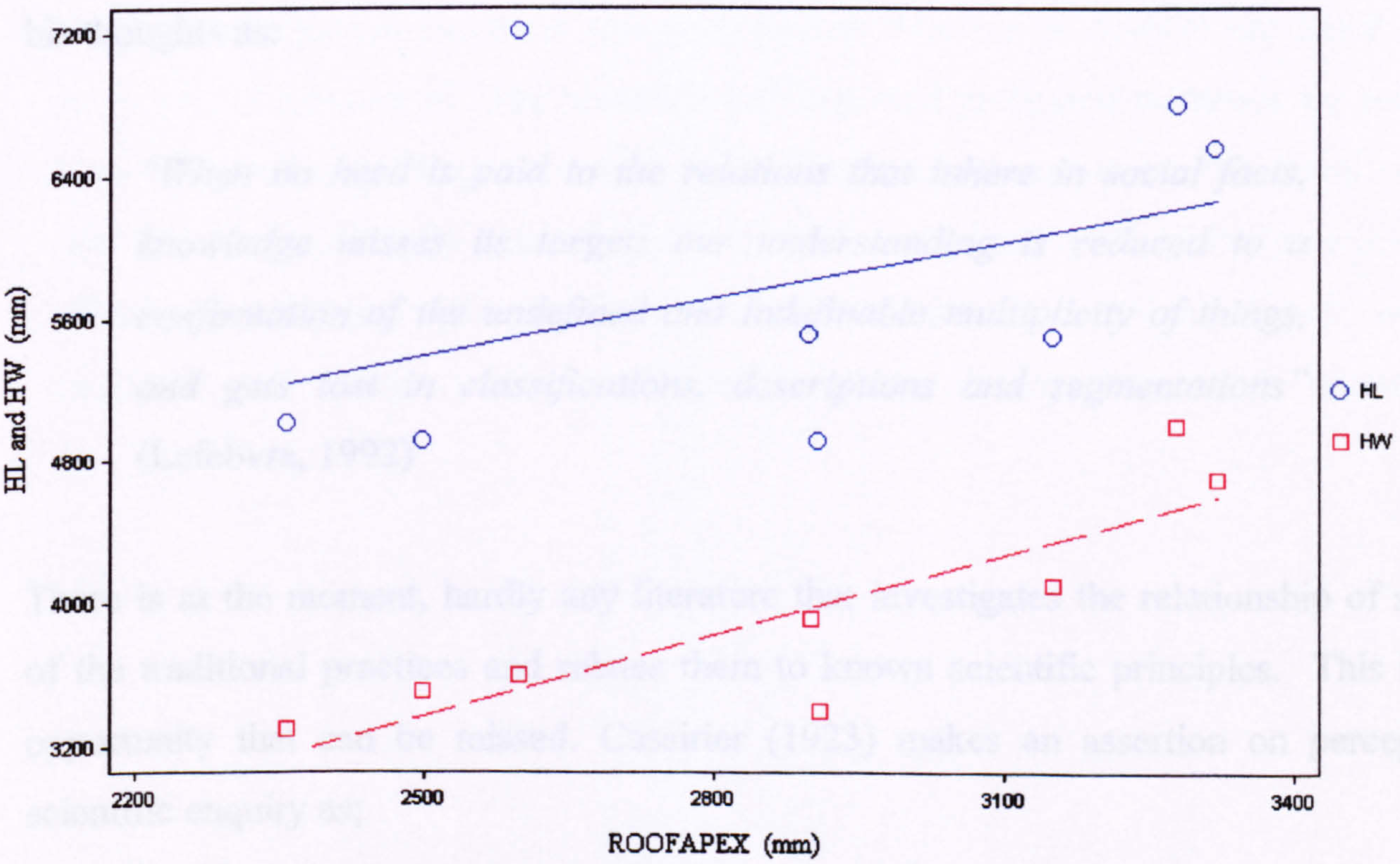

Fig 6.4 A Plot of House Roof Height Against House Length and Width in Mchinji District

Figures 6.1-6.4 show scatter grams of preliminary results of the survey of the relationship between the Height of a house roof against its Length (HL),and the

Width (HW). Although it is geometrically expected that these dimensions would have certain proportional relationships, the subtle point here is that the people do not use tapes or compasses in the construction process. It is suspected here that these dimensions are generated from some knowledge that is a function of the environmental factors since the correlations appear to be typified by the locality. In this case it was decided to do some detailed studies in this area to uncover any empirical rules that may exist in the construction of a typical traditional house. In the preliminary results, it is also important to note that there are obvious differences amongst the districts. These may be due to the terrestrial differences. These differences may be the terrestrial factor that may be part of the consideration in the house design process as part of the local knowledge.

Lefebvre (1992) has described how an opportunity to enquire in time can be missed and therefore an opportunity to extend knowledge to mankind is lost. He sums up his thoughts as:

> *"When no heed is paid to the relations that inhere in social facts, knowledge misses its target; our understanding is reduced to a confirmation of the undefined and indefinable multiplicity of things, and gets lost in classifications, descriptions and segmentations"* (Lefebvre, 1992)

There is at the moment, hardly any literature that investigates the relationship of some of the traditional practices and relates them to known scientific principles. This is an opportunity that can be missed. Cassirier (1923) makes an assertion on perceptive scientific enquiry as;

> *"To 'know' is to advance from the immediacy of sensation and perception to the purely cogitated and meditated 'cause' to dissect the simple matter of sensory impressions into strata of 'grounds' and 'consequences"'* (Cassirier; 1923).

6.3 THE DEPENDENCE AND DEVELOPMENT OF CONSTRUCTION TECHNOLOGY ON LOCAL MATERIALS

The *Intuitive apprenticeship* (Hernandez and Rivera; 1979) in the traditional buildings construction manifests itself in the roof shape. In the house plan and roof shape are reflected effort to construct the house at least cost, but come up with an optimum device effective, and most efficiently to keep out solar radiation and precipitation. Koenigsberger (1978) concludes that an optimum solution for a building shape involves sacrificing light for coolness, acoustic quality for safety, structural simplicity for user convenience, and ease of maintenance for savings in capital investment. Saini (1978) reports that an alternative to air conditioning at any geographical location is a careful selection and use of building materials and techniques that are locally available.

Common indigenous materials and construction schemes in Malawi are listed in table 6.2. A mixture of local materials and imported processed materials are used in modern buildings despite the high cost of imported components. The form and style of traditional buildings have been derived with due regard to the prevailing climatic conditions. The roof shapes have empirically been developed over hundreds of years and are therefore very deterministic and proven.

Table 6.2 Common Construction Materials in Malawi

Building zone.	Type of materials.	Physical limitations.
1.Foundations.	1.1.local earth	1.1.1 harbours termites.
		1.1.2 structural strength decreases with increasing moisture.
	1.2 stone	1.2.1 irregularity of sizes.
2.Walls.	2.1 wooden posts	2.1.1 subject to termite attack.
		2.1.2 uncontrollable variation in size.
	2.2mud and wattle adobe	2.2.1 structural failure due to decay of organic elements in matrix.
		2.2.2 structural members subject to termite attack and insect damage.
		2.2.3 limitation of free span.
	2.3 sun baked bricks	2.3.1 as in 1.1.1 and 1.1.2.
	2.4 fired bricks	2.4.1 labour intensive.
3.Roof.	3.1grass Kanyumbu[1] and Wanje[2]	3.1.1 as in 2.1.1. 3.1.2 subject to attack by ultra violet that denatures the basic carbon bond and leads degradation and rot. 3.1.3 limited freedom on slope of roof
	3.2palm leaves-mlaza[3]	3.2.1 as in 1.1.1; 3.1.2 and
	3.3trees and bamboo's[4]	3.3.1 as in 2.1.1;2.1.2;and

Botanical classification of grasses used for thatching houses in Malawi are as follows

[1]Kanyumbu is *Hyparrhenia nyassae*, [2]Wanje is *Setaria palustri* [3]Mlaza is *Hyphaene Natalensis*

[4]Bamboos; POACEAE family but specifically *Oxytenanthra* and *Orundinaria*

6.4 THEORETICAL CONSIDERATIONS

6.4.1 Power of Solar Radiation Incident on Buildings

Theoretically the total power contained in the part of solar spectrum that is relevant for this work can be defined as follows:

$$\mathbf{P_r} = \int_{300}^{3000} \mathbf{W_s} \lambda \delta\lambda \tag{6.1}$$

If the average absorptance of a building structure is γ, and the average directional reflectance is R; then γ can be defined as :

$$\gamma = \frac{\int_{300}^{3000} (1 - \mathbf{R}_\lambda) \mathbf{W_s} \lambda \delta\lambda}{\int_{300}^{3000} \mathbf{W_s} \lambda \delta\lambda} \tag{6.2}$$

Where $W_{S\lambda}$ is the air mass 2 (or air mass 1) terrestrial radiation at

Wave length λ between λ and $\lambda + \delta\lambda$

$(1 - R_\lambda)\ _\lambda W_s\ \lambda\delta\lambda$ is the total radiation absorbed by the surface.

For a building 60 – 80% of the heat again is through the roof while the 20 - 40% is through the wall (Naher et al; 1998); Nason, (1985) reports that, heat gain in buildings is highest at high solar elevation angles in the tropics.

6.4.2 Seasonal Changes of; Maximum and Minimum Solar Angles

Thermal gains into a building structure are mainly due to solar radiation. Other minor sources are the long wave radiation emitted from human bodies and radiation from lighting and heating activities in the environment or home. From geometrical consideration of the earth's tilt angle and movement (Jones; 1973) the relationship between the tilt angle, hour angle, and altitude of the sun is expressed as

$$\sin \alpha = \sin \mathbf{d} \sin \mathbf{L} + \cos \mathbf{d} \cos \mathbf{L} \cos \mathbf{h}. \tag{6.3}$$

At noon when **h** $= 90^0$ then equation 6.3 reduces to

$$\alpha_{\text{noon}} = 90 - (\mathbf{L}\text{-}\mathbf{d}). \tag{6.4}$$

Table 6.3 Calculated Minimum and Maximum Solar Altitude Angles for Chitipa, Lilongwe and Nsanje Districts.

Place	Latitude	Maximum Solar altitude	Minimum Solar altitude
Chitipa	9^0 S	14.5^0 S (104.5 ^{0}N)	57.5 ^{0}N
Lilongwe	14^0 S	9.5^0 S (99.5 ^{0}N)	52.5 ^{0}N
Nsanje	17^0 S	6.5^0 S (96.5 ^{0}N)	49.5 ^{0}N

(Deduced from equation (6.4), also refer to appendix 1.1 for locations of the places).

Table 6.3; shows that no place in the country experiences solar altitude angle lower than 49½°, which would be the cold season; (latitudes shown are to the nearest degree). On 22nd December at noon, the sun is 14½° south of Chitipa, 9½°south of Lilongwe, 6½° south of Nsanje (refer to Appendix 1.1). These are still at maximum altitude angles for these locations during the year.

A typical house is built with a plinth in the verandah. It has been observed that this plinth, although commonly used for ease of sitting in the verandah, it is designed carefully and intuitively to cut out the direct solar radiation at some critical hour of the day by reducing the aperture of the verandah. In figure 6.5, α_1, α_2 and τ_1,τ_2 are the solar altitude and the Wall -Solar Azimuth angles respectively. Both in cold and hot seasons, the roof of the house has to cut off the critical radiation at the appropriate solar altitude and Wall – Solar Azimuth angles. Thus at any given location the individual through the experience assesses the environmental sense data and the house is then constructed in such a manner that α_1 and α_2 are the critical angles at Wall- Solar Azimuth τ_1, and τ_2 to the effect thermal comfort.

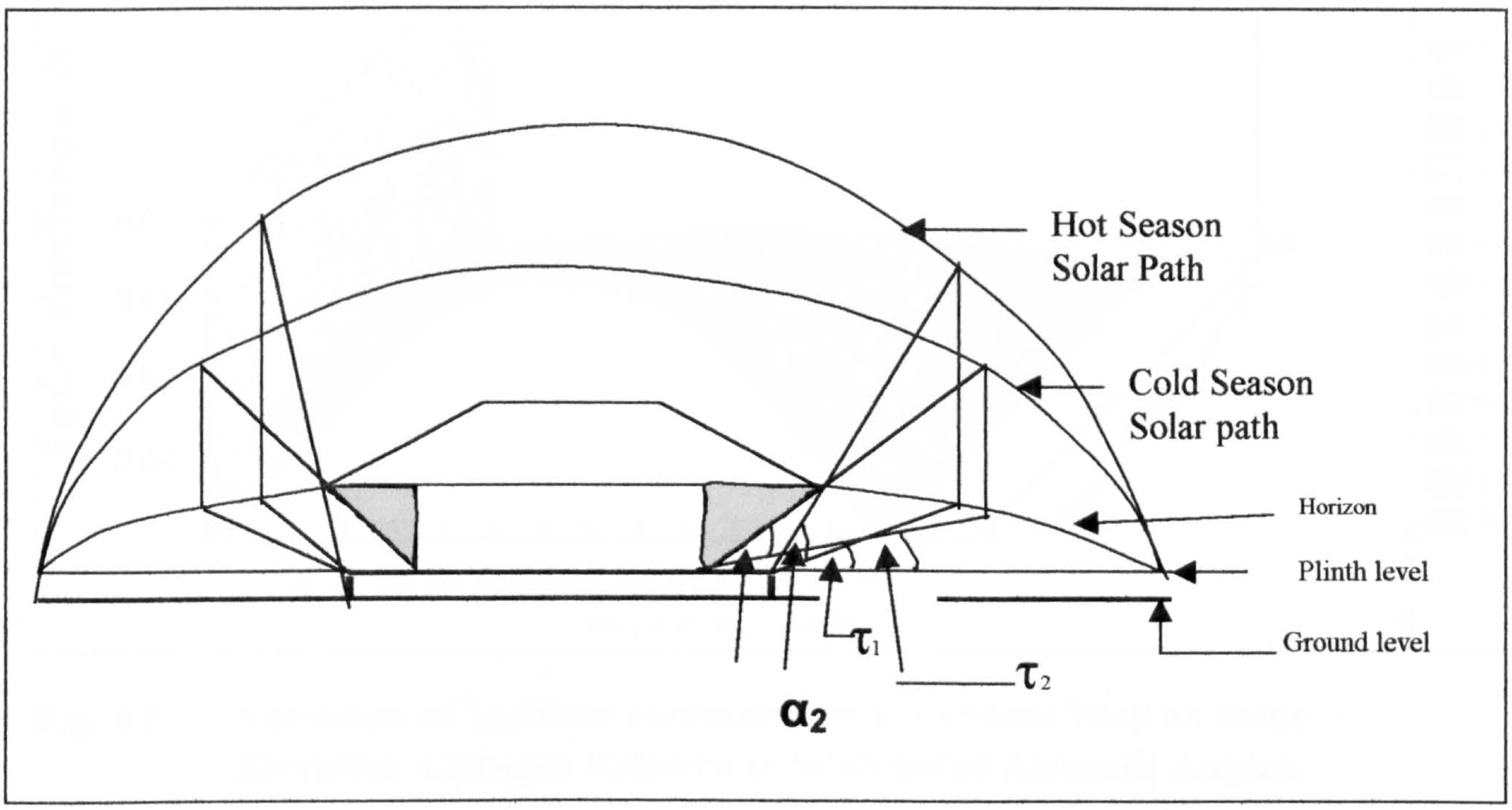

Fig 6.5 Geometry of a Typical Traditional House in Relation to the Solar Path

Figure 6.6 shows how the intensity of solar radiation on a vertical wall varies with the angle of incidence of the solar beam and the Wall –Solar Azimuth angles. These data clearly shows that the most critical solar altitude angles where radiation will be most intense are between 30^{0} and 35^{0}. Figure 6.7 shows the same data in 2D, just to improve the description of the phenomenon. How has this problem been resolved in the traditional roofs?

It is the intention in this research to investigate how this problem has been resolved in the traditional house design, and how an optimum solution for thermal comfort for the entire year has been achieved.

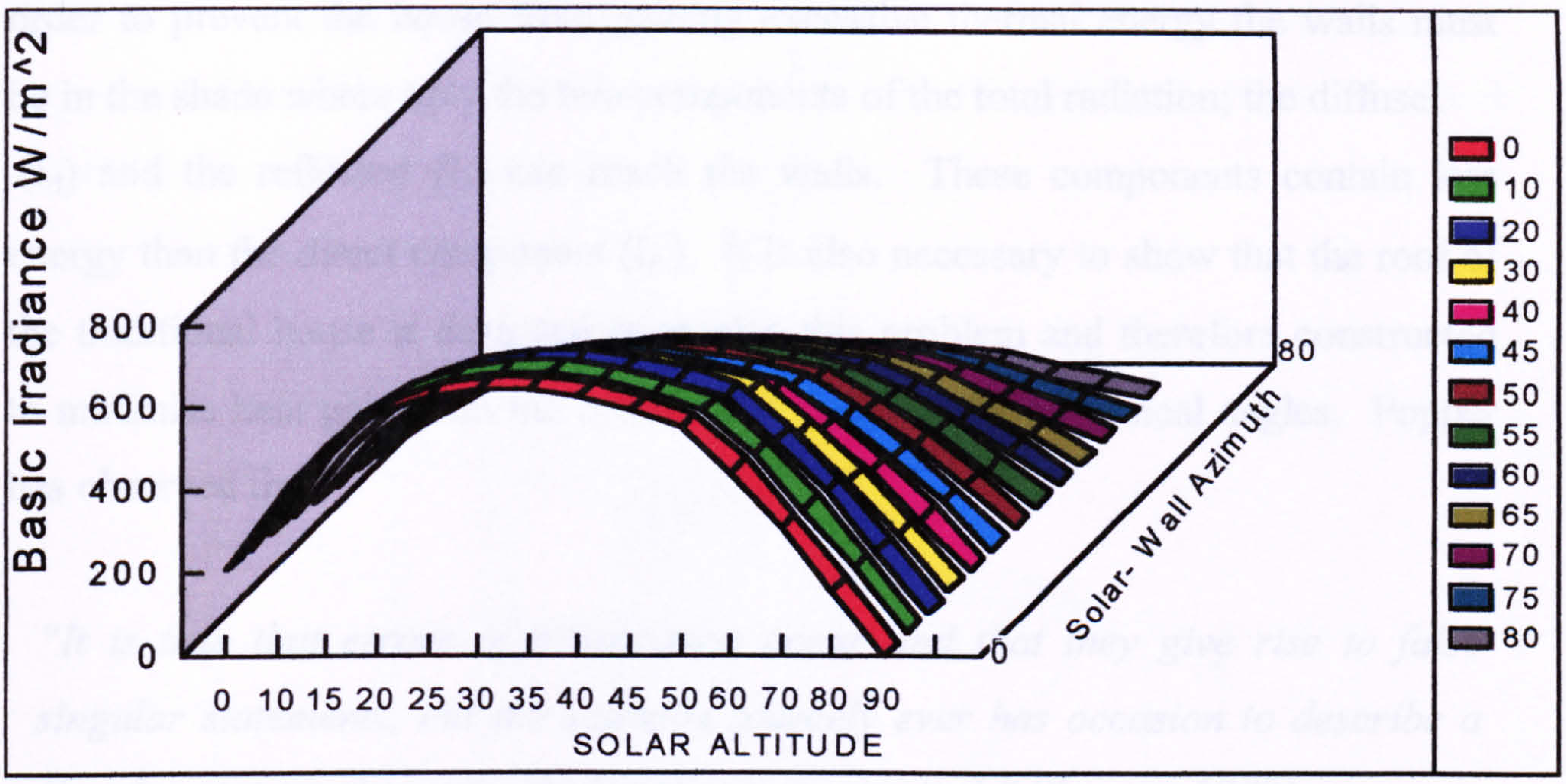

Fig. 6.6; **Variation of Incident Radiation on a Vertical Wall as Solar Elevation Changes Relative to Wall-Solar Azimuth Angles.**

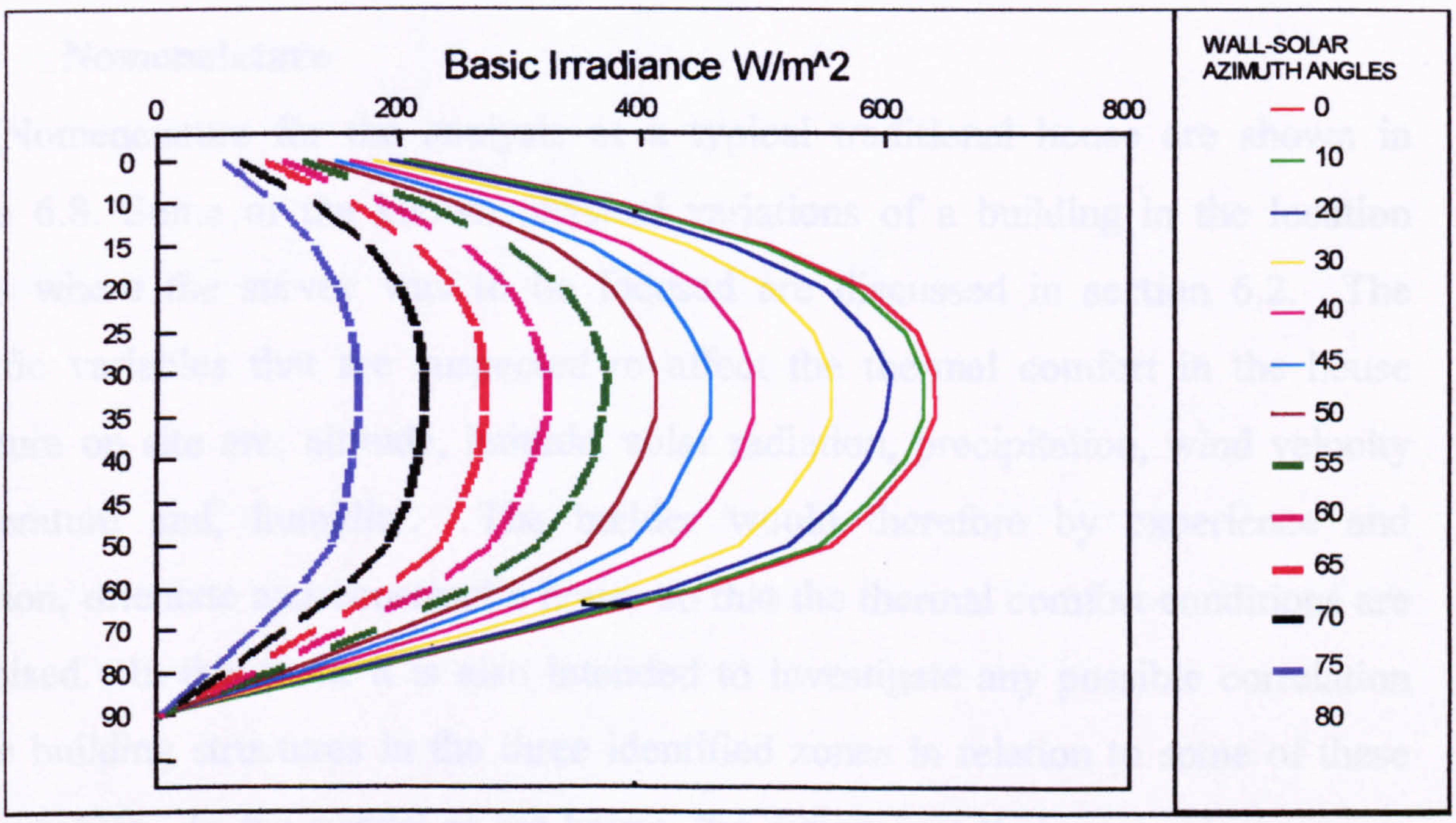

Fig.. 6.7 A 2D Presentation of the figure 6. 6 Showing Irradiance at given Solar Altitude Angles and Wall-Solar Azimuth Angles. (Data abstracted from CIBSE Guide Data applicable to the Lowland Areas at 0-300 m a.m.s.l.

Figure 6.6 shows that at any given Wall-Solar Azimuth angle the maximum irradiance bombarding the walls would be at a Solar Altitude angle of 35°. In order to prevent the house from gaining excessive thermal energy the walls must be in the shade where only the two components of the total radiation; the diffuse (I_d) and the reflected (I_r) can reach the walls. These components contain less energy than the direct component (I_t). It is also necessary to show that the roof of the traditional house is designed to resolve this problem and therefore constructed to minimise heat gain from the direct solar radiation at the critical angles. Popper has observed that;

> *"It is true that errors of observation occur and that they give rise to false singular statements, but the scientist scarcely ever has occasion to describe a singular statement as non-empirical or metaphysical* " (Popper; 1972).

6.5 DETAILED SURVEY OF SELECTED BUILDINGS

6.5.1 Nomenclature

The Nomenclature for the analysis of a typical traditional house are shown in figure 6.8. Some of the known physical variations of a building in the location zones where the survey was to be focused are discussed in section 6.2. The specific variables that are suspected to affect the thermal comfort in the house structure on site are; altitude, latitude, solar radiation, precipitation, wind velocity temperature and, humidity. The builder would therefore by experience and tradition, orientate and construct a house so that the thermal comfort conditions are optimised. In this work it is also intended to investigate any possible correlation of the building structures in the three identified zones in relation to some of these site variables. In the survey of the house, the dimensions that were selected were those that moderate the extreme effects of weather in the house.

One practical decision that was made right at the outset of the survey was to focus the investigations on external structures that would not require the surveyor to enter into a house in order to take the necessary data. This decision paid off in the sense that permission to enter the house was not necessary and that irrespective of whether the house owner was present or not the house data could be recorded. Figure 6.8 shows the variables that were measured. In addition to those described in table 6.4 where all the variables are described.

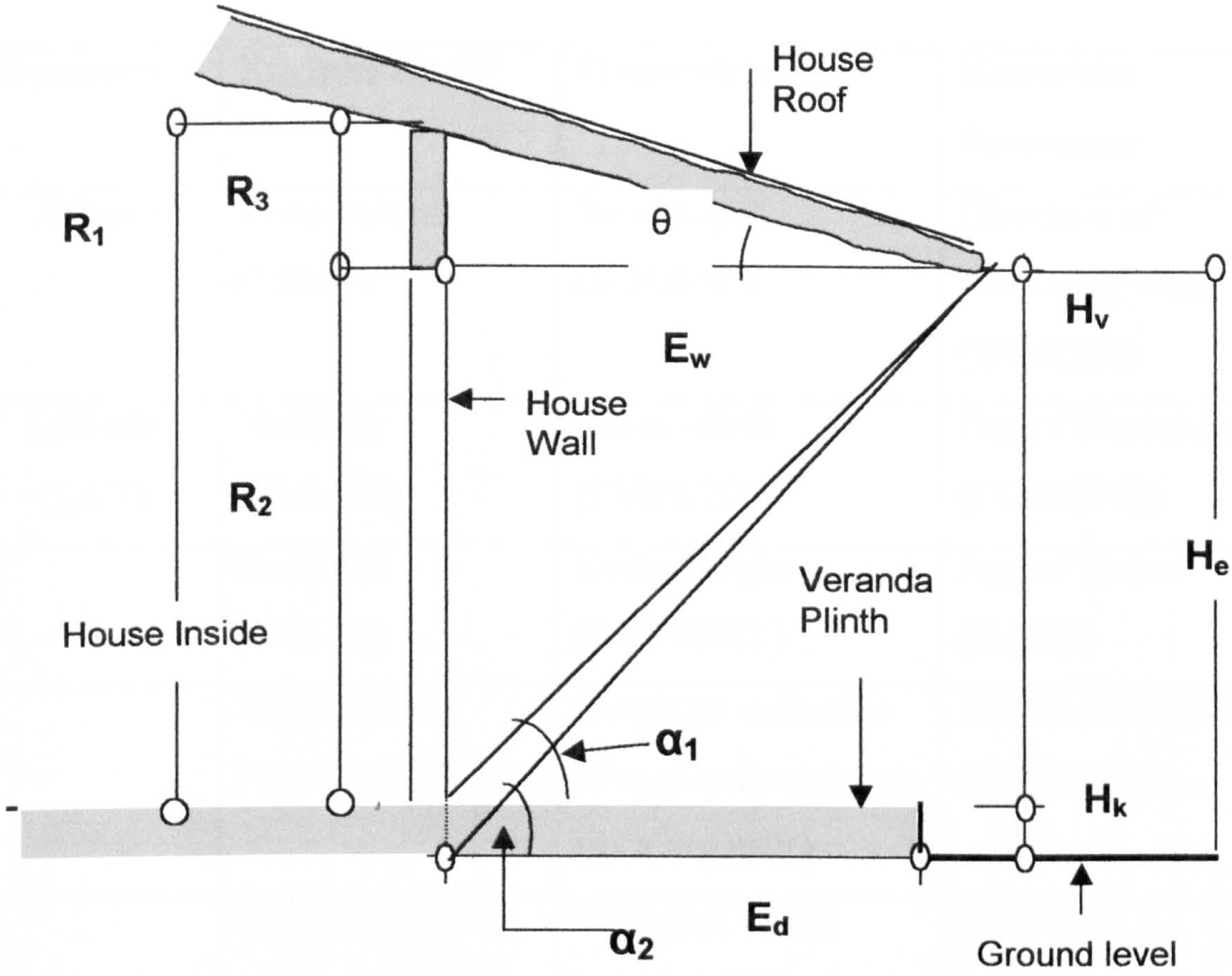

Fig 6.8; A Typical Section Of A House Showing The Wall Height (R_1) at the entrance, Eaves Width (E_W), Verandah Depth (E_d), The Roof Slope (θ), Eaves Height (H_e), and The Verandah Height (H_k)

Table 6.4 Selected House Parameters Were Suspected To Influence Thermal Comfort in a House. (These acronyms are in the analysis to correspond to the data labels in Appendix 6.1)

Terrestrial	**Environmental**	**House structure**	**House/site Parameter**
Altitude	Temperature (TEMP)	Roof slope (ROOFSL)	Direction of Prevailing Wind (WINDIR)
Latitude (LAT)	Humidity (HUMID)	Eaves width (EVSWID)	Door Orientation (DORIENT)
	Radiation (IRRAD)	Eaves Height (EAVESHT)	Age of House (HAGE)
	Wind velocity (WINDV)	Height to underside of roof at Door level (ROOFAPEX)	Roof thatch material (ROOFMAT)
	Rainfall (RAINF)	Verandah plinth height (HKG) House Floor Area (HA)	Roof type. (RTYPE)
		Depth of Verandah (VDEPTH)	

6.5.2 Basis for the Argument

In order to prevent the strong radiation bombarding the walls of a house, the roof must cut off its radiation at angle α. In this argument this angle will be designated the *Critical Solar Angle.* However, the roof has to be constructed at a slope θ that will have been determined by the builder's own judgement through knowledge. It is argued here that since there are no measuring instruments used in setting out of the roof and that the knowledge that the builder has, it is further assumed, is a direct function of the experience in the environment would be the leading determinant of the roof angle θ. Amongst the factors that have to be considered as the environmental experience, is the process of integrating all parameters that would be necessary to achieve a practical roof slope. In this process, the following would be included;

1. The need to cut off the solar irradiance at the *Critical Solar Angle;*.
2. The need to construct the roof at an angle that will maintain the grass on the roof without it sliding down under its own weight. In this case if the grass mass is M; it can be shown that the force $F_{1,}$ acting on the grass downwards; (using simple resolution of forces) would be;

$$F_1 = Mg \sin\theta \tag{6.5}$$

However, the downward force would be opposed by an equal and opposite force $F_{2;}$ acting in the same plane. Thus for the grass to stay on the roof, in the absence of any added forces, including cohesion; then a state of equilibrium would have to hold such that;

$$F_2 = Mg \sin\theta \tag{6.6}$$

Where F_2 would be equal to μMg and μ is the coefficient of friction of the glass on the roof purlins.

3. The need to have a roof slope that would facilitate a maximum water run off coefficient to minimize roof leakages.
4. The need to have a Verandah depth that would minimise the risk of catching a wind gust that would otherwise lift the roof off its anchors in the walls.

The data taken from the houses in the nine districts can reveal the validity of these suppositions. In all, nineteen variables have been included in the data tables in

Appendix 6.1. Plates 6.1-6.4 illustrate the point on how the problem of thermal comfort is dealt with in traditional house construction

Plate No 6.1 Gable roofed Houses At altitude 1149 a.m.s.l and location 13° 59’S and 33° 38’E.

(Lines are inserted to illustrate the angles of the roofs and the photographing camera here is located north of the village but slightly west).

Plate No.6.1 Shows a large village composed of mixed house styles but most of the gable roofed houses are orientated East-West with the roofs sloping at angle θ to cut off the strong solar radiation incident at critical angles such that angles subtended at 0900 hours $<\alpha<$ 1500 hours

Plate No 6.2 A Typical Village In A Valley In Ntcheu District At Altitude 1500 m.a.m.s.l. 14^0 35' S and 34^0 34'E.*(Note the house different sizes but obeying to the same rule).*

Plate No 6.3 A Typical Village In A Valley In Ntcheu District At Altitude 600 m.a.m.s.l at 15^0 10' S and 34^0 50'E .*(Note that all the walls are protected from the strong radiation).*

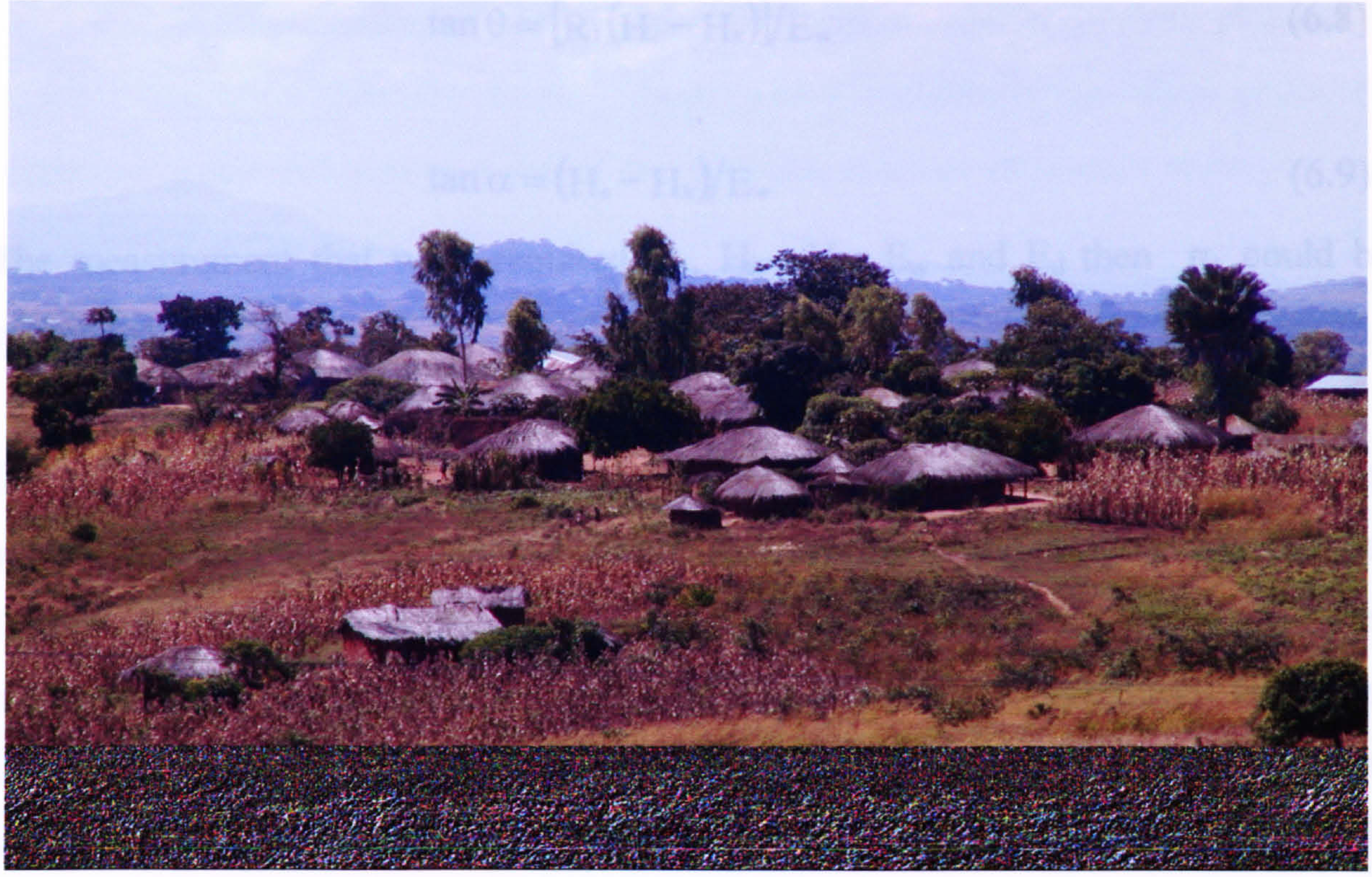

Plate No 6.4 A Typical Village On A Hill In A Valley In Mwanza District At Altitude 1550; at approximately 14° 35’ S and 34° 34’E

(Plates 1-4 illustrate typical villages with houses of different sizes. The differences may well reflect the status and financial ability of the respective owners. However, what is evident is that they all intuitively conform to a certain code of roof construction irrespective of the house plan and form. Note the strong shadow on a typical tropical sun day. House walls are all well protected from the direct sun by the suitable depths of eaves and the roof slope angles. The solar irradiance on this day was at 850 Wm^{-2}).

From a geometric point of view the important parameters in figure 6.8; are the roof slope θ the eaves width E_w, and the *Solar Critical Angle* θ . It has been described in section 6.10 that if the roof construction has not successfully achieve the angle α_1 in the post construction activity of the house; i.e. finishing floor and the verandah height $H_{k;}$ is constructed such that this error is corrected by reducing α_2 to α_1. Very simple relationships can be drawn from figure 6.8 to deduce angles α. and α as shown below.

$$\tan\theta = [R_l(H_e - H_k)]/E_w \tag{6.8}$$

$$\tan\alpha = (H_e - H_k)/E_w \tag{6.9}$$

The measurement that were required R_l, H_e , H_k E_w and E_d then α_l could be calculated

It must be noted that the roof apex was not measured due to the fact that the survey was designed to avoid entry into houses. However, from the relationships derived, the apices can be calculated since the width and length of each house were measured. For purposes of this work that calculation is not necessary. However, the measurement of the house height to underside of the house roof the door was very necessary since geometrically, the apex of every house is proportional to R_l and H_e

In this investigation it will be shown that there are indeed traditional techniques that have been established here and ensure that parameters R_l, H_e, E_w, α and θ are those that optimise the factors listed from 1-4 above. If these parameters have been found to be optimum in traditional practice then they must, without fail, be useful in modern architecture.

It is necessary to investigate how these measured parameters vary with the other physical and environmental parameters namely; latitude; altitude, radiation, ambient temperature, rainfall humidity, and wind velocity. Any correlation amongst these parameters would be useful to architects and engineers in the practice of designing structures in the built environment.

6.6 SELECTION OF DISTRICT AND AREA TO BE SURVEYED

It was imperative to make the house survey as inexpensive cost as possible. In order to cover all the typical zones it was further necessary to travel a distance of about one thousand kilometres from the northern end of the country 9° 20'S to 17°

10'S. It was also necessary to conduct each local survey in an area close to a weather station within the locality from where meteorological data could be extracted. Table 6.5 shows a list of the districts, number of houses surveyed and the selected environmental parameters. The most important point to note is the fact that these districts represented all the typical zones identified in section 4.2.1.

Table 6.5 Classification of the Selected Districts Surveyed and the Number of Houses in each District (N), and the Environmental Parameters

	District Name	Zone Type	Altitude m	Latitude °S	Radiation MJ m^{2}Day^{-1}	Rainfall mm	Wind Velocity ms^{-1}	Humidity %	Temp ^{o}C	N
1	Chitipa	High	1132	9.7	18.21	1039	6.3	71	26.1	48
2	Karonga	Low	529	9095	20.22	1165	3.8	72	29.3	45
3	Nkhata bay	Low	500	11.6	20.01	1695	3.0	72	27.8	18
4	Mzimba	High	1349	11.88	19.05	864	6.3	78	28.3	47
5	Mchinji	High	1200	13.6	19.10	1461	3.8	69	26.6	21
6	Mangochi	Low	482	14.48	20.51	824	3.8	66	29.9	28
7	Dedza	High	1632	14.32	19.46	904	4.5	71	22.2	20
8	Thyolo	Mid	820	16.15	21.47	1273	2.85	76	26.0	25
9	Chikwawa	Low	102	16.50	23.27	811	3.5	69	32.2	27

6.7 METHODOLOGY OF SURVEY

In order to eliminate some local influences on the orientation of a house the following criteria were taken into account in the survey.

6.4.1 -The house had to be away from a road to eliminate the possible influence of the road for the orientation of the entrance door

6.4.2 -The houses in the area had to be heterogeneous; namely that all the house types listed in table 6.6 had to be included.

Table 6.6 House Plan And Roof Types Of The Building Surveyed

House Type	Roof Type
Rectangular	Hip roof or Gable roof
Square	Gable roof or Hip roof
Round.	Round roof

For each location, the prevailing wind direction was recorded by observing the natural vegetation as described in section 5.4.6, and by interviewing the local residents.

To minimise intrusion into people's privacy and to make sure that even those houses whose occupants were not present at the time of the visit the structures to be measured were carefully chosen to give complete and meaningful results. The survey techniques had been perfected in the trial survey in section 6.2; and choice of house elements to be measured had also been made.

6.8 ANALYSIS OF THE FUNCTIONS OF THE HOUSE STRUCTURES

In the analysis the effort was directed at those structural elements that appeared to shield the house from the effect of extreme weather. In figure 6.8. the following elements were observed to have the assigned structural functions:

Depth of the Eaves (E_w)	Cuts off the direct radiation at the appropriate time and prevents the walls from gaining excessive heat.
Height of Eaves (H_e)	reduces the aperture of Verandah
Roof Slope Angle (θ)	Optimises the exclusion of the direct solar radiation during the year from winter to summer and from morning to afternoon.
Height of Verandah (H_k)	Modifies the height of eave to correct the verandah aperture to the optimum size.

The practical principle involved here is that if the strong irradiance starts at solar angle α_1 then this angle must just protect the wall in order to cut off the 60-80% of thermal energy. In this case the critical aperture is H_v. If the house is constructed with eaves height H_e; such that $H_e > H_v$ then there has to be a correction or a modifying structural feature that must; be used to correct this situation so that H_v is the suitable aperture at the critical angle. α_1. This structural element appears to be H_k which is the verandah plinth height. In the analysis it is necessary to prove that there is a correlation between the roof angle θ and correction feature H_k

From Field observation it seems that E_d is not important in the solar radiation exclusion argument. However, it is geometrically correct to conclude that the angle of slope θ defines the Verandah aperture R_2 such that H_v is always equal to R_2. Where this is not achieved during the construction of the house and that the critical solar angle is α_1 becomes α_2 such that $\alpha_2 > \alpha_1$ then intuitively the magnitude of H_k is determined to a level where the relationship represented in equation (6.9) should be maintained in order to have the correct aperture R_3.

For thermal comfort conditions to exist in the house, it is necessary to maximise the exclusion of the strong irradiance. However, since the solar angle varies from hour to hour in each day and from month to month in the course of the year it is suspected here that the roof angle chosen by the builder through experience is the optimum for all the critical days of the year.

6.9 CHOICE OF VARIABLES IN THE HOUSE SURVEY

In order to analyse the relatively large volume data from the nine selected districts, representing all the three zones, as listed in table 6.5; a correlation and significance levels analysis using Pearson's partial relationship was curried out. In the results significance values of $p \leq 0.045$ were regarded as acceptable. Those parameters that were found to have significant correlations were further tested using multi-regression analysis to deduce empirical equations of the relationship. Detailed figures showing all the parameters that are shown in the survey are in listed Appendix 6.1.

It was also decided to explore the distribution of preferred house dimensions in the selected districts. Since the length and width of each house were measured for rectangular and square houses, and diameters for round houses, it was decided to include in the analysis, a factor of the house plan area as an indirect function. It is felt that the area factor would be better than the actual linear dimensions from the survey. Thus there were three classes of variables that were identified; namely the physical, the environmental and the on-site parameters.

6.10 ANALYSIS OF RESULTS

6.10.1 Selected Analysis Techniques.

In order to derive practical information from the survey four statistical techniques were used. These techniques were;

1 Scatter grams;
2 Normal Distribution Histograms;
3 Multiple Regression Analysis; and
4 Pearson's Associations.

6.10.2 Pearson's Associations Test

For a quick review of the correlations amongst all the chosen parameters, the Pearson Association analysis was used and the complete results are shown in appendix 6.2. However, for detailed analysis it is necessary to show relationships that exist between the chosen structural features and the environmental parameters.

From the statistical relationships shown on table 6.7, empirical relationships can be deduced as follows;

1 $H_e = 0.27R_a$

2 $\theta = 0.26R_a - 0.28H_e$

3 $E_d = 0.10R_a + 0.30H_e - 0.19\theta$

4 $E_w = 0.38R_a + 0.11H_e - 0.14\theta + 0.37E_d$

5 $H_K = 0.005R_a + 0.37H_e - 0.04\theta + 0.28E_d - 0.01E_w$

6 $A\oint = 0.49R_a + 0.38H_e - 0.17\theta + 0.32E_d + 0.21E_w + 0.18H_k$

It is desired to accept a significance level of $p \leq 0.045$. In this case and after inspecting the correlations and their significance levels values in table 6.7, then only relationships 1,2 and 6 are acceptable and likely to give correct figures. These relationships may have occurred due to the type of building materials or the physiological dimensions of the occupants

Table 6.7 Correlations and Probabilities Amongst the Structural Elements (N=259)

	STATISTICAL PARAMETER	ROOF APEX ($R\alpha$)	EAVESHT (H_e)	ROOFS (θ)	VDEPTH (E_d)	EAVSWID (E_w)	HKG (H_k)
EAVESHT (H_e)							
	Corr	0.2666					
	p-value	0.0000					
ROOFSL (θ)							
	Corr	0.2553	-0.2839				
	P-value	0.0000	0.0000				
VDEPTH(E_d)							
	Corr	0.0994	0.2948	-0.1914			
	P-value	0.1106	0.0000	0.0020			
EAVESWID(E_w)							
	Corr	0.3787	0.1134	0.1393	0.3569		
	P-value	0.0000	0.0685	0.0250	0.0000		
HKG (H_k)							
	Corr	0.0047	0.3662	-0.0411	0.2811	-0.0117	
	P-value	0.9399	0.0000	0.5097	0.0000	0.8515	
HA ($A\oint$)							
	Corr	0.4883	0.3837	-0.1737	0.3179	0.2081	0.1810
	P-value	0.0000	0.0000	0.0051	0.0000	0.0008	0.0020

Table 6.8 Correlations and Probabilities Amongst the Physical and Environmental Parameters (N=281)

	Statistical Parameter	ALTIIT (H_L)	HUMID (H_m)	IRRAD (T_t)	RAINF (R_f)	LAT (L)	TEMP (t_a)
HUMID (H_m)	Corr	0.0527					
	P-value	0.3787					
IRRAD (I_t)	Corr	-0.6290	-0.3841				
	P-value	0.0000	0.0000				
RAINF (R_f)	Corr	-0.2116	0.8239	-0.1453			
	P-value	0.0004	0.0000	0.0148			
LAT (L)	Corr	-0.2291	-0.1430	-0.3397	-0.2683		
	P-value	0.0001	0.1065	0.0000	0.0000		
TEMP (t_a)	Corr	-0.8626	-0.3757	0.6476	0.344	0.1133	
	P-value	0.0000	0.0000	0.0000	0.5655	0.0578	
WINDV (V)	Corr	0.6611	-0.1935	-0.0072	-0.4396	-0.5260	-0.5189
	P-value	0.0000	0.0011	0.9041	0.0000	0.0000	0.0000

In this table 6.8 the relationships that have acceptable significance values; $p \leqslant 0.045$ are the following;

1 $I_t = -0.63 H_L - 0.38 H_m$

2 $R_r = 0.21 H_L + 0.82 H_m - 0.15 I_t$

This being an empirical relationship the units of the solar radiation in relationship 1 would be in $MJm^{-2}Day^{-1.}$

6.10.3 Distribution Of Structural Features From North To South

One of the easiest visual ways to show how these the differences of magnitudes of these are parameters are distributed from north to the south was to do the skew analysis (ς). These results are shown in figures 6.9-6.15. Table 6.9 shows the important descriptive statistics. These could be very important in drafting National Building Regulations for Malawi.

For practitioners in Malawi, the distribution of these structural features would be useful as guidelines in designing. These structural features may have empirically been designed to function and give optimum performance of the house..

Table 6.9 Descriptive Statistics Showing Technical Values That Could Be Considered In Drawing Up National Building Regulations

Parameter	EAVSWID (E_d) N=279	EAVESHT (H_e) N=281	HA (A_f) N=278	HKG (H_k) N=275	ROOFAPEX (R_a) N=281	VDEPTH (E_d) N=263	ROOFSL (θ) N=281
Mean	594	1916	21	251	2492	867	25.8
Median	500	1880	18	240	2370	850	26
Skew	0.8794	1.0493	1.5797	1.0052	0.6345	0.6306	0.0743

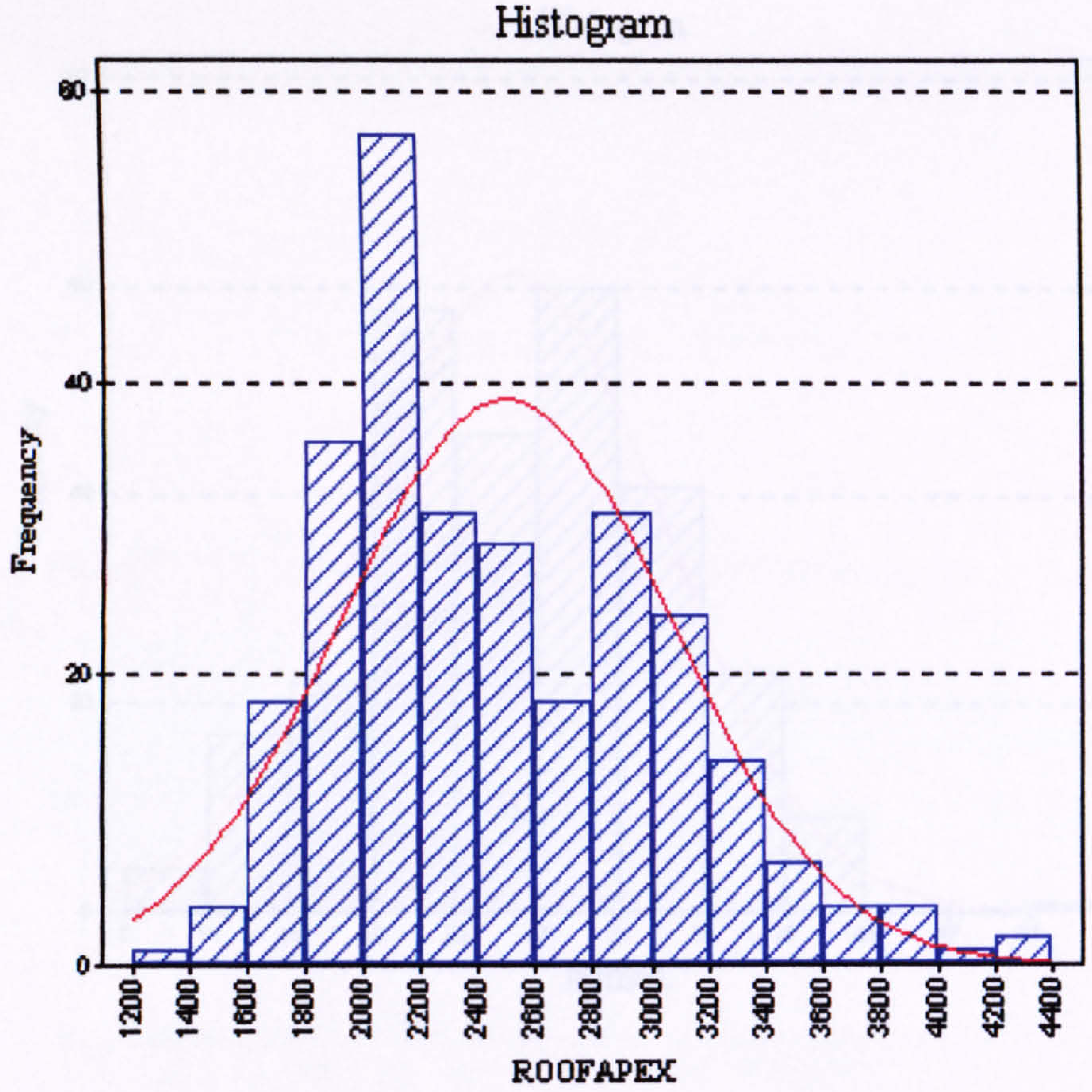

Fig. 6.9 Roof Apex ς =0.6345

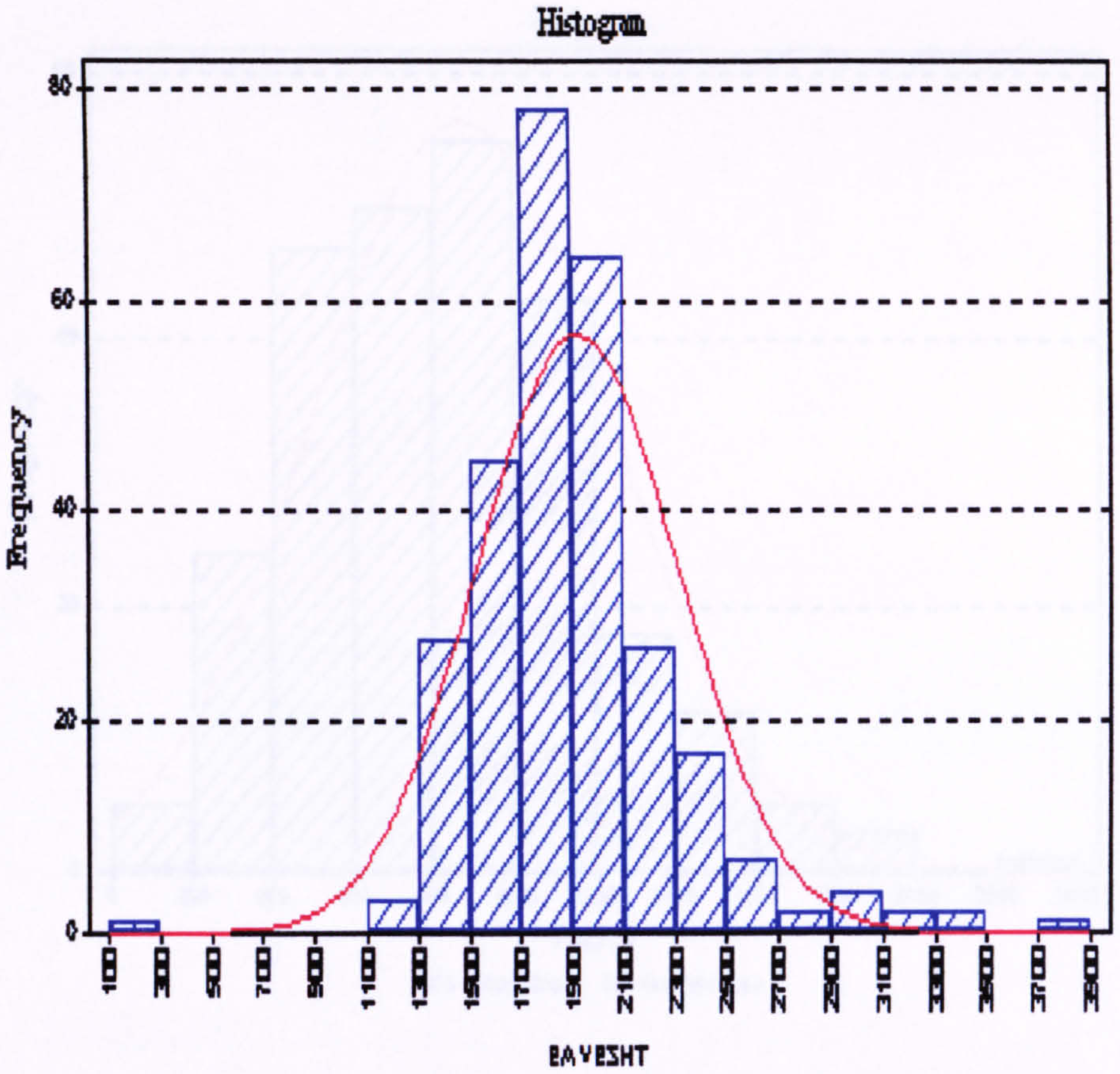

Fig. 6.10 Eaves Height Distribution ς =1.0493

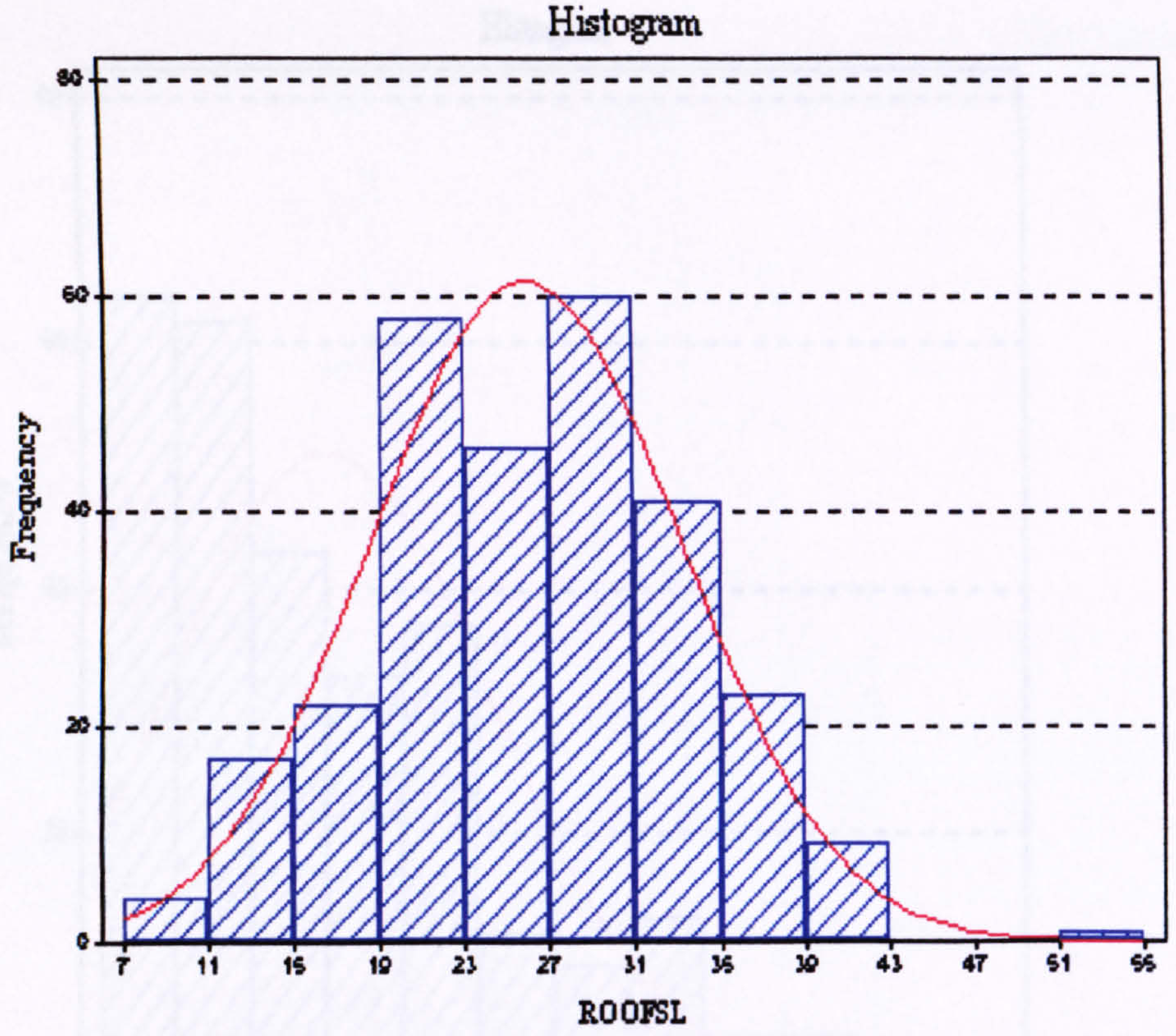

Fig. 6.11 Roof Slope Angle Distribution $\varsigma = 0.0743$

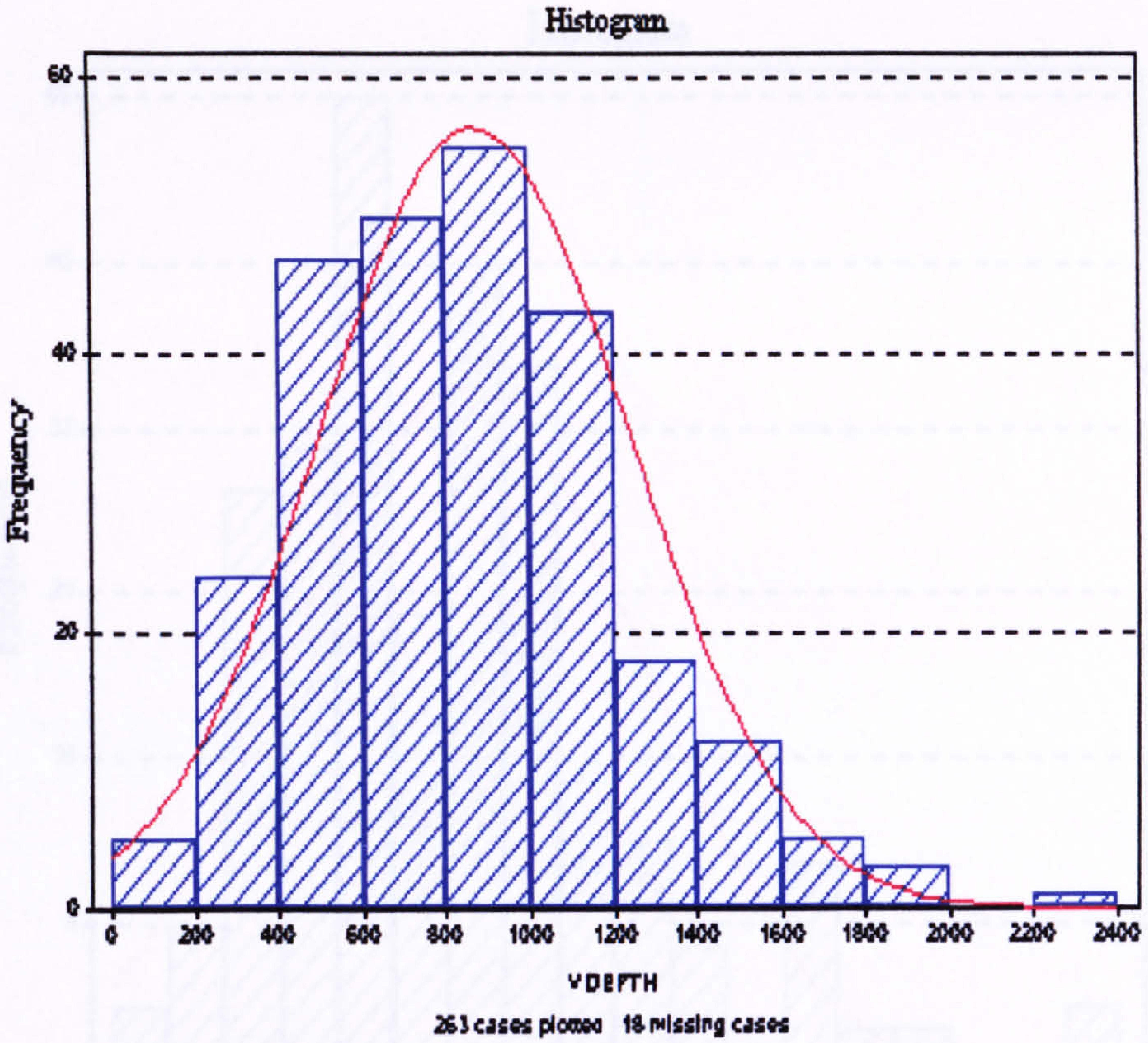

Fig. 6.12 Veranda Depth Distribution $\varsigma = 0.6306$

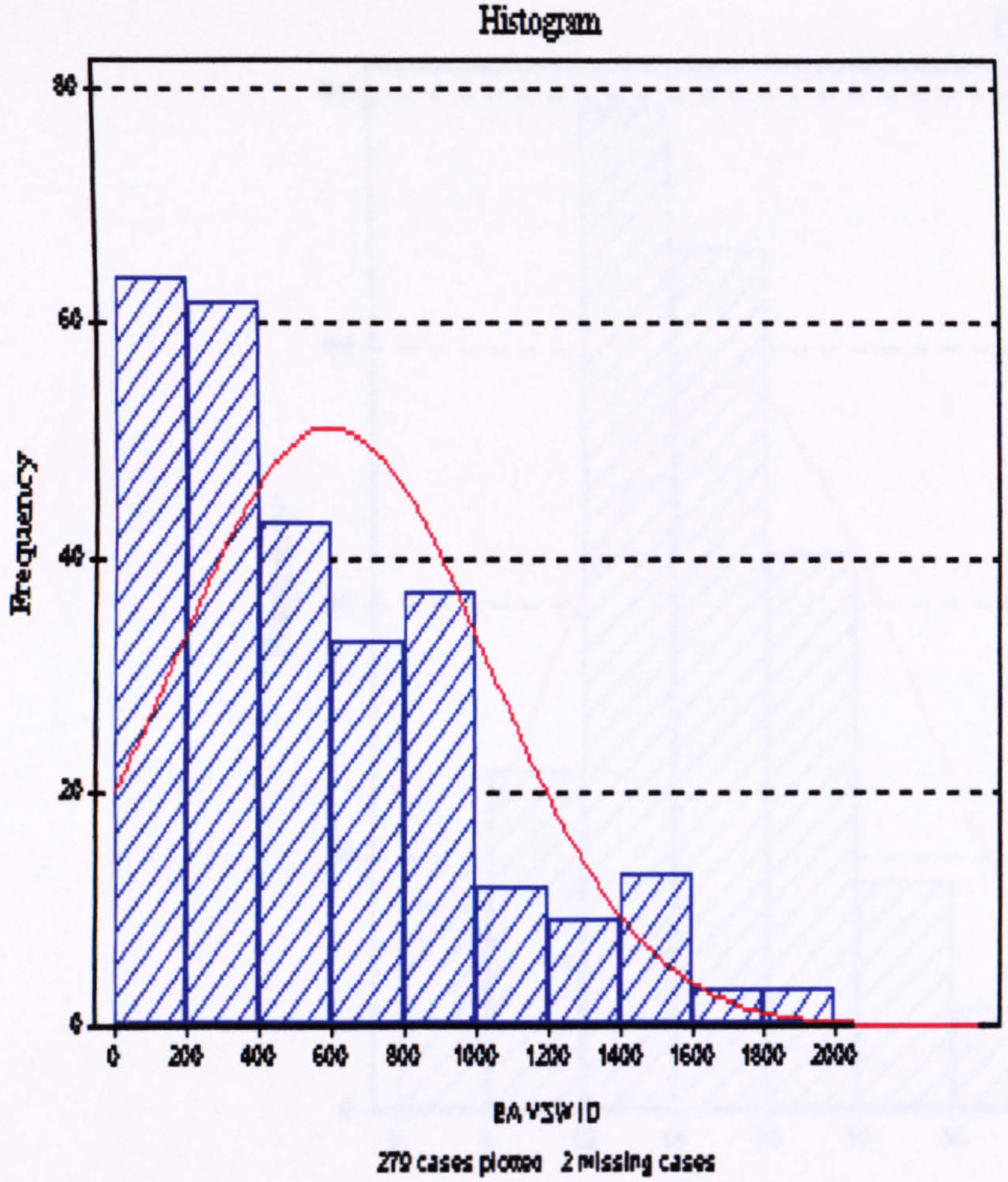

Fig. 6.13 Eaves Width Distribution ς =0.8794

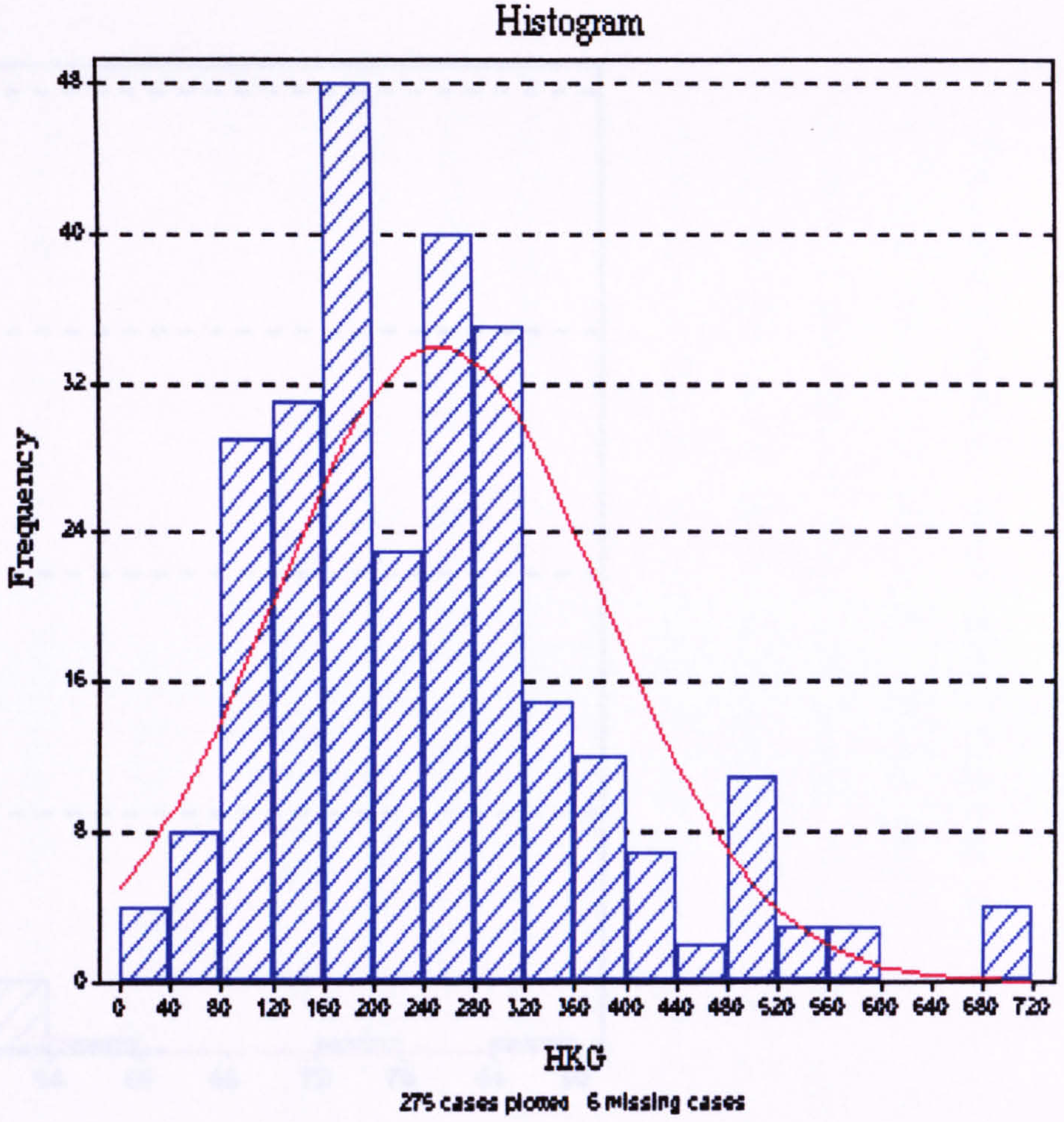

Fig. 6.14 Verandah plinth Height Distribution ς = 0.0052

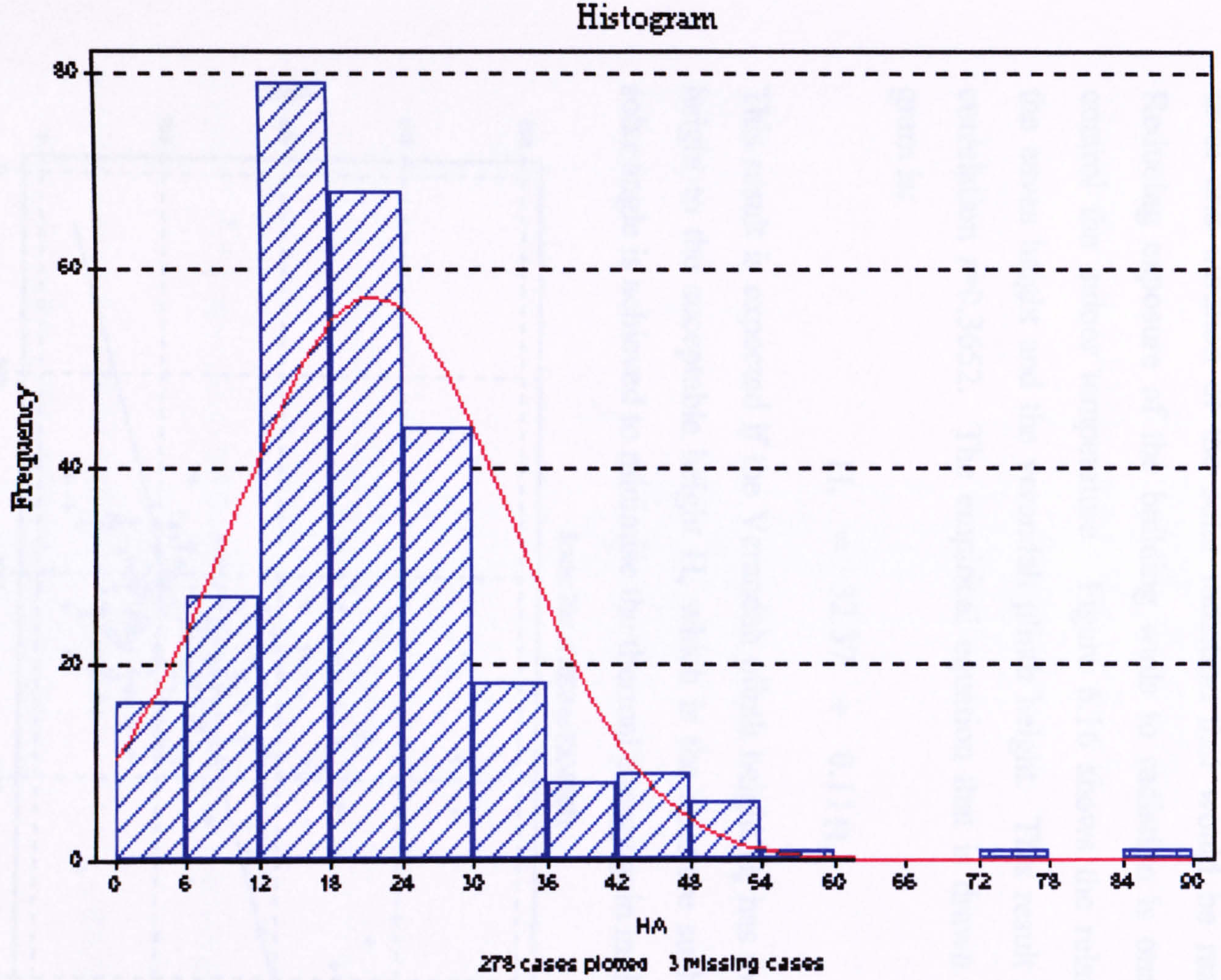

Fig 6.15 Plan Area Distribution $\varsigma = 1.5797$

6.11 VERANDAH PLINTH HEIGHT VERSUS EAVES HEIGHT.

There are a number observations that can be drawn from appendices 6.1 and 6.2 and tables 6.7 and 6.8. These graphs figures 6.16.and6.17 represent measured dimensions from 276 house. Using the least square method it is clear that the best constructed houses are those that fall on the line. One of the relationships that are of interest is that plinth height H_k and H_v determine the level and duration of the solar radiation that would be reaching the walls. Reducing exposure of the building walls to radiation is one of the ways to control the indoor temperature. Figure 6.16 shows the relationship between the eaves height and the verandah plinth height. This result has $p<0.045$ and correlation $r=0.3652$. The empirical equation that is drawn from this scatter gram is;

$$H_v = 32.37 + 0.11 H_k \qquad 6.10).$$

This result is expected if the Verandah plinth height H_k has to adjust the eaves height to the acceptable height H_v which is the aperture such that the critical solar angle is achieved to minimise the thermal energy gain in the house walls

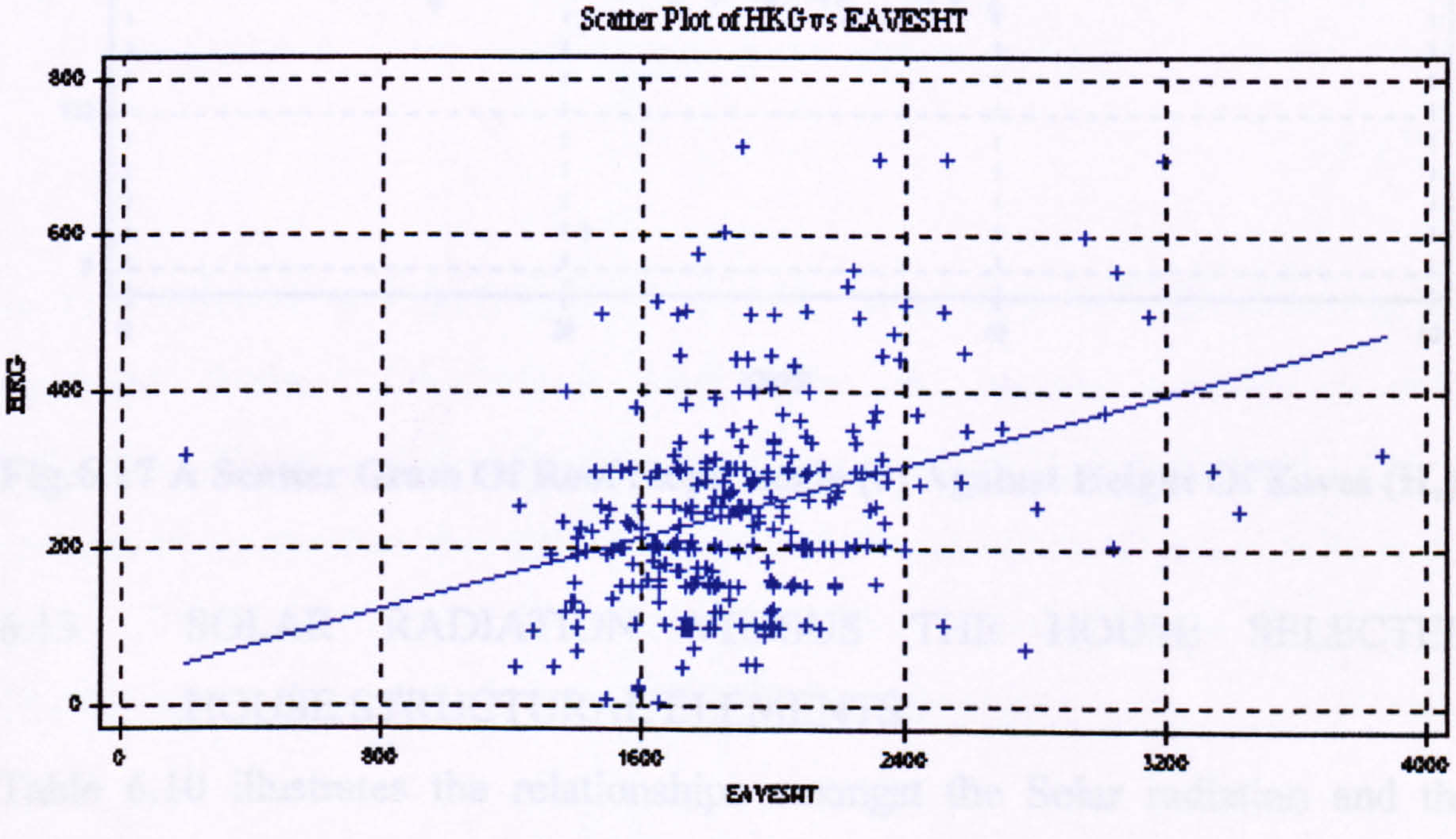

Fig.6.16 A Scatter Gram Of Eaves Height (H_v) Against Verandah Plinth Height (H_k)

6.12 HOUSE ROOF SLOPE VERSUS EAVES HEIGHT

Figure 6.17 Shows the relationship between the Roof slope and the eaves height. This is probably expected given the structural geometry. However, what is important to note here is the fact that figure 6.16 and 6.17 have an inverse relationship. The empirical equation that is drawn from this scatter gram is as follows;

$$\theta = 35.9170 - .00528\, H_k \qquad (6.11)$$

The values of $p<0.045$ and correlation $r = 0.2764$.

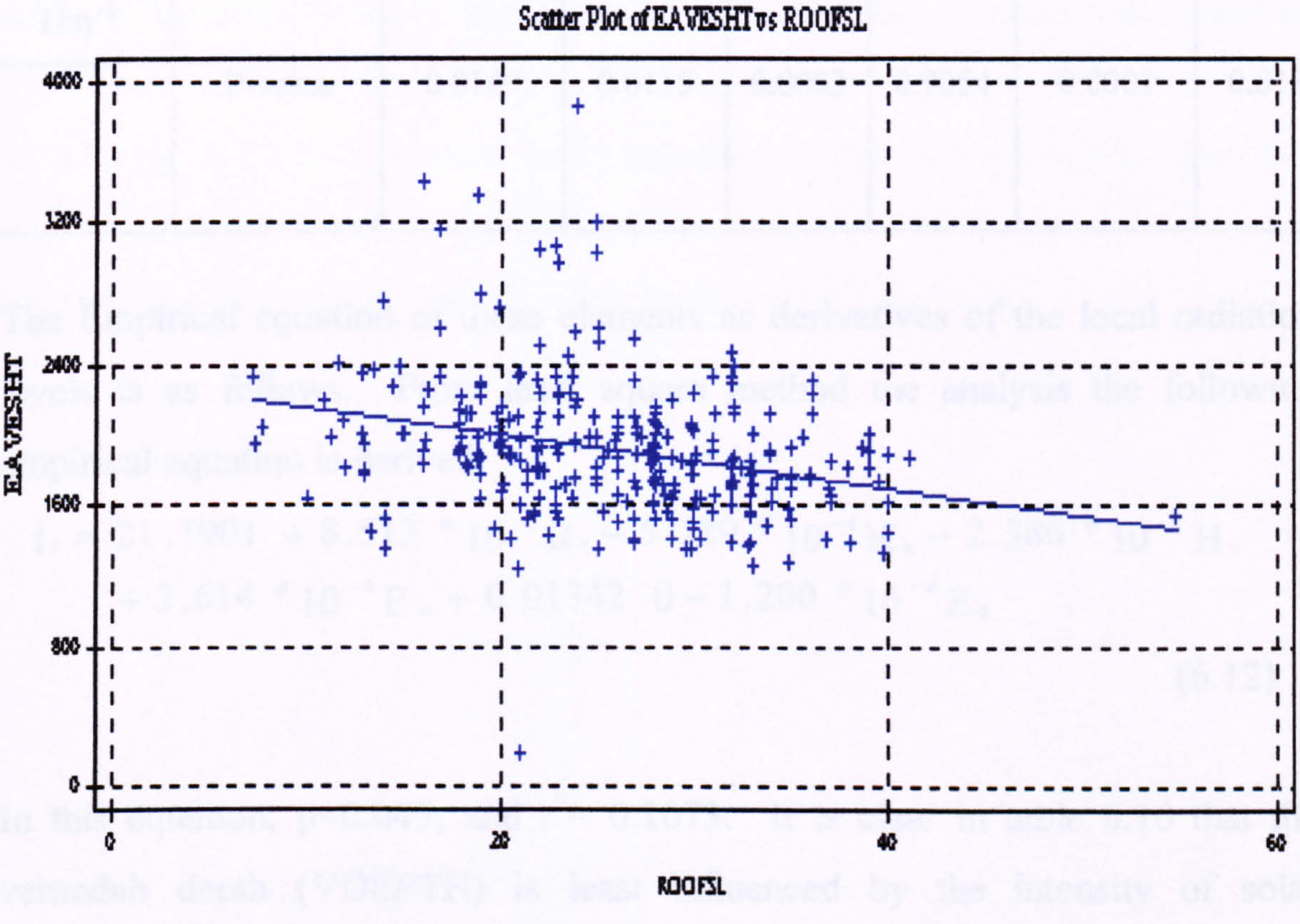

Fig.6.17 A Scatter Gram Of Roof Slope Angle (θ) Against Height Of Eaves (H_v)

6.13 SOLAR RADIATION VERSUS THE HOUSE SELECTED HOUSE STRUCTURAL ELEMENTS

Table 6.10 illustrates the relationships amongst the Solar radiation and the house structure features; Roof slope, Eaves height, Roof apex, Verandah depth, Eaves width and the verandah plinth height.

Table 6.10 Selected Statistical Relationships of Radiation and House Structural Elements (N=261)

		ROOFAPEX (R_l)mm	EAVESHT (H_e) mm	FOOFSL (θ)	VDEPTH (E_d)mm	EAVESWID (E_w)	HKG (H_k).
	Statistical Parameters						
IRRAD MJ m^{-2} Day^{-1}	Cor.	0.1506	0.1561	0.2203	-0.0074	0.2477	-0.1522
	P-value	0.0149	0.0115	0.0003	0.9054	0.0001	0.0138

The Empirical equation of these elements as derivatives of the local radiation levels is as follows. From least square method the analysis the following empirical equation is derived.

$$I_t = 21.1901 + 8.513 * 10^{-5} R_l - 5.189 * 10^{-4} H_k - 2.386 * 10^{-4} H_v + 3.614 * 10^{-4} E_w + 0.01342\ \theta - 1.200 * 10^{-6} E_d \qquad (6.12)$$

In this equation; $p<0.045$; and $r^2 = 0.1073$. It is clear in table 6.10 that the verandah depth (VDEPTH) is least influenced by the intensity of solar radiation. The probability for this parameter (VDEPTH) is $p=0.9045$. This is evidenced by the fact that the coefficient of this factor in equation 6.10 is the least. The most influential parameter to this equation is the Roof Slope (ROOFSL) and the weakest is the VDEPTH relationship.

Equation (6.12) establishes a relationship that exists amongst all the structural features and solar radiation. It is the roof slope that determines the eaves height and then aperture is modified by the plinth height wherever necessary. The subtle conclusion to note is that the solar radiation does not influence the depth of the Verandah. Indeed this should be the expected result. The verandah depth E_d is not necessarily equal to width of the eaves $E_{w.}$ It is also important to note that all other structural features except the verandah depth are intuitively determined by the builder as a direct function of his assessment of the severity of the solar radiation in the environment.

Tables 6.9 and 6.10; show that there are relationships that between the solar radiation and the structural features in the traditional houses. The intuitive skills of the local builders into their designs structural elements that moderate the effects of the environmental factors that promote thermal discomfort. This is a subtle point but provides basic information that is a knowledge gap that must be addressed and this area can be researched further for incorporating this knowledge in the modern construction technologies of houses.

CHAPTER 7

7.0 FINAL DISCUSSION, CONCLUSIONS, AND SUGGESTIONS FOR FUTURE WORK

7.1 DISCUSSION

Malawi is a country within the tropics and its climate can be described as Warm-Humid and Wet- Dry. However, some parts of the country are hot and have climate conditions almost similar to desert conditions in the dry season. Other parts of the country enjoy cool temperature climate that is prevalent in upland areas.

Where the ambient temperatures persistently approach and exceed the body temperature, problems of thermal discomfort are experienced. In this state the body experiences thermal stress and this stress can lead to mental incapacitation, onset of physiological disabilities and even death due to heart failure. This occurs because the body as an engine has to have a cold sink in order to dissipate the excess heat. In the absence of this heat sink, the body's systems efficiency drops to zero and in theory this means that the body is not working.

In this work it is discussed that thermal comfort is critical to creative thinking, maximum physiological output, and physical activity. These activities determine the productivity of a people in any country. The common solution to maintain thermal comfort in a liveable environment in modern times is to use air conditioning. Mechanical air conditioning is only accessible to a few financially able persons, and drains a country's wealth through importation of the cooling devices. This is the problem experienced in Malawi. However careful analysis of the environment and sensitive design to achieve natural cooling and environmental temperature within the thermal comfort range can be achieved.

Extensive research work as reviewed in literature in chapter 2 has shown that thermal comfort temperature is dependent on age, sex, culture, health, clothing level of humidity, local air velocity, ambient temperature and most important of all; levels of solar irradiance.

There is quite substantial evidence that to some extent the state of mind and expectation of persons affects their own degree of thermal comfort. This phenomenon is more related to times of the day and seasonal changes. This phenomenon is designated as *anticipation*.

Thermal comfort is a complex subject that can be defined by using both subjective and objective scale indices. The simplest and most reliable although not very accurate indicator of thermal discomfort is air temperature. For practical purposes and for use at the design stage the annual mean maximum temperature is a useful index in order to avoid over or under assessment..

There are known upper limits of temperatures beyond which the body suffers permanent physiological damage. There are also no irreversible physiological damages that the body suffers from short period exposure to temperatures below the lower comfort limit compared to the risk of exposure for similar periods at the higher temperatures beyond the upper of the thermal comfort limit. The literature survey has shown that the worldwide temperature range for thermal comfort is from 11^0C to 35^0C.

Clothing, humidity, and air velocity play very important roles in moderating the degree of discomfort in environments where temperatures are outside the neutral temperature range of 22- 26^0C. The most common neutral temperature zone extends from 18^0C to 26^0C, where in a vote count, 80% - 100% of the respondents in a given survey would feel comfortable. Rigorous analysis of the data that has been published indicates that the median of the neutral zone is 24^0C. Research conducted in Zambia shows that the neutral temperature fits in within 2^0C on either side of 24^0C· In a survey of preferred shower bath temperatures in Malawi the mid point of the neutral temperature was found to be 24.6^0C. By assigning a range to this point of 2^0C on either side of the mid point the neutral zone for Malawi is approximated to $22\text{-}27^0$C. In this work, 22 – 27^0C is established as the neutral temperature zone for Malawi, which is in close agreement with the ISO 7730 Standard. If a design is based on ISO 7730 the effect would be to over design the air conditioning device and this would be a waste of scarce resources of a nation. The recommendation from this work is that Malawi should adopt this range as the neutral temperature range in order to avoid over designing air conditioning equipment. It must be noted that if the ISO recommendation of a range of PMV as $-0.5<\text{PMV}< +0.5$ were to be taken, then the neutral range for Malawi would be 24.1°C –25.1°C. On the other hand Fanger (Fanger;1988) recommends a comfort range of 20 - 24°C in winter and 23 - 26°C in summer corresponding to **Clo** values of between 1 and 0.5 respectively. Malawi is a tropical country where temperature ranges are as shown on Appendix 4.5. Since acclimatisation in thermal comfort is also important, then the proposed neutral range here is correct as an annual range. From observations the most popular and common clothing in Malawi corresponds to the pictorial designation suggested by Fanger which is between **Clo** 0.3 and Clo 1.0.

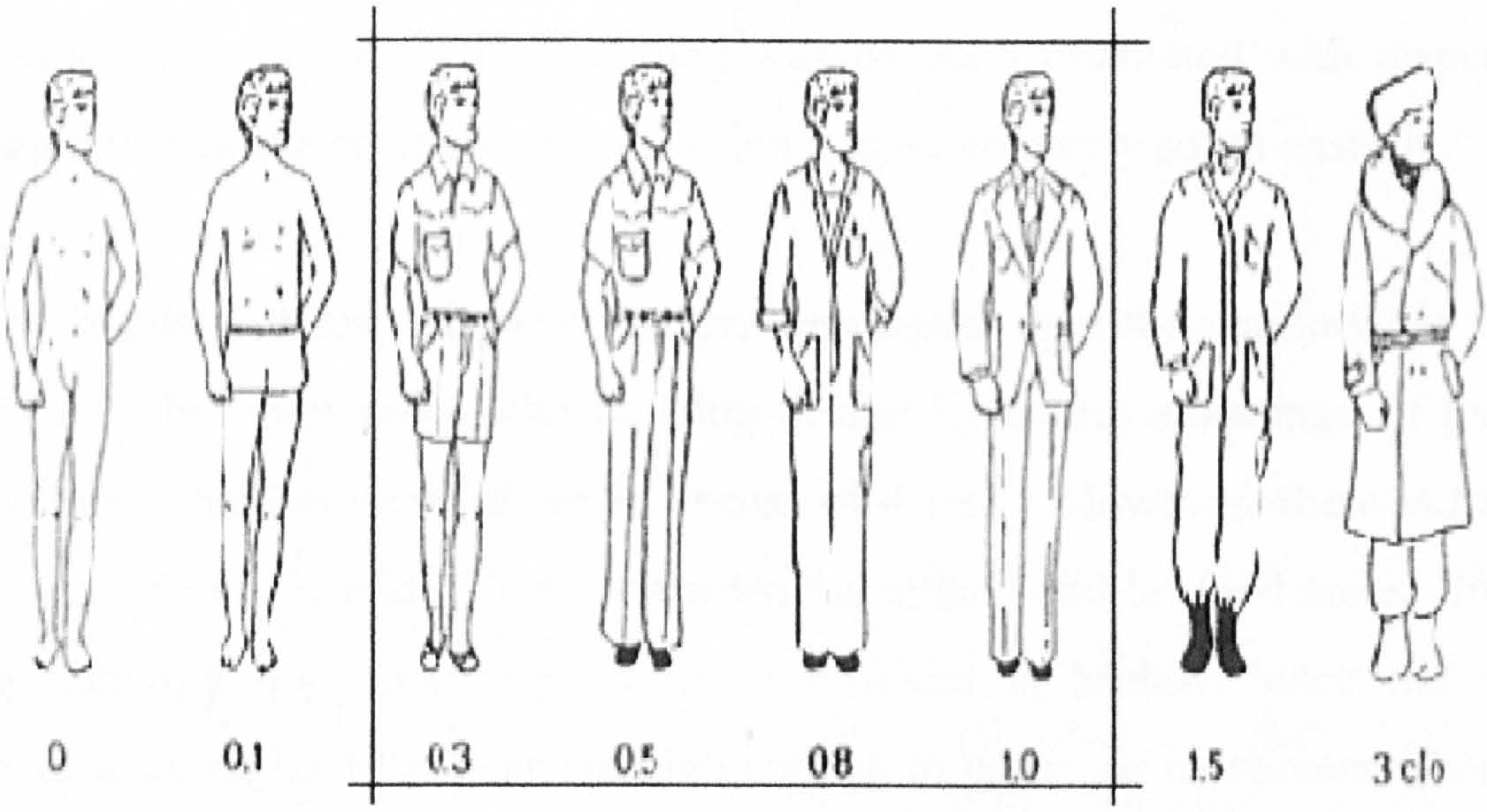

Fig 7.1 **Fanger's Method for classifying the Severity of Clo values (After Fanger1998). Boxed area matches with common clothing practice in Malawi**

For Malawi the problem of thermal discomfort should mainly concentrate on the reduction of room temperature as illustrated in the short study of the three houses in Ekwendeni, and the survey of daily and annual mean-maximum temperatures. This is the area where costs are unnecessarily being incurred by procuring air conditioning equipment that is otherwise not necessary if thorough environmental analyses are carried out at the design stage to allow the incorporation of passive design. Wherever nothing is done about the thermal discomfort, the human physiological output will inevitably be low. The latter is subtle and would manifest itself in low productivity and creativity of the people; as discussed at the end of chapter six, although the people themselves would generally not be aware of this fact.

The solar radiation pattern in Malawi reflects the diverse physical features of the country. Radiation is higher in the low altitude areas than on the high altitude areas. On the other hand, wind velocities are higher on the high altitude areas than in low altitude areas. However, the wind velocities in the low altitude areas are high enough to allow the required minimum indoor wind velocities to be achieved if a building was properly orientated with respect to the direction of the prevailing wind, which is predominantly south-easterly.

In the highland areas, temperatures that are higher than the comfortable range can easily be corrected in the building design by taking advantage of the air velocities, which are sometimes in excess of 4 ms^{-1}. However, there is hardly any difference in humidity levels between the upland and lowland areas. In any case humidity does not seem to be a problem in Malawi since the wind velocities throughout the year are high enough to cause air movement when the humidity levels are high. Humidity above 85% would only be a problem if the wind velocities were to remain below $0.1ms^{-1}$. This is indeed not the situation in Malawi.

Detailed analysis shows that the country can be divided into three zones namely; High altitude areas are over 1000 m.a.m.s.l. Mid altitude areas are 800-1000 m.a.m.s.l., and Low altitude areas are 52-800 m.a.m.s.l. The lowest habitable area with a meteorological station is Ngabu in the extreme south of Malawi where the altitude is 52 m.a.m.s.l.

The air temperature varies inversely with the altitude. The radiation in the low altitude areas can be as high as 21.7 MJ m^{-2} Day $^{-1.}$ The peak irradiance can be as high as 940 Wm^{-2} while the lowest irradiance during the day can be as low as $60Wm^{-2}$ When there are low rain clouds.

The analysis has confirmed that temperatures in the low altitude areas are outside the thermal comfort range in the warm and dry season. Although the analyses of meteorological data show that the air temperature in the cold season, in the high altitude areas can fall below the comfortable range, the field observations have shown that at these low temperatures people don't seem to exhibit desperate signs of discomfort. It is a common observation that when temperatures fall below the comfortable limit people put on clothes of high **Clo** values. This is a simpler solution to restore thermal comfort. However, this simple solution is only possible and convenient at the lower temperature limits. At the upper end of the thermal comfort temperatures limit it is not as simple and convenient to apply a solution

The analysis of the building dimensions surveyed in nine carefully selected representative districts from north to south of Malawi show that there are very important structural elements incorporated in the houses that are intuitively designed to promote thermal comfort. The survey has also shown that these structural elements are related to the terrestrial and environmental factors of latitude, altitude, temperature, humidity, wind velocity, precipitation and solar radiation. There appears to be appreciable differences in these relationships amongst the nine districts. The survey that has been carried out in the nine representative districts has yielded useful information. However, the differences that have been observed trigger further interesting questions on how the problem of thermal discomfort has been dealt in the traditional construction techniques.

The hypothesis that was tested was whether there would be some structural elements in traditional buildings that are intuitively designed to maximise thermal comfort in the environment. The hypothesis suggests that indeed there may be structural features that are intuitively designed to promote thermal comfort. The most important result is that both architects and engineers can learn a lot from adopting the concepts used in the traditional construction techniques. These traditional construction techniques are based on intuition or experience but can be traced to verifiable scientifically principles.

7.2 CONCLUSIONS

Malawi as a country, especially the low altitude areas, can have high temperatures and for the sake of good health, high productivity, and to save the little foreign exchange that is spent to import air conditioning devices it is necessary that thermal comfort through passive design be maintained in the liveable areas. Maintaining the thermal comfort through mechanical ventilation is not always necessary when a careful study of the meteorological data of the area is carefully studied. An Assessment of the severity of thermal discomfort of any given location can be worked out by using the Degree.Day formula.

However, it is possible that by adopting the traditional methods of reducing temperatures, thermal comfort can be achieved in most buildings in low altitude areas.

In this study the following summaries and conclusions are definitely important in considering thermal comfort.

1 **Factors that Affect Thermal Comfort in a Person**

The problem of thermal comfort is a complex one but it has identifiable factors. These factors define how early and severe the thermal comfort can be experienced by any individual. These are sex, age, health condition, psychological condition, body activity state, culture, state of acclimatisation, and anticipation

2 **Range and Zone of Thermal comfort**

While the thermal comfort range worldwide is 11-33°C and the .neutral zone for thermal comfort is 18-26°C' the neutral temperature zone in Malawi is 22-27°C.

3 Temperature Zones in Malawi

There are indices for thermal comfort and the most commonly used index is body temperatures. In Malawi mean air temperatures can be as high as 40°C and as low as 0°C. The air temperature varies inversely with the altitude. Thermal comfort is affected by temperature, humidity and wind velocity. The country can be classified into three zones with respect to altitude in order to deal with the problem of thermal comfort in a rational manner. These zones are;

The high altitude zone $A_L \leq 1000$ m.a.m.s.l
The mid altitude zone $800 < A_L < 1000$ m.a.m.s.l
The low altitude zone $A_L \geq 48$ m.a.m.s.l

These zones have definite climatic differences. Using the results in this work it is now possible to calculate radiation of a location using the terrestrial and environmental parameters. Solar Radiation can also be calculated using the structural elements of traditional buildings as shown in this work.; equation (6.10) repeated below which when rationalised further can be approximated to

4 Levels of Solar Radiation in Malawi

Astronomically the solar radiation in Malawi should have equal peaks in September and March. However, the March peak is lower than the September peak due to high levels of humidity. The available solar radiation data in Malawi has been measured using two different instruments but the results from these instruments are in close agreement. These data are still reliable to be used to assess an environment

Field observations have shown that people basking in the morning sunshine will chose to sit in sunshade at irradiance levels of between 400-600 Wm^{-2}. At irradiance intensities of higher than 600 Wm^{-2} people will certainly sit in the shade

The high thermal gain; 60-80% that occurs through the building walls has been minimised in traditional buildings by the Verandah. Therefore, the problem of thermal comfort in a building can be minimised by keeping out the direct radiation from bombarding the walls.

5 Traditional Techniques That Minimise Thermal Discomfort

Field observations suggest that the thatched roof has better insulation properties than the corrugated iron roof or the concrete tile roof. A survey of houses in nine districts has shown that the indoor temperatures can be reduced if the solar radiation is cut off. In traditional buildings this has been achieved by.

Varying the roof slope angle;
Reducing the house height; and
Maintaining the verandah aperture at a level where the solar – verandah critical angle will be achieved. The veranda plinth height is the device that has been used to achieve a correction if the aperture is outside the acceptable range.

There are some correlations between the house structural elements and local solar radiation levels. Those that have high correlations are the following:

Roof slope
Height of Eaves
Veranda plinth height

These three parameters vary with latitude and altitude. This means that for solar heat gain control, sensitive designs must take into account the latitude and altitude of the location in order to specify the correct roof height and verandah plinth wherever practicable.

6 Tentative Recommendations To Augment The National Building Regulations In Malawi.

In this study it has been shown that in Malawi the thermal conditions especially in the low altitude areas are not optimum for the body to work at its best output levels. The factors that affect thermal comfort are listed and levels of these in different locations in Malawi have been discussed. By analysing the traditional techniques of building construction, structural elements that reduce thermal gain in a building have been identified. The recommendations below are made in the interest of economy of resources, the health, and productivity of the people. Air conditioning should be used as a last resort when and where conditions are extreme and cannot be termed by passive design. The air conditioning solution would vary and should be a function of the house design and shape (Spencer and Anson 1973)

In order to achieve Thermal Comfort Conditions it is recommended that the following design procedures be followed;

1. A map showing contours of a site must always be used at the stage of site investigation. The designer would be able to extract the altitude and latitude of the location from the map.

2. Meteorological data from the nearest agricultural or meteorological; station should be used to derive solar radiation of the location after standardising the data by using equation (4.1). From this exercise the severity of thermal discomfort can be assessed.

3. The direction of prevailing wind should be determined by inspection of a wind Rose Map or by observing the natural vegetation.

4. In the absence of a pyranometer solar radiation levels should be calculated using equation 6.10 as long as those environmental factors are recorded in the locality.

5. Wherever roofing materials are used other than metal the minimum roof slope angle should be 26°. This angle is optimised for the effects of radiation, prevention of roof leakage and minimisation of the roof being blown off the building.

6. In order to maintain minimum solar heat gain in single storey houses, the minimum width of the roof eaves should be 600 mm to cut the strong solar radiation at 0900 and before 1500 hours during the months of August to November when the radiation in Malawi is highest. In order to make sure that the building walls are in shade between 0900 and 1500 hours the local solar critical angle must be calculated and the eaves designed accordingly.

7. If the project funds permit to pay for air conditioning equipment this should be designed to achieve a neutral temperature of 22-27°C.

8. From the empirical analyses of the field data and in order to minimise the negative effects of weather and optimise thermal comfort in single storey buildings, the dimensions listed in table 7 should be adopted minima as abstracted from the mean values in table 6.9.

9 The minimum ceiling height at places of work as specified in the *Public Health Act; Cap. 34.0.,Occupation Health and Safety at Work Act, 1977;* in the Laws of Malawi should be reviewed to take into consideration of functional issues of ceiling height.

Table 7.1 Recommended Minimum Structural Elements For Single Storey Houses For Malawi.

Parameter	Eaves width	Eaves height from ground	Floor area of a house	Height of veranda h from ground5	Height of wall plate at door position	Depth of Verandah	Slope of roof
Mean mm	600 mm	1900 mm	21 m^{-2}	250 mm	2500 mm	900 mm	26^{o}

7.3 SUGGSTIONS FOR FUTURE EXTENSION OF THIS WORK

The importance of thermal comfort and its effect on health have been outlined in this work. Air conditioning devices are not the only way to effect thermal comfort. However, the solution to this problem does not only lie in the use of air conditioning devices. It is argued that if anything the consideration for use of air conditioning must be done as a last option. To many the use of air conditioning devices is a necessity and not a luxury. This is only in the absence of professional advice that can permeate through the building regulations to emphasize that the process of designing of habitable buildings must be a thorough procedure that should include rigorous justification.

One of the areas that will need detailed countrywide analysis is the question of the risk assessment of damage to health. The Degree Day procedure must be assessed in detail to find exactly the excess temperature in each zone. This may mean holding discussions with the meteorological authorities and requesting them to extend/modify or refine some parameters in the data collection system and network.

For thermal risk assessment it is proposed here that the mean maximum temperatures should be used. A detailed frequency analysis on how often and for how long do these occur should be done.

Some of the public buildings such as hospitals and schools have to be examined under the criteria of Thermal Comfort. It is possible that there may be unnecessarily suffering that occurs and causes thermal stress especially in infants and elderly people. The question of academic performance in schools must also be raised. If the temperatures that have been discussed and their effects are to be upheld then there has to be certain rules and regulations in schools that will ensure that pupils and students are not subjected to temperatures where the thermal comfort will compromise their academic performance. One of the obvious research areas on this matter is to conduct a thorough academic performance of pupils in all the three zones.

The other areas to investigate would be to extend the meteorological data base, to study properties of modern materials that respond to solar radiation such as characteristics of glass and its response to the whole of the solar spectrum and develop solutions to the problem of thermal comfort. The ultimate aim of the further investigation would be to understand the built environment and use inexpensive techniques to achieve thermal comfort in buildings and minimise the importation of the air conditioning devices. The statutory law that governs the health of workers at their places of work can continue to be updated in the light of new information.

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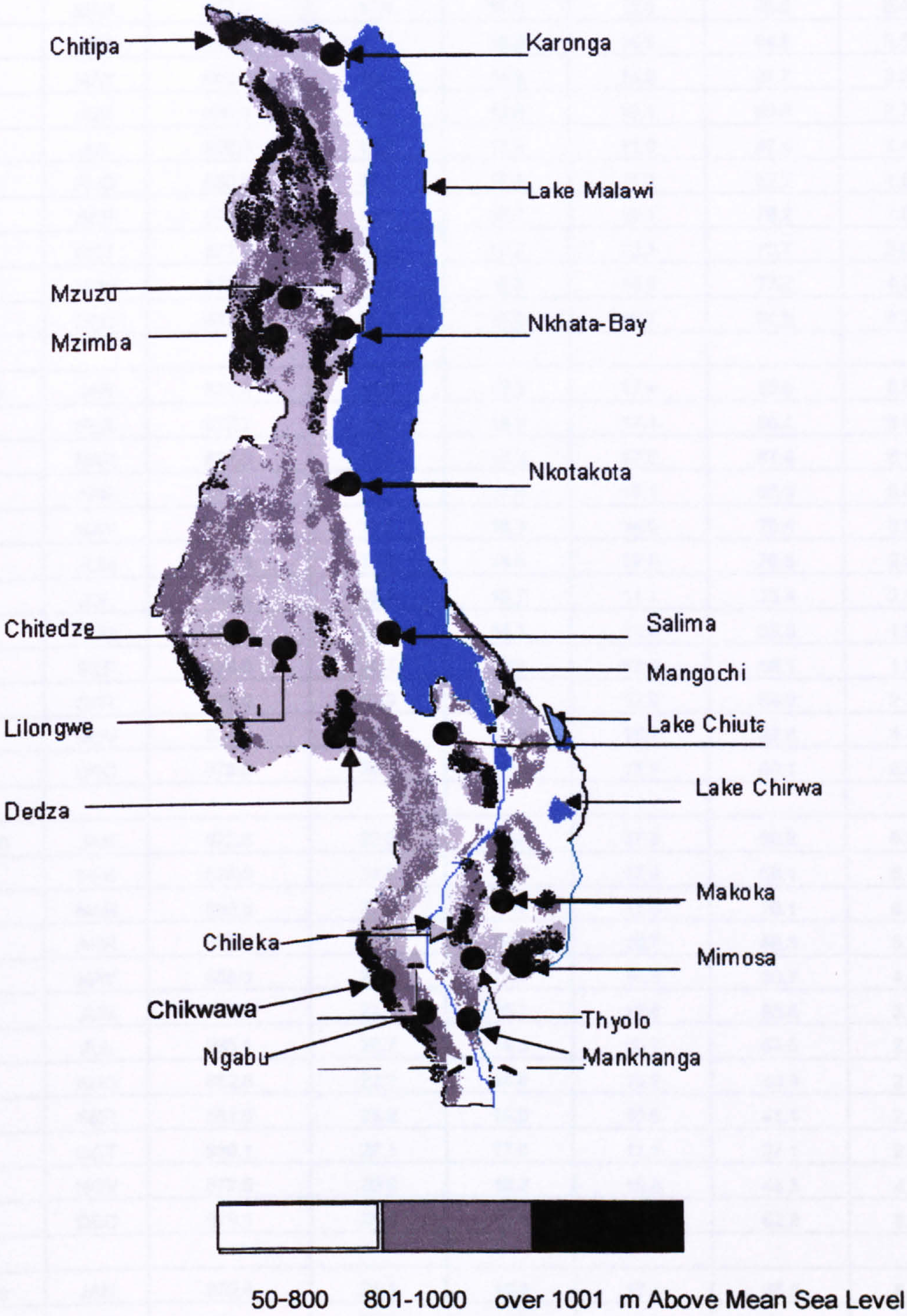
APPENDICES

Appendix 1.1. Map of Physical Features of Malawi



APPENDIX 4.1 MONTHLY MEAN TEMPERATURES AT FIXED HOURS

STATION NAME:	CHITIPA	STATION NUMBER:	421	Latitude /Longitude	9° 42'S 33° 16'E	Altitude	1285m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	872.6	17.7	17.1	16.7	94.9	6.6	1.6
	FEB	876.4	17.6	17.0	16.7	95.6	6.8	1.6
	MAR	877.1	17.4	17.0	16.8	95.6	6.4	2.3
	APR	882.2	17.4	16.8	16.5	94.8	5.6	3.8
	MAY	883.7	15.7	14.8	14.2	91.7	3.5	3.8
	JUN	880.4	13.8	12.8	12.1	89.8	2.7	3.8
	JUL	880.5	13.2	11.9	11.0	87.4	2.4	4.3
	AUG	880.0	14.1	12.4	11.2	82.7	1.8	4.5
	SEP	878.8	16.4	13.7	12.1	79.2	1.9	5.2
	OCT	877.7	18.8	15.2	13.1	70.7	3.0	5.3
	NOV	872.9	19.4	16.7	15.2	77.8	4.7	3.7
	DEC	877.2	18.3	17.3	16.7	91.9	6.3	2.1
800	JAN	873.4	19.9	18.3	17.4	85.6	6.6	2.6
	FEB	877.7	19.8	18.2	17.4	86.4	6.6	2.8
	MAR	878.3	19.8	18.3	17.5	87.4	6.3	3.7
	APR	883.1	19.7	17.9	17.1	85.3	5.8	6.2
	MAY	884.5	18.8	16.3	14.9	79.4	3.9	7.1
	JUN	881.3	17.2	14.5	12.8	76.5	2.9	6.9
	JUL	881.5	16.6	13.7	11.7	73.4	2.5	7.7
	AUG	880.8	18.1	14.1	11.4	65.5	1.9	8.8
	SEP	879.9	20.7	15.2	12.0	58.1	1.9	9.4
	OCT	878.9	22.9	16.5	12.9	54.9	2.7	8.1
	NOV	874.0	22.9	17.8	15.1	62.6	4.4	6.0
	DEC	878.0	20.8	18.3	17.1	80.1	6.0	3.4
1100	JAN	872.8	23.6	19.3	17.3	68.2	6.3	3.9
	FEB	878.9	23.8	19.4	17.4	68.1	6.1	4.1
	MAR	880.0	23.3	19.4	17.6	70.1	6.1	4.9
	APR	887.0	22.8	18.7	16.7	68.3	5.7	7.6
	MAY	888.3	22.4	17.1	14.3	60.7	4.4	7.9
	JUN	883.3	21.0	15.2	11.8	55.8	3.1	7.4
	JUL	883.1	20.7	14.5	10.7	53.5	2.8	9.6
	AUG	882.6	22.1	14.8	10.2	46.9	2.1	10.2
	SEP	881.5	24.8	15.9	10.6	41.1	2.2	9.4
	OCT	880.1	27.1	17.0	11.1	37.1	2.7	9.4
	NOV	872.9	26.8	18.3	13.8	45.3	4.7	6.7
	DEC	879.1	24.2	19.1	16.7	62.9	6.0	4.6
1400	JAN	870.4	24.1	19.3	17.1	65.6	6.4	5.1
	FEB	874.3	24.3	19.6	17.4	64.6	6.3	5.2
	MAR	875.1	24.2	19.6	17.6	67.4	5.8	5.6
	APR	880.5	24.4	19.2	16.7	62.4	4.7	7.7
	MAY	882.4	23.8	17.3	13.8	54.0	3.4	8.0
	JUN	879.3	22.7	15.6	11.2	48.6	2.5	6.9
	JUL	879.5	22.3	14.7	9.9	45.2	2.4	8.7

	AUG	878.5	23.9	15.1	9.3	39.3	1.8	9.2
	SEP	876.7	26.7	16.0	9.3	33.4	2.1	9.6
	OCT	875.4	28.9	17.0	9.8	30.9	2.8	9.0
	NOV	870.0	28.2	18.2	12.7	39.7	4.7	7.3
	DEC	874.7	24.8	19.0	16.2	59.3	6.0	5.7
1700	JAN	870.0	21.9	18.9	17.6	76.1	6.6	3.7
	FEB	876.4	22.1	19.1	17.6	76.1	6.7	3.8
	MAR	877.1	21.6	19.0	17.7	78.6	6.4	4.5
	APR	885.1	21.8	18.5	16.9	72.5	5.5	6.4
	MAY	887.0	20.9	16.8	14.5	67.1	3.3	6.8
	JUN	881.6	19.7	14.9	12.0	62.3	2.3	6.9
	JUL	881.5	19.6	14.2	10.8	56.9	2.1	7.2
	AUG	880.3	21.3	14.5	10.1	49.0	1.7	8.1
	SEP	879.0	23.6	15.5	10.5	43.6	2.2	8.6
	OCT	877.3	25.5	16.5	11.4	42.7	3.1	8.4
	NOV	870.1	25.1	17.7	13.7	50.2	5.0	6.9
	DEC	876.3	22.6	19.7	16.7	70.3	6.3	4.4

STATION NAME:	KARONGA	STATION NUMBER:	423	Latitude/ Longitude	9° 56'S 33° 55'E	Altitude	529m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
500	JAN	951.0	22.1	20.9	20.3	89.5	6.5	1.6
	FEB	950.0	22.3	20.7	20.0	86.8	6.2	1.3
	MAR	950.9	21.8	20.8	20.4	92.2	6.6	1.1
	APR	952.4	21.6	20.4	19.9	90.2	6.4	1.6
	MAY	954.0	20.7	18.7	17.7	83.2	4.8	2.6
	JUN	955.5	19.2	16.8	15.5	79.2	4.3	2.7
	JUL	956.9	18.8	15.8	14.1	74.0	3.7	1.9
	AUG	955.4	18.8	16.4	14.9	78.8	2.2	1.7
	SEP	953.8	20.7	17.7	16.1	74.0	2.1	1.7
	OCT	951.2	22.9	18.6	16.2	66.0	1.8	0.7
	NOV	950.3	24.4	20.3	18.4	69.5	3.0	2.7
	DEC	950.0	23.3	21.1	20.1	82.0	5.9	1.8
600	JAN	953.7	22.2	21.0	20.5	87.7	6.7	1.5
	FEB	954.9	22.0	20.9	20.4	89.7	6.7	1.2
	MAR	953.8	21.7	20.9	20.6	92.6	6.7	1.3
	APR	955.1	21.7	20.7	20.2	89.4	6.2	2.2
	MAY	957.1	19.9	18.4	17.7	84.8	5.0	2.4
	JUN	959.3	18.2	16.2	15.0	78.8	4.6	2.5
	JUL	959.6	17.1	15.1	13.8	78.4	4.3	2.2
	AUG	956.7	17.0	15.2	14.2	81.3	2.7	1.7
	SEP	957.1	18.8	16.5	15.2	77.4	2.4	1.6
	OCT	955.4	21.5	18.2	16.3	70.3	2.8	2.2
	NOV	954.3	23.5	20.2	18.6	71.8	4.6	2.0
	DEC	954.0	22.9	21.2	20.5	84.8	6.3	1.6
800	JAN	954.9	24.7	22.2	21.2	79.7	6.6	2.2
	FEB	954.5	24.4	22.1	21.2	79.6	6.6	2
	MAR	955.7	24.1	22.2	21.4	83.2	6.5	2.1
	APR	956.6	24.1	21.9	21.1	81.1	5.8	3.6
	MAY	958.8	23.2	20.3	18.8	72.4	4.8	4.1
	JUN	960.9	21.6	18.1	16.2	67.0	4.5	4.4
	JUL	960.9	21.1	17.3	15.2	65.9	4.0	4.1
	AUG	960.4	22.2	18.1	15.9	64.3	2.7	3.4
	SEP	958.9	24.8	19.4	16.7	60.5	2.2	4.1
	OCT	957.1	27.3	20.8	17.7	54.3	2.5	5.2
	NOV	955.6	28.1	22.0	19.3	58.4	4.1	5.3
	DEC	955.1	26.0	22.4	20.8	73.3	5.9	2.7
1100	JAN	951.5	27.7	23.1	21.3	68.3	6.3	3.9
	FEB	951.2	27.9	23.3	21.4	68.0	6.1	3.5
	MAR	952.5	27.2	23.1	21.4	70.6	6.0	4.3
	APR	953.7	27.1	22.5	20.6	69.4	5.4	6.0
	MAY	955.8	26.8	20.9	18.1	59.1	4.1	7.3
	JUN	957.9	25.7	19.1	15.5	54.4	3.7	7.5
	JUL	958.3	25.2	18.4	14.6	52.5	3.4	8.3
	AUG	956.8	26.1	18.9	15.0	51.1	2.1	7.9

	SEP	955.3	28.0	20.1	16.0	48.5	2.1	7.8
	OCT	953.1	29.9	21.3	17.1	47.0	2.7	7.7
	NOV	951.7	30.3	22.2	18.6	50.3	4.3	7.1
	DEC	951.5	28.4	23.0	20.7	63.4	5.7	4.6
1400	JAN	951.1	28.3	23.6	21.7	66.8	5.9	4.5
	FEB	950.5	28.3	23.6	21.8	67.3	5.8	4.4
	MAR	951.6	28.1	23.6	21.8	68.9	5.3	4.7
	APR	953.1	28.0	23.1	21.1	64.9	4.3	5.8
	MAY	955.6	27.5	21.4	18.6	57.1	3.3	6.8
	JUN	958.1	26.5	19.6	15.9	50.8	2.7	7.1
	JUL	958.4	26.1	18.7	14.6	48.5	2.4	7.5
	AUG	956.9	27.0	19.4	15.3	47.6	1.7	7.4
	SEP	954.7	28.9	20.6	16.4	45.9	1.8	7.2
	OCT	952.3	30.9	21.7	17.3	46.4	2.7	7.3
	NOV	951.2	30.9	22.8	19.3	50.3	4.0	6.7
	DEC	951.1	28.8	23.3	21.1	62.7	5.5	5.1
1700	JAN	948.3	26.8	22.8	21.2	71.4	6.6	3.1
	FEB	947.8	26.9	22.9	21.2	70.9	6.5	2.9
	MAR	949.1	26.5	22.8	21.4	73.7	6.1	2.9
	APR	950.8	26.3	22.4	20.9	72.1	5.6	3.9
	MAY	953.2	25.6	20.9	18.8	65.9	4.0	3.7
	JUN	955.6	24.5	19.1	16.3	60.5	3.0	4.1
	JUL	955.9	24.1	18.6	15.6	58.9	2.8	4.4
	AUG	954.0	24.8	19.2	16.3	59.6	1.9	3.8
	SEP	952.2	26.4	20.2	17.2	57.3	2.0	3.7
	OCT	949.7	28.3	21.2	17.8	53.8	3.1	3.8
	NOV	948.5	28.5	22.2	19.5	58.9	5.0	3.7
	DEC	948.1	27.4	22.6	20.6	66.8	6.2	3.3

STATION NAME:	MZUZU	STATION NUMBER:	489	Latitude/Longitude	11° 26'S, 34° 01'E	Altitude	1100m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	
500	JAN	874.5	16.6	16.3	16.2	97.3	6.8	_
	FEB	874.5	16.6	16.3	16.2	97.3	6.3	_
	MAR	875.2	16.7	16.4	16.3	96.9	6.5	_
	APR	876.6	16.4	16.2	16.0	97.3	6.2	_
	MAY	877.8	12.9	12.6	12.4	96.9	4.7	_
	JUN	877.1	9.8	9.5	9.3	96.5	4.2	_
	JUL	879.7	8.4	8.1	7.8	95.4	3.5	_
	AUG	878.7	7.9	7.5	7.2	95.4	2.0	_
	SEP	877.5	9.4	8.9	8.6	94.9	2.0	_
	OCT	876.3	12.4	11.7	11.1	91.6	2.6	_
	NOV	875.6	14.7	14.1	13.6	93.7	4.7	_
	DEC	875.2	16.4	16.1	15.8	96.3	6.3	_
								_
600	JAN	875.2	16.6	16.3	16.1	97.0	7.0	_
	FEB	874.8	16.6	16.3	16.1	96.9	7.0	_
	MAR	875.8	16.6	16.3	16.2	97.3	6.9	_
	APR	876.8	16.2	15.9	15.7	97.2	6.6	_
	MAY	878.4	12.8	12.5	12.3	96.8	5.4	_
	JUN	879.7	9.7	9.3	9.1	96.1	4.7	_
	JUL	880.0	8.4	8.1	7.7	95.4	4.4	_
	AUG	879.3	7.7	7.3	6.9	95.0	2.8	_
	SEP	878.2	9.6	9.0	8.6	93.4	2.6	_
	OCT	877.0	13.2	12.3	11.6	90.8	3.3	_
	NOV	876.2	15.7	14.9	14.4	91.1	5.3	_
	DEC	875.8	16.8	16.3	16.1	95.7	6.6	_
								_
800	JAN	876.0	19.4	18.2	17.6	88.9	7.0	_
	FEB	875.8	19.3	18.2	17.6	89.3	6.9	_
	MAR	876.9	19.0	18.1	17.6	91.9	6.9	_
	APR	877.8	18.5	17.7	17.2	92.1	6.7	_
	MAY	879.5	16.6	15.7	15.1	90.9	5.8	_
	JUN	880.9	14.2	13.3	12.8	91.1	5.2	_
	JUL	881.1	13.3	12.4	11.8	90.6	4.8	_
	AUG	880.4	14.7	13.1	12.1	84.5	3.5	_
	SEP	879.4	18.4	15.1	13.1	71.5	3.2	_
	OCT	878.2	21.5	16.8	14.2	63.4	3.6	_
	NOV	877.1	21.8	17.9	15.8	69.5	5.3	_
	DEC	876.5	20.3	18.3	17.3	83.1	6.6	_
1100	JAN	875.4	22.7	19.2	17.5	73.0	6.9	6.2
	FEB	875.4	22.8	19.3	17.7	73.1	6.7	6.5
	MAR	876.5	21.9	19.1	17.8	78.4	6.8	6.7
	APR	877.7	21.0	18.5	17.3	79.8	6.7	7.2
	MAY	879.5	19.7	16.7	15.2	75.6	6.1	7.7
	JUN	880.9	18.1	14.9	13.0	72.3	5.7	7.9

	JUL	881.2	17.5	14.2	12.2	71.3	5.9	8.4
	AUG	880.4	19.3	14.8	12.2	63.6	5.0	8.9
	SEP	879.1	22.2	16.0	12.4	54.0	4.0	9.5
	OCT	877.5	24.9	17.2	13.0	47.9	4.0	9.9
	NOV	876.5	24.8	18.4	15.1	55.1	5.4	8.9
	DEC	875.8	23.2	19.1	17.1	68.6	6.5	6.4
1400	JAN	873.1	23.6	19.5	17.7	69.7	6.6	7.4
	FEB	872.9	23.7	19.7	17.8	69.8	6.6	7.4
	MAR	874.1	23.1	19.6	18.0	73.4	6.5	7.5
	APR	875.6	21.9	18.8	17.4	75.5	6.1	7.8
	MAY	877.5	20.7	17.1	15.2	71.0	5.3	7.8
	JUN	879.0	19.1	15.3	13.0	67.8	4.8	8.1
	JUL	879.3	18.8	14.6	11.9	64.4	4.9	8.6
	AUG	878.3	20.7	15.1	11.6	56.0	3.8	9.2
	SEP	876.9	23.7	15.9	11.3	45.9	3.1	8.9
	OCT	875.2	26.2	17.1	11.9	41.3	3.2	9.8
	NOV	874.2	26.0	18.4	14.5	49.5	4.8	9.4
	DEC	873.5	24.1	19.3	17.0	65	6.3	7.2
1700	JAN	872.7	22.1	19.3	18.0	77.6	6.4	5.8
	FEB	872.4	22.4	19.6	18.3	77.7	6.4	5.6
	MAR	873.7	21.5	19.2	18.2	81.5	6.0	6.2
	APR	875.4	20.2	18.3	17.4	83.9	5.4	5.9
	MAY	877.5	18.9	16.7	15.4	80.8	3.3	5.5
	JUN	879.1	17.2	14.7	13.2	77.5	2.6	5.4
	JUL	879.4	17.0	14.0	12.1	72.7	2.4	5.9
	AUG	878.3	18.8	14.3	11.5	62.9	1.8	6.2
	SEP	876.9	21.6	15.4	11.7	53.9	1.7	6.8
	OCT	875.1	23.9	16.7	12.6	49.2	2.2	7.3
	NOV	873.8	24.1	18.0	14.9	57.1	4.3	6.9
	DEC	873.0	22.6	19.1	17.5	73.3	5.9	5.4

STATION NAME:	NKHATA BAY	STATION NUMBER:	493	Latitude/Longitude	11° 36'S, 34° 18'E	Altitude	500m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	957.0	21.8	20.7	20.3	90.8	6.7	2.4
	FEB	956.7	21.8	20.7	20.3	90.1	6.7	2.4
	MAR	957.4	21.2	20.4	20.1	93.1	6.5	2.5
	APR	958.6	20.7	19.8	19.4	92.6	5.6	2.6
	MAY	961.3	18.3	17.2	16.7	89.5	4.2	3.1
	JUN	963.2	16.3	15.1	14.3	86.9	3.8	3.3
	JUL	963.4	15.7	14.2	13.2	85.6	3.9	3.4
	AUG	962.4	16.2	14.4	13.2	82.6	2.9	3.4
	SEP	960.5	18.1	15.6	14.1	76.8	2.4	3.5
	OCT	958.9	20.7	17.6	15.8	73.6	2.5	3.7
	NOV	957.7	22.4	19.6	18.1	77.5	4.6	3.5
	DEC	957.1	22.1	20.7	20.0	87.9	6.3	2.6
800	JAN	957.8	23.7	21.9	21.2	85.8	6.7	2.2
	FEB	957.9	23.5	21.9	21.2	85.8	6.7	2.2
	MAR	958.7	22.9	21.6	21.1	89.2	6.5	2.4
	APR	959.8	22.9	21.3	20.6	86.9	5.8	2.6
	MAY	962.5	21.1	19.1	18.2	83.7	4.5	3.1
	JUN	964.6	19.0	16.9	15.6	80.1	4.0	3.3
	JUL	964.9	18.2	15.8	14.4	78.7	4.3	3.5
	AUG	963.9	19.3	16.3	14.6	73.7	3.1	3.5
	SEP	962.0	22.5	18.3	16.1	66.7	2.4	3.3
	OCT	962.0	26.1	20.8	18.3	62.7	2.3	4.7
	NOV	958.8	26.6	22.0	20.8	68.6	4.4	3.6
	DEC	957.9	24.7	22.2	21.1	80.3	6.2	2.3
1100	JAN	_	26.8	23.6	22.3	76.2	6.2	2.3
	FEB	_	27.1	23.9	22.6	76.4	5.9	2.2
	MAR	_	26.2	23.2	22.1	77.9	6.1	2.1
	APR	_	26.1	22.8	21.5	76.2	5.2	2.2
	MAY	_	25.2	21.3	19.7	71.4	4.6	2.5
	JUN	_	23.8	19.5	17.4	67.6	4.1	2.7
	JUL	_	25.5	18.8	16.4	64.9	4.2	3.0
	AUG	_	24.8	19.6	16.9	61.8	2.7	3.4
	SEP	_	26.4	20.7	18.1	59.9	2.1	4.2
	OCT	_	27.9	22.1	19.6	60.7	1.9	5.0
	NOV	_	28.1	23.1	20.9	65.3	4.1	4.0
	DEC	_	27.1	23.5	22.1	74.5	5.7	2.7
1400	JAN	953.5	27.4	23.7	22.3	74.0	5.8	2.6
	FEB	954.4	27.3	23.8	22.4	74.8	5.9	2.8
	MAR	955.3	27.4	23.6	22.1	74.0	5.3	2.4
	APR	957.0	27.2	23.0	21.3	71.5	4.2	2.2
	MAY	959.9	26.1	21.4	19.3	69.7	3.1	2.5
	JUN	962.2	24.6	19.6	17.1	63.6	2.8	2.9

	JUL	962.6	24.3	18.8	15.9	60.4	2.6	3.1
	AUG	961.2	25.6	19.4	16.3	58.0	1.6	3.1
	SEP	958.7	27.4	20.8	17.7	55.8	1.6	3.2
	OCT	956.5	29.1	22.2	19.2	56.4	1.7	3.2
	NOV	955.1	29.3	23.1	20.5	62.7	3.4	3.3
	DEC	954.4	28.1	23.7	21.9	70.9	5.2	2.7
1700	JAN	_	26.6	23.2	21.9	75.9	5.7	1.7
	FEB	_	26.7	23.5	22.2	76.8	6.0	1.5
	MAR	_	26.2	22.9	21.6	75.7	5.3	1.1
	APR	_	25.6	22.3	20.9	75.6	4.3	1.0
	MAY	_	24.6	20.8	19.3	72.4	2.6	0.8
	JUN	_	23.1	18.9	16.7	67.6	2.1	1.0
	JUL	_	23.0	18.4	15.9	64.7	2.2	1.1
	AUG	_	24.3	19.1	16.3	60.9	1.3	1.0
	SEP	_	26.3	20.6	17.8	59.7	1.7	0.9
	OCT	_	27.6	22.1	19.6	62.1	1.7	1.6
	NOV	_	27.6	22.7	20.7	66.1	4.0	1.7
	DEC	_	26.9	23.2	21.7	73.3	5.5	1.2

STATION NAME:	MZIMBA	STATION NUMBER:	485	Latitude/ Longitude	11° 53'S 33° 37'E	Altitude	1349m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
500	JAN	865.6	17.1	16.4	16.1	94.0	6.9	1.7
	FEB	865.3	17.2	16.6	16.3	94.0	7.0	1.9
	MAR	865.7	16.6	15.2	14.7	91.7	6.1	4.3
	APR	866.7	16.1	15.2	14.7	91.7	6.1	4.3
	MAY	868.2	14.7	13.4	12.7	91.7	6.1	4.3
	JUN	869.3	12.8	11.4	10.4	85.8	2.9	7.0
	JUL	870.0	12.0	10.4	9.3	83.5	2.2	7.9
	AUG	869.3	13.3	11.0	9.4	79.8	1.6	7.5
	SEP	868.0	15.7	12.7	10.8	73.0	1.6	7.9
	OCT	866.3	17.9	14.3	12.1	69.0	2.7	6.7
	NOV	866.1	18.4	15.9	14.6	78.8	5.7	5.2
	DEC	865.8	17.4	16.4	15.9	91.3	6.7	2.8
600	JAN	866.4	17.1	16.5	16.3	95.5	7.1	1.6
	FEB	865.5	16.9	16.5	16.3	96.0	7.0	1.6
	MAR	866.6	16.8	16.1	15.8	94.0	6.5	2.6
	APR	867.5	16.4	15.6	15.1	91.9	5.0	4.8
	MAY	869.0	14.2	13.1	12.4	89.3	3.0	5.8
	JUN	870.3	12.1	11.0	10.2	87.3	2.4	6.3
	JUL	870.4	11.5	10.1	9.2	85.1	2.4	6.4
	AUG	869.7	12.7	10.8	9.4	79.6	1.7	6.6
	SEP	868.5	15.2	12.4	10.6	73.1	1.8	6.9
	OCT	867.3	18.2	14.4	12.3	70.3	2.7	6.3
	NOV	866.8	18.8	16.1	14.6	78.4	5.1	4.2
	DEC	866.6	17.8	16.7	16.1	91.1	6.6	2.2
800	JAN	867.1	19.7	17.9	17.1	85.4	6.9	2.2
	FEB	867.1	19.2	17.8	17.1	87.2	6.9	2.1
	MAR	867.7	19.6	17.7	16.8	83.9	6.2	4.0
	APR	868.5	19.9	17.3	16.1	79.1	4.6	7.0
	MAY	870.1	18.3	15.3	13.6	74.1	2.9	7.7
	JUN	871.4	16.1	13.2	11.4	73.4	2.4	7.7
	JUL	871.5	15.4	12.3	10.2	71.4	2.5	7.9
	AUG	870.7	17.2	13.1	10.5	64.4	1.9	9.7
	SEP	869.7	20.0	14.6	11.3	56.8	1.9	10.4
	OCT	868.5	22.7	16.3	12.8	54.1	2.6	11.4
	NOV	867.7	23.0	17.6	14.9	62.1	4.7	8.5
	DEC	867.4	21.0	18.1	16.6	78.0	6.4	3.9
1100	JAN	866.1	22.7	18.8	17.1	71.1	6.9	5.0
	FEB	866.6	22.8	19.0	17.3	71.3	6.8	5.1
	MAR	867.5	23.1	18.9	17.1	69.7	6.7	5.8
	APR	868.3	23.0	18.3	16.1	65.1	5.6	7.7
	MAY	870.0	22.1	16.2	13.1	56.9	3.9	7.7

	JUN	871.2	20.4	14.2	10.4	52.7	3.4	8.3
	JUL	871.6	19.7	13.6	9.7	52.8	3.7	8.9
	AUG	870.7	21.2	14.1	9.8	48.5	2.7	10.5
	SEP	869.4	23.7	15.5	10.7	44.1	2.8	10.6
	OCT	967.5	26.1	16.9	12.0	41.4	3.2	11.3
	NOV	873.2	25.8	18.1	14.3	51.2	5.3	9.0
	DEC	866.7	23.8	18.9	16.7	64.4	6.7	5.9
1400	JAN	864.3	23.6	19.2	17.2	67.0	6.8	6.0
	FEB	864.1	23.6	19.3	17.4	67.4	6.7	6.1
	MAR	864.6	23.9	19.2	17.2	66.3	6.5	6.0
	APR	866.1	23.7	18.4	16.0	62.1	5.7	7.2
	MAY	868.0	23.2	16.6	13.0	53.1	4.7	6.7
	JUN	873.2	21.6	14.6	10.4	48.2	4.2	7.2
	JUL	869.7	20.9	13.9	9.4	47.6	4.1	8.0
	AUG	868.8	22.4	14.6	9.7	44.1	3.5	9.1
	SEP	867.4	24.8	15.8	10.4	39.8	3.0	9.9
	OCT	868.8	27.0	17.1	11.6	38.5	3.0	11.1
	NOV	865.2	26.4	18.3	14.2	47.9	5.0	9.6
	DEC	864.5	24.1	18.8	16.4	62.9	6.4	6.3
1700	JAN	863.8	22.2	18.7	17.1	72.9	6.7	4.8
	FEB	863.7	22.6	19.0	17.4	72.6	6.8	4.3
	MAR	864.6	22.1	18.7	17.2	74.2	6.4	5.2
	APR	866.2	21.4	17.6	15.8	70.5	4.9	6.5
	MAY	868.2	20.2	15.9	13.4	65.4	3.2	7.0
	JUN	869.6	18.7	13.9	10.9	61.3	2.6	7.4
	JUL	869.8	18.4	13.2	9.9	57.8	2.5	8.2
	AUG	868.9	19.8	13.6	9.6	51.6	1.9	9.9
	SEP	867.6	22.1	14.6	9.8	45.8	1.8	10.1
	OCT	865.8	24.3	16.0	11.2	44.8	2.7	10.9
	NOV	864.6	24.2	17.4	13.9	52.9	5.0	9.2
	DEC	864.0	22.6	18.6	16.6	68.9	6.4	5.2

STATION NAME:	NKHOTA-KOTA	STATION NUMBER:	591	Latitude/ Longitude	12 ° 56' S 34° 18' E	Altitude	500m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	_	21.9	21.0	20.6	92.6	6.8	2.4
	FEB	_	21.9	21.1	20.7	92.5	6.7	2.3
	MAR	_	21.4	20.5	20.1	92.4	6.2	3.3
	APR	_	20.7	19.5	18.9	89.5	5.0	4.1
	MAY	_	18.3	16.7	15.7	84.5	3.4	4.3
	JUN	_	16.4	14.4	13.1	80.7	3.2	5.2
	JUL	_	16.1	13.7	12.2	78.1	3.5	4.5
	AUG	_	16.7	14.2	12.6	77.2	2.6	3.7
	SEP	_	19.1	16.1	14.3	73.7	2.5	4.3
	OCT	_	22.9	18.8	16.7	69.3	2.5	5.6
	NOV	_	24.1	20.5	18.8	73.9	4.7	4.5
	DEC	_	22.8	21.2	20.6	87.7	6.3	2.8
800	JAN	_	24.1	22.2	21.4	85.0	6.6	2.8
	FEB	_	24.0	22.2	21.3	84.8	6.5	3.0
	MAR	_	23.7	21.8	21.1	85.1	6.0	4.0
	APR	_	23.4	21.1	20.2	82.4	4.7	5.1
	MAY	_	22.0	18.8	17.2	73.9	3.5	5.5
	JUN	_	20.0	16.6	14.6	70.6	3.1	6.0
	JUL	_	19.6	15.8	13.6	68.1	3.4	5.5
	AUG	_	21.1	16.7	14.2	64.9	2.7	5.1
	SEP	_	23.9	18.8	16.1	61.1	2.3	6.1
	OCT	_	26.6	20.6	17.8	59.1	2.2	7.5
	NOV	_	27.1	21.8	19.6	64.6	4.2	6.9
	DEC	_	25.4	22.4	21.2	79.6	6.0	3.9
1100	JAN	_	26.1	22.9	21.6	76.2	6.2	3.9
	FEB	_	26.3	23.1	21.8	76.5	6.1	4.2
	MAR	_	26.3	22.8	21.3	74.4	5.5	5.0
	APR	_	25.9	21.9	20.2	70.7	4.3	5.9
	MAY	_	25.0	20.2	17.9	66.7	2.9	6.6
	JUN	_	23.4	18.2	15.3	60.3	2.8	7.4
	JUL	_	23.2	17.8	14.7	58.7	3.0	7.1
	AUG	_	24.5	18.3	15.0	55.7	2.0	6.2
	SEP	_	26.8	19.5	15.8	50.9	1.6	6.5
	OCT	_	28.9	20.8	17.0	48.9	1.8	7.6
	NOV	_	28.8	21.9	18.9	56.5	3.8	6.8
	DEC	_	27.0	22.9	21.2	70.9	5.7	4.8
1400	JAN	_	27.3	23.2	21.6	71.2	5.8	4.1
	FEB	_	27.2	23.2	21.7	71.3	5.8	4.5
	MAR	_	27.5	22.9	21.1	68.2	4.6	4.5
	APR	_	27.3	22.2	19.9	64.5	3.1	5.2
	MAY	_	26.2	20.2	17.2	57.4	2.0	5.3
	JUN	_	24.7	18.3	14.7	52.9	2.0	5.3
	JUL	_	24.5	17.6	13.4	50.0	2.3	5.3

	AUG	_	26.1	18.4	14.0	47.2	1.6	4.8
	SEP	_	28.5	19.6	14.9	42.9	1.5	5.5
	OCT	_	30.9	21.1	16.2	41.5	1.7	6.0
	NOV	_	30.8	22.2	18.3	48.0	3.3	5.9
	DEC	_	28.4	23.0	20.8	64.3	5.2	4.9
1700	JAN	_	26.3	22.8	21.4	74.5	6.3	3.0
	FEB	_	26.3	22.8	21.4	75.0	6.3	3.2
	MAR	_	26.6	22.7	21.1	71.6	5.2	3.7
	APR	_	25.9	21.7	19.9	69.7	3.5	3.4
	MAY	_	24.6	19.8	17.5	64.9	2.3	2.9
	JUN	_	22.9	17.8	14.9	60.7	2.2	4.1
	JUL	_	22.9	17.3	14.1	57.7	2.6	3.9
	AUG	_	24.3	18.2	14.7	55.7	1.7	3.1
	SEP	_	26.3	19.6	16.1	53.9	1.5	3.6
	OCT	_	28.3	21.0	17.5	52.1	1.8	4.0
	NOV	_	28.4	22.1	19.2	57.9	4.3	4.3
	DEC	_	27.1	22.8	21.0	69.3	5.8	3.3
2000	JAN	_	24.9	22.7	21.7	_	6.1	_
	FEB	_	24.0	22.3	21.7	_	6.4	_
	MAR	_	24.2	22.4	21.7	_	6.3	_
	APR	_	22.4	22.3	21.1	_	4.5	_
	MAY	_	22.9	19.7	18.1	_	3.6	_
	JUN	_	21.0	17.3	15.0	_	3.0	_
	JUL	_	20.6	16.7	13.9	_	2.6	_
	AUG	_	21.8	17.2	14.2	_	2.4	_
	SEP	_	24.6	19.3	16.4	_	2.5	_
	OCT	_	26.9	21.4	18.9	_	2.0	_
	NOV	_	27.1	22.2	20.0	_	4.1	_
	DEC	_	25.5	22.8	21.7	_	6.1	_

STATION NAME:	CHITEDZE	STATION NUMBER:	585	Latitude /Longitude	13° 59'S, 33° 38'E	Altitude	1149m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	–	17.9	17.6	17.3	96.1	6.6	–
	FEB	–	17.7	17.4	17.2	96.8	6.6	–
	MAR	–	16.7	16.4	16.2	96.9	5.8	–
	APR	–	15.1	14.7	14.4	96.2	4.2	–
	MAY	–	11.8	11.4	11.0	94.8	3.1	–
	JUN	–	9.5	8.9	8.3	92.8	2.9	–
	JUL	–	9.0	8.2	7.5	90.1	2.6	–
	AUG	–	10.0	8.8	7.7	85.4	2.0	–
	SEP	–	12.6	10.8	9.3	80.3	1.6	–
	OCT	–	15.9	13.3	11.6	76.3	1.9	–
	NOV	–	18.4	16.4	15.3	81.9	4.4	–
	DEC	–	18.4	17.7	17.3	92.6	5.9	–
800	JAN	–	20.6	19.0	18.2	86.3	6.5	–
	FEB	–	20.1	18.8	18.2	88.7	6.5	–
	MAR	–	19.8	18.4	17.7	87.6	5.6	–
	APR	–	18.8	17.3	16.4	85.7	4.4	–
	MAY	–	16.3	14.4	13.3	81.9	3.0	–
	JUN	–	13.9	12.0	10.6	79.5	2.8	–
	JUL	–	13.4	11.2	9.4	77.0	2.7	–
	AUG	–	15.5	12.1	9.6	67.9	1.8	–
	SEP	–	19.4	14.3	10.9	57.4	1.4	–
	OCT	–	23.1	16.4	12.7	52.5	2.1	–
	NOV	–	23.3	18.0	15.3	62.1	4.3	–
	DEC	–	21.5	19.0	17.8	79.2	6.0	–
1100	JAN	–	23.9	19.9	18.2	70.1	6.6	–
	FEB	–	23.9	20.1	18.4	71.4	6.5	–
	MAR	–	24.1	19.7	17.7	67.5	6.0	–
	APR	–	23.7	18.5	15.9	62.1	5.1	–
	MAY	–	22.9	16.2	12.3	52.7	3.5	–
	JUN	–	21.1	13.9	9.2	47.1	3.3	–
	JUL	–	20.8	13.4	8.3	44.6	3.3	–
	AUG	–	22.7	14.2	8.3	40.1	2.9	–
	SEP	–	25.4	15.7	9.6	36.9	2.8	–
	OCT	–	27.7	17.3	11.4	36.5	3.4	–
	NOV	–	27.3	18.7	14.3	45.2	5.4	–
	DEC	–	25.1	19.7	17.3	61.9	6.3	–
1400	JAN	–	24.9	20.2	18.1	66.1	6.4	5.1
	FEB	–	24.8	20.3	18.3	66.6	6.4	4.8
	MAR	–	25.3	19.9	17.4	61.9	5.8	5.0
	APR	–	25.5	18.9	15.7	55.6	5.0	5.1
	MAY	–	24.8	16.5	11.7	44.3	4.1	5.1
	JUN	–	23.0	14.4	8.7	39.6	4.0	5.7
	JUL	–	22.8	13.7	7.1	36.4	3.8	6.4
	AUG	–	24.6	14.5	7.5	33.3	3.7	6.7
	SEP	–	27.2	15.9	8.8	30.3	3.3	8.1
	OCT	–	29.4	17.3	10.2	30.8	3.6	8.3
	NOV	–	28.4	18.7	13.6	40.5	5.4	7.1
	DEC	–	25.4	19.7	17.0	59.8	6.2	5.9

STATION NAME:	LILONGWE	STATION NUMBER:	587	Latitude/ Longitude	13 °57'S 33° 55' E	Altitude	1135m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
500	JAN	887.5	18.2	17.8	17.6	96.8	6.7	_
	FEB	886.8	18.0	17.7	17.5	97.1	6.3	_
	MAR	888.1	17.2	16.9	16.7	96.8	5.5	_
	APR	889.4	15.6	15.3	15.1	96.8	4.2	_
	MAY	891.1	12.3	11.9	11.6	95.2	2.6	_
	JUN	892.7	10.0	9.3	8.8	92.1	2.3	_
	JUL	893.1	9.5	8.7	7.9	89.9	1.8	_
	AUG	892.0	10.0	9.2	7.8	82.8	1.4	_
	SEP	890.5	13.2	10.9	9.2	76.8	1.2	_
	OCT	889.2	16.0	13.4	11.7	75.9	2.0	_
	NOV	888.3	17.7	15.9	14.8	83.2	4.5	_
	DEC	884.6	18.3	17.6	17.2	93.8	6.3	_
600	JAN	888.0	18.1	17.8	17.6	96.6	6.8	_
	FEB	887.3	17.9	17.7	17.5	97.3	6.8	_
	MAR	888.6	16.9	16.7	16.5	96.6	5.9	_
	APR	889.9	15.2	14.9	14.7	96.7	4.5	_
	MAY	891.7	11.8	11.4	11.2	95.6	3.3	_
	JUN	893.2	9.6	9.1	8.6	93.0	3.2	_
	JUL	893.3	8.9	8.2	7.6	90.8	2.7	_
	AUG	892.6	10.0	8.9	7.8	85.8	2.0	_
	SEP	891.2	12.8	10.9	9.4	79.6	1.7	_
	OCT	889.8	16.3	13.7	11.9	75.1	2.1	_
	NOV	889.1	18.5	16.5	15.3	82.5	4.6	_
	DEC	888.3	18.6	17.8	17.4	93.3	6.2	_
800	JAN	888.4	20.4	18.9	18.2	87.2	6.6	_
	FEB	888.3	20.1	18.9	18.3	89.4	6.6	_
	MAR	889.8	19.7	18.3	17.7	88.4	5.9	_
	APR	891.0	18.6	17.1	16.3	87.5	4.5	_
	MAY	892.8	15.7	14.2	13.2	85.4	3.3	_
	JUN	894.4	13.2	11.6	10.4	82.8	3.0	_
	JUL	895.0	12.7	10.8	9.3	80.1	3.0	_
	AUG	893.8	14.9	11.8	9.5	69.6	1.9	_
	SEP	892.5	18.9	14.1	10.9	58.6	1.5	_
	OCT	891.0	22.7	16.4	12.9	54.5	2.2	_
	NOV	889.9	23.1	18.1	15.5	63.5	4.5	_
	DEC	889.0	21.6	19.0	17.7	80.1	6.1	_
1100	JAN	887.8	23.8	19.9	18.2	70.9	6.7	6.2
	FEB	887.8	23.9	20.1	18.3	70.8	6.6	6.2
	MAR	889.3	24.0	19.6	17.6	67.6	6.2	6.4
	APR	890.5	23.5	18.6	16.1	63.4	5.5	6.9
	MAY	892.4	22.3	16.6	12.4	53.3	5.6	6.9
	JUN	893.9	20.7	13.9	9.4	48.7	3.2	7.5

	JUL	894.3	20.3	13.3	8.4	46.7	3.5	8.3
	AUG	893.4	22.1	14.0	8.5	41.9	2.9	9.3
	SEP	891.8	24.8	15.6	9.8	38.6	2.8	10.7
	OCT	890.0	27.2	17.4	12.0	39.0	3.6	10.7
	NOV	889.0	26.8	18.7	14.6	47.6	5.5	9.6
	DEC	888.1	24.9	19.7	17.3	62.6	6.4	7.2
1400	JAN	885.6	24.9	20.2	18.1	66.0	6.5	7.0
	FEB	885.4	24.9	20.3	18.2	65.5	6.5	7.0
	MAR	886.6	25.2	19.8	17.3	61.1	6.0	6.8
	APR	888.1	25.3	18.9	15.7	55.9	5.2	6.5
	MAY	890.0	24.4	16.4	11.7	44.1	4.2	6.6
	JUN	891.7	22.7	14.3	8.7	39.6	4.2	7.0
	JUL	892.0	22.4	13.6	7.2	37.7	3.9	8.0
	AUG	890.9	24.1	14.5	7.8	34.8	3.8	8.8
	SEP	889.2	26.7	16.0	9.1	31.8	3.3	9.9
	OCT	887.5	29.0	17.5	10.8	31.9	3.7	10.3
	NOV	886.5	28.3	18.8	13.8	41.3	5.4	9.6
	DEC	885.9	25.6	19.8	17.1	59.5	6.4	7.6
1700	JAN	885.0	23.3	19.7	18.1	72.7	6.9	5.9
	FEB	884.9	23.3	19.8	18.2	73.2	6.6	6.1
	MAR	886.3	23.6	19.5	17.6	69.8	6.0	6.1
	APR	888.0	23.2	18.5	16.2	65.4	5.0	6.5
	MAY	890.1	22.1	16.0	12.4	54.4	3.5	6.7
	JUN	891.6	20.7	13.8	9.2	48.1	3.3	7.1
	JUL	892.1	20.6	13.3	8.0	44.1	3.6	8.3
	AUG	890.9	22.4	13.8	7.7	38.9	2.8	9.3
	SEP	889.3	25.1	15.0	8.1	34.1	2.2	10.5
	OCT	887.3	27.2	16.6	10.1	35.5	3.0	10.5
	NOV	886.3	26.1	18.1	13.7	47.2	5.6	9.1
	DEC	885.5	23.6	19.2	17.1	67.3	6.6	7.0
2000	JAN	886.9	20.4	19.1	18.4	88.0	6.6	3.2
	FEB	886.7	20.5	19.2	18.6	88.3	6.6	3.2
	MAR	888.2	20.2	18.7	17.9	87.5	6.0	3.4
	APR	889.8	19.2	17.6	16.7	85.4	4.9	3.7
	MAY	891.6	17.3	14.7	13.1	76.5	2.9	3.6
	JUN	893.3	15.4	12.2	9.8	69.8	2.6	4.1
	JUL	893.5	15.6	11.6	8.5	63.1	2.4	4.3
	AUG	892.2	17.6	12.2	8.2	54.4	1.8	4.4
	SEP	890.5	20.4	13.7	9.1	48.0	1.2	4.2
	OCT	888.8	22.8	15.7	11.3	48.5	2.2	4.9
	NOV	888.0	23.0	17.4	14.4	58.8	4.8	5.4
	DEC	887.5	21.0	18.9	17.9	82.4	6.4	3.7
2300	JAN	887.7	19.4	18.6	18.2	92.7	6.3	2.0
	FEB	887.6	19.3	18.6	18.2	92.9	6.0	2.0
	MAR	888.9	18.8	18.0	17.6	93.0	5.5	1.8
	APR	890.3	17.6	16.7	16.2	91.1	4.2	2.8
	MAY	891.8	14.5	13.3	12.4	87.1	2.0	2.4

	JUN	893.5	12.4	10.7	9.3	81.7	1.7	3.1
	JUL	893.9	12.5	10.3	8.4	76.0	1.6	3.5
	AUG	892.6	14.4	10.9	8.2	66.5	1.1	3.0
	SEP	890.9	17.4	12.7	9.3	58.9	0.7	3.0
	OCT	889.2	19.9	14.8	11.7	59.1	1.4	3.4
	NOV	888.5	20.7	16.9	14.9	69.7	3.9	3.5
	DEC	888.4	19.9	18.6	17.9	88.2	5.9	2.1

STATION NAME:	SALIMA	STATION NUMBER:	597	Latitude /Longitude	13 ° 45' S 34° 35' E	Altitude	512m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	953.4	22.2	21.2	20.8	92.1	6.6	2.1
	FEB	952.9	22.0	21.2	20.8	92.3	6.6	2.1
	MAR	954.4	22.0	20.7	20.1	88.9	6.1	3.3
	APR	956.2	21.3	19.6	18.7	84.5	4.5	4.4
	MAY	958.5	18.6	16.7	15.6	81.9	3.2	3.5
	JUN	960.5	16.8	14.6	13.1	78.1	3.2	3.9
	JUL	961.0	16.9	14.2	12.4	75.5	3.2	4.2
	AUG	959.8	17.8	14.8	13.1	72.8	2.5	3.7
	SEP	958.1	20.0	16.8	14.9	71.8	2.1	3.7
	OCT	956.2	22.7	18.8	16.8	69.0	2.3	3.9
	NOV	955.1	24.4	20.7	19.1	72.8	4.6	3.9
	DEC	954.1	23.2	21.4	20.7	85.2	6.3	2.7
800	JAN	954.1	24.4	22.3	21.4	84.3	6.5	3.9
	FEB	954.0	24.2	22.3	21.5	84.4	6.4	4.0
	MAR	955.7	24.3	21.8	20.8	81.0	5.8	4.9
	APR	957.4	24.1	20.9	19.6	76.0	4.5	6.6
	MAY	959.6	22.2	16.4	16.9	71.5	3.0	6.2
	JUN	961.9	20.1	18.7	14.2	68.5	3.1	6.3
	JUL	962.3	19.9	15.8	13.2	65.2	3.2	6.6
	AUG	961.2	21.4	16.8	14.1	62.4	2.4	6.2
	SEP	959.5	24.0	18.4	15.3	57.5	1.9	6.4
	OCT	957.5	26.8	20.1	16.7	54.4	2.1	6.5
	NOV	956.1	27.4	21.5	18.8	61.2	4.0	6.2
	DEC	954.9	25.6	22.3	20.9	74.9	6.1	4.3
1800	JAN	953.4	26.6	22.9	21.4	73.5	6.1	4.6
	FEB	953.3	26.7	22.9	21.4	73.3	6.1	4.5
	MAR	955.2	26.7	22.6	20.8	70.4	5.3	5.1
	APR	956.9	26.2	21.4	19.3	66.3	3.7	6.2
	MAY	959.0	24.8	19.3	16.4	59.7	2.2	6.0
	JUN	961.6	23.2	17.4	14.0	56.1	2.2	6.5
	JUL	962.1	22.9	16.7	13.0	54.0	2.3	6.9
	AUG	960.8	24.5	17.5	13.4	51.4	1.8	6.5
	SEP	958.7	27.1	18.7	13.9	44.1	1.4	6.3
	OCT	956.3	29.7	20.2	15.2	41.4	2.0	6.4
	NOV	955.0	29.8	21.6	17.7	48.8	3.5	6.1
	DEC	954.0	27.8	22.6	20.4	64.1	5.6	5.1
1400	JAN	950.9	27.9	23.0	21.0	67.4	5.9	4.8
	FEB	950.6	27.9	23.2	21.3	67.5	5.7	4.9
	MAR	952.2	28.3	22.7	20.4	63.0	4.7	4.7
	APR	954.1	28.3	21.8	18.8	57.8	3.0	5.1
	MAY	956.5	27.0	19.6	15.8	51.0	2.1	5.1
	JUN	959.0	25.3	17.7	13.1	46.3	2.1	5.4
	JUL	959.4	25.1	16.9	11.8	44.8	2.3	5.8

	AUG	957.8	27.0	17.6	11.8	38.6	1.6	5.8
	SEP	956.1	29.4	18.9	13.0	35.4	1.7	6.1
	OCT	953.2	31.7	20.6	14.8	35.9	1.9	6.1
	NOV	952.0	31.8	21.9	17.3	43.6	3.4	5.9
	DEC	951.3	29.2	22.7	20.0	58.6	5.4	5.4
1700	JAN	950.3	26.6	22.7	21.2	72.1	6.5	3.2
	FEB	950.2	26.7	22.9	21.3	72.5	6.4	3.2
	MAR	951.6	27.1	22.6	20.7	68.5	5.4	2.9
	APR	953.8	26.6	21.5	19.2	63.9	3.4	2.8
	MAY	956.4	25.1	19.5	16.7	59.6	2.5	2.3
	JUN	959.1	23.6	17.4	13.9	54.9	2.2	2.2
	JUL	959.2	23.6	16.9	12.8	50.8	2.8	2.7
	AUG	957.5	25.3	17.3	12.5	45.1	2.0	3.0
	SEP	956.2	27.7	18.4	13.1	40.9	1.9	3.2
	OCT	952.8	29.6	20.1	15.2	43.3	2.3	3.9
	NOV	951.4	29.6	21.4	17.7	49.8	4.5	4.0
	DEC	950.7	27.7	22.4	20.2	64.1	6.1	3.4

STATION NAME:	MANGOCHI	STATION NUMBER:	695	Latitude/ Longitude	14° 29'S 35° 16'E	Altitude	482m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	957.0	22.3	21.3	20.9	92.2	6.6	1.7
	FEB	956.8	22.1	21.3	20.9	93.0	6.7	1.7
	MAR	958.6	21.7	20.8	20.4	91.9	5.9	2.1
	APR	958.3	20.6	19.5	18.9	90.2	5.2	2.7
	MAY	962.5	17.3	16.2	15.6	89.3	3.3	2.5
	JUN	964.6	15.1	13.9	13.0	87.0	3.4	2.1
	JUL	965.1	15.3	13.7	12.6	84.3	3.4	2.8
	AUG	964.0	16.4	14.4	13.0	80.7	3.0	3.1
	SEP	962.1	19.4	16.1	14.1	71.3	2.1	3.5
	OCT	959.3	22.7	18.3	16.0	65.7	2.6	3.8
	NOV	959.1	23.9	20.1	18.3	71.0	4.6	3.8
	DEC	957.9	23.2	21.4	20.6	85.9	6.4	2.4
800	JAN	957.7	25.0	22.4	21.3	80.0	6.4	3.6
	FEB	957.7	24.7	22.3	21.4	81.9	6.4	3.9
	MAR	959.8	24.4	21.8	20.7	80.3	5.8	4.1
	APR	961.2	23.3	20.7	19.5	79.1	5.1	4.8
	MAY	963.6	21.1	18.3	16.8	76.9	3.1	4.4
	JUN	965.9	18.6	15.9	14.3	76.9	3.1	4.3
	JUL	966.2	18.3	15.4	13.7	74.5	3.1	4.9
	AUG	965.2	20.0	16.2	13.9	68.3	2.8	5.1
	SEP	963.3	23.5	17.8	14.5	57.1	2.0	5.6
	OCT	961.3	26.3	19.4	15.9	55.8	2.4	6.1
	NOV	959.8	26.9	20.8	17.8	57.4	4.2	5.6
	DEC	958.6	25.7	22.2	20.8	73.7	6.2	4.2
1100	JAN	955.7	27.3	22.7	20.8	68.0	6.2	4.6
	FEB	957.2	27.6	23.1	21.2	68.1	6.2	5.0
	MAR	959.1	27.5	22.8	20.8	67.3	5.8	4.8
	APR	960.9	26.6	21.6	19.4	64.9	4.8	5.1
	MAY	963.1	25.1	19.4	16.4	58.8	3.0	4.8
	JUN	965.6	22.7	16.9	13.6	56.6	2.8	5.1
	JUL	966.0	22.6	16.7	13.2	55.0	3.2	5.6
	AUG	964.5	24.8	17.4	12.9	47.8	2.9	6.1
	SEP	960.5	28.0	18.8	13.7	41.4	2.6	6.2
	OCT	958.7	30.1	20.3	15.2	40.8	3.2	6.0
	NOV	958.4	30.9	21.6	17.3	44.3	4.3	5.3
	DEC	957.7	28.4	22.8	20.5	62.0	6.2	5.3
1400	JAN	954.7	28.4	23.0	20.8	63.8	6.2	5.8
	FEB	954.6	28.6	23.1	20.9	63.4	6.2	5.5
	MAR	956.2	29.1	22.8	20.2	59.1	5.7	5.2
	APR	958.3	28.4	21.7	18.7	55.8	4.9	5.1
	MAY	960.4	27.4	19.3	14.9	46.6	3.3	4.9
	JUN	962.9	25.4	17.2	12.1	43.8	3.3	5.1
	JUL	963.3	25.3	16.7	11.1	41.3	3.7	5.5

	AUG	961.7	27.4	17.3	11.0	36.1	3.6	6.0
	SEP	959.0	30.6	18.8	11.9	31.6	3.0	6.4
	OCT	956.6	32.5	20.5	14.1	33	3.8	6.5
	NOV	955.4	32.7	21.7	16.5	38.1	4.7	6.0
	DEC	955.1	29.5	22.9	20.1	57.2	6.3	6.2
1700	JAN	954.0	27.1	22.7	20.9	69.4	6.5	3.6
	FEB	953.8	27.3	22.9	21.1	69.0	6.5	3.2
	MAR	955.4	27.8	22.6	20.4	64.5	5.7	3.4
	APR	956.8	26.9	21.2	18.6	60.4	4.3	3.2
	MAY	960.2	25.7	19.3	15.9	54.9	3.0	2.8
	JUN	962.6	23.8	17.2	13.2	51.6	3.0	2.9
	JUL	962.9	23.9	16.7	12.1	47.5	3.6	3.4
	AUG	961.0	26.0	17.4	12.1	41.8	3.0	3.5
	SEP	958.9	28.4	18.6	12.9	38.6	2.7	4.3
	OCT	956.3	29.9	20.5	15.6	42.3	3.1	4.8
	NOV	954.9	29.6	21.8	18.3	50.5	5.4	4.4
	DEC	954.2	27.7	22.6	20.4	65.0	6.5	3.9

STATION NAME:	MAKOKA	STATION NUMBER:	692	Latitude/Longitude	15° 32'S 35° 11'E	Altitude	1029m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	_	19.2	18.6	18.3	94.9	6.4	1.9
	FEB	_	18.8	18.3	18.1	95.6	6.2	1.9
	MAR	_	18.2	17.8	17.6	96.0	5.8	1.8
	APR	_	16.8	16.4	16.2	94.6	5.5	2.0
	MAY	_	14.3	13.7	13.2	93.3	3.5	1.5
	JUN	_	12.5	11.5	10.7	88.9	3.6	2.1
	JUL	_	12.1	11.0	10.2	88.3	3.5	2.3
	AUG	_	13.1	11.7	10.6	85.6	2.9	2.6
	SEP	_	15.6	13.3	11.8	79.9	2.2	2.7
	OCT	_	18.3	15.7	14.1	76.3	2.8	3.7
	NOV	_	19.7	17.4	16.3	80.8	4.6	3.5
	DEC	_	19.6	18.7	18.2	92.0	6.4	2.3
800	JAN	_	21.7	19.8	18.9	84.4	6.1	3.6
	FEB	_	21.4	19.6	18.9	86.3	6.1	3.8
	MAR	_	20.8	19.2	18.3	85.7	5.8	3.8
	APR	_	19.3	17.8	17.0	84.5	5.3	3.9
	MAY	_	17.8	15.7	14.4	80.7	3.6	4.0
	JUN	_	15.3	13.1	11.7	79.2	3.7	4.7
	JUL	_	15.2	12.8	11.1	76.9	3.5	4.2
	AUG	_	16.6	13.4	11.4	71.4	2.7	5.0
	SEP	_	19.4	14.9	12.2	62.9	2.2	6.1
	OCT	_	22.1	16.9	14.1	60.7	2.7	6.3
	NOV	_	22.7	18.4	16.4	68.0	4.2	5.6
	DEC	_	21.9	19.7	18.7	81.8	6.1	4.2
1100	JAN	_	24.1	20.6	19.1	73.6	6.4	4.2
	FEB	_	24.2	20.6	18.9	72.8	6.2	4.2
	MAR	_	24.1	20.1	18.2	70.3	6.1	3.9
	APR	_	22.9	18.7	16.7	68.0	5.6	4.1
	MAY	_	21.8	16.4	13.4	59.7	4.1	4.6
	JUN	_	19.6	14.2	10.7	56.7	4.1	4.8
	JUL	_	19.1	13.6	9.9	55.5	3.7	5.1
	AUG	_	21.2	14.3	9.8	50.6	3.1	5.4
	SEP	_	24.3	16.0	11.0	43.2	2.5	5.9
	OCT	_	26.2	17.9	13.4	45.1	3.5	6.2
	NOV	_	26.6	19.3	15.8	51.7	4.8	5.2
	DEC	_	24.3	20.3	18.6	70.7	6.1	4.2
1400	JAN	_	24.5	20.7	19.1	72.1	6.5	4.0
	FEB	_	24.7	20.7	18.9	70.3	6.3	3.9
	MAR	_	24.8	20.2	18.2	67.1	6.2	4.0
	APR	_	24.1	19.0	16.6	63.0	5.8	4.0
	MAY	_	23.0	16.6	12.9	54.2	4.4	4.0
	JUN	_	20.8	14.4	10.2	50.9	4.7	4.3
	JUL	_	20.6	13.7	9.1	47.8	4.3	4.6

	AUG	_	22.9	14.4	8.7	40.4	3.9	4.4
	SEP	_	26.3	15.9	9.4	34.8	3.0	5.5
	OCT	_	27.8	17.8	12.1	37.9	4.0	5.9
	NOV	_	27.6	19.1	14.9	46.1	5.5	5.1
	DEC	_	25.2	20.4	18.4	65.9	6.2	4.2
1700	JAN	_	22.8	20.2	19.1	78.7	6.6	2.9
	FEB	_	23.1	20.1	18.8	77.2	6.4	3.2
	MAR	_	22.8	19.6	18.1	75.3	5.9	3.2
	APR	_	21.7	18.5	16.9	74.0	5.0	3.2
	MAY	_	20.3	15.9	13.4	66.0	3.4	2.6
	JUN	_	18.4	13.9	10.9	61.7	3.7	3.1
	JUL	_	18.4	13.4	9.9	60.1	3.8	3.8
	AUG	_	21.1	14.0	9.2	46.6	3.2	4.1
	SEP	_	24.4	15.3	9.6	39.1	2.4	4.2
	OCT	_	26.2	17.1	11.9	41.4	3.4	4.9
	NOV	_	25.6	18.4	14.7	51.8	5.3	4.4
	DEC	_	23.5	19.9	18.3	73.1	6.5	3.6

STATION NAME:	CHILEKA	STATION NUMBER:	693	Latitude/ Longitude	15° 41'S 34° 41'E	Altitude	767m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
500	JAN	925.1	20.7	19.4	18.9	89.6	6.3	3.5
	FEB	924.8	20.5	19.4	18.8	90.1	5.9	3.3
	MAR	926.5	19.9	18.8	18.2	89.4	4.8	3.6
	APR	928.1	18.7	17.3	16.6	87.6	3.6	4.6
	MAY	930.2	16.4	14.6	13.5	83.3	2.4	4.9
	JUN	931.9	14.6	12.5	11.0	78.6	2.3	5.3
	JUL	932.6	14.4	12.2	10.6	77.9	2.4	5.4
	AUG	931.5	15.5	12.8	10.9	74.4	1.8	5.9
	SEP	929.9	17.8	14.1	11.8	68.6	1.4	6.1
	OCT	928.1	20.2	16.1	13.7	66.3	2.3	6.6
	NOV	927.2	20.9	17.9	16.3	75.4	4.6	5.3
	DEC	925.9	20.8	19.1	18.3	85.9	6.1	4.2
600	JAN	925.7	20.7	19.4	18.8	89.2	6.3	4.3
	FEB	925.2	20.4	19.3	18.7	90.3	6.4	3.5
	MAR	927.0	19.9	18.7	18.2	89.8	5.6	3.9
	APR	928.7	18.6	17.3	16.6	88.0	4.6	4.4
	MAY	930.5	16.2	14.5	13.4	83.5	2.9	5.2
	JUN	932.4	14.3	12.3	10.8	81.1	2.9	5.6
	JUL	932.9	14.1	11.9	10.3	78.1	2.8	5.6
	AUG	931.8	15.1	12.4	10.6	74.4	2.6	5.6
	SEP	930.1	17.7	14.2	11.9	68.9	1.9	6.4
	OCT	928.7	20.6	16.4	14.1	66.6	2.6	7.0
	NOV	927.6	21.6	18.2	16.5	73.1	4.4	6.1
	DEC	926.4	21.3	19.6	18.8	86.1	6.3	4.6
800	JAN	926.4	23.3	20.7	19.5	79.6	6.3	5.7
	FEB	926.1	23.1	20.6	19.6	81.0	6.1	5.1
	MAR	928.1	22.6	20.1	19.0	80.5	5.4	5.5
	APR	929.8	21.4	18.7	17.4	78.7	4.6	5.2
	MAY	931.7	19.7	16.3	14.4	71.6	2.8	5.4
	JUN	933.6	17.4	14.0	11.7	70.7	2.9	5.4
	JUL	934.1	16.9	13.4	11.0	68.1	3.0	5.4
	AUG	933.0	18.6	14.2	11.4	62.9	2.4	6.8
	SEP	931.4	21.8	15.9	12.6	55.9	1.6	8.1
	OCT	929.9	24.2	17.8	14.4	52.8	2.5	8.8
	NOV	928.5	24.7	19.4	16.8	61.8	4.4	8.1
	DEC	927.2	23.7	20.6	19.3	76.4	6.2	6.4
1100	JAN	925.7	25.7	21.6	19.9	70.6	6.5	7.9
	FEB	925.7	25.8	21.7	20.1	71.2	6.3	7.4
	MAR	967.6	25.6	21.2	19.4	71.0	6.1	7.6
	APR	929.4	24.6	19.9	17.8	66.5	5.5	7.2
	MAY	931.3	23.4	17.6	14.5	58.8	3.9	7.3
	JUN	933.5	21.4	15.3	11.6	53.9	4.1	7.6
	JUL	934.0	21.2	14.7	10.7	50.5	3.8	7.4

	AUG	932.7	23.1	15.5	10.8	46.3	3.3	7.8
	SEP	930.5	26.2	17.2	12.1	41.6	2.7	8.5
	OCT	928.6	28.2	18.7	13.9	41.4	3.7	8.6
	NOV	927.3	28.1	20.2	16.6	50.0	5.2	8.2
	DEC	926.3	26.3	21.5	19.6	66.8	6.3	8.0
1400	JAN	923.6	26.2	21.6	19.7	67.9	6.6	8.2
	FEB	923.3	26.3	21.8	20.0	68.7	6.3	8.4
	MAR	925.1	26.2	21.4	19.4	67.1	6.1	8.6
	APR	927.0	25.4	20.3	18.1	64.1	5.7	8.4
	MAY	929.0	24.6	17.9	14.3	53.3	4.5	8.3
	JUN	931.2	22.5	15.7	11.7	50.5	4.7	8.4
	JUL	931.6	22.4	15.1	10.5	47.1	4.5	7.8
	AUG	930.0	24.7	15.8	10.3	40.5	4.3	8.1
	SEP	927.7	28.4	17.4	11.1	34.4	3.6	8.6
	OCT	925.9	30.1	18.7	12.7	34.3	4.7	8.7
	NOV	924.7	29.3	20.2	15.8	44.4	5.8	8.2
	DEC	924.0	27.2	21.5	19.2	62.2	6.4	8.2
1700	JAN	923.1	25.1	21.2	19.6	71.9	6.5	6.1
	FEB	923.0	25.1	21.3	91.7	72.2	6.3	6
	MAR	924.9	24.9	20.9	19.2	71.1	5.7	6.3
	APR	927.0	24.1	19.7	17.7	68.3	4.6	6.4
	MAY	929.4	22.6	17.3	14.4	60.2	3.3	6.3
	JUN	931.3	20.9	15.3	11.9	56.6	3.4	6.4
	JUL	931.9	20.8	14.8	10.9	53.6	3.8	7.3
	AUG	930.3	23.6	15.4	10.3	43.9	3.2	7.8
	SEP	928.1	26.9	16.7	10.6	37.3	2.7	8.8
	OCT	925.8	29.0	18.3	12.5	36.8	3.4	8.7
	NOV	924.7	27.7	19.7	15.8	48.9	5.5	8.2
	DEC	923.6	25.9	20.7	18.4	64.0	6.4	6.6
2000	JAN	924.5	23.1	20.6	19.6	80.5	6.0	4.8
	FEB	924.5	23.0	20.6	19.5	81.0	5.7	4.6
	MAR	926.4	22.8	19.9	18.7	78.0	5.0	6.3
	APR	928.4	21.4	18.5	17.1	77.0	3.5	7.2
	MAY	930.5	19.9	16.2	14.1	69.5	2.0	7.4
	JUN	932.4	17.8	14	11.5	67.1	2.6	7.3
	JUL	932.9	18.1	13.6	10.7	62.4	2.4	7.6
	AUG	931.5	20.1	14.2	10.3	53.1	1.9	8.2
	SEP	929.3	23.4	15.7	11.0	45.8	1.5	8.1
	OCT	927.1	25.6	17.3	12.8	44.9	2.2	8.2
	NOV	926.2	24.9	18.9	15.9	57.6	4.4	7.2
	DEC	925.5	23.6	20.3	18.8	74.9	5.9	5.4
2300	JAN	925.6	22.6	20.4	19.5	83.0	5.4	4.7
	FEB	926.0	22.1	20.2	19.4	85.3	5.6	5.0
	MAR	926.5	21.7	19.9	19.1	85.3	5.3	4.7
	APR	928.5	20.8	18.4	17.3	80.0	3.7	6.3
	MAY	930.7	18.6	15.6	13.9	77.0	1.4	7.0
	JUN	933.0	16.8	13.9	12.0	76.7	2.6	7.3

	JUL	932.7	16.6	12.8	10.2	65.5	1.7	7.6
	AUG	932.2	18.0	13.4	10.2	61.0	1.6	8.3
	SEP	929.7	21.4	15.4	11.9	55.0	0.8	8.3
	OCT	928.2	22.1	15.6	11.7	51.0	1.7	8.1
	NOV	925.1	25.2	19.3	16.3	58.0	1.7	7.2
	DEC	925.8	22.7	20.1	18.9	79.0	5.3	4.7

TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	888.6	18.8	18.0	17.6	92.6	6.5	2.1
	FEB	888.0	18.4	17.7	17.3	93.4	6.4	2.1
	MAR	890.1	17.7	17.2	16.9	94.8	5.9	2.7
	APR	891.3	16.3	15.8	15.4	95.1	5.3	2.9
	MAY	893.3	14.2	13.4	12.8	91.5	3.9	2.8
	JUN	895.1	12.3	11.3	10.4	88.2	4.2	3.6
	JUL	895.4	11.7	10.7	9.9	88.8	4.2	3.5
	AUG	894.4	13.1	11.4	10.2	83.1	3.4	3.8
	SEP	893.1	15.4	12.9	11.2	76.3	2.7	4.4
	OCT	891.8	17.8	14.9	13.2	74.2	3.0	4.7
	NOV	890.9	18.9	16.6	15.4	79.8	4.8	4.1
	DEC	889.6	19.2	17.7	17.1	88.0	6.2	2.7
800	JAN	889.3	21.4	19.2	18.2	82.2	6.2	3.7
	FEB	888.7	20.9	19.0	18.1	82.5	6.1	3.7
	MAR	890.9	20.3	18.5	17.6	84.5	5.3	4.3
	APR	892.8	19.1	17.3	16.3	83.8	4.8	4.2
	MAY	894.4	17.6	15.2	13.8	78.6	3.3	4.3
	JUN	896.1	15.2	12.9	11.3	77.7	3.7	5
	JUL	896.5	14.4	12.2	10.6	78.2	3.7	4.7
	AUG	895.6	16.2	12.9	10.7	69.9	2.7	5.7
	SEP	894.3	19.2	14.5	11.6	61.8	2.1	6.3
	OCT	892.9	21.5	16.3	13.5	60.4	2.6	6.4
	NOV	891.7	21.9	17.8	15.7	67.7	4.4	5.5
	DEC	890.2	21.7	18.9	17.6	77.8	5.9	4.2
1100	JAN	888.8	23.6	20.1	18.5	73.3	6.6	4.1
	FEB	889.2	23.5	20.1	18.6	73.8	6.6	4.4
	MAR	891.0	23.3	19.6	18.0	72.1	6.3	4.2
	APR	892.7	22.3	18.3	16.3	69.3	5.7	4.1
	MAY	894.3	21.2	16.0	13.1	60.1	4.3	4.3
	JUN	896.2	19.0	13.8	10.3	57.7	4.3	4.8
	JUL	896.8	18.4	13.2	9.6	56.3	4.2	5.1
	AUG	895.6	20.6	14.0	9.7	50.0	3.3	5.1
	SEP	894.0	23.6	15.7	10.9	44.8	3.1	5.4
	OCT	892.2	25.6	17.3	12.8	45.3	3.7	5.6
	NOV	891.1	25.1	18.7	15.6	56.0	5.4	4.9
	DEC	887.5	24.0	19.8	17.9	69.0	6.3	4.2
1400	JAN	887.0	23.6	20.1	18.6	73.7	6.8	3.7
	FEB	887.3	23.6	20.2	18.7	74.4	6.8	4.2
	MAR	888.4	23.3	19.7	18.1	72.8	6.5	3.9
	APR	890.8	22.6	18.7	16.8	70.1	6.1	3.8
	MAY	892.4	21.9	16.4	13.4	58.6	4.9	4.0
	JUN	893.8	19.6	14.1	10.5	55.9	4.8	4.5
	JUL	894.9	19.3	13.6	9.8	54.2	4.9	4.2
	AUG	893.5	21.8	14.2	9.1	44.4	4.3	4.6

	SEP	891.2	25.1	15.9	10.2	39.3	3.9	5.2
	OCT	889.9	26.9	17.4	12.1	39.8	4.4	5.2
	NOV	888.9	25.7	18.7	15.1	51.9	5.9	4.4
	DEC	887.8	24.1	19.7	17.7	68.5	6.6	3.8
1700	JAN	886.5	22.3	19.4	18.2	77.6	6.7	3.1
	FEB	886.9	22.1	19.6	18.4	79.8	6.4	3.4
	MAR	888.6	21.9	19.2	17.9	78.3	5.9	4.1
	APR	890.8	20.6	17.8	16.3	76.7	5.0	4.0
	MAY	892.6	19.1	15.6	13.6	70.6	3.8	3.4
	JUN	893.9	17.0	13.3	10.8	67.4	4.2	3.7
	JUL	895.0	17.1	12.9	10.1	63.7	4.1	4.1
	AUG	893.3	19.8	13.7	9.6	52.3	3.4	3.9
	SEP	890.8	23.0	15.2	10.2	44.8	3.2	4.9
	OCT	890.0	24.9	16.7	11.8	44.3	3.8	4.7
	NOV	888.0	24.2	18.0	14.8	56.2	5.5	4.4
	DEC	887.3	22.6	19.2	17.6	73.8	6.4	3.5

STATION NAME:	BVUMBWE	STATION NUMBER:	791	Latitude/ Longitude	15° 55'S 35° 04'E	Altitude	1146m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	_	18.3	17.7	17.4	93.9	6.4	2.0
	FEB	_	17.9	17.5	17.3	95.7	6.4	2.4
	MAR	_	17.2	16.8	16.6	91.7	6.0	2.6
	APR	_	15.9	15.7	15.4	96.0	5.3	3.4
	MAY	_	13.7	13.1	12.7	93.9	4.2	3.3
	JUN	_	11.9	11.1	10.5	91.1	4.3	3.4
	JUL	_	11.3	10.6	10.0	90.6	4.3	3.7
	AUG	_	12.4	11.2	10.2	86.3	3.6	3.6
	SEP	_	14.3	12.6	11.4	79.6	3.1	3.8
	OCT	_	17.0	14.7	13.3	78.5	3.2	4.3
	NOV	_	18.4	16.6	15.6	83.8	4.9	3.8
	DEC	_	18.4	17.5	17.0	91.3	6.2	2.6
800	JAN	_	20.8	18.9	18.1	84.1	6.1	3.5
	FEB	_	20.6	18.8	18.0	85.1	6.0	3.7
	MAR	_	19.6	18.1	17.3	87.1	5.6	4.1
	APR	_	18.5	17.0	16.2	86.9	4.8	4.7
	MAY	_	16.7	14.8	13.7	82.6	3.7	4.5
	JUN	_	14.6	12.7	11.4	81.0	3.9	4.5
	JUL	_	13.8	12.0	10.7	81.7	3.9	4.8
	AUG	_	15.5	12.9	11.2	74.5	3.0	5.6
	SEP	_	18.1	14.3	11.9	65.3	2.4	6.5
	OCT	_	20.7	16.1	13.6	63.9	2.6	6.6
	NOV	_	21.4	17.7	15.8	70.8	4.5	5.6
	DEC	_	21.1	18.7	17.5	80.6	5.8	4
1100	JAN	_	22.9	19.7	18.3	75.6	6.5	3.7
	FEB	_	22.9	19.7	18.3	75.3	6.5	4.2
	MAR	_	22.5	19.1	17.5	73.7	6.2	4.0
	APR	_	21.3	17.7	15.8	72.0	5.4	4.5
	MAY	_	19.8	15.4	12.8	64.5	4.4	4.6
	JUN	_	17.7	13.4	10.6	63.3	4.3	5.0
	JUL	_	17.4	12.9	9.9	61.7	4.2	5.3
	AUG	_	19.6	13.8	9.9	53.9	3.4	5.5
	SEP	_	22.4	15.2	10.7	47.7	3.0	6.2
	OCT	_	24.7	16.9	12.7	47.1	3.4	5.7
	NOV	_	24.6	18.4	15.4	56.7	5.5	4.8
	DEC	_	23.4	19.6	17.8	71.0	6.3	4.2
1400	JAN	_	22.9	19.8	18.4	75.6	6.6	3.4
	FEB	_	23.2	19.9	18.4	75.0	6.5	4.0
	MAR	_	22.7	19.4	17.8	73.9	6.4	4.1
	APR	_	21.9	18.2	16.2	70.8	5.7	4.2
	MAY	_	20.8	15.8	13.0	62.6	4.6	4.1
	JUN	_	18.8	13.9	10.7	59.8	4.6	4.5
	JUL	_	18.4	13.3	9.8	58.1	4.7	5.0
	AUG	_	20.9	14.1	9.5	47.8	3.9	5.1

	SEP	_	24.0	15.6	10.3	41.4	3.5	5.7
	OCT	_	26.2	17.1	11.9	40.5	4.1	5.4
	NOV	_	25.2	18.6	15.3	54.4	5.9	4.2
	DEC	_	23.4	19.4	17.6	70.8	6.5	3.9
1700	JAN	_	21.9	19.3	18.2	79.3	6.6	2.7
	FEB	_	21.7	19.4	18.3	81.5	6.4	2.8
	MAR	_	21.1	18.8	17.7	81.4	5.7	3.2
	APR	_	19.6	17.4	16.3	81.3	4.7	3.6
	MAY	_	18.0	15.2	13.6	75.7	3.4	2.8
	JUN	_	15.8	13.1	11.3	74.6	3.5	2.8
	JUL	_	15.9	12.7	10.4	70.9	3.7	3.6
	AUG	_	18.7	13.4	9.3	56.7	2.7	3.8
	SEP	_	21.9	14.7	10.1	47.4	2.5	4.4
	OCT	_	24.1	16.2	11.5	45.6	3.2	4.2
	NOV	_	23.4	17.8	14.9	59.5	5.4	4.0
	DEC	_	22.1	19.0	17.5	74.9	6.4	3.2

STATION NAME:	THYOLO	STATION NUMBER:	793	Latitude Longitude	16° 08'S 35° 08'E	Altitude	820m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
500	JAN	_	19.4	18.6	18.2	83.3	5.2	1.9
	FEB	_	19.2	18.7	18.5	96.0	5.6	1.9
	MAR	_	18.9	18.5	18.3	96.3	5.2	1.5
	APR	_	17.8	17.4	17.3	98.3	5.0	1.1
	MAY	_	14.6	13.9	13.7	95.0	4.0	1.7
	JUN	_	12.7	12.4	12.1	96.0	4.3	1.3
	JUL	_	12.1	11.6	11.2	94.7	3.8	1.8
	AUG	_	13.2	12.3	11.7	90.7	3.3	2.0
	SEP	_	14.6	13.2	12.3	86.7	2.5	2.2
	OCT	_	17.4	15.6	14.4	82.0	3.5	2.3
	NOV	_	18.8	17.4	16.7	88.0	5.7	1.6
	DEC	_	19.4	18.7	18.3	93.0	6.5	1.8
600	JAN	_	19.6	18.8	18.5	93.5	6.3	1.9
	FEB	_	19.5	18.8	18.5	94.3	6.2	1.6
	MAR	_	18.8	18.3	18.1	96.6	5.9	1.4
	APR	_	17.3	16.9	16.7	96.3	5.1	1.3
	MAY	_	14.8	14.2	13.8	94.6	4.1	1.6
	JUN	_	12.7	12.1	11.6	93.4	4.3	1.7
	JUL	_	12.3	11.6	11.1	93.9	4.4	1.5
	AUG	_	13.4	12.3	11.4	89.1	3.5	1.9
	SEP	_	15.4	13.6	12.4	81.1	3.1	2.7
	OCT	_	18.6	15.8	14.3	77.4	3.0	3.9
	NOV	_	19.7	17.7	16.6	82.8	4.9	2.8
	DEC	_	19.9	18.9	18.4	90.4	6.1	2
800	JAN	_	22.3	20.2	19.2	81.9	6.0	3.7
	FEB	_	22.2	20.2	19.3	81.9	5.8	2.9
	MAR	_	21.3	19.7	18.9	86.6	5.5	2.9
	APR	_	20.1	18.5	17.7	86.7	4.6	2.8
	MAY	_	17.9	16.2	15.2	84.4	3.9	2.6
	JUN	_	15.6	14.1	13.2	85.8	4.1	2.2
	JUL	_	15.2	13.7	12.6	85.6	4.2	2.4
	AUG	_	16.8	14.3	12.7	76.9	3.2	3.7
	SEP	_	19.6	15.6	13.3	66.2	2.4	5.4
	OCT	_	22.5	17.4	14.8	62.3	2.6	7.2
	NOV	_	23.3	19.0	17.0	67.8	4.5	5.5
	DEC	_	22.8	20.1	18.8	77.7	5.6	3.9
1100	JAN	_	25.3	21.3	19.7	71.5	6.3	4.4
	FEB	_	25.1	21.2	19.7	72.1	5.9	4.1
	MAR	_	24.7	20.8	19.2	73.3	5.6	3.8
	APR	_	23.4	19.4	17.6	70.2	4.7	3.4
	MAY	_	22.1	17.3	14.9	64.1	3.6	3.5
	JUN	_	20.1	15.4	12.6	62.6	3.7	3.4
	JUL	_	19.6	14.9	12.1	62.1	3.8	3.6

	AUG	_	22.1	15.7	11.8	52.9	2.8	4.6
	SEP	_	24.8	17.0	12.6	47.1	2.6	5.2
	OCT	_	27.1	18.6	14.2	45.3	3.0	5.8
	NOV	_	27.1	20.1	16.9	54.2	4.7	4.9
	DEC	_	25.8	21.1	19.2	67.1	5.9	4.4
1400	JAN	_	25.3	21.3	19.7	71.5	6.5	4.0
	FEB	_	25.3	21.5	19.9	71.9	6.3	3.9
	MAR	_	24.7	20.9	19.3	72.0	6.0	3.4
	APR	_	24.1	19.8	17.9	68.6	5.2	3.0
	MAY	_	22.7	17.5	14.8	60.6	4.1	3.0
	JUN	_	20.9	15.6	12.4	59.6	4.1	3.3
	JUL	_	20.7	15.1	11.7	56.7	4.3	3.3
	AUG	_	23.5	15.9	11.3	46.9	3.5	3.7
	SEP	_	26.4	17.2	12.0	41.3	3.1	4.1
	OCT	_	28.9	18.7	13.5	39.0	3.8	4.2
	NOV	_	27.6	20.1	16.7	51.2	5.5	3.8
	DEC	_	25.6	20.9	19.0	66.4	6.3	3.8
1700	JAN	_	24.3	21.1	19.6	75.5	6.4	2.6
	FEB	_	24.1	21.0	19.7	77.1	6.0	2.6
	MAR	_	23.7	20.8	19.5	76.2	5.1	1.9
	APR	_	22.2	19.3	18.0	76.7	4.3	1.5
	MAY	_	20.8	17.4	15.7	72.8	3.0	0.9
	JUN	_	18.6	15.3	13.4	72.2	3.1	1.2
	JUL	_	18.7	14.9	12.7	68.2	3.6	1.6
	AUG	_	21.7	15.6	12.1	54.6	2.5	1.8
	SEP	_	24.6	16.8	12.4	46.9	2.2	2.3
	OCT	_	27.0	18.2	13.5	43.7	2.8	2.5
	NOV	_	26.2	19.7	16.6	56.3	5.0	2.5
	DEC	_	24.6	20.6	18.9	70.3	6.2	2.3
2000	JAN	_	22.2	19.8	18.6	_	5.9	_
	FEB	_	21.7	20.1	19.2	_	6.3	_
	MAR	_	21.5	20.1	19.4	_	6.3	_
	APR	_	21.0	19.3	18.3	_	5.2	_
	MAY	_	18.4	16.4	15.3	_	4.7	_
	JUN	_	17.1	14.6	12.8	_	3.7	_
	JUL	_	16.3	13.9	12.2	_	3.5	_
	AUG	_	16.9	14.2	12.2	_	3.6	_
	SEP	_	20.2	16.4	13.9	_	3.2	_
	OCT	_	22.9	18.2	15.3	_	2.9	_
	NOV	_	23.4	19.2	16.9	_	4.5	_
	DEC	_	22.4	20.2	19.2	_	6.3	_

STATION NAME:	NGABU	STATION NUMBER:	796	Latitude/ Longitude	16° 30'S 34° 57'E	Altitude	102m	
TIME	MONTH	STATION PRESSURE HPA	DRY BULB TEMP. DEG. C	WET BULB TEMP DEG.C	DEW POINT TEMP DEG. C	RELATIVE HUMIDITY %	CLOUD AMOUNT OCTAS	WIND RUN KNOTS
600	JAN	_	24.1	22.8	22.3	89.8	6.2	0.9
	FEB	_	23.6	22.6	22.2	91.0	6.6	0.9
	MAR	_	23.1	22.3	22.0	91.1	5.8	0.7
	APR	_	21.3	20.4	20.0	92.9	4.9	0.7
	MAY	_	18.2	17.2	16.7	91.0	3.6	0.5
	JUN	_	15.8	14.8	14.3	91.1	3.7	0.7
	JUL	_	15.7	14.6	13.8	90.6	3.6	2.0
	AUG	_	16.8	15.4	14.6	87.0	2.6	1.1
	SEP	_	20.1	17.7	16.4	80.0	2.3	2.2
	OCT	_	23.1	19.6	17.9	73.2	2.7	2.9
	NOV	_	24.5	21.3	19.8	72.3	4.9	2.6
	DEC	_	24.4	22.6	21.8	85.4	6.3	1.6
800	JAN	_	26.8	23.8	22.7	78.0	6.2	2.4
	FEB	_	26.4	23.7	22.7	80.3	6.3	2.4
	MAR	_	25.7	23.4	22.6	83.1	5.8	2.5
	APR	_	24.1	21.9	21.0	83.0	5.1	2.5
	MAY	_	21.6	19.3	18.3	80.9	3.7	2.5
	JUN	_	18.6	16.7	15.7	83.0	3.8	1.8
	JUL	_	18.4	16.3	15.1	82.7	3.6	2.1
	AUG	_	20.3	17.3	15.7	75.2	2.8	3.2
	SEP	_	23.8	19.5	17.3	68.8	2.2	4.8
	OCT	_	27.0	21.1	18.3	59.2	3.0	5.7
	NOV	_	27.8	22.5	20.3	63.6	4.9	4.5
	DEC	_	27.3	23.6	22.2	74.0	6.2	3.0
11000	JAN	_	30.6	24.7	22.5	62.3	6.1	2.1
	FEB	_	30.1	24.6	22.4	65.7	6.2	2.4
	MAR	_	29.3	24.5	22.6	67.0	5.8	1.9
	APR	_	27.7	22.8	20.8	66.3	5.0	1.9
	MAY	_	26.5	20.8	18.2	61.0	3.7	2.0
	JUN	_	24.1	18.7	15.9	60.4	3.9	2.0
	JUL	_	23.8	18.2	15.1	58.3	3.9	2.1
	AUG	_	26.1	19.0	15.1	58.0	2.8	2.8
	SEP	_	29.4	20.7	16.3	45.5	2.3	3.3
	OCT	_	32.1	22.0	17.3	41.7	2.9	3.5
	NOV	_	32.6	23.3	19.4	45.7	4.6	3.1
	DEC	_	31.2	24.4	21.8	57.9	5.9	2.4
1400	JAN	_	32.0	24.7	21.8	55.3	6.4	3.0
	FEB	_	31.9	24.9	22.1	56.1	6.2	3.1
	MAR	_	31.1	24.6	22.1	59.1	5.8	2.5
	APR	_	29.6	22.9	20.2	57.1	5.1	3.2
	MAY	_	29.1	20.9	17.1	48.7	4.0	2.4
	JUN	_	26.5	18.8	14.7	48.9	4.2	2.8

	JUL	_	26.3	18.2	13.6	45.9	4.2	2.9
	AUG	_	29.2	19.0	13.2	37.5	3.4	3.5
	SEP	_	32.8	20.8	14.7	33.7	2.4	4.2
	OCT	_	35.0	21.9	15.5	31.5	3.7	5.0
	NOV	_	34.8	23.3	18.2	37.9	5.0	4.1
	DEC	_	32.7	24.2	20.7	49.4	6.1	3.5
1700	JAN	_	30.0	24.3	22.1	64.7	6.6	2.6
	FEB	_	30.2	24.6	22.3	63.0	6.2	2.3
	MAR	_	29.2	24.2	22.1	66.0	5.6	2.0
	APR	_	27.8	22.7	20.5	65.0	4.7	1.5
	MAY	_	27.2	20.6	17.4	55.7	3.5	1.6
	JUN	_	24.6	18.4	15.0	55.7	3.7	1.3
	JUL	_	25.1	17.8	13.5	51.7	3.7	1.8
	AUG	_	28.3	18.6	13.0	39.2	2.7	2.4
	SEP	_	31.6	20.2	13.9	37.7	2.1	3.8
	OCT	_	33.6	21.2	14.9	32.8	3.0	4.8
	NOV	_	33.3	22.7	17.8	40.1	5.0	4.1
	DEC	_	30.7	23.9	21.0	56.8	6.4	3.1

APPENDIX 4.2 MET. STATIONS, ALTITUDE, AND PERIOD OF DATA COLLECTION

LOCATION	ALTITUDE	PERIOD OF DATA COLLECTION	NO .OF YEARS
DEDZA	1632	1958_1978	20
MZIMBA	1349	1949_1978	29
CHITIPA	1285	1956_1978	22
CHITEDZE	1149	1952_1978	26
BVUMBWE	1146	1957_1978	21
LILONGWE	1135	1949_1978	29
CHICHIRI	1132	1966_1978	16
MZUZU	1100	1963_1977	14
MAKOKA	1029	1969_1978	9
TYOLO	820	1949_1978	29
CHILEKA	676	1968_1978	10
MIMOSA	652	1969_1978	9
KARONGA	512	1949_1978	29
SALIMA	512	1954_1977	23
NKOTA KOTA	500	1950_1978	28
NKATA BAY	500	1955_1977	22
MANGOCHI	482	1969_1978	9
NGABU	102	1972_1978	6
MAKHANGA	52	1962_1978	16
MEAN PERIOD			19.3

APPENDIX 4.3

LEVELS OF IRRANDIATION FROM NINETEEN METEOROLOGICAL STATIONS Cals/cm^2/Day and MJ/m^2/Day

ALTITUDE	1196.8	1133.1	767.1	1149.9	1285.6	1633.3	529.2	1134.6	51.9	1029.4	481.9	652.7	1349.6	1255.1	102.2	500.2	500.2	512.4	820.5
LOCATION	BVUMBWE	CHICHIRI	CHILEKA	CHITEDZE	CHITIPA	DEDZA	KARONGA	LILONG WE	MAKHANGA	MAKOKA	MANGOCHI	MIMOSA	MZIMBA	MZUZU	NGABU	NKHATA BAY	NKHOT A KOTA	SALIMA	THYOLO
MONHTS																			
January	490	492	505	473	435	465	483	468	561	497	521	503	455	449	556	478	470	490	513
MJ/m^2/Day	20.51	20.60	21.14	19.80	18.21	19.46	20.22	19.59	23.48	20.80	21.81	21.06	19.05	18.80	23.27	20.01	19.67	20.51	21.47
February	456	466	485	468	470	453	494	447	518	479	504	475	464	475	531	507	476	492	472
MJ/m^2/Day	19.09	19.51	20.30	19.59	19.67	18.96	20.68	18.71	21.68	20.05	21.10	19.88	19.42	19.88	22.23	21.22	19.93	20.60	19.76
March	446	455	474	466	445	463	496	450	500	451	498	467	434	438	477	460	461	498	458
MJ/m^2/Day	18.67	19.05	19.84	19.51	18.63	19.38	20.76	18.84	20.93	18.88	20.85	19.55	18.17	18.33	19.97	19.26	19.30	20.85	19.17
April	408	423	455	463	456	429	453	455	467	410	476	398	453	404	455	436	475	471	415
MJ/m^2/Day	17.08	17.71	19.05	19.38	19.09	17.96	18.96	19.05	19.55	17.16	19.93	16.66	18.96	16.91	19.05	18.25	19.88	19.72	17.37
May	417	430	449	452	467	446	470	455	433	408	473	413	462	424	433	457	472	501	423
MJ/m^2/Day	17.46	18.00	18.80	18.92	19.55	18.67	19.67	19.05	18.13	17.08	19.80	17.29	19.34	17.75	18.13	19.13	19.76	20.97	17.71
June	373	392	399	422	495	414	458	422	383	382	427	366	462	419	388	428	466	459	374
MJ/m^2/Day	15.61	16.41	16.70	17.66	20.72	17.33	19.17	17.66	16.03	15.99	17.87	15.32	19.34	17.54	16.24	17.92	19.51	19.21	15.66
July	392	406	417	427	512	427	486	428	400	403	437	373	470	436	400	454	464	460	390
MJ/m^2/Day	16.41	17.00	17.46	17.87	21.43	17.87	20.34	17.92	16.74	16.87	18.29	15.61	19.67	18.25	16.74	19.00	19.42	19.26	16.33
August	479	488	496	509	574	504	576	508	498	477	510	469	558	526	501	544	540	542	493
MJ/m^2/Day	20.05	20.43	20.76	21.31	24.03	21.10	24.11	21.26	20.85	19.97	21.35	19.63	23.36	22.02	20.97	22.77	22.60	22.69	20.64
September	551	564	560	590	615	590	625	581	552	568	588	551	618	608	555	615	596	602	537
MJ/m^2/Day	23.06	23.61	23.44	24.70	25.74	24.70	26.16	24.32	23.11	23.78	24.61	23.06	25.87	25.45	23.23	25.74	24.95	25.20	22.48
October	590	606	599	634	635	642	655	627	610	603	637	591	664	648	582	601	641	651	605
MJ/m^2/Day	24.70	25.37	25.07	26.54	26.58	26.87	27.42	26.25	25.53	25.24	26.66	24.74	27.80	27.13	24.36	25.16	26.83	27.25	25.33
November	553	592	579	547	593	586	630	566	610	566	616	572	595	610	607	625	627	636	569
MJ/m^2/Day	23.15	24.78	24.24	22.90	24.82	24.53	26.37	23.69	25.53	23.69	25.79	23.94	24.91	25.53	25.41	26.16	26.25	26.62	23.82
December	479	485	511	475	487	492	549	479	544	476	544	489	489	506	519	536	527	534	476
MJ/m^2/Day	20.05	20.30	21.39	19.88	20.39	20.60	22.98	20.05	22.77	19.93	22.77	20.47	20.47	21.18	21.73	22.44	22.06	22.35	19.93

APPENDIX 4.4 SOLAR RADIATION AS RECORDED IN ALL THE STATIONS UNDER STUDY
Cals cm^{-2} Day^{-1}

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
SALIMA	512	523	557	529	502	462	468	503	553	602	604	539
CHITIPA	435	470	445	456	476	495	512	574	615	635	593	487
TYOLO	537	536	521	494	481	425	430	506	565	600	582	535
NGABU	556	531	477	455	433	388	400	501	555	582	607	519
MZUZU	449	475	438	404	424	419	426	526	608	648	610	506
CHILEKA	505	485	474	455	449	399	417	496	560	599	579	511
BVUMBWE	404	425	421	394	410	378	378	437	488	493	463	399
CHITEDZE	456	467	519	473	411	423	411	474	520	527	537	469
MKHANGA	551	538	529	436	450	421	432	499	538	573	579	550
MIMOSA	533	520	504	457	442	385	390	462	540	570	562	524
CHICHIRI	490	456	446	408	417	373	392	479	551	590	553	479
DEDZA	465	453	463	429	446	414	427	504	590	642	586	492
KARONGA	483	494	496	453	470	453	486	576	625	655	630	549
LILONGWE	468	447	450	455	455	422	428	508	581	627	566	479
MAKOKA	497	479	451	410	408	382	403	477	568	603	566	476
MANGOCHI	521	504	498	476	473	427	437	510	588	637	616	544
MZIMBA	455	464	434	453	462	462	470	558	618	664	595	489
NKATA BAY	478	507	460	436	457	428	454	544	615	601	625	536

PPENDIX 4.5 METEOROLOGICAL DATA FOR 24 HOUR (DAILY) MEAN TEMPERATURE SUMMARIES

Station Number:	CHITIPA	Station Number	421	Latitude Longitude	9° 42'S 33° 16'E	Altitude	1285m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	20.3	20.3	20.2	20.1	18.8	17.2	16.7	18.1	20.7	23.0	23.1	21.0	20.0
REL HUMIDITY (%)	83.0	83.0	84.0	82.0	76.0	72.0	69.0	62.0	54.0	49.0	59.0	77.0	71.0
WIND (2 meter height) m/s	0.6	0.6	0.8	1.3	1.3	1.3	1.5	1.7	1.9	1.9	1.4	1.3	2.8
WIND (10 metres height) m/s													
EVAPORATION (mm)	132.5	126.2	132.8	126.7	157.9	149.8	175	188.4	289.5	309.6	289.0	156.9	2234.3
EVAPOTRANSPIRATION mm)	126.2	114.2	125.9	124.5	123.7	112.5	126.8	158.1	193.8	225.7	185.1	137.6	1754.1
POT. EVAPOTRANSP. (mm)	162.4	147.3	162.4	161.7	162.1	140.2	165.2	201.5	240.6	277.1	230.4	175.8	2234.7
RAINFALL (mm)	208.2	213.6	199.3	58.9	6.8	0.5	1.0	0.0	0.2	4.5	60.1	205.2	1038.8
RAINY DAYS 0.3 mm	22	21	20	11	3	0	0	0	0	1	7	20	9
1.0mm	19	17	17	9	2	0	0	0	0	1	5	17	7
10.0mm	6	7	7	2	0	0	0	0	0	0	2	7	3
SUNSHINE (HOURS)	4.6	4.7	5.2	6.9	8.5	9.4	9.4	9.9	9.9	9.5	7.8	5.2	7.6
CLOUDS (OCTAS)	6.3	6.4	6.1	5.6	3.9	2.9	2.5	1.8	2.0	2.9	4.7	6.0	4.3
THUNDER DAYS	24	22	21	9	1	0	0	0	0	3	13	27	120
PRESSURE (HPA)													

Station Name	KARONGA	Station Number	423	Latitude/ Longitude	9^0 56'S 33° 55'E	Altitude	529m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	25.0	24.8	24.6	24.5	23.3	21.8	21.2	21.9	23.7	25.8	26.8	25.7	24.1
REL HUMIDITY (%)	80.0	80.0	83.0	80.0	75.0	69.0	67.0	67.0	64.0	60.0	64.0	76.0	72.0
WIND (2 meters height) m/s	1.3	1.3	1.3	1.7	1.7	1.9	2	1.9	2	2.1	1.9	1.5	1.7
WIND (10 meters height) m/s													
EVAPORATION (mm)	168.6	159.5	170.6	156.9	184.4	189.9	196.5	213.8	264.4	310.6	264.4	215.9	2495.5
EVAPOTRANSPIRATION (mm)	151.6	139.2	148.2	138.9	137.3	125.4	134.9	154.1	180	216.7	199.5	167.4	1893.2
POT. EVAPOTRANSP. mm)	192.5	177.5	190.0	178.1	176.1	161.4	173.9	198.7	228.9	271.9	250.2	212.0	2411.6
RAINFALL (mm)	180.3	161.5	334.7	223	35.0	6.3	1.5	1.7	0.2	3.5	47.7	169.4	1164.8
RAINY DAYS 0.3mm	17	16	21	16	6	2	1	1	0	0	5	15	8
1.0mm	13	14	19	14	3	1	1	0	0	0	4	14	7
10.0mm	5	6	10	7	1	0	0	0	0	0	2	6	3
SUNSHINE (HOURS)	5.7	6.2	6.7	7.0	8.4	8.7	9.0	10.1	10.3	10.4	9.1	6.9	8.2
CLOUDS (OCTAS)	6.4	6.3	6.2	5.5	4.4	3.8	3.5	2.2	2.1	2.8	4.7	6.0	4.5
THUNDER DAYS	23	21	25	15	3	0	0	0	0	1	10	22	120
PRESSURE (HPA)													

Station Name:	CHITEDZE	Station Number	585	Latitude/ Longitude	13° 59'S, 33° 38'E	Altitude	1149m		585				
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	20.8	20.7	20.5	19.6	17.6	15.5	15.4	17	19.8	22.3	22.7	21.3	19.5
REL HUMIDITY (%)	84.0	85.0	83.0	79.0	72.0	67.0	63.0	58.0	52.0	50.0	60.0	78.0	69.0
WIND (2 meters height) m/s	1.3	1.1	1.2	1.3	1.4	1.6	1.8	2	2.3	2.4	2.2	1.6	1.7
WIND (10 meters height) m/s													
EVAPORATION (mm)	108.4	100.8	116.0	112.2	111.2	108.4	122.4	154.4	209.0	255.5	206.5	147.0	1751.8
EVAPOTRANSPIRATION (mm)	131.4	115.1	127.1	114.6	99.5	84.3	94.2	119.4	150.9	183.2	167.4	138	1525.1
POT. EVAPOTRANSP. (mm)	169.6	149.2	166.5	152.1	133.6	113.4	124.6	155.9	193.8	233.4	211.8	176.4	1980.3
RAINFALL (mm)	229.3	197.1	138.6	48.0	9.6	2.5	0.5	0.5	2.0	4.3	82.0	204.7	919.1
RAINY DAYS 0.3mm	20	18	14	7	2	1	0	0	0	1	7	18	7
1.0mm	17	16	11	6	1	0	0	0	0	1	6	16	6
10.0mm	7	6	4	2	0	0	0	0	0	0	3	6	2
SUNSHINE (HOURS)	5.1	5.4	6.6	7.8	8.5	8.1	7.9	8.7	9.3	9.8	7.7	5.4	7.5
CLOUDS (OCTAS)	6.5	6.3	5.8	4.8	3.4	3.1	3.0	2.4	2.1	2.9	5.0	6.2	4.3
THUNDER DAYS	20	16	12	6	1	0	0	0	1	3	11	21	91
PRESSURE (HPA)													

STATION NAME:	MZUZU	Station Number	489	Latitude/ Longitude	11° 26'S 34° 01'E	Altitude	1100m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	19.7	19.8	19.3	18.5	16	13.6	12.8	13.7	16.3	19.1	20.5	19.9	17.4
REL HUMIDITY (%)	86.0	86.0	89.0	90.0	90.0	89.0	87.0	81.0	72.0	65.0	73.0	83.0	83.0
WIND (2meters height) m/s	1.5	1.5	1.6	1.8	1.7	1.7	1.7	1.7	1.9	2.1	2	1.5	1.7
WIND (10 meters height) m/s	1.9	2	2	2.6	2.2	2.4	2.3	2.5	2.5	3	2.5	2	2.3
EVAPORATION (mm)	112.2	110.2	114.3	87.8	94.9	84.8	90.6	108.7	178	220.7	212.8	151.8	1566.8
EVAPOTRANSPIRATION (mm)	121.5	110.6	114.7	100.8	88	72.3	72.2	98	128.4	160	151.5	129.3	1352.3
POT. EVAPOTRANSP.	157.2	143.4	150	132.9	120.0	100.5	107.6	134.2	170.4	208.3	196.5	167.1	1788.1
RAINFALL (mm)	198.6	181.3	226.5	201.6	51.8	34.5	22.8	11.4	11.6	22.3	67.0	188.9	1218.3
RAINY DAYS 0.3mm	22	20	22	20	10	7	5	3	2	3	9	19	12
1.0mm	18	15	18	16	7	5	4	2	1	2	6	15	9
10.0mm	7	5	8	7	1	1	1	0	0	1	2	6	3
SUNSHINE (HOURS)	4.8	5.0	5.4	5.7	7.0	7.5	7.6	8.9	9.7	10.0	8.7	5.7	7.2
CLOUDS (OCTAS)	6.8	6.7	6.5	6.3	5.3	4.7	4.6	3.5	3.1	3.3	5.0	6.3	5.2
THUNDER DAYS	20	19	18	8	1	0	0	0	0	1	9	22	98
PRESSURE (HPA)													

Station Name	MZIMBA	Station Number	485	Latitude/ Longitude	11° 53'S 33° 37'E	Altitude	1349m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	19.9	m9.8	19.7	19.4	17.7	15.8	15.3	16.7	19.4	22.0	22.1	20.6	19.0
REL HUMIDITY (%)	84.0	84.0	83.0	80.0	74.0	71.0	69.0	63.0	57.0	54.0	63.0	78.0	72.0
WIND (2 meters height) m/s		1	1.1	11.3	1.5	1.7	1.8	2	2.1	2.1	1.7	1.1	1.5
WIND (10meters height) m/s	1.8	1.9	2.3	3.1	3.4	3.6	3.8	4.3	4.6	4.6	3.5	2.2	3.2
EVAPORATION (mm)	113.0	111.5	110.9	114.0	121.4	120.9	132.5	143.5	183.8	251.9	211.5	145.7	1760.6
EVAPOTRANSPIRATION (mm)	122.8	114.4	124.6	120.9	118.1	101.4	109.1	138.9	173.4	209.9	177.3	135.8	1646.3
POT. EVAPOTRANSP. (mm)	158.4	144.2	160.9	156.9	154.7	134.1	142.9	178.9	219.3	262.3	222.9	173.3	2108.8
RAINFALL (mm)	223.7	197.3	156.2	40.8	7.1	1.2	1.0	0.5	1.5	2.7	57.6	174.7	864.3
RAINY DAYS 0.3 mm	21	20	16	8	2	1	1	1	0	1	6	17	8
1.0mm	18	15	13	5	1	0	1	0	0	1	5	15	6
10.0mm	8	6	5	1	0	0	0	0	0	0	2	6	3
SUNSHINE (HOURS)	4.4	4.5	5.3	7.2	8.6	8.7	8.7	9.5	9.9	10.2	8.2	5.4	7.6
CLOUDS (OCTAS)	6.9	6.7	6.4	5.3	3.6	3.0	3.2	2.3	2.2	3.0	5.1	6.5	4.6
THUNDER DAYS	18	16	13	5	1	0	0	0	0	3	10	18	84
PRESSURE (HPA)	865.6	865.6	866.4	867.3	869.1	870.3	870.6	869.7	868.5	867.0	866.1	865.9	867.7

Station Name:	NKHATA BAY	Station Name	493	Latitude/ Longitude	11° 36'S, 34° 18'E	Altitude	500m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	24.4	24.3	23.8	23.5	21.7	19.9	19.3	20.4	22.4	24.5	25.6	24.8	22.8
REL HUMIDITY (%)	84.0	84.0	85.0	84.0	81.0	79.0	75.0	72.0	69.0	67.0	70.0	80.0	78.0
WIND (2 meters height) m/s	1.1	1.1	1.1	1.1	1.3	1.4	1.5	1.6	1.6	1.7	1.5	1.2	1.3
WIND (10 meters height) m/s													
EVAPORATION (mm)	120.3	127.2	122.4	112.7	116.0	108.2	117.8	143.7	184.1	214.6	211.0	150.1	728.1
EVAPOTRANSPIRATION (mm)	143.8	130.2	139.2	127.2	121.2	106.2	17.2	139.5	164.4	196.5	184.5	156.2	1726.1
POT. EVAPOTRANSP . (mm)	183.2	178.2	178.6	163.5	157.2	138.3	151.9	180.7	210.9	249.2	233.7	198.4	2223.8
RAINFALL (mm)	274.5	212.5	372.1	290.8	105.9	55.1	28.4	5.8	4.0	11.6	103.3	230.3	1694.6
RAINY DAYS 0.3mm	21	19	22	19	10	7	5	2	1	1	6	16	11
1.0mm	17	15	20	17	8	4	3	1	1	1	6	15	9
10.0mm	8	6	11	8	3	1	1	0	0	0	3	7	4
SUNSHINE (HOURS)	5.6	5.9	5.9	6.6	7.8	8.1	8.1	9.4	10.1	10.5	9.0	6.7	7.7
CLOUDS (OCTAS)	6.3	6.1	5.9	5.1	4.1	3.4	3.6	2.4	2.1	2.1	4.1	5.8	4.3
THUNDER DAYS	21	20	21	11	2	0	0	0	0	2	9	20	106
PRESSURE (HPA)													

Station Name	NKHOTAKOTA	Station Number	591	Latitude/ Longitude	12 ° 56' S 34° 18' E	Altitude	500m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	42.2	24.3	24.2	23.8	22.0	20.2	19.9	21	23.2	25.8	26.5	25.2	23.3
REL HUMIDITY (%)	84.0	83.0	81.0	79.0	73.0	69.0	65.0	63.0	61.0	57.0	63.0	77.0	71.0
WIND (2 meters height) m/s	0.8	0.8	0.9	1	1.2	1.3	1.4	1.3	1.3	1.4	1.3	1	1.1
WIND (10 meters height) m/s													
EVAPORATION (mm)	136.1	132.0	136.9	134.6	159.7	163.3	189.4	218.1	245.1	309.3	289.0	193.2	2306.7
EVAPOTRANSPIRATION (mm)	145.7	131.6	147.3	135.6	130.5	115.5	124.9	146.3	173.7	212.4	196.8	159.3	1819.6
POT. EVAPOTRANSP. (mm)	186.0	167.7	188.5	174.3	169.3	149.7	160.6	187.6	220.2	266.0	246.3	201.8	2318.0
RAINFALL (mm)	344.9	325.1	381.0	197.1	39.6	10.9	8.1	2.2	1.2	9.1	65.0	246.6	1630.8
RAINY DAYS 0.3 mm	21	20	20	13	5	3	2	1	0	1	6	16	9
1.0mm	19	16	18	12	3	2	1	0	0	1	5	15	8
10.0mm	10	7	9	5	1	0	0	0	0	0	2	8	4
SUNSHINE (HOURS)	5.3	5.7	6.6	7.8	9.2	9.4	9.0	9.6	10.0	10.3	9.2	6.5	8.2
CLOUDS (OCTAS)	6.3	6.2	5.6	4.7	2.9	2.7	3.0	2.2	1.9	2.1	4.1	5.9	4.0
THUNDER DAYS	22	19	21	10	1	0	0	0	0	2	11	20	106
PRESSURE (HPA)													

Station Name:	CHITEDZE	Station Number	585	Latitude/ Longitude	13° 59'S, 33° 38'E	Altitude	1149m		585				
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	20.8	20.7	20.5	19.6	17.6	15.5	15.4	17	19.8	22.3	22.7	21.3	19.5
REL HUMIDITY (%)	84.0	85.0	83.0	79.0	72.0	67.0	63.0	58.0	52.0	50.0	60.0	78.0	69.0
WIND (2 meters height) m/s	1.3	1.1	1.2	1.3	1.4	1.6	1.8	2	2.3	2.4	2.2	1.6	1.7
WIND (10 meters height) m/s													
EVAPORATION (mm)	108.4	100.8	116.0	112.2	111.2	108.4	122.4	154.4	209.0	255.5	206.5	147.0	1751.8
EVAPOTRANSPIRATION (mm)	131.4	115.1	127.1	114.6	99.5	84.3	94.2	119.4	150.9	183.2	167.4	138	1525.1
POT. EVAPOTRANSP. (mm)	169.6	149.2	166.5	152.1	133.6	113.4	124.6	155.9	193.8	233.4	211.8	176.4	1980.3
RAINFALL (mm)	229.3	197.1	138.6	48.0	9.6	2.5	0.5	0.5	2.0	4.3	82.0	204.7	919.1
RAINY DAYS 0.3mm	20	18	14	7	2	1	0	0	0	1	7	18	7
1.0mm	17	16	11	6	1	0	0	0	0	1	6	16	6
10.0mm	7	6	4	2	0	0	0	0	0	0	3	6	2
SUNSHINE (HOURS)	5.1	5.4	6.6	7.8	8.5	8.1	7.9	8.7	9.3	9.8	7.7	5.4	7.5
CLOUDS (OCTAS)	6.5	6.3	5.8	4.8	3.4	3.1	3.0	2.4	2.1	2.9	5.0	6.2	4.3
THUNDER DAYS	20	16	12	6	1	0	0	0	1	3	11	21	91
PRESSURE (HPA)													

Station Name:	LILONGWE	Station Number	587	Latitude/ Longitude	13 ° 57'S 33° 55' E	Altitude	1135m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	21.0	20.9	20.7	19.7	17.6	15.6	15.2	17.0	19.9	22.7	23.0	21.7	19.6
REL HUMIDITY (%)	84.0	85.0	82.0	79.0	72.0	68.0	64.0	58.0	53.0	51.0	62.0	78.0	70.0
WIND (2 meters height) m/s													
WIND (10 meters height) m/s	3.5	3.6	3.9	4.4	4.4	5.1	5.5	5.7	6.3	6.6	5.8	4.1	4.9
EVAPORATION (mm)	135.3	112.5	122.1	112.5	127.7	119.3	128.2	163.3	207.7	263.9	216.6	154.9	1864.0
EVAPOTRANSPIRATION (m/s)	132.4	116.8	130.8	117.9	105.1	91.2	100.8	127.7	159.0	193.4	174.9	139.5	1589.5
POT. EVAPOTRANSP. (m/s)	169.9	150.6	169.6	154.5	139.5	120.3	131.1	164.6	201.6	243.4	219.6	177.6	2042.3
RAINFALL (mm)	215.3	202.9	133.8	41.9	8.8	1.0	1.0	1.0	3.3	6.0	66.2	166.3	847.5
RAINY DAYS 0.3 mm	20.0	18.0	14.0	7.0	2.0	1.0	0.0	0.0	1.0	1.0	7.0	16.0	7.0
1.0mm	17.0	14.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	16.0	1.0
10.0mm	7	6	0	0	0	0	0	0	0	0	0	1	0
SUNSHINE (HOURS)	4.8	5.2	6.3	7.7	8.4	8.0	7.9	8.5	9.1	9.7	7.6	5.3	7.4
CLOUDS (OCTAS)	6.6	6.6	6.0	5.1	3.6	3.3	3.4	2.7	2.3	3.1	5.3	6.4	4.6
THUNDER DAYS	21	17	15	6	1	0	0	0	1	3	11	21	96
PRESSURE (HPA)	886.9	886.8	888.1	889.5	891.4	892.9	893.3	892.2	890.6	888.7	888.0	887.3	889.7

Station Name	SALIMA	Station Number	597	Latitude/ Longitude	13 ° 45' S 34° 35' E	Altitude	512m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	24.7	24.5	24.7	24.3	22.2	20.6	20.4	21.7	23.9	26.3	27.1	25.6	23.9
REL HUMIDITY (%)	80.0	82.0	77.0	72.0	68.0	63.0	60.0	56.0	54.0	52.0	58.0	73.0	66.0
WIND (2 meters height) m/s	0.7	0.8	0.9	1.1	1.1	1.1	1.2	1.1	1.0	1.1	1.1	0.9	1.0
WIND (10 meters height) m/s												3.2	2.2
EVAPORATION (mm)	151.8	159.2	180.8	190.2	198.8	179.5	168.6	187.7	232.4	296.1	282.7	204.4	2432.2
EVAPOTRANSPIRATION (mm)	153.5	135.0	158.1	140.2	132.1	115.5	125.2	145.7	170.4	209.6	198.6	166.2	1858.1
POT. EVAPOTRANSP. (mm)	195.3	172.2	201.5	109.6	171.4	149.4	160.6	187.2	216.9	263.5	248.7	209.6	2365.9
RAINFALL (mm)	337.0	304.8	258.0	91.1	12.7	2.7	0.5	0.5	1.0	5.3	37.3	230.3	1281.2
RAINY DAYS 0.3mm	19	18	14	7	1	1	0	0	0	1	5	14	7
1.0mm	17	15	13	6	1	0	0	0	0	1	4	12	6
10.0mm	10	8	7	3	1	0	0	0	0	0	2	7	3
SUNSHINE (HOURS)	5.8	6.1	7.4	8.8	9.5	9.1	8.8	9.7	9.9	10.2	8.9	6.7	8.4
CLOUDS (OCTAS)	6.3	6.3	5.6	4.1	2.5	2.5	2.7	2.1	1.8	2.1	4.0	5.8	3.8
THUNDER DAYS	25	21	19	7	1	0	0	0	0	2	9	25	109

Station Name:	DEDZA	Station Number:	689	Latitude Longitu	14 ° 19' S 34° 16' E	Altitude	1632m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	18.2	18.2	17.8	17.1	15.5	13.6	13.2	14.7	17.3	19.5	19.7	18.6	16.9
REL HUMIDITY (%)	84.0	85.0	83.0	81.0	72.0	69.0	66.0	61.0	56.0	55.0	64.0	79.0	71.0
WIND (2 meters height) m/s	1.7	1.7	1.7	1.8	1.7	1.7	1.8	2.2	2.6	2.8	2.4	1.9	2.0
WIND (10 meters height) m/s													
EVAPORATION (mm)	124.2	103.6	108.7	92.9	98.0	98.0	104.9	138.6	189.2	211.3	204.7	141.7	1615.8
EVAPOTRANSPIRATION (mm)	124.0	107.8	119.0	105.3	95.8	80.7	87.1	113.2	146.1	175.5	158.7	129.3	1442.5
POT. EVAPOTRANSP (mm)	160.3	140.0	155.6	140.7	129.0	109.5	116.9	149.1	188.7	223.8	201.6	166.2	1881.4
RAINFALL (mm)	247.3	199.8	122.6	53.5	12.1	5.5	3.3	1.5	3.5	7.8	53.0	195.3	905.2
RAINY DAYS 0.3mm	22	20	15	8	2	2	2	1	1	2	8	18	9
1.0mm	19	17	12	6	2	1	1	1	0	2	7	15	7
10.0mm	9	7	3	1	1	0	0	0	0	0	2	7	3
SUNSHINE (HOURS)	4.9	4.9	6.2	7.1	8.2	8.0	7.7	8.6	9.3	9.8	7.7	5.3	7.3
CLOUDS (OCTAS)	6.7	6.5	6.1	5.0	3.4	3.5	3.4	2.8	2.4	2.9	5.0	6.3	4.5
THUNDER DAYS	20	16	12	5	1	0	0	0	1	4	11	19	89

Station Name:	MANGOCHI	Station Number	695	Latitude/ Longitude	14° 29'S 35° 16'E	Altitude	482m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	24.9	24.8	24.7	23.9	21.7	19.7	19.7	21.4	24.1	26.7	27.1	25.7	23.7
REL HUMIDITY (%)	79.0	79.0	76.0	73.0	69.0	66.0	62.0	57.0	52.0	49.0	57.0	72.0	66.0
WIND (2 metres) m/s	1.3	1.3	1.4	1.7	1.7	1.7	1.9	1.9	2	2.1	2	1.6	1.7
WIND (10 metres) m/s													
EVAPORATION (mm)	173.4	152.1	163.3	154.4	158.7	140.4	160.5	193.2	240.7	298.7	280.6	217.1	2333.1
EVAPOTRANSPIRATION (mm)	161.5	141.7	156.2	138.0	121.8	99.9	112.2	136.7	170.7	209.3	195.6	167.7	1811.3
POT. EVAPOTRANSP. (mm)	205.8	181.2	200.6	178.2	159.7	131.4	145.1	176.1	216.3	262.0	244.8	211.7	2312.9
RAINFALL (mm)	215.1	188.4	135.6	41.6	5.3	4.5	3.5	1.7	5	11.9	57.1	153.9	823.6
RAINY DAYS 0.3 mm	18	16	14	6	2	2	1	0	1	1	6	13	6
1.0mm	16	13	12	5	1	1	1	0	1	1	6	13	6
10.0mm	6	6	4	1	0	0	0	0	0	0	2	5	2
SUNSHINE (HOURS)	6.7	6.8	7.8	8.1	9.1	8.5	8.3	8.9	9.7	10.1	8.9	6.8	8.3
CLOUDS (OCTAS)	6.2	6.1	5.5	4.4	3.0	2.9	3.3	2.7	2.3	2.6	4.6	5.9	4.2
THUNDER DAYS	21	16	14	5	1	0	1	0	2	5	12	21	98

Station Name	MAKOKA	Station Number	692	Latitude/ Longitude	15° 32'S 35° 11'E	Altitude	1029m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	21.4	21.2	20.9	19.7	18.0	16.0	15.8	17.7	20.6	22.7	22.7	22.0	19.8
REL HUMIDITY (%)	85.0	85.0	82.0	81.0	74.0	70.0	68.0	60.0	53.0	54.0	64.0	80.0	72.0
WIND (2 metres) m/s	1.4	1.4	1.5	1.4	1.4	1.7	1.8	2	2.2	2.4	2.2	1.7	1.7
WIND (10 metres) m/s													
EVAPORATION (mm)	135.6	118.8	116.0	102.3	103.1	97.0	106.1	140.7	197.8	244.6	203.4	152.9	1718.3
EVAPOTRANSPIRATION (mm)	138.3	119.8	127.9	107.1	97.3	81.6	89.3	115.9	150.3	176.1	164.4	140.7	1508.7
POT. EVAPOTRANSP. (mm)	178.6	155.1	157.2	140.1	129.6	108.9	118.1	151.6	192.6	223.2	208.2	179.2	1942.4
RAINFALL (mm)	255.7	198.1	173.2	65.0	14.9	9.3	2.2	1.2	0.0	17.0	92.4	215.1	1044.1
RAINY DAYS 0.3mm	21	17	16	9	3	3	2	1	0	3	9	20	9
1.0mm	18	14	13	7	2	2	1	1	0	2	7	16	7
10.0mm	8	7	6	2	0	0	0	0	0	1	3	7	3
SUNSHINE (HOURS)	5.7	5.8	6.1	6.1	7.4	7.2	7.4	8.3	9.4	9.1	7.5	5.4	7.1
CLOUDS (OCTAS)	6.2	6.1	5.9	5.2	3.7	3.9	3.6	2.9	2.4	3.1	4.7	6.1	4.5
THUNDER DAYS	20	16	14	5	1	0	0	0	1	6	13	19	95

Station Name	CHICHIRI	Station Number	687	Latitude/ Longitude	15 ° 47' S 35° 02' E	Altitude	1132m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	20.7	20.7	20.1	19	17.3	15.3	15.0	16.8	19.6	21.6	21.6	20.9	19.1
REL HUMIDITY (%)	85.0	86.0	86.0	85.0	77.0	74.0	72.0	63.0	57.0	57.0	68.0	81.0	74.0
WIND (2 meters height) m/s	0.9	0.8	0.9	1	0.9	1.1	1.3	1.4	1.5	1.6	1.5	1	1.1
WIND (10meters height) m/s													
EVAPORATION (mm)	120.6	108.7	123.6	106.6	118.3	102.8	109.9	153.6	214.1	249.1	198.6	136.6	1742.5
EVAPOTRANSPIRATION (mm)	136.4	119.3	123.4	108.3	96.1	81.3	89.6	120.9	154.5	177.9	164.1	138.9	1510.7
POT. EVAPOTRANSP. (mm)	176.4	154.8	160.9	142.8	128.7	108.3	117.5	156.2	196.2	223.2	207.6	177.9	1950.5
RAINFALL (mm)	258.8	207.2	190.5	72.3	17.2	13.9	13.2	4.8	2.2	19.8	102.3	219.9	1122.1
RAINY DAYS 0.3 mm	21	18	18	11	7	6	5	2	1	3	11	18	10
1.0mm	18	15	14	9	4	3	3	2	1	3	8	16	8
10.0mm	9	7	6	2	0	0	0	0	0	1	3	7	3
SUNSHINE (HOURS)	5.9	6.0	6.2	6.7	7.9	7.4	7.3	8.4	9.2	9.1	7.5	6.0	7.3
CLOUDS (OCTAS)	6.5	6.3	5.8	5.3	3.9	4.0	4.1	3.1	2.7	3.3	5.0	6.0	4.8
THUNDER DAYS	18	13	13	5	1	0	0	0	1	6	13	18	88
PRESSURE (HPA)	888.1	888.2	890.0	891.6	893.4	895.3	895.8	894.4	893.0	884.8	889.9	888.7	891.1

Station Name	CHILEKA	Station Number	693	Latitude/ Longitude	15° 41'S 34° 41'E	Altitude	767m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	23.2	23.1	22.7	22.0	20.1	18.2	18.1	19.8	22.6	25.1	24.9	23.8	22.0
REL HUMIDITY (%)	80.0	81.0	79.0	76.0	69.0	66.0	64.0	57.0	51.0	50.0	61.0	75.0	67.0
WIND (2 metres) m/s	2.4	2.2	2.5	2.5	2.6	2.7	2.8	3.0	3.2	3.3	3.0	2.5	2.7
WIND (10 metres) m/s	2.7	2.7	3.1	3.4	3.5	3.6	3.7	4	4.3	4.2	3.7	3.1	3.5
EVAPORATION (mm)	168.9	145.7	164.5	184.9	180.5	164.3	157.9	245.8	296.4	363.4	295.1	197.6	2565.0
EVAPOTRANSPIRATION(mm)	151.3	134.7	143.5	125.7	110.7	91.5	102.3	129.3	163.5	196.2	180.6	156.6	1685.9
POT. EVAPOTRANSP. (mm)	193.4	173.0	184.5	163.2	145.4	120.0	132.4	165.5	205.8	244.6	225.6	198.4	2151.8
RAINFALL (mm)	205.7	173.2	135.1	40.8	10.1	3.3	2.5	1.2	3.3	21.8	84.8	175.7	857.5
RAINY DAYS 0.3mm	17	16	14	7	2	2	2	1	1	3	10	15	8
1.0mm	15	13	10	6	1	1	1	0	0	2	7	13	6
10.0mm	6	5	3	2	0	0	0	0	0	1	3	6	2
SUNSHINE (HOURS)	6.1	6.3	6.5	7.6	8.2	7.4	7.4	8.2	8.6	8.8	7.4	6.1	7.4
CLOUDS (OCTAS)	6.4	6.2	5.7	4.7	3.4	3.5	3.7	2.9	2.7	3.2	5.0	6.1	4.5
THUNDER DAYS	19	15	14	5	1	0	0	0	1	7	13	20	95
PRESSURE (HPA)	925.1	925.0	926.7	928.5	930.7	932.8	933.1	925.8	930.1	927.9	926.7	925.8	928.2

Station Name:	BVUMBWE	Station Number	791	Latitude/ Longitude	15° 55'S 35° 04'E	Altitude	1146m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	20.3	20.2	19.6	18.5	16.7	14.7	14.3	16.1	18.6	21.1	21.1	20.5	18.5
REL HUMIDITY (%)	87.0	87.0	87.0	85.0	80.0	77.0	75.0	67.0	62.0	59.0	70.0	82.0	77.0
WIND (2 meters height) m/s	1.5	1.3	1.7	1.8	1.7	1.9	2	2.1	2.3	1.5	2.1	1.9	1.9
WIND (10 meters height) m/s													
EVAPORATION (mm)	104.3	92.2	102.6	86.1	98.8	81.0	90.6	120.3	159.2	176.7	136.9	108.9	1357.6
EVAPOTRANSPIRATION (mm)	132.1	114.0	118.1	102.6	89.6	72.9	81.2	108.8	140.7	169.0	155.4	133.3	1417.7
POT. EVAPOTRANSP. (mm)	171.1	148.1	154.4	135.9	120.6	98.7	108.2	142.9	180.6	214.8	197.7	171.4	1844.4
RAINFALL (mm)	272.7	206.7	165.6	91.6	18.7	20	18.7	13.2	6.6	23.1	92.9	229.1	1158.9
RAINY DAYS 0.3 mm	20	18	17	12	7	7	6	3	2	5	11	18	11
1.0mm	18	15	14	9	5	5	4	2	1	3	9	15	8
10.0mm	8	7	5	2	0	0	0	0	0	0	3	7	3
SUNSHINE (HOURS)	5.4	5.6	5.9	6.5	7.3	6.8	6.8	7.9	8.5	8.6	7.0	5.4	6.8
CLOUDS (OCTAS)	6.4	6.2	6.0	5.1	3.9	4.1	3.9	3.0	2.6	3.2	5.1	6.1	4.7
THUNDER DAYS	18	13	15	5	2	2	0	0	2	6	14	19	96
PRESSURE (HPA)													

Station Name:	THYOLO	Station Number	793	Latitude/ Longitude	16° 08'S 35° 08'E	Altitude	820m						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMPERATURE	22.2	22.1	21.3	20.3	18.1	16.0	15.8	17.6	20.3	23.1	22.9	225	20.1
REL HUMIDITY (%)	84.0	84.0	86.0	84.0	80.0	79.0	77.0	68.0	61.0	57.0	68.0	80.0	76.0
WIND (2 meters height) m/s	1.3	1.3	1.1	1	1	0.9	1	1.3	1.6	1.9	1.7	1.4	1.3
WIND (10 meters height) m/s													
EVAPORATION (mm)	138.9	110.4	105.1	93.9	97.2	77.9	83.5	126.4	157.4	203.2	181.8	128.7	1504.4
EVAPOTRANSPIRATION (mm)	142.0	124.6	125.9	106.5	89.6	70.5	77.2	105.4	138.3	171.4	162.0	142.3	1455.7
POT. EVAPOTRANSP. (mm)	183.2	161.3	164.0	141.0	121.2	96.6	105.1	140.4	179.4	218.2	206.7	182.0	1899.1
RAINFALL (mm)	240.2	214.6	207.2	107.1	35	31.7	30.2	15.4	10.6	29.9	108.7	242.5	1273.1
RAINY DAYS 0.3 mm	19	17	18	12	8	8	6	4	2	4	11	17	11
1.0mm	17	14	15	10	5	6	5	2	2	3	8	16	9
10.0mm	7	6	6	3	0	1	1	0	0	1	3	7	3
SUNSHINE (HOURS)	6.0	6.1	6.3	6.8	7.6	6.8	7.0	8.3	8.7	8.8	7.5	5.9	7.2
CLOUDS (OCTAS)	6	5.9	5.4	4.6	3.5	3.6	3.8	2.8	2.4	2.9	4.6	5.9	4.7
THUNDER DAYS	19	13	13	4	1	0	0	0	1	6	15	19	91
PRESSURE (HPA)													

Station Name:	MIMOSA	Station Number	699	Latitude/ Longitude	16° 5'S 35° 36'E	Altitude	652m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	23.2	23.1	22.4	21.3	19.0	17.0	16.7	18.2	21.0	23.6	24.0	23.3	21.1
REL HUMIDITY (%)	83.0	84.0	84.0	82.0	78.0	76.0	74.0	67.0	60.0	58.0	69.0	80.0	74.0
WIND (2 meters height) m/s	0.9	0.8	0.9	0.8	0.7	0.8	0.8	1	1.2	1.3	1.1	0.9	0.9
WIND (10 meters height) m/s													
EVAPORATION (mm)	148.6	121.4	125.9	97.7	94.2	76.4	82.2	106.9	149.6	179.8	155.1	139.7	1477.55
EVAPOTRANSPIRATION (mm)	143.2	124.3	127.7	107.7	90.2	72	77.8	102.3	132.9	161.8	148.8	143.2	1431.9
POT. EVAPOTRANSP. (mm)	184.5	160.7	166.2	142.2	09.7	97.5	104.8	136.1	172.8	208.6	190.8	183.8	1857.7
RAINY DAYS 0.3mm	20	19	20	13	9	9	8	5	3	5	11	18	12
1.0mm	17	15	17	11	7	7	6	3	2	4	9	16	9
10.0mm	8	7	8	5	2	2	1	1	1	1	4	8	4
SUNSHINE (HOURS)	5.8	5.9	5.9	6.5	7.2	6.4	6.4	7.7	8.2	8.7	7.4	5.9	6.8
CLOUDS (OCTAS)	6.0	6.0	5.5	4.7	3.7	3.8	4.0	3.2	2.6	3.1	4.6	5.7	4.4
THUNDER DAYS	19	15	13	5	2	3	0	1	3	6	14	20	101
PRESSURE (HPA)													

Station Name	NGABU	Station Number	796	Latitude/ Longitude	16°.30'S 34° 57'E	Altitude	102m		796				
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	27.7	27.3	26.6	25.1	23.3	20.7	20.7	22.1	26.4	29.1	29.3	28.3	25.5
REL HUMIDITY (%)	75.0	76.0	80.0	78.0	73.0	73.0	69.0	64.0	55.0	52.0	57.0	70.0	69.0
WIND (2 metres height) m/s	1.3	1.3	1.1	1	0.9	1.1	1.1	1.7	2.5	2.6	2.5	1.7	1.6
WIND (10 meters height m/s													
EVAPORATION (mm)	187.4	161.2	144.5	132	132	102.6	114	176.7	273.8	324.3	292.8	210.5	2251.8
EVAPOTRANSPIRATION (mm)	188.5	170.4	160.3	134.1	113.2	91.5	107	145.4	191.4	234.7	230.7	190.7	1957.9
POT. EVAPOTRANSP .(mm)	238.4	216.3	204.3	172.8	148.5	120.6	138.0	183.8	236.4	285.8	282.0	237.8	2464.7
RAINFALL (mm)	146.0	143.5	168.6	58.6	18.0	18.7	10.6	6.8	1.2	13.7	62.7	163.5	811.4
RAINY DAYS 0.3 mm	12	11	14	9	4	6	5	2	1	2	6	13	8
1.0mm	11	9	12	7	3	5	4	2	0	2	4	11	6
10.0mm	4	5	5	2	0	0	0	0	0	1	2	5	2
SUNSHINE (HOURS)	7.6	7.5	7.3	7.5	8.3	7.6	7.5	8.8	9.3	9.4	8.9	7.2	8.0
CLOUDS (OCTAS)	6.1	6.2	5.2	5.1	3.7	3.8	3.7	2.8	2.2	3.2	4.7	6.0	4.5
THUNDER DAYS	15	13	10	2	0	0	0	0	1	3	8	16	68
PRESSURE (HPA)													

Station Name :	MAKHANGA	Station Number	797	Latitude/Longitude	16° 31'S 35° 9'E	Altitude	52m					
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
DRY BULB TEMP DEG.C	27.0	26.7	26.1	24.8	22.3	20.2	20.2	22.4	25.7	28.4	28.4	27.4	25.0
REL HUMIDITY (%)	78.0	79.0	78.0	76.0	73.0	72.0	70.0	62.0	54.0	51.0	59.0	71.0	68.0
WIND (2 meters height) m/s	1.2	1.1	1.1	1.2	1.1	1.1	1.2	1.6	2.1	2.5	2.1	1.5	1.5
WIND (10 meters height) m/s													
EVAPORATION (mm)	176.2	151.3	161.0	144.7	132.8	112.5	122.4	172.4	239.5	314.9	268.2	207.7	2203.6
EVAPOTRANSPIRATION (mm)	174.8	152.3	159.0	134.1	111.0	86.7	98.0	130.8	174.0	217.6	213.3	184.5	1836.1
POT. EVAPOTRANSP. (mm)	222.0	207.9	203.4	173.4	145.7	115.2	128.3	168.6	217.2	268.2	263.7	231.6	2345.2
RAINFALL (mm)	183.1	97.5	111.7	39.1	14.4	16.7	17.5	9.1	4.5	21.5	68.3	181.1	764.5
RAINY DAYS 0.3 mm	14	11	12	7	4	5	5	2	1	3	8	13	7
1.0mm	12	9	9	5	3	4	3	2	1	2	6	11	5
10.0mm	6	3	3	1	0	0	1	0	0	1	2	5	2
SUNSHINE (HOURS)	7.1	7.5	7.8	8	8.1	7.5	7.5	8.6	9.0	9.4	8.5	7.4	8.0
CLOUDS (OCTAS)	5.9	5.7	5.1	4.4	3.3	3.6	3.6	2.6	2.1	2.7	4.3	5.4	4.1
THUNDER DAYS	17	12	10	3	1	0	0	0	1	4	12	18	78
PRESSURE (HPA)													

APPENDIX 4.6 SOLAR IRRADIANCE MEASURED ON A BEN-GULLAN SPHERERICAL PYRANOMETER CAL cm^{-2} Day^{-1}

	BVUMBWE				LATITUDE 15 ° 55S				LONGITUDE 35° 04'E				
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1967	472	504	_	464	453	453	375	435	534	546	549	542	484
68	532	473	473	507	521	455	487	556	567	655	489	484	517
69	460	509	515	451	479	484	485	491	565	542	563	369	493
70	473	474	506	463	458	373	445	481	476	439		388	452
71	358	417	394	348	299	283	312	408	433	443	377	346	368
72	306	323	330	298	300	304	263	384	439	470	364	376	346
73	343	315	362	234	346	264	323	337	470	426	473	259	347
74	294	_	_	_	_	_	_	_	_	_	_	_	_
75	_	_	_	_	_	_	_	_	_	_	_	_	_
76	_												
77	397	405	365	384	425	405	335	401	435	477	401	417	404
MEAN	404	428	421	394	410	378	378	437	488	493	463	399	429

	CHITEDZE			LATITUDE 15 ° 59 S				LONGITUDE 33 ° 39'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1967	428	422		489	446	389	391	471	503	579	494	497	426
68	491	434	537	440	418	381	395	504	513	606	468	395	465
69	426	426	501	465	412	370	552	433	523	581	583	448	460
70	483	538	531	463	466	404	424	395	505	537		400	468
71	395	453	480	459	443	348	415	481	548	592	561	514	474
72	489	496	504	454	446	504	404	503	568	554	558	522	500
73	489	_	657	484	603	547	535	548	_	648	572	536	
74	483	489	556	538	_	_	_	_	_	_	_	_	517
75	_	_	_	_	_	_	_	_	_	_	_	_	_
76	_	_	_	_	_	_	_	485	493	507	534	443	492
77	420	477	389	467	473	441	373	448	505	544	525	_	460
MEAN	456	467	519	473	411	423	411	474	520	572	537	469	474

	MAKHANGA	LATITUDE 16° 31'S					LONGITUDE 35° 10'E						
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1967	561	546	_	_	464	428	368	457	563	619	652	639	530
68	622	565	513	478	470	399	439	509	540	336	_	_	517
69	_	_	_	_	_	_	_	_	_	_	_	_	_
70	_	_	_	_	_	_	_	_	_	_	_	_	_
71	_	_	_	_	_	_	441	531	544	601	562	540	537
72	523	530	532	507	461	431	436	505	533	537	572		506
73	496	559	531	443	453	392	450	493	452	556	534	479	494
74	526	505	499	457	389	418	381	507	525	543	560	503	484
75	543	500	519	495	468	389	411	448	505	548	551	552	494
76	547	507	_	_	437	432	523	554	546	602	620	574	534
77	589	594	581	534	523	482	439	486	545	601	582	563	543
MEAN	551	538	529	486	458	421	432	499	538	583	579	550	515

	MAKOKA		LATITUDE 35° 13'E				LONGITUDE 15° 31'S						
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1976	_	_	_	_	_	_	_	_	451	421	466	533	_
77	377	388	338	363	386	354	318	357	408	462	381	397	377
78	370	388	325	317	_	_	_	_	_	_	_	_	_

	NGABU		LATITUDE 16° 36'S					LONGITUDE 34° 57'E31'S					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1976	_	_	_	_	_	_	_	_	_	_	419	375	_
77	486	477	449	460	_	416	382	416	_	_	_	_	_
78	468	477	429	407	_	_	_	_	_	_	_	_	_

	SALIMA		LATITUDE. 13° 45'S				LONGITUDE. 34 ° 'E						
YEAR	JAN.	FEB	MAR	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	MEAN
1968	560	499	601	565	512	480	484	541	568	635	614	489	546
1969	526	526	590	563	584	437	448	486	528	587	604	509	528
1970	524	559	597	545	516	463	464	481	543	600	551	527	531
1971	436	543	555	538	496	458	474	477	550	605	581	589	525
1972	513	485	582	520	515	460	471	526	559	610	635	671	537
1973	525	563	550	475	507	460	473	493	556	602	615	542	530
1974	456	482	486	509	431	463	449	509	560	600	591	503	503
1975	550	532	557	534	507	471	461	492	563	605	601	587	538
1976	559	473	514	497	499	467	519	531	549	562	652	566	532
1977	474	563	536	549	502	458	433	495	551	617	594	510	523
													529
MEAN	512	523	557	529	502	462	468	503	553	602	604	539	529

	MIMOSA		LATITUDE 16 ° 05'S				LONGITUDE 35 ° 38'E						
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1967	521	528	_	488	415	392	332	418	538	519	555	570	480
68	582	485	444	473	460	410	409	510	522	598	469	495	496
69	458	497	494	411	406	395	373	424	503	572	605	436	465
70	558	549	525	478	464	332	408	447	543	533	_	513	486
71	472	571	532	520	402	354	379	499	546	588	548	554	497
72	516	477	530	479	422	409	378	499	534	576	542	610	498
73	550	552	543	379	495	381	409	459	557	575	542	503	495
74	_	457	488	446	_	400	366	486	573	587	574	495	487
75	578	519	523	463	479	366	410	444	590	576	580	567	508
76	562	533	488	420	405	388	496	490	536	571	647	513	504
77	533	549	470	472	471	412	330	402	502	477	562	513	483
MEAN	533	520	504	457	442	385	390	462	540	570	562	524	_

	MZIMBA		LATITUDE ° 53'S					LONGITUDE 33 ° 38'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1976	_	_	_	_	_	_	_	517	544	466	451	375	
77	318	367	361	344	339	338	342	412	493	527	447	379	
78	281	367	341	351	_	_	_	_	_	_	_	_	_

	THYOLO		LATITUDE 16° 09'S					LONGITUDE 35 ° 13'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D	MEAN
1967	513	537	_	481	436	388	341	428	523	550	564	568	485
68	563	479	463	476	465	406	441	504	533	605	474	507	493
69	453	509	497	455	478	462	447	500	561	576	635	440	501
70	584	601	604	542	519	394	474	527	579	579	_	535	540
71	492	607	569	584	472	410	442	569	554	533	586	578	541
72	498	560	538	529	504	472	436	561	587	616	585	627	543
73	537	577	585	456	560	424	480	537	621	601	564	517	538
74	540	430	490	458	403	452	389	542	584	616	590	507	500
75	578	537	546	531	519	418	466	485	585	629	604	541	537
76	601	516	475	422	409	396	455	485	559	575	652	540	507
77	545	547	443	498	527	447	354	431	529	618	567	521	502
MEAN	537	536	521	494	481	425	430	506	565	600	582	535	517

APPENDIX 4.7 SOLAR IRRADIANCE MEASURED ON A CAPMBELL STOKES SUNSHINE RECORDER

Carls Cm^{-2} Day^{-1}

		CHITIPA	LATITUDE 9° 42'S						LONGITUDE 33° 16'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	358	423	387	372	539	503	517	521	616	653	579	491
74	429	496	464	467	429	498	491	590	631	649	583	488
75	487	476	460	495	489	498	515	577	612	611	610	480
76	456	473	445	481	469	461	518	641	599	630	652	525
77	444	480	471	463	455	514	521	542	606	630	541	450
MEAN	435	470	445	456	476	495	512	574	615	635	593	487

KARONGA			LATITUDE 9° 56'S				LONGITUDE 33° 55'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	406	475	436	401	510	472	498	578	624	684	640	560
74	499	390	531	459	431	481	460	585	645	664	621	549
75	553	535	486	481	480	459	496	565	634	645	629	533
76	495	543	505	477	484	431	473	603	593	633	679	575
77	461	426	524	445	447	448	505	547	627	649	583	529
MEAN	483	494	496	453	470	458	486	576	625	655	630	549

LILONGWE			LATITUDE 13° 57'S				LONGITUDE 33° 55'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	440	430	422	377	511	420	450	487	571	611	520	474
74	426	403	461	502	365	430	404	511	589	656	578	460
75	500	469	503	446	493	397	432	444	585	618	567	479
76	524	434	431	432	437	418	472	626	589	615	601	510
77	450	500	435	520	471	447	378	471	571	637	563	471
MEAN	468	447	450	455	455	422	428	508	581	627	566	479

DEDZA			LATITUDE 14° 19'S				LONGITUDE 34° 16'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	427	450	494	355	478	415	444	475	609	633	564	479
74	470	402	434	441	372	410	402	508	597	656	594	472
75	513	484	479	441	487	401	429	445	594	633	594	515
76	470	433	453	437	443	395	481	603	576	645	633	511
77	446	496	453	469	452	448	381	489	572	641	544	484
MEAN	465	453	463	429	446	414	427	504	590	642	586	492

MANGOCHI			LATITUDE 14^{0} 29'S				LONGITUDE 35^{0} 16'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	470	496	452	387	511	433	447	490	597	617	618	524
74	503	443	470	488	398	425	420	497	585	656	590	521
75	569	513	563	599	498	440	454	461	585	637	644	587
76	561	490	481	464	464	392	475	603	599	614	667	560
77	503	578	522	540	495	446	390	500	574	659	563	529
MEAN	521	504	498	476	473	427	437	510	588	637	616	544

MAKOKA			LATITUDE 15^{0} 32'S				LONGITUDE 35^{0} 11'E					
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	442	461	497	331	400	390	414	463	591	582	530	459
74	484	408	424	410	335	398	375	486	576	612	568	452
75	546	474	506	445	459	357	415	421	551	608	568	499
76	546	466	417	407	381	365	448	570	562	593	630	475
77	468	586	413	455	465	398	364	447	558	619	533	495
MEAN	497	479	451	410	408	382	403	477	568	603	566	476

MIMOSA			LATITUDE 16^{0} 5'S					LONGITUDE 35^{0} 36'E				
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	464	461	497	320	455	356	389	452	563	577	526	480
74	492	404	444	403	344	379	335	481	549	604	565	464
75	546	481	504	427	448	338	401	427	575	585	580	516
76	519	497	455	379	362	353	409	555	531	581	646	464
77	492	531	437	462	457	402	332	430	535	608	542	522
MEAN	503	475	467	398	413	366	373	469	551	591	572	489

MAKHANGA			LATITUDE 16^{0} 31'S					LONGITUDE 35^{0} 9'E				
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	498	551	465	386	466	372	423	490	561	599	563	523
74	559	485	499	470	373	401	362	507	549	622	621	531
75	590	550	536	497	462	378	418	455	567	603	629	589
76	586	531			387	355	427	588	546	603	663	528
77	570	474	499	514	477	410	371	448	539	622	575	551
MEAN	561	518	500	467	433	383	400	498	552	610	610	544

MZIMBA			LATITUDE 11^{0} 53'S						LONGITUDE 33^{0} 37'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	425	431	455	392	484	461	486	552	631	665	592	494
74	417	443	440	445	388	455	430	558	622	673	588	483
75	506	493	421	473	484	455	475	514	619	665	599	491

76	486	458	440	455	487	476	496	423	608	643	645	510
77	440	497	462	498	465	461	462	541	608	673	553	468
MEAN	455	464	434	453	462	462	470	558	618	664	595	489

MZUZU			LATITUDE 11^0 26'S						LONGITUDE 34^0 01'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	414	421	424	340	464	412	453	452	621	658	603	508
74	424	478	459	379	364	447	400	548	612	659	599	501
75	505	474	402	436	451	382	451	487	601	632	607	501
76	466	509	444	432	422	419	470	586	601	640	684	547
77	435	493	459	432	419	435	408	487	406	651	557	471
MEAN	449	475	438	404	424	419	436	526	608	648	610	506

NGABU			LATITUDE 16^0 30'S						LONGITUDE 34^0 57'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	488	531	398	386	459	365	418	507	569	603	567	507
74	549	485	480	463	379	419	356	503	560	630	_	495
75	487	543	547	500	462	375	421	465	553	463	648	574
76	599	535	484	415	385	364	427	592	549	599	648	507
77	556	562	477	511	480	419	377	439	542	615	563	510
MEAN	556	531	477	455	433	388	400	501	555	582	607	519

NKHATA BAY			LATITUDE 11^0 36'S						LONGITUDE 34^0 18'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	434	454	414	378	540	418	467	537	617	662	638	562
74	473	513	486	425	389	455	426	564	622	661	614	552
75	551	521	433	489	476	397	464	486	608	383	618	494
76	474	518	428	464	454	440	489	612		639	683	563
77	451	528	486	425	425	430	424	520	611	658	572	510
MEAN	478	507	460	436	457	428	454	544	615	601	625	536

NKHOTA KOTA			LATITUDE 12^0 56'S						LONGITUDE 34^0 18'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	428	441	438	428	481	455	489	525	612	630	645	522
74	444	462	453	496	410	481	461	543	608	650	622	492
75	529	501	491	503	487	475	475	507	583	650	618	572
76	506	458	457	457	503	451	487	619	594	635	660	565
77	444	520	468	489	481	469	410	507	583	638	591	484
MEAN	470	476	461	475	472	466	464	540	596	641	627	527

SALIMA			LATITUDE 13^0 45'S						LONGITUDE 34^0 35'E			
YEAR	J		M	A	M	J	J	A	S	O	N	D
1973	463	481	476	432	582	458	473	530	608	641	635	536
74	438	442	466	524	426	473	451	540	613	668	627	506
75	551	531	545	395	521	470	477	500	599	664	635	567
76	531	457	496	461	483	443	492	630	596	634	689	563
77	465	551	507	542	493	452	407	510	592	649	596	497
MEAN	490	492	498	471	501	459	460	542	602	651	636	534

THYOLO			LATITUDE 16^0 08'S						LONGITUDE 35^0 08'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	471	477	463	350	456	358	412	481	510	577	523	464
74	481	396	460	410	355	390	338	498	552	615	569	468
75	547	500	496	457	453	361	415	439	549	660	585	503
76	559	485	440	389	374	361	430	589	552	570	620	456
77	508	504	433	468	475	401	353	459	520	604	550	491
MEAN	513	472	458	415	423	374	390	493	537	605	569	476

CHITEDZE			LATITUDE 13^0 59'S						LONGITUDE 33^0 38'E			
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	440		472	383	493	424	444	481	603	622	536	490
74	442	409	469	491	362	432	392	504	599	660	432	468
75	504	484	506	484	490	400	432	458	578	633	578	468
76	512	461	446	446	440	412	477	626	596	611	617	495
77	469	519	439	512	475	444	390	478	574	645	574	453
MEAN	473	468	466	463	452	422	427	509	590	634	547	475

CHICHIRI			LATITUDE 15^0 47'S					LONGITUDE 35^0 02'E				
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	442	468	455	358	466	393	421	458	598	585	545	490
74	484	404	427	432	349	402	382	491	569	623	580	467
75	553	493	524	442	466	384	421	439	551	600	584	509
76	499	485	434	405	395	375	453	597	555	589	619	463
77	480	481	434	477	472	404	355	455	548	631	634	497
MEAN	492	466	455	423	430	392	406	488	564	606	592	485

CHILEKA			LATITUDE 15^0 41'S					LONGITUDE 34^0 41'E				
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	440	508	474	390	476	390	437	481	595	574	542	
74	495	427	438	480	371	419	398	504	571	619	576	490
75	565	512	554	470	488	390	420	426	535	597	596	559

76	523	474	435	436	426	381	459	604	557	597	631	490
77	503	505	468	501	485	413	369	465	542	608	549	509
MEAN	505	485	474	455	449	399	417	496	560	599	579	511
BVUMBWE			**LATITUDE 15^{0}55'S**					**LONGITUDE 35^{0} 04'E**				
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1973	459	454	452	407	449	365	408	455	575	559	511	460
74	472	389	423	394	342	395	360	489	555	604	557	456
75	518	481	482	425	419	372	418	434	545	600	573	525
76	523	473	449	373	385	348	424	581	552	574	604	463
77	476	481	423	442	458	386	349	434	526	612	519	490
MEAN	490	456	446	408	417	373	392	479	551	590	553	479

APPENDIX 4.8 ANNUAL TEMPERATURES RECORDED AT STATIONS UNDER STUDY

				MEAN TEMPERATURES										
	MONTH	JAN	FEB	MAR	APRL	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	
LOCATION														ALTITUDE
DEDZA		19	19.1	19	18	16.5	14.2	13.9	15.4	18	20	20.6	19.5	1632
MZUZU		20.6	20.7	20.1	19.2	16.4	13.8	13	13.8	16.3	19	20.7	20.7	1100
MZIMBA		20.7	20.7	20.6	20.2	18.6	16.6	16	17.2	19.8	22.3	22.7	21.4	1349
BVUMBWE		21.1	21.2	20.7	19.2	17.6	15.4	15.1	16.8	19.5	22	21.8	21.5	1146
CHITIPA		21.6	21.8	21.6	21.2	19.9	18	17.8	19.1	21.6	23.8	24	22.2	1285
CHICHIRI		21.6	21.5	21	20.1	18.5	16.2	15.8	17.6	20.2	22.3	22.4	21.9	1132
CHITEDZE		21.8	21.7	21.5	20.6	18.5	16.5	16.1	17.5	20	22.4	23.4	22.4	1149
LILONGWE		22	23	21.5	20.3	18	15.8	15.5	16.9	19.6	22.4	23.3	22.6	1135
MAKOKA		22.2	22.2	21.8	20.6	18.8	16.8	16.6	18.2	21	23.1	23.4	22.6	1029
TYOLO		23	22.8	22.2	21.1	18.8	16.7	16.5	18.1	20.6	23.5	23.7	23.3	820
CHILEKA		24	23.9	23.5	22.3	20.6	18.5	18.3	20.1	23.1	25.3	25.6	24.5	767
MIMOSA		24	23.8	23.1	22	19.5	17.5	17.1	18.6	21.2	23.9	24.5	24.2	652
NKOTA KOTA		24.7	24.7	24.6	24.1	22.3	20.5	20.2	21.2	23.5	26.1	26.9	25.9	500
NKATA BAY		24.7	24.7	24.4	22.2	22.3	20.5	20	20.8	22.7	24.7	25.7	25.1	500
SALIMA		25.2	25.1	25.1	24.7	22.6	20.8	20.7	22	24.2	26.7	27.6	26.1	512
KARONGA		25.4	25.5	25.1	24.9	24	22.5	22	22.7	24.9	27.1	27.7	26.2	529
MANGOCHI		25.7	25.5	25.3	24.5	22.2	20.2	20.1	21.6	24.3	27.2	27.7	26.4	482
MAKHANGA		27.7	27.6	26.9	25.5	23	20.9	20.6	22.7	25.8	28.6	29.1	28.2	52
NGABU		28.6	28.2	27.5	26	24	21.3	21.1	23.3	27	29.3	30	29.1	102

				MEAN MAXIMUM TEMPERATURES										
	MONTH	JAN	FEB	MAR	APRL	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	
LOCATION														ALTITUDE
DEDZA		22.7	22.8	22.7	22.1	22.3	19.1	18.9	20.4	23.2	25	25.2	23.4	1632
BVUMBWE		24.8	25	24.6	23	21.9	19.7	19.5	22	25.2	27.7	26.8	25.4	1100
MZIMBA		25.2	25.2	25.3	25.1	24.2	22.5	22	23.2	25.7	27.8	28	26.2	1349
MZUZU		25.3	25.5	24.4	23.2	21.8	20.3	18.7	21.8	24.7	27.2	27.2	25.8	1146
CHICHIRI		25.6	25.5	25	24.3	23.3	21	20.6	22.9	26.1	28.1	27.5	26.2	1285
CHITIPA		26.1	26.5	26	25.3	24.8	23.3	23.2	24.6	27.5	29.6	29.6	27	1132
MAKOKA		26.2	26.3	26.1	25.1	24.1	22	21.8	23.9	27.1	29.1	28.6	26.7	1149
CHITEDZE		26.3	26.5	26.7	26.3	25.8	23.9	23.7	25.5	28.2	30.1	30.1	27.3	1135
LILONGWE		26.4	26.6	26.6	26.5	25.5	23.8	23	25.1	27.6	30	29.6	27.7	1029
TYOLO		27.3	27.1	26.4	25.5	23.7	21.7	21.7	24.1	27.1	29.9	29.3	27.9	820
CHILEKA		28.1	28.1	27.8	26.8	25.8	23.7	23.6	25.9	29.5	31.5	31	29	767
NKOTA KOTA		28.3	28.2	28.3	28.1	23.9	25.5	25.3	26.7	29.3	31.7	31.8	29.5	652
NKATA BAY		28.4	28.3	28.2	27.9	26.9	25.5	25.1	26.3	28.3	30	30.4	29	500
MIMOSA		29.1	28.9	28.1	27.3	25.6	23.6	23.4	25.7	28.9	31.9	30.6	29.4	500
SALIMA		29.1	29	29.1	29	27.7	26.1	25.9	27.8	30.3	32.7	32.8	30.4	512
KARONGA		29.2	29.5	28.9	28.7	23.3	27.2	26.9	28	30.3	32.5	32.6	30.3	529
MANGOCHI		30	29.8	30	29.6	28.2	26.5	26.3	28.3	31.7	33.8	33.6	31.2	482
MAKHANGA		32.8	32.7	32.1	31.1	29.4	27.6	27.4	30.1	33.8	36	35.6	33.7	52
NGABU		33.8	33.3	32.3	31	30.1	27.7	27.6	30.3	34.1	36.3	35.6	34.8	102

MEAN MINIMUMTEMPERATURES

	MONTH	JAN	FEB	MAR	APRL	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	
LOCATION														ALTITUDE
DEDZA		15.3	15.3	15	13.8	11.8	9.3	9	10.4	12.8	15	15.8	15.6	1632
BVUMBWE														1100
MZIMBA		16.7	16.1	15.9	15.4	13	10.7	10	11.2	14.1	16.8	17.3	16.7	1349
MZUZU		16	15.9	15.7	15.1	11	7.3	7.2	5.9	7.9	10.9	13.8	15.6	1146
CHICHIRI		17.6	17.6	17	15.7	13.6	11.4	10.9	12.2	14.3	19.5	17.3	17.6	1285
CHITIPA		17.1	17.1	17.1	17	15	12.7	12.4	13.5	15.7	18	18.3	17.5	1132
MAKOKA		18.3	18.3	17.6	16.1	13.7	11.7	11.3	12.5	14.8	17.1	18.1	18.5	1149
CHITEDZE		17.3	17	16.3	14.8	11.3	8.8	8.5	9.5	11.7	14.7	16.7	17.5	1135
LILONGWE		17.5	17.2	16.4	14.2	10.6	7.8	7.7	8.6	11.6	14.8	17	17.6	1029
CHILEKA		19.8	19.7	19.2	17.9	15.4	13.3	13	14.2	16.9	19.4	2.2	2.0.1	820
NKOTA KOTA		21.1	21.1	20.7	20.1	17.7	15.6	15.1	15.7	17.7	20.5	22.1	21.6	767
NKATA BAY		21.1	21.1	20.7	20.3	17.8	15.6	14.8	15.4	17.2	19.5	21.1	21.2	652
MIMOSA		18.8	18.7	18.2	16.6	13.4	11.3	10.8	11.4	13.5	16.3	17.9	18.7	500
SALIMA		21.2	21.2	21.1	20.5	17.5	15.6	15.6	16.3	18.2	20.6	22.3	21.8	500
KARONGA		21.5	21.5	21.2	21.1	19.7	17.7	17	17.4	19.3	21.8	23	22.2	512
MANGOCHI		21.3	21.2	20.7	19.3	16.3	14.1	14	14.9	17.5	20.5	21.8	21.6	529
MAKHANGA		22.7	22.5	21.6	19.9	16.5	13.9	13.8	15.3	18.3	22.3	22.6	22.7	482
NGABU		23.3	2.1	22.7	20.8	17.8	14.8	14.7	16.3	19.8	22.3	23.3	23.3	52

Appendix 4.9 Cumulative Degree Day Figures In Excess Of 27°c

Month ➔		JAN		FEB		MAR		APRL		MAY	JUN	JULY	AUG	SEPT		OCT		NOV		DEC		
LOCATION																						Cumulat .Degree Days
DEDZA		19		19.1		19		18		16.5	14.2	13.9	15.4	18		20		20.6		19.5		
MZUZU		20.6		20.7		20.1		19.2		16.4	13.8	13	13.8	16.3		19		20.7		20.7		
MZIMBA		20.7		20.7		20.6		20.2		18.6	16.6	16	17.2	19.8		22.3		22.7		21.4		
BVUMBWE		21.1		21.2		20.7		19.2		17.6	15.4	15.1	16.8	19.5		22		21.8		21.5		
CHITIPA		21.6		21.8		21.6		21.2		19.9	18	17.8	19.1	21.6		23.8		24		22.2		
CHICHIRI		21.6		21.5		21		20.1		18.5	16.2	15.8	17.6	20.2		22.3		22.4		21.9		
CHITEDZE		21.8		21.7		21.5		20.6		18.5	16.5	16.1	17.5	20		22.4		23.4		22.4		
LILONGWE		22		23		21.5		20.3		18	15.8	15.5	16.9	19.6		22.4		23.3		22.6		
MAKOKA		22.2		22.2		21.8		20.6		18.8	16.8	16.6	18.2	21		23.1		23.4		22.6		
TYOLO		23		22.8		22.2		21.1		18.8	16.7	16.5	18.1	20.6		23.5		23.7		23.3		
CHILEKA		24		23.9		23.5		22.3		20.6	18.5	18.3	20.1	23.1		25.3		25.6		24.5	31	
Degree Days																1.3	31	1.6	30	0.5	31	109.8
MIMOSA		24		23.8		23.1		22		19.5	17.5	17.1	18.6	21.2		23.9		24.5	30	24.2	31	
Degree Days																		0.5	30	0.2	31	21.2
NKOTA KOTA		24.7		24.7		24.6		24.1		22.3	20.5	20.2	21.2	23.5		26.1		26.9	30	25.9	31	
Degree Days		0.7	31	0.7	28	0.6	31	0.1	30							2.1	31	2.9	30	1.9	31	273.9
NKATA BAY		24.7	31	24.7	28	24.4	31	22.2		22.3	20.5	20	20.8	22.7		24.7	31	25.7	30	25.1	31	
Degree Days		0.7	31	0.7	28	0.4	31									0.7	31	1.7	30	1.1	31	160.5
SALIMA		25.2	31	25.1	28	25.1	31	24.7		22.6	20.8	20.7	22	24.2		26.7	31	27.6	30	26.1	31	
Degree Days		1.2	31	1.1	28	1.1	31	0.7	30					0.2	30	2.7	31	3.6	30	2.1	31	385.9
KARONGA		25.4	31	25.5	28	25.1	31	24.9	30	24	22.5	22	22.7	24.9	30	27.1	31	27.7	30	26.2	31	
Degree Days		1.4	31	1.5	28	1.1	31	0.9	30					0.9	30	3.1	31	3.7	30	2.2	31	443
MANGOCHI		25.7	31	25.5	28	25.3	31	24.5	30	22.2	20.2	20.1	21.6	24.3	30	27.2	31	27.7	30	26.4	31	
Degree Days		1.7	31	1.5	28	1.3	31	0.5	30					0.3	30	3.2	31	3.7	30	2.4	31	437.4
MAKHANGA		27.7	31	27.6	28	26.9	31	25.5	30	23	20.9	20.6	22.7	25.8	30	28.6	31	29.1	30	28.2	31	
Degree Days		3.7	31	3.6	28	2.9	31	1.5	30					1.8	30	4.6	31	5.1	30	3.2	31	799.2
NGABU		28.6	31	28.2	28	27.5	31	26	30	24	21.3	21.1	23.3	27	30	29.3	31	30	30	29.1	31	
Degree Days		4.6	31	4.2	28	3.5	31	2	30					3	30	5.3	31	6	30	5.1	31	1021.1

APPENDIX 4.10 MEAN WIND SPEEDS OF IN THE THREE ZONES

WIND SPEEDS IN THE HIGH LAND AREAS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CHITIPA	1.4	1.4	1.7	2.5	2.8	3.0	3.4	3.8	4.2	4.3	3.2	1.8
MZUZU	1.5	1.5	1.6	1.8	1.7	1.7	1.7	1.7	1.9	2.1	2.0	1.5
CHITEDZE	1.3	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.3	2.4	2.2	1.6
LILONGWE	1.6	1.6	1.7	2.0	2.0	2.3	2.5	2.5	2.8	3.0	2.6	1.8
CHICHIRI	1.6	1.5	1.8	1.9	1.8	2.2	2.5	2.8	3.0	3.2	3.0	1.9
DEDZA	1.7	1.7	1.7	1.8	1.7	1.7	1.8	2.2	2.6	2.8	2.4	1.9
NTCHEU	1.6	1.7	1.7	2.1	2.0	2.0	2.2	2.3	2.5	2.3	1.9	1.8
MZIMBA	1.0	1.0	1.1	1.3	1.5	1.7	1.8	2.0	2.1	2.1	1.7	1.1
MAKOKA	1.4	1.4	1.5	1.4	1.4	1.7	1.8	2.0	2.2	2.4	2.2	1.7
BVUMBWE	1.5	1.3	1.7	1.8	1.7	1.9	2.0	2.1	2.3	2.5	2.1	1.7
Mean	1.5	1.4	1.6	1.8	1.8	2.0	2.2	2.3	2.6	2.7	2.3	1.7

WIND SPEED IN THE MIDLAND AREAS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CHILEKA	2.4	2.2	2.5	2.5	2.6	2.7	2.8	3.0	3.2	3.3	3.0	2.5
MIMOSA	0.9	0.8	0.9	0.8	0.7	0.8	0.8	1.0	1.2	1.3	1.1	0.9
THYOLO	1.3	1.3	1.1	1.0	1.0	0.9	1.0	1.3	1.6	1.9	1.7	1.4
Mean	1.5	1.4	1.5	1.4	1.4	1.5	1.5	1.7	2.0	2.1	1.9	1.6

WIND SPEED IN THE LOW LYING AREAS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
KARONGA	1.3	1.3	1.3	1.7	1.7	1.9	2.0	1.9	2.0	2.1	1.9	1.5
SALIMA	1.4	1.5	1.8	2.1	2.1	2.2	2.3	2.1	2.0	2.1	2.1	1.7
MANGOCHI	1.3	1.3	1.4	1.7	1.7	1.7	1.9	1.9	2.0	2.1	2.0	1.6
NGABU	1.3	1.3	1.1	1.0	0.9	1.1	1.1	1.7	2.5	2.9	2.5	1.7
MAKHANGA	1.2	1.1	1.1	1.2	1.1	1.1	1.2	1.6	2.1	2.5	2.1	1.5
NKHATA BAY	1.1	1.1	1.1	1.1	1.3	1.4	1.5	1.6	1.6	1.7	1.5	1.2
NKHOTAKOTA	1.5	1.6	1.7	2.0	2.3	2.5	2.7	2.5	2.6	2.8	2.6	1.9
Mean	1.3	1.1	1.3	1.5	1.6	1.7	1.8	1.9	2.1	2.3	2.1	1.6

ANNUAL MEAN WIND SPEEDS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean-Highland	1.5	1.4	1.6	1.8	1.8	2.0	2.2	2.3	2.6	2.7	2.3	1.7
Mean-Midland	1.5	1.4	1.5	1.4	1.4	1.5	1.5	1.7	2.0	2.1	1.9	1.6
Mean-Lowland	1.3	1.1	1.3	1.5	1.6	1.7	1.8	1.9	2.1	2.3	2.1	1.6

COMPUTED EXPECTED INDOOR MINIMUM WIND SPEEDS AT 40% OF THE EXTERNAL VALUES

Mean-Highland-40%	0.6	0.56	0.64	0.72	0.72	0.8	0.88	0.92	1.04	1.08	0.92	0.68
Mean-Midland-40%	0.6	0.56	0.6	0.56	0.56	0.6	0.6	0.68	0.8	0.84	0.76	0.65
Mean-Lowland-40%	0.52	0.44	0.52	0.6	0.64	0.68	0.72	0.76	0.84	0.92	0.84	0.64

APPENDIX 4.11 HUMIDITY LEVELS OF All SATTIONS UNDER STUDY

LOCATION	KARONGA	NKATA BAY	NKHOTA KOTA	SALIMA	CHILEKA	MANGOCHI	MIMOSA	NGABU	MAKHANGA	THYOLO	MIMOSA	CHILEKA	CHITIPA	MZUZU	CHITENDZE	LILONGWE	CHICHIRI	DEDZA	NTCHEU	MAKOKA	BVUMBWE
MONTH																					
JAN	80	84	84	80	80	79	83	75	78	84	83	80	83	86	84	84	85	84	85	85	87
FEB	80	84	83	82	81	79	84	76	79	84	84	81	83	86	85	85	86	85	86	85	87
MAR	83	85	81	77	79	76	84	80	78	86	84	79	84	89	83	82	86	83	82	82	87
APR	80	84	79	72	76	73	82	78	73	84	82	76	82	90	79	79	85	81	78	81	85
MAY	75	81	73	68	69	69	78	73	72	80	78	69	76	90	72	72	77	72	71	74	80
JUN	69	79	69	63	66	66	76	73	70	79	76	66	72	89	67	68	74	69	66	70	77
JUL	67	75	65	60	64	62	74	69	62	77	74	64	69	87	63	64	72	66	61	68	75
AUG	67	72	63	56	57	57	67	64	54	68	67	57	62	81	58	58	63	61	56	60	67
SEPT	64	69	61	54	51	52	60	55	51	61	60	51	54	72	52	53	57	56	53	53	62
OCT	60	67	57	52	50	49	58	52	59	57	58	50	49	65	50	51	57	55	51	54	59
NOV	64	70	63	58	61	57	69	57	71	68	69	61	59	73	60	62	68	64	64	64	70
DEC	76	80	77	73	75	72	80	70	68	80	80	75	77	83	78	78	81	79	79	80	82

Appendix 5.1

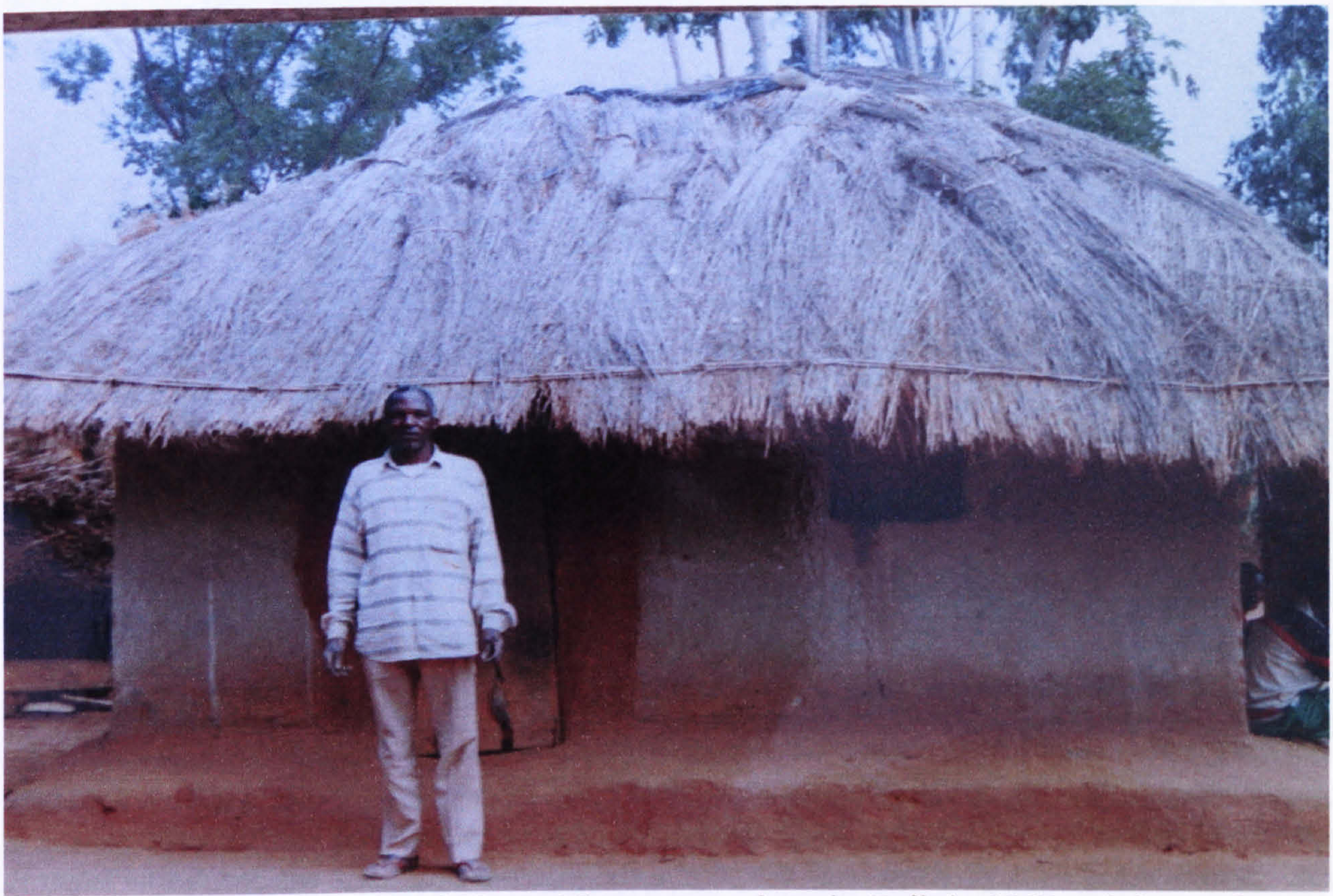


Plate 5.2 The actual Traditional House That was monitored. Built in 1967 and the roof renewed three times. The Owner/ Architect was quite willing to show the visiting team tall parts of the house and relate its history.

Plate 5.3 The same traditional house taken at a different hour of the day to illustrate how the roof protects all the walls from the strong irradiance at the high hour angles.

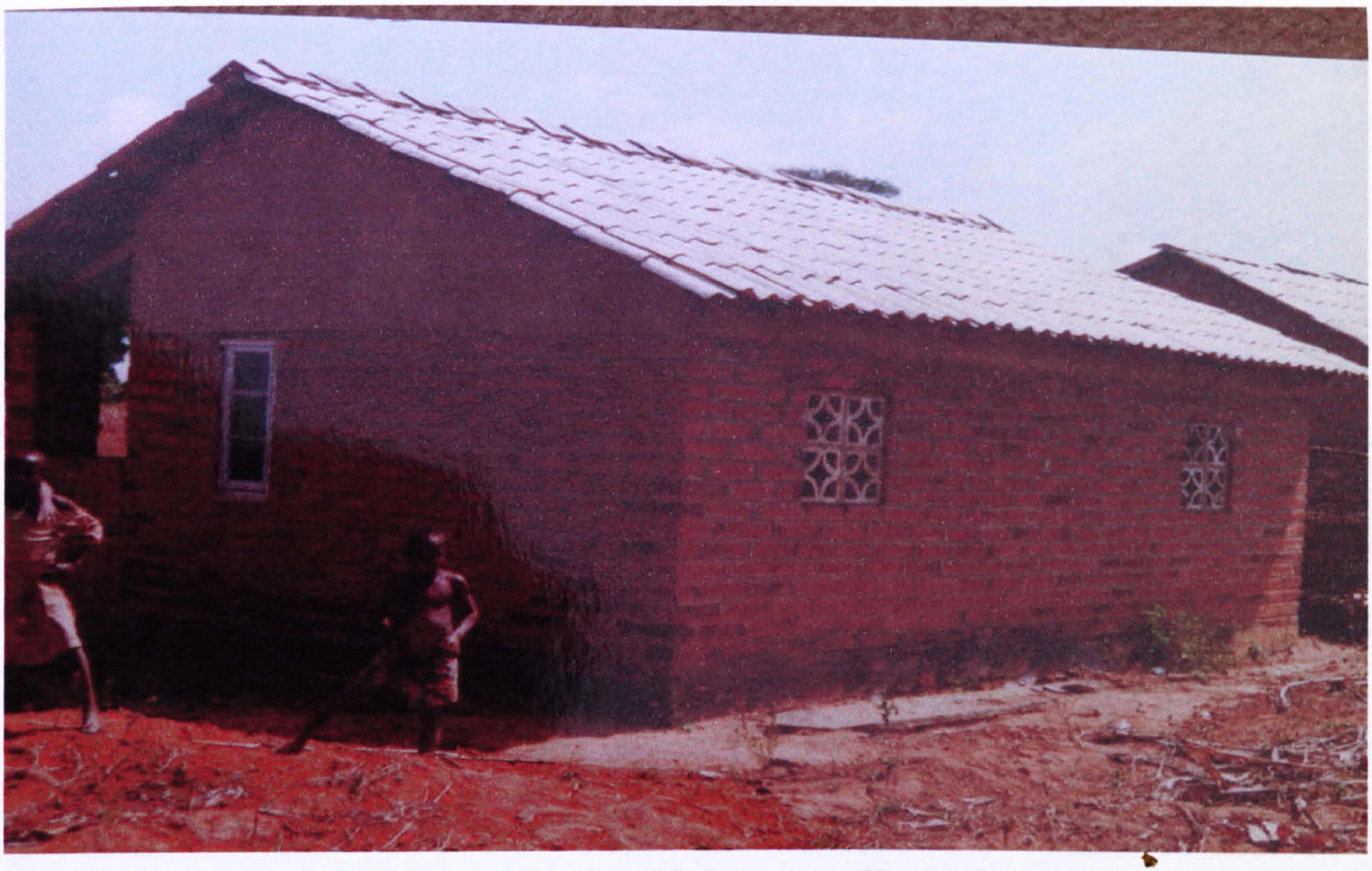


Plate 5.4 An intermediate technology house. This is the actual house that was measured. This was a special construction programme where government through the United Nations Programme; ***Habitat*** introduced the sisal fibre/cement roof which was hand made by each house owner. Some of the windows were simple concrete hollow blocks

Plate 5.5 Another intermediate technology house. Although the windows have been improved, the walls are not fully protected from the strong irradiance during the late morning and early afternoon. Note the insolation through the window and the exposure of half of the front wall. Note the small verandah and plinth.

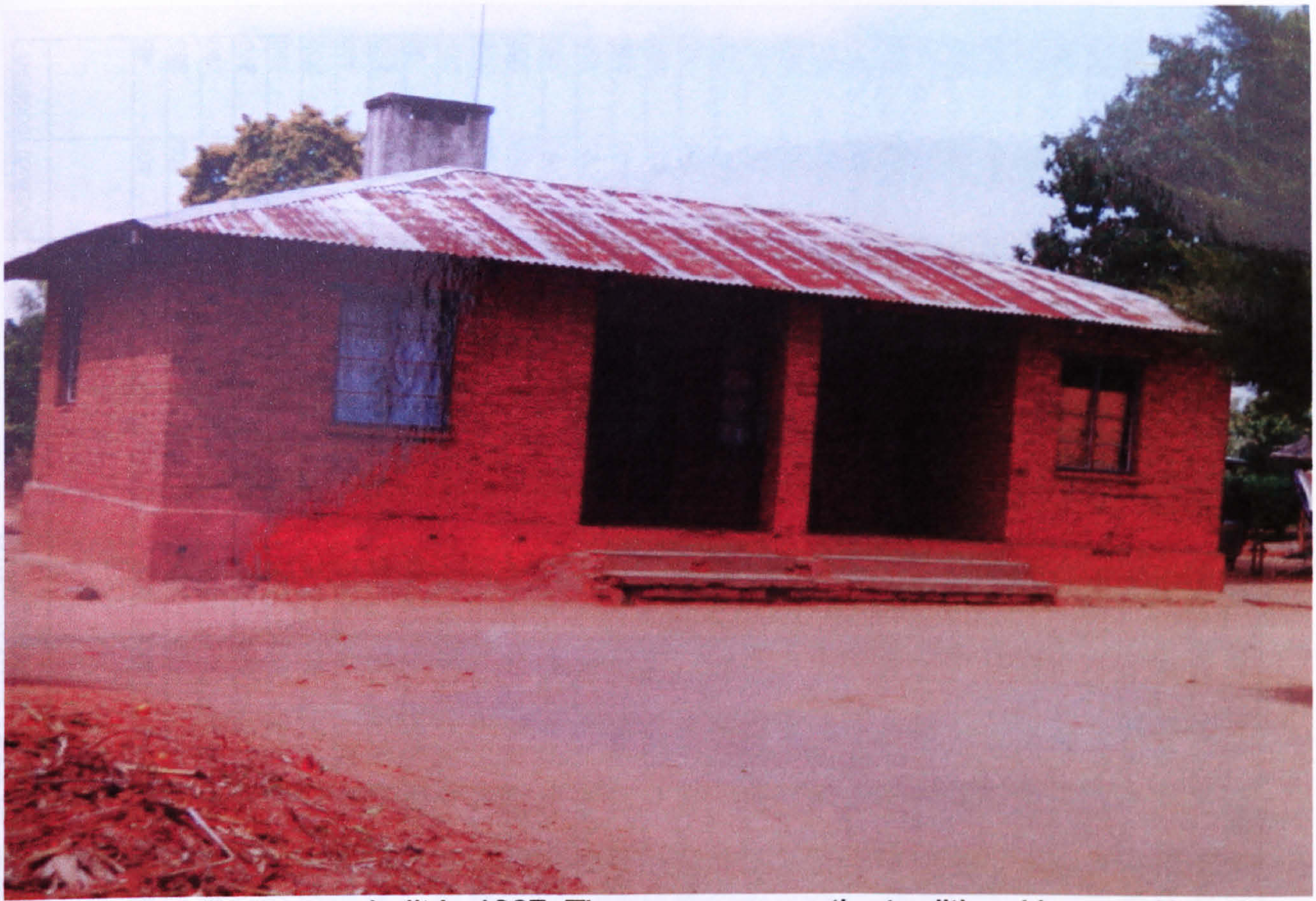


Plate 5.6 This house was built in 1967; The same year as the traditional house. Note the rusting on the corrugated iron sheets. The owner admitted that he had never painted the roof. Thirty five years later the roof has rusted. Note the high plinth and the poor protection of the walls from the strong irradiance.

PAGE
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ORIGINAL

Appendix 6.1 Survey Data Of Houses In Nine Representative Districts

(Wind speeds are recorded in miles per hour at 2000 mm height)

SER.NO	DISTR.	IRRAD	LAT	RAINF	TEMP	WIND	WINDIR	ALT	ROOFAP	EAVESHT	HL	HW	HD	HA	VDEPTH	HKG	RTYPE	ROOFMAT	HAGE	ROOFSL	EAVESWID	DOORIENT
CHITIPA																						
1	1	18.9	9.7	1039	20	6.3	90	1250	3500	2250	6500	3480	M	22.62	900	300	3	5	3	36	400	45
2	1	18.9	9.7	1039	20	6.3	90	1250	2650	1700	5340	2960	M	15.81	550	200	2	5	4	33	800	360
3	1	18.9	9.7	1039	20	6.3	90	1250	4000	2400	9200	5170	M	47.56	1150	200	M	5	10	32	600	90
4	1	18.9	9.7	1039	20	6.3	90	1250	3010	1800	4550	3070	M	13.97	500	100	3	5	2	38	1000	270
5	1	18.9	9.7	1039	20	6.3	90	1250	2680	1750	3500	2700	M	9.45	650	100	3	5	12	35	850	180
6	1	18.9	9.7	1039	20	6.3	90	1250	3000	2000	7100	3850	M	27.34	900	120	2	5	8	28	1000	270
7	1	18.9	9.7	1039	20	6.3	90	1250	2550	1750	6570	3460	M	22.73	700	100	3	5	7	25	200	360
8	1	18.9	9.7	1039	20	6.3	90	1250	3630	2100	7900	4530	M	35.79	900	150	M	5	2	34	500	270
9	1	18.9	9.7	1039	20	6.3	90	1250	2250	1350	M	M	3100	7.55	M	M	1	5	12	30	600	90
10	1	18.9	9.7	1039	20	6.3	90	1250	2700	1700	5100	3150	M	16.07	1050	500	3	5	31	32	600	270
11	1	18.9	9.7	1039	20	6.3	90	1250	3270	1970	5670	4250	M	24.10	M	100	3	5	5	31	850	225
12	1	18.9	9.7	1039	20	6.3	90	1250	2000	1400	M	M	2200	3.80	M	M	1	5	5	29	550	360
13	1	18.9	9.7	1039	20	6.3	90	1250	3300	1850	6500	3350	M	21.78	600	200	3	5	5	41	550	180
14	1	18.9	9.7	1039	20	6.3	90	1250	2970	1900	M	M	2700	5.73	600	250	1	5	6	39	300	135
15	1	18.9	9.7	1039	20	6.3	90	1250.5	2480	1730	5320	2850	M	15.16	450	300	2	5	6	28	900	360
16	1	18.9	9.7	1039	20	6.3	90	1250.5	3120	200	8380	6000	M	50.28	600	320	M	5	6	21	900	180
17	1	18.9	9.7	1039	20	6.3	90	1243	2950	1850	7750	3500	M	27.13	570	120	3	5	5	32	950	90
18	1	18.9	9.7	1039	20	6.3	90	1243	3930	2120	10000	5100	M	51.00	600	200	3	5	5	36	1050	180
19	1	18.9	9.7	1039	20	6.3	90	1266	3750	2200	8150	5600	M	45.64	840	270	3	2	19	29	900	180
20	1	18.9	9.7	1039	20	6.3	90	1281	2570	1570	3900	2930	M	11.43	500	180	3	2	3	35	650	270
21	1	18.9	9.7	1039	20	6.3	90	1281	3560	2300	8080	5080	M	41.05	1000	250	3	2	5	27	1080	270
22	1	18.9	9.7	1039	20	6.3	90	1258	3530	2250	5900	4460	M	26.31	800	350	3	2	16	30	1100	270
23	1	18.9	9.7	1039	20	6.3	90	1258	4300	2460	8810	5930	M	52.24	980	0.28	3	2	31	32	1400	270
24	1	18.9	9.7	1039	20	6.3	90	1266	2590	1600	3530	2670	M	9.43	320	250	3	2	18	37	740	270
25	1	18.9	9.7	1039	20	6.3	90	1273	3520	2120	7260	4480	M	32.52	900	400	3	2	15	32	1030	270
26	1	18.9	9.7	1039	20	6.3	90	1258	3950	2300	8400	5330	M	44.77	800	200	3	2	19	32	1500	180
27	1	18.9	9.7	1039	20	6.3	90	1250.5	3640	2000	7350	4000	M	29.40	800	150	3	2	6	39	1500	270
28	1	18.9	9.7	1039	20	6.3	90	1258	2980	1800	4600	2880	M	13.25	570	150	3	2	1	39	600	180
29	1	18.9	9.7	1039	20	6.3	90	1250.5	4320	2320	9500	5530	M	52.54	113	700	3	2	14	36	1500	270
30	1	18.9	9.7	1039	20	6.3	90	1250.5	2940	1940	4460	2900	M	12.93	780	500	3	2	12	35	800	360
31	1	18.9	9.7	1039	20	6.3	90	1245	3540	2320	7580	4080	M	30.93	600	150	3	2	22	31	1150	270
32	1	18.9	9.7	1039	20	6.3	90	1245	2560	1700	3440	2560	M	8.81	400	300	4	2	22	34	600	90
33	1	18.9	9.7	1039	20	6.3	90	1245	2160	1560	M	M	2800	6.16	280	230	3	2	22	23	800	315

34	1	18.9	9.7	1039	20	6.3	90	1245	3010	1930	7440	5700	M	42.41	1130	280	3	2	22	24	790	270
35	1	18.9	9.7	1039	20	6.3	90	1235	2090	1410	M	.M	2680	5.64	M	190	3	5	16	27	300	180
36	1	18.9	9.7	1039	20	6.3	90	1235	2900	1940	6000	3650	M	21.90	1030	400	3	5	15	28	1500	270
37	1	18.9	9.7	1039	20	6.3	90	1235	2700	1830	4500	3000	M	13.50	900	120	3	2	13	30	1300	180
38	1	18.9	9.7	1039	20	6.3	90	1243	3550	2170	8000	4470	M	35.76	1100	260	3	2	15	32	1600	360
39	1	18.9	9.7	1039	20	6.3	90	1243	2720	1830	4950	2800	M	13.86	450	260	3	5	11	32	1200	360
40	1	18.9	9.7	1039	20	6.3	90	1235	2450	1720	3940	2670	M	10.52	550	300	3	2	8	29	970	90
41	1	18.9	9.7	1039	20	6.3	90	1243	2820	1700	3960	3000	M	11.88	430	170	3	2	3	37	900	270
42	1	18.9	9.7	1039	20	6.3	90	1250.5	2810	1640	4000	3600	M	14.40	660	300	3	2	10	33	900	270
43	1	18.9	9.7	1039	20	6.3	90	1250.5	3710	2340	9120	4460	M	40.68	1000	200	3	2	16	32	1500	360
44	1	18.9	9.7	1039	20	6.3	90	1238	2570	1730	3900	2630	M	10.26	600	100	3	2	5	32	900	180
45	1	18.9	9.7	1039	20	6.3	90	1258	3080	1760	5380	3750	M	20.18	600	150	3	2	6	35	800	360
46	1	18.9	9.7	1039	20	6.3	90	1258	2830	1630	3640	2840	M	10.34	480	180	3	5	1	40	750	270
47	1	18.9	9.7	1039	20	6.3	90	1258	2920	1880	4820	3050	M	14.70	680	270	3	5	4	34	900	90
48	1	18.9	9.7	1039	20	6.3	90	1258	2910	1670	5230	3300	M	17.26	710	100	3	5	3	37	1400	270

KARONGA

1	2	19.4	9.95	1164	24.1	3.8	90	529	2600	1980	4940	3220	M	15.91	960	180	3	3	4	21	900	270
2	2	19.4	9.95	1164	24.1	3.8	90	529	3500	1850	6450	4450	M	28.70	750	280	3	3	12	37	M	315
3	2	19.4	9.95	1164	24.1	3.8	90	529	2700	1870	3600	2700	M	9.72	400	300	3	3	12	32	650	180
4	2	19.4	9.95	1164	24.1	3.8	90	529	3220	1840	4960	4200	M	20.83	1570	250	3	3	3	33	120	135
5	2	19.4	9.95	1164	24.1	3.8	90	529	2750	1900	8650	4900	M	42.39	1100	190	M	3	6	19	700	360
6	2	19.4	9.95	1164	24.1	3.8	90	529	2900	2070	5440	3200	M	17.41	700	150	3	3	1	28	0.7	90
7	2	19.4	9.95	1164	24.1	3.8	90	529	3240	2060	7850	4060	M	31.87	1040	200	M	3	2	30	400	180
8	2	19.4	9.95	1164	24.1	3.8	90	529	2100	1500	3540	2500	M	8.85	800	10	M	3	0.5	26	300	270
9	2	19.4	9.95	1164	24.1	3.8	90	529	2800	1960	5440	3200	M	17.41	1000	230	M	3	4	28	700	180
10	2	19.4	9.95	1164	24.1	3.8	90	529	3290	2220	8060	6100	M	49.17	1100	200	2	3	17	19	500	45
11	2	19.4	9.95	1164	24.1	3.8	90	529	3000	2020	7040	3420	M	24.08	1200	1000	2	2	3	30	600	90
12	2	19.4	9.95	1164	24.1	3.8	90	529	3000	1720	4720	4080	M	19.26	980	50	2	3	2	32	1000	90
13	2	19.4	9.95	1164	24.1	3.8	90	529	3100	1800	7340	3960	M	29.07	870	300	2	3	12	33	800	90
14	2	19.4	9.95	1164	24.1	3.8	90	529	2950	2050	4970	3640	M	18.09	800	220	2	3	12	27	750	360
15	2	19.4	9.95	1164	24.1	3.8	90	529	2500	1700	4850	3100	M	15.04	750	250	2	3	6	27	500	360
16	2	19.4	9.95	1164	24.1	3.8	90	529	1870	1340	3000	2330	M	6.99	500	50	2	3	2	25	600	180
17	2	19.4	9.95	1164	24.1	3.8	90	529	2920	1860	8100	4470	M	36.21	860	300	2	3	2	26	600	360
18	2	19.4	9.95	1164	24.1	3.8	90	529	3060	2320	7200	3600	M	25.92	900	250	2	3	2	22	200	180
19	2	19.4	9.95	1164	24.1	3.8	90	529	2540	1890	5400	2900	M	15.66	600	440	2	3	5	18	600	360
20	2	19.4	9.95	1164	24.1	3.8	90	529	2800	1800	5020	3250	M	16.32	800	310	2	3	3	32	300	270
21	2	19.4	9.95	1164	24.1	3.8	90	529	3350	2700	5200	3500	M	18.20	720	350	2	3	5	20	500	360

22	2	19.4	9.95	1164	24.1	3.8	90	529	2230	1600	5530	3220	M	17.81	450	225	2	3	4	21	800	180
23	2	19.4	9.95	1164	24.1	3.8	90	529	2100	1820	5430	2700	M	14.66	840	250	2	3	12	12	300	180
24	2	19.4	9.95	1164	24.1	3.8	90	529	2510	1780	4240	2260	M	9.58	700	280	2	3	2	33	340	270
25	2	19.4	9.95	1164	24.1	3.8	90	529	2650	1750	4070	2500	M	10.18	500	250	2	3	3	36	400	360
26	2	19.4	9.95	1164	24.1	3.8	90	529	2590	1920	5000	3150	M	15.75	900	50	2	3	3	23	960	180
27	2	19.4	9.95	1164	24.1	3.8	90	529	2170	1400	3880	2400	M	9.31	360	100	M	3	3	33	800	360
28	2	19.4	9.95	1164	24.1	3.8	90	529	3310	1900	4850	3410	M	16.54	750	250	2	3	4	40	900	180
29	2	19.4	9.95	1164	24.1	3.8	90	529	3130	1740	M	M	3850	11.64	560	250	1	3	3	36	560	90
30	2	19.4	9.95	1164	24.1	3.8	90	529	3220	1900	5500	3880	M	21.34	750	100	3	3	3	34	1200	270
31	2	19.4	9.95	1164	24.1	3.8	90	529	2370	1540	4900	2750	M	13.48	1000	300	2	3	4	31	600	180

NKATA BAY

1	3	18.7	11.6	1695	22.8	3	135	500	4150	1850	10650	8200	M	87.33	2350	600	3	3	31	29	900	180
2	3	18.7	11.6	1695	22.8	3	135	500	1970	1500	M	M	1970	3.05	M	M	2	3	2	27	450	135
3	3	18.7	11.6	1695	22.8	3	135	500	1980	1550	M	M	1300	1.33	M	230	1	3	1	33	500	45
4	3	18.7	11.6	1695	22.8	3	135	500	2300	1500	4500	2820	M	12.69	450	250	2	3	4	29	350	135
5	3	18.7	11.6	1695	22.8	3	135	500	2080	1630	M	M	1700	2.27	M	M	1	3	2	28	500	270
6	3	18.7	11.6	1695	22.8	3	135	500	2100	1600	M	M	1850	2.69	M	20	2	3	3	28	590	180
7	3	18.7	11.6	1695	22.8	3	135	500	2100	1400	4400	2700	M	11.88	630	70	2	3	5	27	650	225
8	3	18.7	11.6	1695	22.8	3	135	500	2060	1590	M	M	1650	2.14	M	20	2	3	3	30	450	135
9	3	18.7	11.6	1695	22.8	3	135	500	2500	1650	4700	2880	M	13.54	800	200	2	3	8	31	460	180
10	3	18.7	11.6	1695	22.8	3	135	500	2030	1470	M	M	1940	2.96	M	500	2	3	1	30	400	315
11	3	18.7	11.6	1695	22.8	3	135	500	2830	1950	7400	3500	M	25.90	1400	280	2	4	6	26	850	360
12	3	18.7	11.6	1695	22.8	3	135	500	2300	1370	5100	2950	M	15.05	500	400	2	4	5	32	900	360
13	3	18.7	11.6	1695	22.8	3	135	500	1850	1360	M	M	1950	2.99	M	230	1	4	6	14	460	45
14	3	18.7	11.6	1695	22.8	3	135	500	3030	1730	7330	5150	M	37.75	1400	500	3	2	13	27	8500	90
15	3	18.7	11.6	1695	22.8	3	135	500	2400	1750	3500	2450	M	8.58	M	100	2	3	1	28	450	270
16	3	18.7	11.6	1695	22.8	3	135	500	2600	1770	5300	2900	M	15.37	800	170	2	3	5	30	480	180
17	3	18.7	11.6	1695	22.8	3	135	500	3050	2050	5070	3450	M	17.49	950	300	2	3	2	30	M	90
18	3	18.7	11.6	1695	22.8	3	135	500	2600	2000	4150	2500	M	10.38	650	100	2	2	1	26	700	180

MZIMBA

1	4	18.6	11.88	864	19	3.4	180	1400	1720	2580	5200	3740	M	19.45	900	280	2	2	31	25	870	M
2	4	18.6	11.88	864	19	3.4	180	1400	2120	3020	4830	3920	M	18.93	1400	370	3	2	28	25	650	M
3	4	18.6	11.88	864	19	3.4	180	1400	2420	3870	6930	6500	M	45.05	1200	3200	3	2	5	24	500	M
4	4	18.6	11.88	864	19	3.4	180	1400	1880	2580	4490	3150	M	14.14	950	450	2	2	5	24	300	M
5	4	18.6	11.88	864	19	3.4	180	1400	2380	3430	6650	7220	M	48.01	M	250	2	2	3	16	950	M
6	4	18.6	11.88	864	19	3.4	180	1400	1880	2520	4150	3100	M	12.87	1000	500	2	2	5	25	500	M

7	4	18.6	11.88	864	19	3.4	180	1400	2150	3350	8230	7160	M	58.93	1200	300	M	2	2	19	800	M
8	4	18.6	11.88	864	19	3.4	180	1400	1800	2600	5060	5120	M	25.91	950	350	2	2	2	17	750	M
9	4	18.6	11.88	864	19	3.4	180	1400	2050	3050	6020	4900	M	29.50	1200	550	2	2	2	22	1100	M
10	4	18.6	11.88	864	19	3.4	180	1400	2250	3150	7550	5970	M	45.07	850	500	2	1	2	17	500	M
11	4	18.6	11.88	864	19	3.4	180	1400	1900	3200	5820	5600	M	32.59	1200	700	3	2	2.5	25	1400	M
12	4	18.6	11.88	864	19	3.4	180	1400	1800	2540	4670	2900	M	13.54	950	700	2	2	2	27	400	M
13	4	18.6	11.88	864	19	3.4	180	1400	2200	2950	5270	3480	M	18.34	1000	600	3	2	2	23	150	M
14	4	18.6	11.88	864	19	3.4	180	1400	1910	2810	6200	5100	M	31.62	1150	250	2	2	3	19	700	M
15	4	18.6	11.88	864	19	3.4	180	1400	2070	2770	6400	5440	M	34.82	910	70	2	2	3	14	1150	M
16	4	18.6	11.88	864	19	3.4	180	1400	1820	2520	3860	3550	M	13.70	800	100	2	2	2	22	450	M
17	4	18.6	11.88	864	19	3.4	180	1400	2800	1900	5900	5680	M	33.51	1230	250	2	2	6	18	600	M
18	4	18.6	11.88	864	19	3.4	90	1425	2950	1830	3550	4300	M	15.27	500	150	3	2	3	28	850	180
19	4	18.6	11.88	864	19	3.4	90	1475	3150	2250	5050	4550	M	22.98	900	200	3	2	4	22	650	270
20	4	18.6	11.88	864	19	3.4	90	1425	3250	2250	7250	4650	M	33.71	900	550	3	2	5	23	200	270
21	4	18.6	11.88	864	19	3.4	90	1425	2850	2100	6400	3600	M	23.04	800	200	3	2	3	23	1000	270
22	4	18.6	11.88	864	19	3.4	90	1400	3030	2150	6150	4900	M	30.14	950	200	3	2	5	20	700	270
23	4	18.6	11.88	864	19	3.4	90	1400	2850	2100	4620	3550	M	16.40	870	100	3	2	1	31	430	270
24	4	18.6	11.88	864	19	3.4	90	1400	3200	2150	6200	4050	M	25.11	800	200	3	2	3	28	400	270
25	4	18.6	11.88	864	19	3.4	90	1400	2950	2050	6100	4500	M	27.45	600	150	3	2	5	22	400	270
26	4	18.6	11.88	864	19	3.4	90	1400	3150	1650	3500	3250	M	11.38	350	150	2	2	3	10	650	180
27	4	18.6	11.88	864	19	3.4	90	1400	2500	1900	4550	3000	M	13.65	500	150	2	2	4	22	700	270
28	4	18.6	11.88	864	19	3.4	90	1400	2750	2000	4900	3200	M	15.68	600	100	3	2	5	25	100	270
29	4	18.6	11.88	864	19	3.4	90	1500	2350	1600	M	M	2250	3.98	400	150	1	2	4	34	600	360
30	4	18.6	11.88	864	19	3.4	90	1500	2930	2030	6500	4880	M	31.72	850	250	3	2	4	20	350	270
31	4	18.6	11.88	864	19	3.4	90	1500	2400	1730	4200	3150	M	13.23	800	150	2	2	5	32	100	270
32	4	18.6	11.88	864	19	3.4	90	1400	3870	3050	5450	3900	M	21.26	670	200	3	2	4	23	500	270
33	4	18.6	11.88	864	19	3.4	90	1400	3300	2150	5550	5250	M	29.14	1460	100	3	2	4	24	900	270
34	4	18.6	11.88	864	19	3.4	90	1450	3030	1940	5150	4850	M	24.98	1300	200	3	2	11	24	900	270
35	4	18.6	11.88	864	19	3.4	90	1450	2250	1720	3400	2320	M	7.89	400	100	3	2	12	25	700	270
36	4	18.6	11.88	864	19	3.4	90	1450	2800	1980	4950	4520	M	22.37	400	300	3	2	1	20	700	270
37	4	18.6	11.88	864	19	3.4	90	1450	3200	2100	7250	5600	M	40.60	1050	200	3	2	8	22	1250	270
38	4	18.6	11.88	864	19	3.4	90	1450	3030	2300	5400	4250	M	22.95	1100	200	3	2	7	19	900	270
39	4	18.6	11.88	864	19	3.4	90	1450	2470	1840	5850	3250	M	19.01	800	150	2	2	10	21	1000	270
40	4	18.6	11.88	864	19	3.4	90	1450	2900	1880	5750	3700	M	21.28	500	350	3	2	8	29	880	270
41	4	18.6	11.88	864	19	3.4	90	1500	3000	2100	6100	4800	M	29.28	1050	200	2	2	7	21	350	360
42	4	18.6	11.88	864	19	3.4	90	1475	3050	2100	4800	3600	M	17.28	1050	200	2	2	5	28	350	270
43	4	18.6	11.88	864	19	3.4	90	1500	3200	2200	5400	4600	M	24.84	480	150	3	2	3	23	500	360
44	4	18.6	11.88	864	19	3.4	90	1500	2500	1700	5550	3050	M	16.93	500	200	2	2	3	28	600	270
45	4	18.6	11.88	864	19	3.4	90	1475	2350	1800	6500	4880	M	31.72	700	150	3	2	4	13	600	360

46	4	18.6	11.88	864	19	3.4	90	1425	3300	2050	5600	5200	M	29.12	500	300	3	2	6	26	500	360
47	4	18.6	11.88	864	19	3.4	90	1425	2900	1880	5750	3900	M	22.43	1100	300	3	2	6	28	310	180

MCHINJI

1	5	18	13.98	919	19.5	3.8	135	1144	2340	1650	4250	3900	M	16.58	1200	300	2	1	10	19	550	90
2	5	18	13.98	919	19.5	3.8	135	1144	2672	1940	4700	4550	M	21.39	850	230	3	2	5	18	950	270
3	5	18	13.98	919	19.5	3.8	135	1144	3400	2270	6750	6550	M	44.21	950	300	3	2	18	19	1200	360
4	5	18	13.98	919	19.5	3.8	135	1174	3020	2350	6000	5700	M	34.20	1250	280	2	2	18	13	850	360
5	5	18	13.98	919	19.5	3.8	135	1159	2920	2200	5200	4350	M	22.62	1600	260	M	2	17	18	600	360
6	5	18	13.98	919	19.5	3.8	135	1159	3140	2180	6850	4350	M	29.80	650	200	2	2	23	24	900	360
7	5	18	13.98	919	19.5	3.8	135	1159	2140	1580	M	M	2660	5.56	M	100	1	2	4	23	800	45
8	5	18	13.98	919	19.5	3.8	90	1190	2100	1500	M	M	2710	5.77	M	M	1	2	3	23	350	180
9	5	18	13.98	919	19.5	3.8	135	1144	2830	1830	6600	5900	M	38.94	750	100	2	2	2	19	550	180
10	5	18	13.98	919	19.5	3.8	135	1144	2960	2190	9550	7900	M	75.45	1100	150	2	2	2	11	650	90
11	5	18	13.98	919	19.5	3.8	135	1144	2600	2000	5150	3650	M	18.80	1000	150	2	1	3	18	720	225
12	5	18	13.98	919	19.5	3.8	135	1144	2400	1650	4900	3020	700	5.56	250	2	2	1	3	26	900	360
13	5	18	13.98	919	19.5	3.8	135	1144	3058	1750	5900	5000	M	29.50	100	150	3	2	3	36	625	225
14	5	18	13.98	919	19.5	3.8	135	1251	2630	1900	5000	3350	M	16.75	700	250	3	2	4	23	50	270
15	5	18	13.98	919	19.5	3.8	135	1251	3030	2310	6300	4530	M	28.54	1650	360	2	2	15	17	400	270
16	5	18	13.98	919	19.5	3.8	135	1251	2200	1770	3550	2150	M	7.63	M	70	2	2	15	22	370	180
17	5	18	13.98	919	19.5	3.8	135	1251	2330	1870	M	M	2600	5.56	M	150	1	2	6	19	800	315
18	5	18	13.98	919	19.5	3.8	135	1129	2580	2070	5900	4960	M	29.26	1270	430	M	2	5	12	900	270
19	5	18	13.98	919	19.5	3.8	135	1129	1830	1220	4000	3150	M	12.60	750	50	2	2	1	21	450	180
20	5	18	13.98	919	19.5	3.8	135	1144	3200	1950	7670	5760	M	44.18	1400	50	3	2	1	24	1000	180
21	5	18	13.98	919	19.5	3.8	135	1129	2900	1940	M	M	5320	5.56	M	M	3	2	2	20	750	360
22	5	18	13.98	919	19.5	3.8	135	1080	1850	2000	4500	3830	M	17.24	410	330	1	1	2	13	360	M
23	5	18	13.98	919	19.5	3.8	135	1080	1940	2000	5700	4400	M	25.08	350	220	1	1	1	15	90	M
24	5	18	13.98	919	19.5	3.8	135	1080	1770	1940	8900	4400	M	39.16	300	250	1	1	1	7.5	360	M
25	5	18	13.98	919	19.5	3.8	135	1080	2020	1850	5500	4000	M	22.00	390	260	1	1	3	20.5	360	M
26	5	18	13.98	919	19.5	3.8	135	1080	1860	1830	4750	3460	M	16.44	310	200	1	1	3	29.4	360	M
27	5	18	13.98	919	19.5	3.8	135	1080	1960	1820	4860	3770	M	18.32	300	170	1	1	1	18.2	135	M
28	5	18	13.98	919	19.5	3.8	135	1080	2100	1230	5800	4080	M	23.66	400	250	1	1	30	33	135	M
29	5	18	13.98	919	19.5	3.8	135	1080	1810	1700	5540	3420	M	18.95	420	320	1	1	5	21.4	360	M
30	5	18	13.98	919	19.5	3.8	135	1080	2170	2000	6330	4370	M	27.66	720	340	1	1	4	28.56	90	M
31	5	18	13.98	919	19.5	3.8	135	1080	3320	2100	6550	4700	M	30.79	700	500	1	1	9	26	90	M
32	5	18	13.98	919	19.5	3.8	135	1080	3280	2000	6800	5000	M	34.00	700	500	1	1	8	27	90	M
33	5	18	13.98	919	19.5	3.8	135	1080	2500	1800	4900	3500	M	17.15	300	2400	1	1	8	22	90	M

34	5	18	13.98	919	19.5	3.8	135	1080	2600	2000	7200	3600	M	25.92	400	1200	1	1	4	19	90	M
35	5	18	13.98	919	19.5	3.8	135	1080	2910	1910	4900	3400	M	16.66	700	300	1	1	4.5	31	90	M
36	5	18	13.98	919	19.5	3.8	135	1080	3150	2100	5500	4100	M	22.55	1000	200	1	1	10	27	90	M
37	5	18	13.98	919	19.5	3.8	135	1080	2900	1900	5500	3900	M	21.45	830	400	1	1	14	27	90	M
38	5	18	13.98	919	19.5	3.8	135	1080	2360	1900	5000	3300	M	16.50	900	2500	1	1	4	16	90	M
DEDZA																						
1	6	20.6	14.32	905	16.9	4.5	135	1600	2370	2120	5340	4625	M	24.70	1650	300	1	1	2	18.4	90	M
2	6	20.6	14.32	905	16.9	4.5	135	1600	2000	1930	3800	2710	M	10.30	950	280	1	1	9	20.2	360	M
3	6	20.6	14.32	905	16.9	4.5	135	1600	2090	1940	5160	2700	M	13.93	1080	290	1	1	12	22.16	360	M
4	6	20.6	14.32	905	16.9	4.5	135	1600	2170	1990	4920	3760	M	18.50	810	400	1	1	11	35.6	360	M
5	6	20.6	14.32	905	16.9	4.5	135	1600	2160	1820	3600	2940	M	10.58	1020	310	1	1	10	32.5	90	M
6	6	20.6	14.32	905	16.9	4.5	135	1600	2240	1900	4500	3840	M	17.28	1400	330	1	1	2	25.6	360	M
7	6	20.6	14.32	905	16.9	4.5	135	1600	2170	1990	4900	4090	M	20.04	1330	290	1	1	2	19.46	360	M
8	6	20.6	14.32	905	16.9	4.5	45	1600	2220	2100	5070	4130	M	20.94	1270	340	1	1	4	19.9	90	M
9	6	20.6	14.32	905	16.9	4.5	45	1600	2030	1870	5020	4170	M	20.93	1150	270	1	1	7	20.5	360	M
10	6	20.6	14.32	905	16.9	4.5	45	1600	2150	2090	5520	4100	M	22.63	1120	360	1	1	7	20.56	360	M
11	6	20.6	14.32	905	16.9	4.5	45	1600	2160	2000	5070	4660	M	23.63	1040	320	1	1	14	24.7	360	M
12	6	20.6	14.32	905	16.9	4.5	45	1600	2090	1960	4520	3160	M	14.28	1020	240	1	1	13	19.94	45	M
13	6	20.6	14.32	905	16.9	4.5	45	1600	2200	2380	5700	4730	M	26.96	1200	470	1	1	17	13.59	90	M
14	6	20.6	14.32	905	16.9	4.5	45	1600	2150	2390	5180	3880	M	20.10	970	440	1	1	16	11.65	90	M
15	6	20.6	14.32	905	16.9	4.5	45	1600	2340	2110	4500	4020	M	18.09	1060	260	1	1	15	24.8	360	M
16	6	20.6	14.32	905	16.9	4.5	45	1600	2260	2250	4640	3895	M	18.07	1160	330	1	1	16	16.34	360	M
17	6	20.6	14.32	905	16.9	4.5	90	1600	2130	2220	4580	3660	M	16.76	1010	530	1	1	16	23.54	360	M
18	6	20.6	14.32	905	16.9	4.5	90	1600	2560	2440	5890	4800	M	28.27	1130	370	1	1	17	23.44	360	M
19	6	20.6	14.32	905	16.9	4.5	90	1600	2390	2000	5420	4980	M	26.99	1600	440	1	1	10	27.4	440	M
20	6	20.6	14.32	905	16.9	4.5	90	1600	2140	2320	7000	4740	M	33.18	1100	370	1	1	6	7.26	360	M
21	6	20.6	14.32	905	16.9	4.5	135	1600	2220	2040	5050	3800	M	19.19	1300	240	1	1	4	17.9	90	M
22	6	20.6	14.32	905	16.9	4.5	135	1600	2230	1870	4400	3600	M	15.84	1030	130	1	1	10	25.44	360	M
23	6	20.6	14.32	905	16.9	4.5	135	1600	2480	2340	4940	4740	M	23.42	1310	440	1	1	10	23.88	360	M
24	6	20.6	14.32	905	16.9	4.5	135	1600	2070	2260	4260	3770	M	16.06	1170	490	1	1	7	14.38	360	M
25	6	20.6	14.32	905	16.9	4.5	135	1600	2060	1740	4690	3300	M	15.48	1030	380	1	1	11	34.2	360	M
26	6	20.6	14.32	905	16.9	4.5	135	1600	2080	2000	4910	4720	M	23.18	1140	150	1	1	19	11.4	360	M
27	6	20.6	14.32	905	16.9	4.5	135	1600	2660	2340	6620	5480	M	36.28	1300	230	1	1	7	22.93	360	M
28	6	20.6	14.32	905	16.9	4.5	45	1600	2320	1930	5540	4975	M	27.56	1040	440	1	1	1	38.59	90	M
29	6	20.6	14.32	905	16.9	4.5	135	1600	2090	2100	4505	4010	M	18.07	850	290	1	1	11	18.23	360	M

MANGOCHI

1	7	19	14.48	823	23.7	3.8	180	484	2245	2160	4680	4310	M	20.17	1390	300	1	5	27	16	1390	M
2	77	19	14.48	823	23.7	3.8	180	484	2440	1750	6000	4950	M	29.70	1600	210	1	5	14	30	1600	M
3	7	19	14.48	823	23.7	3.8	180	484	2200	1800	4760	3880	M	18.47	1600	340	1	5	16	25	1600	M
4	7	19	14.48	823	23.7	3.8	180	484	2552	1710	5050	4600	M	23.23	1700	336	1	5	7	35	1700	M
5	7	19	14.48	823	23.7	3.8	180	484	2730	2310	5530	4550	M	25.16	1880	300	1	5	7	21	1880	M
6	7	19	14.48	823	23.7	3.8	180	484	2400	2120	4700	3600	M	16.92	1900	330	1	5	7	18	1900	M
7	7	19	14.48	823	23.7	3.8	180	484	2778	2340	5900	5100	M	30.09	2000	310	1	5	16	21	2000	M
8	7	19	14.48	823	23.7	3.8	180	484	2350	1650	4950	4600	M	22.77	1630	510	1	5	7	37	1630	M
9	7	19	14.48	823	23.7	3.8	180	484	2020	1650	4700	3140	M	14.76	1150	250	1	5	M	29	1150	M
10	7	19	14.48	823	23.7	3.8	180	484	1890	1560	4800	3700	M	17.76	1000	300	1	5	M	33	1000	M
11	7	19	14.48	823	23.7	3.8	180	484	1800	1750	3620	3950	M	14.30	1100	200	1	5	M	13	1100	M
12	7	19	14.48	823	23.7	3.8	180	484	2020	1660	4030	3530	M	14.23	1420	130	1	5	0.17	20	1420	M
13	7	19	14.48	823	23.7	3.8	180	484	2120	1800	4500	3470	M	15.62	1250	280	1	5	1	26	1250	M
14	7	19	14.48	823	23.7	3.8	180	484	2540	2050	5760	4870	M	28.05	1560	320	1	5	3	28	1560	M
15	7	19	14.48	823	23.7	3.8	180	484	1990	1500	3330	4160	M	13.85	1280	230	1	5	3	30	1280	M
16	7	19	14.48	823	23.7	3.8	270	484	2040	1760	5230	5130	M	26.83	1570	240	1	5	7	19	1570	M
17	7	19	14.48	823	23.7	3.8	270	484	1980	1650	4400	3750	M	16.50	1350	200	1	5	7	22	1350	M
18	7	19	14.48	823	23.7	3.8	270	484	2030	1500	4250	3670	M	15.60	1570	300	1	5	1	28	1570	M
19	7	19	14.48	823	23.7	3.8	180	484	2360	1660	4560	4100	M	18.70	1610	170	1	5	1	29	1610	M
20	7	19	14.48	823	23.7	3.8	180	484	2250	1780	4440	4200	M	18.65	1580	160	1	5	4	22	1580	M

THYOLO

1	8	17.4	16.15	1273	20.1	2.9	135	820	2180	2400	5150	3970	M	20.45	940	510	1	1	15	14.9	135	M
2	8	17.4	16.15	1273	20.1	2.9	135	820	1540	1500	3740	3730	M	13.95	370	190	1	1	2	14.2	90	M
3	8	17.4	16.15	1273	20.1	2.9	135	820	2120	2000	6210	4260	M	26.45	930	260	1	1	4	15.19	135	M
4	8	17.4	16.15	1273	20.1	2.9	135	820	2060	1710	4490	4140	M	18.59	800	210	1	1	2	28.5	360	M
5	8	17.4	16.15	1273	20.1	2.9	135	820	1770	1570	3710	3670	M	13.62	670	180	1	1	7	25.4	135	M
6	8	17.4	16.15	1273	20.1	2.9	135	820	2150	1570	4430	4140	M	18.34	980	150	1	1	12	28.6	90	M
7	8	17.4	16.15	1273	20.1	2.9	135	820	1240	2030	4050	3540	M	14.34	590	250	1	1	1	7.7	135	M
8	8	17.4	16.15	1273	20.1	2.9	135	820	2140	2040	3710	3350	M	12.43	600	370	1	1	10	28.1	135	M
9	8	17.4	16.15	1273	20.1	2.9	135	820	2000	1900	4810	3750	M	18.04	890	710	1	1	2	30.1	90	M
11	8	17.4	16.15	1273	20.1	2.9	135	820	2000	1610	4940	4080	M	20.16	870	160	1	1	16	26.56	135	M
12	8	17.4	16.15	1273	20.1	2.9	135	820	2010	1650	5020	4530	M	22.74	600	160	1	1	14	30.02	135	M
13	8	17.4	16.15	1273	20.1	2.9	135	820	1930	1640	4770	4360	M	20.80	600	200	1	1	2	28.56	90	M
15	8	17.4	16.15	1273	20.1	2.9	135	820	1900	1680	4470	3400	M	15.20	1050	180	1	1	11	22.8	90	M

16	8	17.4	16.15	1273	20.1	2.9	135	820	1840	1390	6000	4950	M	29.70	570	130	1	1	3	38.09	360	M
17	8	17.4	16.15	1273	20.1	2.9	135	820	1870	1580	5330	4760	M	25.37	960	380	1	1	7	32.05	360	M
18	8	17.4	16.15	1273	20.1	2.9	135	820	1840	1410	5070	4400	M	22.31	760	210	1	1	1	30.4	90	M
19	8	17.4	16.15	1273	20.1	2.9	135	820	1990	1940	4200	3480	M	14.62	680	350	1	1	3	22	135	M
20	8	17.4	16.15	1273	20.1	2.9	135	820	1630	1320	4070	3660	M	14.90	540	190	1	1	4	39.8	360	M
21	8	17.4	16.15	1273	20.1	2.9	135	820	1720	1520	5350	3500	M	18.73	950	195	1	1	30	21.9	135	M
22	8	17.4	16.15	1273	20.1	2.9	90	820	1870	1770	4400	4370	M	19.23	700	200	1	1	3	21.5	360	M
23	8	17.4	16.15	1273	20.1	2.9	135	820	2140	1980	5230	4700	M	24.58	200	90	1	1	3	16.08	90	M
24	8	17.4	16.15	1273	20.1	2.9	135	820	2300	2000	5110	4300	M	21.97	400	161	1	1	9	33	135	M
25	8	17.4	16.15	1273	20.1	2.9	135	820	1800	1800	4230	3900	M	16.50	450	170	1	1	4	18.4	90	M
CHIKWAWA																						
1	9	18.3	16.5	811	25.5	3.5	135	110	1950	1380	4800	4000	M	19.20	970	130	1	1	2	32.7	90	M
2	9	18.3	16.5	811	25.5	3.5	135	110	1520	1440	4730	3600	M	17.03	570	215	1	1	2	19.8	360	M
3	9	18.3	16.5	811	25.5	3.5	135	110	1630	1550	4900	3720	M	18.23	530	200	1	1	4	54.9	360	M
4	9	18.3	16.5	811	25.5	3.5	135	110	2180	1840	5100	3920	M	19.99	740	240	1	1	2	27.8	360	M
5	9	18.3	16.5	811	25.5	3.5	135	110	2000	1270	4370	3770	M	16.47	810	90	1	1	11	35	360	M
6	9	18.3	16.5	811	25.5	3.5	135	110	2000	1470	4300	3200	M	13.76	1080	250	1	1	11	33.7	90	M
7	9	18.3	16.5	811	25.5	3.5	135	110	1700	1400	5850	4770	M	27.90	1120	150	1	1	2	20.6	90	M
8	9	18.3	16.5	811	25.5	3.5	135	110	1670	1620	5560	4370	M	24.30	370	290	1	1	4	23.8	90	M
9	9	18.3	16.5	811	25.5	3.5	135	110	1880	1870	4590	3540	M	16.25	390	240	1	1	2	20.7	90	M
10	9	18.3	16.5	811	25.5	3.5	135	110	2480	1910	6200	4730	M	29.33	960	240	1	1	17	27.6	90	M
11	9	18.3	16.5	811	25.5	3.5	90	110	2150	1720	4800	3830	M	18.38	990	170	1	1	11	23.5	90	M
12	9	18.3	16.5	811	25.5	3.5	135	110	1650	1640	5330	4900	M	26.12	200	200	1	1	21	30.3	90	M
13	9	18.3	16.5	811	25.5	3.5	135	110	1880	1450	4130	3230	M	13.34	590	300	1	1	5	40	90	M
14	9	18.3	16.5	811	25.5	3.5	135	110	1730	1720	5300	4450	M	23.59	370	230	1	1	10	20.3	90	M
15	9	18.3	16.5	811	25.5	3.5	135	110	1700	1410	3400	2220	M	7.55	570	220	1	1	5	36.8	90	M
16	9	18.3	16.5	811	25.5	3.5	135	110	2070	1800	5840	4910	M	28.67	370	100	1	1	5	22.2	360	M
17	9	18.3	16.5	811	25.5	3.5	135	110	2020	1730	4850	4130	M	20.03	660	110	1	1	1	24	90	M
18	9	18.3	16.5	811	25.5	3.5	135	110	1800	1420	4440	3500	M	15.54	800	120	1	1	7	22.6	360	M
19	9	18.3	16.5	811	25.5	3.5	135	110	1420	1430	3700	3190	M	11.80	620	190	1	1	4	13.5	90	M
20	9	18.3	16.5	811	25.5	3.5	135	110	2090	1520	3310	3300	M	10.92	510	130	1	1	9	35.1	90	M
21	9	18.3	16.5	811	25.5	3.5	135	110	1770	1540	5200	3560	M	18.51	700	200	1	1	10	21.8	360	M
22	9	18.3	16.5	811	25.5	3.5	135	110	1850	1770	3830	3685	M	14.11	900	570	1	1	3	28.4	90	M
23	9	18.3	16.5	811	25.5	3.5	135	110	2100	1950	6130	3530	M	21.64	700	100	1	1	9	13	360	M
24	9	18.3	16.5	811	25.5	3.5	90	110	1600	1530	4120	3600	M	14.83	200	150	1	1	7	21.5	90	M
25	9	18.3	16.5	811	25.5	3.5	135	110	1830	1820	4950	4940	M	24.45	1460	390	1	1	32	16	90	M
26	9	18.3	16.5	811	25.5	3.5	135	110	2050	1720	4830	3370	M	16.28	750	440	1	1	18	39.5	360	M
27	9	18.3	16.5	811	25.5	3.5	135	110	1790	1360	4620	3700	M	17.09	470	120	1	1	8	29.6	360	M

APPENDIX 6.2 Cross Correlations Amongst The Terrestrial, Environmental, And House Structural Elements

		ROOFAPEX	EAVESHT	ROOFSL	VDEPTH	EAVESWID	HKG	ALTITUDE	LATITUDE	WINDV	RRAD	TEMP	HUMIDITY	RAINFALL	HW	HL	HA
EAVESHT	C	0.02706															
	P	0.0000															
ROOFSL	C	0.2409	-0.2764														
	P	0.0001	0.0000														
VDEPTH	C	0.1161	0.1104	-0.0383													
	P	0.0702	0.0852	0.5520													
EAVESWID	C	0.3760	0.1224	0.1370	0.1936												
	P	0.0000	0.0563	0.0325	0.0024												
HKG	C	0.0046	0.3652	-0.0270	0.1541	0.0018											
	P	0.9429	0.0000	0.6752	0.0160	0.9782											
ALTITUDE	C	0.3635	0.4061	-0.0636	0.1057	-0.0127	0.1374										
	P	0.0000	0.0000	0.3228	0.0995	0.8438	0.0319										
LATITUDE	C	-0.6874	0.2551	-0.1986	-0.0725	-0.4139	0.0341	-0.6452									
	P	0.0000	0.0001	0.0018	0.2592	0.0000	0.5962	0.0000									
WINDV	C	0.6763	0.0120	0.1259	-0.1103	0.3138	-0.1846	0.3143	-0.6091								
	P	0.0000	0.8522	0.0496	0.0855	0.0000	0.0038	0.0000	0.0000								
IRRAD	C	0.1343	0.1342	0.2033	0.0901	0.2368	-0.1420	-0.2829	-0.2720	0.0480							
	P	0.0361	0.0362	0.0014	0.1605	0.0002	0.0266	0.0000	0.0000	0.4555							
TEMP	C	-0.2427	0.1800	0.1092	0.1779	0.3656	-0.0383	-0.5698	0.1765	-0.4878	0.6338						
	P	0.0001	0.0048	0.0886	0.0053	0.0000	0.5520	0.0000	0.0057	0.0000	0.0000						
HUMIDITY	C	-0.0615	0.4006	-0.1050	-0.0606	-0.2899	0.1189	0.4492	-0.1396	-0.1859	-0.4237	-0.4067					
	P	0.2938	0.0000	0.1019	0.3461	0.0000	0.0638	0.0000	0.0292	0.0036	0.0000	0.0000					
RAINFALL	C	-0.1128	0.4427	-0.0035	0.0359	-0.0545	0.2183	0.3827	-0.2373	-0.4182	-0.2190	-0.0183	0.8340				
	P	0.0786	0.0000	0.9561	0.5764	0.3969	0.0006	0.0000	0.0002	0.0000	0.0006	0.7761	0.0000				
HW	C	0.3113	0.3757	-0.2509	0.1909	0.1779	0.1816	-0.0021	0.0463	0.0359	-0.1165	-0.0642	0.1112	0.0608			
	P	0.0000	0.0000	0.0001	0.0028	0.0053	0.0044	0.9743	0.4717	0.5769	0.0692	0.3182	0.0829	0.3446			
HL	C	0.6098	0.3529	-0.0555	0.2120	0.2253	0.1215	0.2134	-0.3487	0.2569	0.0610	-0.1319	0.0528	0.0761	0.6732		
	P	0.0000	0.0000	-0.3879	0.0009	0.3334	0.0581	0.0008	0.0000	0.0000	0.3428	0.0395	0.4120	0.2362	0.0000		
HA	C	0.5100	0.3744	-0.1429	0.2081	0.2176	0.1738	0.1308	-0.1959	0.1587	-0.0021	-0.0952	0.0943	0.0916	0.8985	0.8990	
	P	0.0000	0.0000	0.0256	0.0011	0.0006	0.0065	0.0412	0.0021	0.0130	0.9742	0.1380	0.1419	0.1536	0.0000	0.0000	
WINDIR	C	-0.4179	0.0746	0.1436	0.0872	0.2264	0.1065	-0.3994	0.3729	-0.5096	0.0334	0.5657	-0.0658	0.1892	0.1481	-0.1406	-0.0047
	P	0.0000	0.2460	0.0248	0.1744	0.0004	0.0969	0.0000	0.0000	0.0000	0.6037	0.0000	0.3056	0.0030	0.0207	0.0281	0.9423

Cases Included : 244 , Missing: 37