IN THE NAME OF GOD

****

This thesis judged by:

Rev. Michael Humphreys and Mr Ian ward

The University of Sheffield

Shahin Heidari

Thermal Comfort in Iranian Courtyard Housing

Doctor of Philosophy

2000

Thermal Comfort in Iranian Courtyard Housing

A field study of thermal environments in western Iran

Shahin Heidari

School of Architecture
The University of Sheffield

This thesis is submitted for the degree of Doctor of Philosophy

April 2000

SUMMARY

Thermal comfort in Iranian courtyard housing

(Shahin Heidari)

School of Architectural Studies, University of Sheffield

This thesis investigated thermal comfort for naturally ventilated housing in Iran with special reference to Ilam. An important aim was to establish the neutral temperature and the acceptable range of environmental conditions for Ilam people in their houses.

The methodology used for this aim was field studies. These studies were divided into two parts- one in the hot season and the other in the cool season.

The results showed a good relationship between neutral temperature and mean indoor temperature and also between outdoor temperature and neutral temperature.

The indoor comfort temperature (T_n), which is dependent on outdoor temperature (T_{om}), could be found from the following equation:

$$T_n = 17.3 + 0.36\, T_{om}$$

The findings of the study revealed that the Ilam people could achieve comfort at higher indoor air temperatures compared with the recommendations by international standards like ISO 7730.

The results also showed that passive systems as a main comfort strategy could be applied to housing design in Ilam. By using the results of this study, strategies to minimise housing energy consumption, not only for Ilam but also for other regions, which have similar climates and cultures to Ilam, can be proposed.

This thesis is dedicated to

My wife

Acknowledgements

After spending three years on a research project, there are many of people who have assisted academically, technically and of course socially. Many people, both past and present, have helped and encouraged me in various ways, and for this I would like to express my deepest gratitude.

Initially thanks must go to both of my supervisors, *Professor Steve Sharples* and *Dr. Adrian. C. Pitts*, who have assisted me and had patience and understanding throughout the duration of my work. This is closely followed by and with special thanks to *Rev. Michael Humphreys* and *Fergus Nicol* for their invaluable advice during the study. Thanks are also due to *Ian Ward* for his comments and advice.

I would like to express thanks to my office mate, *Kitchai,* for numerous thermal comfort discussions. I would also like to thanks *Mrs Hazel Hall, Mrs Pat Hodjkinson* and *Mrs Doreen Spurr* from the general office, *Ms Lois Bert* and *Mrs Elaine Ashton* in the library for being very helpful.

In Ilam, without all the Ilam subjects, the surveys would have been impossible; I would like to thank all the subjects. In particular thanks to all my friends in the Ilam University.

My gratitude also goes to my brother *Shahdad.* He helped me through some difficult moments and made these moments a lot easier.

Finally, no words of thanks can match those for my wife, *Janet* for being very inspirational and supportive and most importantly understanding, and my son *Hossien* for letting me do my work.

Content

List of symbols

AMV	Actual mean vote
A_v	Air movement vote on three point scale
C	Comfort vote on Bedford scale
ET	Effective temperature, °C
ET*	New effective temperature, °C
H_v	Humidity vote on three point scale
P_3	Preference vote on three point McIntyre scale
P_5	Preference vote on five point scale
P_a	Water vapour pressure, millibar
PMV	Predicted mean vote
PPD	Predicted percentage of discomfort
Rh	Relative humidity, %
R	The average annual rainfall, mm
S	Sensation vote on ASHRAE scale
SET	Standard effective temperature, °C
T	The average annual temperature, °C
T_a	Indoor air temperature at the time of questionnaires, °C
T_c	Comfort temperature, °C
T_{cG}	Griffiths comfort temperature, °C
T_d	Thermal discomfort
T_g	Indoor globe temperature at the time of questionnaires, °C
T_i	Mean indoor temperature, °C
T_n	Neutral temperature, °C
T_o	Daily mean outdoor temperature, °C

T_{olt}	Long term average outdoor temperature, °C
T_{om}	Monthly mean outdoor temperature, °C
T_{ope}	Mean indoor operative temperature, °C
$T_{o(max)}$	Monthly mean maximum outdoor temperature, °C
$T_{o(min)}$	Monthly mean minimum outdoor temperature, °C
T_p	Preferred temperature, °C
T_{ope}	Operative temperature, °C
V	Air velocity, ms^{-1}

Chapter One

Introduction

1.1 Background

Charles Correia said:

"To live in the third world is to respond to climate"

This statement reflects the philosophy and practice of traditional vernacular architecture in which dwelling types and construction materials responded to their natural environment to provide the desired levels of comfort [Brobby; 1987]. Unfortunately, in the third world today borrowing architectural ideas from the western modern style is usual. Developing countries started to receive a major influx of foreign ideas that were very different from their local traditions. As an example, the Egyptian minister of public works, Ali Mubarak wrote: "*today people have abandoned the old ways in construction in favour of the European style because of its more pleasant appearance, better standards and lower costs. In the new system rooms are either square or rectangular in shape. In the old system living rooms together with their dependencies were disordered, corridors and courtyards occupied a lot of space, most of the spaces lacked fresh air and sunlight, which are the essential criteria for health, thus humidity accumulated in these spaces causing disease......facades never followed any geometric order and thus looked like those of cemeteries. In the new system facades are ordered and have a good, familiar look*" [1888]. This statement was made a century ago, when everything in developing countries was going to change. Today's problems are because of such ideas.

One of the more unfortunate aspects of modern global development (not only in developing countries but also in developed countries) has been the introduction and widespread acceptance of the use of mechanical means for providing desired comfort levels for human habitation. This caused increasing demand of energy to power the mechanical comfort devices. In fact the proportion of energy used in buildings for providing indoor comfort conditions has significantly increased within recent years. The main question is:

"With this amount of energy used in the design do the indoor temperatures match to the occupants' requirements"?

Much evidence shows the answer to be "no". Surveys in air conditioned buildings carried out by students of Oxford Brookes University showed that almost 30% of occupants found the buildings too hot in winter on a daily basis [Nicol; 1993]. Different comfort conditions for people derived from field studies (in the real world) and comfort conditions from standards is a good example of the waste of energy for providing comfort conditions. There is evidence to suggest occupants are more tolerant of variation in conditions.

Fortunately, designers are now actively encouraged to look at energy usage and conservation in many different fields. Studies of indoor thermal comfort will provide an estimate of indoor thermal conditions which are most suitable for the building's occupants. It is useful for guiding the design of buildings and enclosed environments, for achieving energy savings and to guide the control of environments which people can not control for themselves [Raw and Oseland; 1994]

The thermal comfort of building occupants is related to three groups of factors, namely physiological and psychological parameters together with behaviour of occupants, design of the building and the outdoor environment. Achieving comfort conditions requires an understanding of the interaction between these factors. Thus, any study of thermal comfort should take all these considerations into account. It is important to link climate and climatic elements with methods of building design according to human needs. Also, there is much evidence that people prefer to control their own thermal environment and use a wide range of possibilities in creating comfort conditions. It may be possible using these principles to establish a set of guidelines for providing thermal comfort conditions in buildings. If buildings are not well designed in terms of climatic response then the resulting conditions will make the demand for air-conditioning perfectly reasonable [Baker; 1987].

It cannot be questioned that thermal comfort has been recognised by people in different ways according to different insights and different expectations of life.

These are numerous strategies to achieve thermal comfort. In many climates humans spend most of their time in cleverly constructed shelters and are interested in thermal comfort. In line with other thermal comfort researchers, this thesis aims to enlarge the pool of knowledge of building science.

1.2 Aims of this study

While most developed countries have been trying to reduce as much as possible their energy expenditure in buildings, Iran is still some way behind. The use of energy is dependent on climatic conditions and the demand for energy to modify the internal environment in order to achieve indoor comfort. In Iran more than anywhere, architectural solutions to the provision of pleasant indoor conditions have been replaced by energy intensive mechanical systems [Hashemi; 1996].

Figure 1.1 Example of modern office built in Ilam

After the war between Iran and Iraq (1991), about 3500 houses in the traditional parts of five cities in Iran were replaced with new and modern houses with central heating systems [The Revenue Operation; 1994]. The Iranian government also built more than 65000 m^2 work places in Ilam [The Revenue Operation; 1994] with modern style and without any attention to climate [Heidari; 1996]. Figure (1.1) shows one of these buildings. According to the study's researcher experience in his city, people are satisfied in terms of indoor environment condition in their naturally ventilated houses which are built with passive systems. It seems, however, they do not need mechanical means for heating or cooling in their houses. Whether this is true or not was one of the main aims of the present study.

The objective of this study will be a systematic investigation of thermal comfort in housing in a city in the hot region of Iran. It is important because of people's desire to feel thermally comfortable

The following are the aims to be achieved:

1- To use the science of thermal comfort to improve the understanding of the conditions under which people in buildings will be comfortable

2- To identify a set of conditions which are considered comfortable by people who are living in the hot and dry climate in the west part of Iran. The set of comfort conditions can be used in the housing design of Iran. So another aim is to create design recommendations to be applied to hot dry regions of Iran.

3- To determine the neutral temperature in the hot and cool seasons.

4- To find out the relationship between neutral temperature and indoor temperature.

5- To find out if there is any effect between indoor neutral temperature and outdoor temperature. Is it a real effect?

6- To compare the neutral temperature of people who are living in traditional courtyard housing and in contemporary courtyard housing.

7- According to Humphreys [1994] "People will make themselves comfortable if they wish" so another and important aim of this study is to identify some of the adaptive behaviours used by people for providing comfort conditions.

8- Make recommendations for future work in Iran.

1.3 Scope of study

Experimental work in this study consists of two parts. Firstly, a field study of thermal comfort in the courtyard housing of Iran. The important aim of this part of the study was to identify a set of comfort conditions. Secondly, field studies illustrate what has become known as the adaptive approach to thermal comfort.

The two parts are restricted in scope to the following:

1- Only courtyards housing (traditional and contemporary) were used in this study.

2- All houses were naturally ventilated housing.

3- This study concentrated on Ilam, which is one of the cities in the hot dry zone of Iran.

4- Activity level and clothing value cannot be measured precisely. However, prediction values have been made as close as possible by using a check list recommended by ISO 7730-1994 and for unusual clothing, which is used in Iran, this study used a list of clo. values in Nicol's work [1994] and his team in the field study of thermal comfort in Pakistan.

1.4 Structure of the study

After this Chapter, Chapter Two discusses the geography and climate of Iran with a focus on Ilam, which is selected for the field studies. Next, Chapter Three looks at traditional and contemporary courtyard housing in Iran. It starts off by discussing the concept of traditional housing in the hot dry zone of Iran and reviews some advantages, especially with respect to climatic considerations in this style of design. It further looks at contemporary housing in Ilam. Chapter Four reviews thermal comfort research. The Chapter begins with a brief outline of the history and current approaches to thermal comfort theory. In Chapter Five some previous studies on relevant research are reviewed. Chapters Six and Seven discuss the results of four thermal comfort field surveys taken during two seasons in Ilam. The methodology of the study is introduced in the first part of Chapter Six. The results of the four experimental works in Ilam, based on adaptation theory in a wider context, are discussed in Chapter Eight. A comparative analysis between the findings of this study and other studies are in Chapter Eight. This Chapter also attempts to compare the bioclimatic chart concept as well as Mahoney tables for Ilam. Chapter Nine is the concluding one and summarises this study and gives some suggestions for future research.

Chapter Two

Geography and Climates of Iran

2.1 Introduction

One of the main steps toward an acceptable study in thermal comfort is a survey of climate and climatic elements at a given location. The purpose of this chapter is to provide a general understanding of the nature of the hot climate, focusing on the geographical area of the present study.

The review starts by looking at a general description of the history and geography of Iran. It continues with a study of climate and climatic elements, climatic classification, and the nature of hot arid zone of Iran. A brief illustration of Ilam and climatic elements of this city, which is used in this field study, is in this chapter. It is needed and will be helpful in understanding later chapters

2.2 Iran and the geography of Iran

2.2.1 History

The land know today as Iran and called Pars or Persia in the past has a history as ancient as human civilisation [Wilson; 1930]. The history of ancient Iran can be divided into a period prior to the arrival of the Aryans and the one afterwards. The latter period itself is divided into pre – Islamic and Islamic periods.

In the Aryan period, various ethnic groups lived here, as attested to by traces of their rules and civilisations. The most ancient among them were the Ilamites; (The present Ilam is a big part of primitive Ilam). After the arrival of the Aryans, Iranian culture liberated itself from Greek dominance and Pahlavi becomes the official language of the country. The Islamic era in Iran can be subdivided into several periods. From various viewpoints, including the proclamation of an official religion, the creation of a strong central government, the subjugation of local warlords, resistance against foreign intrusion, a flourishing economy, and rural and urban development, particularly in Esfahan and its magnificent monumental architecture, this period was one of country's most important periods of glory and development.

2.2.2 Population

Iran had a population of about 10 million around the year 1900, which has increased more than six-fold in less than a century. Over 60% of the population lives in towns and cities, a little under 40% lives in rural areas and a small portion are seasonal migrants. The town-dwelling ratio in Iran has always been higher than the world average, for instance in 1996, while this ratio stood at 36% in developing countries and at around 45% in the world at large, it rose to over 60% in Iran, [Zandjani;1998].

2.2.3 Geography

Iran is located in Southwest Asia and shares border with Turkmenistan, Armenian, Afghanistan, Iraq, Pakistan and Turkey, (Figure 2.1).

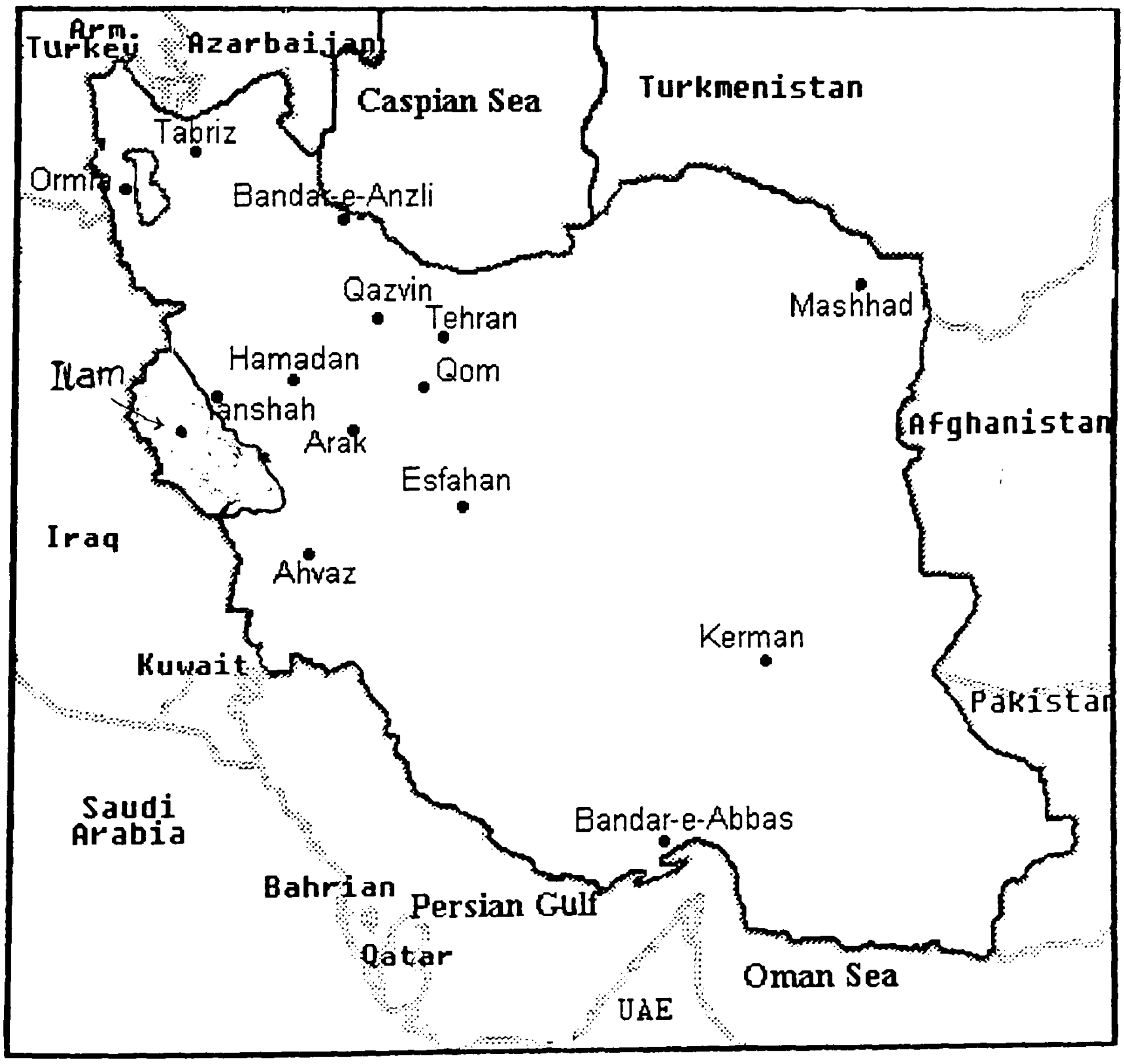


Figure 2.1- Geographical map of Iran

Iran covers an area of some 1648000 sq. km and extends between 25° and 40° N, and longitude 44° and 63° E [Bahadori; 1973].

Iran has a frontier that has been estimated at 4455 km in total length, of which over half is seacoast, with 650 km lying along the Southern Caspian shore, and the remainder comprising the northern parts of the Gulf of Oman and Persian Gulf.

In terms of physical geography, Iran covers part of the Iranian plateau, located at the centre of the vast dry Eurasian belt, and lies at an equal distance from the desert steppes of Central Asia and the arid regions of northern Africa and therefore includes both cold mountainous regions and torrid, arid deserts. The Alborz mountain range, on the north, separates the alluvial regions of the Caspian Coast from the Central Iranian plateau. This range runs from the country's borders with Turkey and Armenia, to the Hindu Kush in Afghanistan, culminating at Mt. Damavand, which rises to an elevation of 5671 meters Northeast of Tehran [Ehlers; 1986]. Western Iran is shaped by the particular environment of the Zagros range. These two ranges, as well as smaller ones in central Iran, have created various environmental and climatic conditions.

2.3 Climate

2.3.1 Definition

Climate is defined by the Oxford English Dictionary as "region with certain conditions of temperature, dryness, wind, light, etc".

For a scientific and semantic definition, according to Koenigsberger et al [1973], climate is 'an integration in time of the physical states of the atmospheric environment, characteristic of a certain geographical location'. In this definition two things are important- time and location- which produce an infinite variety of climates. Also, this variety is changeable by natural and man - made forces.

2.3.2 Classification of climate

The boundaries of climatic zones are vague and cannot be accurately mapped. However, for a good approach to building design with climatic considerations a classification of climate is essential and very closely related to the amount of knowledge of climatic patterns. Indeed, the primary objective of building is to provide an acceptable habitat. In the classification of climate, the constituents of climate which promote a particular mode of heat dissipation from the human body and call for certain specific features in building design, are combined together to form a particular climate zone.

Climatic classification is usually based on the various climatic studies for a region. This can be a single element or a combination of elements with attention to the relationships between them. Relationships should be identified, because the combined effect of different elements is usually different from the effect of one, [Gotz; 1986].

The variation in judgement of climate also depends on altitude, past experience, physiological metabolism of individuals and desirable conditions.

There are many climatic classification systems, but W.Koppen's [1936] system is generally accepted. Koppen's method was first published in 1918, based upon organising the many types of climate into several classes. Its simplicity is one of the most attractive characteristics of this method. A benefit of this scheme is that it uses numerical values for defining the boundaries and symbols for the great types of climate as well as lesser subdivisions.

Koppen determined five basic climate zones, using the relationship of climate to vegetation, which are:

1- Hot- humid or tropical rainy climates with no cool season

2- Hot- arid and semiarid or dry climates

3- Temperate or middle- latitude rainy climates with mild season

4- Cold or middle- latitude snow climates with severe winter

5- Arctic or polar climates with no warm season

The second category, which is important in the present study. is divided into two subgroups: semiarid and desert.

According to Olgyay, [1963], the details of Koppen's classification are not directly applicable to housing. He noted that for architects' use human need is the determining factor. However, according to the scope of this study a hot dry region which is a main class or subclass of any climatic classification system, is used.

2.3.3 Hot dry region

Hot dry regions are found in the subtropical latitudes, approximately between 15 and 30 degrees North and South of the equator, in central and western Asia, the Middle East, Africa, North and South America and in central and Northwest Australia. These regions are characterised mainly by their aridity, high summer daytime temperature, large diurnal temperatures range and high solar radiation and low humidity [Givoni; 1998]. Such characteristics affect human comfort and building design. Summer is the more stressful season and winter in some hot dry regions is comfortable while others may have winter temperatures well below freezing, such as Southern New Mexico in the United State or in Iran.

The boundary between this category by Koppen (Semiarid and desert) is fixed by the rainfall value and can be determined by the following formulae:

For semiarid :

- If rainfall evenly distributed: $R > T + 7$
- If rainfall concentrated in winter: $R > T$
- If rainfall concentrated in summer: $R > T + 14$

For desert:

- If rainfall evenly distributed: $R < T + 7$
- If rainfall concentrated in winter: $R < T$

- If rainfall concentrated in summer: $R < T + 14$

where: R is the average annual rainfall in (cm)

T is the average annual temperature in (°C)

2.3.4 Climatic elements

In the hot region, the principal climatic elements for building design are solar radiation, air temperature, humidity and wind.

This section briefly describes these elements which will be helpful. A full description is beyond the scope of this study.

Solar radiation is the source of almost all the earth's energy and is, as a result, the dominating influence on all climatic phenomena. The intensity of solar radiation at the upper limits of the atmosphere varies according to the earth's distance from the sun and the solar activity. A part of the incoming solar radiation is reflected by the surface of the clouds, and part is absorbed by the atmosphere in layers, while a certain amount is scattered in all directions by the air molecules themselves. In arid zones a large percentage of the radiation reaches the ground. Solar radiation varies greatly with the geographic location, the altitude and the weather.

The four main channels of radiation heat transfer affecting buildings are direct short- wave radiation from the sun; diffused (part of the scattered radiation) short- wave radiation from the sky –vault; short- wave radiation reflected from the surrounding terrain; and long- wave radiation from the heated ground and nearby objects. These affect buildings in two ways, first by entering through windows and being absorbed by internal surfaces, and then, through being absorbed by the outside surfaces of the building. Another major form of heat transfer affecting buildings is longwave radiation exchange to the sky, an effect which is reduced when the sky is clouded and is strongest when the atmosphere is clear and dry as in hot- arid zones where it can be utilised as a source of energy for cooling buildings, [Konya; 1980]. In the hot climate, it is particularly important that the designer influences these effects, and knows how this can be done.

For solar radiation measurements, a simple sunshine recorder will register the duration of sunshine, which can be expressed as number of sunshine hours per days, as an average for each month, [Koisingberger et al;1973].

Along with solar radiation, air temperature is important. According to Givoni [1976], the rate of heating and cooling of the surface of the earth is the main factor determining the temperature of the air above it. At night the surface of the earth is usually colder than the air as a result of long- wave radiation to the sky, and so the net heat exchange is reversed and air in contact with the ground is cooled. In general, temperatures are lowest just before sunrise, as diffused radiation from the sky causes the temperatures to rise even before dawn, and highest over land about two hours after noon, when the effects of the direct solar radiation and the high air temperatures already prevailing are combined.

The available local meteorological data on air temperature can be used for architectural design purposes. Furthermore monthly mean, minimum and maximum temperature will give an indication of the diurnal variations. These can be large in the hot arid zone. Building design must make allowances for this.

Although in hot arid regions relative humidity is normally low, it should be a consideration and it is important to measure it in the hot climates. Relative humidity, as well as vapour pressure, is used to express the moisture content of air. The relative humidity of the air concerned will vary with any change in temperature. It is the ratio of the actual humidity in a given volume of air to the maximum moisture capacity at that particular temperature.

Wind is the last parameter, which is very unstable. The variability of the wind is revealed in its direction and its speed. Both of them are strongly influenced by several factors, such as the daily variations in heating and cooling of land and sea, the topography and the seasonal global distribution of air pressure. Wind is characterised by three variables: direction (winds are always named by the direction they come from), speed and the degree of uniformity (wind is not a steady current but is made up of a succession of gusts, slightly variable in direction, and separated by lulls).

Wind is important in the hot climate and is used for ventilation in this zone. For any ventilation system, as well as for the level and size of any openings, wind will determine the pattern of what is needed.

2.3.5 Climate and climatic classification of Iran

Iran has a complex climate, ranging from subtropical to sub - polar. In winter, a high pressure belt slashes west and south to the interior of Iran, while low-pressure systems develop over the warm waters of the Caspian, the Persian Gulf, and the Mediterranean. During the summer the winds are dominated by the Indian monsoon system. Its direction over most of Iran is again more or less from north or north- west, but topography plays a great part in modifying this general picture. On the other hand because of the special disposition of the mountain ranges and the influences of the seas, air temperature is different from one place to another. In the summer, temperatures vary from a high of 53°C in Dehloran that is near Ilam, to a low of 1°C in the north - west of the country. Precipitation also varies greatly, ranging from less than 25 mm in the south- east to about 200 mm in the Caspian region.

From time to time, the country is exposed to the movement of air masses that originate in distant places and are therefore initially of totally different temperatures from those prevailing in Iran. Such air masses can exert a great influence on the pattern of temperature distribution within Iran. The middle of summer time is July and August, which are the warmest months of the year.

Hariry et al [1985] divided the country into 8 zones, Kassmai [1992] suggested 12. However according to the Iranian National Building Code by the Ministry of Housing and Development [1993], the country is divided into five main climatic zones which are:

[A]- Winter temperate, summer hot and dry- this region experiences generally higher temperatures. July is warm and dry, but December and January are pleasant.

[B]- winter temperate, summer warm and humid- characterised by a low annual range of temperature, with relatively high values. The mean monthly minimum is reached in February. August is the month with the highest mean temperature, and both these characteristics are due to the retarding influences of the sea, as has already been intimated.

[C]- winter cold, summer hot and dry- the mean monthly temperatures in this zone are high with very low relative humidity. Four months in each year are very hot and dry (June- September). During summer daytimes are hot and night-time is pleasant.

[D]- winter warm but summer hot and humid- in this area, January is the coldest month, and July is hottest. Relative humidity is often high more than (60%) during the year.

[E]- winter cold but summer warm and dry- this is characterised by a low December and January mean value, which almost approaches freezing point. August is the warmest month and often relative humidity is high during winter. Five months in each year, it is cold and humid (November- March).

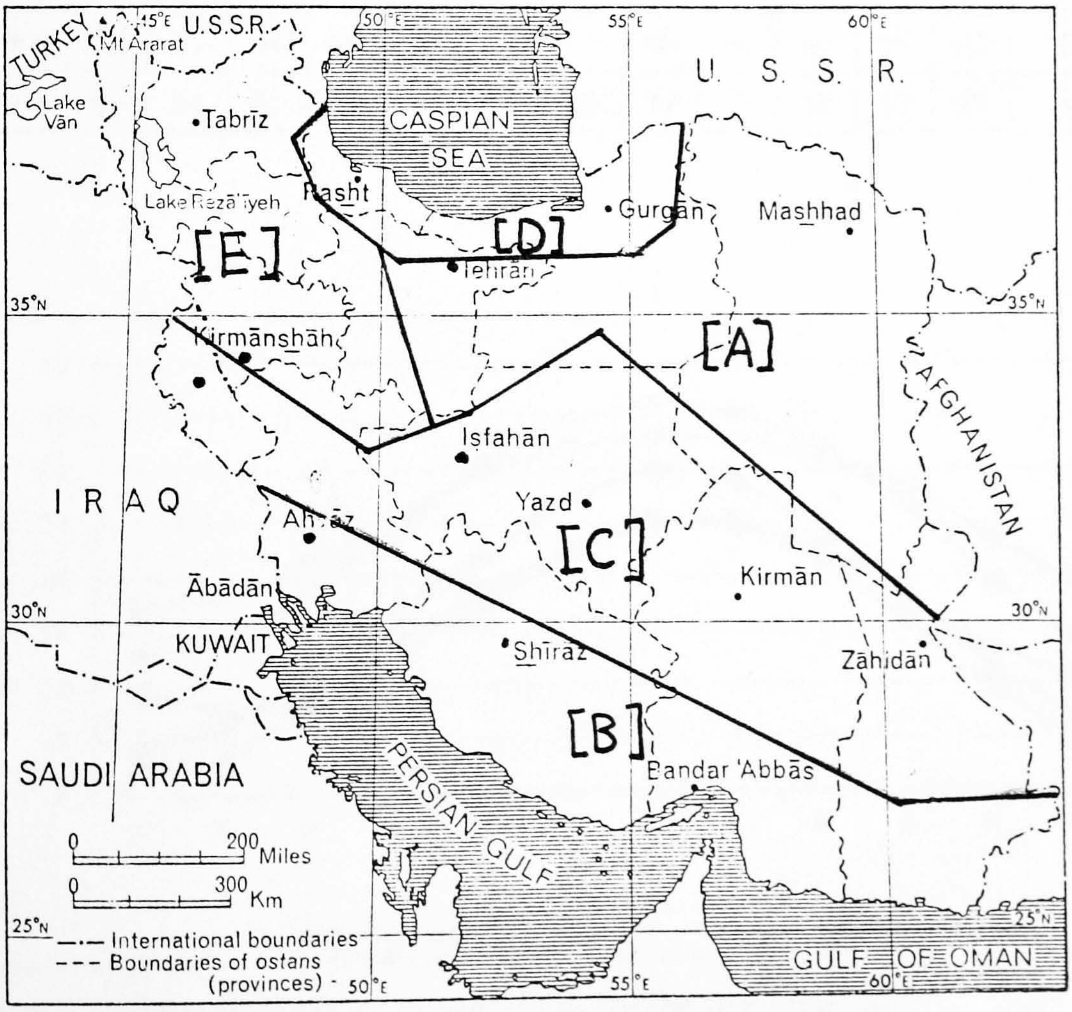


Figure 2.2 The boundaries of the various climatic regions of Iran

The boundaries of the various climatic regions are marked in Figure (2.2).

Tables (2.1 and 2.2) as well as Figures (2.3 and 2.4) shows the mean monthly air temperature and relative humidity in each group.

Table 2.1 Mean monthly air temperature for the five main climatic zones of Iran

Months		J	F	M	A	M	J	J	A	S	O	N	D	*Year*
A	T_{om}	12.7	14.4	19.0	24.5	30.6	34.7	36.3	35.3	32.2	26.6	19.4	14.2	**24.9**
B	T_{om}	9.2	7.7	8.7	14.0	18.7	22.6	25.3	25.2	22.7	17.8	13.1	10.6	**16.0**
C	T_{om}	4.4	6.1	11.2	17.0	22.1	27.5	30.2	28.8	24.8	18.4	11.4	6.8	**16.9**
D	T_{om}	17.4	18.2	21.6	25.6	29.9	32.2	33.1	32.7	31.1	28.3	23.4	19.4	**26.1**
E	T_{om}	2.4	3.2	8.3	13.3	17.5	22.3	25.5	24.8	21.5	15.9	9.5	4.6	**14.8**

Table 2.2 Mean monthly relative humidity for the five main climatic zones of Iran

Months		J	F	M	A	M	J	J	A	S	O	N	D	*Year*
A	Rh%	68	63	54	46	38	34	31	35	37	41	51	66	**44%**
B	Rh%	83	86	85	83	79	78	75	78	79	82	82	79	**81%**
C	Rh%	63	61	51	42	35	24	21	21	26	34	45	66	**45%**
D	Rh%	65	67	64	60	59	64	71	66	64	66	60	63	**62%**
E	Rh%	69	64	61	53	51	45	40	39	37	48	58	67	**52%**

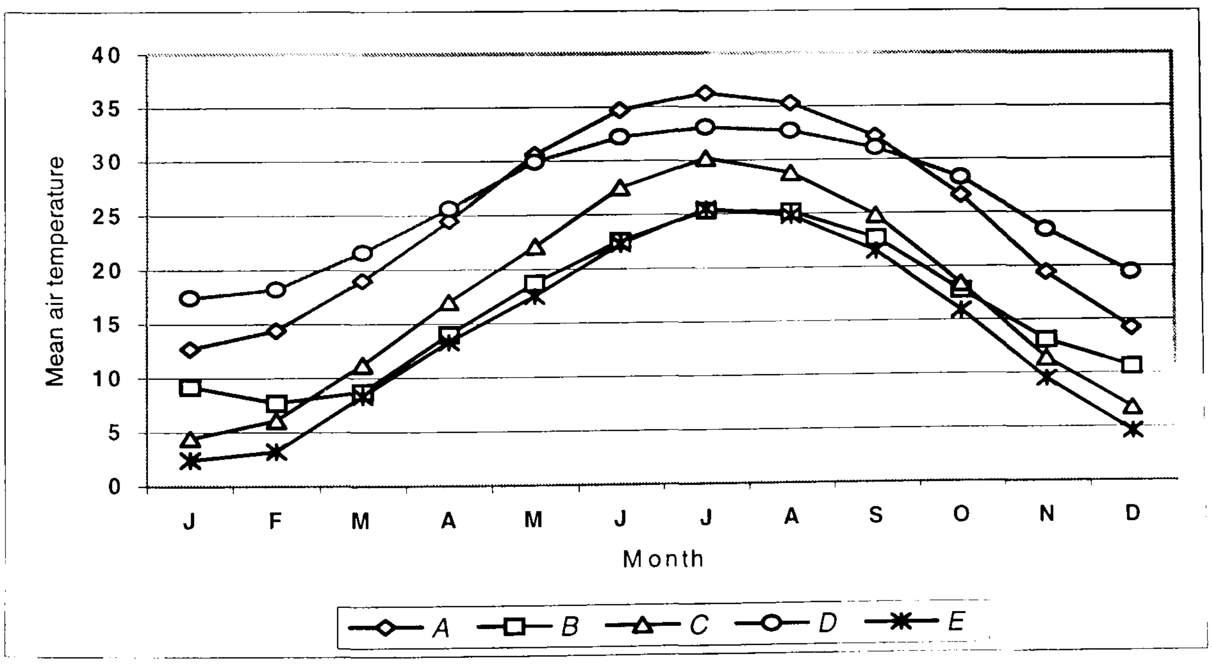


Figure 2.3 Mean monthly air temperatures for the five main climatic zones

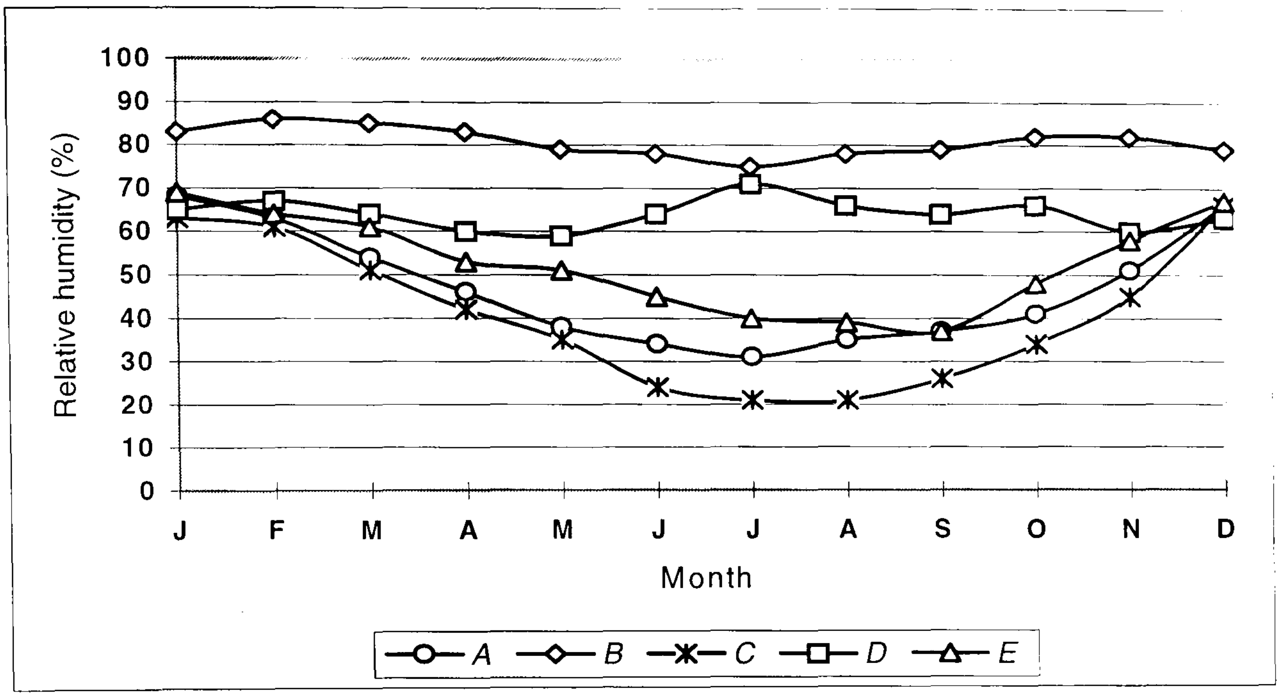


Figure 2.4 Mean monthly relative humidity for the five main climatic zones of Iran

2.4 The City of Ilam

2.4.1 Geography

The city of Ilam is located in the west of Iran, and it lies at 1319 meters above sea level on latitude 33° 38′ N and 46° 26′ E longitude. According to Fisher [1968] Ilam is in the Zagros region which is one of the four major parts of Iran. In this region, in terms of structure and topography, two distinct sub-regions may be recognised as a North-western section and the main Zagros. The general topographical effect on the north-west section is consequently that of a series of irregular tablelands, which lie at an average altitude of 1500 to 2000 m over much of the area, but another part of this region is quite different from the point of altitude. Kermansha with 1322m, Dezful with 144m, Ilam with 1319m and Mehran with 155m all are in main Zagros. On the other hand according to the Iranian National Building Code [1993], Ilam is in the group [C] of their climatic classification, which is hot and dry zone of Iran. In terms of climatic elements, this is exactly right, but there is a doubt in terms of physical geography and the arid zone nature of Iran. However, it is acceptable that Ilam is in a hot and dry region of the country, [Tavassoli, 1980].

2.4.2 Climate

The temperature difference between summer and winter and also between day and night is great, so that is creates an environmental conflict when determining the appropriate form and orientation for both the buildings and the whole settlement.

Two months in the winter and five months in the year are periods featuring rather harsh conditions as cold and hot respectively. During the critical summer months relative humidity is low and diurnal temperature difference is high. The whole historical climatic data for a period of 10 years (1982- 1992) is given in Table (2.3). A longer period of historical data (such as Mehrabad airport office) was available. Because of the accuracy of the data of the war office, the present study used such data

The most critical months of the year, from the point of view of temperature studies, are the midsummer and midwinter months, during which extremes of temperatures usually occur. In Ilam July is the hottest month with low relative humidity. Figure (2.5) shows the historical air temperature of Ilam for a period of 10 years and Figure (2.6) show the equivalent relative humidity data.

Table 2.3 Historical monthly climatic data of Ilam

Months	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
T_{om} (Max)	12.1	14.4	18.7	25.4	28.5	35.8	41.0	38.2	34.8	28.5	24.8	18.3
T_{om} (Min)	2.1	3.7	7.1	9.9	14.6	18.7	21.4	19.3	17.1	12.8	8.9	5.5
T_{om} (Ave)	7.1	9.2	12.9	16.7	20.4	25.7	31.5	28.7	24.3	20.6	16.8	11.9
Rh% (Max)	70	69	61	53	47	35	29	31	35	47	60	66
Rh% (Min)	46	41	37	32	23	19	15	18	20	25	40	43

(Period of 10 years 1982-1992- data from war meteorological office of Ilam)

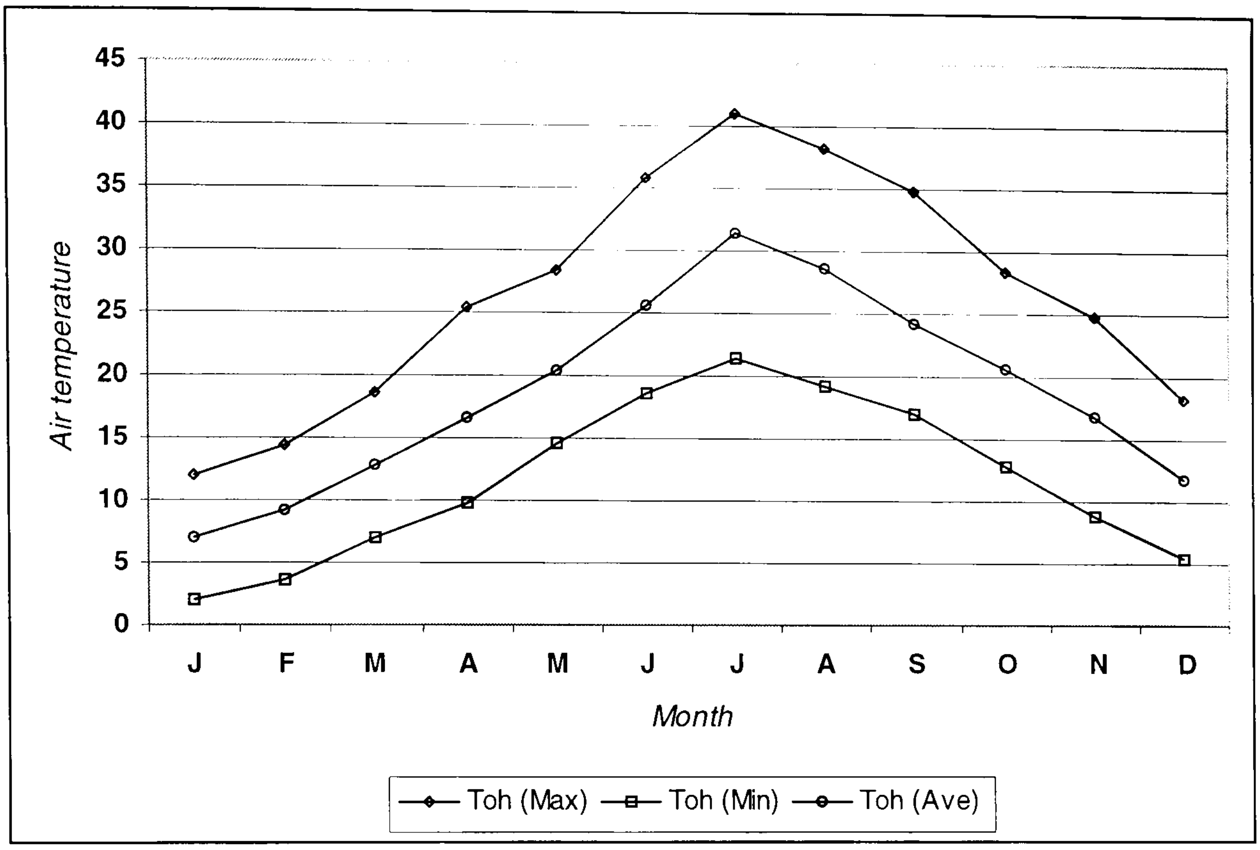


Figure 2.5 Monthly air temperatures of Ilam- (Maximum, Average and Minimum)

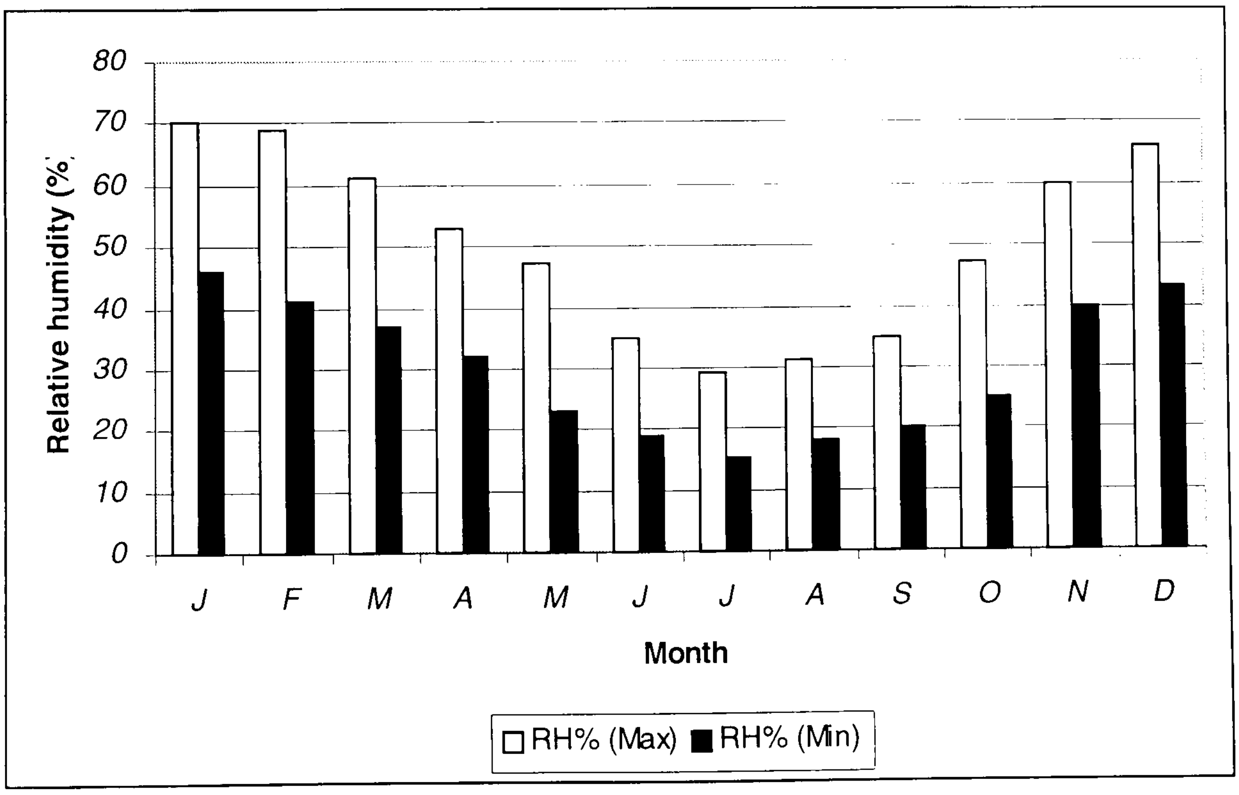


Figure 2.6 Monthly maximum and minimum relative humidity of Ilam

2.5 Conclusion

This chapter has discussed the characteristics of the climate in general and the hot dry climate in particular. A general outline of Iran in terms of history and geography with special reference to Ilam has been given.

The next chapter will discuss the features of housing in Iran and also the effects of climatic conditions in housing design are presented.

Chapter Three

Iranian Housing

3.1 Introduction

All agree with the comment that designing comfortable housing for a hot dry climate requires considerable skill and knowledge. It is not only knowledge of building technology but also knowledge of life styles. To understand better the architectural demands an understanding of the way of life, especially when a traditional society is under consideration. Rapoport [1969] argues that many groups of people built their shelter not only to protect themselves from the rigours of the physical environment, but also as an expression of their way of life. This can help explain why some people use tents as shelter while others use thick mud walled houses in the same climate. In fact a range of adaptive mechanisms for comfortable conditions according to culture and climatic variables has been divied during the course of man's experience with hot dry zone living. This chapter will briefly attempt to look at the relationship between housing design and comfort conditions.

Two categories of housing are identifiable: traditional housing and contemporary housing. Iranian people in traditional housing have, over the centuries, attempted to exploit the local resources within the means at their disposal in order to solve the thermal problems facing them. Successive processes of trial and error over long periods of time have resulted in the development of some concepts concerning the thermal performance of housing. These evolving concepts were influenced by changes in people's requirements induced by changes gradually taking place in their societies [Mohsen; 1978]. On the other hand contemporary houses are built in response to new technology and modern life styles. The progress in the means of communication has helped in the exchange of ideas between people of different backgrounds. It seems that the contemporary house has many problems because of its concepts which were originally formulated by European and American architects in entirely different contexts [Cornell; 1957]. Therefore, another aim of this chapter is to compare traditional and contemporary housing in terms of sensitivity to climate in Iran.

3.2 General Consideration

3.2.1 Definition of traditional and contemporary houses

Although the definition of traditional architecture is unclear, it seems the underlying meaning is indigenous architecture by an indigenous community [Denyer; 1978]. Moreover it is commonly used to mean architecture indigenous to a region, using local materials, and low-level technology and not designed by experts. Another definition that is accepted, is "the traditional architecture is a type of architecture developed by the community, not an individual, as an expression of its culture and as a shelter from the rigours of the climate". According to this terminology, the term traditional house which is used in the present study simply means a house constructed with traditional methods and materials and generally built by a non- architect to house an extended family living in the traditional way.

A contemporary house, on the other hand, is built with new materials and new modes of construction. The word "contemporary" is defined as meaning "existing, living, occurring at the same time as". The word implies a comparison between at least two things, and it conveys no hint of approval or disapproval, but as used by many people, the word does carry a value judgement. It means something like "relevant to its time" and hence to be approved, while "anachronistic" means "irrelevant to its time" and is a term of disapproval. This raises the two questions of what it meant by time and what we mean by relevance- and to what? To judge the criterion of contemporaneity, we must sense the forces that are working for change, and must not passively follow them but rather control and direct them where we think they should aim [*after* Fathy; 1986].

Two words also are used in the present study repeatedly, which are "indoor" and "courtyard". The term "indoor" is used in this study to refer to a building, which is closed, and minimising the flow of hot (cold) outdoor air through it. The conductive heat gain can be controlled by walls or other elements, or by the thermal resistance of the building envelope. The term "courtyard" is used for an uncovered space, which is open to the flow of the ambient air. People staying in courtyards are exposed to several direct and indirect forms of solar radiation.

3.2.2 Traditional courtyard housing in hot dry zone of Iran

Traditional courtyard houses in Iran are the products of a long period of evaluation, incorporating qualities and characteristics, which are the distillation of generations: of the combination of experience and invention, of climatic influence, of Muslim lifestyle and craft traditions.

The traditional houses all obey one fundamental rule of being planned around a central open courtyard, which is either square, as an ideal courtyard, or rectangular, with various sizes, depending on the socio-economic level of the family (Figure 3.1).

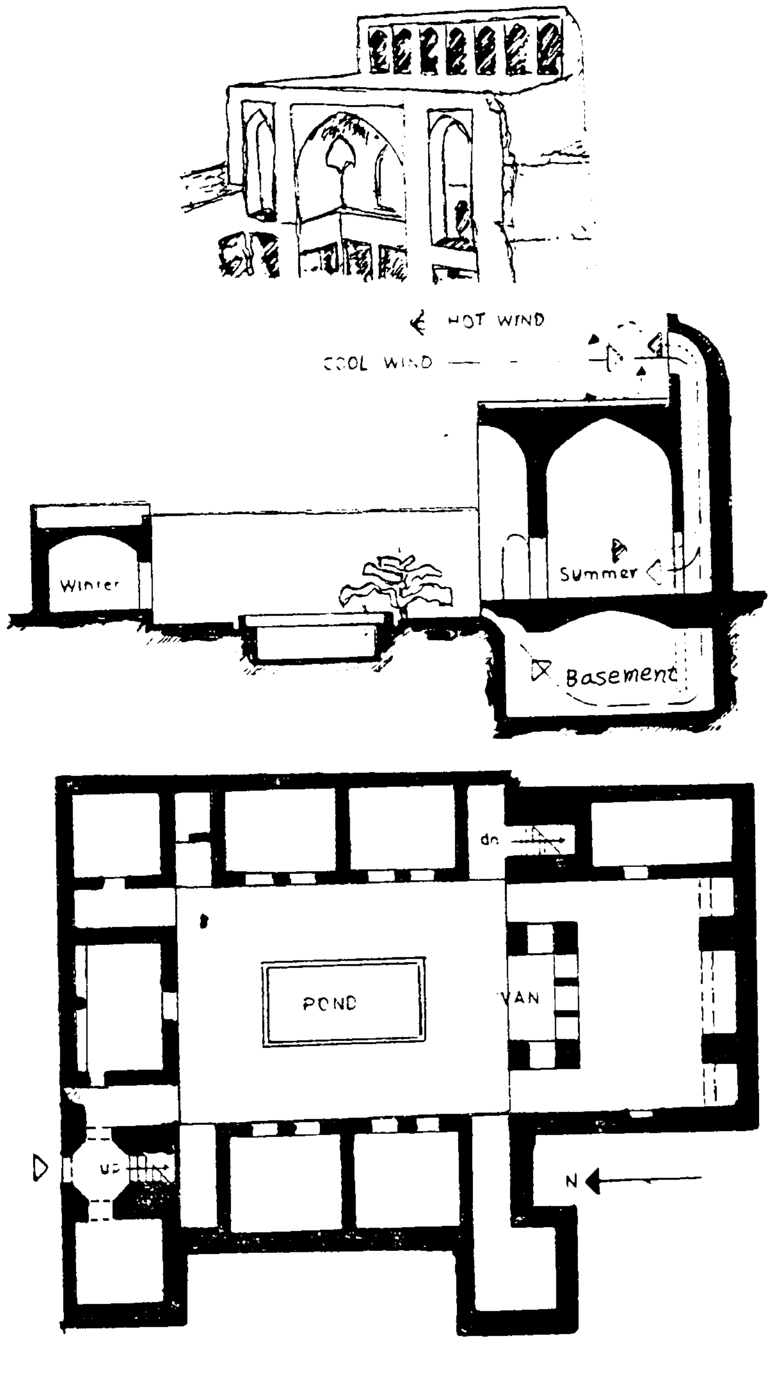


Figure 3.1 A typical courtyard house in dry region of Iran (Source. Tavassoli; 1980)

A typical courtyard generally has a planted, paved section and one pool. Various trees and flowers may grow in the courtyard and help to create a microclimate. The paved section is used for many activities, especially in the summertime. and pools are again typical features of courtyards. Water in there is used for household work and for watering the paved area. Depending on the time of the day there is always a shaded area in the courtyard, enabling the family to carry on their activity and at the same time to enjoy nature, water and cool breezes. It also provides a useful living and sleeping area for adults and a safe play area for small children. In the summer the courtyard is used mainly in the evenings while in the winter it is normally used for day activities.

Other spaces within the house are placed around the courtyard and open their doors and windows towards that direction. The great room is the Ursi, which is always at its most interesting and dramatic seen from within where the rich patterns set against the light of the courtyard and the subdued broken filigrees create soft and complex harmonies carpeting the room with a pattern of light. In the best arrangement it has doorways at each end, symmetrically opposed in the short sides and reached from the Ivan. It is used for sitting, especially in winter, as a celebration room.

Every traditional house has an Ivan as part of the house, which is semi open, closed on three sides and on top and connected to the courtyard by its open end. Ivan is a very important space for the family since it is always shaded and has the advantage of being open. In fact it is like the living room of houses in summer. Women do their housework, carry on some activities together or chat in there.

Due to seasonal division of houses, other rooms around the courtyard are divided; the ones used during summer have a northern orientation, which secures shading as well as day and night breezes. Winter rooms generally have a southern orientation and provide sunny, warm days. This is reflected in daily living to achieve comfort conditions. People live indoors during the day, but never stay inside at night.

The traditional houses are sharing party- walls with minimal street elevation. Off the narrow streets, through ornamental doorways, the entrance passageway lead into the courtyard which is always shielded by a break in alignment, a turn, or at worst, simply a screen. The doorways themselves are arranged so that they are not directly opposed across the street, and so, from the outside, nothing of the life of the household would be visible.

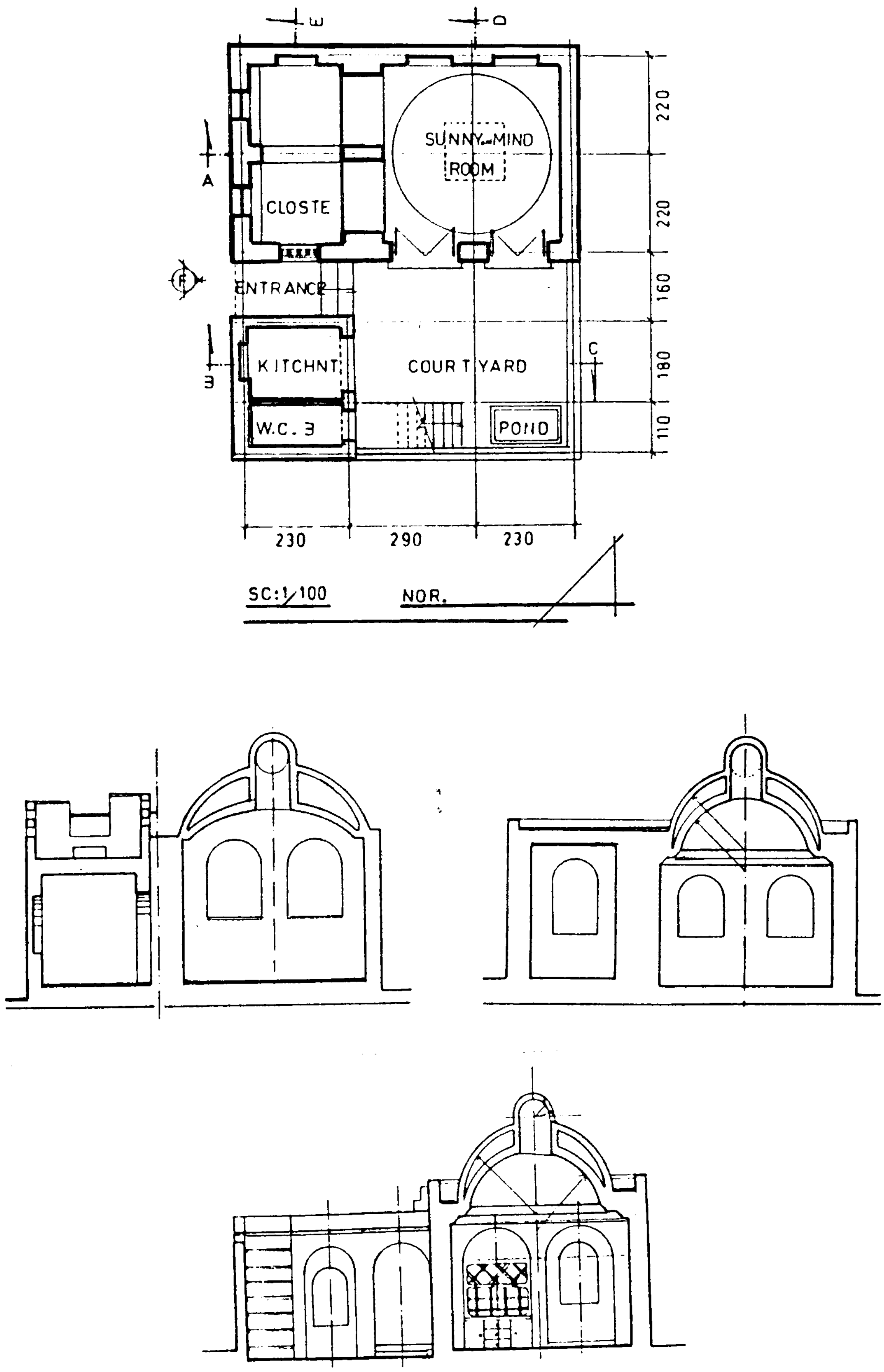


Figure 3.2 A small courtyard house in Ilam- Dehloran (Source, Ghiasy, 1991)

Most of the houses have an underground level, which are semi- basements. They are brick- vaulted rooms and gain light and ventilation from the courtyard.

Many of the traditional houses have two kitchens, one indoors for winter use, which is small and often underground, and one outdoors for summer use. Washing and food preparation are carried out in the courtyard, with the kitchen being no more than a cooking place. For the preparation of large feasts the whole courtyard might be turned into a kitchen.

Bathrooms are rare and most of the citizens make use of the public bathhouses of the city. The small bathroom of the contemporary house is unknown in the traditional house.

Examples of traditional courtyard housing still exist in the old districts of many cites of Iran such as Ilam, and a few of them are preserved in a good condition (see Figure 3.2).

3.2.3 The contemporary housing in Iran

Encounters with the manifestations of nineteenth century European civilisation and the arrival of a number of Western manufactured goods in Iran brought about changes in housing design [Saremi; 1998]. An example is the transformation of Ursi and Ivan of ancient houses into large halls flanking elaborate, majestic stairways, which upsets the originality of traditional Iranian houses. At the same time, socio-economic changes affected the houses in other ways; they were divided into smaller units, which destroys the unity and philosophy behind the original design. On the other hand, because of the lack of conservation policy the rest of the traditional houses were being destroyed and replaced by new houses. The central courtyard disappeared and was replaced by a yard in front or behind the house without any architectural elements. All rooms were grouped around a central hall, which served as the gathering place for family members (Figure 3.3). The small wooden windows were replaced by large openings, which increased the intensity of light and ultraviolet radiation in many parts of the house.

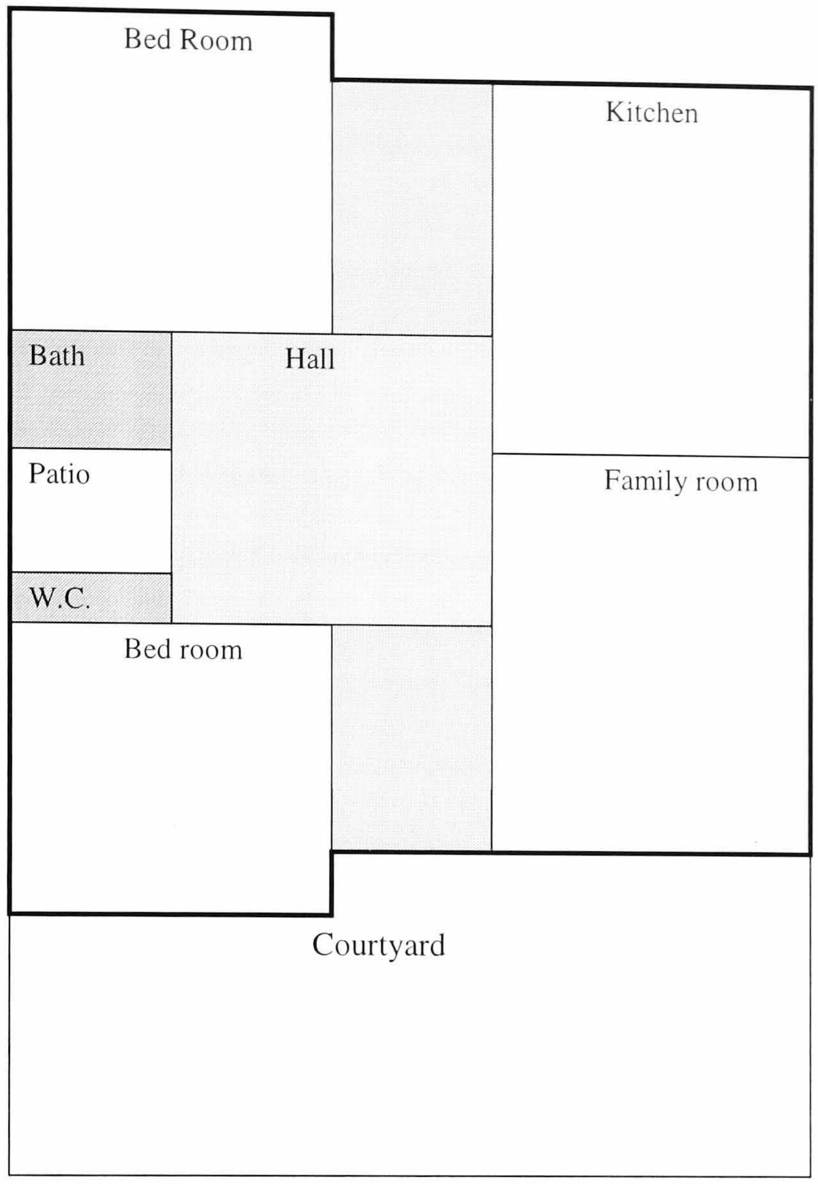


Figure 3.3 A typical contemporary housing

In one way, the contemporary houses anywhere of Iran are quite similar. All are based on a European style, concept and materials. The use of this concept and these materials is considered to be a symbol of wealth.

In Ilam nearly all contemporary houses are informal and created without approval of the authorities. In general these houses consist of a main hall, a living room, one or two or three bedrooms, a kitchen and a bathroom. External and internal walls of one or two storey houses are brick-made and roof materials are steel, brick, gatch (a mixture of chalk and water) and clay. Internal plaster of the roof is made of gatch and external cover with cement and smeared with tar. Door and window frames are in steel. It seems these materials, especially roof materials, are not suitable in terms of energy conservation and thermal capacity.

3.3 Hot climate, housing design and people's behaviour

Before the advent of the industrial era and mechanisation, man depended on natural sources of energy and available local materials in forming his habitat according to his physiological needs. Over many centuries, people everywhere appear to have learned to interact with their climate. They built houses that were more or less satisfactory in providing them with the microclimate that they needed. In consideration of climatic design the traditional houses have a lot of advantages [Rapoport; 1969], [Konya; 1980]. But, in the eagerness to become modern, many people have abandoned their traditional age-old solutions to the problems presented by local climate. Modern architects have attempted to solve climatic building design with modern technology and this is the beginning of many problems. What should be done? It is true that the present conditions are different from the past conditions but it is also true that the climate has not changed, so some of the traditional solutions are still applicable. It is not being suggested here that house designs as in all places should return to the principles that were utilised prior to the present time, as social, cultural and economic conditions are not the same. However, there are many aspects of these methods that seem to have been simply ignored. Obviously not all traditional architecture is climate sensitive, but there are some important lessons that can be learnt from studying them [Koenigsberger at al; 1973].

Unfortunately, not only are many useful spaces in traditional styles of building design not used but also the modern style has created many problems for people who are living in the traditional houses. This can be seen in the old part of the many cities of Iran. Contemporary high buildings with different proportions cut off the wind, destroy the microclimate of houses, and overload the sewage and water supply system of the old part of city. Many people cannot sleep on roofs comfortably because new buildings cut off the breeze and overlook their roofs and courtyards. Water cannot be supplied to pools and the majority of pools are dry and filled up and trees have difficulty to survive. For these reasons, the atmosphere of traditional houses in Iran is changing rapidly; they are losing all their microclimatic advantages.

The importance of climatic considerations in the housing design is clear, because a principal purpose of housing is to change the microclimate. In fact, the essence of climatic building design is that it recognises the role of the building as a mediator between the external climates as provided by nature, and the internal climate as required for the comfort of occupants, [Baker; 1987]. Givoni [1994] notes that architectural means for achieving climatic design include such conventional design elements as the layout of buildings; orientation; size; location and detail of windows; shading devices; thermal resistance and heat capacity of its envelope.

In the hot arid zone of Iran climatic consideration in traditional housing design was very important. There is no doubt that climate had its impact on a number of design and construction elements of traditional houses, such as internal circulation, external orientation and the used of materials and architectural elements. People were forced to devise ways to cool their houses with only natural sources of energy and physical phenomena. In fact they use numerous strategies to achieve thermal comfort which can be divided in two categories.

1- Permanent behaviour, such as the choice of a suitable site for houses, right direction, best shape, thermal capacity of materials and the choice of heating and cooling systems. In fact people have adapted to create comfortable places for themselves. Some of them are described as follows:

When the outdoor temperature is higher than the indoor temperature, the roof and walls are exposed to the sun and are heated. They transmit this heat to the inner room surfaces, where it raises the temperature of the air in contact with it by conduction. Heat is radiated and intercepted by people and objects indoors, thereby affecting thermal comfort. In hot countries it is popularly believed that the roof is the main heating element of a house and then walls [Givoni; 1976].

A method that was used in Ilam was to cover the roof by wooden beams and slabs with a layer of earth and then a plaster of clay, straw and salt on top of them. This traditional method for a flat roof gives good heat insulation and a considerable heat capacity. The light colour of this roof has much benefit. Light colours will reflect a large part of the incident solar radiation. On the other hand the thermal performance of roofs is closely associated with the problem of ceiling height. It is generally believed that high ceilings are more effective in providing cool interiors in buildings in hot dry areas than lower ceilings [Saini; 1962].

It is interesting that in the traditional housing of Iran summer parts and Ivan often have high ceiling of more than 3.30 m, which is recommended by Givoni [1962 and 1976] (Figure 3.4).

Figure 3.4 High ceiling of Ivan (3L) to compare with low ceiling of winter area (2L) (Source: Tavassoli; 1980)

In the traditional housing in Iran surfaces exposed to the sun are reduced and walls are thick to provide good thermal capacity. The walls are built of mud, so they have a low rate of heat absorption and also reflect the sunlight. People also reduce the exposed surfaces of the houses by constructing houses attached to each other with common walls, in a cluster form. They reduced solar gain on the walls by building deep courtyards surrounded by rooms, planting, trees and shrubs in them, and entrapping the cool night air for several hours of the next morning [Tavasoli; 1980].

In hot dry regions provided the openings are carefully designed and located, the insulation value and heat-storage capacity of opaque material wall panels is considerable [Saini; 1973]. The primary function of a window is to admit light and provide ventilation and view while limiting the entry of undesirable elements of the outdoor environment. The openings on summer area walls in traditional housing in Iran are small and are normally opened in the night time, because during the day the absence of openings would be most desirable, or at least openings as small as possible, located high on the walls.

Many people of Ilam (as well as in other cities of dry zones of Iran) lived in basements particularly during the hot summer afternoons. This was because the relatively low ground temperature kept the basement rooms cool. They also often provide a more comfortable humidity. The primary reason for basements in hot dry areas is the protection it gives from the severe climate. However, basements can be quite comfortable, provided that proper precautions are taken against moisture effects on walls and one is prepared to accept a windowless building.

Rational planting of vegetation can offer significant shade, which is important for site temperature reductions. Atkinson [1962] has produced a comprehensive list of various available forms of vegetation. These have been set out according to their shape, size and denseness of foliage, which affect their shade producing qualities. The interesting point is that in nearly all traditional courtyards housing in Ilam one can see grape trees, common crack-willow, and weeping willow and plane tall trees, which are suggestion by Atkinson.

People built large, deep cisterns, filled them with cold water in winter, and kept them cool through the summer by providing a continuous and natural evaporation of water from their surfaces [Bahadori; 1979].

2- Transient behaviour, such as the choice of clothing, activities, movement between different places and changes of posture.

People play an instrumental role in creating their own thermal preferences through the way they interact with the environment or modify their own behaviour or generally adapt their expectations to match the thermal environment [de Dear and Brager; 1998].

The following are some of the transient behaviours by Ilam people to achieve comfort in their houses:

1- Select a roof and courtyard for sleeping in the hot season

2- Open the windows and doors during sleeping time when they are sleeping in the courtyard or on the roof

3- Use of wooden throne (a big wooden bed, like a sofa, which is covered with small carpet) on the pond in the courtyard for sitting and sleeping

4- Use of stool, stool- like frame of wood, which is, covered all about with quilts and blankets and under which a fire is placed for heating the legs in the cool period.

5- Use of felt carpet during cool season

6- Cook hot meals during the cool season and cold meals during the hot season

7- Change of sleeping time and working time during cool and hot periods

8- Use of two sorts of clothing, winter clothing and summer clothing

9- Use of two separate places in their houses, winter rooms and summer areas

3.4 The climatic housing design strategies

The climatic housing design strategies, which are suitable for the hot dry zone of Iran according to the results of many experimental works and also many lessons from traditional architecture of this region, can be summarised under the following:

Courtyard- one of the specific recommendations for housing design in the hot climate is courtyard housing in a compact layout. In this way two things are important: first the effect of courtyard design on indoor conditions and second providing comfort conditions in the courtyards. There is a difference between providing comfort in a courtyard (or any open spaces) and for indoor conditions.

According to Givoni [1994], the indoor maximum temperature, without any cooling system, can be lowered by appropriate building design, below the outdoor level by up to about 8°C, while lowering air temperature in the courtyard below the surrounding level is limited. Difference of radiant load between them is also important. Within a closed space solar radiation can be eliminated and the mean radiant temperature is usually close to the indoor air temperature. In the inside of houses people usually are protected from direct exposure to solar radiation, and the radiant heat load is not a significant factor affecting comfort. However, in courtyards the reflected solar radiation and emitted long wave radiation from the surrounding hot ground can cause significant radiant heat load and therefore should be minimised by the treatment of the outdoor space.

It should be noted that a courtyard can be cooled by systems that may not be used indoors, including wet walls and fine droplet fountains. Some of the systems suitable for courtyard cooling can use water that is not suitable for indoors evaporative cooler. For example, they can use brackish water, which is often available in arid regions [Givoni; 1994].

As main elements in traditional housing, courtyards are helpful in maintaining good thermal comfort both in the courtyard itself and in the adjacent spaces inside the house. According to Donham [1960], the small courtyard is an excellent thermal regulator in many ways. High walls cut off the sun, and large areas of the inner surfaces and the courtyard floor are shaded during the day. Cooler air, cooler surfaces and earth beneath the courtyard will draw heat from the surrounding areas, re-emitting it to the open sky during the night. The use of the courtyard is to enclose not only the interior living spaces but to frame a part of the sky, to pave a few metres of hot dry areas and to invest these fragments of nature with man's mark, a symbol of shelter.

The important point is how the courtyard can moderate its own personal climate. Clearly with a good design, courtyard houses can be suitable. With some details the courtyards can provide a pleasant outdoor environment and also improve the indoors thermal conditions. With other details courtyard may elevate the indoor temperature of the house around them and cause poor ventilation in the rooms located on the leeward side [Givoni;1994]. This has been demonstrated in a study done by Etzion [1990], who measured air temperatures at one-metre height in two courtyards. Both had concrete pavement over their whole areas. The temperatures of the two courtyards were very similar and in both cases the temperatures were higher, day and night, than the ambient air in the open space nearly at the same height. The average minimum temperature was higher by about 0.5°C and maximum by about 2.3°C.

In hot climates the phenomenon of outgoing radiation, whereby the Earth and buildings on it lose heat, becomes important. In the early morning before sunrise, the outer surfaces of built forms are at their minimum temperature. The outside air temperature too is at its minimum value. After sunrise, the rays make a small angle with the horizon; the effect on the surface is still minimal. As the sun moves, the intensity of its radiation becomes greater and the sunlit surfaces are heated up, hence the flow of heat starts reversing its direction and heat flows inward. The indoor temperature is lower than outdoors. The temperature reaches a maximum in the afternoon. The incidence of the sunrays are concerned, the geometry of houses and the geometry of courtyard especially in compact houses around courtyard at the scale of town structure. After sunset the sky becomes much colder than the surfaces of the courtyard. Because of this the surfaces lose heat and the temperature of the adjacent layer of air gradually decreases. The cold air, being denser than the relatively warm air in the courtyard, tends to sink down; the cold air is collected inside the courtyard. Exchange between this cold air and the warmer indoor air takes place through the opening in the surrounding walls and as well the outward heat flow through the materials of walls and roof. On the other hand, as evening advances, the warm air of the courtyard, which was heated directly by the sun and indirectly by the warm buildings, rises and is gradually replaced by the already cooled night air from above. This cool air accumulates in the courtyard in laminar layers and seeps into the surrounding rooms, cooling them. The warm wind passing above the house during the day does not enter the courtyard but merely creates eddies inside, unless baffles have been installed to deflect the airflow. In this way, the courtyard serves as a reservoir of coolness [Donham; 1960].

These brief descriptions show why people, in order to enhance their thermal comfort, have used the courtyard, and why this phenomenon created the courtyard concept house. People learned to close their houses to the outside and open them inwardly onto internal courtyards [Fathy; 1986].

Some studies have been directed towards recommending that a small courtyard for providing a satisfactory conditions is most suitable [Donham; 1960- Olgyay; 1963- Koenigsberger; 1973]. This is because, if the courtyard's size is kept small enough to achieve shade during the day, it will allow less thermal impact and more heat dissipation from surrounding indoor spaces. Olgyay [1963] has shown that the optimum form is a rectangle in plan having a proportion of (1:1.3). Importantly the height around the courtyard is the most important factor of courtyard plan size. As an experience when traditional houses in Iran were built on one floor the parapets of the houses were built well about the roofline, the reason again being a need to create shade and protection. This also gave the courtyard a greater depth and made the house's courtyard a well-defined, more comfortable place. In many houses another desirable method of creating shade is to construct roof overhangs.

However, most hot arid zones are located in lower latitudes, i.e. latitudes in which the angle of the sun during the summer is high, close to zenith: this makes the design of a self shading courtyards (which shade themselves by their own geometrical layout) almost impossible. According to Givoni [1994], in arid regions shading the outdoor spaces by trees and plants is one of the best ways for providing comfortable conditions. But unfortunately growing trees and other vegetation for the purpose of shading the courtyards is not an easy task, due to the lack of water and the harsh climate. In every traditional courtyard in Iran the use of two or four small gardens (about 1.5 m^2) and a small pond between them is usual.

Another important element for lowering the air temperature is the paving in the courtyard. In fact treatment can be applied in courtyards to lower the surface temperature by the use of suitable paving materials and cooling the paving of the area itself. Paving heats up quickly causing both painful glare and reflected heat radiation toward the inside of house [Koenigsberger; 1973]. In the early morning the paving receives the diffuse radiation coming from the sky and from the surrounding walls. As the sun rises the ground surface loses heat to the adjacent cold air layer. The rising heated air is replaced by relatively colder air until the air temperature of inside the courtyard reaches that of the outside air. The duration of paving exposure to intense radiation is greater than that of any vertical wall; this accounts for the criticality of the treatment of its surface. However, for lowering air temperature the material and colour of paving, amount of mosture and shade of pavement are important. In the hot dry zone of Iran and also Ilam burnt clay brick for pavement is one of the most widely used materials. The light colour, the good absorption of water, ability of evaporation of water in time of need and availability are some of the burnt clay brick's good properties.

Walls and roof- in hot dry areas external surfaces (such as walls and roof) and their materials for providing thermal comfort are important. The major function of the walls in hot dry areas is to withstand the onslaught of solar radiation and high daytime outdoor temperatures, and to control the inward flow of both heat and hot air for most of the day during the summer seasons. In this way heat capacity of the walls is quite important because it is moderates the rates of heat flow in and out of the building interior, and hence the indoor temperature fluctuations. On the other hands such walls cool slowly at night and have appreciably higher nocturnal temperatures than low heat capacity structures [Givoni; 1976].

Thermal mass can act as a regulator, smoothing temperature swings, delaying peak temperature, decreasing mean radiant temperature and providing better comfort conditions. Givoni [1993] conducted an experiment for the effectiveness of mass in lowering the indoor air temperatures. He chose two buildings with same heat loss coefficient but with different mass levels: a low- mass (conventional stud-wall construction) and a high- mass (insulated concrete walls), were monitored during summer. One of the experimental conditions was windows un- shaded closed day and night. The indoor average temperature of both buildings at different mass levels were different and all above the outdoor maxima. The temperature elevation of low mass building maximum was about 6.7°C above the outdoors' maxima while that of the high mass building was about 4.5°C. Fathy [1986] conducted tests on experimental buildings. The materials used were mud brick walls and roof 50-cm thick and prefabricated concrete panel walls and roof 10-cm thickness. The air temperature fluctuation inside the mud brick model did not exceed 2°C during the 24 hours period, varying from 21-23°C which is within the comfort zone. On the other hand the maximum air temperature inside the prefabricated model reached 36°C, or 13°C higher than the mud brick model and 9°C higher than outdoor air temperature. The indoor temperature of the prefabricated concrete room is higher than the thermal comfort level most of the day. These examples have shown the importance of mass in buildings.

On the other hand, surface treatment and the selection of a wall's colour will influence the thermal behaviour of the building and can help in reducing the heat load. Light colours will reflect a large part of the incident solar radiation, thus much less heat will actually enter the building fabric. Bansal et al [1992] performed some experiments on the effect of colour on the interior temperatures in a hot dry climate by using two similar enclosures, one which was black and the other white. The black enclosure recorded a maximum temperature which was 7°C more than the white painted enclosure during hours of maximum solar radiation. Use of light colour in traditional parts of hot dry cities in Iran as well as in Ilam show how people knew the importance of colour. External roof colour also is the main determining factor for the roof temperature pattern and consequently for occupants' comfort. The effect of roof colour on its temperature is of course related to the thermal resistance and heat capacity of the roof structure. Givoni [1976] argues that the differences between the ceiling temperatures of the black and whitewashed roofs were much greater for a 7-cm thick roof than for that 20-cm thick.

In hot dry regions windows are important. Large windows may cause glare discomfort, reinforcing the notion that small windows are more suitable. But with special design details, large windows can provide thermal advantages. When highly insulated shutters are added to large openable windows, their thermal effect can be adjusted to varying needs, both diurnally and annually. In summer the shutters can be closed during the hot hours. Then, light will filter into the house only through the small areas provided by the shutters. In the evening, the shutters and the windows can be opened, increasing the rate of cooling of the interior. In winter, large southern windows can provide significant direct solar heating of the interior. Closing the insulated shutters during the night traps the heat indoors and reduces the rate of cooling. This helps to maintain comfortable indoor night temperature [Givoni; 1998]. It should be important for designers to know that heat gain through windows, per unit area, is much higher than through walls or roofs.

In hot countries it is popularly believed that the roof is the main heating element of a house [Givoni; 1976]. Thus, a useful idea for providing indoor comfort condition is to shade the roof more naturally by designing it to suit popular traditions. One or two small rooms in the roof level with suitable overhangs have two functions which are shading the roof during the day and providing physiologically comfortable areas during sleep time. These rooms can be used by youngish people (during days they are out of the house or with parents for having food and other things like that). In this way the parapets around the roof can be used. Parapets not only make it a safe place for children, but also it is a good element for more shade on the roof. The high parapet has two other benefits: first, it shields the roof from the dusty summer winds and second the courtyards and streets can be narrow, so that the parapets shade the neighbouring elements, reducing the solar heat load.

The shape and height of the roof is also important. In hot areas mud domes are a common means of covering spaces. The form of the dome allows winds to cool its surface easily, and it also ensures minimal frequency of intense radiation at any one point. The double dome is an excellent solution to the problem of intense radiation. The space between the inner and outer dome acts as an insulation layer. Therefore, when there is intense summer solar radiation, the outer dome becomes extremely hot, while the inner dome remains cool. Circulation of air between the two domes reduces the radiation problem.

3.5 Conclusion

The traditional housing design of Iran is essentially based on a simple design with many aims such as providing comfort condition for occupants. In popular constructions, the walls are made of earth and the roofs of wood beams.

Throughout various social and cultural needs, the typology defines the general frame of the hot dry zones. It has been shown that traditional housing was designed mostly to counter the effects of the climate.

Contemporary housing in Iran has been considered. It has also been noted that contemporary housing are based on western models which offer no real solution as these are often inadequate and irrelevant to climate and culture. The results tend to be alien and alienating.

In this chapter some adaptive behaviour for achieving comfort conditions in terms of permanent and transient behaviour were considered. The results of such actions in both ways can have potentially significant and positive impacts on improving comfort and reducing energy consumption. Some climatic housing design strategies, which are suitable for the hot dry regions, were mentioned.

Chapter Four

Theory of Thermal Comfort

4.1 Introduction

All humans have exhibited physiological and behavioural responses to heat and cold, from cave man, through ancient civilizations to the present day. Such responses have undergone systematic scientific investigation [Parsons; 1993]. It has been stated that man's desire is to be comfortable [Fanger; 1970] and that this helps people's performance of tasks.

This chapter is split into three sections. The first section looks at the theory of thermal comfort. It begins with a brief history of thermal comfort and is followed by a definition and the importance of studying thermal comfort. Heat exchange processes of the body and the main factors affecting thermal comfort are discussed. In the second section research methods of thermal comfort are discussed and compared. The third section will explain the adaptive model of thermal comfort. Definition, factors and advantages of the adaptive model are discussed.

4.2 Theory of thermal comfort

4.2.1 History of thermal comfort

Up to the Industrial Revolution thermal comfort was not a practical issue, as there were very few tools available to influence it. When it was cold, a fire was lit to ameliorate the conditions, when it was hot, the use of hand-fans was the only relief [Auliciems and Szokolay; 1997]. Haldane, in the U.K. [1905], carried out the first systematic study on thermal comfort with regard to the effect of high temperatures. In the early 1920s of this century a basic study was carried out in the U.S.A. It was an attempt to find a comfort zone according to humidity level and air temperature. In England the motivation came from industrial hygiene: the limits of environmental conditions for work. Vernon and

Warner in 1932 and Bedford in 1936 carried out empirical studies among factory works. Extensive field surveys of thermal conditions by Bedford produced the equivalent temperature scale. Gagge [1937] did analytical work in the U.S.A. and made a significant contribution to this topic. A fundamental report by Victor Olgyay [1963] was the first to bring together findings of the various disciplines and interpret these for practical (Architectural) purposes. In these studies and later on, three ways can be recognised:

1- Studies directed toward the prevention of heat illness in the armed forces

2- Studies to make the formulation of the heat stress indices

3- The introduction of psychological research methods

All provided the data on comfort conditions, which formed the basis of Fanger's comfort equation [after McIntyre: 1980].

4.2.2 Definition of thermal comfort

Thermal comfort is often defined as "that *condition of mind* which expresses satisfaction with the thermal environment"[ASHRAE; 1966, 1981, 1992]. "Condition of mind" is directly related to a perceptual process and implies that psychological as well as physiological factors are involved. Heijs [1994] argues that from the ASHRAE definition there is no explanation of what "condition of mind" could be the result of either perceptual process, or a state of knowledge or cognition, or a general feeling or attitude, and could take many different forms such as in a pattern of behaviour or clothing. If comfort were regarded as a subjectively mental state, it would be elusive, because it cannot be measured objectively and it is continuously changing depending on various factors.

ASHRAE [1993], contend that the problem relating to the identification of the "condition of mind" can be avoided by developing empirical equations that can relate comfort perceptions or feelings to physiological responses. However the ASHRAE thermal comfort definition is most widely accepted, although this definition has come under some criticism. Clearly the specific definition for thermal comfort is not easy to state because of many things which are related to comfort conditions and are not easy to measure objectively. In line with Hensen [1990] this study is in agreement with the definition by Benziger [1979], which is "thermal comfort is a state in which there are no driving impulses to correct the environment by behaviour". Hensen [1990] believes that this is a more objective definition than the ASHRAE definition.

It is important that when thermal comfort is applied to a group of people, who are subject to the same climate condition, the aim is to create optimal thermal comfort for the highest possible percentage of the group.

With regard to a building, comfort is a particular condition that provides pleasant sensations for the occupants [Limb; 1992]. This definition implied thermal comfort is an emotional experience, but is pleasant an absolute value? According to McIntyre [1980] it is not. He states that pleasant sensation is a condition without discomfort. It seems it is vague.

Olgyay [1963], in terms of the comfort zone, noted that thermal comfort is a condition under which man succeeds in minimising expenditure of energy needed to adjust himself to his environment. This definition may be correct, but the range of the comfort is changeable from one person to another. It seems an assumption of a conventional range should be created, but it cannot to be achieved easily. This range is complicated.

More recently, thermal comfort was defined by Givoni [1998] as "the range of climatic conditions considered comfortable and acceptable inside buildings". It implies an absence of any sensation of thermal (heat or cold) discomfort. Clearly operationally the definition by Givoni is more reasonable than others.

It is noticeable that in discussing the theory of thermal comfort the difference between thermal comfort and thermal sensation is considered.

Thermal sensation is an expression of the sensation of warmth or its lack. The thermal sensation, over the whole range from very cold to very hot, is often graded along seven-point numerical scales. In fact thermal sensation is related to how people feel and is therefore a sensory experience and a psychological phenomenon. It is not possible to define sensation in physical or physiological terms [Parsons; 1993]. Hensel [1981] sees the difference as follows:

Thermal sensation is a rational experience that can be described as being directed towards an objective world in terms of cold and warm, but thermal comfort is an emotional experience. He stated that thermal sensations depend mainly on the activity of thermoreceptors in skin whereas thermal comfort or discomfort reflects a general state of the thermoregulatory systems. Baker [1996] argues that it is increasingly evident that thermal comfort is largely behavioural and psychological which shifts the emphasis away from solely engineering solution, to include the social and architectural environment.

The basic but fundamental question is: how can people express their feeling? Perhaps a simple way is to ask subjects to indicate their feeling referring to (comfortable / uncomfortable) or (warmth). There are a number of subjective scales, which have been used in the assessment of thermal environments. The two main scales used are the Bedford scale [Bedford; 1936] and the ASHRAE scale (Table 4.1).

Table 4.1 The Bedford and the ASHRAE scales

Bedford scale	*Much too cool*	*Too cool*	Comfortable cool	**Comfort able**	Comfortable warm	*Too warm*	*Much too warm*
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
ASHRAE scale	*Cold*	*Cool*	Slightly cool	**Neutral**	Slightly warm	*Warm*	*Hot*

Bedford first used the Bedford scale in his survey of comfort in England; the ASHRAE scale was used in American work. As mentioned and according to Nicol [1993] the main difference between these two scales is in the inclusion of the concept of comfort in the scale. However the two scales in practice behave in a very similar way, and the results obtained by them may be compared directly with each other [Humphreys ;1976, 1999, McIntyre; 1980, Brager et al;

1994]. Fox et al [1973] suggests supplementation by the preference McIntyre scale which subjects can respond to by indicating their preference: warmer, no change or cooler as a way of checking for any bias.

The form and method of administering the scale is important. Nicol [1993] recommended that "you use a semantic differential scale with seven unnumbered spaces or boxes for people to tick and if your aim is to investigate the use of scales then a variety of scales can be used" (also see Parsons; 1993). Psychological research has shown seven points to be a good choice when people are presented with a set of stimuli which vary in one dimension only. It turns out that the number of stimuli that can unambiguously identified is surprisingly small [McIntyre; 1980]. Miller [1956] investigated this range, for several different types of stimulus and found that in general people can not deal with more than about seven levels of sensation without confusion.

4.2.3 Neutral temperature and comfort temperature

Fanger [1970] noted that the condition in which the subject would prefer neither warmer nor cooler surroundings is thermal neutrality. Fanger's definition is similar to the Markus and Morris [1980] definition. They argued that "state in which a person will judge -the environment to be neither too cold nor too warm- a kind of neutral point defined by absence of any feeling of discomfort".

The neutral temperature is the temperature at which people experience a sensation, which is neither slightly warm nor slightly cool. In this temperature the mean votes of subject (or group) is neutral or middle point of the seven point ASHRAE scale. On the other hand comfort temperature is the temperature at which the respondent expresses comfort feelings voting with the middle category of the comfort scale. The middle category is known as comfortable. Despite this, and because of similar results from sensation and comfort scales, comfort temperature can be the same as the neutral temperature. It is noticeable that the neutral temperature or the comfort temperature is the optimum for the group.

4.2.4 Preferred temperature and thermal acceptability

There is evidence that the temperature which a group prefers may correspond to a sensation above or below middle category on the warmth scale [McIntyre; 1980]. Fox et al [1973] found that although subjects reported a sensation of thermal neutrality, they often said that they would prefer a warmer temperature. During a survey of 45 households, the respondents were asked which was their preferred state on the Bedford scale; 75% said comfortably warm [Hunt and Gidman; 1979]. Thus preferred temperature is the temperature at which a respondent requests no change in temperature or at which the greatest percentage of group of people request no change in temperature.

Preferred temperature can be found by asking the direct question and using a present-time condition: would you like to be: Cooler or No change or Warmer? (McIntyre scale). Answer of No change can be acceptable condition for subject. Another more widely used method is an indirect measure that equates acceptability with the three central categories of the seven-point thermal sensation scale. ASHRAE standard (55-1992) defines an acceptable thermal environment as one that satisfies at least 80% of the occupants.

4.3 Why is thermal comfort important?

According to Nicol [1993] there are three reasons for the importance of thermal comfort:

1- To provide a satisfactory condition for people

2- To control energy consumption

3- To suggest and set standards

All elements of buildings should be designed to respond to the climate and to provide comfort conditions for occupants because, all human conditions will be generally be at their peak when they are in their most comfortable state and they will decrease in the unfavourable seasons [Hunting; 1951].

Raw and Oseland [1994] have identified six advantages for doing research in thermal comfort:

1- Control over environments by people

2- Improving internal air quality

3- Achieving energy saving

4- Reduce the harm on the environment by reduced CO_2 production

5- Affecting the work efficiency of the building occupants

6- Reasonable recommendation for improving or changing standards

For almost all of the twentieth century, and often before, there has been an active interest in research into the conditions, which produce thermal comfort. Emphasis has not been on understanding why people report comfort or discomfort, but on what conditions will produce thermal comfort and acceptable thermal environments [Parsons; 1993].

4.4 Heat exchange processes of the body

The human body is continuously generating heat, with output varying from about 100W for a sedentary person to 1000W for a person exercising strenuously [ASHRAE; 1993]. Thermal comfort for sedentary person is achieved by keeping core temperature within a narrow range of 36.5-37.5°C and a skin temperature of 30°C at the extremities and 34-35°C at body stem and head. Any deviation from these ranges results in a sensation of discomfort which, under extreme conditions, may even be a medical threat [Hensel; 1981]. Body temperature is the result of a heat balance between heat gained by the body namely metabolism (M), radiation (R), and convection (C), and heat dissipated from the body such as mechanical work (W), radiation (R), convection (C) and sweat evaporation (E). Two sources contribute to heat accumulation: internal heat and external heat. The metabolic heat production, which is from metabolic processes, can be calculated by subtracting the mechanical work (W) from the total metabolic energy production (M) as (M-W). Another source of heat contributing to body temperature is the environmental heat which is absorbed from the surroundings mainly by radiation and convection (R+C), [Shapiro, Epstein; 1984]. On a warm sunny day when solar radiation is high; the body absorbs heat whereas on cold cloudy days when ambient temperature is below skin temperature heat is dissipated from the body by means of radiation and convection. Two models are often used to describe the heat balance between the body and the environment: Fanger's steady-state model [Fanger; 1970] and Gagge's two- node energy balance [Gagge et al; 1971].

Fanger assumes that the body is in a state of thermal equilibrium with negligible heat storage and the body is assumed to be near thermal neutrality. At steady-state, the rate of heat generation is equal to the rate of heat loss and the energy balance is:

$$M - W = Q_{sk} + Q_{res} = (C + R + E_{sk}) + (C_{res} + E_{res}) \qquad (4.1)$$

Where: M= rate of metabolic energy production W/ m²

W= rate of mechanical work done W/ m^2

Q_{sk} = total rate of heat loss from the skin W/ m^2

Q_{res} = total rate of heat loss by respiration W/ m^2

C+R = the sensible heat loss from the skin W/ m^2

E_{sk} = rate of total evaporative heat loss from skin

E_{res} = the rate of evaporative heat loss from respiration W/ m^2

This model is the basis for the determination of thermal comfort in moderate thermal environments as embodied in an international standard ISO 7730- 1984. It also is widely used by ASHRAE for various combinations of temperature and humidity in developing comfort charts.

Gagge assumes two concentric cylinders of appropriate dimension and thermal properties. These represent an inner core and an outer shell. The inner represents the body core (skeleton, muscle, and internal organs) and the outer represents the skin layer. There are some assumptions, namely conductive heat exchange from the skin in negligible; the temperature in each compartment is uniform; metabolic heat production, external work and respiratory losses are associated with the core compartment and finally the core and the skin compartments exchange heat passively through direct contact and through the thermoregulatory controlled peripheral blood flow. This model is described by two-coupled heat balance equation, one applied to each compartment:

Core: $S_{cr} = M - W - (C_{res} + E_{res}) - Q_{crsk}$ (4.2)

Skin: $S_{sk} = Q_{crsk} - (C + R + E_{sk})$ (4.3)

Where: S_{cr} is the rate of heat storage in each compartment W/m^2

S_{sk} is the rate of heat storage in the skin compartment W/m^2

Q_{crsk} is the ratio of heat transfer from core to skin W/ m^2

Humphreys [1970] explained a simple theoretical derivation of thermal comfort conditions. It is quite useful and easy to understand. He divided the heat transfer from human body into three stages. The first stage is from the body core to the skin. The body core temperature rises with increase in metabolic rate and it is independent of the temperature of the environment over a very wide range. The body surrounded by peripheral tissue having thermal resistance, which is governed by the quantity of blood flowing near the skin. The tissue thermal resistance is smallest when the vessels are dilated and the heart rate is high and is greatest when the vessels are constricted and the heart rate is low. Extreme values of thermal tissue are not consistent with comfort, but it is possible to choose a narrower range which people do find comfortable. The range chosen may differ for people acclimatised to different environments. The equation of heat flow from the body core to skin may be written:

$$M R_b = T_b - T_{sk} \qquad (4.4)$$

where: M is metabolic rate (W/m^2)

R_b is the thermal resistance of the peripheral tissues (m^2 °C/W)

T_b is the body core temperature (°C)

T_{sk} is the area weighted mean skin temperature (°C)

The second step is heat flow from the skin to the outer surface of the clothing. At the skin surface and from the lungs some of the metabolic heat is released to the environment by evaporation of moisture. The remainder (kM) is dissipated by conduction, convection and radiation to the clothing surface. For resting people (which is the proportion of the metabolic heat dissipated by means other than evaporation) "k" is about 0.7 and appears to decrease slightly to the region of 0.6 for active people in thermal comfort. The equation of heat flow through the clothing is:

$$kMR_c = T_{sk} - T_c \quad (4.5)$$

Where: R_c is the thermal resistance of the clothing in use expressed in terms of the body area (m^2 °C/W)

T_c is the area weighted mean outer surface temperature of clothes and exposed skin (°C)

The final step according to Humphreys is heat flow from the clothing to the surroundings with following equation:

$$R_e = T_c - T_g \qquad (R_e = 1/(h_c + h_r)) \quad (4\text{-}6)$$

where: T_g is the globe temperature

h_c is the coefficient of convection heat transfer, expressed in terms of Dubois surface area (W/m^2 °C)

h_r is the coefficient of radiant heat transfer expressed in terms of Dubois surface area (W/m^2 °C)

The value of h_c is closely proportional to the square root of the air velocity relative to the person. For the smaller variations of air velocity the effect of variations in R_e are often unimportant.

However, adding equations (4.4, 4.5 and 4.6) give equation (4.7) which can be used for the flow of heat from the body core to the thermal environment

$$T_g = T_b - M\,(R_b + kR_c + kR_e) \qquad (4.7)$$

However, the purpose of a thermal comfort study is to establish comfort zones or a range of temperatures within which a large proportion of persons concerned will be thermally comfortable [Angus; 1968]. Here, the question is from which ways researchers on thermal comfort can be able to find comfort range? Humphreys [1992] found some evidence that the theory based on optimisation of six combinations of variables (as mentioned) cannot explain comfort conditions. There are some differences between steady- state energy balance models of man's actual condition in the real world.

4.5 Behavioural thermoregulation

The human heat balance equations describes how the body can maintain an internal temperature near 37°C in terms of heat generation and heat exchange with the environment. In practice, what is achieved is not a steady state but a dynamic equilibrium: as external conditions continually change, so the body responds to regulate the internal body temperature [Parsons; 1993].

However, in addition to the above models there are important behavioural responses greatly affecting the human thermal environment. A simple change in posture, orientation toward a heat source, putting on of clothes or movement within the environmental can all have significant effects [Parsons; 1993]. A person who feels too hot or too cold will usually make some change in his clothing, posture or activity in order to become comfortable again. He/she may open windows or turn up the heating so that the environment is more to their liking. These changes are an integral part of the system by which the body temperatures is regulated [Nicol and Humphreys; 1973]. Further behavioural responses could also be termed technical regulation [Hensel; 1981]. This includes building of shelter and involves designing the environment of human occupancy (see Chapter Three). Buildings and climatic architecture can be considered as creating micro climates which together with clothing have allowed humans to inhabit the whole of the surface of the earth [Parson; 1993]. Hensel [1981] provides the more holistic system of human temperature regulation shown in Figure (4.1).

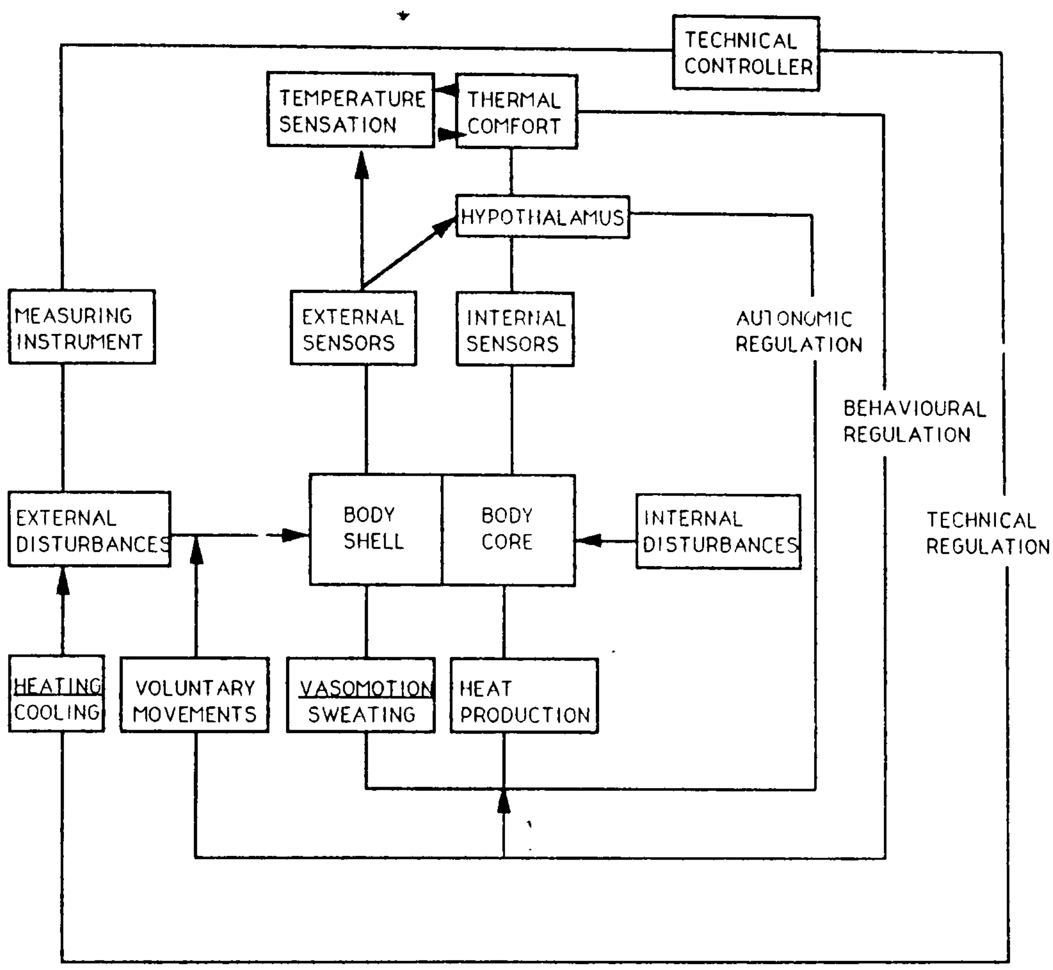


Figure 4.1 Shematic diagram of autonomic, behavioural and technical temperature regulation in man (source Parsons, 1993)

An interesting area for consideration is the extent to which humans learn to respond to thermal stimuli, in both a physiological way and behavioural way. It is known that humans plan and model the world and test scenarios; they use memory to utilise previous experience. The role of such a model of a human in holistic (physiological, autonomic and behavioural) thermoregulation has yet to be comprehensively explored [Parson; 1993].

Nicol and Humpherys [1973] recognised three ways for behavioural thermos-regulation:

1- Changes in metabolic rate (by changes in posture or activity)

2- Changes in clothing insulation

3- Changes in the thermal environment

These cannot be regarded merely as independent variables in heat-exchange calculations.

4.6 Comfort factors

Air temperature, radiant temperature, humidity and air movement are the four basic environmental parameters. Combined with individual parameters of metabolic heat generated by human activity and clothing worn by a person, they provide the six fundamental factors in two main categories, which define human thermal environments. These factors provide a minimum requirement for a useful conceptual basis upon which a realistic consideration of human thermal environments can be based [Parson; 1993]. In the specific situations other factors such as a posture, behavioural can be important. Cena [1994] argues that in thermal comfort research the physical, emotional and social status of the individuals influence the individual responses of subjects. This idea shows that thermal comfort has a psychological aspect and non-physical factors may be just as important as the physical factors.

4.6.1 Environmental factors

Air temperature is an important parameter affecting thermal comfort conditions. It can be defined as the temperature of air surrounding the human body which is representative of that aspect of the surroundings which determines heat flow between the human body and the air. With lower air temperature the body loses heat; with higher temperature it gains heat by convection.

The *mean radiant temperature* of the enclosure determines the radiant heat exchange between the skin and the environment, similar to the effect of air temperature on the convective heat exchange. Mean radiant temperature is a measure for the radiative flux of the heat from surrounding surfaces such as ceiling, walls, doors, windows and floor. It is also defined as the temperature of a uniform enclosure with which a small black sphere at the test point would have the same radiation exchange as it does with the real environment. For a sphere the mean radiant temperature will not depend upon its orientation in the surroundings. For a non- spheroid shape such as the human body, the concept of effective mean radiant temperature is used: the temperature of a uniform enclosure with which the test surface would have the same radiation exchange as it does with the real environment. This will depend upon the orientation of the object in the surroundings [Parsons; 1993]. Hoppe [1988] measured the effect of mean radiant temperature in thermal comfort as a function of the mean skin temperature increases along with the increase of mean radiant temperature.

The effect of *air velocity* in human thermal comfort is different. In fact, it depends on environmental temperature and humidity, as well as on the clothing. When air temperature is above the skin temperature, the effect of air movement will be the same as other climatic factors and the increase of air movement will raise the skin temperature [Hoppe; 1988]. Air movement is more noticeable when the air is cool and the difference between skin and air temperature is large. Conversely, if the air is only slightly below skin temperature, very large increases in air speed are needed to achieve an increase in convective cooling [McIntyre; 1980]. However variation in air velocity is important. ISO 7730, [1992] suggests that both mean air velocity and the standard deviation of the value should be taken. The air movement, in combination with air temperature, will affect the rate at which warm air or vapour (for example) is taken away from the body, thus affecting body temperature [Parsons; 1993].

Humidity is the ratio of the prevailing partial pressure of water vapour to the saturated water vapour pressure. Very low humidity may cause irritation: the skin becomes too dry and cracks may appear in some membranes (e.g., the lips). At higher humidity levels its effect on human comfort and physiology is indirect, through its effect on the evaporative capacity of the air. A higher humidity reduces the evaporative cooling potential from a given surface area of the skin, but the body can counter this reduction by spreading the sweat over the skin and thus increasing the fraction of the skin surface from which evaporation takes place. As a result of this physiological control mechanism the same amount of sweat evaporation, and of evaporative cooling, can be obtained over a wide range of humidities [Givoni; 1998]. In real conditions, people from dry climates might suffer from the high humidity when visiting such humid tropical areas.

4.6.2 Individual factors

The metabolic rate, as an individual factor on thermal comfort, varies over a wide range depending on type of activities performed by man. The ratio of heat production between a person sitting quietly, and the same person digging the garden may as great as 1:8. This is of great consequence to comfort and thermoregulation. Heat has a direct effect on the metabolic processes, since an increase in temperature increases the speed of the chemical reaction involved. However, the effect of raised ambient temperature on metabolic rate is not straight forward, since both physiological and behavioural responses are involved. Consolazio et al [1963] found that when a subject performed a given task at different ambient temperatures, there was an increase in metabolic rate of about 12% as the ambient temperature rose from 29°C to 38°C. In tropical countries, self-paced work is generally done at a leisurely pace, so that the metabolic rate may be lowered in practice [Mayer; 1993]. Met is the unit used to express the metabolic rate per unit Dubois area and is defined as " the metabolic rate of a sedentary person and 1 met = 58.2 W/m^2" [ASHRAE; 1993].

Clothing is important because any clothes worn by a person will effect the heat exchange between his body and the surrounding environment, thus will effect the state of comfort of the person concerned. In hot climates where temperatures are typically closer to body temperature, clothing plays a more important role in enabling man to survive outside than in other regions [Nicol; 1993]. The insulation of the clothing is generally expressed in "clo units". The clo unit was introduced to facilitate the visualization of clothing level, and 1 clo is the insulation necessary to keep a person comfortable at 21°C – about that of an office worker's suit. A thermal insulation of 1 clo = 0.155 m^2 K/W. For most purposes the value can be read from tables, but there is always a big problem with such descriptive tables: they are culturally defined and a thick suit in one climate might be counted rather thin in another [Nicol; 1993]. Another problem is the insulating effect of chairs which in some cases causes the discrepancies between the reported and predicted mean sensation votes [Oseland; 1994a]. The importance of chair clo values has been recognized too and ISO 7730 indicates that chairs may accounts for about 0.1 to 0.4 clo. Humphreys [1994] noted that despite the existence of extensive tables for the estimation of insulation of clothing ensembles, it is not easy to estimate the clo-values in real life because people change their clothing from day to day and season and fashions change. Posture changes clothing values but no guidance on adjustments of clothing values for posture are given. Nicol [1993] noticed that in hot climates people on long coach trips lean forwards in their seats to cool down.

Wyon [1994] points out that clothing values do not characterize the distribution of insulation over the body surface, and sectional heat loss can vary causing sensations of thermal discomfort which are similar to those caused by draught. Cena [1994] recommends that current tables of clothing values should be supplemented with the data available on style and cut.

Clearly clothing insulation has a great effect on thermal comfort and has particular importance to the adaptive model of thermal comfort. Oseland [1994a] noted that increasing the clothing insulation value by 0.2 clo can cause a 1.0°C decrease in neutral temperature.

In brief and according to Oseland [1994a] the accuracy of measurement of activity and clothing are critical in determining optimum room temperature by re- computing the comfort equation. It was found that increasing the activity level by 0.2 met can cause a 2.5°C decrease in neutral temperature. Fanger [1994] argues that the spread of neutral temperatures due to minor changes in activity and clothing allows some flexibility in specifying optimum room temperatures.

4.6.3 Other factors

Other factors such as gender, age, body shape, food and drink can influence the condition of thermal comfort in man, although Fanger [1970] argued that most of these factors have little or no effect upon the comfort conditions. Auliciems and Szokolay [1997] have separate categories for such factors which are contributing factors, included food and drink, acclimatisation, age, gender, body shape and subcutaneous fat. According to them body shape and subcutaneous fat are important factors. Heat production is proportionate to the body mass, but heat dissipation depends on the body surface.

4.7 Research in thermal comfort

4.7.1 Field study or climatic chamber study?

With regard to new building technology and modern heating and cooling systems the main question is "what conditions for people are comfortable and what must we aim to provide?". Clearly and because of many reasons, before the Industrial Revolution our generations lived in harsh climates without abundant sources of energy.

There are two methods for ascertaining people's thermal comfort, which are based on questionnaires: experimental work carried out in a climatic chamber and field studies carried out in the real world. Although the crisis of thermal comfort is often perceived as a conflict between these two methodologies both are important and necessary. According to Humphreys [1992] this is to misunderstand the problem. Attention must be paid to the process of securing comfort. The two methods are described as follows:

1- Climate chamber or analytical approaches- this methodology is conducted in environmental test chambers that can alter a range of climatic conditions. The personal variables are determined by the task, and are normally assumed to be fixed. The advantages of using a chamber are self- evident, the ability to produce the desired environmental conditions is the first one and then the control of unwanted variables, which might otherwise influence the results. The subjects are asked to vote on the ASHRAE or Bedford thermal sensation scales indicating their thermal experience. According to McIntyre [1982], climate chamber studies have been central to thermal comfort research for many years. He also identified two approaches in climatic chamber studies, which are the direct determination of preferred temperature and the use of rating scales for subjective thermal responses.

2- Field study of thermal comfort- the aim of this method is to study thermal comfort in the real world. Research is conducted as subjects go about normally with their work and there is no attempt to control the environmental measurements that may have varied from just the air temperature to all factors, but in many surveys clothing value and metabolic rate are recorded. Furthermore a field study will give other factors, not directly because of the experiment but indirectly, such as cultural and psychological factors. The first aim is to discover what combination of environmental variables best describes the subjective responses of the subjects and the underlying assumption of the field survey is that people are able to act as meters of their environment [Nicol; 1993].

4.7.2 Two methods and different results

Nicol [1993] stated that there is a discrepancy between the findings from field studies and the comfort predictions based on the heat balance model [Figure 4.2].

Figure (4.2) shows that people are comfortable in a wider range of indoor climates than would have been expected from the heat exchange models. When Humphreys [1992] calculated the PMV by using data from some field studies, he noted that the calculated PMV different from actual mean vote and the PMV almost always underestimates the actual mean votes. Fanger [1994] suggests that the difference in results arise from "poor data input". To make a fair comparison, it is essential that all four environmental factors are property measured and that a careful estimation is made of the activity and clothing. Malama [1997] noted that difference may arise due to the:

1- Difficulty of accurately measuring the parameters of Fanger's equation in the field

2- Difficulty in accounting for short term fluctuation in those parameters in field,

3- Impact of psychological and cultural factors in the field

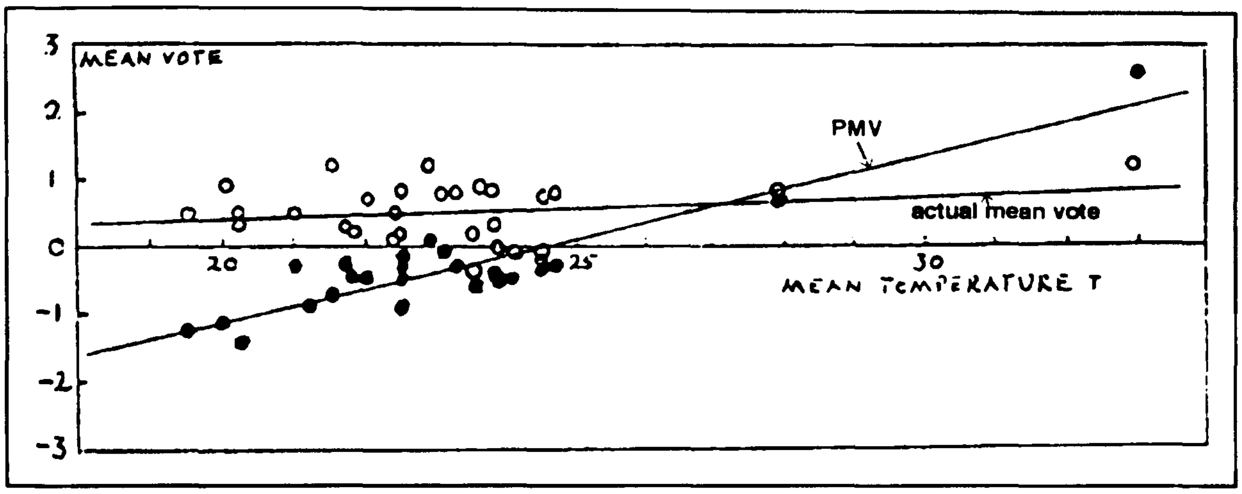


Figure 4.2 The difference of comfort predictions between the actual mean vote and the PMV in some field surveys. (*After* Humphreys 1992)

Note: (o) = actual mean vote (MV) and (●) = PMV.

4.7.3 Two methods and their problems

Both methods have some problems. The first problem with the analytical approach is that it is based on steady state conditions, which are rarely encountered in practice. In daily life sudden changes are common because of changes in clothing, activity and location. Indeed "perfectly static conditions do not occur in nature"[Koenigsberger et al 1973]. Another problem is that the prediction of conditions for optimal comfort requires a knowledge of the clothing insulation and metabolic rate [Nicol;1993]. Nicol also noted that there is some problem for the environmental designer with this method:

1- He must know what clothing the occupants of the building will wear

2- He must know what activity they will be engaged in and there is an additional problem for buildings where a number of activities are taking place in the same space

3- He must assume that conditions in the building approach those of the steady- state in the climate chamber

Such considerations render the method very difficult to apply to buildings with no mechanical heating and ventilation. On the other hand one main problem with field surveys exist. The accepted method of analysis for a field survey is the use of statistics where comfort vote is taken as the dependent variable and the environmental parameters as the independent variables. At the same time people are left to suit themselves in their choice of clothing, their use of environmental controls their posture, activity and so on. Many of these actions will have been taken in response to the comfort vote. So it is not true to say that the environment is independent of comfort vote [Nicol; 1993].

Because of the different results that are obtained in both methods, there has been a debate on which method gives more accurate results, or in the short question which one is better? Humphreys' idea [1994] is important: it could be asserted that the field studies were suspect, being incomplete in their assessments, or biased in some way. Alternatively, it could be asserted that the heat exchange equations were suspect, being inaccurate or inappropriate, for reasons not apparent. He stated there is no definite conclusion can be made about which method is most appropriate for predicting thermal comfort conditions. Baker and Standeven [1996] believed that both methods are correct, but the discrepancy between them is the result of a series of adaptive errors. Berger et al [1994] commented that laboratory studies provide fundamental insight of human thermopysiology, while field studies are equally important to complement the information about thermal comfort in real buildings where the dynamics of both people and indoor climate are complex. When somebody is asking "which one?" he / she does not know what is the problem [refer to Humphreys; 1994].

4.7.4 Steady state or transient conditions

The steady-state model of Fanger [1970] assumes that the whole body is in a state of thermal equilibrium with negligible heat storage. In fact, the rate of heat generation is equal to the rate of heat loss, and thus energy balance. Fanger accepted that his model could be employed only when minor fluctuations of the variables are found, but the mean value should be reasonably constant or quasi-steady-state. For a sudden large change, it is believed that there is an unhealthy "shock" effect. Furthermore, he believed that the changing thermal sensation from neutral to other conditions, is correlated with skin temperature and sweat rate in the same way as under steady-state conditions, but it fails in the transient reversed proceeding. Hardy et al [1971] reported that comfort is independent from the skin temperature. According to Wang and Paterson [1992] if a person undergoes a climate change, the thermal sensation will be experienced as non stationary within a wide range of skin temperatures from 28°C to 34°C, a person can be either comfortable or uncomfortable, so the sensation of comfort depends largely on heat storage within the body, not skin temperature.

As mentioned above, Fanger's comfort equation, the ASHRAE standard and ISO standard are based on the assumption of steady-state conditions and the main reason is that environmental conditions do not vary very much. This assumption is important to:

1- Determine the rate of heat gain in building

2- Better understanding of heat transfer problems

3- Finding practical methods for predicting a particular thermal environment

4- Calculate the capacity of the mechanical controls.

But in real situations, people always interact with various thermal effects between buildings, between control systems and so on. According to Humphreys [1994] in daily life sudden changes are common because of changes in clothing, activity and location.

In thermal comfort transient research it is the temperature changes that have been of most interest e.g. going from one thermal environment to another.

One of the main question is: which one can be better? Humphreys [1994] noted that the general application of a steady-state equation is inappropriate and can produce not only random errors but also systematic bias. Clearly steady-state conditions are rarely encountered in practice [Hensen; 1990]. In transient condition the sensation of comfort depends more on heat storage within the body than it does on skin temperature [Wang and Patterson; 1992].

It seems that to provide thermally comfortable conditions in buildings, transient studies are significantly necessary, because the assumption of thermal balance is not very practical since in reality this will not always be the case.

Fanger [1994] explained that steady state conditions are fairly well understood and the challenge is to examine how transient environments affect comfort.

4.8 The adaptive model

Fanger [1995] noted that "in my opinion it has always been our primary duty as building services engineers to serve people and accept them as they are. We should begin with the human being and provide the building services required to meet his or her needs in an economical and energy- efficient way". He continued that "we try to improve indoor conditions for human beings."

The comfort (or neutral) temperatures determined from various field studies vary notably from one another and are sometimes difficult to reconcile with the temperatures calculated from the rational indices. Concern of these phenomena led to viewing thermal comfort as part of a self- regulating system which has become generally known as the adaptive model [Humphreys and Nicol; 1998].

This model has been supported by many studies in thermal comfort. Fountain et al [1996] examined how culture and climate influence people's sensation. Abdulshukor [1993] showed how Malaysians living in London were acclimatizing with environmental conditions of London. Humphreys [1994] produced a table, which showed different comfort temperature from climate chambers (Table 4.2). He argues that this proves that different people in different parts of the world will experience comfort at different temperatures. contrary to the theory that neutral temperatures are the same world wide which is the theory behind the PMV and therefore ISO 7730.

Table 4.2. Neutral temperature from climate chamber tests

Location	Neutral temperature
Danish	25.7°C
American	25.6°C
Hong Kong	24.9°C
Khartoum	29.0°C
Japan	26.3°C
Iraq	25.9°C
Chinese	28.0°C
Malays	28.7°C
Malays(London)	25.7°C
Singapore	26.4°C

Humphreys and Nicol [1970] investigated many field studies that show the relationship between the comfort votes and the climate of office workers and compared the results (Figure 4.3).

On the other hand, there are real discrepancies between the empirical findings from field study research and the predictions of comfort equations. It is not easy to attribute such differences entirely to systematic or random errors of physical measurment or to the uncertainties in the estimation of clothing insulation and metabolic rate [Humphreys and Nicol; 1998]. A feedback adaptive model for thermal comfort is able to offer an explanation of the differences between the results of Fanger's model and field studies.

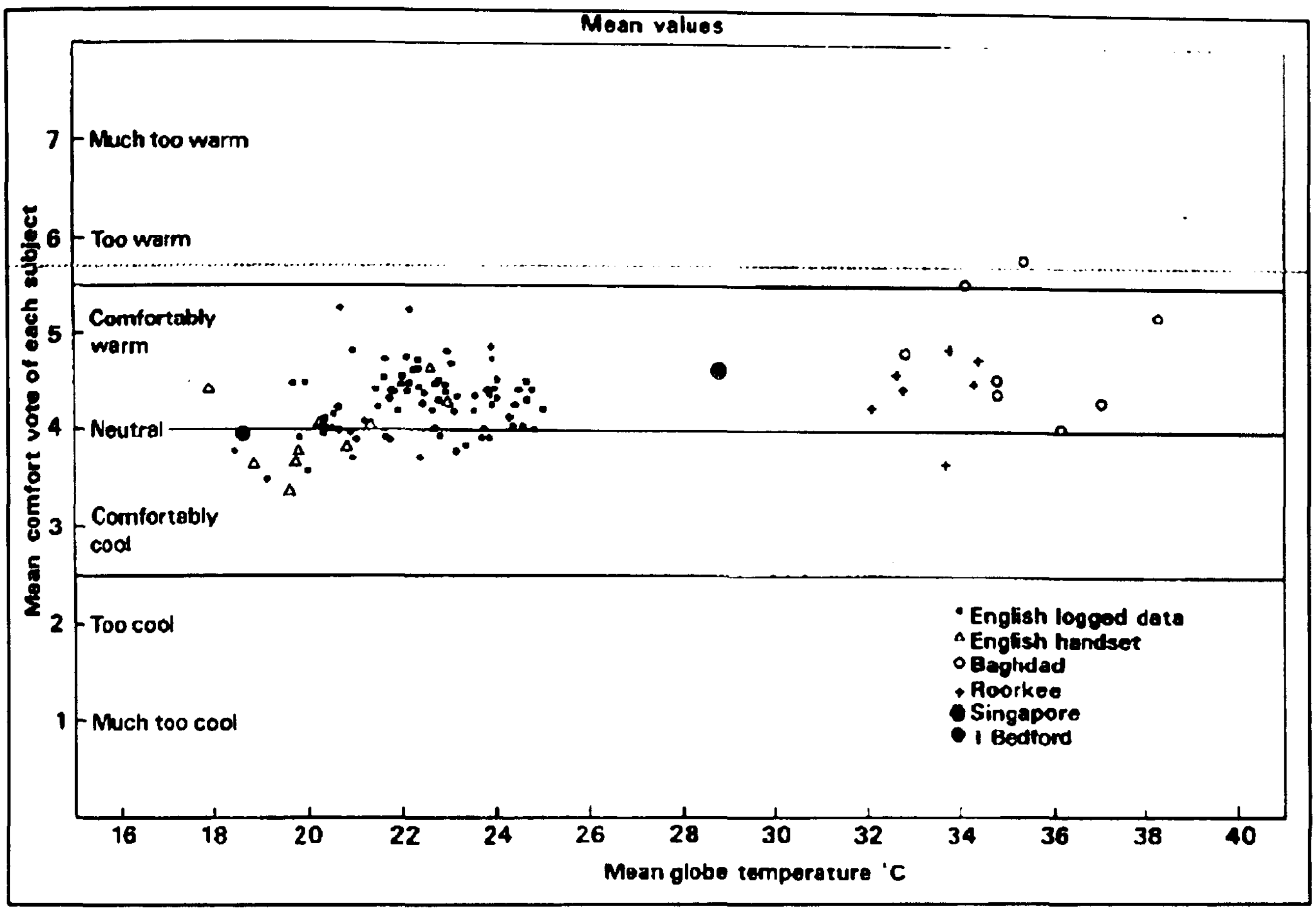


Figure 4.3 Relationship between mean comfort votes and mean globe temperatures. (*After Humphreys and Nicol 1970*)

In fact, results from this can be generalized to match the circumstances of every day life [Oseland and Humphreys 1994]. A feedback adaptive model should not be seen as a rival to the heat exchange approach, for heat exchange is part of the internal underlying mechanism of the cybernetic loop, and a satisfactory state of heat exchange is intrinsic to thermal comfort. Also there will be conditions where feedback can not operate to produce comfort. This is typically the case when a person's task requires a fixed ensemble of clothing, and a fixed thermal environment, as may be the case in certain industrial and military circumstances [Humphreys; 1994]. Humphreys also noted that knowledge of the heat exchange, checked out by experimental verification, would be the best approach, unless the person can be given control over the thermal environment.

The concept of adaptive feedback will help to unite the results of two methods (climatic chamber and field study), and is essential to the understanding of field study results.

However, according to Humphreys and Nicol [1998] if change occurs such as to produce discomfort, people react in ways that tend to restore their comfort. This is called the adaptive principle and these reactions are referred to as adaptations.

The adaptive principle recognizes that a person is not a passive receiver of sense impressions but is an active participant in dynamic equilibrium with the thermal environment. Humphreys and Nicol also noted, according to this understanding, comfort and discomfort are dynamic in character and it is, therefore, unlikely that a comfort zone can be adequately described by means of temperature intervals alone; the time-dimension will also need to be incorporated into its definition.

In fact, the theory of adaptation contends that people are continually seeking to achieve comfort and usually adapt various methods to achieve this.

De Dear [1994], in the best illustration of the adaptive hypothesis, noted that one's satisfaction with an indoor climate is achieved by a correct matching between the actual thermal environmental conditions prevailing at that point in time and space, and one's thermal expectations of what the indoor climate should be like. Figure (4.4) show these all important expectations result from a confluence of one's past thermal experiences, cultural and technical [Auliciemes; 1981; 1986].

The fundamental distinction between the heat balance theory and adaptive model is their underlying basis or cause for the shift in comfort temperature. The former permits only adjustments to heat balance variables such as clothing or air velocity, whereas the adaptive model is premised on changing the expectations of building occupants [de Dear; 1994].

The underlying hypotesis of the adaptive model is that one's satisfaction with the thermal environment is guided by adaptive adjustments to not only the previling environment conditions but to what we expect our indoor conditions to be.

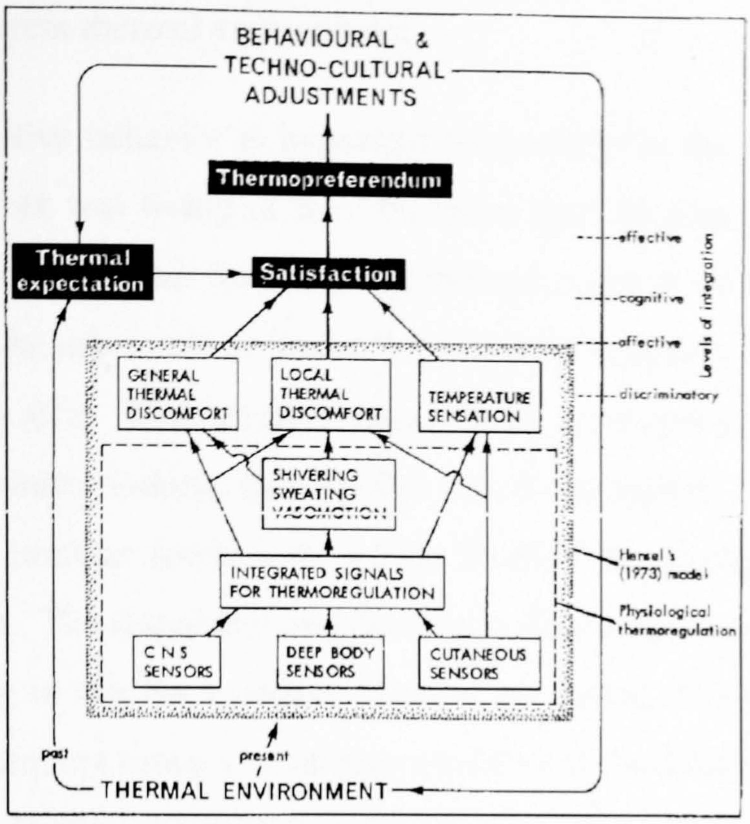


Figure 4.4 Hypothetical model of psycho-physiological warmth perception (*After Auliciems 1981*)

The close relationship between comfort temperature and mean temperature which the subjects experience [from Humphreys; 1976] is largely attributable to behavioural thermoregulation- people learn to adapt their environment or themselves to remain comfortable [Nicol and Raja; 1996]. Humpherys [1994] noted that we should expect comfort to be sought by making successive attempts to satisfy a set of continually varying desires and needs. In this way a person is in dynamic equilibrium with the environment. If the various facts of the environment are not independently controllable, the person may have to trade off one kind of comfort against another: opening a window to cool the air may let in too much noise, and so a compromise must be found. Humphreys also listed most actions people take to secure thermal comfort, which are:

1- Modify the internal heat generation

2- Modify the rate of body heat loss

3- Modify the thermal environment

4- Select a different thermal environment

Obviously adaptive behavior is important particularly in the present study. The study's researcher was living in Ilam for more than 25 years. His observations confirm adaptive behaviour for achieving thermal comfort. When he asked: "why must we go to the other side of house?", the answer was because the other side is cooler than this side. With weather changing all were going to change; summer clothing with winter clothing, thin blanket with thick blanket, summer rooms with winter rooms, summer foods with winter foods, even working times, sleeping times and so on. The researcher and his family, like many people in Ilam, did not use any cooling or heating systems. This is interesting if the climate of Ilam is reviewed. During hot times a small moving fan was used and during cool times a small brazier. Father and mother believed not to use a brazier during sleeping time. The researcher does not remember any problem in terms of environmental conditions.

Many Iranian people *are adapted* to the resulting environment whether at 15.0°C or at 30°C [refer to letter of Fanger, 1995, which wrote *must adapt*].

4.9 Acclimatization

Acclimatisation refers to the substantial physiological changes which take place after prolonged exposure to heat [Parson; 1993]. It is particularly important in hot climates. Newcomers to a hot region, who previously have lived in cooler regions, are likely to suffer more from the heat than persons already living in these places [Givoni; 1998].

The seasonal variations of a temperate climate are sufficient to keep the adaptive process alert and efficient. That there is a change in the level of adaptability between summer and winter is well shown when a premature hot spell arrives early in the year.

In terms of the human body, the thermo-regulatory centre is situated in the hypothalamus, which in response to an increase in temperature of the blood produces a general cutaneous vaso-dilatation. This enables the blood to carry its heat load to the skin where, if the ambient air is cooler, it may lose heat directly. If the skin fails to lose heat fast enough and the blood temperature continues to rise the hypothalamus further initiates sweating, the evaporation of which cools the skin and enables the blood to lose more heat [Brodal; 1950].

Thus the primary mechanisms by which the body can lose heat is the evaporation of sweat. In addition small amounts of heat may be lost in the saturation and warming of inhaled air, in the warming of food and drink and in the evaporation of latent perspiration.

The cooling of the body by convection and radiation can only take place if the environmental temperature is less than that of the skin. In the hot and dry climate this is actually greater and the body would gain heat by radiation and convection from the warmer air. In such a climate sweating is the only natural means by which the body can loss heat. For sweat to evaporate the air must be relatively dry. The greater the humidity the less sweat will evaporate. In the humid climates a condition of complete saturation is not infrequent and loss of heat can only be accomplished by radiation, conduction and convection to the surrounding objects and air which in these conditions are below the temperature of the body.

A question frequently asked is why sweating should continue in a saturated atmosphere where none can evaporate? The answer could be simple, the thermoregulatory centre reacts to the heat of the body, not of the environment and if the former rises above the threshold for sweating, sweating will commence even though it is valueless.

Winslow [1949] describe a zone of thermal equilibrium between shivering and sweating which shifts with acclimatisation, i.e. sweating in the hot climate starts earlier and is more profuse- it may even be doubled with training. Ladell [1954] also showed that a raised body temperature and raised skin temperature both acted centrally and that in an acclimatised subject sweating stared earlier.

Adolph [1947] advised desert travellers to limit heat gain by resting in the shade during the day, to remain clothed and to work or move at night. He described the onset of acclimatisation as beginning within four hours of exposure and increasing thereafter with a diminishing rise in pules rate under stress and increasing comfort at work. More details of recent work in this topic is in Parsons [1993].

However, there is no doubt then that in the adaptation of the human body to climates many factors are involved. But some researchers confine the term adaptation to the type of physiological or psychological acclimatisation through which a person might come to prefer or accept a different set of skin temperatures or sweat rates for comfort. The narrower use of the term has led to misunderstanding and to the rejection of the adaptive approach by those who believe that this kind of acclimatisation dose not occur. However, the adaptive model does not depend on the existence of this type of acclimatisation, and the adaptive approach affords useful insights irrespective of the outcome of the current debate about the effects (if any) of acclimatisation on the physiological conditions for comfort [Humphreys and Nicol; 1998].

4.10 Room temperature and adaptation

Thermal comfort researchers regress the thermal sensation votes by the room temperatures to determine the temperature at which the occupants are in a state of neutral thermal sensation. This method assumes that people's thermal sensation is dependent on room temperature, but is any room temperature acceptable?

Fanger [1994] noted that setting the room temperature to that which is optimum for a group will make some people too warm or too cool but considers methods such as ISO 7730 a means of providing an appropriate range of temperatures for certain activities and clothing.

Humphreys and Nicol [1998] noted that one of the objections sometimes raised about the adaptive model is that it implies that virtually any room temperature would be acceptable. They contend that scrutiny of conceivable adaptive actions shows that, in a particular set of circumstances, some may not be practicable and others may be limited in range. It is these circumstantial restrictions on the adaptive actions, viewed together as an entire set, that determine the particular room temperature, or range of room temperatures at which comfort is obtained, or perhaps even prevent comfort being achieved at all.

For a clear illustration, mathematically, the room temperature for comfort (T_c) will depend upon several constraints ($C_1, C_2, \ldots C_n$) hence:

$$T_c = f(C_1, C_2, \ldots C_n)$$

The thermal discomfort (T_d) will depend on the difference between the comfort temperature (T_c) and actual temperature (T):

$$T_d = f(T_c - T)$$

Logically people want:

$$T_d = \text{Limit}\ f(T_c - T) = 0$$

And it is when:

$$(T_c - T) \rightarrow 0$$

providing people have many options. Some options are capable of being used by people and some of are not. The main problem in this researcher's opinion is that building services engineers forgot their task and the extent of it. They think that providing a condition of minimum thermal discomfort is their task. People seek to be comfortable, and act to secure thermal comfort. They are not often passive recipients of the provided environment. People will modify the environment [Humphreys; 1994]. The extent of the building services engineer's task and a knowledge of people's behaviour should be known. If it is not, many of the problems can not be solved in the right way. For example in the air-conditioned building opening the windows when the system is ON for providing cooler condition in the cool season.

Obviously in all the time of year room temperature can not be an acceptable temperature for occupiers. People interact with the environment such that if they are too warm they cool themselves down by, if possible adjusting the room temperature. If it is not possible, they used other methods which do not effect room temperature. But over a reasonable time of perhaps several days, the mean room temperature people experience would be close to the temperature they found on average to be comfortable. Results from field studies over many years demonstrate this fact.

There are various factors, which may operate as boundary conditions. Thus the comfortable room temperature will depend on such factors as wealth of the occupants, the climate, the design of the building, the cost of fuel, the cost of clothes, the requirements of other people, the socially correct dress, the controllability of heating system, the normal dresses for time of year, whether the person must stay at fixed location, whether the activity is fixed or may be varied, whether uniform or special clothing is required, and so on [Humphreys; 1994].

4.11 Conclusion

This chapter has described the theory of thermal comfort. It has been one of humanity's major preoccupations and partly explains the need for shelter. This theory believed that the thermal environment has significant effects on human health and affected productivity. Differences between some terms in thermal comfort studies, which are important to use, and factors affecting thermal comfort are presented.

Thermal comfort has been studied through classic theory of heat transfer between the human body and its surroundings, and thermoregulatory system. Both of them were briefly described in this chapter.

There is an on-going debate over the difference in results from field studies and from climatic chamber studies, thus the chapter has shown that research in thermal comfort must make use of both ways. Both are important and attention must be paid to the process of securing comfort, and many of the difficulties are explicable if an adaptive model for thermal comfort is used. Humans have a fairly broad adaptability, a capacity for acclimatization to different conditions. Living in artificially maintained and homogenized environments would reduce this adaptability, however the end part of this chapter described the concepts and the theory behind it.

Overall the main step is to establish what is the range of thermal conditions commensurate with comfort, without causing ill effects to occupants.

Chapter Five

Review of some thermal comfort studies

5.1 Introduction

There are many reasons for choosing and reviewing the following literature study on field surveys and climatic chamber experiments of thermal comfort. These include:

1- Importance of the findings of some researchers on thermal comfort not only for improving the present study but also for comparison between some of them

2- to understand discrepancies between field studies and climatic chamber studies in a practical way.

Two main categories in the present literature study are:

1-Climatic Chamber is important because:

The investigation of a particular parameter is possible [Fanger; 1970]. It is apparent that in the field studies it is impossible to set any desired parameters as accurately as in a chamber [Cena; 1994]

2- Field studies of thermal comfort important because:

2-1- this thesis is based on field studies of thermal comfort

2-2- field surveys provide more convincing information

2-3- the results of field studies are more applicable

2-4- results of other field studies can be comparable with results of present study

2-5- the strengths and weaknesses of the present study will be known

5.2 Selected review of climatic chambers studies

According to McIntyre [1982] climatic chamber studies have been central to thermal comfort research for many years. Such studies have been carried throughout the particular regions with particular aims. Some of them are briefly introduced according to the scope of the present study. The literature of climatic chamber studies helps understand the conditions of thermal comfort on controllable basis.

Nevins et al [1966] carried out an important study on thermal comfort under chamber conditions with 720 American college-age subjects who were half of them male and other half female. The subjects were wearing 0.52 clo. Researchers introduced a temperature- humidity chart for thermal comfort of seated persons. Although they used a very good range of humidity (15%-85%) in eight steps, the range of air temperature was narrow (18.9°C –27.8°C). This means that subjects were in a nearly comfortable or slightly comfortable condition. Were Nevins's subjects comfortable or uncomfortable at for example 28.9°C? The important results of this study were:

1- A strong linear effect between air temperature and sensation votes

2- A small effect of relative humidity

3- In terms of sensation votes there was no difference between male and female subjects

4- The results show subjects in 75% of conditions were comfortable

5- The comfort condition based on effective temperature was at 25.6°C with 50% relative humidity

The results of Nevins work are comparable with the McIntyre and Griffiths study [1975]. Their work was on three levels of humidity (20%, 50%, 75%) at 23.0°C and 28.0°C. They examined the effect of humidity on subjective thermal responses. The findings show pronounced increases in the warmth vote with increasing humidity at 28.0°C, which is quite similar with Nevins's results at 27.8°C. Furthermore the results of McIntyre and Griffiths work which was a level of 50% Rh was more comfortable than 20% or 75%, which is in agreement with results of Nevins in 45% Rh.

Three years after Nevins works, Fanger [1970] conducted an experimental work in eight different thermal conditions. Fanger's subjects were 128 Danish college-age and 128 Danish elderly persons (with a mean of 68 years of age). Half were male and other halves were female. They wore the standard uniform of 0.6 clo and sedentary activity during three-hour sessions. The results were:

1- There was a good correlation between ambient temperature and mean votes

2- Fanger's study showed that gender and age did not influence thermal neutrality

3- Neutral temperature for the two groups was 25.7°C with the slope of regression equation about 0.32 in the both groups

In other climatic chamber studies, such as Tanaba and Kimura [1987, 1994], the researchers had a similar idea. They determined the comfort condition for Japanese college-age subjects and they also found that female subjects preferred slightly higher temperatures and were more sensitive to cold than male subjects. In fact this agrees with Fanger's work because the comfort temperature between genders in the Fanger study was sometimes different. The neutral temperatures of male and female were close (female 25.5°C and male 26.1°C). However, Fanger concludes that gender does not influence thermal neutrality because the difference was not statistically significant. In his work the females preferred a slightly higher temperature than males. In Tanaba and Kimura's study subjects wore 0.6 clo under sedentary activity. The neutral temperature (when relative humidity was 50%, air velocity 0.1 m/s and metabolic rate 1 met) was 26.3°C for summer and 25.3°C for winter. The other result also was: at higher air temperature subjects preferred higher air velocities.

Two works by de Dear et al [1991a,b,c] in Singapore are relevant. The researchers used thirty-two subjects in the first work and ninety-eight subjects in the second work. The neutral temperature was 25.4°C with the comfortable range of 23.1-29.9°C at 50% relative humidity. These results were reported in the first work. However the main findings were:

1- Thermal sensation tending toward slightly cool; also that was not similar with preferred state.

2- No statistically significant difference between temperature preferred by male and females

3- Humidity had a negligible effect on thermal sensation as well thermal comfort, if ambient temperatures are lower than 28°C

5.3 Review of field studies

Humphreys' review [1976] of field studies of thermal comfort was the first and most fundamental. He has reviewed thirty-six field studies in a basic and thoughtful way. Different environmental conditions (ranging from winter in Sweden to summer in Iraq, difference measurement of variables, various scales, and various techniques) were problems which Humphreys had to solve for a uniform comparison.

The use of just mean internal air temperature to predict neutral temperature is one of the many interesting points arrived from this study.

The regression line, which predicts neutral temperature from the mean indoor temperature is:

$$T_n = 2.56 + 0.831\ T_i \qquad (5.1)$$

T_n is neutral temperature

T_i is mean indoor temperature

In another study Humphreys [1978a] demonstrated that the neutral comfort temperature is strongly related to the mean outdoor temperatures, that is:

$$T_n = 0.531\, T_{om} + 11.9 \quad (5.2)$$

T_{om} is outdoor temperature

Initial interpretations of such findings emphasised adaptive processes such as adaptive behaviour, habituation and acclimatisation. In fact, Humphreys shows the principal effect of adaptive processes on thermal comfort is that the mean comfort temperatures is close to mean the temperature experienced and that is varies with mean outdoor temperature. This study is also a main step for introducing adaptive theory, which has quite an important effect on comfort (neutral) temperature.

The following review is based on Humphreys' approach in 1976. Information has been also obtained from some recent field studies of thermal comfort in housing.

5.3.1 Thermal comfort study in Pakistan

Nicol and his teams [1994] conducted a longitudinal survey of thermal comfort in Pakistan during July 1993 (summer) and December / January 1994 (winter). They divided Pakistan into five different climatic zones to reflect the climatic variation of Pakistan. The aims were to examine the appropriateness of the existing design indoor temperatures recommended by the standards derived from laboratory studies, and to suggest a new standard, which related indoor temperatures to local climate and seasons. The main results of this work are:

1- The mean comfort vote and mean preference vote were more consistent in summertime but more variable in wintertime

2- Summer comfort temperatures varied between 26.7°C and 29.9°C, while in winter the variation was 19.8-25.2°C.

3- Half to two-thirds of the difference between the comfort temperature in summer and that in winter is accounted for by changes in the clothing worn.

4- The temperature which people will find comfortable in the summer was predicted with reasonable accuracy from the equation:

$$T_c = 12.1 + 0.534 T_{om} \tag{5.3}$$

T_c is comfort temperature

T_{om} is outdoor temperature which is ½(monthly mean max.+ monthly mean min.)

5- The comfort temperature in winter in unheated or partly heated buildings is about 2.4 K higher than that defined by equation (5-3).

6- Air movement and humidity do not show a significant effect on comfort temperatures during winter

7- Normal air velocity gave cooling equivalent of a shift of up to 4K in summer

8- Skin moisture and the clothing insulation showed seasonal variations averaging about 0.35 votes and 0.45 clo respectively.

9- Mean activity showed very little seasonal variation

5.3.2 Thermal comfort study in Iraq

Based on Webb's data in Baghdad, Nicol [1972] reported results of his analysis, which are interesting. Webb made observations with subjects in their homes in June- July 1962 while the weather of Baghdad was hot and dry. The subjects homes were of modern design with walls of concert blocks.

Globe temperature, relative humidity and air velocities were measured and for sensation of subjects the Bedford scale (seven points) was used. Nicol found that Baghdad people were more comfortable at a globe temperature of 32°C. In the multiple regression equation computed for the responses a statistically significant air velocity was present but the humidity was not significant. Nicol also found that the air velocity was greater than 0.25 m/s, and the sedentary acclimatised subjects had little discomfort. Thermal discomfort exceeded 20% when the temperature rose above 36.0°C.

5.3.3 Thermal comfort study in Zambia

Malama [1997] reported two field studies in Zambia during the cool and warm seasons. Zambia is in the category of tropical upland climate with high diurnal range of temperatures and relative humidity varies between 20% and 75%.

Malama measured globe temperature, relative humidity, and air velocity. The two individual parameters, namely clothing insulation and metabolic rate, also were recorded.

A total of 43 subjects filled 3800 questionnaires against a wide range of globe temperatures. The average clothing values were 0.45 in warm season and 0.7 in cool season for men and were 0.60 in warm and 0.85 in cool season for women.

The results revealed that the mean comfort vote in the cool season was –0.6 and in the warm season was 0.7. The neutral temperature was 26.0°C in the cool season and 25.2°C in the warm season. The results also showed that in the cool season clothing and control of environment (such as closing of door and windows) were the main forms of adaptation behaviour. In the warm season only the environmental controls were used by the subjects as a method of adjusting to their thermal environment.

Malama showed that the globe temperature is the most accurate predictor and has a greater effect on thermal comfort than air velocity and relative humidity. He noted people in traditional housing were more comfortable than in contemporary housing in the cool season, but that there was no significant difference between them in the warm season. In both cool and warm seasons there was little difference in comfort temperature between the males and female.

5.3.4 Thermal comfort study in Bangladesh

Mallick [1996] studied the thermal comfort of people who are living in urban housing in Bangladesh which is in the warm humid tropics. High temperatures for most of the year and very high humidity mark the climate of Bangladesh. The periods of observations were between February and September, which covered the short hot and dry period and the hot humid period.

Mallik measured air and globe temperatures, humidity and airflow, which were generated by the ceiling fan. For individual parameters he assumed a metabolic rate between 0.8 to 1.2 met and clothing insulation of 0.5 clo.

He found that the comfort temperatures increase with air movement for certain values. For air movement up to 0.15 m/s no appreciable change in the range of comfort temperature was observed. For air flow of 0.3 m/s there is a rise in the lower and upper limits of temperatures by 2.4°C and 2.2°C respectively. For higher air flow of 0.45 m/s the change in both limits are less than 1°C.

However, the results showed that the tolerance of the subjects was with high temperatures of 24.0 –32.0°C and high relative humidity up to 95% and neutral temperature was 28.0°C.

5.3.5 Thermal comfort study in England

Oseland [1994b] carried out field studies of new homes during the winter and summer of 1988-1990. Eight hundred and eight occupants voted on an ASHRAE thermal sensation scale. They wore 0.7 clo in summer and 0.9 clo in winter. Mean outdoor temperature in winter was 12.1°C and in summer was19.2°C while indoor mean temperature was 19.2°C in winter and 21.7°C in summer. Against these means, mean sensation votes were 0.6 in winter and 0.3 in summer. Neutral temperature from linear regression analysis was 17.0°C and 18.9°C for winter and summer respectively. On average, the respondents rated themselves warmer in winter than in summer even though the room temperatures were lower. Oseland noted that this is possibly because of the relative difference in the indoor and outdoor temperature.

Furthermore the respondents prefered to be slightly warm in winter and neutral in summer. Oseland believed that these thermal sensations correspond to lower indoor temperature in winter than in summer. This may be due to using the ASHRAE scale differently across seasons, compared with the relative difference in outdoor temperature.

5.3.6 Thermal comfort study in Solomon Islands

Subjects of Woolard's [1980] comfort study in naturally ventilated houses in the Solomon Islands were asked to indicate how they felt on a graphic scale of thermal sensation which was calibrated with the ASHRAE scale. Some 1500 respondents wore light clothing and had a light activity during the time of the questionnaires. These observations were made in June, July and August 1976 when the weather was warm and humid. Air temperature, globe temperature, relative humidity and air velocity were measured.

Thermal sensation votes were correlated with air temperature and globe temperature (S_v:T_a = 0.56 and S_v:T_g = 0.57). Neutral temperature from regression analysis was about 27.5°C with a range of neutrality of 4.5°C. Woolard found that the air temperature was a reasonable thermal index and also he found that Solomon Islanders were not substantially different in their comfort requirements to other peoples resident in the warm humid tropic.

One thing which is important is that it has been established that humidity has little effect in the thermal comfort range and that away from the comfort zone, humidity is of increasing importance [Winslow et al; 1937], but in Woolard's work this tendency does not appear to be supported.

5.3.7 BRE survey

In 1986 the BRE conducted a survey in one- bedroom and bedsit starter homes. From environmental parameters just air temperatures were measured. A main question in the survey was about thermal sensation of subjects according to the seven point ASHRAE scales. Three hundred and eighty three British subjects with an age range of 21-30 years filled their questionnaires in nearly sedentary condition. Subjects had mean clothing value about 0.6 clo. The linear correlation between the mean thermal sensation vote and air temperature rounded to the nearest 1°C, was good (r = 0.95). the neutral temperature was 18.7 °C (or 16.3 °C predicted from the regression equation)

5.4 Overview of field studies

Data from the above field studies and three further field studies in housing are tabulated in Table (5.1). Together they consist of over 21000 observations made in a variety of climates and countries. In all cases air/globe temperatures have been measured but in some of them humidity and air velocity were recorded. Comfort votes on the Bedford scale, C, or the ASHRAE sensation votes, S, are also shown.

Table 5.1 Summary of some information of some field studies

No	*1*	2	*3*	*4*	*5*	*6*	*7*	*8*
Ca.	Researcher	Year	Season	Country	Obs.	T_a(°C)	T_{om}(°C)	S/C
1	*Humphreys*	1993	Summer	Pakistan	568	29.4	26.1	0.89
2	*Hancock*	1993	Summer	Pakistan	556	30.2	31.6	0.60
3	*Ballantyne*	1967	Winter	Papua	1992	28.3	-	0.74
4	*Humphreys*	1994	Winter	Pakistan	515	18.6	13.3	-0.78
5	*Humphreys*	1994	Winter	Pakistan	548	12.7	9.0	-2.36
6	*Mallik*	1995	Summer	Bangladesh	400	29.4	-	-
7	*Malama*	1997	Warm	Zambia	1790	28.9	-	0.7
8	*Malama*	1997	Cool	Zambia	1780	20.4	-	-0.6
9	*Nicol*	1974	Summer	Iraq	1284	35.9	-	0.66
10	*Nicol*	1993	Summer	Pakistan	437	30.2	32.4	0.56
11	*Nicol*	1994	Winter	Pakistan	470	24.6	20.1	-0.19
12	*Nicol*	1994	Winter	Pakistan	582	18.7	14.4	-1.25
13	*Fox*	1973	Winter	England	769	17.2	-	-0.06
14	*Oseland*	1991	Winter	England	515	19.2	12.1	0.6
15	*Oseland*	1992	Summer	England	293	21.7	19.2	0.3
16	*Oseland*	1994	-	England	350	21.9	-	0.5
17	*Roaf*	1993	Summer	Pakistan	492	29.6	25.8	0.77
18	*Sykes*	1993	Summer	Pakistan	190	31.4	30.0	0.49
19	*Sykes*	1994	Winter	Pakistan	425	19.4	6.0	0.29
20	*Woolard*	1976	Summer	Honiara	1965	27.7	-	0.08
21	*Goromosov*	1963	Heat	USSR	5902	28.8	-	1.4
22	*BRE*	1986	-	England	383	19.1	-	-

Table 5.1.(continue) Summary of some information of some field studies in housing

No	*9*	*10*	*11*	*12*	*13*	*14*	*15*
case	Neu.(°C)	Clo. V.	Stand.*	r(T_i:S)	r(T_i:Clo)	T_n(Hu)**	City
1	23.8	0.74	0.74	0.59	-0.03	27.0	Saidu
2	28.0	0.69	0.77	0.56	-0.10	27.7	Peshawar
3	25.3	-	0.67	-	-	26.0	-
4	23.1	1.15	0.2	0.43	-0.44	18.0	Peshawar
5	22.8	1.28	-0.1	-0.05	-0.17	13.1	Saidu
6	28.0	0.5	0.73	-	-	27.0	Dhaka
7	25.4	0.50	0.7	0.50	0	26.6	Kitwe
8	26.0	0.7	0.28	-	-0.54	19.5	Kitwe
9	32.5	-	1.0	0.70	-	32.4	Baghdad
10	27.8	0.63	0.77	0.55	0	27.7	Multan
11	26.2	0.98	0.5	0.33	0.03	23.0	Karachi
12	29.7	1.27	0.2	0.49	-0.09	18.0	Multan
13	17.5	-	0.12	-	-	16.9	-
14	17.0	0.9	0.22	-	-	18.5	-
15	18.9	0.7	0.35	-	-	20.6	-
16	20.6	1	-0.35	0.53	-	20.7	-
17	24.5	0.68	0.74	0.43	0	27.1	Quetta
18	23.7	0.56	0.83	-0.07	-0.45	28.7	Karachi
19	22.9	1.17	0.23	0.28	0.23	18.6	Quetta
20	27.4	-	0.64	-	-	25.6	-
21	22.4	-	0.70	-	-	22.4	-
22	18.7	0.6	0.17	0.95	-	18.4	-

* Standardised mean thermal responses (Humphreys 1976)

**Neutral temperature from Humphreys' equation

In these studies, for the two basic designs, namely longitudinal and transverse, longitudinal is more used than transverse.

Clothing as an important individual parameter was recorded except in two cases (9 and 12). The correlation of clothing with temperature (Column 13) in some of the studies is interesting which is negative and high (Cases 4,5,8 and 18). Three of those are during cool periods and case "18" is during summer time. This is to be expected as the subjects were using clothing insulation as a way of adapting to the environment. On the other hand differences between clothing values during a hot and cool period in the same area is important and that is another reason for adaptive behaviour. The mean clothing values during hot period (according to the season of each study and mean outdoor temperature) was 0.62 clo while it was 0.98 during cool period.

For sensation (or comfort) votes researchers used ASHRAE (7-points) or Bedford (7-points) except in Goromosov's work where he used a four point. As mentioned in the previous chapter the ASHRAE scale and the Bedford scale have been found to behave more or less the same in most practical situations.

Column 12 of Table (5.1) shows the correlation coefficients between air/globe temperatures and sensation (or comfort) votes. When air temperatures are increased the subjects vote their sensation to be going to warm. Thus correlation coefficients between them should be high and positive. But it should be remembered that much adaptive behaviour could effect such a correlation. If the subjects had no control over their environment, it should be expected that a correlation coefficient between air/globe temperature and comfort votes to be near unity. However, this is not so, because people can change in postures, can dress themselves individually as they wish and so on.

From Column 12 in most of the studies the correlation coefficient between comfort votes and air/globe temperatures is high and significant, except two of those (case 5 and case18). In both cases significant correlation between clothing values and globe temperatures (Column 13) could be an important reason for such low correlation. However this implies some adaptation is taking place. Another reason could be because of a small variation of temperatures during time of questionnaires.

The means range of air temperature was from 17.2°C for case "13" to 35.9°C in case "9". Such a range of indoor air temperature is against mean comfort (sensation) votes between –2.36 (Case 5) and 0.89 (Case1). Figure (5.1) is a scatter diagram of the mean sensation votes against the mean temperature, with the exception of case "21". It seems Saidu subjects (Case 5) were not happy with their environment. Their mean outdoor air temperature was low, but the indoor temperature equals 12.7°C, which implies a sensation votes of about

"-0.10". This comes from the regression equation, presented by Humphreys [1976]. This equation is:

$$Y = -0.244 + 0.0166X \quad (5.4)$$

Y is standardised mean thermal sensation response

X is mean air or globe temperature

Other sensation votes of field studies agreed with Humphreys' equation as shown in Column 11.

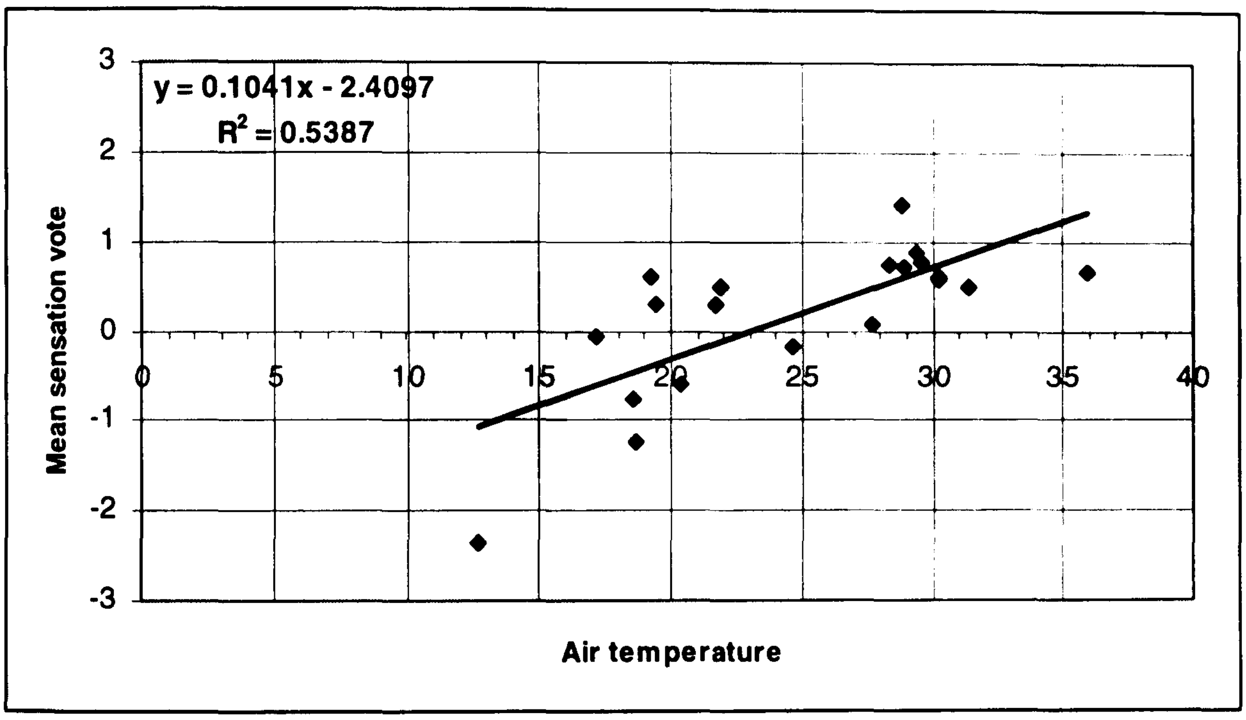


Figure 5.1 Scatter diagram of mean temperature against sensation votes

The comparisons of the mean thermal sensation responses from field studies, which are presented in Table (5.1), are made. They are regressed against mean air or globe temperatures shown in Figure (5.1). The regression equation is:

$$S = 0.08\, T_i - 1.74 \quad \text{(eq. 5-5)}$$

T_i is mean temperature

S is sensation vote

All studies for calculation of neutral temperatures used simple linear regression analysis, although some of the researchers calculated neutral temperature with probit analysis but they are not presented here.

However, neutral temperatures derived by regression analysis are shown in column "9" (Table 5.1). The range of neutral temperatures are between 17.0°C (case 14) and 32.5°C (case 9). According to Humphreys [1976] three factors apart from the thermal environment, can combine to produce different neutral temperatures. They are the levels of activity, clothing insulation and the physiological state, which is considered by the respondents to be "neutral". Humphreys [1976] found that between mean indoor temperature and neutral temperature is a very high and positive relationship. The equation of the regression line between them, which is used to predict the neutral temperature from the mean indoor air or globe temperature, is equation (5.1).

This equation shows that the neutral temperature will be low when in the moderate climates and it will be high in the hot climates. However Figure (5.2) is a scatter diagram showing the mean temperature and the neutral temperature from data of Table (5.1).

From Column"9" and Column "14" (Table 5.1) deviations between neutral temperatures from regression analysis (actual data) and Humphreys equation can be found. The neutral temperatures in cases 2, 3, 6, 7, 9, 10, 13, 14, 15, 16 and 20 agree with Humphreys' equation. Clearly because of high clothing value in cases 4, 5, 11 and 19, the neutral temperatures of subjects is higher than neutrally predicted by Humphreys' equation. Because of a lack of any more information about Goromosov's work (case 21), it can not be explained here why there is a difference of about 4K between his neutral temperature and predicted neutral temperature from Humphreys' equation. This is maybe because of time of observation, which was during the heat of day.

Differences between neutral temperatures of Malama's work [1997] and predicted neutrality by Humphreys equation is also important. Malama's subjects during the warm season were neutrally fitted by producing neutral temperatures by Humphreys' equation, but in cool season did not. Surprisingly the neutral temperature in the warm season is higher than the cool season. Differences between clothing value in both seasons is not great, so this difference cannot be because of clothing insulation.

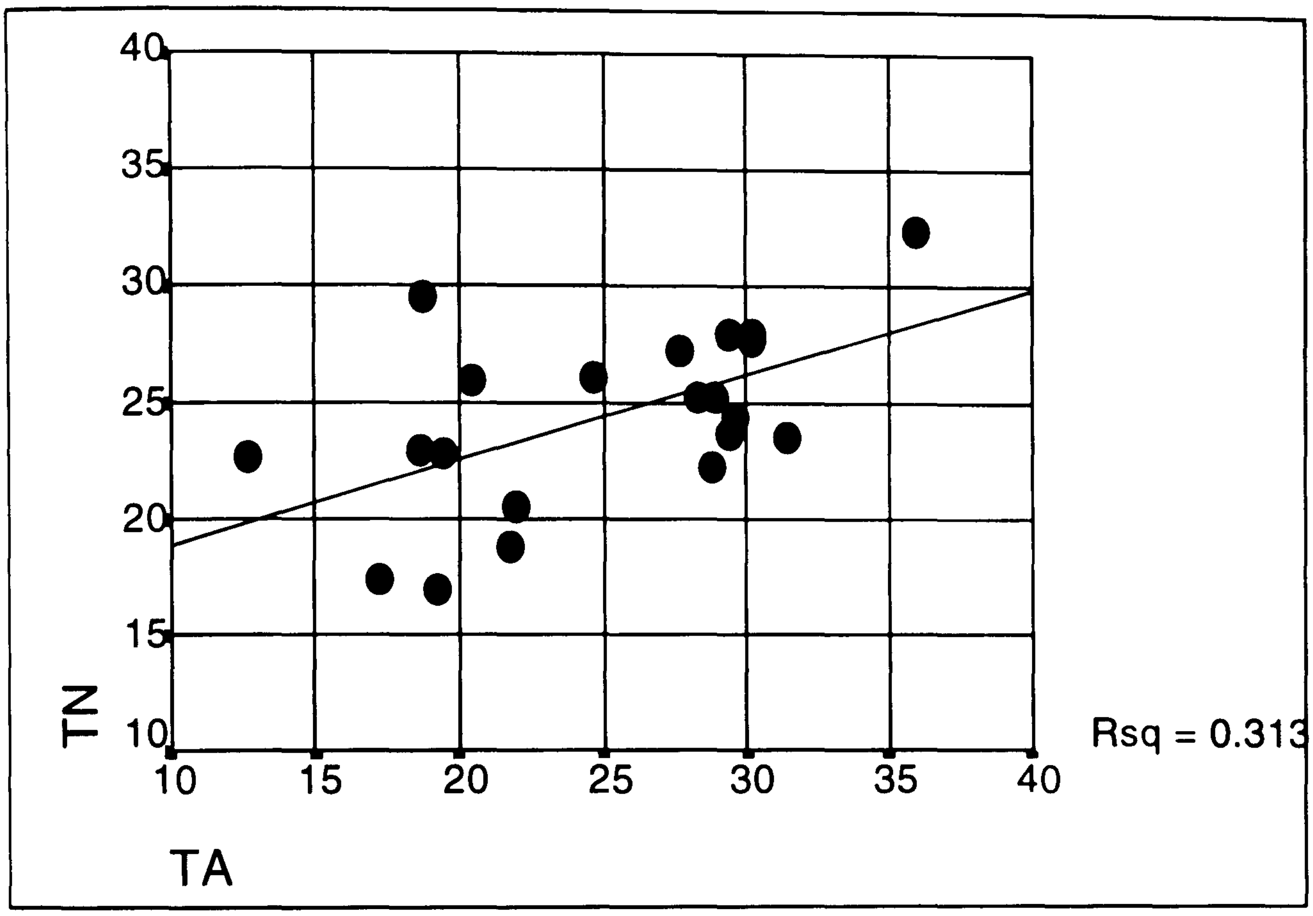


Figure 5.2 Scatter diagram of neutral temperature against mean temperature

If air velocity is taken into account, it can not also explain the discrepancy of about 6.5°C. On the other hand Auliciem's equation ($T_n = 0.73\ T_i + 5.41$) is not a good predictor for Malama's subjects. When, because of unreliable regression coefficient, Malama used Griffiths' equation ($T_n = T_i + (0 - C_m)/ a$ *), it yielded a neutral temperature of 22.2°C for the cool season and 25.4°C for the warm season. According to Nicol and Roaf [1996] there is some evidence that in free running buildings in winter the comfort temperature is some 2-3°C higher than that predicted by Humphreys equation.

5.5 Differences, strengths and weaknesses of both methods

Because of the different results from climatic chamber studies and field studies, there has been a debate on which method gives the more accurate results. Fanger [1970] suggests that the difference in results arise from poor data input. He notes that to make a fair comparison, it is essential that all four environmental factors are properly measured and that a careful estimation is made of the activity and clothing. However to arrive at a decision, it seems some points in both methods should be considered.

According to Humphreys [1994] in terms of temperature for thermal comfort from climatic chambers, there is rather more diversity than might have been expected, opening the possibility that comfort is dependent on factors other than clothing and metabolic rate. He collected neutral temperatures from climatic chamber tests, which is shown in Table (4.2).

Humphreys noted that these results, taken in conjunction with the wider than expected differences among other recent results, suggests that the assumption that comfort temperatures are invariant is not always true. Especially Abdulshukor [1993] shows a highly significant 3°C difference in comfort temperature between Malay student in London and Malaysia. In fact this proves that different people in different parts of the world will experience comfort at different temperatures, contrary to the theory that comfort temperatures are the same world-wide, which is the theory behind the PMV and therefore ISO 7730.

On the other hand Humphreys [1976] noted that the lack of control over the respondents or their environment is at once the strength and weakness of the field study. Because they are free to continue their normal activity in their normal clothing and surroundings the respondent's assessments are likely to be reliable descriptions of their feelings in daily life, and not merely transient impressions of unfamiliar environments.

In terms of the particular parameters the results of climatic chamber studies are more reasonable. For example, the possibility of using climatic chamber studies for understanding the effect of air movement and thermal radiation on subjects is greater than for field studies. Research has been performed on such studies in climatic chamber conditions [Oseland and Humphreys; 1994].

However, there is a difference between neutral temperatures that come from both models, but the fundamental question is: are such differences due to a genuine context effect or due to differences in measurement or statistical technique [Oseland; 1994a]?

Humphreys [1994] noted that the climate versus field study differences are not the fundamental problem in thermal comfort research, whereas applying steady state heat- exchange equations to a variable environment is. Wyon [1994] reports that in different environments the regression slope relating the reported thermal sensation to temperature will vary due to differences in expectations of that environment, thus different neutral temperatures will be produced.

5.6 Conclusion

The principal findings are:

1- An important discrepancy exists between field study results and climatic chamber results in the temperatures they predict for the thermal comfort of occupants

2- A strong linear effect exists between air temperature and sensation votes in both climatic chamber and field studies

3- The findings from field studies show the relationship of comfort temperatures with the environment to which the subjects were exposed to

4- Air temperature is an important thermal comfort index

5- The occupant has a dynamic relationship with his environment, and will generally take action to secure his own comfort, unless he is prevented from doing so.

6- The neutral temperatures varied from one climate to another, from one culture to another

7- A small effect of relative humidity on neutral temperature and comfort conditions exists but step changes in humidity do produce quite large but temporary changes in the sensation of warmth

8- Gender and age do not influence thermal neutrality

Chapter Six

Thermal comfort surveys in Ilam

6.1 Introduction

This chapter presents the results of thermal comfort field surveys in Ilam. There are two comfort surveys: the first was in July and August 1998 during the hot season and the second one in December 1998 during the cool season.

The first section of this chapter looks at the methodology and variables measured, which are important in any thermal comfort study. The methodology will be explained in terms of: kind and level of this experimental study; choices of housings and problems. Next to this, measurements of individual parameters, scales and questionnaires are presented. The second section describes the results of the surveys in Ilam. This section is divided into two main parts: results and analysis of results. More discussions and comparison to other studies are presented in Chapter Eight.

This chapter also will examine the effects of some variables on human comfort. The neutral and range of comfort condition zone has been established.

6.2 Methodology

The field study of thermal comfort is the methodology used for the present study, which is based on observations in the actual environments.

There are two main methods of determining thermal comfort i.e. through climate chamber experiments or through field studies. Climate chamber experiments can be performed in laboratory conditions, while field studies can be done anywhere as long as the right instruments are available. The important advantage of the field studies is that it is an in-situ experiment, which means that the results of the method can be directly applied to similar thermal environments. The environmental parameters and personal parameters cannot be closely controlled, so the results are applicable to the normal conditions encountered by the respondents during the season of study.

Nicol [1993] has divided field surveys into three levels:

Level I - simple measurements of temperature in occupied dwellings, with no subjective responses.

Level II- measurements of the thermal environment and subjective response to it.

Level III- surveys, which included all factors, needed to calculate the heat exchange between a person and the environment together with subjective responses.

The present field surveys used level II and level III.

Two basic designs also have been used in the field studies; the longitudinal and the transverse. The longitudinal is to collect the survey data from comparatively few respondents and repeat the surveys over a period of weeks or months. From longitudinal it is possible to investigate the consistency of individual response and to observe the progress of adjustment to changing conditions. Because of the small number of respondents such a study may not provide data which is representative of the wider population. The transverse is to use a large number of respondents and make only one assessment at a particular time and space. This type of study indicates the extent of variation among individuals responses and gives good estimates for the population [Humphreys; 1976].

The main difference between longitudinal and transverse is that the results of longitudinal types should not be used as a representative for a wider population, and this is because of the small number of respondents involved, while transverse is to use a large number of respondents and make only one assessment at a particular time and space. This will indicate the extent of variation among individual responses for population group. However the two types of study are complementary [Humphreys; 1976].

This current field study uses the transverse design survey. In a small section of the experimental work the longitudinal survey also was used. In total 1400 transverse sampling data sets and 476 longitudinal sampling data sets were taken.

The place of field study is important. There are two principal locations where thermal comfort surveys may be conducted: the places where people live and the places where they work [Cena; 1994]. Cena also noted that it tends to be more difficult to organise an extensive study in private homes than in work places. This is due to the natural reservation of the occupants to have any intrusion into their private lives. It is particularly important in countries with special customs, culture and with different definitions of privacy according to their religion (like Iran). However, information about comfort conditions in houses is very important, not only in terms of energy conservation but also in terms of user satisfaction.

Nicol [1993] noted "we are interested in the relationship between the subjects and their environment. If the room is atypical, or the building of unusual design this may limit the applicability of your results". This study was looking for typical housing in Ilam. It was not difficult for contemporary housing but was more difficult when selecting traditional housing. Some of them were useless and a few of them were not in traditional conditions. For example street widening, especially after the war between Iran and Iraq, caused changes in the amount of shade on the houses. Many years ago in such housing the west facade had a good condition because of narrow streets but today west facades have a very bad condition because of street widening. This study was not able to ignore such traditional housing. However the main point which is quite important in this study is that all families were living in the traditional way.

The choice of the houses to be used for the survey was based on the following criteria:

1- Located in Ilam, the city in the west part of Iran

2- All houses must be courtyard housing

3- Courtyard in traditional housing should be small in size and as much as possible central courtyard (rooms or other spaces around courtyard)

4- Recently built houses as contemporary houses (no more than 20 years old)

5- Naturally ventilated

6- Typical in terms of design and material as far as possible

There was a main problem. When a researcher is going to any house for a field survey, he/she is going to break the main aim of the field study of thermal comfort because the normal activity and normal clothing of the occupants immediately change (influence of religion and culture), particularly in transverse sampling. However the main problem in the present study was how is it possible to arrange a program without this problem? Some solutions were:

1- Explain to subjects a day before what the survey is for

2- Attempt to make the time as short as possible between arriving into the houses and completing of questionnaires.

3- Some time after placing of equipment in the suitable location, the researcher wanted questionnaires completing at a specific time.

6.3 Measurement as a main step

According to Nicol [1993] the first thing to be said to anyone contemplating conducting a field survey is that you should have a clear idea of what it is you want to measure, and how you intend to measure it. Environmental and personal measurements in the present study are described as below:

6.3.1 Environmental variables

Air temperature is the most important environmental factor [Auliciems and Szokolay; 1997]. Humphreys [1976] noted that often (in field studies) for simplicity, air temperatures alone have been measured, but in these cases there has usually been no attempt to shield the thermometer from radiation, so its reading would have been affected to some extent by the mean radiant temperature of the surrounding surfaces. Indeed it is. However three conditions may be:

1- If the air is warm, but the walls are cold, some radiation will be emitted from the globe and the reading will be below the air temperature - $[T_g < T_a]$

2- If radiation is received, the reading will be higher than the air temperature- $[T_g > T_a]$

Despite the argument for both globe temperature and air temperature, some researchers use just air temperature in their comfort studies. This is because of the high correlation between them with a small standard deviation and furthermore with almost equal means of them. For example, Webb's work in Singapore [1959]. He noted that the globe temperature was found to agree closely with the air temperature and was subsequently ignored (S.D. was ± 0.2°C). Data from experimental work by Nicol and his team [1994] in their Pakistan field survey showed that globe temperature and air temperature were similar. The difference in summer and winter was less than 0.4°C in different homes, however Nicol noted that he used globe temperature because it takes account of radiation as well as air temperature which is widely used in comfort studies. The present study used air temperature as a principal physical variable.

Air temperatures were obtained from Skye Data Hog, data- loggers that gathered and stored results automatically (see Appendix A).

Hensen [1990] concluded that the effect of humidity on thermal comfort and thermal sensation is probably considered as a minor influence. However, when temperatures are inside or near the comfort zone, fluctuations of relative humidity from 20% to 60% do not have any effect. It will be of significant effect when the environments become warmer [Gonzalez and Gagge; 1973 – Nevins et al 1973]. De Dear et al [1989] found that people feel cooler instantly for decreases of relative humidity and they feel warmer instantly for increases.

Such evidence shows the importance of humidity, even in hot- dry climates. Nicol [1993] advised the use of water pressure rather than the relative humidity, because it is the most basic measure of the water contained in the atmosphere and the most relevant measure physically. In the present study Rh% was converted to water vapour pressure (P_a) using values of T_a in the equation:

$$P_a = Rh \times \exp(18.956 - 4030.18 / (T_a + 235)) \ \mathit{millibar} \quad (6.1)$$

(from McIntyre; 1980)

The Skye Data Hogs (together with air temperature) took relative humidity. It is well to say that 5% Rh or ±2 mb water vapour pressure seems a reasonable accuracy [Nicol; 1993].

In the naturally ventilated spaces, especially if these are in a hot climate, air movement will have a big effect on the thermal comfort of the subjects [Nicol; 1974]. Nicol [1993] noted that Rohles (as quoted in Nicol;1993) in the field and in the laboratory both estimate the effect of introducing air movement to be the equivalent of a drop in temperature of about three degrees.

However, the measurements of air velocity, especially in hot climates are important but present a number of problems. It is so variable from place to place in a room as well as in direction and magnitude. A problem for the comfort researcher is to present all this variability in a meaningful way [Nicol; 1993].

In the present study an airflow meter, Solomat MPM 500e, measured air velocity. The amount of air velocity is reported by square root of air velocity, because when averaging the air velocities, it might seem logical to take a simple average of (V) over a set time period, say 3 minutes. However it should be remembered that we are interested in the air velocity for its cooling power and not its absolute value. The cooling power is more closely described by the square root of the air velocity, so averaging $\sqrt{V}$ would give more useful results [Nicol; 1993].

The main question is: how were environmental variables measured?

For this survey the data loggers and air velocity meter were carried from subject to subject and measurements of the environmental data taken for the subject making a comfort assessment. The time was accurately written on the questionnaire. The number of data loggers, which were used in each house was equal to number of the subjects except when subjects were in the same place. The consideration in the environmental measurements were:

1- The data logger was not in a permanent position in each house

2- The position of the data logger was up to the subject

3- The vertical height of data loggers were 60 cm- 120 cm on a horizontal plane

4- The data logger was not less than a metre from any wall.

5- In courtyard data logger was in shade place except when the subject was unshaded, however it was used with sun protector (Figure 6.1).

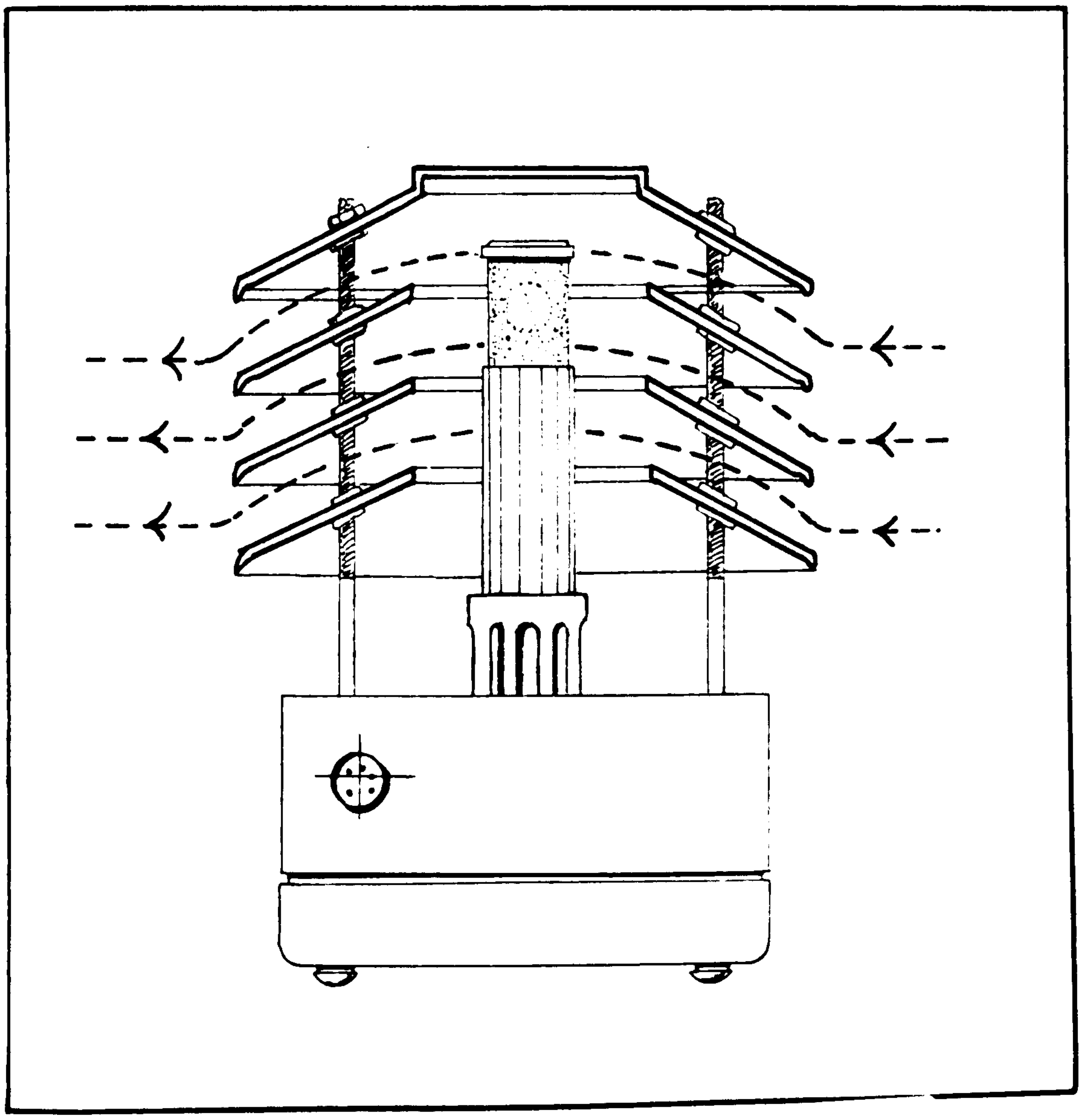


Figure 6.1 The data logger with sun protector

6- After data collection the equipment was moved to the next house

7- Air movement was measurement in two directions at the time of questionnaires. Average values are reported

6.3.2 Individual parameters

Clothing is an important factor contributing to human response. It is not controlled in field studies, but has often been recorded. The usefulness of the record of clothing is two fold, [Humphreys; 1976]:

1- It gives insight into the way people have adjusted to the prevailing temperatures

2- If the thermal insulation of the ensemble is estimated, a theoretical prediction of the respondent's thermal state can be made from a comfort equation

In the present study data on clothing were very important because clothing plays a more important role in tropical regions than other regions [Nicol; 1993]. For this survey value of clothing insulation were derived from Appendix (C) of Nicol's book [1993] as well as clo. values which were used by Nicol and his team in thermal comfort survey in Pakistan [1994]. This is because of similar clothing type between Pakistanian and Iranian people such as Chador, Scarf etc, which are used in both countries with similar shape and materials (see Appendix C of this thesis).

Clo units for clothing insulation are used. The clo unit was introduced to facilitate the visualisation of clothing level and is insulation necessary to keep a person comfortable at 21°C – about that of an office worker's suit. A thermal insulation of 1 clo = 0.155 m^2 K/W [Nicol; 1993].

According to Nicol [1993] the measurement of metabolic rate is not really necessary in field studies, being a function of the social and climatic milieu and of the task for which a comfort temperature is being found. It is also reported by Humphreys [1976] that variations of activity have not often been recorded in field studies of thermal comfort. Most experimenters have given only a general description of the activity of their respondents. In this study tables of metabolic rate which are presented by ISO 7730; 1994 was used (see Appendix B). As with Nicol's et al [1994] work in Pakistan no attempt has been made to relate this to any measure of metabolic energy output. It is measured in met where 1met = 58.2 W/m^2.

6.3.3 Subjective scales

In terms of sensation votes two forms of subjective scales with minor variations are about equally common: the Bedford scale and the ASHRAE scale (Table 4.1)

The Bedford scale is a combined estimate of warmth and comfort and this feature has been criticised on the ground that the relation between the two is not necessarily constant. The ASHRAE scale by contrast in its revised form contains no explicit reference to either comfort or pleasantness [Humphreys; 1976]. The two scales in practice behave in a very similar way and the results obtained by them may be compared directly with each other [McIntyre; 1980]. In terms of comfort terminology the results are referred to as the comfort temperature when the Bedford scale is used and referred to as the neutral temperature when the ASHRAE scale is used.

In this study the ASHRAE scale is used because of the problem in the translation of the word 'comfortable' in the *KURDISH* language (*KURDISH* is local language in Ilam). In terms of general description the word RAHATAE is equal with 'comfortable', but when environmental condition is the aim, comfortable is equal with KHOSHAE. The main point is some people are using both of them interchangeably. ASHRAE scale was easier for translation than Bedford scale. Humphreys [1999] reported that in terms of results they are the same.

Thermal preference is to examine the subject's preferred temperature, which the neutral temperature cannot represent. According to Oseland and Humphreys [1994] "would a person like to be cooler or warmer" is the most important question and it is not too difficult to find the answer. Fisk [1981] defined the idea of preference that relates to a choice for alternatives. However the preference vote which is most common and was used in the present study is the three point suggested by McIntyre et al [1976].

Two further three point scales specifically address perceptions of humidity and air movement. It seems any idea about the amount of humidity or air movement is difficult to say especially when we are using a wide category. It is particular important in a hot and dry climate, where the humidity is low and air movement is very variable. It is difficult to recognise between two categories when the discrepancy is little especially in these two limits (low and very). Table (6.1) shows humidity and air movement scales.

Table 6.1 The air movement and the humidity scales

Air movement scale		Humidity scale
Still	-1	Dry
Just right	0	Just right
Breezy	+1	Humid

6.3.4 Questionnaires

The questionnaires contained six questions and personal information of subjects. They are in order of thermal sensation: using a seven point ASHRAE scale; preference, using a three point McIntyre scale; humidity vote and air movement vote, using a three point scale two other were about activity and metabolic rate. The questions required the respondents only to tick the appropriate choices (see Appendix D).

6.4 The programme

The programme of work included four phases of field study in the city of Ilam:

1- July– August 1998 – During hot season with 809 subjects in transverse sampling at about 50 traditional houses and 70 contemporary houses (Table 6.2)

2- July– August 1999- during hot season with 190 subjects in transverse sampling at about 40 poor quality houses with low income families (Chapter seven)

Table 6.2 Summary of field study of thermal comfort in Ilam-Iran (Jul. / Aug. 1998)

No	DATE	Places*			TIME		Subj.		No of que.
		C.H (237)	T.H (276)	Y.H 296	Start	Finish	M	F	
1	27 JUL.				9.00	19.00	48	38	**86**
2	28 JUL				11.00	17.00	43	36	**79**
3	31 JUL				9.00	20.00	21	24	**45**
4	1 AUG				17.00	22.00	15	16	**31**
5	2 AUG				11.00	18.00	47	33	**80**
6	3 AUG				8.00	22.00	36	26	**62**
7	4 AUG				10.00	19.00	20	20	**40**
8	5 AUG				15.00	22.00	24	17	**41**
9	9 AUG				22.00	23.00	2	2	**4**
10	10 AUG				14.00	16.00	6	5	**11**
11	12 AUG				7.00	15.00	5	7	**12**
12	13 AUG				10.00	12.00	3	2	**5**
13	14 AUG				9.00	20.00	37	61	**98**
14	15 AUG				600	22.00	43	44	**87**
15	19 AUG				10.00	16.00	23	17	**40**
16	20 AUG				9.00	20.00	23	18	**41**
17	24 AUG				9.00	20.00	29	18	**47**
TOTAL	**M**	**109**	**136**	**180**	--------	------	**425**	**384**	**809**
	F	**128**	**140**	**116**					

CH: Contemporary Housing- Hot season

TH: Traditional Housing- Hot season

YH: Courtyard Condition- Hot season

3- July– August 1998- during hot season with 6 subjects [467 sets of data] longitudinal sampling at a traditional courtyard house (Chapter seven)

4- December 1998– during cool season, with 378 subjects in transverse sampling at about 30 traditional courtyard houses and 40 contemporary courtyard houses (Table 6.3)

Table 6.3 Summary of field study of thermal comfort in Ilam-Iran (Dec. 1998)

	DATE	Places		Time		Subjects		No
		C.C (216)	T.C (162)	Start	Finish	M	F	
1	14 Dec.			11.00	23.00	23	19	**42**
2	15 Dec.			8.00	19.00	22	16	**38**
3	16 Dec.			8.00	18.00	16	17	**33**
4	17 Dec.			10.00	23.00	19	18	**37**
5	18 Dec.			8.00	20.00	11	10	**21**
6	19 Dec.			10.00	21.00	17	18	**35**
7	20 Dec.			11.00	19.00	9	5	**14**
8	21 Dec.			9.00	19.00	11	7	**18**
9	22 Dec.			10.00	23.00	15	10	**25**
10	23 Dec.			8.00	21.00	15	14	**29**
11	24 Dec.			9.00	23.00	18	11	**29**
12	25 Dec.			8.00	23.00	15	14	**29**
13	26 Dec.			8.00	22.00	12	16	**28**
Total		12 days	8 days	8.00	23.00	**203**	**175**	**378**

C.C= Contemporary housing- Cool season
T.C= Traditional housing- Cool season

All houses were naturally ventilated without any heating or cooling systems. This chapter will report on two of the experimental studies. The first experimental work was carried out from 27th July 1998 to 24th August 1998 (about one month). The start time of the survey in each day was often before 10.00 and finish time was about 22.00. The number of subjects was variable in each day from 4 persons to 99 persons and had a mean of about 50 persons in each day. The second experiment was carried out from 14th to 26th December 1998. The number of subjects votes also varied from 14 persons to 42 persons and with a mean of 32 persons in each day. Table (6.2) and Table (6.3) show the start and finish time of each day of experimental work as well as number of subjects.

6.5 Data

6.5.1 Subject information

The total sample of responses numbered 1187 drawn from occupants in two types of Iranian housing namely traditional courtyard houses and contemporary courtyard houses during hot and cool periods. Eight hundred and nine sets of these were obtained in the hot period and 378 sets were in the cool period.

More data in the cool period were not possible because of two things:

1- A big part of the cool period (one month) was Ramadan. Muslim people during Ramadan have a different condition than other months. They do not have food or drink in the daytime and they like a private place to worship (prayer and other things like that). The number of people that were not in this condition was very limited. Two hundred and ninety two sets of cool period data were obtained before Ramadan (14 December- 23 December) and just 86 sets were obtained during Ramadan.

2- Iranian schools exams time is in December. Many people don't accept any inconvenience at this time.

From all subjects 628 were men and 559 were women, also 734 were living in the traditional housing and 453 were living in the contemporary housing. About one-quarter of sample comes from courtyard (semi-open space) which was obtained just in the hot period.

The age of the subjects ranged from 12 to 75 years with a mean of 36. All subjects were in good and normal health with the exception of one person during the hot season. He had migraine, which is a periodic sickness. This subject during the time of the questionnaires was in a good condition.

Summary of personal information of the respondents is presented in Table (6.4).

Table 6.4 Statistical summary of personal information

		Y.H 296	C.H 237	T.H 276	C.C 216	T.C 162	All.H 809	All.C 378	*All 1187*
Age (Year)	10 - 19	30	35	53	52	30	118	82	***200***
	20 - 29	76	38	71	37	45	185	82	***267***
	30 - 39	47	54	48	35	30	149	65	***214***
	40 - 49	91	58	60	43	29	209	72	***281***
	50 - 59	28	42	18	20	13	88	33	***121***
	60 -69	23	10	22	25	10	55	35	***90***
	70 - 79	1	0	4	4	5	5	9	***14***
Gender	Male	180	109	136	117	86	425	203	***628***
	Female	116	128	140	99	76	384	175	***559***
Height (cm)	130 - 139	0	0	2	7	5	2	12	***14***
	140 - 149	13	0	22	23	18	35	41	***76***
	150 - 159	38	39	21	26	33	98	59	***157***
	160 - 169	110	101	116	79	53	327	132	***459***
	170 - 179	106	97	106	69	42	309	111	***420***
	180 - 189	29	0	9	12	11	38	23	***61***
Weight (kg)	30 - 39	2	8	16	3	2	26	5	***31***
	40 - 49	20	17	12	14	15	49	29	***78***
	50 -59	69	54	56	53	35	179	88	***267***
	60 - 69	91	112	102	81	66	305	147	***452***
	70 - 79	62	36	59	45	29	157	74	***231***
	80 - 89	25	10	28	17	13	63	30	***93***
	90 - 99	27	0	3	3	2	30	5	***35***
Health	Good	262	185	256	206	149	703	355	***1058***
	Normal	34	52	19	10	13	105	23	***128***
	Poor	0	0	1	0	0	1	0	***1***

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons

CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
All.H: All subjects – Hot season
All.C: All subjects- Cool season

6.5.2 Distribution of physical data

The summaries of the climatic data in their means, ranges and standard deviation are tabulated in Table (6.5) for the hot and cool seasons.

In this study air temperatures were measured in all spaces but globe temperatures often were only collected at indoor conditions during hot season. The correlation coefficient of the globe temperature with air temperature was very high and positive [r (T_a, T_g) = 0.98] while the mean value of air temperature was 30.4°C, nearly the same as globe temperature (30.5°C). Standard deviation of air temperature and globe temperature were the same. Figure (6.2) shows the scatter diagram between them.

This study uses just air temperature as a main comfort index. Oseland [1992] noted a research by Humphreys [1976] showing that air temperature did not significantly differ from radiant temperature in homes.

Table 6.5 Mean and standard deviation of environmental data

	Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
Mean T_a	31.7	30.4	29.6	20.5	19.3	30.6	20.0	***27.2***
SD	5.35	1.09	1.36	1.20	2.05	2.51	1.73	***5.43***
Min.	25.4	28.0	26.7	17.0	15.4	25.4	15.4	***15.4***
Max.	44.3	32.6	32.7	23.0	22.5	44.4	23.0	***44.4***
Mean P_a	9.54	11.7	12.97	14.86	14.18	11.19	14.56	***12.26***
SD	3.01	2.58	3.72	2.11	2.62	3.47	2.37	***5.53***
Min.	3.59	5.92	6.45	9.63	9.63	3.59	9.63	***5.59***
Max.	14.93	17.86	21.82	19.00	17.87	21.85	19.00	***21.82***
Mean $\sqrt{V}$	0.45	0.33	0.32	0.17	0.16	0.37	0.17	***0.30***
SD	0.11	0.06	0.06	0.06	0.06	0.10	0.06	***0.13***
Min.	0.28	0.17	0.20	0	0	0.17	0	***0***
Max.	0.73	0.45	0.45	0.32	0.30	0.73	0.31	***0.73***

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons
CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
All.H: All subjects – Hot season
All.C: All subjects- Cool season

Indoor air temperatures ranged from a low of 15.5°C in traditional housing during the cool season to a high of 32.7°C in traditional housing during the hot season. The low and high temperatures during the hot season for courtyards in traditional housing were 25.4°C and 44.3°C respectively.

Temperatures averaging around 30°C for all spaces with 10°C difference between hot and cool seasons (around 20°C in cool season) makes a good opportunity for significant results in the present study.

Mean square roots of air velocity in both traditional and contemporary housing were same as 0.3 $(m/s)^{0.5}$ in hot season while courtyard has an average of 0.5 $(m/s)^{0.5}$. Clearly air velocities of indoor and outdoor are generally different. This amount was 0.2 $(m/s)^{0.5}$ for indoor condition during cool season. There is no difference between traditional housing and contemporary housing.

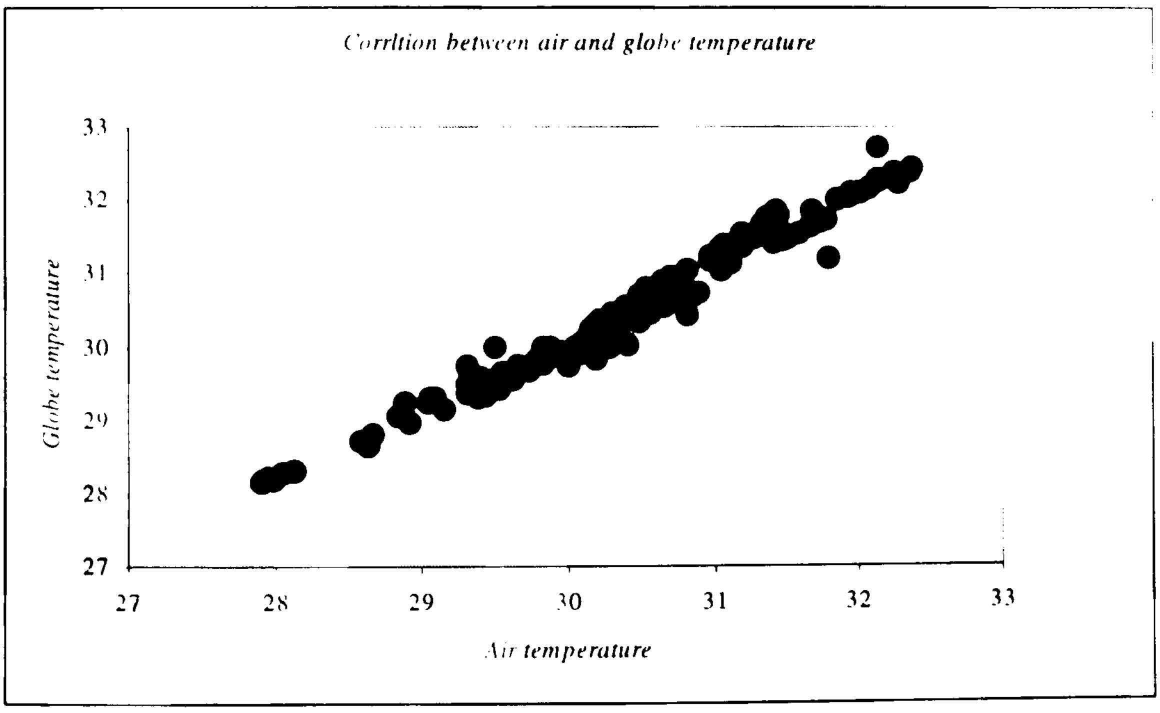


Figure 6.2 Scatter diagram of air temperature and globe temperature (indoor condition)

Vapour pressure (P_a) data was derived from the Rh measurements. The mean vapour pressure was 11.2 (millibar) during hot season and 14.6 (millibar) during cool season. There is not any difference between traditional housing and contemporary housing in the both seasons. Vapour pressures in the cool season had mean value higher than the hot season.

6.5.3 Distribution of individual parameters

Clothing value as physical data has a great effect on thermal comfort. It is individual and has a difference from one person to another. Table (6.6) presented summary of clothing information during two experimental works.

Table 6.6 Mean and standard divination of clothing value

	Y.H	C.H	T.H	C.C	T.C	All.H	All.C	All
Mean clo.	0.66	0.54	0.57	1.39	1.61	0.60	1.49	*0.88*
SD	0.24	0.15	0.16	0.30	0.35	0.19	0.34	*0.48*
Min.	0.37	0.37	0.37	0.90	0.90	0.37	0.90	*0.37*
Max.	1.92	0.84	1.13	2.00	2.19	1.92	2.19	*2.19*

Mean clothing value of courtyard was 0.66 while mean clothing value of indoor was about 0.55. It seemed that the indoor and outdoor conditions had an effect on clothing. There was no difference in clothing value between traditional housing and contemporary housing. On the other hand the amount of clothing in all groups had been increased in the cool season and there was a difference between them in each group. It should be noted that the local winter clothing is more used by people who are living in the traditional part of the city while local summer wear clothing is used by all people in Ilam. Difference between local clothing in summer and winter is an important point especially in adaptation behaviour. In the cool season, the average clothing value was 1.49 clo. This is a high mean clothing level but because of traditional clothing it is reasonable. For example the usual men's clothing wear is SHALWAR and KAMEEZ which has a 0.87 clo value or for women CHADOR is usual dress and it has 0.69 clo value. In the hot season the average of clothing insulation for all group was 0.60 clo which is similar to other works especially with the amount of clothing value in Fanger's work [1970].

As shown in Table (6.7) the metabolic rate varied between all groups with a relatively high standard deviation. Minimum metabolic rate was in traditional housing during hot season and maximum of that in contemporary housing during this season. It should be noted that some medium activity levels in houses like carpet or clothes weaving and baking are usual in Ilam. As a result metabolic rate will be higher than usual metabolic rates in houses. Overall people in Ilam had a similar activity during both seasons. It seems the environmental conditions did not have an influence on the activities.

Table 6.7 Mean and standard deviation of metabolic rate

	Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
Mean met.	1.67	2.04	1.27	1.44	1.61	1.64	1.51	***1.60***
SD	0.41	0.49	0.37	0.50	0.50	0.52	0.51	***0.52***
Min.	0.80	0.80	0.80	0.80	0.80	0.80	0.80	***0.80***
Max.	2.00	2.40	1.90	1.90	1.90	2.40	1.90	***2.40***

6.5.4 Distribution of sensation votes and preference votes

The distribution of sensation votes for both seasons is shown in Figure (6.3) and Tables (6.8), (6.9). The first and important point is that over 90% of subject votes during both seasons in indoor conditions indicated one of three central categories, between slightly cool and slightly warm. It is surprising according to the range of air temperature during both seasons that this is enough for the range of comfortable condition. It is also shown that people can be comfortable in many environmental conditions. However the distribution of votes is different for both seasons and as well for places. About 77% of subjects in traditional housing were in a neutral condition during hot season, while just 28% of subjects in contemporary housing were in neutral condition. In the other hand this situation was the reverse in cool season. Almost 82% of subjects in contemporary housing selected neutral condition whereas about 64% of traditional housing did so. This amount during the hot season for subjects in courtyards was just 40%. About three-quarters of courtyard subjects voted the central three categories. The peak vote was at neutral. The mean sensation vote in courtyards is higher than in traditional housing while this amount is similar with contemporary housing in the hot season. One reason may be that the mean air temperature in courtyard is higher than indoor of contemporary housing. Also, the mean indoor air temperature in traditional housing is lower than contemporary housing, while on the other hand people who lived in traditional housing had slightly cooler sensation than those in contemporary housing during cool season. Indoor air temperature of traditional housing was cooler than indoor of contemporary housing (about 1.2 K).

Table 6.8 Mean and standard deviation of sensation votes

	Y.H	**C.H**	**T.H**	**C.C**	**T.C**	**All.H**	**All.C**	***All***
Mean S	0.82	0.71	0.24	0	-0.42	0.59	-0.2	***0.34***
SD	0.98	0.47	0.44	0.46	0.66	0.74	0.59	***0.78***
Min.	-1	-1	0	-2	-2	-1	-2	***-2***
Max.	3	2	2	1	1	3	3	***3***

The mean sensation votes on the ASHRAE scale were 0.59 in hot season (slightly warm). In the cool season this vote was –0.20 or slightly cool.

Responses to the McIntyre scale were 23% preferring “no change”, 76% for cooler and 1% for warmer during the hot season while these amounts in the cool seasons for warmer and cooler was vice versa and “no change” was equal with hot season. From both experimental work 23% preferring ”no change” 52% preferring “cooler” and 25% preferring ”warmer”.

A relatively big contrast existed between the samples in contemporary housing and traditional housing during the hot season. Ninety three percent of the subjects of contemporary housing votes fell into the cooler category, whereas the fraction was 65% in traditional samples. “No change” was the stated preference of 34% in the traditional housing, where only 7% chose similarly in the contemporary housing.

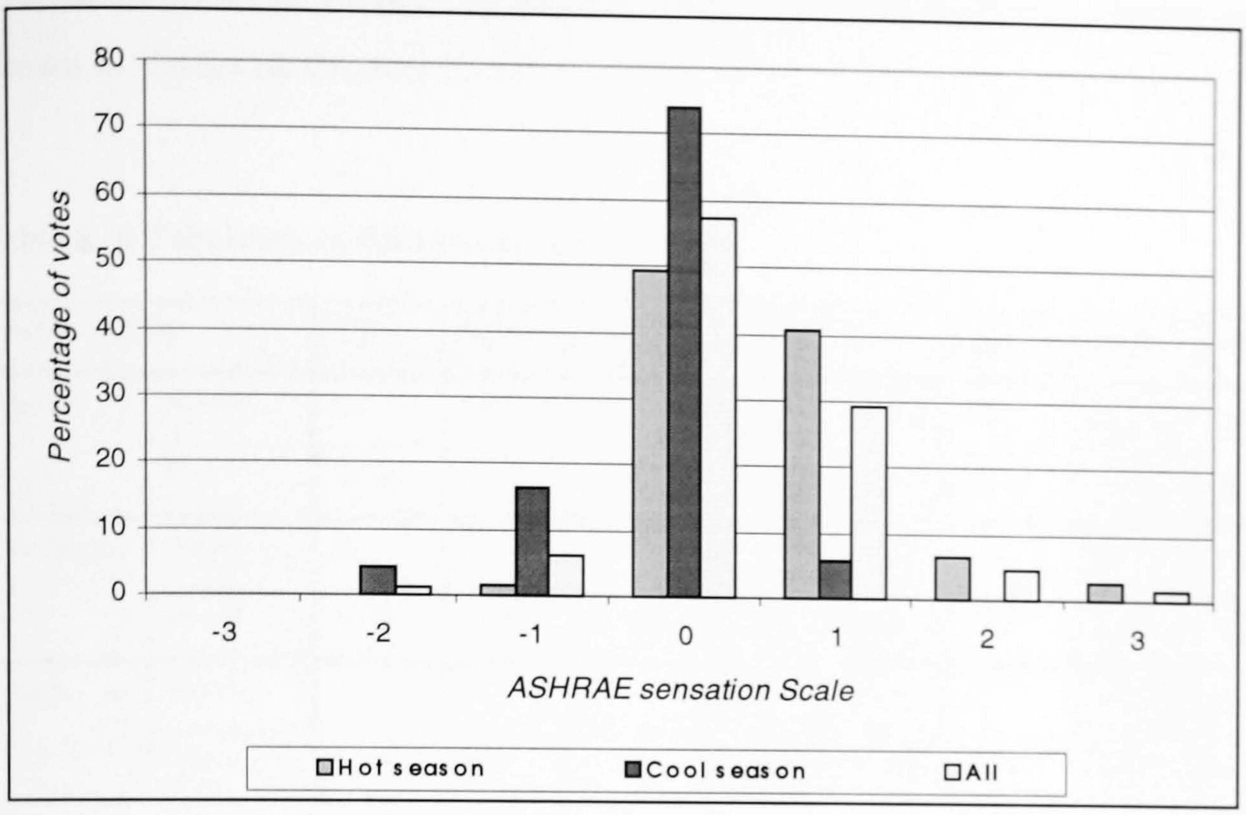


Figure 6.3 Histograms of sensation votes in both seasons

Table 6.9 Tabulation of thermal sensation votes in both seasons and all housing

Sensation scale		Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
Cold	Number	0	0	0	0	0	0	0	*0*
(-3)	Percent	0	0	0	0	0	0	0	*0*
Cool	Number	0	0	0	2	13	0	15	*15*
(-2)	Percent	0	0	0	0.9%	8%	0	4%	*1.3%*
Sli. Cool	Number	11	1	0	18	44	12	62	*74*
(-1)	Percent	3.7%	0.4%	0	8.3%	27.2%	1.5%	16.4%	*6.2%*
Neutral	Number	120	67	212	177	103	399	280	*679*
(0)	Percent	40.5%	28.3%	76.5%	81.9%	63.6%	49.3%	74.1%	*57.2%*
Sli. Warm	Number	95	168	63	19	2	326	21	*347*
(1)	Percent	32.1%	70.9%	23.1%	8.8%	1.2%	40.4%	5.6&	*29.2%*
Warm	Number	50	1	1	0	0	52	0	*52*
(2)	Percent	16.9%	0.4%	0.4%	0	0	6.4%	0	*4.4%*
Hot	Number	20	0	0	0	0	20	0	*20*
(3)	Percent	6.8%	0	0	0	0	2.5%	0	*1.7%*

The distributions of thermal preference votes in the hot and cool seasons are shown in Tables (6.10), (6.11).

Table 6.10 Tabulation of thermal preference votes

Preference scale		Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
Cooler	Number	211	221	180	5	1	612	6	***617***
(-1)	Percent	71.3%	93.2%	65.0%	2.0%	0.5%	75.5%	1.5%	***52.0%***
No change	Number	81	16	93	84	16	190	100	***273***
(0)	Percent	27.4%	6.8%	34.0%	39.0%	10.0%	23.5%	26.5%	***23.0%***
Warmer	Number	4	0	3	127	145	7	272	***297***
(1)	Percent	1.4%	0%	1.0%	59.0%	89.5%	1.0%	72%	***25.0%***

Table 6.11 Mean and standard deviation of preference votes

	Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
Mean P_3	-0.70	-0.93	-0.64	0.54	0.89	-0.75	0.70	***-0.28***
SD	0.49	0.25	0.51	0.56	0.33	0.46	0.49	***0.82***
Min.	-1	-1	-1	-1	-1	-1	-1	***-1***
Max.	1	0	1	1	1	1	1	***1***

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons
CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
All.H: All subjects – Hot season
All.C: All subjects- Cool season

The main point from this part is that over 90% of subject votes were within the central three categories on ASHRAE scale while the range of indoor air temperature during two experimental works was 15.4 – 32.7°C. There were no responses on either extreme sides in sensation votes.

6.5.5 Distribution of humidity votes and air movement votes

Subjects indicated their feeling in terms of air movement and humidity on a three-category scale. This study used the three-point scale. More than three categories becomes difficult to recognise.

Humidity patterns are shown in Figure (6.4). More than 80% of people indicated their vote on the middle of categories, which is just right in hot season. In cool season subject votes were about 77% on humid point. They were because of difference amount of humidity between two seasons. Table (6.12) shows more information about humidity votes.

From Table (6.13) and Figure (6.5) it seems most people were in "just right" condition in terms of airflow during hot season, which is about 70%. The subjective assessment of the air movement by subjects was still (about 73%) during cool season.

Table 6.12 Tabulation of humidity votes

Scale		**Y.H**	**C.H**	**T.H**	**C.C**	**T.C**	**All.H**	**All.C**	***All***
Dry	Number	63	0	1	1	0	64	1	***65***
(-1)	Percent	21.3%	0	0.4%	0.5%	0	8%	0.3%	***5.5%***
Just right	Number	198	232	221	64	21	651	85	***736***
(0)	Percent	66.9%	97.2%	80.2%	29.6%	13%	80.4%	22.5%	***62%***
Humid	Number	35	5	54	151	141	94	292	***386***
(1)	Percent	11.8%	2.1%	19.5%	69.9%	87%	11.6%	77.2%	***32.5%***
Mean		-0.09	0.02	0.19	0.69	0.87	0.08	0.80	***0.27***

Table 6.13 Tabulation of air movement votes

Scale		**Y.H**	**C.H**	**T.H**	**C.C**	**T.C**	**All.H**	**All.C**	***All***
Still	Number	0	0	9	139	136	9	275	***284***
(-1)	Percent	0	0	3.2%	64.4%	84%	1%	72.8%	***23.9%***
Just right	Number	120	201	240	55	23	561	78	***639***
(0)	Percent	40.6%	84.8%	87%	25.5%	14.2%	69.5%	20.6%	***53.8%***
Breezy	Number	176	36	27	22	3	239	25	***264***
(1)	Percent	59.4%	15.2%	9.8%	10.2%	1.8%	29.5%	6.6%	***22.3%***
Mean		0.59	0.15	0.07	-0.54	-0.82	0.28	-0.66	***-0.02***

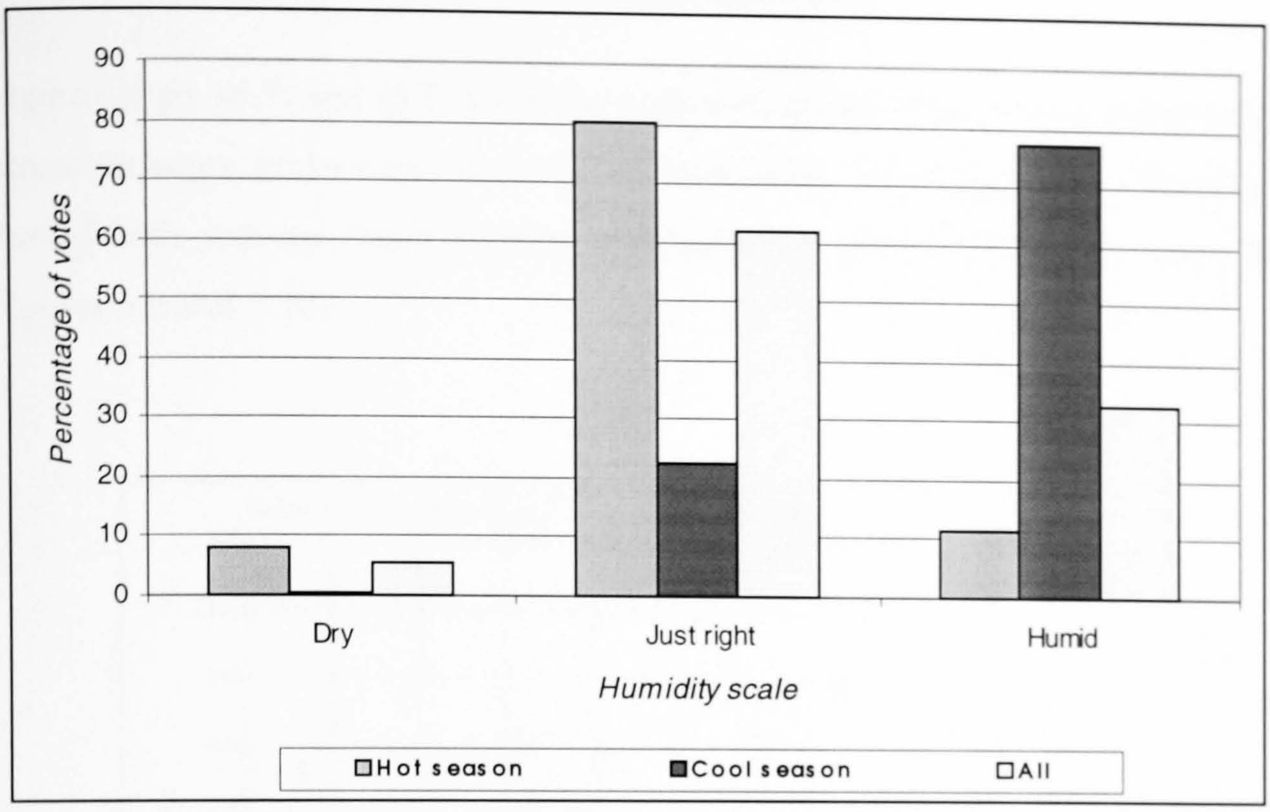


Figure 6.4 Histograms of humidity votes in the both seasons

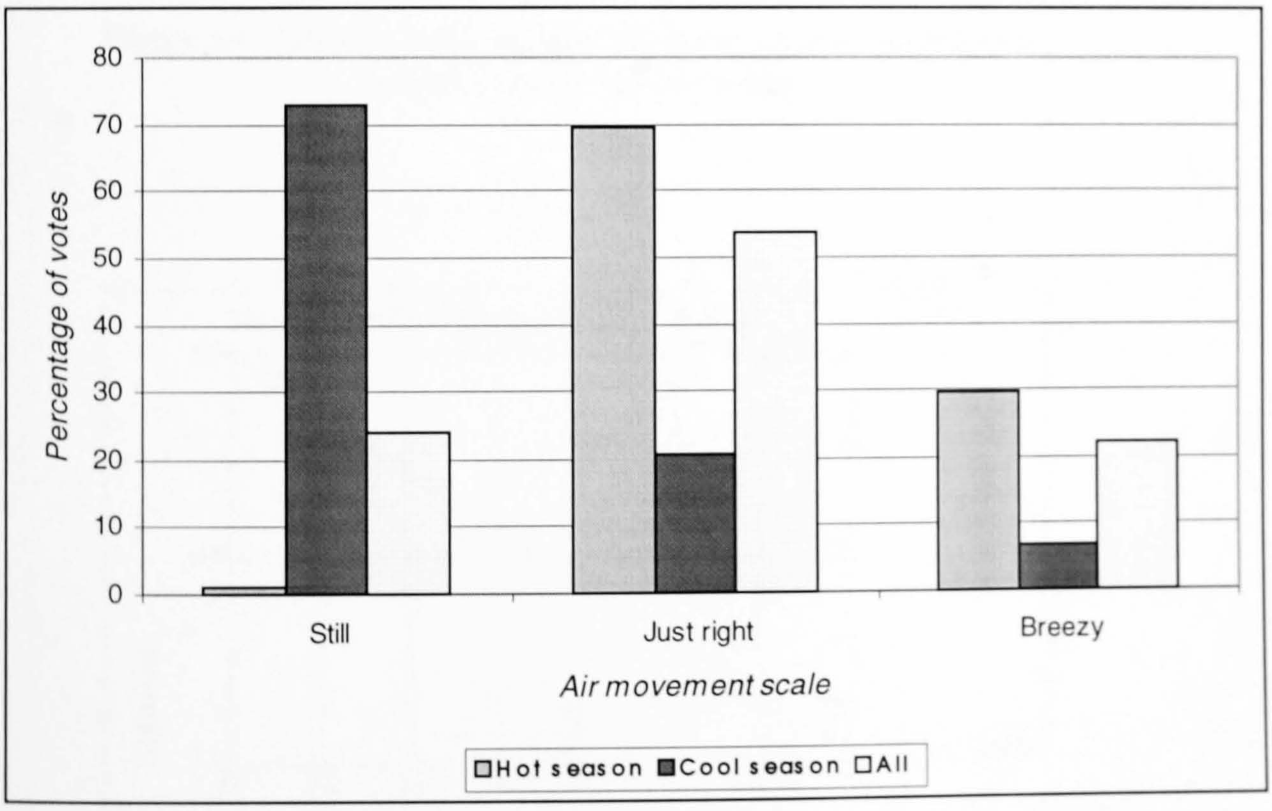


Figure 6.5 Histograms of air movement votes in the both seasons

6.6 Relationship between mean of variables

Figures (6.6), (6.7) and (6.8) show the scatter diagrams of air temperatures with sensation votes, preference votes and clothing value in five groups of responses during both seasons (such Figures are presented with all subjects' votes in Figures 6.9 and 6.10).

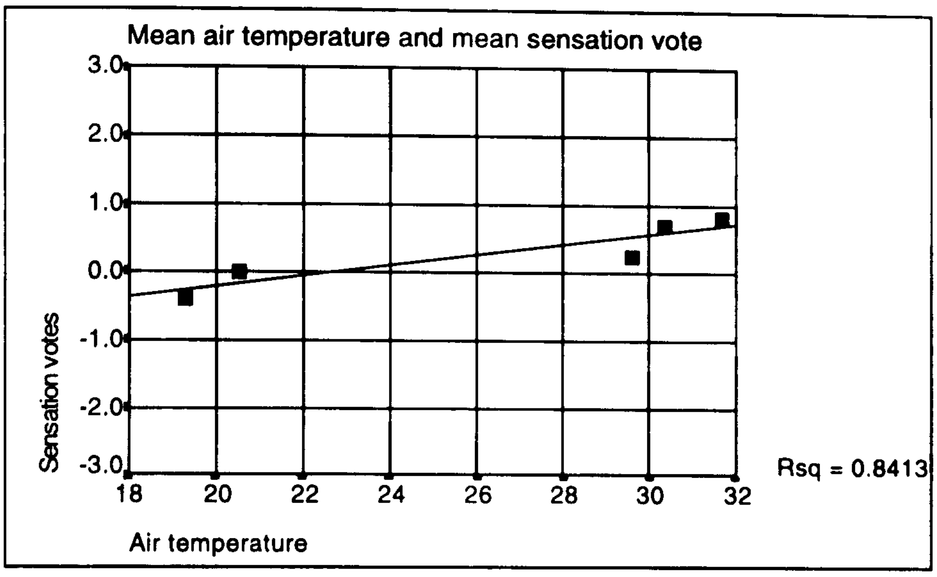


Figure 6.6 Relation between air temperature and sensation votes in both seasons and all groups

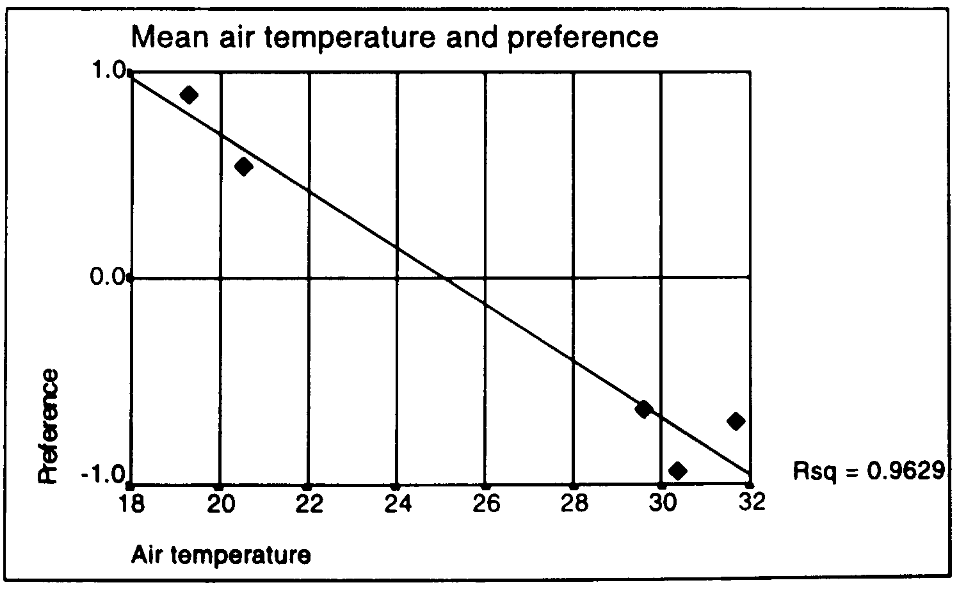


Figure 6.7 Relation between air temperature and preference votes in both seasons and all groups

There is a high and positive relationship between air temperature and sensation votes, the higher the temperatures the warmer the sensation. Furthermore it is interesting that the range of the mean sensation votes are in the comfort range (slightly cool to slightly warm) while the mean air temperature varied from 19°C to 32°C. Such a relationship also exists between air temperatures and preference votes but negative. As shown in Figure (6.7), most of the subjects wanted cooler or warmer conditions.

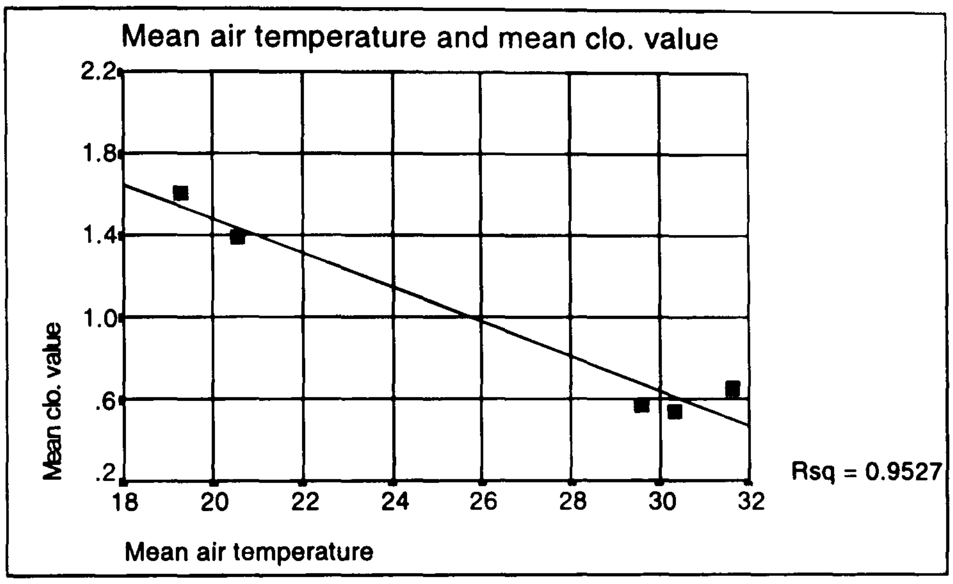


Figure 6.8 Relation between air temperature and clo. value in both seasons and all groups

Figure (6.8) shows the mean value of clothing insulation with mean air temperature. There is a high and negative relationship between these variables. Lower temperatures are related to higher clothing insulation.

6.7 Standard deviation

The standard deviation of environmental variables allows comparison of several sets of data, with respect to their locations and their variability. According to this statements:

1- Air temperatures in the courtyard conditions have a greater variability than the indoor conditions of traditional housing and contemporary housing in hot season. On the other hand the sensation votes of subjects in courtyards is greater than other places. It means people are more sensitive to air temperature. This suggests that adaptation to air temperature change is not complete. It is reasonable in courtyard as a unprivate place.

2- Variability of air temperature in traditional housing was greater than contemporary housing in hot season and cool season

3- Variability of vapour pressure in traditional housing was greater than contemporary housing, while variability of square roots of air velocity in both houses type were similar during hot and cool season.

4- Standard deviation of sensation votes were 0.74 and 0.59 for hot and cool seasons respectively. The standard deviation gives the expression of uniformity between respondents (while in a longitudinal design, it gives the deviation of the consistency of individual respondents) [both from Humphreys; 1976]. Standard deviation in the present study is lower than Nicol's et al [1994] work in Pakistan. Clearly such a difference is because of the different types of field studies (transverse and longitudinal).

5- Standard deviation of clothing value in both seasons was great. It seems people were using different clothing according to their needs.

6.8 Correlation coefficient

Correlation coefficient is a statistical technique used to explore the relationship between two variables. A correlation coefficient of (+1) or (-1) implies that all the points fall on a straight line; when it is equal to zero (0) they are scattered and give no evidence of a linear relationship. Any other value between (-1) and (+1) suggested the degree to which the points tend to be linearly related. The square of the correlation coefficient gives a measure of the proportion of the variation the value of variable which can be explained by the variation of the other [Nicol; 1994]. It is noticeable that the correlation coefficients in the present study signify their statistically significant level beyond 0.05, 0.01 and 0.001.

Based on Nicol's et al work [1994] in Pakistan, correlation have been divided into three groups (Nicol had five groups).

Correlation between the environmental variables (Table 6.14)

The correlation of air temperatures and vapour pressures was very low during the hot season except in contemporary housing. Between these variables the correlation was relatively high in the cool season. It is reasonable because of the relatively highly humid, with warm range of air temperature (between 15.5°C-23°C) during cool season. Some cooking in room or kettle of water on heater does have an effect on such correlation in the cool season.

Table 6.14 Correlation coefficient between environmental variables

	Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
$T_a : P_a$	.07	-0.21	0.06	0.55	0.65	-0.19	0.61	***-0.42***
P=	.213	.001	.306	.000	.000	.000	.000	***.000***
$T_a : \sqrt{V}$	0.07	-0.38	0.23	0.28	0.08	0.17	0.19	***0.70***
P=	.249	.000	.000	.000	0.341	.000	.000	***.000***
$P_a : \sqrt{V}$	-0.11	0.11	0.55	0.02	-0.13	-0.14	0.04	***-0.40***
P=	.062	.088	.000	.804	.094	.000	.457	***.000***

Air velocity does consistently correlate with air temperature except in traditional housing during hot season. It is interesting, when the temperatures are highest, the air movement is higher. The important point is that four correlations out of five are highly significant.

Correlation between sensation votes; preference votes and other variables

Correlation coefficient of the sensation vote with preference vote and the environmental data are presented in Table (6.15).

Table 6.15 Correlation coefficient between sensation votes, preference votes and environmental variables

	Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
S : P_3	-0.60	-0.41	-0.39	-0.40	-0.24	-0.48	-0.39	***-0.61***
P=	.000	.000	.000	.000	.000	.000	.000	***.000***
S :T_a	0.85	0.55	0.67	0.61	0.78	0.80	0.75	***0.72***
P=	.000	.000	.000	.000	.000	.000	.000	***.000***
S : P_a	0.10	0.01	0.19	0.44	0.57	-0.14	0.53	***-0.21***
P=	.103	.825	.002	.000	.000	.000	.000	***.000***
S :$\sqrt{V}$	-0.10	-0.15	-0.31	0.17	0.22	0.13	0.22	***0.42***
P=	0.101	.002	.000	.010	.004	.000	.000	***.000***

The correlation between sensation and preference votes is relatively high as might be expected. The sensations votes also are well correlated with air temperature and in all spaces were significant. However sensation votes also are correlated with vapour pressures during cool seasons. From Table (6.16), it seems that the correlation of preference with air temperature is high, similar to sensation votes. Preference generally shows a slightly lower correlation with air temperature than does sensation [Nicol; 1994].

Table 6.16 Correlation coefficient between environmental variables and preference votes

	Y.H	C.H	T.H	C.C	T.C	All.H	All.C	*All*
P_3: T_a	-0.55	-0.40	-0.68	-0.63	-0.39	-0.47	-0.53	***-0.86***
P=	.000	.000	.000	.000	.000	.000	.000	***.000***
P_3 : P_a	0.22	-.07	0.8	-0.32	0.06	0.02	0.21	***0.35***
P=	.000	.266	.002	.000	.459	.646	.000	***.000***
P_3 : $\sqrt{V}$	0.08	0.16	0.12	-0.14	-0.15	0.06	-0.17	***-0.59***
P=	.159	.012	.051	.042	.058	.081	.001	***.000***

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons

CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
All.H: All subjects – Hot season
All.C: All subjects- Cool season

The correlation coefficient between clothing insulation and air temperature is interesting. The higher negative correlation between air temperature and clo-value during the cool season shows a very good relationship between these two variables. The warmer it is the less people wear. It is an indication that the subjects were using clothing as a way of adjusting to the thermal environment in cool season. This relationship has been found in other surveys such as Nicol et al [1994].

The correlation coefficient between clothing and indoor air temperature were r = -0.23 for contemporary housing and r = -0.19 for traditional housing during hot season. The reason for the low correlation is that the clothing worn was a minimum as much as possible. In the case of the courtyard correlation is positive. In fact subjects in private indoors are freer to use any thermal comfort adaptive behaviours, but because of cultural and religions attitudes the courtyard, as an open space, would not allow the same adaptive freedom, such as freedom of suitable clothing according to environment condition. Correlation coefficient between clothing insulation and air temperature is strong and highly significant during cool season (-0.62).

The correlation of air temperature with metabolic rate during the two experimental studies was not significant except in the traditional housing during hot season, which is the same as other studies in thermal comfort (Table 6.17).

Table 6.17. Correlation coefficient between air temperature and individual parameters

	Y.H	**C.H**	**T.H**	**C.C**	**T.C**	**All.H**	**All.C**	***All***
met: T_a	-0.03	0.11	-0.14	0.08	0.02	-0.07	-0.08	***0.12***
P=	.600	.083	.019	.263	.853	.050	.116	***.000***
clo: T_a	0.34	-0.23	-0.19	-0.40	-0.70	0.24	-0.62	***-0.79***
P=	.000	.000	.002	.000	.000	.000	.000	***.000***

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons
CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
All.H: All subjects – Hot season
All.C: All subjects- Cool season

The main points from this part are:

1- The correlation between sensation votes and preference votes was relatively high.

2- The sensation votes had a good and high significant correlation with air temperature, the preference vote also had a good and negative correlation with air temperature

3- The correlation between clothing insulation and air temperature during cool season is high and negative. Surprisingly, high correlation between both air temperature and clothing value and as well between air temperature and sensation votes rarely occur in field studies.

6.9 Neutral temperature and acceptable condition

6.9.1 Regression analysis

One recognised method to predict the subjective comfort which results from a given temperature, or combination of environmental variables, is regression analysis [Nicol; 1994]. The simple linear regression formulated by simple equation:

$$Y = aX + b \quad (6.2)$$

where (in thermal comfort study):

Y is thermal response

X is air or globe temperature

a is slope

b is regression constant

For most purposes the neutral line (0) crosses the prediction line, a line is projected down to the temperature at which the line cuts the temperature axis. Nicol [1994] noted that the regression analysis can be affected by:

1- The distribution often is not normal while regression analysis assumes normal distribution of the comfort vote

2- Ignored is the effect of clothing changing or other kinds of adaptation

3- Data with very small temperature variation is usually unpredictable as it shows a very weak relationship between temperature and comfort votes

However simple linear regression was performed of the ASHRAE scale responses versus air temperature to determine the strength of the relationship between them.

Table (6.18) shows the comfort equations in all groups during two seasons. As shown in Table (6.18) the slope of sensation responses in all groups is around 0.24 /°C [between 0.21/°C and 0.25/°C in traditional housing during hot and cool season respectively]. Nicol [1993] reported that 0.25/°C is the most common regression slope in field surveys, Humphreys [1976] also found a slope of 0.22/°C from a world- wide field studies review. Such slopes are less steep than the slope of 0.33/°C by Fanger [1970] from his climate chamber experiments. According to Humphreys [1976] the lower values of the slope suggest the occurrence of adaptation of respondents to their thermal environments. Wynn [1994] suggested that in different environments the regression slope relating the reported thermal sensation to temperature will vary due to differences in expectations of that environment, thus different neutral temperatures will be produced.

The neutral temperature during the hot season was 28.1°C and during the cool season was 20.8°C. They are comparable with neutral temperatures from other field studies in tropical regions. Notably those of Webb [1959] with 27.2°C in Singapore; Nicol [1974] with 32.5°C in Iraq (the mean outdoor temperature was about 6°C higher than outdoor temperature of present study); Nicol [1972] with

31.1°C in India; Nicol at al [1994] with 26.7°C – 29.9°C in summer and 19.8°C – 25.2°C in winter from Pakistani subjects in five different cities and Mallick [1996] with approximately 28°C in Bangladesh.

Table 6.18 Data from simple regression for all groups

Groups	Slope	Intercept	R^2	T_n (°C)	Equations
Y.H	0.24	-6.62	0.71	***28.2***	= 0.24 T_a - 6.62
C.H	0.24	-6.52	0.30	***27.4***	= 0.23 T_a - 6.62
T.H	0.21	-6.05	0.44	***28.5***	= 0.21 T_a - 6.05
C.C	0.23	-4.80	0.38	***20.6***	= 0.23 T_a - 4.80
T.C	0.25	-5.24	0.61	***21.0***	= 0.25 T_a - 5.24
All.H	0.24	-6.63	0.64	***28.1***	= 0.24 T_a - 6.63
All.C	0.25	-5.29	0.57	***20.8***	= 0.25 T_a - 5.29

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons
CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
All.H: All subjects – Hot season
All.C: All subjects- Cool season

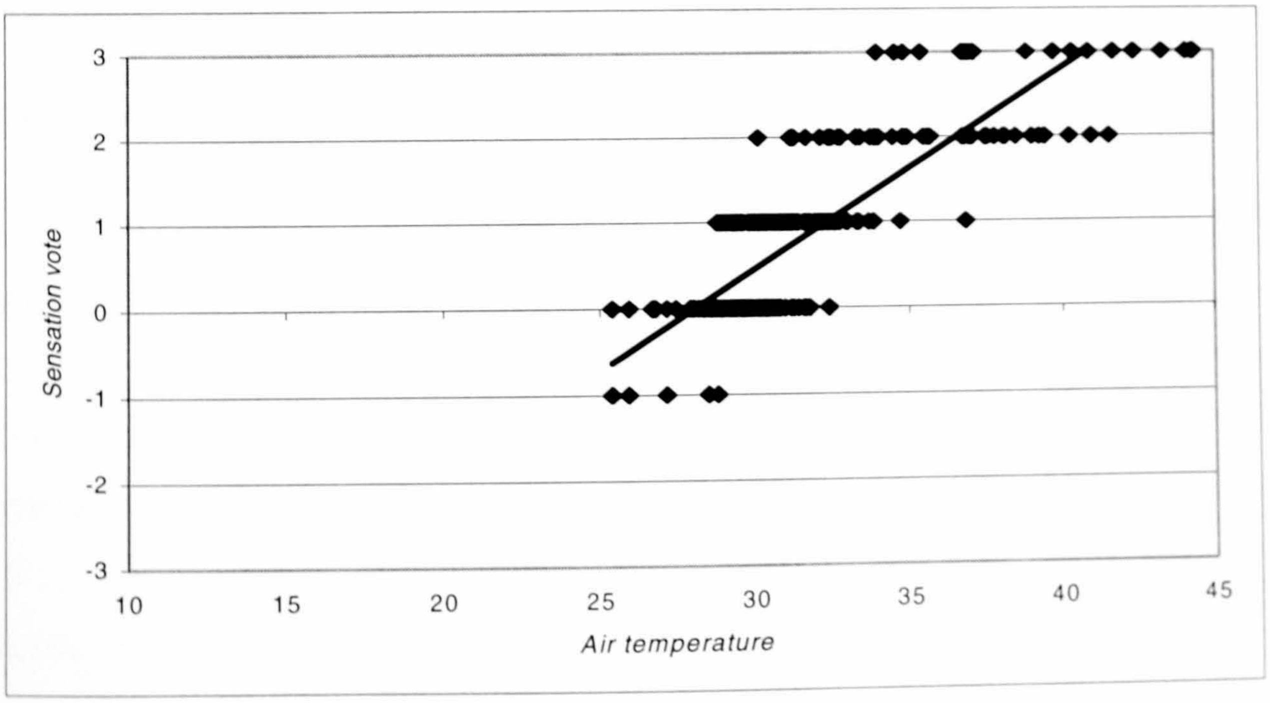


Figure 6.9 Scatter diagram of sensation votes with air temperature (hot season)

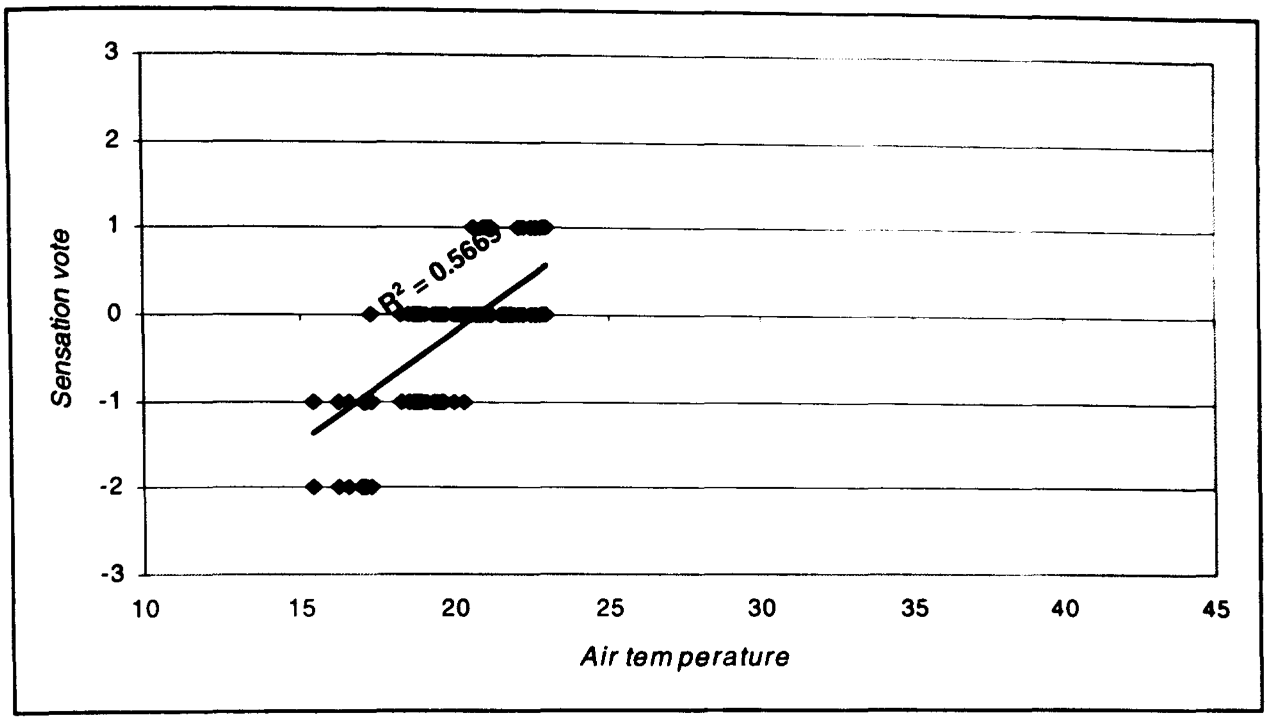


Figure 6.10 Scatter diagram of sensation votes with air temperature (cool season)

The scatter diagrams and the regression lines of thermal sensation of all subjects during both seasons are presented in Figure (6.9) and Figure (6.10). High correlation coefficient between air temperature and sensation votes indicated a well fitting regression line between them.

6.9.2 Acceptable conditions

As an accepted method for predict boundaries of comfort conditions and according to ISO 7730- 1994, the range of PMV (predict mean votes) between [-1 to +1] (of sensation votes on ASHRAE seven point scale) would result in 75% of subjects feeling satisfaction with their thermal environment. For satisfaction of 90% of subjects the range of PMV would be between [-0.5 to +0.5]. In line with this acceptable method and shown in Figures (6.9) and (6.10), the neutral temperature and boundaries of acceptable conditions in both seasons are presented in Table (6.19).

Table 6.19 Neutral temperature and comfort zone during both seasons

	Neutral temperature	R^2	Acceptable condition (75%)	Acceptable condition (90%)
Hot season	28.1°C	0.64	23.8 - 32.3°C	25.9 - 30.2°C
Cool season	20.8°C	0.57	16.8- 24.7°C	18.8 - 22.7°C

The results of this study show that in the range of air temperature of 23.0– 30.0 °C around 70% of subjects were in a neutral condition (sensation vote = 0) and all subjects were in comfortable condition [-1 to +1] during hot season. Ninety-six percents of subjects at the range of 17– 24°C also were in a comfortable condition during cool season. These results show that the proportion of subjects feeling comfortable within the range of [-1 to +1] are higher than those predicted by the PMV model in ISO – 7730 (1994). ASHRAE standard 55 defines an acceptable thermal environment as one that satisfies at least 80% of the occupants. In this study 80% of subjects were comfortable during hot season, when the upper limit of the comfort zone was 31.8°C. On the other hand thermal preference was for "no change" on the three-point McIntyre scale, thereby assuming satisfaction without any desire to "cooler" or "warmer". In this study a low proportion of the total sample had conditions within the satisfaction range and it is below the standard's 80% satisfaction criterion. Many researchers [McIntyre; 1980, Oseland; 1993, Nicol et al; 1994] believed that the centre of the ASHRAE scale and preference scale do not coincide, the peak preference for "no change" does not occur when the sensation vote is neutral (S=0).

6.9.3 Relationship between sensation votes and preference votes

Cross- tabulation of thermal sensation and thermal preference scales by seasons are shown in Tables (6.20) and (6.21). Twenty seven percent of subjects in the cool season indicated "no change" while 96% voted within the central three categories on ASHRAE scale. This is to be expected since the survey was conducted in the cool season and this tendency has been reported elsewhere e.g. Brager et al [1994]. Similarly, 23% of respondents in the hot season indicated "no change" while 91% voted within the central three categories. However such amounts for preference votes are a rather high figure compared with 96% and 91% comfort level indicated on the sensation scale. Clearly only one - quarter of all subjects wanted "no change", so the preferred temperature during the hot season is lower than neutral temperature and during cool season is higher. Kwok [1998] noted that standards based on the goal of neutrality may be inappropriate. Because many people in the tropics want to feel much cooler than neutral. The present study agrees with this idea. Furthermore and for a clear picture it seems the proportion of sensation votes against preference votes in specific range of air temperature should be determined. As shown in Tables (6.22) and (6.23), when the range of air temperature is low, the percentages of wanted to be warmer decreased in the cool season, while this is quite different during the hot season. In this study during the hot season 100% of subjects at 28.0°C of air temperature indicated neutral condition. At a lower than this temperature (27.0°C) 97% indicated neutral and just 3% indicated slightly cool. In the upper (29.0°C) 82% of votes were neutral. However preference votes is quite interesting, at 28.0°C, 82% of responses indicated "no change" while just 18% wanted cooler condition. For degree higher, 40% wanted "no change" and for one degree lower about 60% wanted "no change". One degree centigrade change in air temperature created a small difference in the percentage of people who wanted neutral (S=0) but there is a big difference between preference votes. It is because when some subjects indicated slightly cool (or slightly warm) on ASHRAE scale, it also seems a reasonable answer on the McIntyre scale is to be warmer (or cooler). So the proportion of respondents who indicate "no change" can not be used for acceptable condition in this study. Several works have found that preferred temperature is below the comfort temperature in hot conditions and above comfort temperature in the cold [Nicol et al; 1994]. Thus subjects are seeking a quite comfortable condition (neither warm nor cool) while something is optional for them. According to results of the Nicol and Raja study [1996] in a room that is generally cool the subjects show greater preference for being a bit warmer when they are cool, whereas those in a room which is generally warm room prefer to be a bit cool. This result agrees with results of this study.

Table 6.20 Cross tabulation of the sensation vote and preference for all (both seasons)

Sensation vo. scale	% Preference			
	-1	0	1	Total
-3	-	-	-	-
-2	-	-	100%	1.3%
-1	8%	35%	57%	6.2%
0	27%	38%	35%	57.2%
1	60%	33%	7%	29.2%
2	100%	-	-	4.4%
3	100%	-	-	1.7%
TOTAL	52%	23%	25%	

Table 6.21 Cross tabulation of the sensation vote and preference vote for each season

Sensat. votes ↓	% Preference vote							
	-1		0		1		Total	
	Hot	Cool	Hot	Cool	Hot	Cool	Hot	Cool
-3	-	-	-	-	-	-	-	-
-2	-	-	-	-	-	5.5%	-	4%
-1	1.6%	-	96.8%	1%	1.6%	23.5%	1.5%	16.4%
0	33%	36%	45.5%	85%	1.5%	69.5%	49.3%	74.1%
1	99.5%	64%	0.5%	14%	-	1.5%	40.4%	5.6%
2	100%	-	-	-	-	-	6.4%	-
3	100%	-	-	-	-	-	2.5%	-
Total	**75.5%**	**1.6%**	**23.5%**	**26.5%**	**1%**	**72%**		

Table 6.22 Percentage of preference votes in the different range of air temperature (hot season)

	No change	*To be cooler*
27-33°C	25% (49%)	75%
28-33°C	21% (45%)	79%
29-33°C	19% (42%)	81%
30-33°C	11% (22%)	89%
31-33°C	1% (15%)	99%

Numbers in parentheses indicated percentage of neutral vote (S=0) on ASHRAE seven point scale

Table 6.23 Percentage of preference votes in the different range of air temperature (cool season)

	No change		*To be warmer*
18-24°C	30%	(74%)	70%
19-24°C	32%	(73%)	68%
20-24°C	38%	(63%)	62%
21-24°C	50%	(36%)	50%
22-24°C	75%	(16%)	25%

Numbers in parentheses indicated percentage of neutral vote (S=0) on ASHRAE seven point scale

6.10 Effect of humidity and air movement on thermal sensation

The impact of humidity on human thermal balance and on comfort is complex. Humidity does not directly affect the heat balance and the sensory or physiological responses to the thermal environment, expect for the evaporation within the lungs and diffusion through the skin. The role of humidity is in its effect on the environmental potential for evaporation and the way by which the body adapts to changes in the evaporative potential. Very low humidity may cause irritation: the skin becomes too dry and cracks may appear in some membranes. At higher humidity levels its effect on human comfort and physiology is indirect, through its effect on the evaporative capacity of the air [Givoni; 1998].

ISO standard 7730 (ISO 1984) also shows a rather small impact of humidity on thermal comfort.

In this study, three categories of relative humidity were selected. Relative humidity below 20%, between 20% - 40% and between 40%- 60%. In these ranges mean clothing value and mean square root of air velocities was calculated.

As shown in Table (6.24) in each category mean clothing value and mean square root of air velocities is nearly the same, except for the clothing value in the first category (Rh<20%). In addition, six bands of air temperature also were formed. From Table (6.24) and Figure (6.11), when relative humidity is going to high mean sensation votes in each category of air temperature is close to neutral condition. This means that humidity has an effect on sensation votes at different temperatures, particularly in the range of 30.0- 40.0°C of air temperature. It also seems that at higher air temperatures the effect of humidity on sensation votes is greater.

On the other hand the effect of air movement is important. First, an acceptable air movement may be different in residential buildings and in office building. In naturally ventilated residential buildings the air movement limit can be based on its effect on comfort which depends on the temperature [Givoni; 1998].

ASHRAE standard 55 sets an upper limit of around 0.2 m/s (assuming typical turbulence around 40%) for air velocities within the basic comfort zone to reduce the risk of discomfort from drafts. Higher air speeds are acceptable in an extended zone up to 0.8 m/s if the person has individual control of the local air speed and "to increase temperature to 3°C above the comfort zone" [ASHRAE; 1992].

Table 6.24 Sensation votes in the three range of relative humidity at different range of air temperature

RH%	Clo value	√V	**Air temperature**					
			25-27	**28-30**	**31-33**	**34-36**	**37-39**	**40-42**
RH <20%	**0.65**	**0.40**	-	0.26	0.96	2.42	2.23	2.62
20%< RH <40%	**0.56**	**0.34**	-0.20	0.23	0.86	1.75	2.00	2.25
40%< RH <60%	**0.58**	**0.36**	-0.17	0.19	0.69	1.51	1.93	-

Nicol [1972] in his analysis on Webb's data in Iraq and India noted that air movement reduced discomfort from heat at temperatures above 31°C; below this temperature there were few votes indicating heat discomfort. At temperatures exceeding 40°C discomfort from heat was experienced whatever the air velocity. Similarly, and according to Givoni [1998], at temperatures below 33°C, increasing air velocity reduces the heat sensation. At temperatures between 33°C and 37°C, air velocity does not affect significantly the thermal sensation. At temperatures above about 37°C increased air velocity actually increases the thermal sensation of heat.

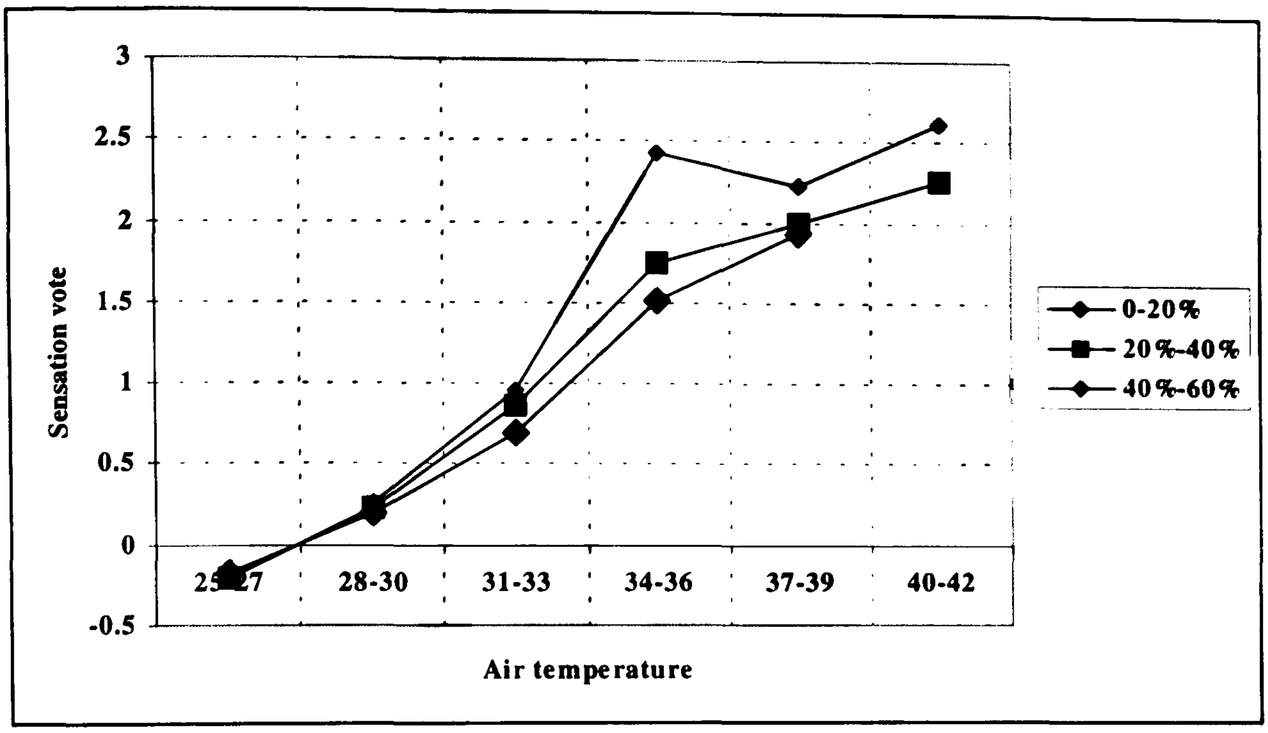


Figure 6.11 Sensation votes in the different categories of relative humidity and air temperature

Table (6.25) and Figure (6.12) show the effect of air movement on sensation votes at different ranges of air temperatures in the present study. These results agree with results of Nicol's [1972] work. Air movement reduced discomfort from heat at temperatures above 31°C, although it seems that in the range of 31.0-33°C the difference between sensation votes in the two categories is little, but it is noticeable that clothing insulation of subjects in low air velocity category (*V(m/s)< 0.25*) was 0.53 clo while in another category it was 0.72 clo. About 0.2 clo difference between clothing value implies more difference between sensation votes. At temperatures below 37°C, increased air velocity has a cooling effect on the thermal sensation and this is in agreement with Givoni's idea. Mallick [1996], in a thermal comfort study in Bangladesh, noted that the comfort temperatures of subjects increase with air movement of 0.3 m/s. There is a rise in the lower and upper limits of comfort range by 2.4°C and 2.2°C respectively.

It is possible that within the range of the comfort zone air velocity does not have an effect on the thermal sensation, but at temperatures beyond the upper limit of the comfort zone air velocity has a cooling effect on the thermal sensation (but for air temperatures less than 40°C).

The difference between mean indoor air velocity during hot and cool seasons is interesting. The mean value of air velocity in the hot season is 0.14 m/s and in winter 0.03 m/s. This is equivalent to a change of at least 1.0°C in neutral temperature. As mentioned, there was a good relationship between temperature and air velocity within the hot and cool seasons.

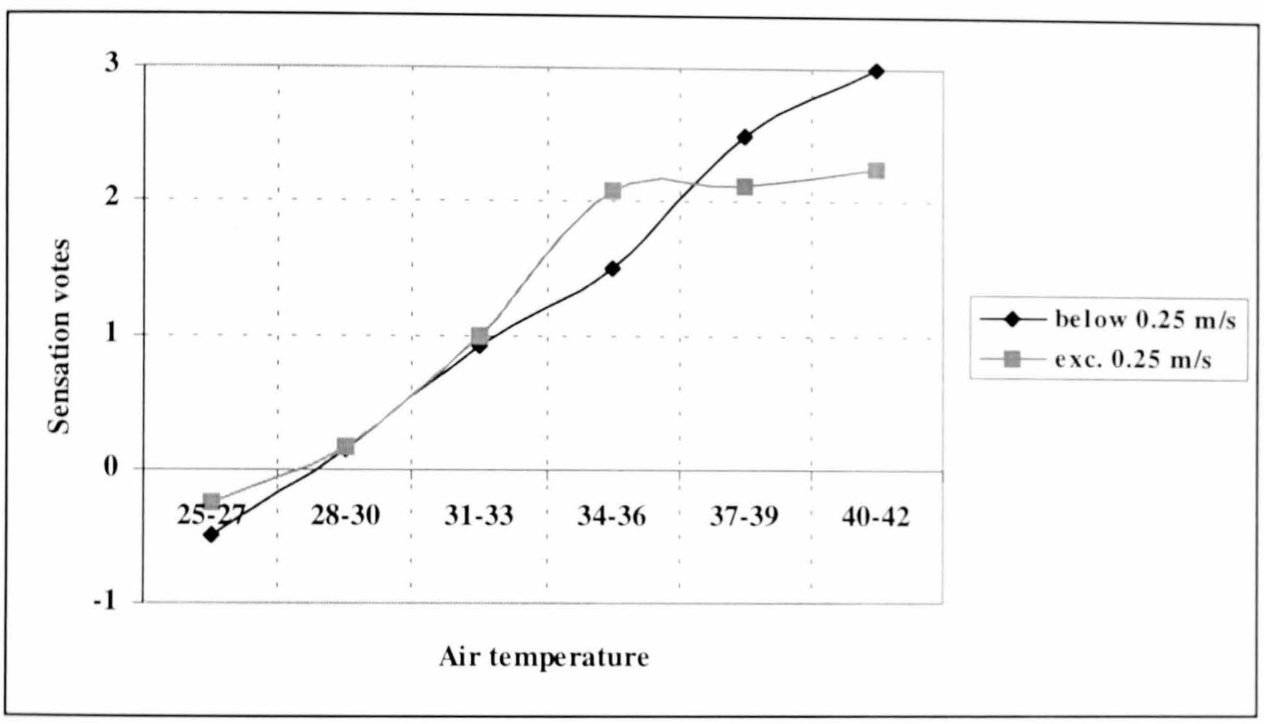


Figure 6.12 Sensation votes in the different categories of air temperature and air movement

Table 6.25 Effect of air velocity on thermal sensation at different temperature and air velocity ranges

Range of air temperature		*25-27*	*28-30*	*31-33*	*34-36*	*37-39*	*40-42*
Mean of Sensation votes	*V(m/s)> 0.25*	-0.5	0.14	0.91	1.5	2.5	3
	V(m/s)< 0.25	-0.25	0.16	1	2.08	2.11	2.25

6.11 Effect of clo value on thermal sensation

The clothing values in the cool season were higher than assumed in existing standards such as ISO [1994], whereas the values in the hot season were a little bit higher. Such differences can have an effect on the neutral temperature as a change of 0.5 clo is offset by 3.5-4.0°C. It has also been found that there were differences in clothing insulation of subjects who were in a courtyard as a open space and those indoors during the hot season. One question is, why do people not reduce their clothing in courtyards, while the mean sensation vote is about 0.82. This is because the courtyard is an open space and women wear socks and a big scarf on their head and all subjects used shoes. In fact subjects are able to reduce clothing levels for better condition but their religion doesn't allow that. However a difference of 0.1 clo in clothing insulation and 1.1°C in mean air temperature caused about 0.5 higher mean sensation votes in courtyard.

The effect of clothing for indoor conditions during the cool season is interesting. Although in private indoors women are free of any problem for choosing their clothing, they still used scarfs all the time. Different clothing in terms of kind and material during different season, are a very good example of adaptation behaviour.

6.12 Outdoor and indoor neutral temperature

Around three hundreds of the subjects in traditional housing during the hot season were in courtyards. All courtyards were central and small in size and often 50cm deeper than ground floor (see Chapter Three).

The mean air temperature of the courtyard was 31.7°C with a range of 25.4°C to 44.3°C, while mean indoor temperature was 29.6°C. Mean sensation votes of subjects in courtyard was 0.82, which is 0.58 more than indoor condition. The mean clothing value for the courtyard was 0.66 while the mean clothing value for indoor was 0.57.

Linear regression of neutrality on temperature produced a neutral temperature of 28.2°C in the courtyard and 28.5°C in indoor conditions. In the first place, it seems this discrepancy is more because of the amount of air movement in the courtyard, which was 0.2 m/s while indoors it was about 0.1 m/s. This air movement difference can be equivalent to a change of 1°C in neutral temperature. Some possible reasons for such a discrepancy can be:

1- Subjects in private indoor conditions are freer to use any thermal comfort adaptive behaviour, but because of cultural and religious attitudes the courtyard, as an open space, would not allow the same adaptive freedom.

2- The effect of comfort expectations is quite important and is rooted in psychological attitudes, which vary from one person to another, and from one place to another.

In the second place the subjects in the courtyard had about 0.1 clo more than those indoors, which implies about 0.7 °C different in neutral temperature. The acceptable condition in the courtyard was between 23.9- 32.4°C while indoors acceptable condition was between 23.8- 33.2°C (both with about 9°C wide range).

6.13 Thermal sensation in traditional and contemporary housing

The mean indoor air temperatures for traditional housing is 29.6°C with a range of 26.7°C to 32.7°C while in contemporary housing it is 30.4°C with a range of 28.0°C to 32.6°C during the hot season. In both types of housing the difference of air temperatures in terms of mean, ranges and standard deviation is little.

On the other hand the mean of thermal sensation is 0.24 in traditional housing and is 0.71 in contemporary, a difference of about 0.5, while the mean of clothing insulation is the same at around 0.55 clo. From linear regression, neutral temperature in traditional housing is 28.5°C and in contemporary housing is 27.4°C. The slope of the regression line in traditional housing is less than in contemporary housing (0.21 and 0.24). It means that the acceptable range in traditional housing is wider than contemporary housing (acceptable comfort range for traditional housing is 23.8-33.2°C and for contemporary housing is 23.2°C-31.6°C). However it seems that the adaptive behaviour in traditional housing is used more than in contemporary housing.

Higher activity levels in contemporary housing than in the traditional housing could be a reason for such discrepancy of the neutral temperature between them.

Similarly in the cool season the mean indoor air temperatures at the time of the questionnaires in the traditional housing and contemporary housing were 19.3°C and 20.5°C with a range of 15.4-22.5°C and 17.0-23.0°C respectively.

The mean of sensation votes is neutral for contemporary housing and is slightly cool in traditional housing. Neutral temperature in both traditional and contemporary housing is around 21.0°C and an acceptable comfort range is between 17.0°C – 25.0°C.

Correlation coefficients between air temperatures and clothing value is –0.62 during cool season, which is high and negative. This coefficient is –0.70 in traditional housing and is –0.40 in contemporary housing.

However, as expected the neutral temperatures and acceptable range of the two types of houses were not different because of the same culture, same life style and same environment. It means that neutral temperature will not vary within the same climate but the difference is because of some adaptation behaviour of subjects.

6.14 Effect of seasons

The experimental results during both seasons could be easily compared. It is because the same area and same housing types were used. The main aim can be to get a clear annual picture of comfort condition.

The environmental data were varying from season to season. The difference between air temperatures ranges in the hot season and cool season is over 10°C. while the indoor temperature range in both seasons was about 7°C. The amount of air movement also was different. Mean indoor air velocities in the hot season are higher than cool season, which were 0.14 m/s and 0.03 m/s respectively. The mean sensation votes were slightly cool in the cool season and were slightly warm in the hot season. There was a bias on the cool side in the cool season and warm side in the warm season. This implies that there is less than full adaptation to the prevailing temperature at the hottest and coldest times of the year [Nicol and Roaf; 1996]. The difference between neutral temperatures in both seasons is about 7.5°C. Much of this change can be accounted for by changes in clothing between the two seasons (a change in clothing insulation of 0.5 clo implies a change of neutral temperature 3.5-4.0°C [Nicol et al; 1994]). A difference of 0.8 clo caused about a 6°C change of neutral temperature. Humphreys [1994] and Nicol et al [1994] concluded that as much as one- half the seasonal changes in comfort temperature could be attributed to clothing flexibility. Remaining difference would be accounted for by the change in mean air velocity. According to Nicol et al [1994] other smaller effects such as changes in posture, activity and the way in which clothes are worn could account for the rest of the change.

6.15 Effect of gender on thermal sensation

Some researchers have believed that many factors, such as gender, age and body build, have an effect on neutral temperature. In this section the effect of gender on neutral temperatures is described.

The results of some studies about the effect of gender on thermal sensation indicated that there was no difference between male and female thermal sensation. Some of them are:

1- Hickish [1955] in the field study of thermal comfort in Southern England found no significant different in neutral temperature in male and female workers in light industry.

2- De Dear [1991] showed no significant difference between male and female in their preferred temperature.

But some researchers have shown a difference:

1- The results of Chung and Tong's [1990] experimental work in climatic chamber conditions showed female subjects preferred a slightly higher air temperature (by 1°C) and were more sensitive to temperature changes than male subjects.

2- Ellis [1953] found a different of 1°C among neutral temperatures for various groups of men and women.

In the present study, the mean air temperature at the time of the questionnaires for males was 30.5°C and for females was 30.6°C which were similar during the hot season. The mean air temperature for females was 0.7°C higher than for males during the cool season (20.0°C and 19.3°C), but in terms of standard deviation both were the same during hot and cool seasons. Overall the two group's temperature were similar.

The mean sensation votes in the hot season for the males was 0.56 while for female was 0.63. The amount in the cool season was about 0.20 for male and female.

Table (6.26) shows more details. Results from this study show that the neutral temperature of female subjects was 28.2°C in the hot season and it was 20.8°C in the cool season. Similarly the neutral temperature of males was 28.1°C and 20.7°C for hot and cool season respectively. There was no difference between them. Clothing insulation can be taken into account. If it is, however, with other things being equal the neutral temperatures for men and women differ by about 0.5 °C. Humphreys [1976] suggested that if differences do exist between neutral temperature for men and women, they are very slight and probably less than 0.5°C. This is shown in this study.

The standard deviation of female clothing shows more variability than male clothing during the hot season. It suggest that women are capable of closer behavioural adaptation to thermal variations, but this is vice versa during the cool season.

Table 6.26 Male and female sensation votes and nutrality

	Seasons		Male	Female
Sensation votes	**Hot season**	Mean	0.56	0.63
		SD	0.71	0.74
	Cool season	Mean	-0.18	-0.19
		SD	0.61	0.56
Clo. value	**Hot season**	Mean	0.52	0.68
		SD	0.16	0.20
	Cool season	Mean	1.45	1.52
		SD	0.36	0.30
Metabolic rates	**Hot season**	Mean	1.61	1.68
		SD	0.51	0.53
	Cool season	Mean	1.5	1.53
		SD	0.52	0.49
Mean air temperature	**Hot season**	Mean	30.5	30.6
		SD	2.68	2.3
	Cool season	Mean	19.3	20.0
		SD	1.78	1.69
Neutral	**Hot season**		28.1	28.2
	Cool season		20.7	20.8
Equation	**Hot season**		$= 0.23T_a - 6.29$	$= 0.25\ T_a - 7.15$
	Cool season		$= 0.26\ T_a - 5.38$	$= 0.25\ T_a - 5.17$

6.16 Conclusion

1- The surveys were done in both traditional and contemporary housing during two seasons (hot and cool) in the city of Ilam with about 1200 sets of data. One quarter of samples came from courtyards which were obtained just in the hot period.

2- Air temperature, relative humidity, air velocity, clothing insulation and metabolic rates were recorded at the time of questionnaires

3- The pattern of sensation votes showed that more than 90 percent of voters indicated one of three central categories on the seven point ASHRAE scale.

4- Mean clothing value was 0.60 during hot season and was 1.49 during cool season. Mean clothing value of courtyard subjects was 0.1 clo. higher than those indoors. This study also showed a high relationship (but negative) between clothing insulation and air temperature during the cool season. As an important point the present study well shows that lower temperatures are related to higher clothing insulation

5- The environmental conditions did not have an influence on the activities

6- The mean sensation votes were 0.59 in the hot season and -0.20 in the cool season. The neutral temperature was 28.1°C with acceptability limits of 24.0°C to 31.8°C (80% satisfied) and a regression slope of 0.24 for hot period and it was 20.8°C with acceptability limits of 17.2°C to 24.2°C (80% satisfied) and a regression slope of 0.25 during cool period

7- The neutral temperature was lower in the contemporary housing as compared to the traditional housing during the hot season. Higher activity levels in the contemporary housing could be a reason for such discrepancy

8- In both seasons there was a little difference in neutral temperature between males subjects and females subjects (about 0.5°C)

9- The seasonal changes in neutral temperature could be attributed to clothing flexibility and change in mean air velocity

10- A difference about 0.5°C between neutral temperature of indoor subjects and courtyard subjects exists.

Chapter Seven

Two further thermal comfort surveys in Ilam

7.1 Introduction

Two other thermal comfort surveys performed in Ilam are presented in this chapter. The first was in July and August 1998 and second one was in July 1999, both during the hot season. The major thermal comfort survey was described in Chapter six. It was possible to perform two smaller studies on specific issues- namely thermal comfort in housing for the poor and adaptive behaviour in a courtyard house. For the researcher it was important to see why results of three point scale of preference votes were unreliable in the previous study (Chapter Six), so one of the reasons for such study was to test a five point preference scale. Is there any difference in terms of results between them?

The chapter is divided into two separate sections. In the first section the results of a thermal comfort field survey in a small part of the city of Ilam are discussed. A total of two hundred low income people in the low cost housing completed questionnaires. Air temperatures, humidity and air velocity were measured. At the same time clothing insulation was estimated. The results of this section will be used to check another study in the previous year (Chapter Six- the results of hot season) and are presented in the next Chapter.

Section two reports on a short-term study of thermal comfort in a traditional house. Obviously traditional housing types have evolved to try and help people to adapt to a state of thermal comfort under adverse conditions. There are several thermal comfort adaptive actions and one is moving to a different thermal environment. This section shows how people adapted themselves thermally to achieve comfort in a typical courtyard house. This special reference to the adaptive model is presented.

7.2 Low income subjects in the Ilam survey

This field study was conducted in a village suburb of Ilam. This part consists of about 75 houses with more than 500 people. Some of the men are quarrymen and others are farmers. Both types of work are hard and heavy especially during summer. Nearly all women are housewives except some who make local handcrafts.

The men's daily programme normally is: At 5.00 a.m. they wake up for prayer and breakfast, then they start their work from 6.00 until 11.00 in the morning time. At 11.00 they come back for lunch and then they leave their houses for afternoon work at 14.00. Finish time of work is about 17.00. They go to bed at 22.00 every summer day. During the day the women are in the home.

Their homes are essentially based on earth, stone and occasionally sun-baked mud bricks. In a popular construction, the walls are made of stone, the roofs of wood beams covered with reeds, bushes, perches (young tree- trunks) and layers of earth. The lines are generally simple and never result from elaborate arrangements or technical feats. The geometry is generally simple, strong and based on the square and the rectangle. They show a remarkable understanding of their environment (Figure 7.1).

In 1991 the Iranian government built 50 houses (Figure 7.2) for these people. After about one year many of them left their new houses and they came back to their old housing [Ghasemi; 1996].

The survey was carried out from 25th July to 5th August 1999, at two times of each day. The first time was between 12.00 and 14.00 and the second time was between 17.30 and 20.00. The total number of subjects was 213 but 191 questionnaries were completed successfully. Sixty one per cent of subjects were male and 39% were female. The subjects' mean age was 35 years.

Methodology and measurement of variables were the same as in previous surveys, which are presented in Chapter six, although there is a small difference. In particular, this study used a five- point scale for preference (much cooler, a bit cooler, no change, a bit warmer, much warmer). Changing the preference scale from three-point in the last survey to five in this survey was because of a weak match between sensation votes and preference votes in the previous work.

Because of the time of questionnaires in each day, subjects were in a nearly rest condition, so the metabolic rate assumed was at about 1 met.

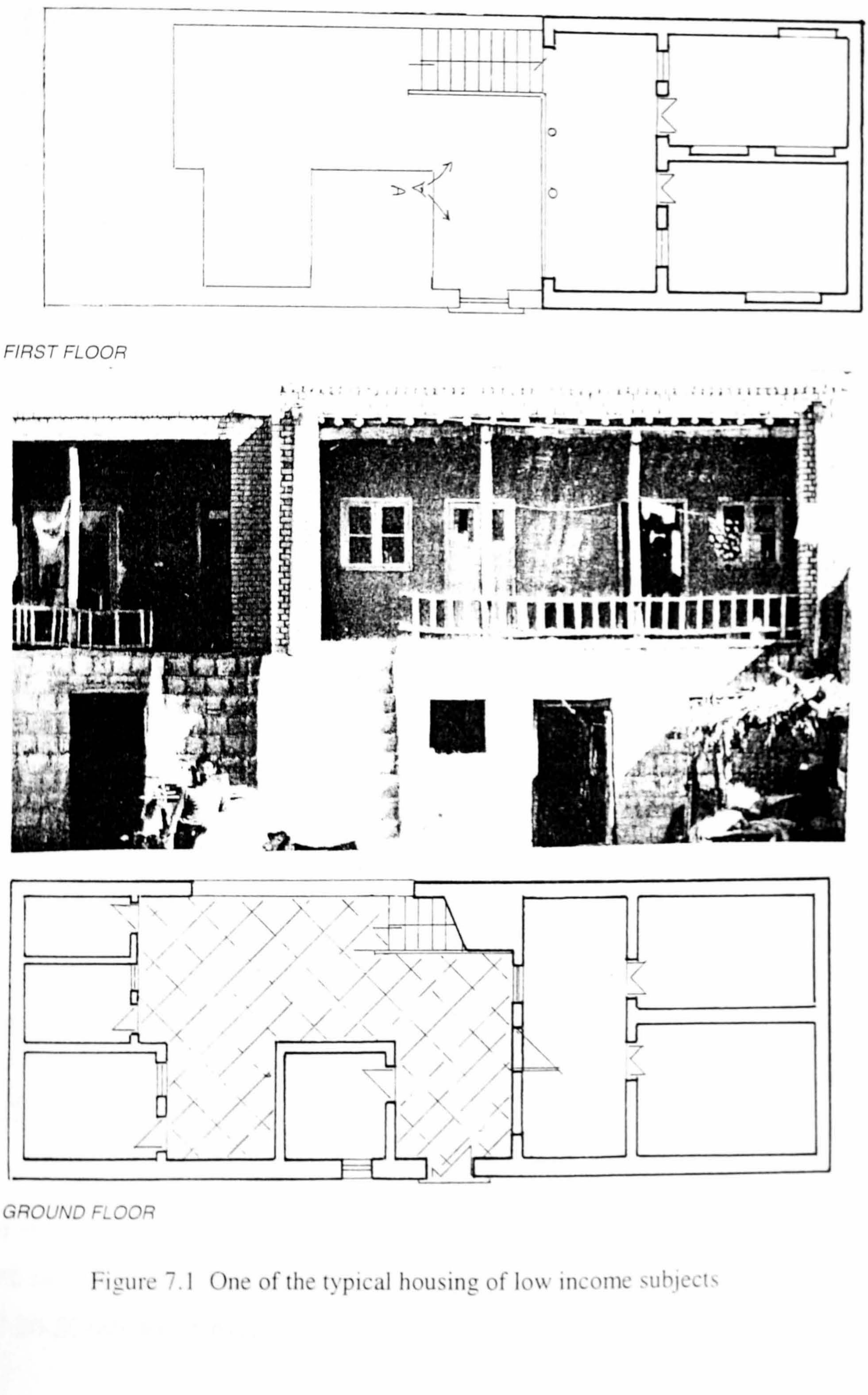


Figure 7.1 One of the typical housing of low income subjects

Figure 7.2 New housing for low income family (Ilam; 1991)

7.2.1 Summary results

Table (7.1) shows the distribution of climatic data at the time of each thermal assessment. The range of air temperature is about 9K with a minimum of 23.2°C and a maximum of 32.4°C. Mean air temperature for the first time of the survey (12.00- 14.00) was 30.2°C while the mean air temperature of the second time (17.30-20.00) was 26.3°C.

Table 7.1 Distribution of climatic data

	T_a (°C)	RH%	Pa (mb)	V (m/s)	$\sqrt{V}$ $(m/s)^{0.5}$
Maximum	32.4	57	18.4	0.25	0.46
Minimum	23.2	20	8.6	0.01	0.1
S.D.	2.36	8.56	2.13	0.05	0.07
Mean	28.2	35	12.5	0.09	0.22

For the survey period the mean of relative humidity was 35% with a range of 20% to 57%. The range of relative humidity in the second period of the survey (17.30-20.00) was between about 30% to 57%, which is within the comfort zone of 30%-70% suggested by ISO 7730 (1994) while the range of relative humidity for the first part of the day was between 20% to 40%.

The mean air velocity during the time of the questionnaires was about 0.1 m/s, with a range of 0.01 to 0.25 m/s.

Against such climatic data, subjects' mean sensation votes was 0.23 or slightly warm. Almost 63% of the votes were cast in the zero category of the ASHRAE scale while more than 92% voted in the central three categories. The rest of them indicated warm condition (+2).

Responses to the preference scale were 32% preferring "no change", 54% wanted "a bit cooler" and 8% of subjects wanted "a bit warmer". About 6% wanted "much cooler" condition. Taking votes of (a bit cooler, no change, a bit warmer) as corresponding to the comfort zone revealed that 94% of the votes cast wanted "no change" which is in keeping with the voting patterns in the comfort scale. The mean preference vote also was (–0.58). Figure (7.3) shows the distribution of sensation votes and preference votes.

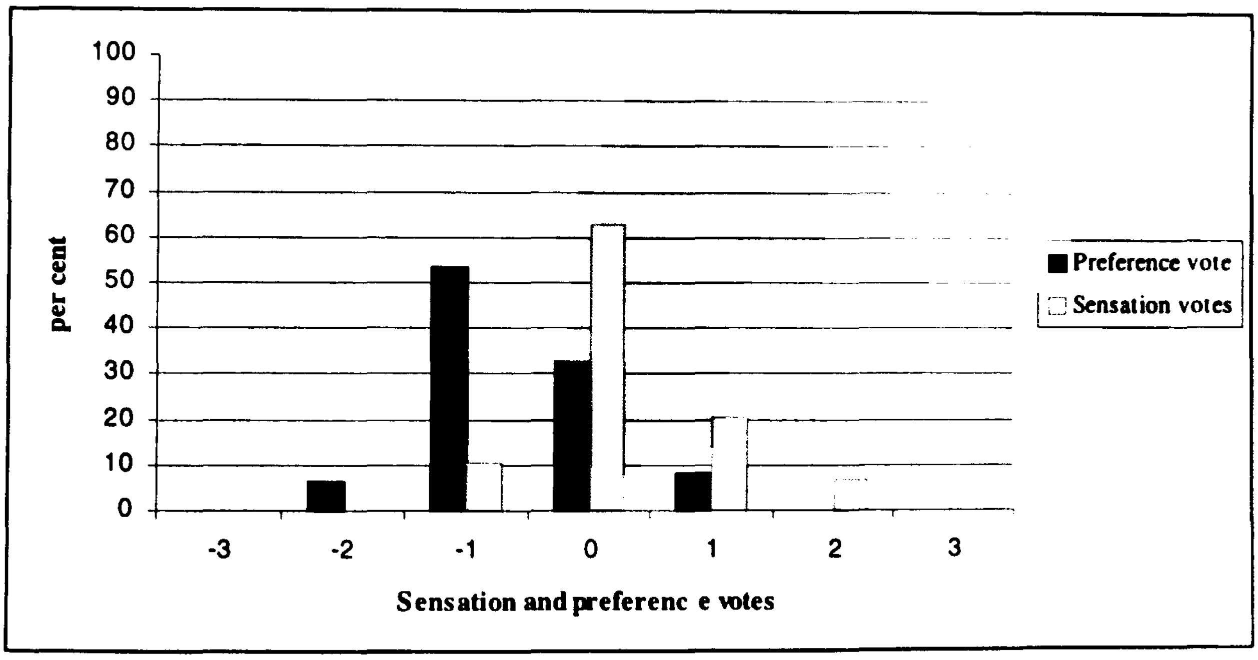


Figure 7.3 Distribution of sensation votes and preference votes

The average clothing value was 0.55. Clothing value for the first time of the survey (12.00-14.00, warmer condition) was 0.51 while for second time (17.30-20.00) it was 0.59, which indicated that the warmer condition the less the clothing insulation. A summary of thermal responses and clothing insulation are presented in Table (7.2).

Table 7.2 Summary of thermal responses and clothing insulation

	Mean	S.D.	Minimum	Maximum
Sensation votes	0.23	0.72	-1	2
Prefer. votes	-0.58	0.73	-2	1
Clothing insulation	0.55	0.1	0.41	0.84

7.2.2 Relationship between the means

Thermal responses were examined in relationship to the air temperatures. For each degree of air temperature, mean sensation votes and mean preference votes were calculated. Figures (7.4 and 7.5) shows the scatter diagrams of them.

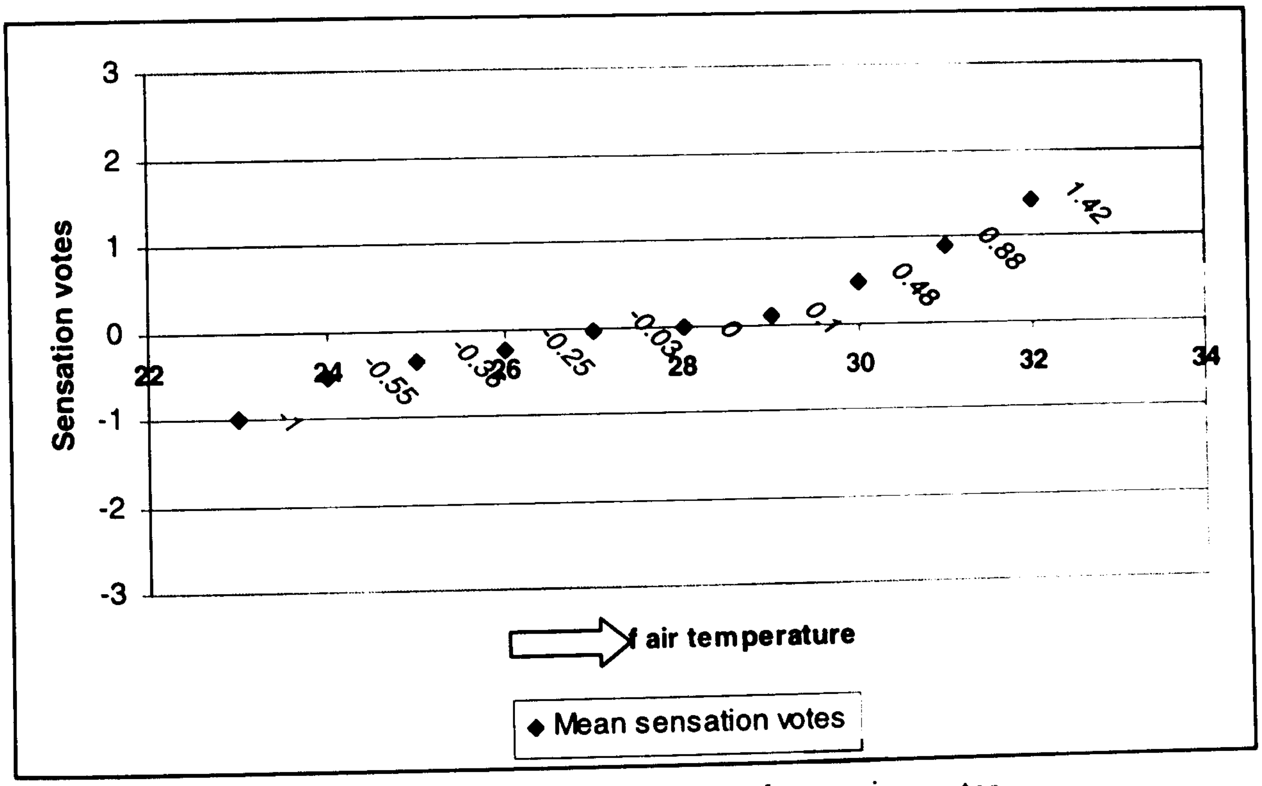


Figure 7.4 Scatter diagram of air temperatures and sensation votes

The symmetrical pattern of preference votes and sensation votes is interesting. The variation of preference votes with air temperature is in the opposite direction. Overall, there is a good relationship between the mean thermal responses and the mean air temperatures.

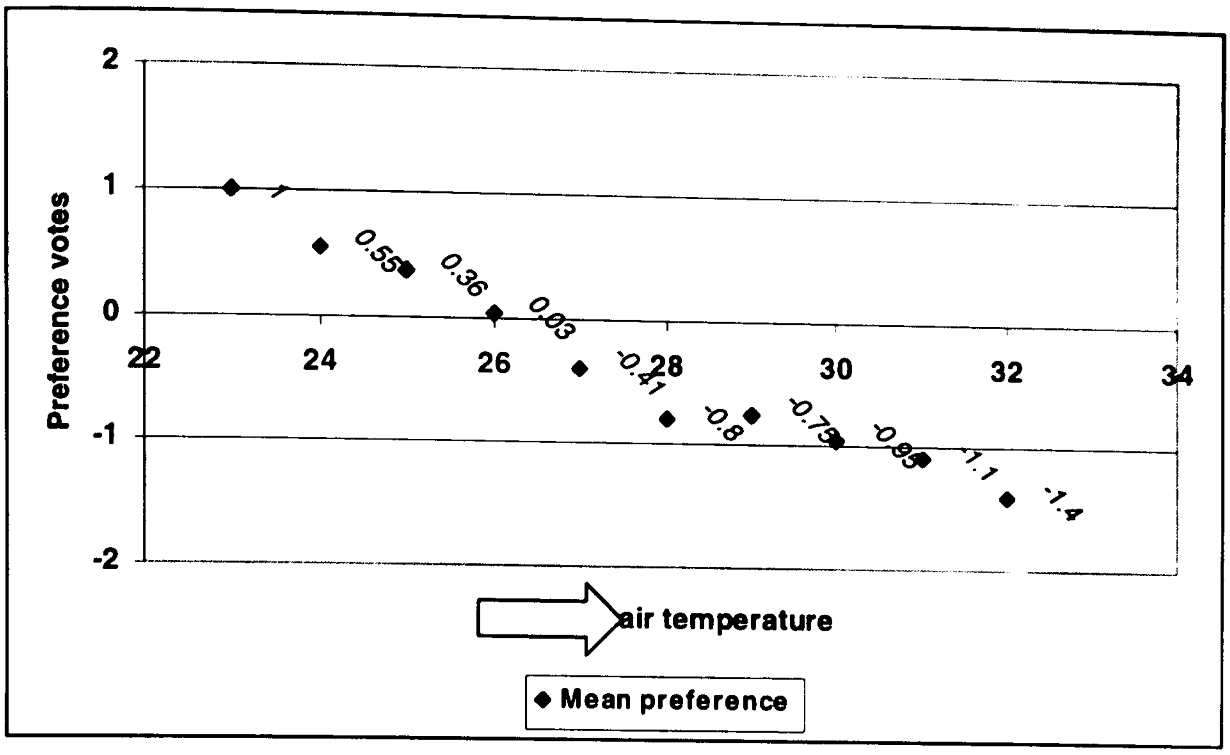


Figure 7.5 Scatter diagram of air temperature and preference votes

Table (7.3) and Figure (7.6) shows the relationship between sensation votes and preference votes. There is a the negative and quite strong relationship.

Table 7.3 Relationship between sensation votes and preference votes

Sensation votes → **Preference votes ↓**	-3	-2	-1	0	1	2	3
-2	-	-	-	**0.5%**	**1.5%**	**4%**	-
-1	-	-	-	**32.5%**	**19%**	**2%**	-
0	-	-	**6%**	**27%**	-	-	-
1	-	-	**5%**	**2.5%**	-	-	-
2	-	-	-	-	-	-	-

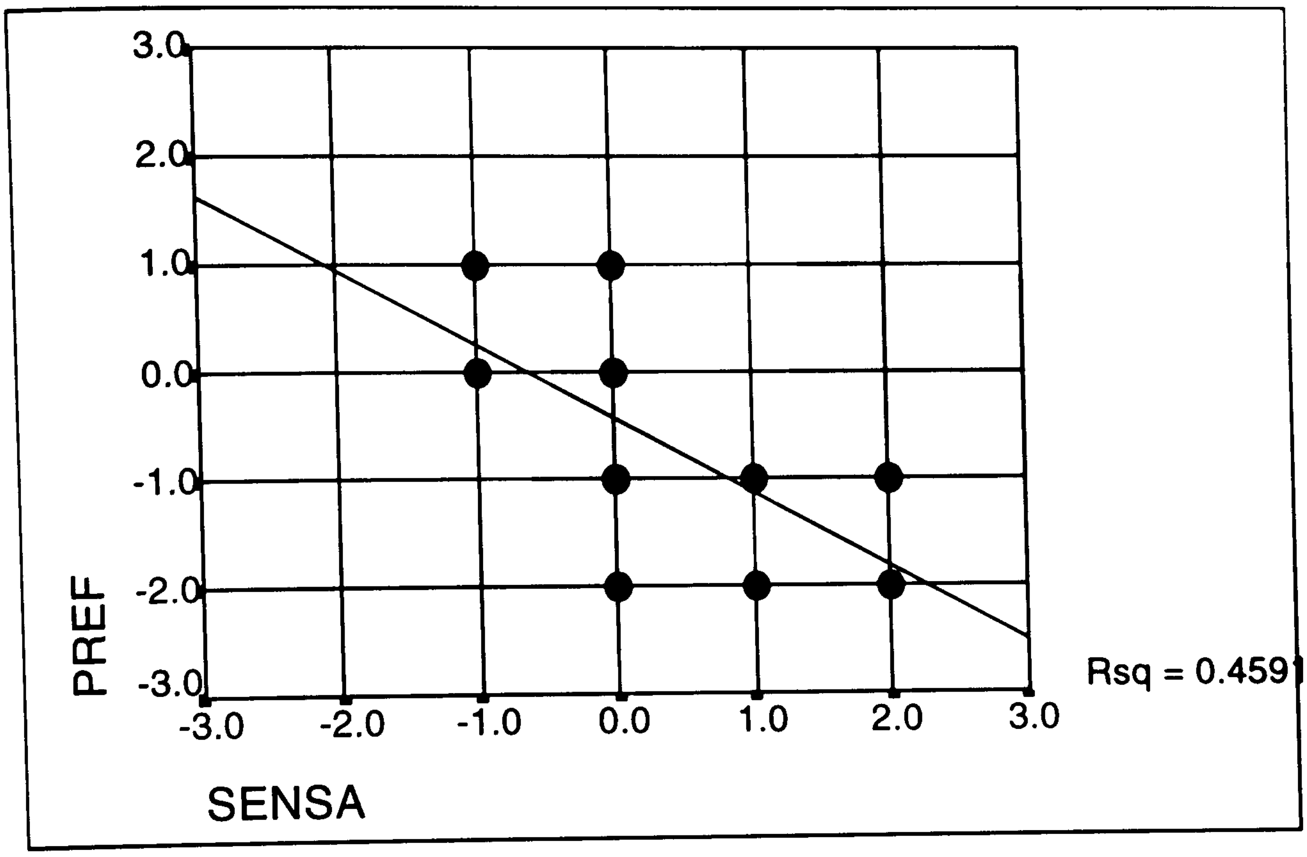


Figure 7.6 Scatter diagram between sensation votes and preference votes

7.2.3 Correlation coefficients

The correlation coefficient between air temperature and air velocity is small and it shows no significant relationship. A similar result is reported elsewhere, such as Nicol et al [1994] in Pakistan. Between air temperature and relative humidity there is a significant but negative correlation, which is (-0.59). This means that when air temperature was increasing the relative humidity is decreasing.

As might be expected there is a rather high correlation between the sensation votes and preference votes. In fact the subjects would like to be cooler (or warmer) when they feel warm (or cool). The correlation between sensation votes and air temperatures is also relatively high. Such correlation between preference votes and air temperatures is significantly high.

Clothing insulation does not seem to be well correlated with air temperature. This is because of the minimum amount of clothing which subjects wore.

The correlation coefficient between variables is shown in Table (7.4).

Table 7.4 Correlation coefficient between variables

	Air temperature	*Sensation votes*	*Preference votes*	*Clothing*
Air temperature	1.00	0.79	-0.80	-0.05
Sensation votes	0.79	1.00	-0.68	-0.03
Preference votes	-0.80	-0.68	1.00	0.06
Clothing	-0.05	-0.03	0.06	1.00

7.2.4 Calculating the neutral temperature

Figure (7.7) shows the scatter diagram and regression lines of thermal sensation on air temperatures. The slope of sensation line is 0.24/°C, which is the same slope as the other surveys in Ilam. The sensation lines give the intercept of (–6.45) and R^2 of (0.61).

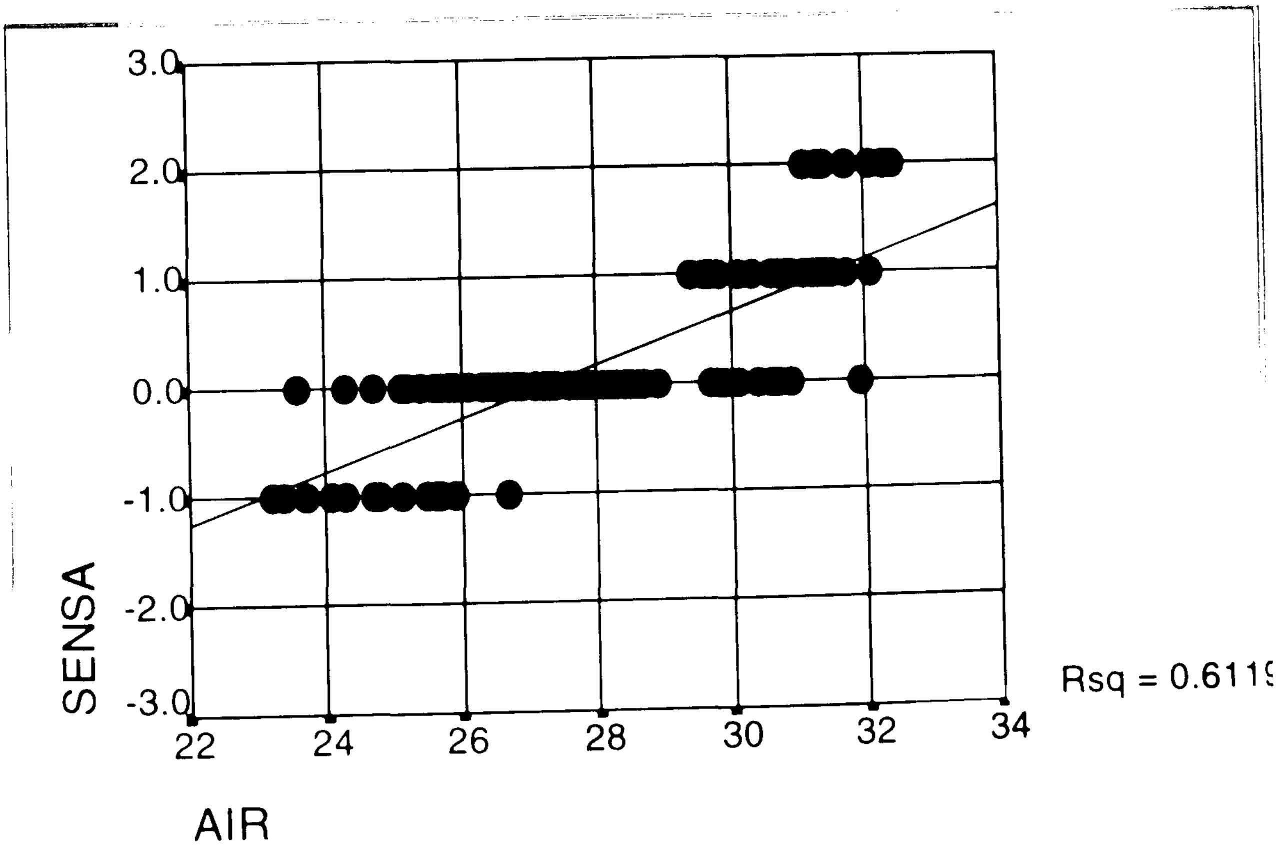


Figure 7.7 Scatter diagram of thermal sensation and air temperature

Such knowledge can be used to estimated the neutral temperature. The neutral temperature is 27.2°C and the acceptable limits are between 23.1°C and 31.4°C.

Similarly the preferred temperature is 25.8°C at range of 21.8°C to 29.9°C. the slope of preference line is -0.25/°C. Figure (7.8) shows the scatter diagram of preference votes and air temperature.

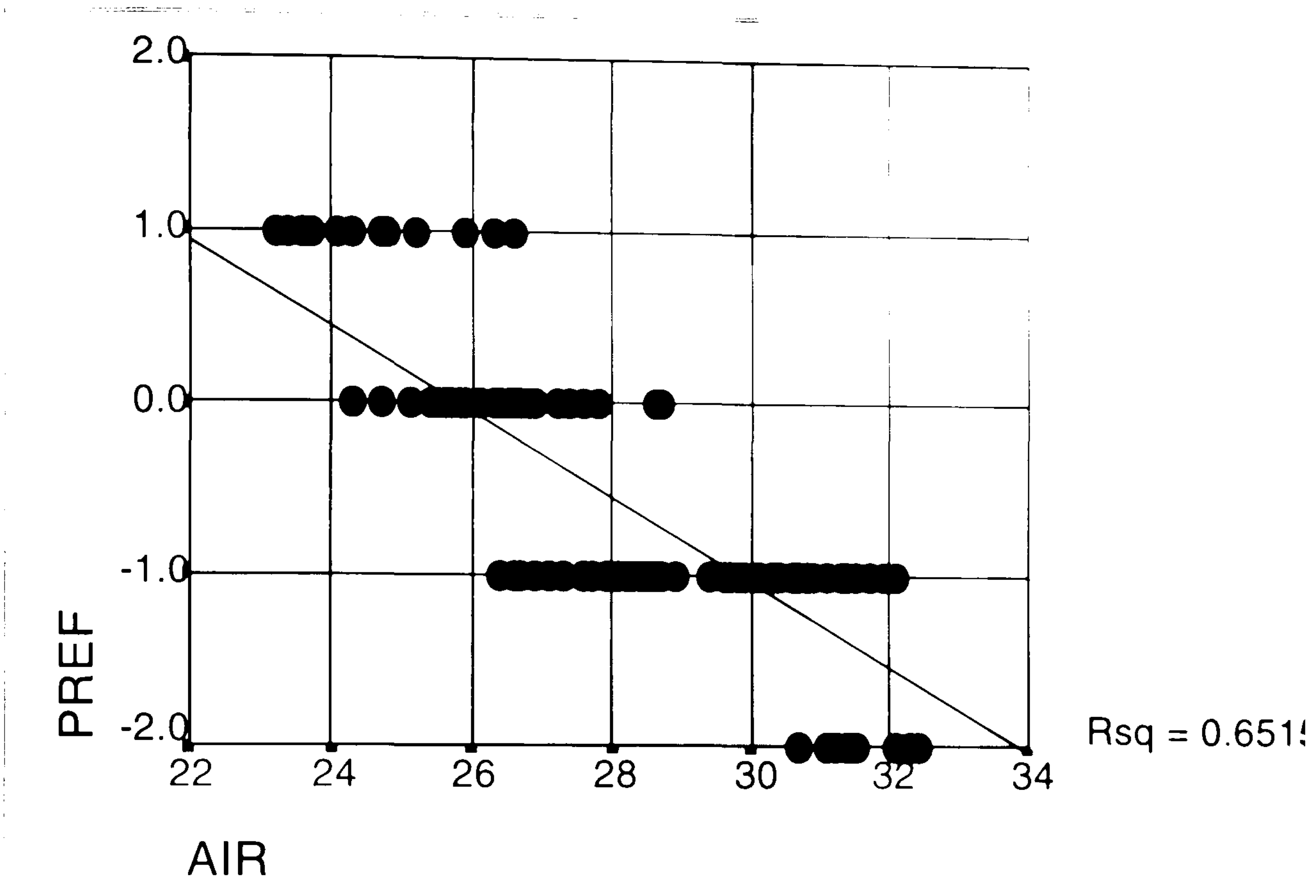


Figure 7.8 Scatter diagram of air temperature and preference votes

7.2.5 Thermal acceptability

As mentioned, the ASHRAE comfort standard specifies the environmental conditions necessary for neutral thermal sensation and also gives a range of parameter values that are expected to provide an environment that is thermally acceptable to at least 80% of occupants. The traditional and most commonly used method is an indirect measure that equates satisfaction with the central three categories of the seven- point thermal sensation scale. More than 90% of occupants were satisfied with their thermal conditions in the present study.

The second method is that: votes of "no change" on the McIntyre scale represent an assumption of acceptability. If 80% or more of occupants indicated "no change" it means this condition is an acceptable condition. There is some doubt about this due to the number of points on the McIntyre scale. Here this point is explained from the findings of the two studies of this thesis during two hot periods in Ilam.

In the first study the 3-point McIntyre scale (cooler, no change, warmer) was used. The results are:

1- At a range of air temperatures of 25.0°C to 32.7°C, more than 90% of subjects were in the comfortable condition (three central point of ASHRAE scale)

2- responses to the McIntyre scale were just 23% preferring "no change" (More details of this work is presented in Chapter six)

Surprisingly, this is a rather high figure compared with 90% comfort level indicated on sensation scale. Clearly the preferred temperature is much lower than the neutral temperature.

It is maybe because when some of subjects indicated slightly cool (or slightly warm) on the ASHRAE scale, it seems that a reasonable answer on the McIntyre scale is warmer (or cooler). Because subjects are seeking a comfortable condition while something is optional for them. In the other study which is the subject of this present section, the 5-point scale (much cooler, a bit cooler, no change, a bit warmer, much warmer) is used. The results are:

1- For a range of air temperatures of 23.2°C to 32.4°C more than 90% of subjects were in a comfortable condition

2- Responses to 5-point scale were 32% preferring "no change" or a little bit change

3- Taking the three middle preference points as the comfortable condition revealed that 92% of the voters wanted "no change"

The preferred temperature is slightly lower than the neutral temperature and this is reasonable. On the other hand, four subjects indicated "warm" in their sensation (S=2), while they wanted "a bit cooler" in preference scale and this is usual. Three subjects wanted "cooler" condition in preference scale while indicated slightly warm in sensation votes. Others who were voting outside the central three scales are the same people in both cases. From 62% of neutral votes (S=0) 26% wanted "no change", 31% wanted "a little bit cooler" and 2% wanted "a little bit warmer". About 20% who voted slightly warm on ASHRAE scale, wanted "a bit cooler" on preference scale and all who voted "slightly cool" wanted "a bit cooler" on preference scale. According to the above and taking votes of three central points preference scale as corresponding to the acceptable zone revealed that more than 90% of the votes cast wanted little "no change" which is in keeping with the voting patterns in the sensation scale. This showed that about all subjects had a comfort condition.

However such acceptable conditions (from both sensation and preference scales) in the range of air temperature between 23.0°C to 32.0°C more than 90% of subjects which is exceeding the standard's 80% indicated wide range of comfort condition without any problems. Which standard can apply to this fact? Are the standards correctly updated? Are the standards applicable universally or do individual factors and cultural differences influence comfort requirements? (Parsons; 1995).

7.3 A short term study of thermal comfort adaptive behaviour

A basic aim of low energy architecture is to create a thermally comfortable internal environment for building occupants whilst consuming the least possible amount of energy. In hot countries this aim is more difficult to achive since high ambient air temperatures create a barrier to comfort. Traditional housing types of these countries, such as courtyard housing, have evolved to try and help people to adapt to a state of thermal comfort under these adverse conditions.

This study has identified several thermal comfort adaptive actions that a person might take to achieve comfort. One of these actions is moving to a different thermal environment from the one causing the discomfort. The present section examined how people adapted themselves thermally to achieve comfort in a typical Iranian courtyard house moved between different spaces in the house during the day to try and obtain thermal comfort.

For the family living in the hot dry zone of Iran through the summer months without mechanical ventilation or in winter without heating, the year may be passed comfortably in a gentle migration around the house. With the traditional arrangement of rooms around a courtyard a major migration is effected every year. In December or January occupants migrate to the winter rooms on the south-facing wall of the house and in June/ July or August to the north-facing rooms on the courtyard.

A survey was conducted during the hot season (July/August, 1998) in a courtyard house in the city of Ilam. The house was selected at random from more than twenty in the area.

Figure (7.9) shows the plan and section of this house and introduces the different spaces. A sample of six subjects, four male and two female, completed questionnaires for seven days for every hour of the day when they were in the house and wake. A summary of subjects' information is presented in Table (7.5).

Table 7.5. Summary of personal information

Code	Gender	Weight (kg)	Height (m)	Age (year)	Job
S1	M	58	172	65	Retired
S2	F	55	159	57	Housewife
S3	M	79	180	41	Shopkeeper
S4	F	67	165	35	Teacher
S5	M	54	167	16	Student
S6	M	46	154	14	Student
Mean	-	60	166	38	-

The questionnaires requested information on thermal sensation (ASHRAE seven point scale), clothing, activity level and location of person in the house.

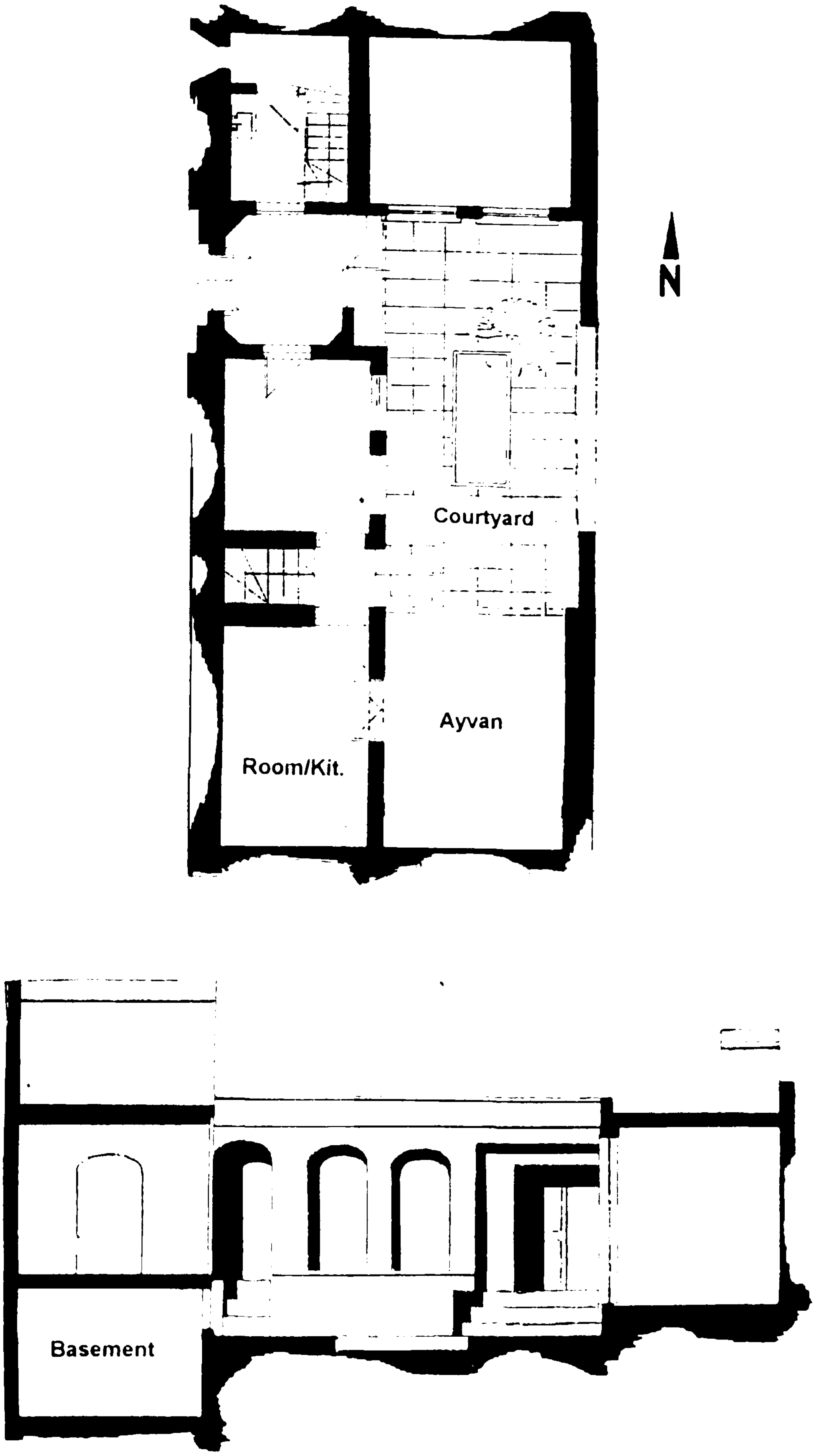


Figure 7.9 Plan and section of selected house

Four thermally separate spaces in the house were identified which were, Ayvan (closed on five sides and open to the courtyard), courtyard, room (room and small open kitchen were together) and basement. Air temperatures were measured in each of these spaces for the duration of the survey. Some 467 data sets were obtained during the one-week longitudinal sampling survey. Means and numbers of questionnaires, which were filled by each subject, are shown in Table (7.6). Table (7.7) shows the number of questionnaires against each hour.

Table 7.6 Number and mean of observations by each subject

Subjects	S1	S2	S3	S4	S5	S6
No of observation	101	104	71	94	54	43
Mean (each day)	14	15	10	13	8	6

Table 7.7- Number of observations in each hour

Time	*No*	*Time*	*No*	*Time*	*No*	*Time*	*No*
7.00	**28**	*11.00*	**18**	*15.00*	**38**	*19.00*	**31**
8.00	**27**	*12.00*	**31**	*16.00*	**33**	*20.00*	**33**
9.00	**39**	*13.00*	**31**	*17.00*	**21**	*21.00*	**35**
10.00	**19**	*14.00*	**30**	*18.00*	**25**	*22.00*	**28**

7.3.1 Individual and environmental data

Mean clothing insulation was 0.48 clo, which is lower than the amount of clothing in the other field surveys in Ilam. This is because clothing values were recorded in the whole of the day and also the week. Clothing insulation of men (0.46 clo) was lower than women (0.58 clo) which is reasonable according to the subject's religion. The interesting point is that clothing value in two categories of time were different. Clothing insulation for the heat of the day (10.00-17.00) and other times of day (7.00-9.00 and 18.00-22.00) were 0.42 clo and 0.52 clo respectively. Table (7.8) indicates the difference between clothing value of subjects during these separate times.

The average metabolic rate is 1.2 met. The observations in all surveys in Ilam suggested that the environmental conditions did not have an influence on the activities of the subjects.

Table 7.8 Different clothing insulation in two categories of day

Subjects	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**All**
Clothing value (10.00- 18.00)	0.45	0.58	0.39	0.51	0.36	0.40	0.42
Clothing value (other times)	0.55	0.66	0.49	0.57	0.43	0.43	0.52

During the survey air temperatures were recorded and calculated for two conditions; air temperature measured at the time of the questionnaires and air temperature measured between 7.00- 22.00, which is the active period. Table (7.9) shows air temperatures in different spaces in the two categories.

Air temperatures were a maximum in the courtyard and a minimum in the basement. The basement had low mean air temperatures and the room had high temperatures.

Throughout the period of the survey (one week) outdoor temperature was obtained from the meteorological office of Ilam with the mean of 28.5°C.

Table 7.9 Air temperature in different spaces

	Courtyard		**Ayvan**		**Room/Kitchen**		**Basement**	
	T_a	T_{ac}	T_a	T_{ac}	T_a	T_{ac}	T_a	T_{ac}
Mean	28.2	29.8	28.3	29.7	29.6	29.9	28.7	26.8
Max.	31.4	34.4	31.3	34.0	32.5	32.5	29.3	29.3
Min.	24.1	24.1	24.5	24.5	25.3	25.3	26.2	22.4

T_a – measured air temperature at time of questionnaires

T_{ac}- measured air temperature in active period

7.3.2 Sensation votes

Figure (7.10) show the mean thermal sensation of each subject during a week for each hour. Responses vary over three central points of the seven-point scale. The mean sensation votes of each subject are presented in Table (7.10).

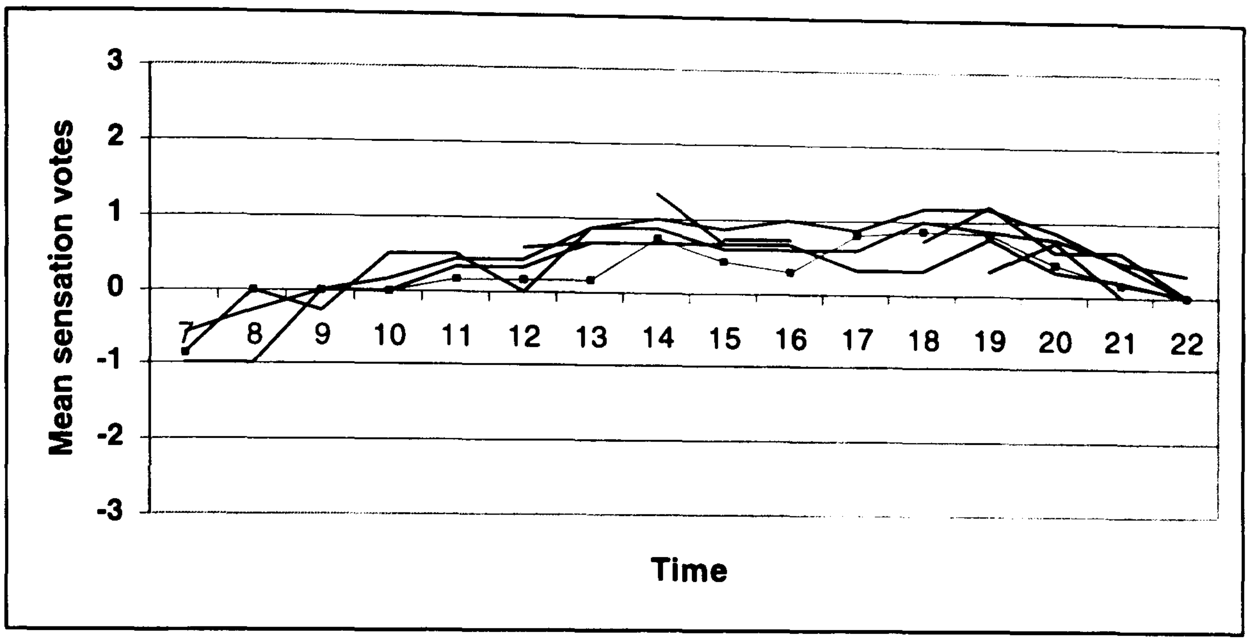


Figure 7.10 Sensation votes of subjects during a week (time of day)

Table 7.10 Mean sensation votes of each subject during survey

Subjects	S1	S2	S3	S4	S5	S6	All
Mean sensation votes during week	0.42	0.52	0.25	0.25	0.57	0.52	0.39

All subjects were in a slightly warm condition while subject (5) had higher sensation votes than the others. Mean sensation votes in each space during use by occupants was calculated as shown in Table (7.11).

Table 7.11 Mean sensation votes of each space during survey

Spaces	Courtyard	Ayvan	Room/K.	Basement
Mean sensation votes	0.51	0.29	0.38	0.76

Table (7.11) shows that the basement had a high sensation value (0.76) while the Ayvan had a low value (0.29). It is maybe because of high outdoor temperatures during using of basement which was the hot time of the day or may be because of subject's expectation during the hot time.

Mean sensation votes were also calculated according to the different times of each day. People were warmer at 14.00 and had slightly cool condition at 7.00. Obviously in the hot time of the day people are warmer than cool time. Table (7.12) shows such values.

Table 7.12 Sensation votes in different time of day

Time	*Sens. V.*	*Time*	*Sens. V.*	*Time*	*Sens. V.*	*Time*	*Sens. V.*
7.00	**-0.82**	*11.00*	**0.34**	*15.00*	**0.65**	*19.00*	**0.85**
8.00	**-0.32**	*12.00*	**0.29**	*16.00*	**0.65**	*20.00*	**0.60**
9.00	**-0.05**	*13.00*	**0.63**	*17.00*	**0.65**	*21.00*	**0.29**
10.00	**0.16**	*14.00*	**0.91**	*18.00*	**0.76**	*22.00*	**0.06**

7.3.3 Correlation coefficient

The correlation coefficient between sensation votes and air temperature was high and positive, (0.87). The correlation between air temperature and clothing values was significant and negative which is (-0.24). This implies people used change of clothing as a kind of adaptive behaviour to achieve thermal comfort conditions.

7.3.4 Relationship between air temperatures and sensation votes

Figure (7.11) shows the scatter diagram of mean sensation votes and air temperature. The variations of mean sensation votes with air temperature show a positive relationship. The range of air temperatures between 24.0°C to 31.0°C was against a very narrow range of sensation votes (-1 to 1).

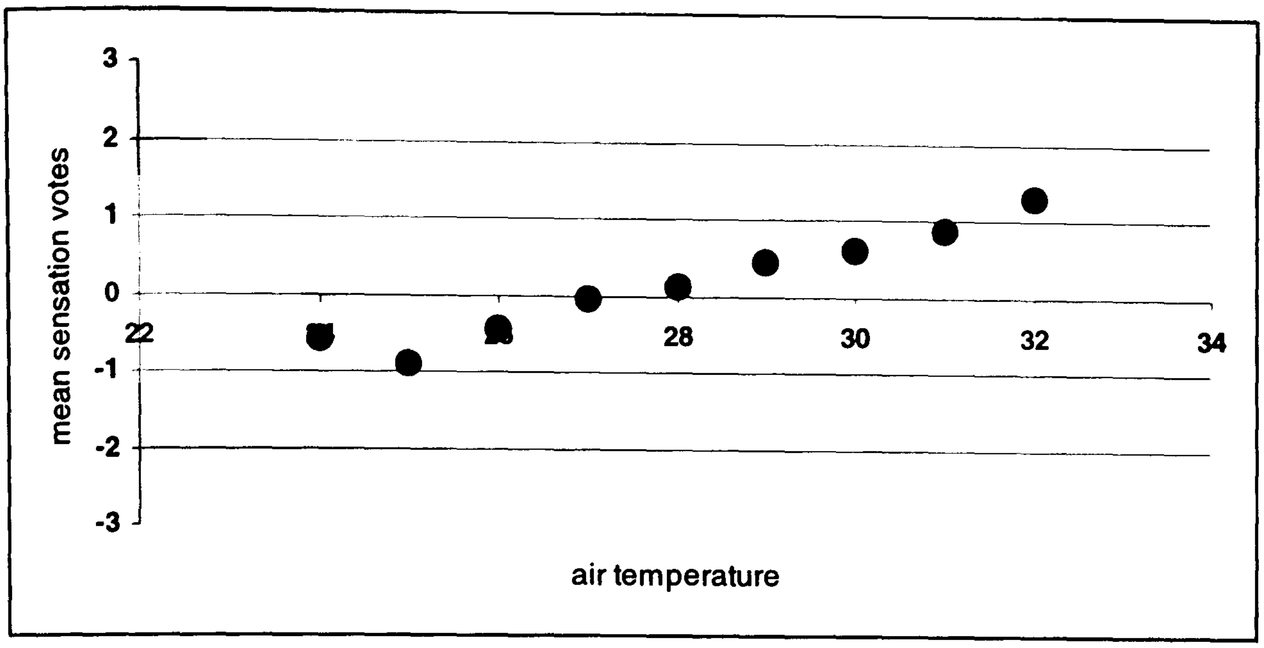


Figure 7.11 Scatter diagram of mean sensation votes and air temperature

7.3.5 Neutral temperature

As with previous calculations of neutral temperature in this thesis, a simple linear regression analysis is used with two important points: thermal sensation votes as dependent variable and air temperature as independent variables. Figure (7.12) show the scatter diagram of sensation votes and air temperature.

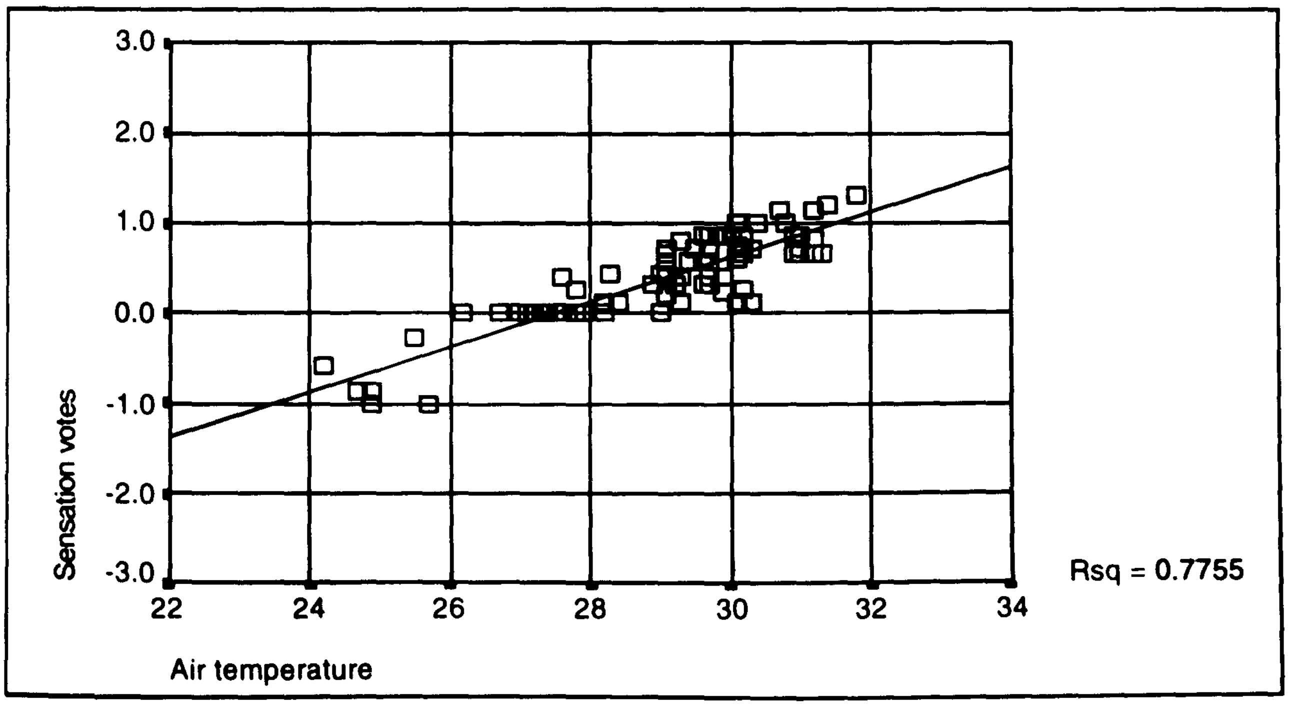


Figure 7.12 Scatter diagram of mean sensation votes of each subjects hourly and air temperature

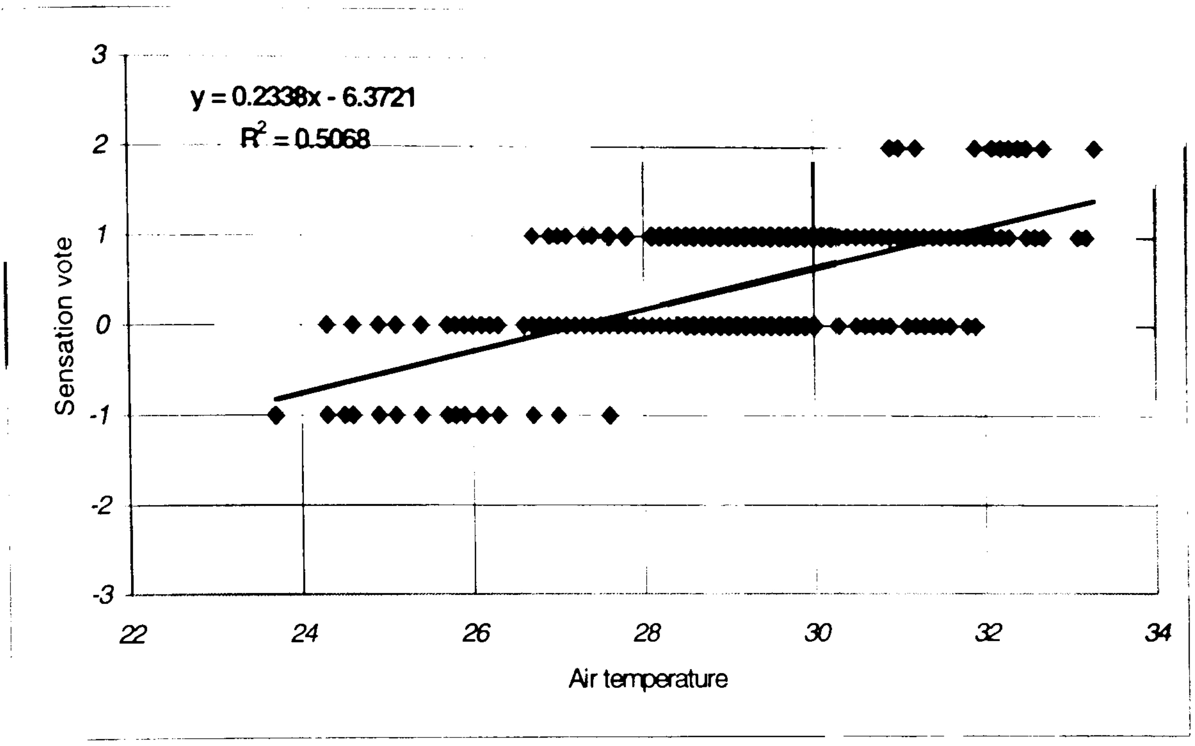


Figure 7.13 Scatter diagram of air temperatures with all subjects' sensation votes

Figure (7.13) show the scatter diagrams of air temperatures and sensation votes with all subjects' votes during a week. The neutral temperature was 27.3 °C with equations' slope of 0.23/°C.

7.3.6 The main finding

Humphreys and Nicol [1998] noted that one of a person's reactions to heat is moving from one place to another.

The author does not need to explain or prove this point to him, because it was achieved and proved for himself from his direct experiences. During the hot season breakfast was in the Ayvan, lunch was in the main room and dinner was in the Courtyard. The place of night time sleeping was the roof or courtyard and the place of noontime sleeping was in the basement. In cool conditions everything was going to change. All in order to achieve thermal comfort conditions.

One of the questions for the subjects was about their location in the house. It had been explained to them this meant that they should be in there for at least 15 minutes.

From this question calculating the mean percentage of use of each spaces hourly during a week (f_i) was possible as shown in Table (7.13).

Table 7.13 Percentage use of each space during a week

Time→* *Space↓*	*7&8*	*9&10*	*11&12*	*13&14*	*15&16*	*17&18*	*19&20*	*21&22*	All
Courtyard	4%	6%	2%	0%	0%	12%	7%	7%	**5%**
Ayvan	30%	39%	47%	0%	0%	20%	85%	62%	**35%**
Room/K	35%	35%	32%	65%	20%	20%	2%	5%	**27%**
Basement	0%	7%	6%	18%	65%	35%	0%	0%	**16%**
Other	31%	13%	13%	17%	15%	13%	6%	26%	**17%**

*Used for a couple of hours is more reasonable

People mainly used the Ayvan as a semi open space and they spent just 5% of their time in courtyard.

Another step was calculating the mean air temperature for each space during the fixed time in the space. It is shown in Table (7.14).

Table 7.14 Mean air temperature for each space during use by subjects

Time→ *Space↓*	*7&8*	*9&10*	*11&12*	*13&14*	*15&16*	*17&18*	*19&20*	*21&22*
Courtyard	24.7	27.6	30.8	33.3	34.3	32.2	28.6	26.6
Ayvan	25.1	27.1	29.3	32.2	33.8	32.0	29.8	27.9
Room/K	25.7	27.9	29.4	31.3	32.1	32.3	31.2	28.9
Basement	23.1	25.6	27.0	27.9	28.9	29.1	27.8	25.1

For a clear picture, weighted mean air temperature depending on hour of use was calculated by the following equation:

$$M^* = \Sigma(f_i \,.\, T_i) / \Sigma f_i \qquad (7.1)$$

M^* is weighted mean air temperature

f_i is percentage of use

T_i is mean air temperature

Tables (7.15 and 7.16) shows the results of this equation.

Table 7.15 Calculating of ($f_i \cdot T_i$)

Time→ Space↓	*7&8*	*9&10*	*11&12*	*13&14*	*15&16*	*17&18*	*19&20*	*21&22*
Courtyard	99	165	61	0	0	386	200	186
Ayvan	753	1057	1377	0	0	640	2533	1729
Room/K	899	976	940	2034	642	646	62	144
Basement	0	179	162	502	1878	1018	0	0

Table 7.16 Amount of M* in the fixed time

Time→	*7&8*	*9&10*	*11&12*	*13&14*	*15&16*	*17&18*	*19&20*	*21&22*
$\Sigma(f_i \cdot T_i)$	1751	2377	2540	2536	2520	2690	2795	2059
Σf_i	69	87	87	83	85	87	94	74
M*	25.4	27.3	29.2	30.5	29.6	30.9	29.7	27.8

M* shows the air temperature which subjects were exposed to. Figure (7.14) shows the amount of M* for comparison with higher and lower air temperature of spaces. This figure shows people were using places where the air temperature for them was within the comfort zone.

Figure (7.15) also shows a similar pattern. The percentage use of different spaces according to their air temperature is shown in each column of Figure (7.15).

One of the interesting points that can be obtained from Table (7.9) supports this claim. Air temperatures at the time of the questionnaires indicated the air temperatures which subjects were exposed to. In all spaces the range of air temperature at the time of the questionnaires were within the comfort condition. Figure (7.16) shows in other form Table (7.9) and better explains this fact. Figure (7.16) show percentage of using of each space is as a function of air temperature.

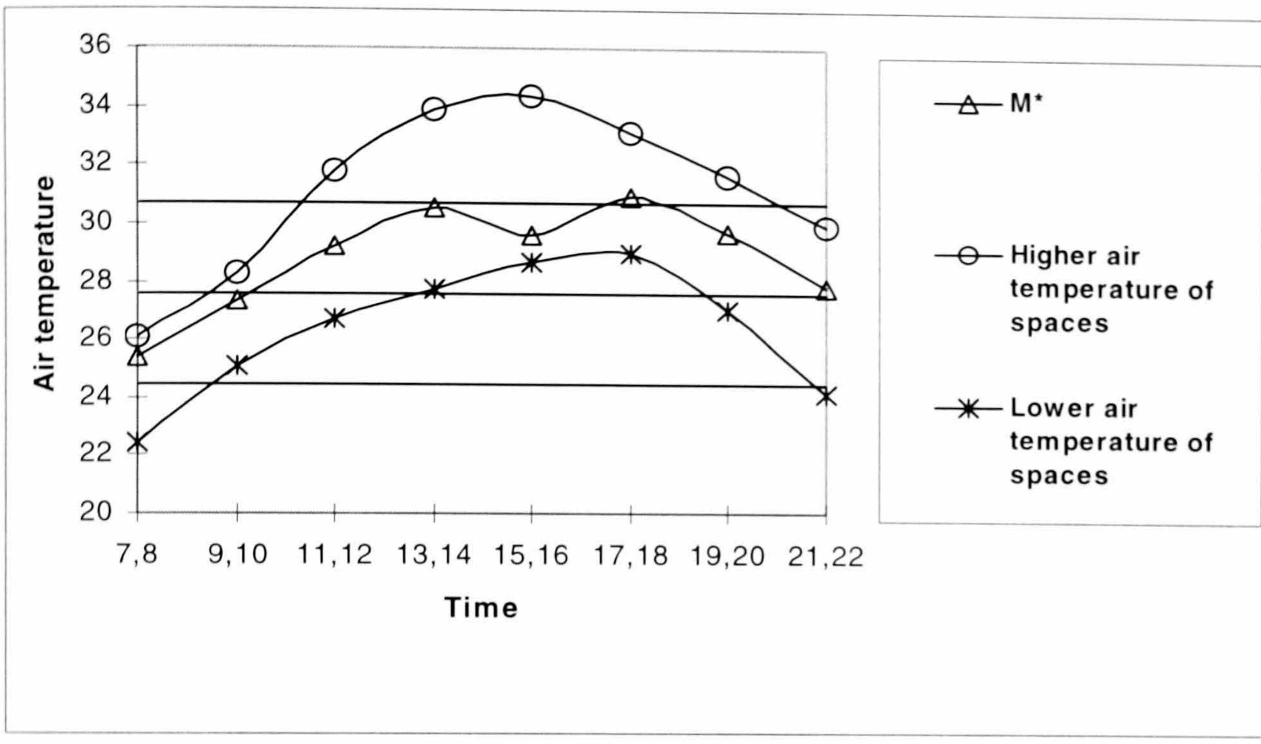


Figure 7.14 Comparison between M* with higher and lower air temperature of spaces

Time→	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
34-35 °C																
33-34°C								0	0	0						
32-33°C							0	0			0					
31-32°C						0	0	63	24	24	25	22	6			
30-31°C							94					67		0		
29-30°C					4	99					75		89		6	
28-29°C					84			37	76	76		11	5	90		
27-28°C			22	82			6						0	10	71	7
26-27°C			78	18	12	1								0	17	93
25-26°C		93													6	0
24-25°C	94	7	0													
23-24°C	6	0														0
22-23°C																
21-22°C	0															

Figure 7.15 Percentage of using according to air temperature of each space

In Figure (7.15) the shaded boxes indicated the temperature of zones which occupants could select to occupy. The Figure in each shaded box represent the percentage of use.

Correlation between air temperature and percentage of using spaces is important. When the air temperature of a space is below 25.0°C the correlation coefficient is high and positive. It means when air temperature is near to comfort temperature the percentage use of spaces is increase. When air temperature of spaces is within the comfort zone there is no significant correlation. Finally when air temperature is more than 30.0°C correlation is high but negative. It means that when air temperature is going higher than the upper limits of the comfort zone, use of such spaces was going to decrease. Table (7.16) shows correlation coefficients between air temperature of spaces and percentage of using of spaces.

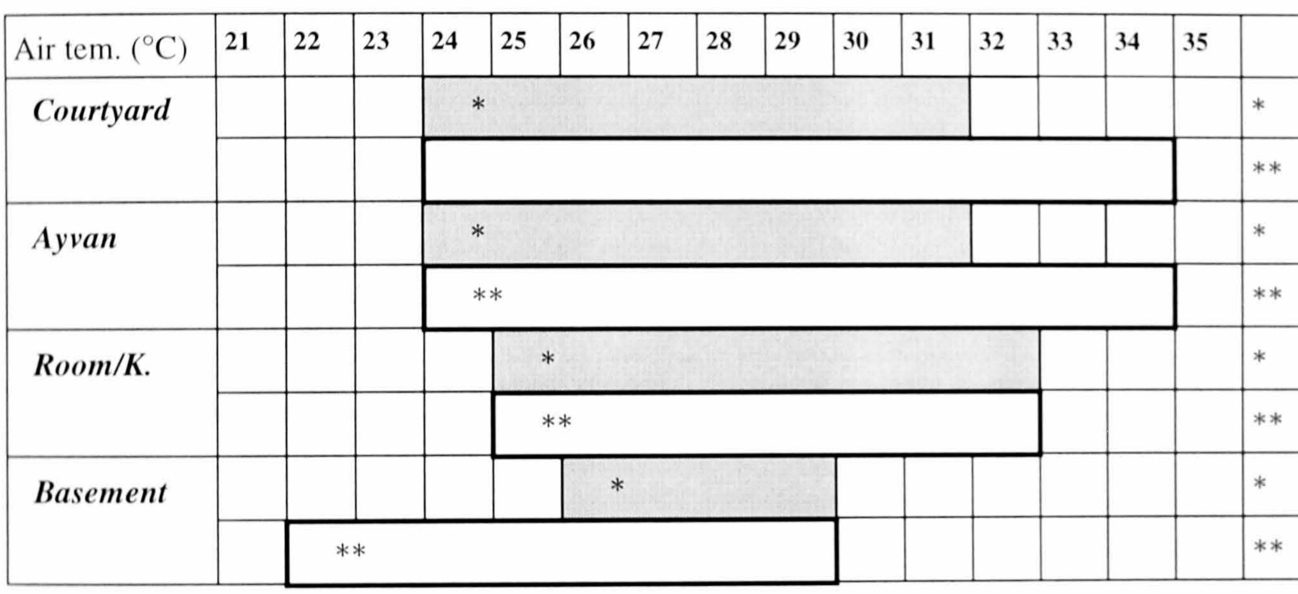


Figure 7.15 Range of air temperature during using of spaces by occupants (*) and during whole of the day (**)

Range of air temperature at time of questionnaire [*]
Range of air temperature in the active period (7.00 – 22.00) [**]

Table 7.16 Correlation coefficient between air temperature and percentage of using spaces

Air temperature (T_a)	Correlation coefficient
T_a<25.0°C	+0.57
25.0°C< T_a < 27.5°C	0.03
27.5°C < T_a <30.0°C	+0.24
30.0°C< T_a	-0.65

Thus subjects sought out more thermally comfortable spaces in the house and one of the main forms of adaptation was movement from one place to another.

7.4 Conclusion

Two studies of thermal comfort in Iranian courtyard housing have been carried out in the hot season. Two basic types of field survey were carried out in these field studies. The transverse type in the first study and the longitudinal type in the second one. The important points in the first study are:

1- Air temperatures are well correlated with thermal sensation votes. Such a correlation between preference votes and air temperatures was significantly high

2- The neutral temperature was 27.2°C with a thermally acceptable range of 23.1°C to 31.4°C

3- The preferred temperature was 25.8°C

4- Taking votes of three central points preference scale (from 5-points) as corresponding to acceptable zone revealed that more than 90% of the votes cast wanted little or "no change" which is in keeping with the voting patterns in the sensation scale.

5- According to results of this study a 5-point preference scale can be better than a 3-point scale.

The second field survey has described a week-long study of how and when six people used different thermal spaces in their courtyard house during the hot season. There was some evidence of clothing being used as an adaptive measure. The subjects tended to actively seek out more thermally comfortable spaces in the house during the course of a day, suggesting that one of the main forms of adaptation for the subjects was movement from one place to another within their courtyard house. Furthermore, simple linear regression can be used to establish the neutral temperature for subjects. The neutral temperature was

27.5°C at an acceptable range of 23.5°C to 31.7°C. The regression slope was 0.25/°C. An interesting relationship was also found between clothing insulation and air temperature. Results of this study agreed with the results of other studies in Ilam.

Chapter Eight

Discussions and comparative analysis of the results

8.1 Introduction

The range of comfort for Ilam people in their houses was found in the present study to be between 17.2°C and 31.8°C for which around 80% of subjects were likely to be comfortable. At a neutral temperature of 28°C, the study indicated all subjects would be comfortable with sensation "neutral" on the ASHRAE scale and "no change" on the preference scale during a hot period and similarly at air temperature of 21.0°C during a cool period. The range of Ilam outdoor air temperatures shows a great opportunity for the housing designer to provide indoor thermal comfort. Thus some strategies which may be applicable to housing design in Ilam are investigated.

This Chapter looks at a comparative analysis of all the field studies' results of this thesis during two seasons in the city of Ilam with other studies.

The Chapter will start with a discussion of the thermal sensation and acceptable conditions suggested by the results of this study. Next, two models (from Humphreys and Auliciems) and later on, another model from de Dear, are discussed which imply that neutral temperature is related to outdoor temperature as well as indoor temperature. The focus is on the relationship between these models and findings of this study. The Griffiths' model is introduced to estimate the neutral temperature for all groups of subjects in Ilam. This Chapter also looks at the other evidences for behaviour adaptation.

The present Chapter is the best place for a discussion about PMV index and the issue of standards of thermal comfort. There have been many arguments whether standards are appropriate to be applied to the or in the real buildings.

Two bioclimatic charts of Olgyay and Givoni will be compared with acceptable boundaries of comfort conditions for Ilam people. This Chapter also shows how the results of experimental works in Ilam can be applied to passive buildings with a discussion of Mahony's tables as a passive systems guideline.

8.2 Comparison of thermal sensation to standardized equation

The mean sensation votes from all the groups of Ilam subjects on the ASHRAE scale is 0.34, or slightly warmer than neutral (mean air temperature is 27.8°C). Thus there was a bias towards the warm side of the scale. Obviously at the different mean air temperatures, patterns of sensation votes could be different. Humphreys [1976] showed a highly significant correlation between mean responses versus mean air or globe temperatures from more than 200,000 observations (Figure 8.1). The equation derived from linear regression analysis is:

$$\textit{Standardised mean sensation} = -0.244 + 0.0166\, T_i \qquad (8.1)$$

T_i is mean indoor air temperature

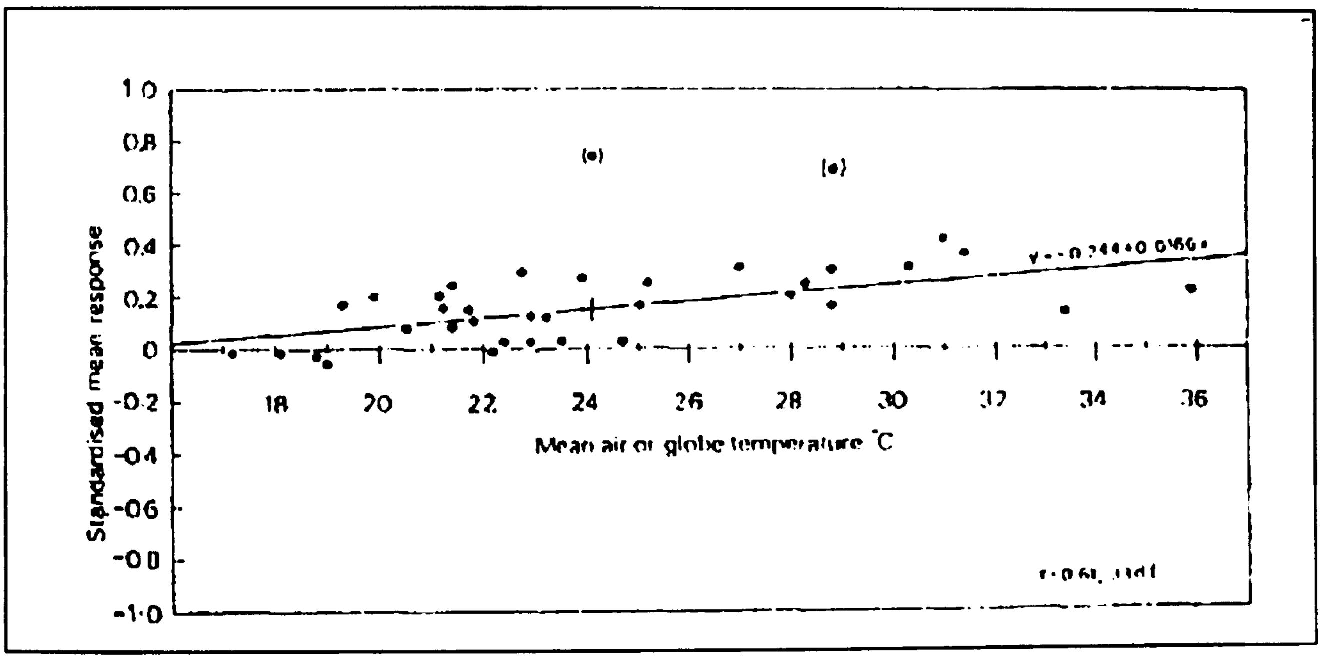


Figure 8.1 Standardised mean thermal responses against mean temperatures.

(After Humphreys 1976)

Because of different numbers of categories in various scales, Humphreys used a standardised form by dividing the absolute mean response by the number of positive categories on the scale. Do standardised mean sensation votes of the Ilam study fit to the regression line of Humphreys' study?

Table (8.1) shows these values in different groups and in all the samples.

Table 8.1 Mean standardized sensation votes

	C.H	T.H	Y.H	C.C	T.C	P.H	A.H	All
Mean air temperature °C	30.4	29.6	31.7	20.5	19.3	28.2	29.1	27.8
Standardised sensation votes	0.24	0.08	0.27	0	-0.14	0.08	0.13	0.12
Predicted by Humphrey's eq.	0.26	0.24	0.28	0.09	0.07	0.22	0.23	0.21

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons
CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
PH: Low income subjects – Hot season
AH: Longitudinal work in a house -Hot season

All standardised sensation values of Ilam subjects are lower than those predicted by Humphreys' equation. It implies that Ilam people are more adapted to hot conditions and less to cool conditions than the means of world- wide subjects. Such a finding was reported by Nicol et al [1994] for Peshawar subjects. Figure (8.2) also shows the regression line of Humphreys' study [1976] and all the standardised mean thermal sensation responses in the present study.

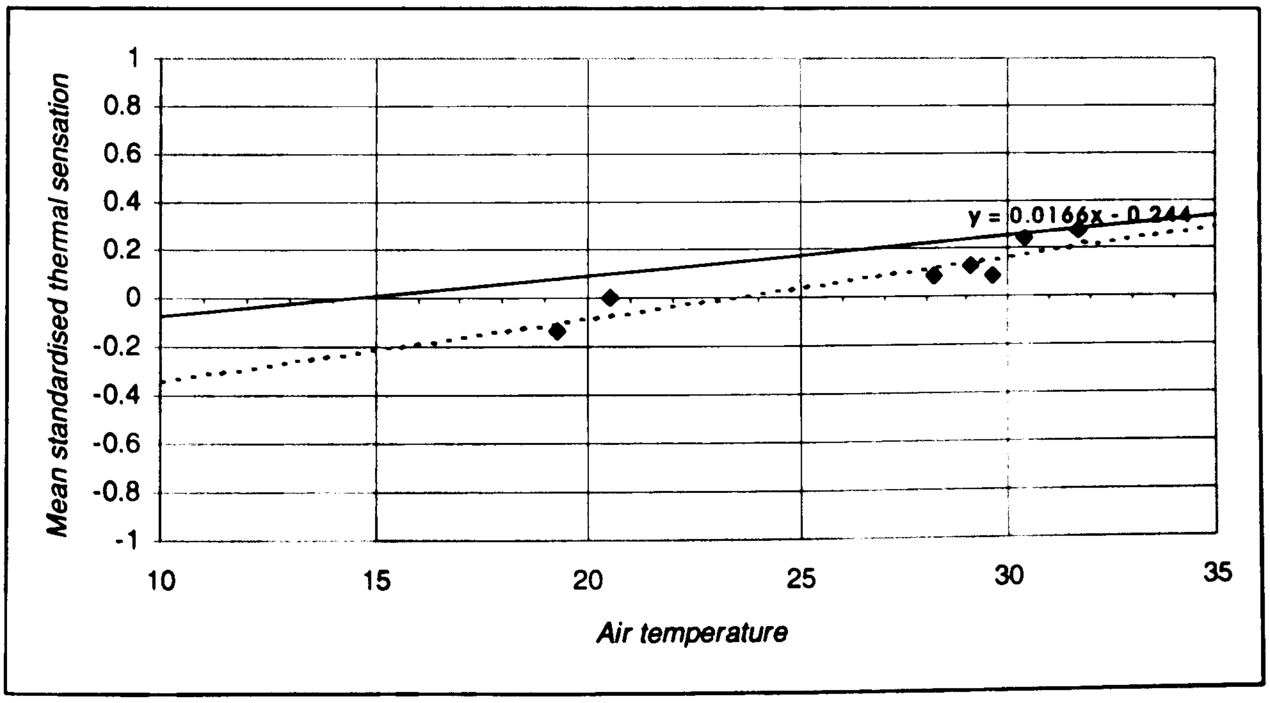


Figure 8.2 Regression line of Humphreys study (thicker line) and standardised mean sensation votes in all groups of present study

As shown in Figure (8.2) all points are generally positive and there are no extreme values. They all lie below the Humphreys' line, which is the same as subjects in Iraq and India [Nicol; 1974] and Singapore [Webb; 1959]. The regression equation fitted to the Ilam surveys is:

$$\textit{Standardised mean sensation votes} = -0.592 + 0.0254\, T_i \qquad (8.2)$$

The slope of equation (8.2) is steeper than that found by Humphreys.

Table 8.2 Cross- tabulation of air temperature against ASHRAE scale (all in transverse sampling)

Ta (°C)	-3	-2	-1	0	1	2	3	Row	Totals
15		20%	80%					*0.9*	12
16		60%	40%					*0.6*	8
17		30%	63%	7%				*1.7*	24
18			50%	50%				*0.3*	4
19			37%	63%				*4.5*	62
20			8%	92%				*8.2*	113
21				94%	6%			*5.7*	78
22				94%	6%			*4.2*	58
23			8%	32%	60%			*1.5*	21
24			55%	45%				*0.7*	9
25			45%	55%				*1.5*	20
26			32%	68%				*2.7*	37
27			3%	97%				*4.4*	60
28				100%				*3.5*	48
29			1%	83%	16%			*15.5*	214
30				68%	31%	1%		*15.8*	218
31				21%	73%	6%		*14.1*	195
32				8%	81%	11%		*7.8*	108
33					82%	18%		*2.4*	33
34					25%	63%	12%	*0.6*	8
36					12%	50%	38%	*0.6*	8
36						100%		*0.1*	2
37					6%	59%	35%	*1.2*	17
38						100%		*0.4*	6
39						75%	25%	*0.3*	4
40						33%	67%	*0.2*	3
41						50%	50%	*0.1*	2
42						33%	67%	*0.2*	3
43							100%	*0.1*	1
44							100%	*0.2*	3
	0%	**1.1%**	**6.8%**	**57.9%**	**28.1%**	**4.6%**	**1.5%**	***100***	**1379**

[Shading colour indicates about 95% of data, which are collected during cool season]

For a clear picture of the pattern of sensation votes against air temperature a cross-tabulation between them is presented in Table (8.2). This table shows the percentage of votes at each scale category within 1°C range.

Table (8.2) shows that subjects were satisfied with their condition whether at 20.0°C or at 28.0°C. It should be noted that if the neutral temperature was calculated by heat balance theory and the comfort equation [Fanger; 1970], its range could be found to be only 5-6K. A range of 8K must be affected by other parameters not just the *six parameters* of standard thermal comfort.

A comparison is also made between English subjects (data from Table 5.1) and Ilam subjects during the hot season. Figure (8.3) shows English subjects were more sensitive to heat than Ilam subjects. The English subjects were in the neutral condition at the air temperature of 17.2°C while Ilam subjects had a similar situation at air temperature of 28.1°C.

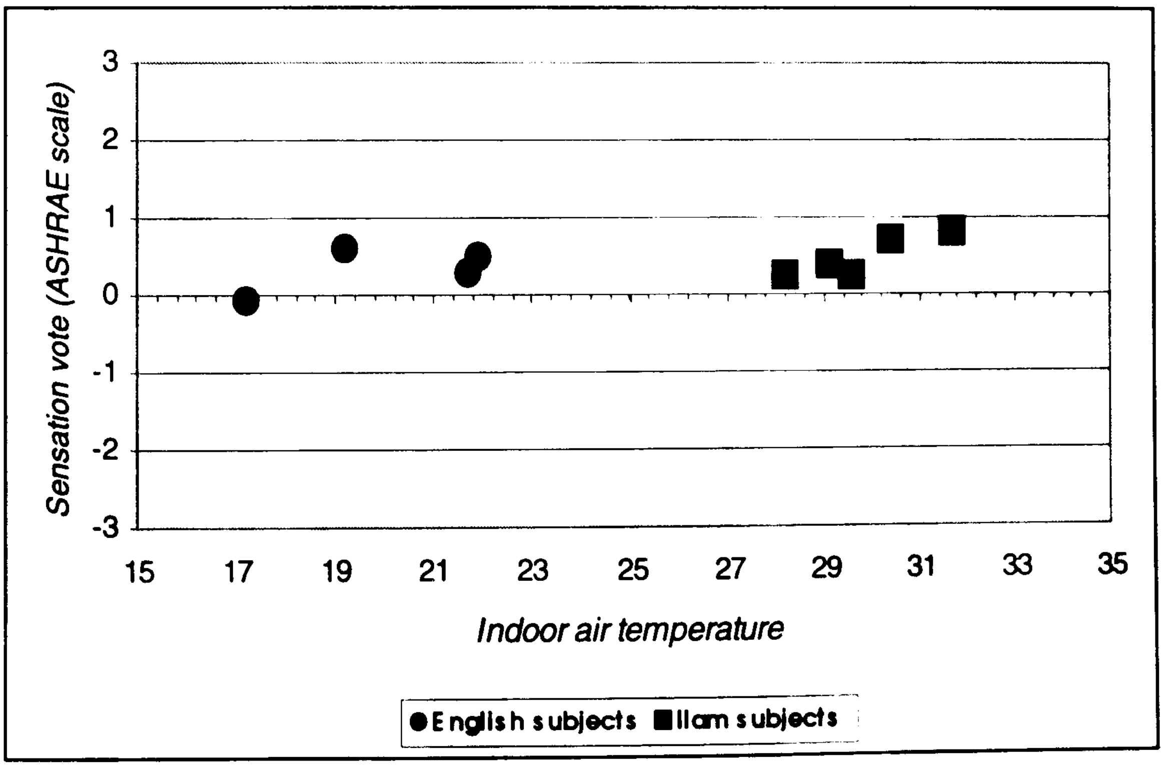


Figure 8.3 Different thermal sensation of English and Ilam subjects

8.3 Thermal acceptability

Olgyay [1963] noted that "where no feelings of discomfort occur is the comfort zone". Markham [1947] proposed a range of temperature from 15.5°C to 24.5°C as constituting an ideal zone, with relative humidity at noon varying from 40% to 70%. Givoni [1992] has attempted to define a comfort zone for naturally ventilated buildings with two categories: developed countries and developing countries. ISO 7730 [1993], based on Fanger's work, gives the comfort zone for summer as 23°C to 26°C and for winter 20°C to 24°C in resultant temperature. The comfort zone, however, does not have real boundaries for the comfort condition because it depends on sex, age, acclimatisation according to geographical locations, type of clothing and activity, as well as cultural factors and life style. Thus the range of comfort for building design strategies will be based on field studies at certain locations.

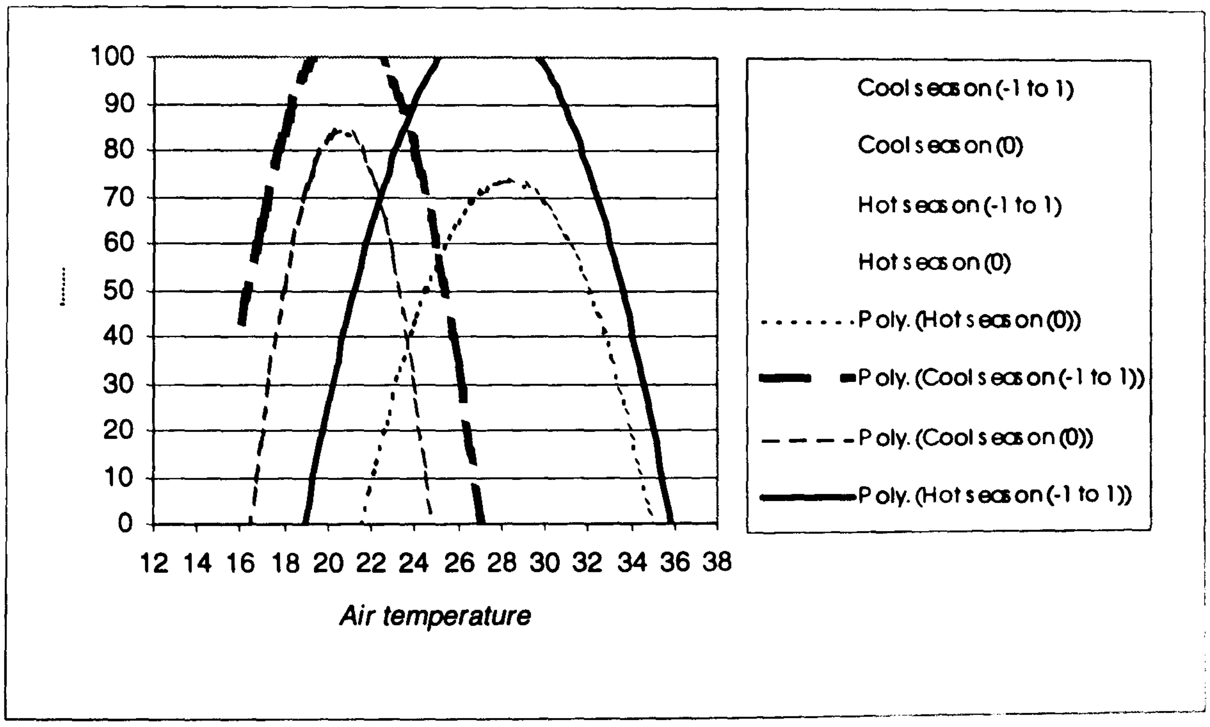


Figure 8.4 Percent of sensation votes between slightly cool and slightly warm as well as neutral sensation votes (S=0) during both seasons

As mentioned in Chapters six the use of preference scale to determine acceptable condition is not necessary in this study. However, by using the conventional method considering thermal sensation votes within the three central points of the seven- point ASHRAE sensation scale and at least 80% of the respondents who were satisfied by their environment, thermal acceptability of Ilam subjects can be established. For this aim a quadratic equation was used to estimate the curves lines. The data of all subjects in the hot and the cool seasons is used to draw Figure (8.4).

Limits of air temperatures between 17.2°C and 24.2°C for cool periods and 24.0°C to 31.8°C for hot periods can be boundaries of acceptable conditions for Ilam subjects.

In the present study the average of air velocity during the time of questionnaires was about 0.1 m/s which is in the category of still air. However, with increasing air velocity the upper air temperature limit of the comfort condition can be increased of air temperature. The range of acceptable conditions from the present study is much wider than that predicted by standards such as ISO 7730 (1994) or ASHRAE standard 55 (1992).

8.4 Neutral temperature and mean indoor temperature

Humphreys [1976] showed a strong relationship between the mean indoor temperature and neutral temperature (Figure 8.5). The simple regression equation is:

$$T_n = 0.831\ T_i + 2.6 \qquad (8.3)$$

T_n is the neutral temperature

T_i is the mean indoor temperature

Humpherys [1976] noted that it is interesting that such an accurate prediction (for neutral temperature) can be made simply from a knowledge of the mean temperature experienced by the respondents during the observation.

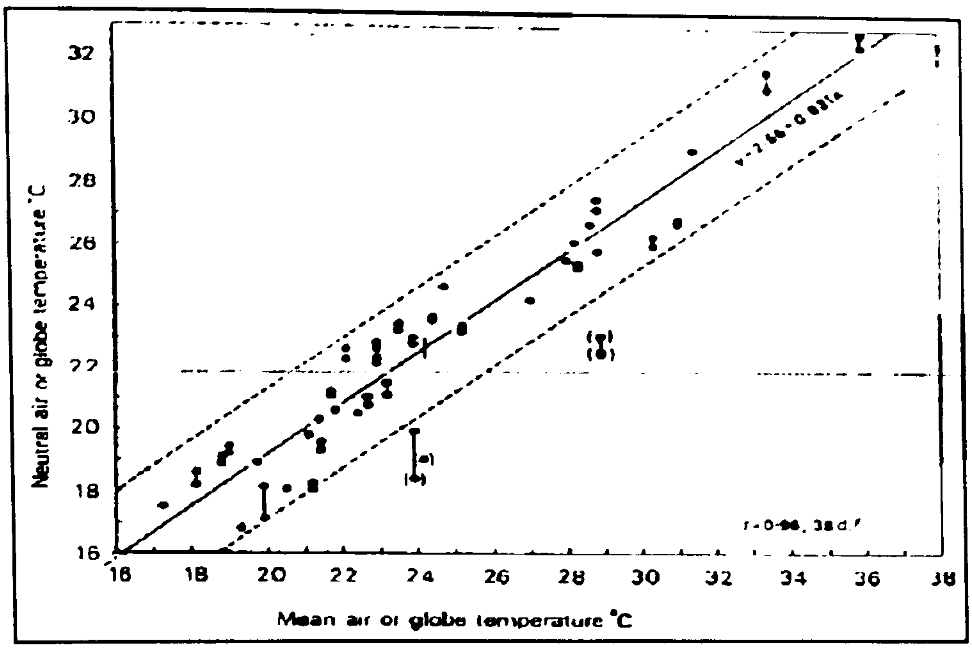


Figure 8.5 Relationship between indoor air temperatures and neutral temperatures. (*After Humphreys 1976*)

Auliciems et al [1986] developed another equation. They used minimum group discomfort as a function of mean indoor air temperatures by simple linear regression analysis (Figure 8.6). This equation is:

$$T_n = 0.73T_i + 5.41 \qquad (8.4)$$

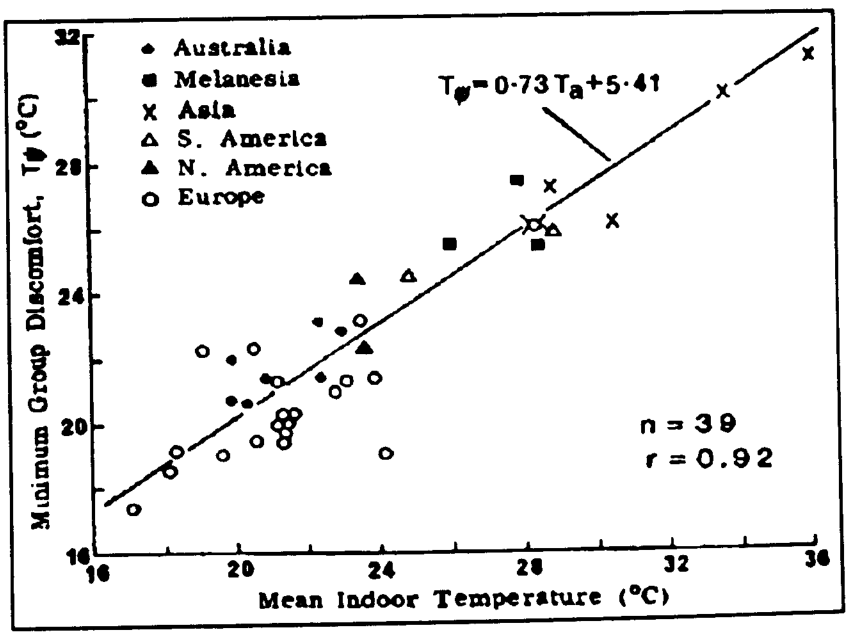


Figure 8.6 Relationship between mean indoor temperatures and neutral temperatures. (*After Auliciems and de Dear 1986*)

From ASHRAE research project 884, de Dear and Brager [1998] proposed the equation based onthe knowledge of mean indoor temperature which is:

$$T_n = 15.47 + 0.33\ T_{ope.} \tag{8.5}$$

$T_{ope.}$ is mean indoor operative temperature

To apply equation (8.5) two things should be considered which are: the variables must be composite thermal indices such as the operative temperature and then it should be applied to subjects with sedentary activity.

However, the calculated neutral temperatures from these equations for Ilam are shown in Table (8.3). The end column of the table shows neutral temperature from simple regression analysis.

Table 8.3 Prediction of Neutral temperature by Humphreys, Auliciems and de Dear models

	Humphrey eq.	*Aulicimes eq.*	*De Dear eq.*	*Simple reg.*
All hot season	28.0°C	27.7°C	26.2°C	28.1°C
All cool season	19.2°C	20.0°C	22.5°C	20.8°C
Low income subjects	26.0°C	26.0°C	25.3°C	27.2°C
Longitudinal work	26.7°C	26.7°C	25.7°C	27.5°C

Compared with the neutral temperatures from simple regression analysis Humphreys and Auliciems models indicated a small difference between them. The two models can well be used as predicting tools for neutral temperature for all groups of people in Ilam, although it seems Auliciems' equation for the cool season is a better predictor than Humphreys' equation. But de Dear's equation can not be used in Ilam although two modifications of this model can be made on the results. However, the nature of these equations makes it difficult to apply them, because they are related to indoor temperature and this is not easy to obtain.

From all experimental data in the present study equation (8.6) can be derived:

$T_n = 0.68\ T_i + 7.42$ (8.6)

T_n is neutral temperature

T_i is indoor temperature

This equation is similar to Humphreys, equation but close to Auliciems' equation in terms of slope and intercept. The lower slope in equation (8.6) than slope of Humphreys' equation indicated that adaptation processes are not complete especially at extreme temperatures.

In other words, one of the principal findings of the adaptive model is that the comfort temperature reflects the mean temperature experienced T_i [Nicol et al; 1994]. For comparison, neutral temperatures found in the Ilam study were plotted against the mean air temperatures experienced by subjects. Figure (8.7) shows such points as well as the line of equality. All points derived from the hot season surveys are shown below the equality line and points from the cool season surveys lie above the line. These results are similar with Nicol et al [1994] in Pakistan. As a resonable work if we ignored from courtyard data the slop of equation (8.6) will be 0.72/°C which is the same as slope of Auliciems' equation.

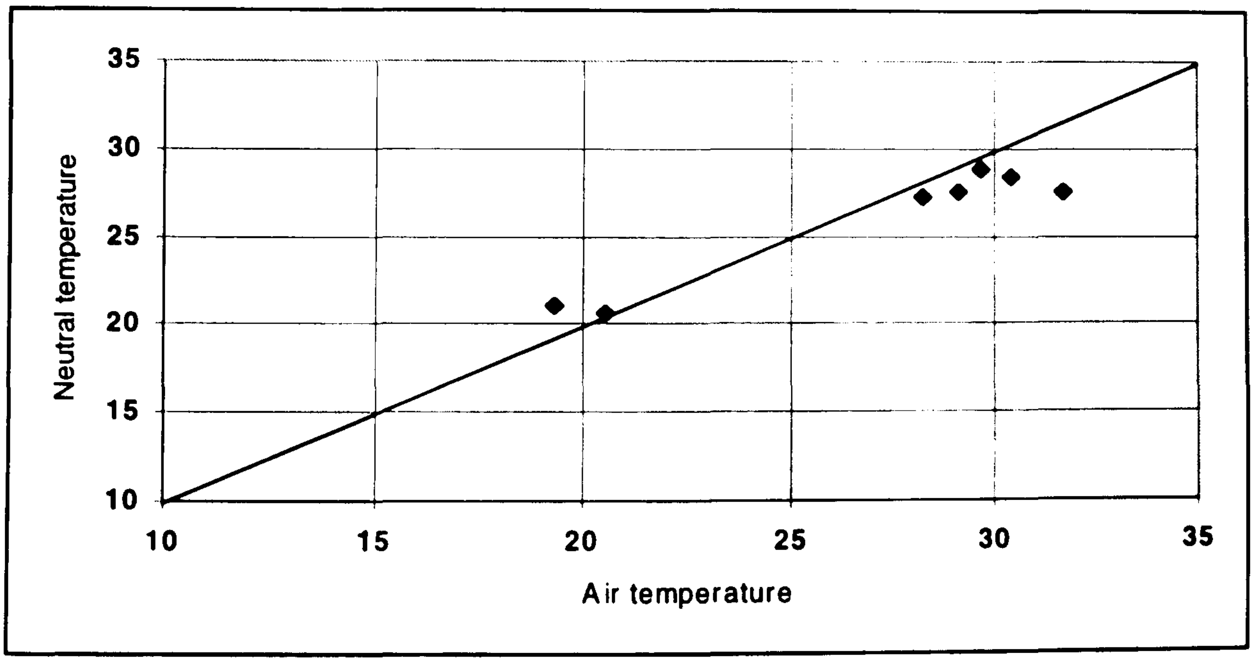


Figure 8.7 Scatter diagram of mean indoor temperature and neutral temperature

8.5 Griffiths model

Griffiths [1990] suggested a way in which the comfort temperature can be deduced from a small sample of data [Nicol et al; 1994]. Nicol noted that the method can be applied to each comfort vote to estimate the comfort temperature. The method can also be applied to a sample where the variance of the data is very small or the regression coefficient unreliable.

The assumption of Griffiths is that the increase in temperature of each scale point on the subjective comfort scale is 3K for a seven-point scale. This scale category width is used to refer to a regression line of sample regression analysis with a slope of 0.33°C. In this method each vote as a point will projected on to the temperature axis with the slope line of 0.33°C. If the temperatures axis passing zero of the comfort scale line so the mean of projected points is comfort temperature. The following equation shows Griffiths model:

$$T_n = T_i + [(0- C)/a^*] \qquad (8.7)$$

T_n is neutral temperature (°C)

T_i is indoor temperature (°C)

C is comfort vote

a^* is regression coefficient of 0.33°C

Nicol et al [1993] showed that regression analysis is liable to error because of feedback and it was decided to use Griffiths's equation with a regression coefficient of 0.33. In fact the reason for the calculated neutral temperature with a slope of 0.33 for the Griffiths method is that it does give the temperature which the subject is adapted at the time of voting [Nicol et al; 1994]. Nicol and his team [1994] applied the method to the centre points of the data from their survey. Humphreys and Nicol [1999] suggested a modification of Griffiths's method which is not used in this study.

In the present study a slope of 0.24 in two sets of summer data and slope of 0.25 during winter were obtained. The value of 0.33 has been used to calculate values of neutral temperature in all groups of subjects.

Table 8.4 Neutral temperature from Griffiths method

	T.H	C.H	Y.H	T.C	C.C	P.H	A.H	All.H	All.C
Griffiths value	28.9	28.2	29.2	19.2	20.5	27.5	27.9	28.8	19.5
Simple linear regression	28.5	27.4	28.2	21.0	20.6	27.2	27.5	28.1	20.8

CH: Contemporary Housing- Hot season
TH: Traditional Housing- Hot season
YH: Courtyard Condition- Hot season
All : All subjects during both seasons
CC: Contemporary Housing- Cool season
TC: Traditional Housing – Cool season
PH: Low income subjects – Hot season
AH: Longitudinal work in a house -Hot season

As shown in Table (8.4) the neutral temperatures from simple regression analysis during the hot season are slightly lower than the Griffiths' value, while during the cool season it is slightly higher.

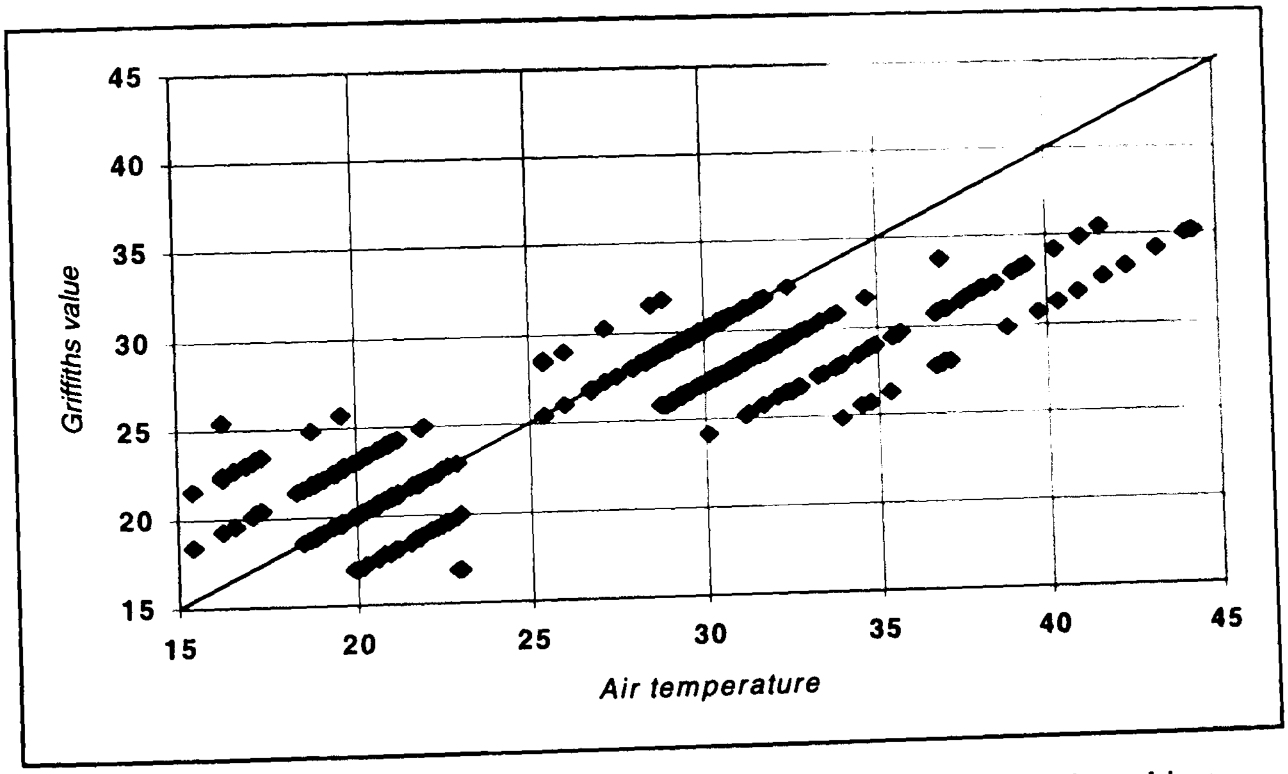


Figure 8.8 Scatter diagrams of Griffiths value and indoor temperature for subjects

Figure (8.8) shows the Griffiths value for each subject during both seasons. In this graph a similar pattern is shown. The linear regression equation of Griffiths's value in this study is:

$$T_n = 0.65\, T_i + 8.54 \tag{8.8}$$

However equation (8.6) is in agreement with other field studies and can be applied for Ilam.

8.6 Neutral temperature and mean outdoor temperature

Humphreys [1978] indicated a strong relationship between the outdoor temperatures and the comfort indoors. This model shows that there is a strong linear relationship between the monthly mean outdoor temperatures (T_{om}) and the indoor comfort temperatures (T_n) for the "free-running" buildings, but a fairly strong curvilinear line for other buildings (Figure 8.9).

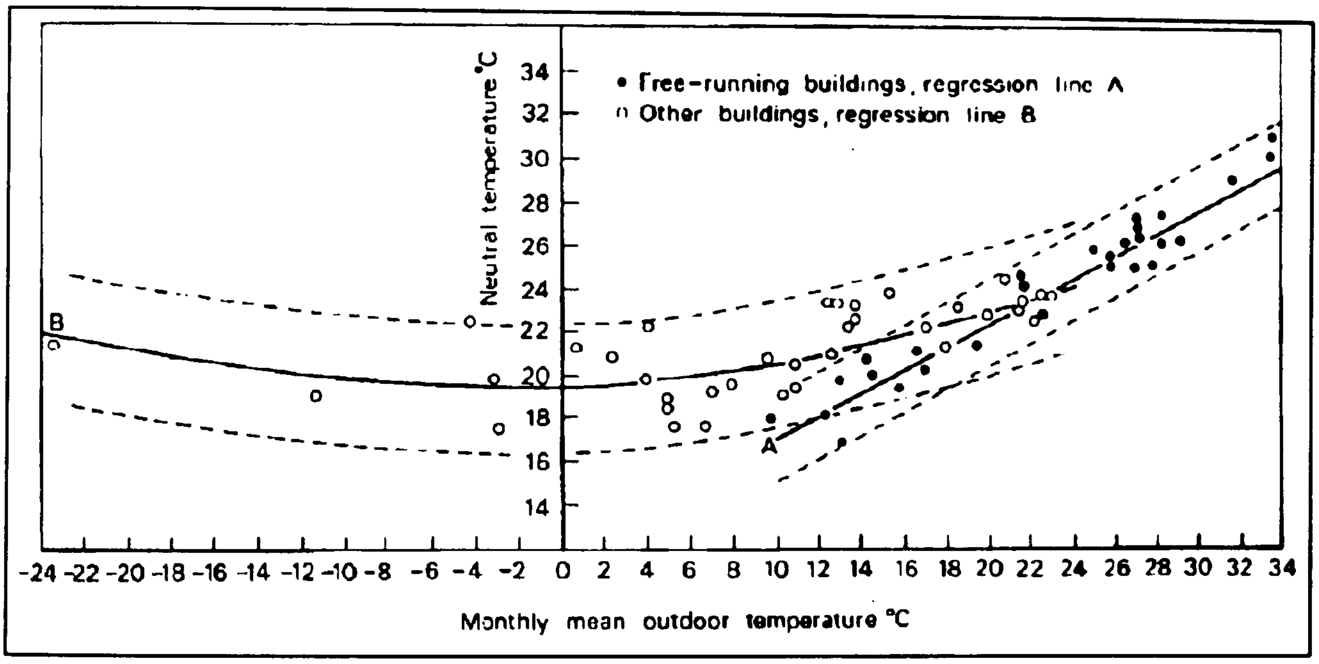


Figure 8.9 Relationship between monthly mean outdoor temperatures and neutral temperatures. (*After Humphreys 1978*)

The regression line A of the "free-running" buildings suggests that for every degree change in the monthly mean outdoor temperatures (T_{om}), the neutral temperatures (T_n) will approximately change over half a degree. The surveys found that 94 per cent of the variations of the neutral temperatures are associated with the variations of the mean outdoor temperatures and their correlation coefficient is 0.97. The standard deviation of the prediction is 1.0 K and the range of application is between 10°C and 33°C. The regression equation is:

$$T_c = 11.9 + 0.534\, T_{om} \tag{8.9}$$

T_c is comfort temperature

T_{om} is outdoor temperature

For the heated or cooled buildings (the regression line B) there is no data from hot environments. The curvature shows over the range between (-24°C and +24° C) outdoor temperatures. The best fit is found to suit the following equation:

$$T_n = 23.9 + 0.295\,(T_{om} - 22)\, exp\,\{-[(T_{om} - 22)\,/\,(24\sqrt{2})]^2\} \tag{8.10}$$

Humphreys [1978a] advised that the intersection area of line A and line B indicates the joint optimum indoor temperatures for both types of buildings. This zone implies that the buildings with heating or cooling plant should use energy by the "free-running" conditions, which can then achieve comfort and saving energy.

There is however, the important question: what does Humphreys mean by outdoor temperature? Humphreys [1994] queried if it meant the outdoor temperature at the moment or its history over the last few weeks. Normally thermal comfort studies take a few weeks to do, and then the results are pooled. The outdoor temperature might have had a different pattern of variation, which might have influenced the results. So the survey should choose a season of the year where there will be a clear sequence of outdoor temperature and see what it does to the sequence of indoor preferred temperatures.

The outdoor temperature in this study is defined as:

(monthly mean maximum + monthly mean minimum)/2

For calculated neutral temperature from outdoor temperature, this study used two categories: historical value (T_{olt}) and mean outdoor temperature during the surveys, which were obtained from the war meteorological office in Ilam. Table (8.5) shows outdoor temperatures in both categories.

Table 8.5 Outdoor temperature of Ilam

	Y.H	C.H	T.H	C.C	T.C	P.H	A.H
Historical	30.1	30.1	30.1	11.9	11.9	30.1	28.7
During survey	29.8	29.8	29.8	9.7	9.7	29.2	28.5

*When a survey was conducted in for length of two months, the mean outdoor temperature was used (from historical category)

Neutral temperature from Humphreys' equation can be estimated with a knowledge of Table (8.5). Auliciems and De dear [1986] proposed a single line for all buildings. The relationship they found between comfort temperature and outdoors-mean temperature (for 5°C < T_{om} < 30°C) was:

$$T_c = 17.6 + 0.31\, T_{om} \qquad (8.10)$$

Table (8.6) shows neutral temperatures for Ilam according to Humphreys, and Auliciems' equations.

Table 8.6 Results from Humphreys and Auliciems equations and the field surveys

		Y.H	C.H	T.H	C.C	T.C	P.H	A.H
Humphreys equation	Historical	28.0	28.0	28.0	18.3	18.3	28.0	27.2
	During Survey	27.8	27.8	27.8	17.1	17.1	27.5	27.1
Auliciems equation.	Historical	26.9	26.9	26.9	21.3	21.3	26.9	26.5
	During Survey	26.8	26.8	26.8	20.6	20.6	26.7	26.4
Simple regression		28.2	27.4	28.5	20.6	21.0	27.2	27.5

From Table (8.6) it can be seen that there was a very small difference in the results from Humphreys' equation and actual results during the hot season, but there is a difference with Auliciems' equation. The difference in the cool season was more than 2°C between actual data and Humphreys' equation, but there is no difference between actual data and results of Auliciems equation. It means that during hot periods Humphreys' equation is a better predictor while during cool periods Auliciems equation is best.

From ASHRAE research project 884, the predicted comfort temperature also will be derived from the knowledge of mean outdoor temperature:

$$T_n = 18.9 + 0.26\, ET^*_{out.} \quad (8.12)$$

This model is related to subjects with sedentary work and the new effective temperature (ET^*_{out}). Table (8.7) shows neutral temperature for Ilam people according to this equation in two categories.

Table 8.7 Neutral temperature according to outdoor temperature (if ET^*_{out} is equal with air temperature) from de Dear equation for Ilam people

		Y.H	C.H	T.H	C.C	T.C	P.H	A.H
de Dear equation	Historical	26.7	26.7	26.7	22.0	22.0	26.7	26.4
	During Survey	26.6	26.6	26.6	21.4	21.4	26.5	26.3

As shown in Table (8.7) there is a difference between results of simple regression analysis and such findings.

From the actual data of these studies and mean outdoor temperatures during the field studies equation (8.13) can be derived:

$$T_c = 0.36\, T_{om} + 17.3 \quad (8.13)$$

This equation is close to Auliciems' equation. The regression equation using historical mean outdoor temperatures gives the following equation:

$$T_c = 0.39\, T_{om} + 16.1 \quad (8\text{-}14)$$

which is the same slope as Auliciems' equation but with difference of about 1°C in intercept.

The relationship between the mean historical outdoor temperature and Griffiths value for all subjects is shown in Figure (8.10). The equation of this relationship is:

$$T_c = 0.41\ T_{om} + 16.01 \qquad (8.15)$$

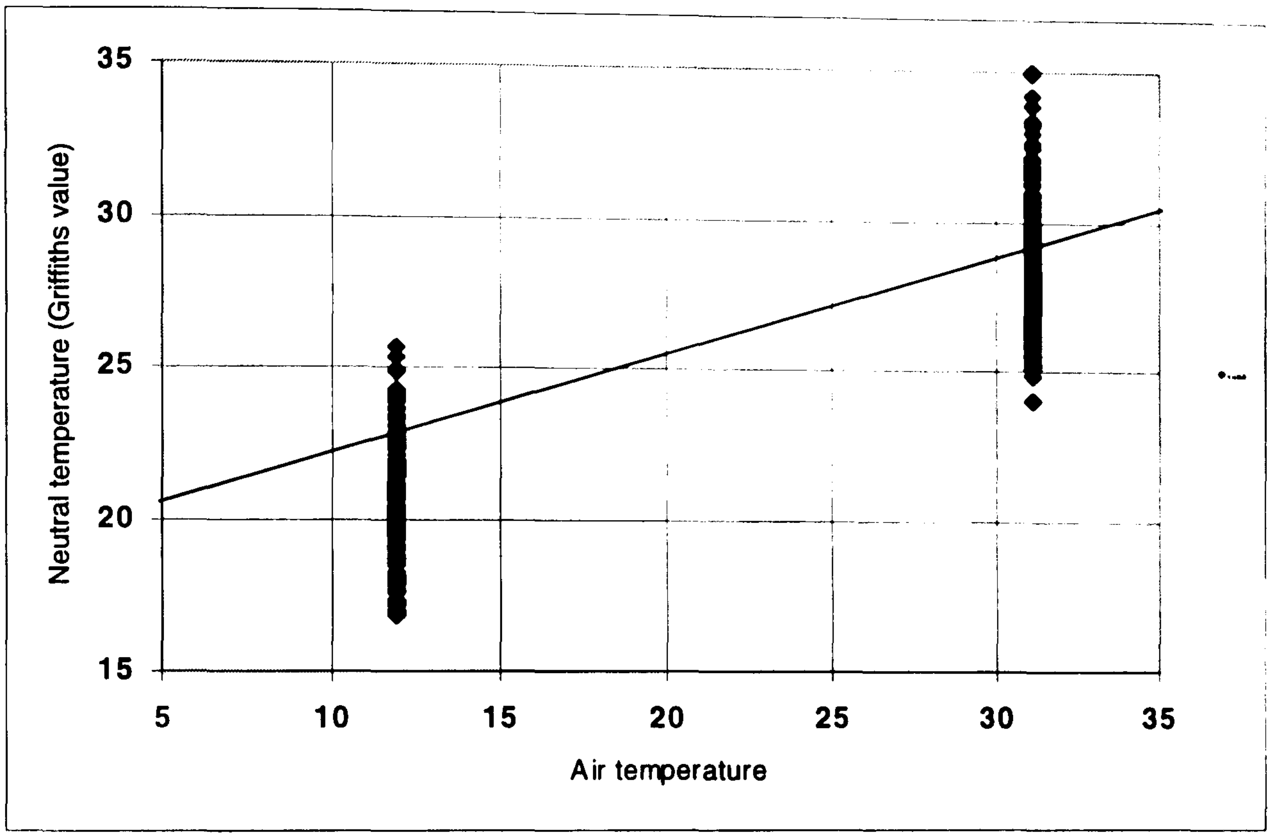


Figure 8.10 Relationship between mean historical outdoor temperature and Griffiths value for all subjects

8.7 Behaviour adaptation

Some actions relating to changes of environmental conditions included some personal and some unpersonal factors. Relationships between such actions and environmental factors were strong and significant in the present study.

1- The correlation coefficients between air temperature and thermal sensation votes in the first experimental work during hot season, in the second during cool season and in the third during hot season were (r=0.80), (r=0.75) and (r=0.79) respectively. Thus the main cause of comfort was affected by air temperature

2- Relationship between clothing values and air temperature was significant especially during cool season. Clothing insulation had a strong linear dependence on outdoor temperature and season. Mean clothing value of Ilam subjects during cool period was about 0.9 clo more than mean clothing value during hot period. Figure (8.11) shows scatter diagram between air temperature and clothing value of all subjects, which indicated that value of clothing insulation, is related to air temperature. It is possible from Figure (8.11) to suggest that removing clothing is an adaptation option down to a certain clothing level, but beyond that level social and cultural factors dominate people's clothing response.

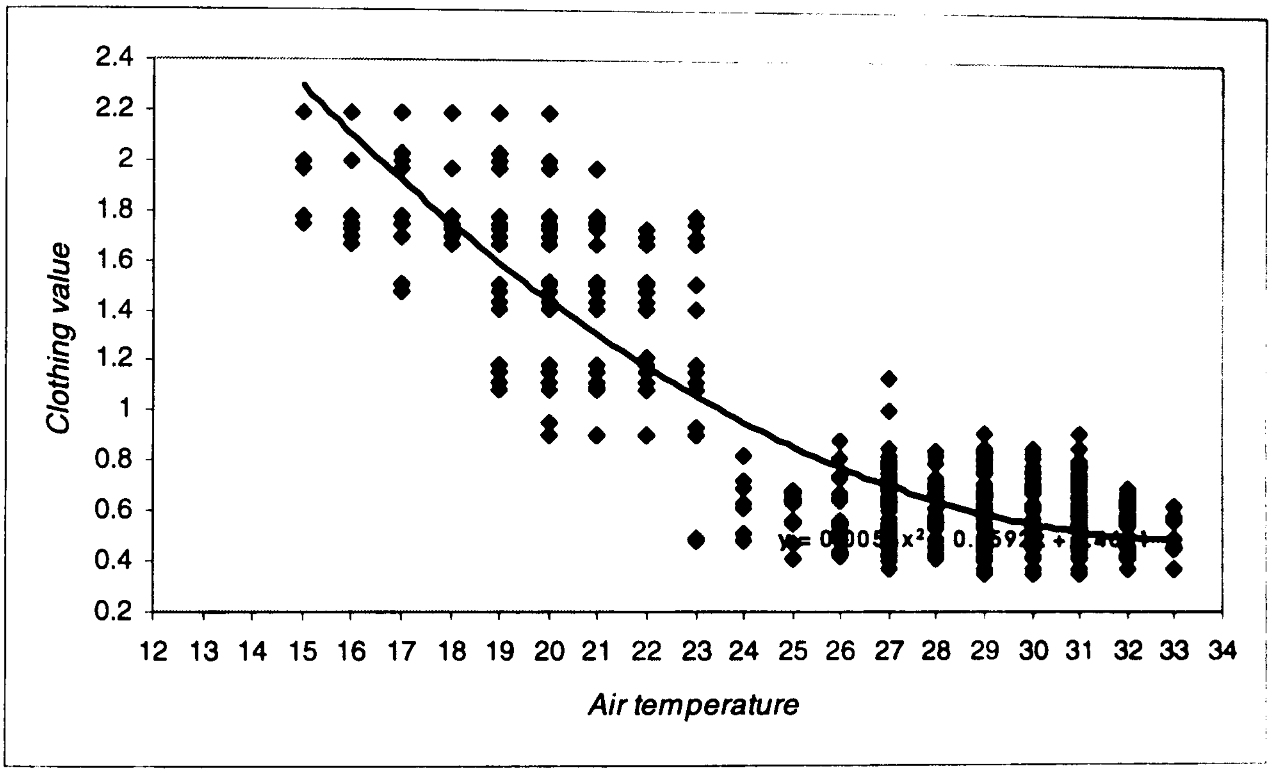


Figure 8.11 Scatter diagram between clothing and air temperature

(Equation is : **$Y= 0.0054 X^2 - 0.3592X +6.4691$ - $R^2 = 0.78$**)

3- Mean indoor air velocity is another indication of behavioural adjustment to indoor temperature. Building occupants, particularly in naturally ventilated buildings, might be expected to increase general air movement within their occupied zone, either through openable windows or fans, as air temperatures increased [de Dear and Brager; 1998]. Figure (8.12) shows a scatter diagram between indoor air temperature and air velocity. The general pattern of air velocity during cool season shows nearly all openings were kept closed, however Figure (8.12) shows a low value of air velocity at time of questionnaires during hot season. It is because of two things: Ilam people normally used hand fans (Figure 8.13). When they were filling in the questionnaire (by themselves or by interviewer), they put hand fan on floor. Thus the record of air velocity which subjects were exposed to was not possible. A second reason is that a low outdoor air velocity had an effect on low indoor air velocity. Furthermore some times in thick walls houses windows and door are normally closed during daytime and open during night-time.

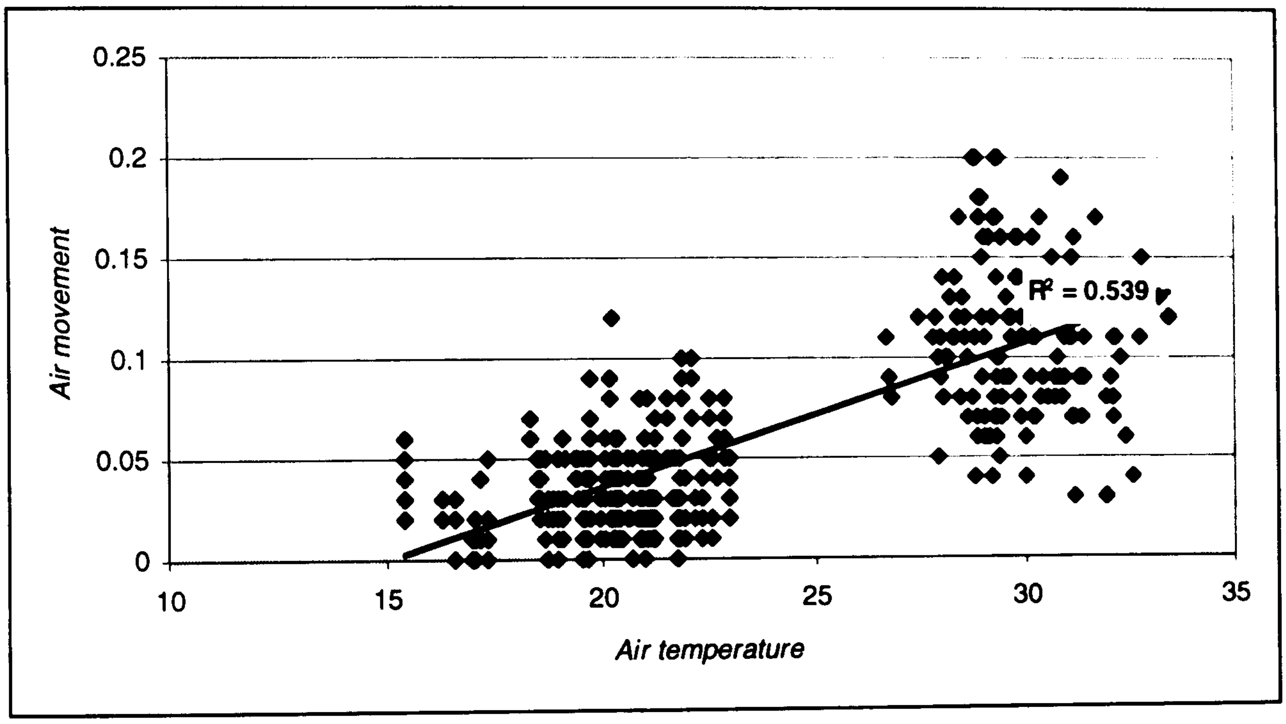
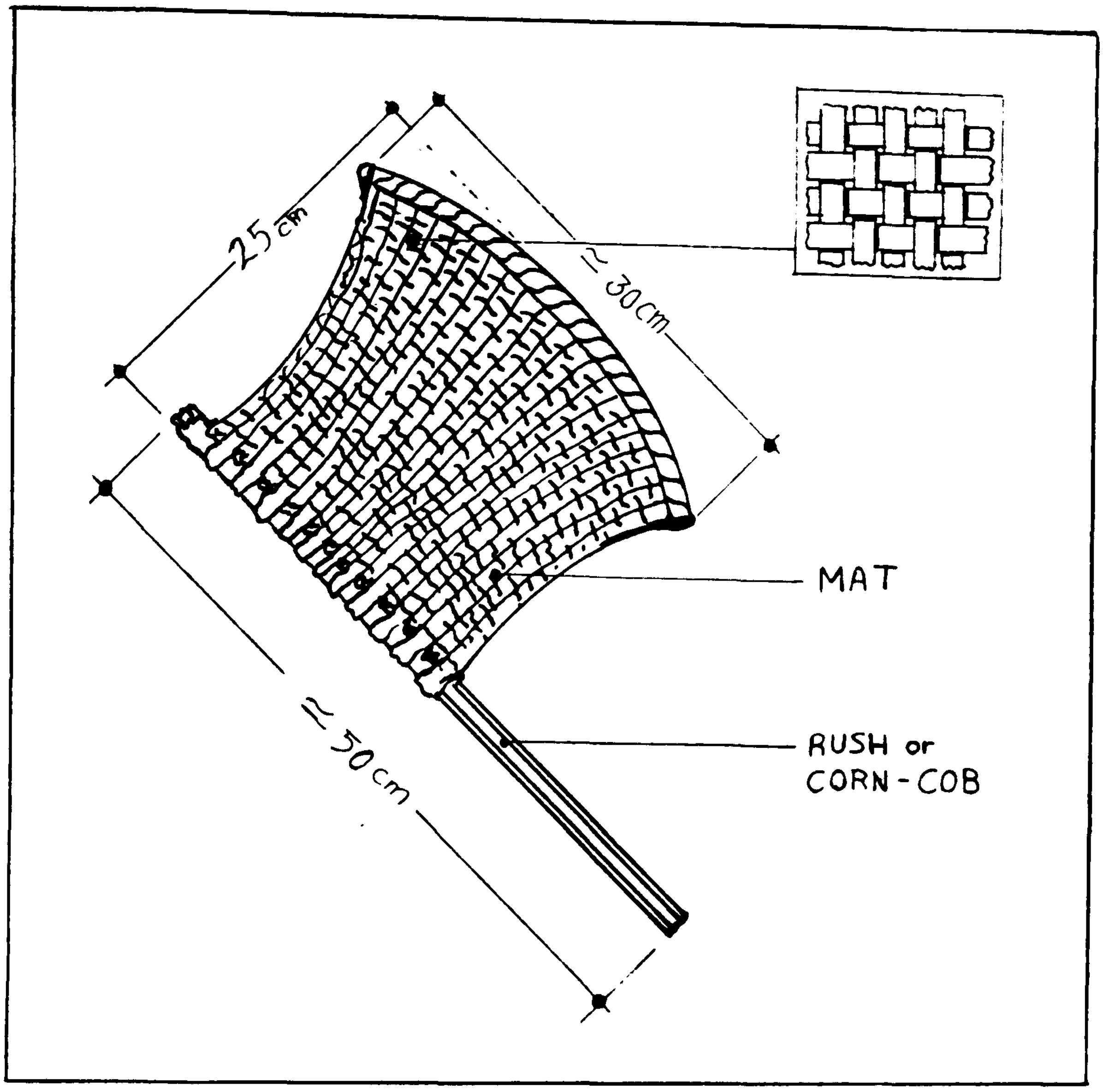


Figure 8.12 Scatter diagram of indoor air temperature and indoor air speed

*The gap between 23°C till 26°C is because of ignored from data of courtyard

4- The another important point is shown in Table (8.8) which is the changing of expectation and effect of some adaptive behaviour according to outdoor temperature and season on thermal neutrality. Table (8.8) shows percentage of each category of preference scale (three point McIntyre scale) in the different categories of air temperature during hot and cool season. Seventy four percent of subjects at 23°C wanted "no change" in their environment and 26 percent wanted cooler condition during cool season while at air temperature of 25°C (2°C higher) twenty two percent of subjects wanted warmer condition and 75% wanted "no change". It implies that subjects had different responses to environmental condition in terms of thermal acceptability.



8.13 Hand fan

Table 8.8 Percent of each category of preference vote at different air temperatures

	Cool season		Hot season		
	22°C	*23°C*	*25°C*	*27°C*	*28°C*
Percent of " wanted cooler condition"	2	26	0	0	20
Percent of " wanted no change in their condition"	67	74	78	87	82
Percent of " wanted warmer condition"	31	0	22	13	0

5- Another behaviour adaptations was moving to a different thermal environment from the one causing the discomfort, as described on part two of

Chapter seven. Results of this part showed that the subjects tended to actively seek out more thermally comfortable spaces in the house during course of a day, suggesting that one of the main forms of adaptation for Ilam subjects was movement from one place to another to another within their house.

8.8 Comparison of the PMV and AMV

Nigel Oseland [1992] made some comparison between results of a BRE thermal comfort survey in one- bedroom and bedsit starter homes in England and climatic chambers study. This part will describe such comparison between the findings of the present study during hot season (three surveys) and results of climatic chamber study as Oseland did.

Table (8.9) shows the environmental conditions in the two studies. According to information from this table some comparison could be made.

Figure (8.14) shows scatter diagram between mean thermal sensation and indoor air temperatures of Fanger's experiment and finding from Ilam study.

Table 8.9 The environmental conditions in climate chamber study and Ilam field study

	Climatic chamber	**Field studies (hot season)**
Environment	Climatic chamber	Homes
Subjects	256 Danish subjects	About 700 Ilam subjects
Clothing	Standardised 0.6 clo	Approx. 0.6 clo
Activity	Sedentary	Approx. sedentary
Temperature	21°C -28°C	Not controlled 26°C- 33°C
Air velocity	Approx. 0.1 m/s	Approx. 0.1 m/s
Humidity	30% & 70%	20% - 70%
Radiant temperature	Equal to air temperature	Approx equal to air temperature

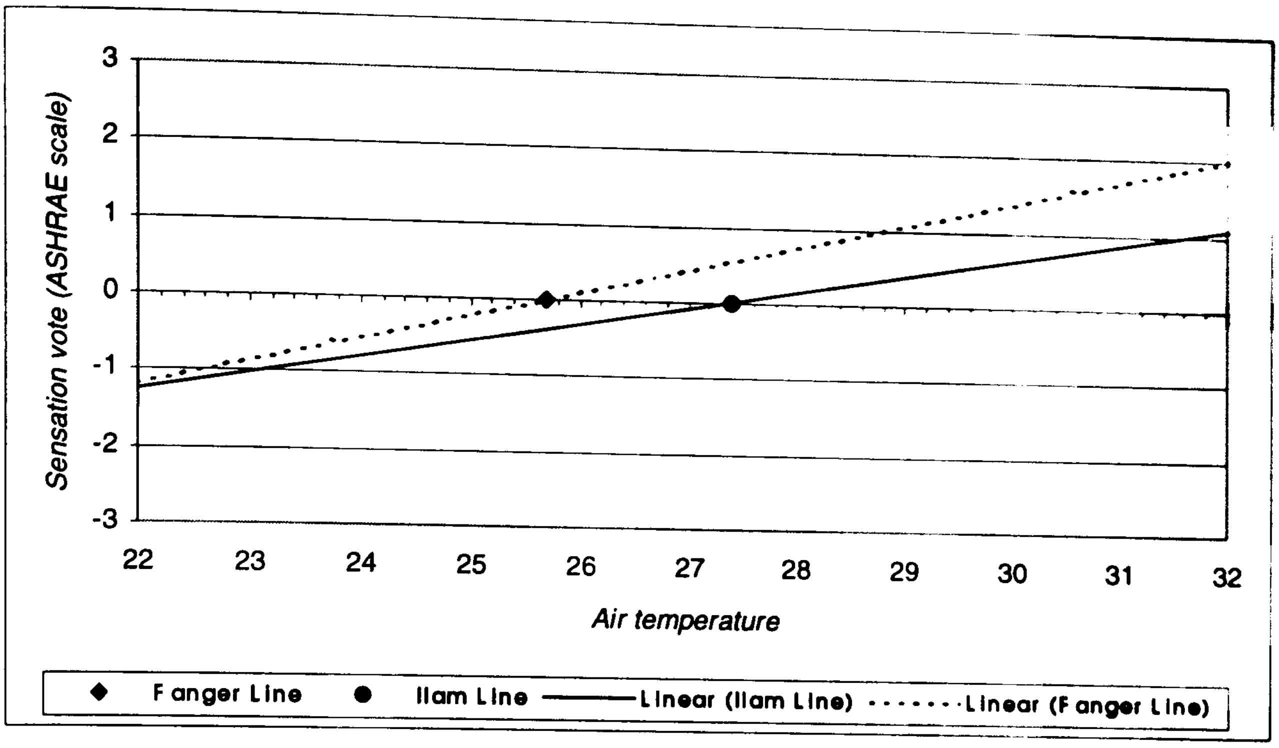


Figure 8.14 Diagrame of air temperature and sensation votes

The Ilam line in Figure (8.14) is obtained by equation which comes from three surveys (Chapter Six). As shown in Figure (8.14) slope of Fanger's line is steeper than Ilam's line and there is a difference (more than 2°C) between the neutral temperature from both studies. Furthermore Fanger's subjects were comfortable at half range of Ilam subjects. Fanger (1992) noted that comparative study by Oseland (1992) might not be correct because he only measured air temperature from six variables and clothing insulation was not reported and described as "medium dress". Fanger continued that Oseland states his occupants were sedentary, but he may be ignoring the psychological circumstances under which they were studied.

As another way the PMV values in Ilam survey during hot season are determined by a thermal comfort prediction tool ("Win- Comf" on Windows [Fountain et al: 1996a,b]). First, the indoor air temperature of the Ilam study was rounded to the nearest 0.5°C and second, just subjects who wear a value of clothing between 0.55 clo and 0.65 clo with sedentary activity about 1.2 met were used. Overall data from 200 subjects were put in computer programme. The actual and predicted sensation vote of each subject and air temperature is plotted in Figure (8.15).

The regression coefficient of the PMV is 0.30/°C and is much higher than that of the actual mean vote (AMV) of 0.21/°C. Such a discrepancy between estimated neutral temperature from PMV line and AMV line exists. The neutral temperature of the actual mean vote is 27.4°C while the predicted temperature from PMV is 24.2°C. The difference about 3K is in line with findings from Humphreys study [1994], (see Chapter Five).

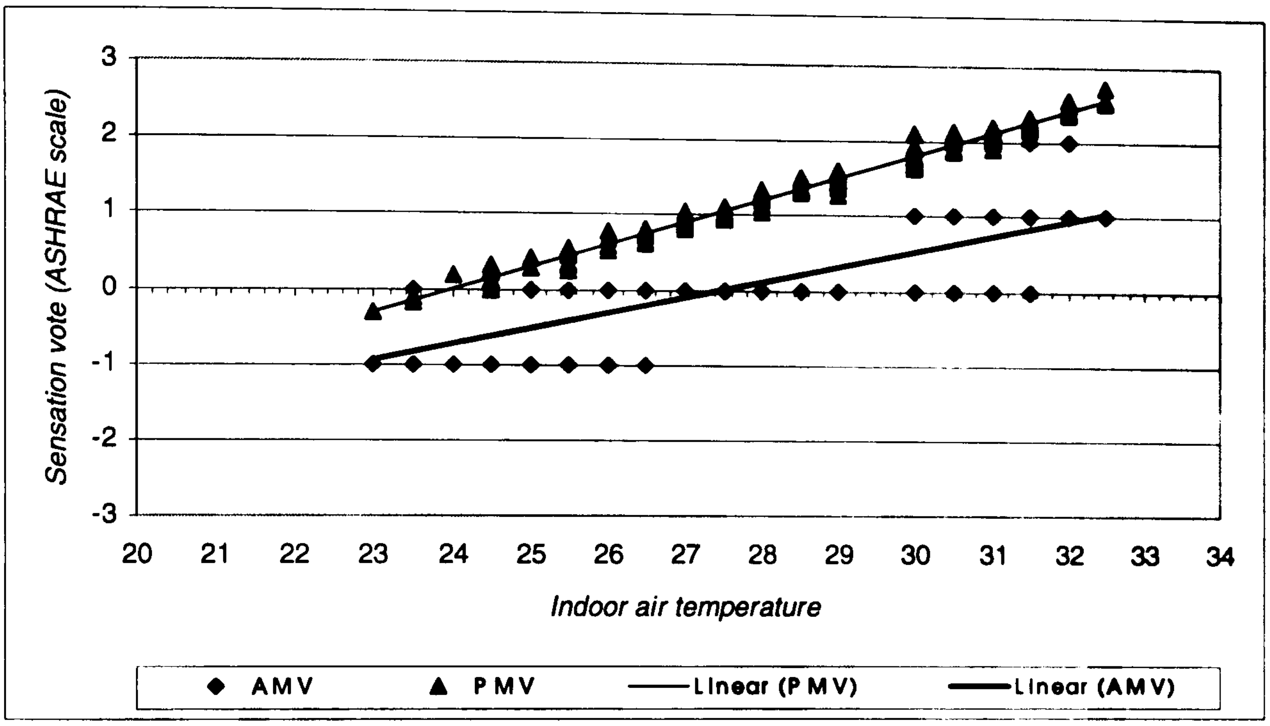


Figure 8.17 Scatter diagram of predicted mean votes and actual mean votes with air temperature for Ilam subjects

*For PMV (Y= 0.302 X -7.2542 & R^2=0.98) and for AMV (Y=0.208 X -5.7366 & R^2=0.58)

8.9 Comparison to the bioclimatic charts

The first published graphic presentation of climatic data, designed specifically as a basis for evaluating human comfort need and building design objectives was by Victor and Aladar Olgyay in the early 1950s [Olgyay and Olgyay; 1963]. According to Givoni [1976], this was the first attempt to propose a systematic procedure for adapting the design of a building to the human requirements and climatic conditions. The Olgyay bioclimatic chart is a temperature-humidity diagram used to display the comfort needs of a sedentary person. The chart is applicable to people living in temperate regions of the USA at elevations below 300m above sea level. Olgyay noted that it can be applied to climatic regions other than latitude 40° by elevating the lower perimeter of the summer comfort zone by 0.42°C for every 5° latitude change towards lower latitudes and upper perimeter similarly, but not above 29.4°C.

The Olgyay recommended comfort zone for people living in Ilam is found to be about 21.5°C to 28.3°C. Figure (8.16) shows an average yearly evaluation of the conditions for Ilam. Figure (8.16) shows the points of mean monthly air temperatures maxima and minima with their corresponding mean monthly relative humidity minima and maxima.

It is apparent that most of the year the relative humidity is within the humidity comfort zone bounded by the curved 20% and 80% Rh line. Only in July is this zone exceeded when the air is too dry and hot. Figure (8.16) also indicates that during January, February, March and December, the Ilam condition is cold both day and night, while there are hot conditions during June, July, August and September.

Olgyay has made the comment that, in his experience, indoor temperatures are very close to the outdoor level [Givoni; 1992]. Therefore he has suggested that these charts could be used also as guidelines for buildings. This can be a reasonable approximation in light weight buildings in humid regions, where Olgyay has lived and where residential buildings are usually ventilated naturally during the summer through open, although usually screened, windows. But even in this case indoor night temperatures, even in winter, are significantly higher than the outdoors even in unheated buildings, leading to overestimation of the need for heating [Givoni; 1998]. Thus in the context of hot dry regions and naturally ventilated housing, there are some problems to applying Olgyay charts, such as:

1- The upper and lower limits of acceptable condition for Ilam people in the present study are beyond that those predicted by Olgyay chart

2- The summer indoor daytime temperature measured in this study shows a considerable difference from the outdoor temperature, so the Olgyay chart may not be the right guideline for indoor comfort.

3- Indoor night temperatures are often above the outdoor temperature, thus using the Olgyay charts cause the overestimation of the heating need during night time during the cool season

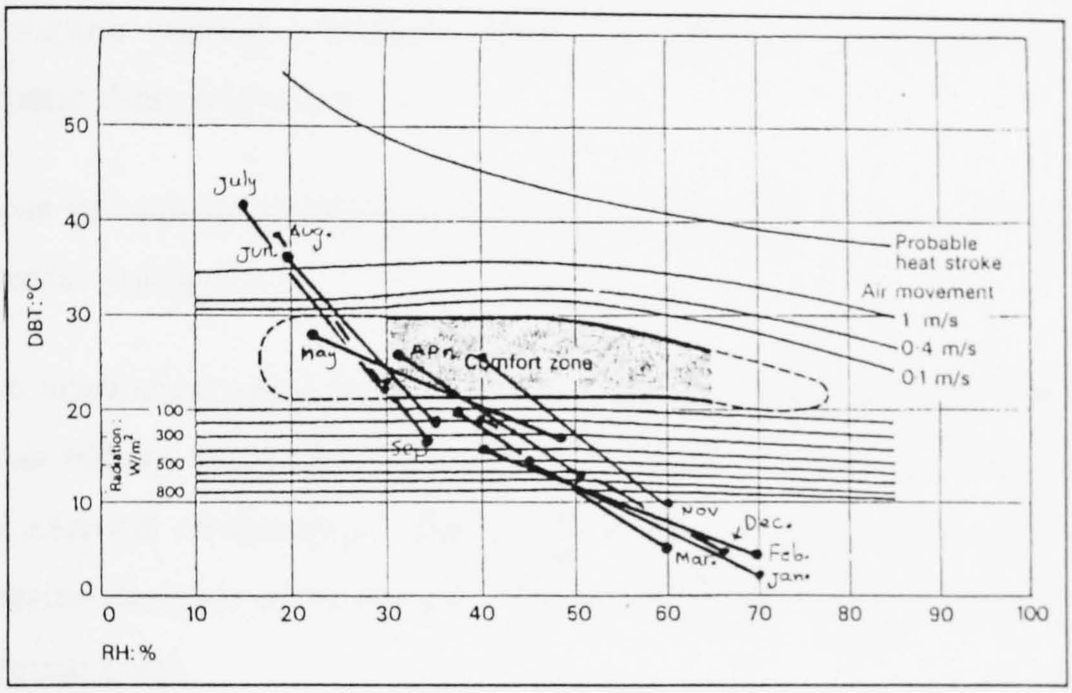


Figure 8.16 Bioclimatic charts of Olgyay and Ilam yearly conditions

4- Olgyay chart suggested ventilation during summer daytime. The result is heat storage within the building's mass. This stored heat will be released during the night time where the indoor condition is at comfort, so this caused discomfort during the night-time

Another building bioclimatic chart was developed by Givoni [1976] to address the weaknesses identified in Olgyay's bioclimatic chart. Givoni based his study on the linear relationship between the temperature and vapour pressure of the outdoor air in various regions. In his chart and according to the relationship between the average monthly vapour pressure and temperature amplitude of the outdoor air, the appropriate passive cooling strategies are defined according to the climatic conditions prevailing outside the building envelope. The chart was later revised to differentiate between people living in the developed and developing countries to take account of the acclimatisation resulting from living in unconditioned buildings in hot climates [Givoni; 1992]. The comfort zones are for acclimatised people at rest or engaged in sedentary activity in still air. The comfort zones for people living in developed countries are 18-25°C (winter) and 20-27°C (summer), the upper temperature limits are applicable only at humidities below vapour contents of 10 g/kg, while the upper limit of humidity was 15g/kg. For inhabitants of the hot developing countries Givoni [1992] suggests an increase of 2°C on the upper temperature limit and 2g/kg on the upper vapour content. Watson [1981] identified the limitations of Givoni's bioclimatic chart analysis as:

1- It can be applied mainly to residential scale structures, which are free of any internal heat gains.

2- The ventilation upper boundary zone is based on the assumption that indoor mean radiant temperature and vapour pressure is nearly the same as those of the external environment. This necessitates a building of low mass and an exterior structure of medium to high thermal resistance provided with white external paint.

3- The thermal mass effectiveness is based on the assumption that all windows are closed during the daytime, a still indoor air and the indoor vapour pressure is higher than the outside.

The Givoni chart (Figure 8.17) suggests boundaries of the climatic conditions within which various building design strategies, as well as passive and low energy cooling systems, can provide indoor comfort in hot climates without air conditioning.

These cooling options included:

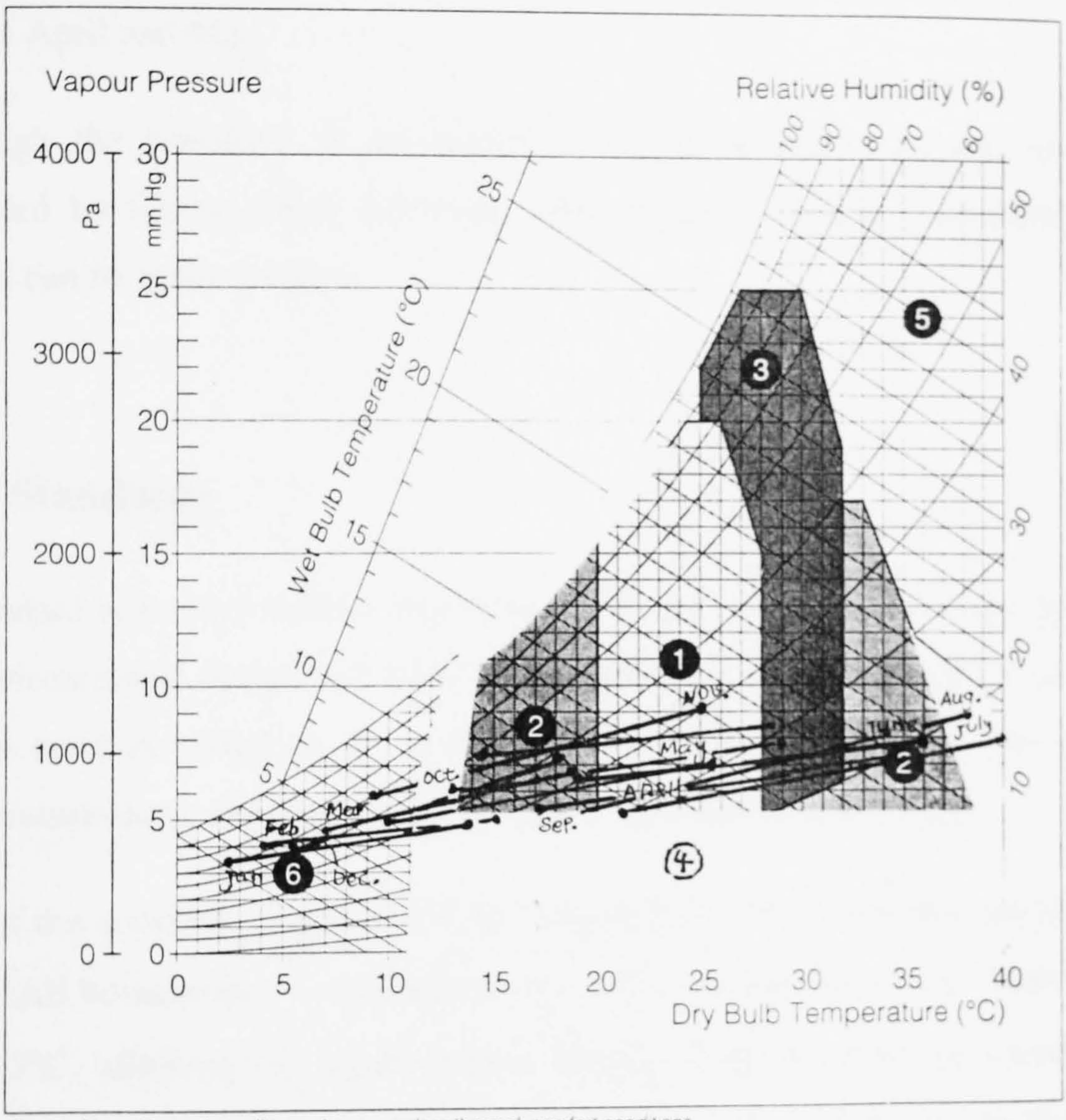
1- Day time ventilation

2- High mass, with or without and nocturnal ventilation

3- Direct evaporative cooling

4- Indirect evaporative cooling by roof ponds

Figure (8.17) also shows Ilam condition during the year.



Graph of hygrothermal conditions showing indoor thermal comfort conditions

1. Comfort zone
2. Zone of influence of thermal inertia
3. Zone of influence of ventilation
4. Zone of influence of occupant behaviour
5. Air conditioning zone
6. Heating zone

Figure 8.17 Givoni's buildings bioclimatic chart and Ilam condition

According to knowledge of the Givoni chart, people of Ilam need heating systems in their houses during January, February and December because of the monthly maximum and minimum of air temperature and relative humidity. Both daytime and night-time are cold. During the night time for the months of June, July, August, September and the daytime of April the condition is comfortable while the night time of March and November are quite cold so the heating systems are need. With changing of clothing and other adaptive behaviour people will be comfortable in the daytime of March. The chart indicates that high mass building coupled with ventilation can effectively restore comfort for the day times of June, August, September, October, November and also the night time of April and May.

Although the boundary of acceptable condition in this is beyond than that predicted by Givoni chart, however, some passive systems recommended by Givoni can be apply for Ilam.

8.10 Standards

A standard is used to define conditions of thermal comfort to provide guidance on environmental design and control. The main expectation of current standards is that comfort condition is "stable". Humphreys [1994] noted that comfort temperatures have changed markedly during the last hundred years.

One of the standards is the ASHRAE standard, which is used extensively. The ASHRAE boundaries of acceptable temperature in summer extends from 23.0°C to 26.5°C, allowing the upper limit to change with changing air speed (up to 28.0°C). The acceptable upper humidity limit is not affected at all by the higher air speed in the ASHRAE standard. This standard is not flexible beyond these limits.

Another current standard is ISO based on Fanger's comfort equation, which is more flexible than ASHRAE. According to Humphreys [1994] ISO is a standard method rather than a standard environment. To obtain comfort temperatures from the equation it is necessary to supply from tabulated information estimates of the clothing insulation and the rate of metabolic heat production of the people [Humphreys; 1994]. Parsons [1994] noted that no doubt those ISO standards have made a significant impact on the design and assessment of spaces for thermal comfort. But the Fanger equation has not been consistently successful in estimating comfort temperatures for normal living, particularly if conditions differ sharply from those from which the comfort equation was derived [Humphreys; 1994], (see also above part 8.8).

Present field studies have demonstrated the upper and lower limits of comfort condition are flexible. In agreement with Humphreys and Nicol [1970], and according to much reasonable data from field studies of thermal comfort and especially according to the Ilam results, it is suggested that air temperature alone is a good indicator for thermal comfort. One thing, however, should be a consideration. Some evidence (such as Oseland; 1993, Brager et al; 1994, Heijs; 1994, de Dear; 1994) implies that design temperatures should not be based on neutral thermal sensation but on what is preferred. According to Oseland [1994] the importance of level of control over the thermal environment may be underestimated in current guidance on optimum thermal design, although SCANVAC [1991] suggests that the best design will offer individual control to the occupants.

8.11 Applying the survey results to housing design in Ilam

8.11.1 Neutral temperature in different months

Based on Humphreys' equation (8.9), Auliciems' equation (8.11) and predicted equation based on Ilam experimental data (8.13) the predicted neutral temperature for Ilam in the different months is shown in Figure (8.18).

Figure (8.18) shows Auliciems' rate has overvalued thermal neutrality temperature for ten months of the year compared to Humphreys value while both rates during June are the same and during July Humphreys' rate has overvalued. Comparison between Auliciems' value and the results of the Ilam surveys shows a similar pattern for most time of the year while Humphreys' values for cool times are far from Ilam results. One reason can be that Auliciems for his model added some data from hot regions. However, the three equations have nearly the same rate for six months of the year. According to such comparisons it seems that the results of the present survey can be applied to the whole of the year.

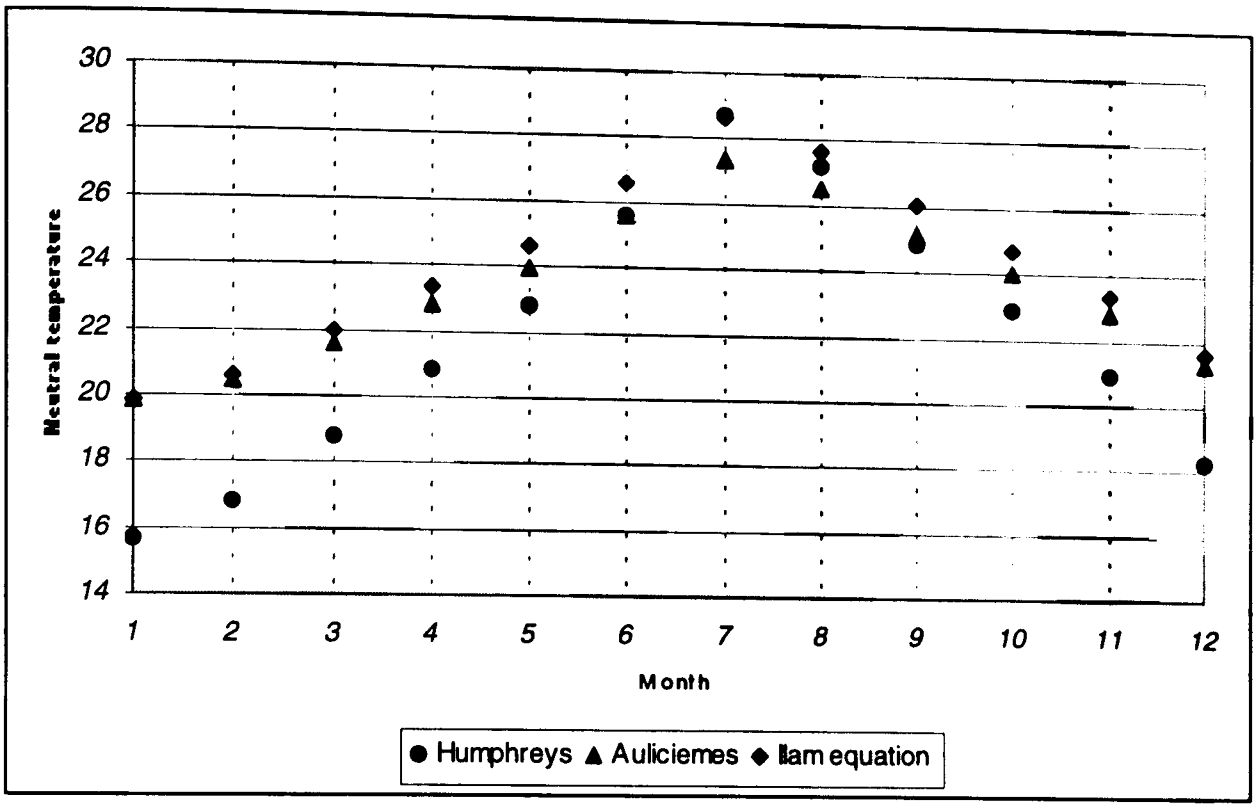


Figure 8.18 Comparison of Humphreys and Auliciems neutral temperature and results of Ilam survey

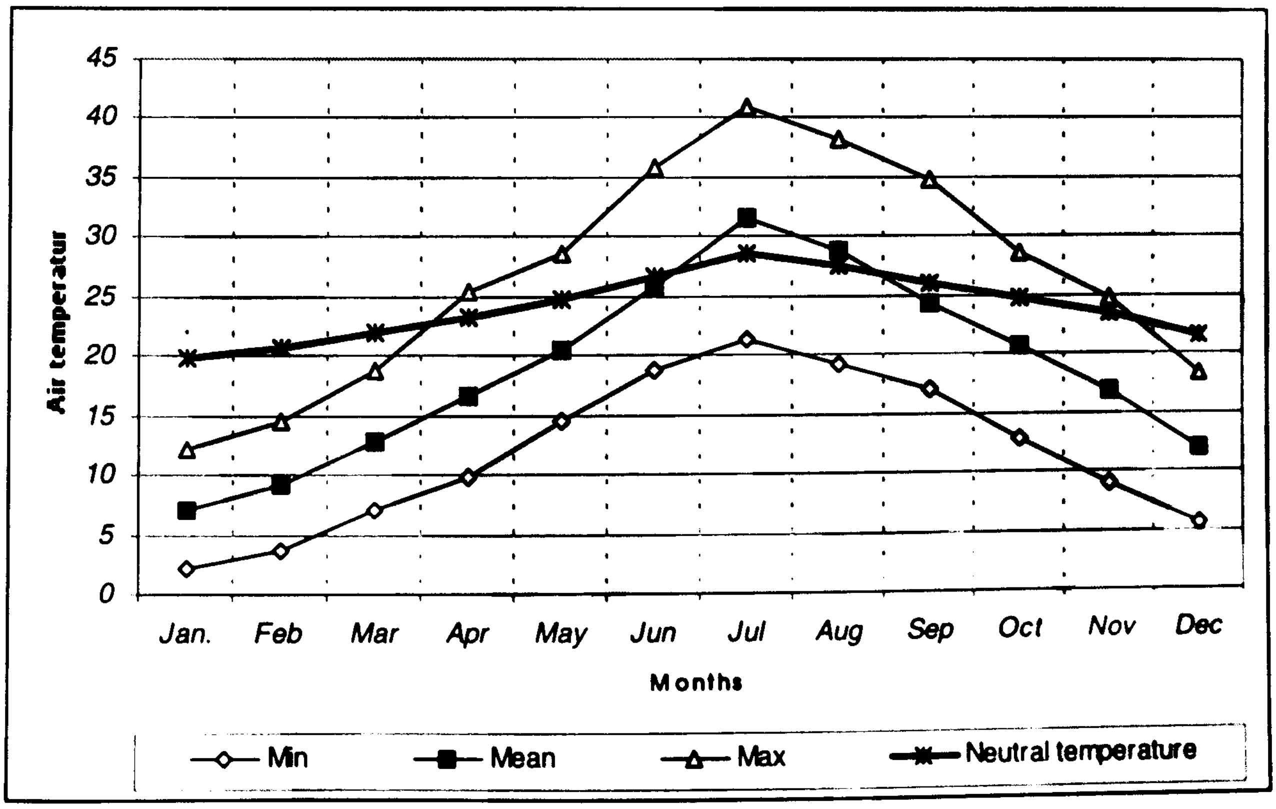


Figure 8.19 Neutral temperature for different months in Ilam

Therefore one of the best predictors of the neutral temperature for Ilam is equation (8.13):

$$T_n = 17.3+0.36\ T_{om} \tag{8.13}$$

Figure (8.19) shows the neutral temperature for different months in Ilam. The mean and range of historical outdoor temperature are also shows in Figure (8.19).

Equation (8.13) indicated that the indoors neutral temperature equals the outdoor mean temperature at 27.0°C. Thus the neutral temperature of May, June, July, August and September will to be close to the outdoor mean temperature of Ilam and during January, February, March and December the maximum outdoor temperatures are below the neutral temperature while neutrality of April, May, October and November are below the line of maximum outdoor temperature (as shown in Figure 8.19). Three periods, however, in Ilam can be recognized: hot period (June, July, August and September), moderate period (April, may, October and November) and cool period (January, February, March and December). For hot period passive-cooling systems can be applied. Nighttime ventilation and evaporative cooling in hot times of the day are two ways to achieve comfort. It should be noted that high-mass buildings with negligible heat gain or sun penetration are more suitable. In the cool period use of solar gain and closing the building at night and ventilating with warmer air during the day can be used. When such ways fail, indoor heating will be needed.

As a result, and in agreement with Nicol and Roaf [1996], an indoor air temperature which varies with climate and season is not incompatible with existing vernacular architecture. Used as a guide to desirable indoor temperatures, it can help to suggest the appropriate passive strategy for new buildings in Ilam and improving the present buildings.

8.11.2 Indoor, outdoor, and acceptable temperatures

Table (6.6) in Chapter six has shown that the mean internal air temperatures during hot season is between 26.7°C to 32.7°C in the traditional housing and between 28.0°C to 32.6°C in the contemporary housing. Such ranges during the cool season is 17.0°C to 23.0°C in the contemporary housing and between 15.4°C to 22.5°C in the traditional housing. According to start time and finish time of the survey in each day (Tables 6.3 and 6.4) and standard deviation of air temperature, it seems Ilam people can keep indoor air temperatures of their houses at a minimum of 26.5°C and at a maximum of 33.0°C in hot season where historical outdoor temperatures showed the range of 19.3°C to 41.0°C. Similarly during cool season when indoor air temperatures are between 15.0°C and 23.0°C, outdoor temperatures are at range of 5.5°C to 18.3°C. Figures (8.20) and (8.21) shows external, internal and neutral temperatures during both seasons.

In the hot season the maximum indoor temperatures, which often occurred at noontime, are well below maximum outdoor temperatures while during cool season maximum indoor temperatures are below maximum outdoor temperatures. However, due to the large diurnal range of the outdoor temperatures in both seasons a considerable part of the day is usually outside the acceptable range. This means that achieving comfort will entail a reduction of the diurnal range.

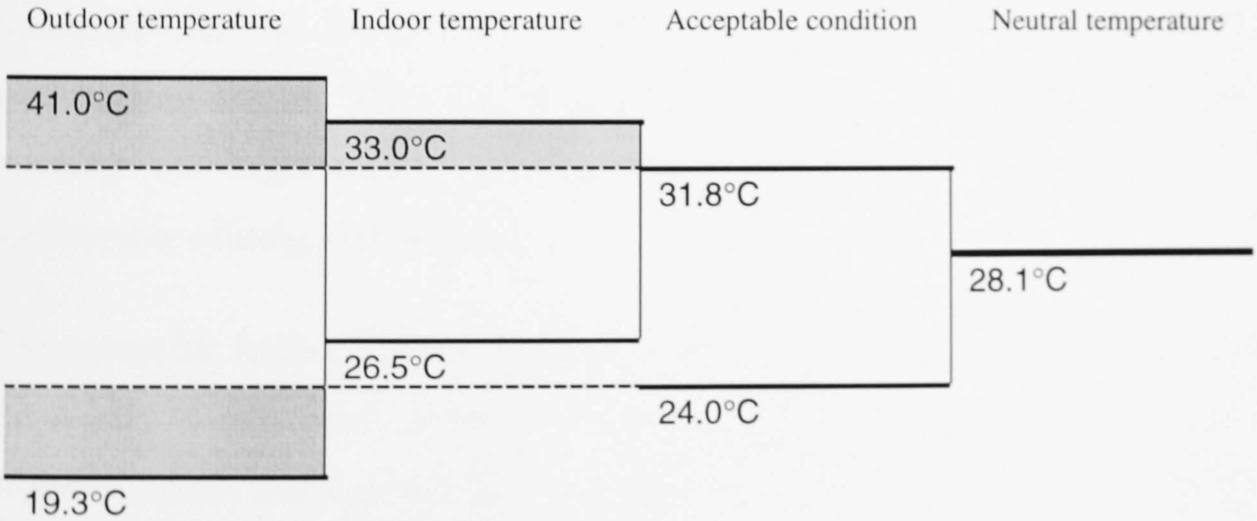


Figure 8.20 Comparison between outdoors, indoor and acceptable condition for Ilam people during hot season

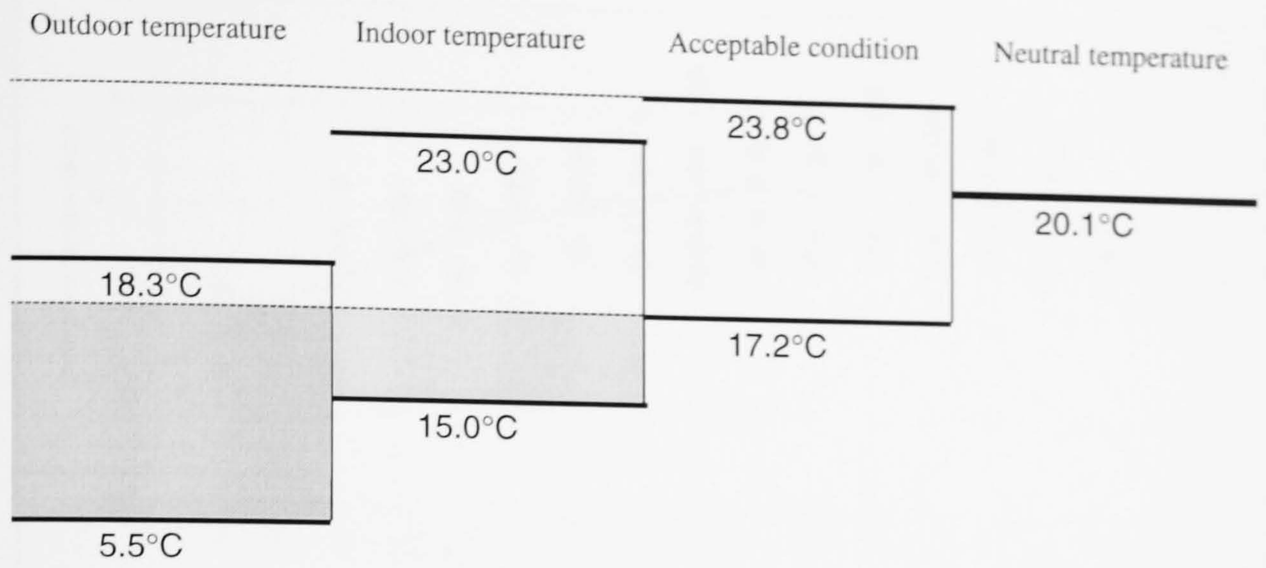


Figure 8.21 Comparison between outdoors, indoor and acceptable condition for Ilam people during hot season

Figures (8.22) and (8.23) shows scatter points between indoor air temperature and time for hot and cool periods, and the Figures indicate an interesting point. There is a variation in temperature as the day progresses with a peak in the afternoon/evening. In the cool season pattern there is a slight tendency to a lower temperature in the afternoon. Since houses are not all free- running there are a number of possible ways that the temperatures might react in this way. Some of the subjects have their heating ON during the evening and night but not during the day. In the naturally ventilated housing of Ilam people sometimes used heating means, when their experience shows the condition is cool. Early morning and night time were cool but often between 10.00 and 16.00 is comfortable (during cool season).

The researcher knows his data for such results can not be quite correct because of the nature of transverse work in the large number of different houses in the different times, but it is not far from the truth. The indoors cool condition in early morning and night-time with small heating means could be same as noontime without heating means. Another reason could be that activity rate is high during day but is low during night as well as during morning time because of this people are not interested to use of heating.

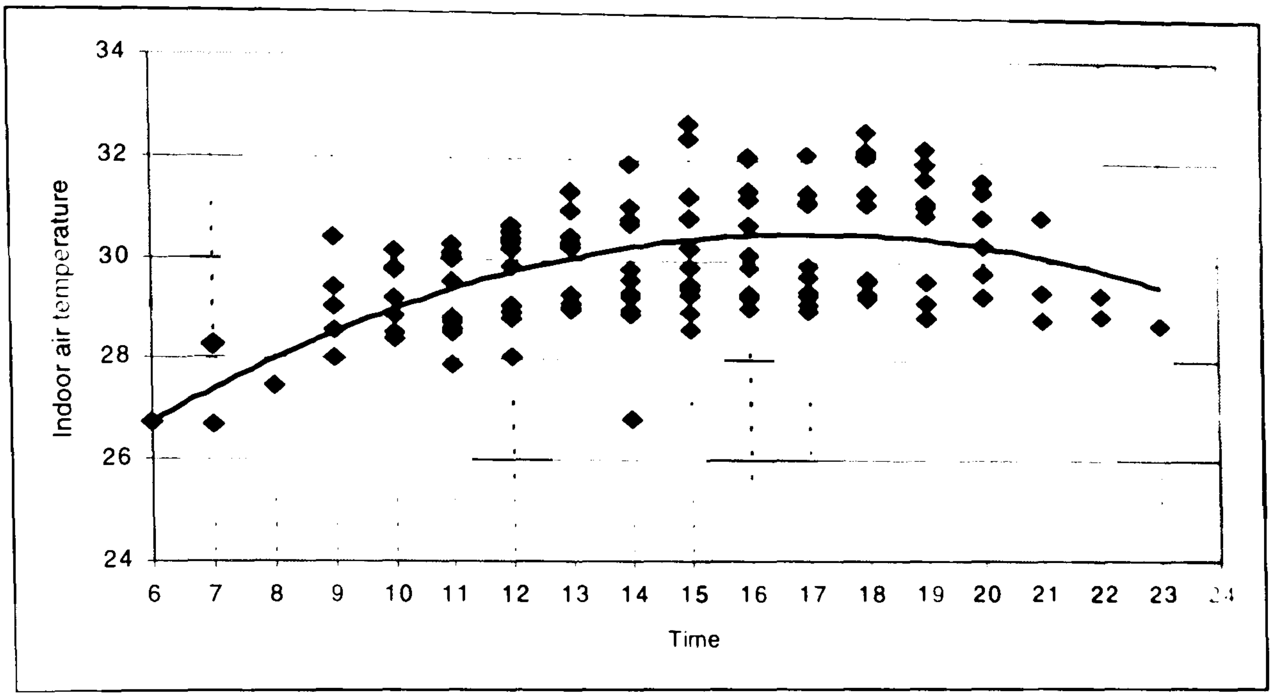


Figure 8.22 The scatter diagram of indoor temperatures and time with fitted line during hot season

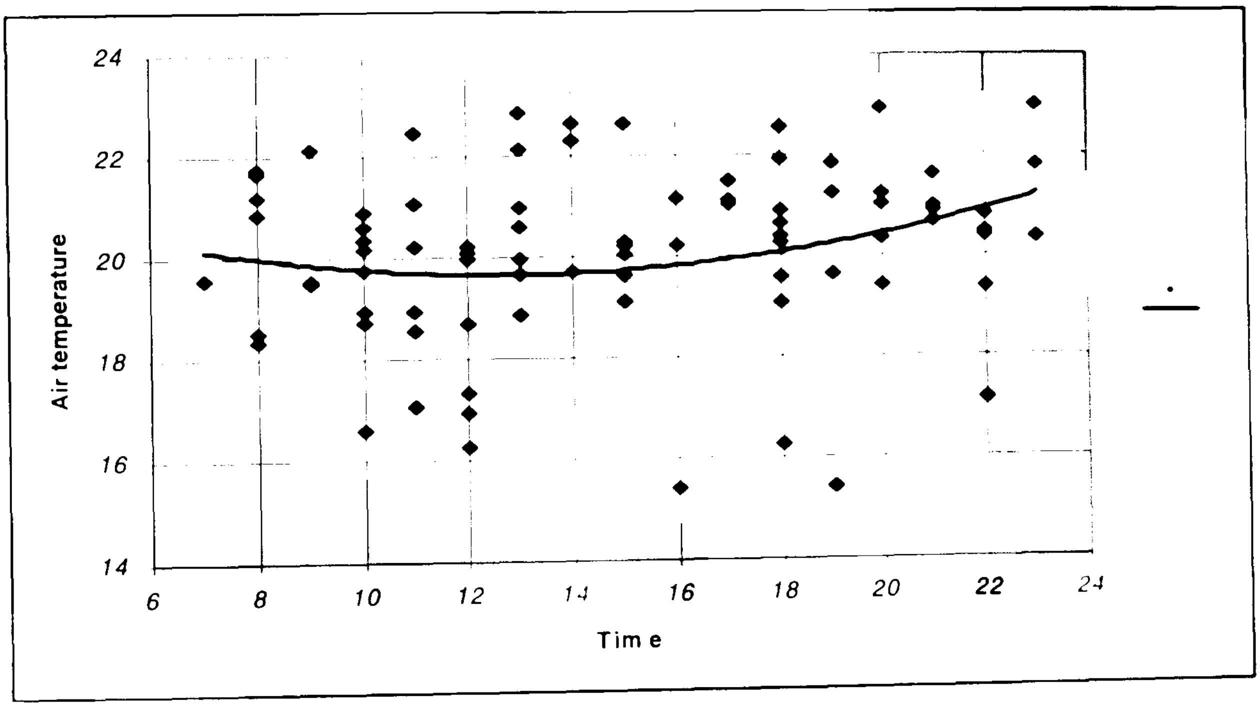


Figure 8.23 The scatter diagram of indoor temperatures and time with fitted line during cool season

As mentioned above, the winter scatter suggests that there is a slight upward ramp of temperatures as the day goes on which then drops off over night-again.

In other word the subjects keep the room they occupy at slightly warmer. Looking at the daily variation in the mean comfort vote suggests that they become more comfortable as that day wears on - in other words they are adapting their environment to suit themselves.

8.11.3 Mahony's tables

A good result of the present study is that some passive systems can be applied for housing design in Ilam. However, Mahony tables, with some correction according to acceptable limits of Ilam people, can be used as a guideline.

For the purpose of systematic climatic analysis and building design guidelines, the Department of Development and Tropical Studies of the Architectural Association in London introduced the Mahony Tables. The Tables are used to analyse the climatic characteristics, from which design indicators are obtained. From these indicators a preliminary picture of layout, orientation, shape and structure of the climatic responsive design can be obtained. In this system climatic parameters are grouped into different ranges. Mean monthly relative humidity is divided into four categories: below 30%, between 30-50%, between 50-70% and above 70%. These values can be found for each month by adding the monthly mean maxima and mean minima of relative humidity and dividing it by two. In later lines of the first Table, monthly mean maximum and mean minimum air temperature values (should be rounded to the nearest 0.5°C), mean range of air temperature for each month and monthly average rainfall (in mm) should be entered respectively. Ilam data are tabulated for Ilam in Table (8.10).

Table 8.10 The first Table of Mahony tables for Ilam

	J	F	M	A	M	J	J	A	S	O	N	D
Average of RH%	58	55	49	42.5	35	27	22	24.5	27.5	36	50	54.5
Humidity group	3	3	2	2	2	1	1	1	1	2	3	3
Monthly mean max. Ta	12	14.5	18.5	25.5	28.5	36	41	38	35	28.5	25	18.5
Monthly mean min. Ta	2	3.5	7	10	14.5	18.5	21.5	19.5	17	13	9	5.5
Monthly mean range	10	11	11.5	15.5	14	17.5	19.5	18.5	18	15.5	14	13
Rain fall (mm)	93	72	30	27	11	0	0	0	0	18	33	85

The monthly mean maxima and minima of the site in question are compared to the day and night comfort limits for each month. For comfort conditions the following classification should be used:

***H** (hot)- if mean is above limit*

***O** (comfort) - if mean is within limits*

***C** (cold) - if mean is below the limit*

The upper and lower comfort limits for day and night can be achieved from Table (8.11) according to humidity groups and AMT (AMT is annual mean temperature, which is found by adding the highest of the twelve maxima and lowest of the twelve minima of air temperature and then dividing by two). In this case AMT is 19.5°C.

Table (8.12) shows thermal stress during day and night in Ilam. Certain groups of the thermal stress indicate the remedial action that could be taken. The method developed uses six indicators (three humid indicated: H1, H2, H3, and three arid indicators A1, A2, A3) as defined in the Table (8.13).

Table 8.11 The upper and lower comfort limits during day and night according to the AMT

		AMT > 20°C		**15°C < AMT < 20°C**		**AMT < 15°C**	
		Day	*Night*	*Day*	*Night*	*Day*	*Night*
Humidity Groups	**1**	26-34°C	17-25°C	23-32°C	14-23°C	21-30°C	12-21°C
	2	25-31°C	17-24°C	22-30°C	14-22°C	20-27°C	12-20°C
	3	23-29°C	17-23°C	21-28°C	14-21°C	19-26°C	12-19°C
	4	22-27°C	17-21°C	20-25°C	14-20°C	18-24°C	12-18°C

Thermal stress during day and night are also calculated according to the results of the present study (equation 8.13) which pay attention to one point: the discrepancy between day and night upper and lower limits of the comfort condition are as same with Mahony method. Thermal stress in different months of Ilam is tabulated in Table (8.15). Table (8.15) indicated comfort condition during daytime of March and December while table (8.13) shows cold condition.

Table 8.12 Thermal stress during day and night in Ilam.

	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean Max.	12	14.5	18.5	25.5	28.5	36	41	38	35	28.5	25	18.5
Day comfort: upper	28	28	30	30	30	32	32	32	32	30	28	28
Day comfort: lower	21	21	22	22	22	23	23	23	23	22	21	21
Monthly mean Min	2	3.5	7	10	14.5	18.5	21.5	19.5	17	13	9	5.5
Night comfort: upper	21	21	22	22	22	23	23	23	23	22	21	21
Night comfort: lower	14	14	14	14	14	14	14	14	14	14	14	14
Thermal stress day	C	C	C	O	O	H	H	H	H	O	O	C
Thermal stress night	C	C	C	C	O	O	O	O	O	C	C	C

Table 8.13 The group of the thermal stress

Indicator	Thermal Stress		Rain fall	Humidity Group	Monthly Mean rang
	Day	Night			
H1	H			4	
	H			2&3	Less than 10°C
H2	O			4	
H3			OVER 200 mm		
A1				1&2&3	More than 10°C
A2		H		1&2	More than 10°C
	H	O		1&2	
A3	C				

From Table (8.14) specific recommendation for Ilam can be determined. Table (8.15) indicated comfort conditions during daytime of March and December while Table (8.12) shows cold conditions. Figures (8.24) and (8.25) also shown differences between upper and lower comfort condition for day-times and night-times. For cool periods such a discrepancy is about 4K which indicated Ilam people could be comfortable in the lower indoor temperature than predicted by Mahony. From Table (8.15) specific recommendation for Ilam can be recognised. These recommendations for building design in Ilam are shown in Table (8.16).

Table 8.14 Ilam humid and arid indicators

		J	F	M	A	M	J	J	A	S	O	N	D	
Humid	H1													0
	H2													0
	H3													0
Arid	A1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	12
	A2						✓	✓	✓	✓				4
	A3	✓	✓											2

Table 8.15 Thermal stress during day and night in Ilam based on actual data

	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean Max.	12	14.5	18.5	25.5	28.5	36	41	38	35	28.5	25	18.5
Day comfort: upper	23.5	24	25.5	27	28.5	30.5	32	31	30	28.5	27	25
Day comfort: lower	16.5	17	18.5	20	21.5	23.5	25	24	23	21.5	20	18
Monthly mean Min	2	3.5	7	10	14.5	18.5	21.5	19.5	17	13	9	5.5
Night comfort: upper	16.5	17	17.5	19	20.5	21.5	23	22	21	20.5	20	18
Night comfort: lower	9.5	10	10.5	12	13.5	14.5	16	15	14	13.5	13	11
Humidity groups	*3*	*3*	*2*	*2*	*2*	*1*	*1*	*1*	*1*	*2*	*3*	*3*
Thermal stress day	**C**	**C**	**O**	**O**	**O**	**H**	**H**	**H**	**H**	**O**	**O**	**O**
Thermal stress night	**C**	**C**	**C**	**C**	**O**	**O**	**O**	**O**	**O**	**C**	**C**	**C**

Table 8.16 Specific recommendations for housing design in Ilam

Element	**Recommendations**
Layout	Compact courtyard planning
Air movement	Double banked rooms, temporary provision for air movement
Opening	Very small opening, 10-20%
Walls	Heavy external and internal walls
Roofs	Heavy roofs, over 8h time-lag
Out door sleeping	Space for outdoor sleeping required

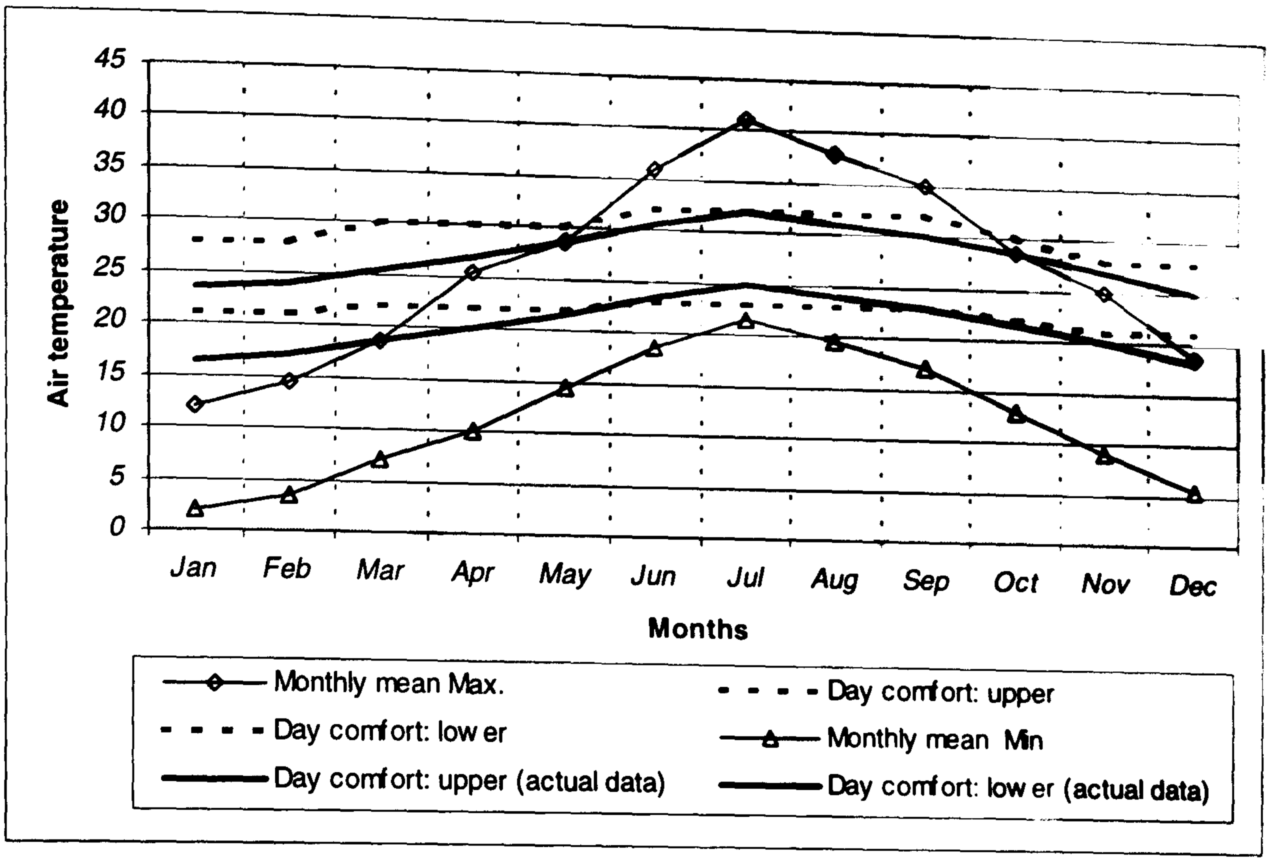


Figure 9.3 Day comfort upper and lower limits predicted by Mahony and from actual data of Ilam based on Mahony analysis

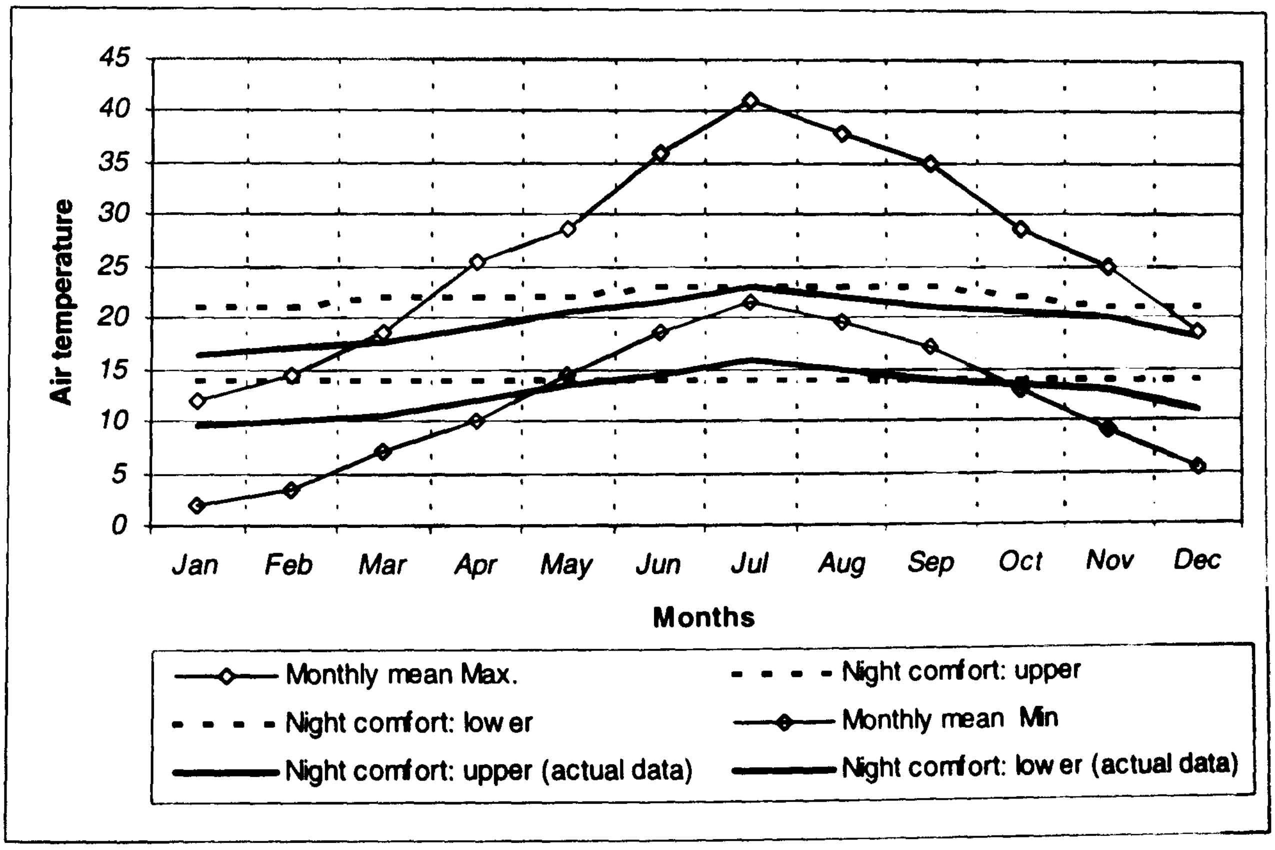


Figure 9.4 Night comfort upper and lower limits predicted by Mahony and from actual data of Ilam based on Mahony analysis

8.10 Conclusion

The main points of this Chapter are:

1- The mean sensation vote of all groups of subjects in the present study are in agreement with other field studies which Humphreys reviewed

2- The results of this study showed the strong relationship between prevailing temperatures and neutral temperature which is in good agreement with Humphreys's model

3- Limits of air temperatures between about 17.5°C and 24°C for cool period and 24°C to 31.5°C for hot period can be a boundaries of acceptable condition for Ilam people

4- The neutral temperature of subjects during the hot period was slightly lower than the neutral temperature derived from Griffiths value, but during the cool period was slightly higher than Griffiths' value

5- One of the findings of this study well showed that neutral temperature can be predicted from outdoor mean temperature

6- Some behaviour adaptations were identified, such as high correlation between air temperature and clothing value and as well as between air temperature and air movement

7- In comparison with the PMV model, the pridicted responses in the sensation scale is not matched to the actual mean votes

8- Air temperature alone can be a better indicate of thermal comfort, rather than other indices

9- The results of this study suggested that an appropriate passive strategy for building design can be enough for desirable indoor condition

Chapter Nine

Conclusions

9.1 General conclusion

This thesis has looked at some housing types in Iran in terms of thermal comfort. The methodology of this study was field surveys in the real world using a large number of subjects and as well as a large number of houses during two extreme conditions, hot and cool. The main objective was to make recommendations for an acceptable range of indoor temperatures for Ilam people and for those who are living in other area of Iran with similar climate, culture and religion.

The results showed that the respondents were thermally comfortable in a wider range of air temperatures than which is indicated by current standards. From such results it seems that international standard based on Fanger's PMV tend to predict that indoor temperatures will feel hotter than they actually do, especially in the hot periods.

This study has identified several thermal comfort adaptive actions that a person might take to achieve comfort such as moving to a different thermal environment from one causing the discomfort or changing the clothing to suit prevailing conditions or changing the amount of indoor air velocity.

The main findings of the study were the variability of acceptable conditions at different times of the year, a good relationship between neutral and room temperatures and also between neutral and outdoor temperatures. These findings are similar to the pattern of results from many previous surveys. Attention to the role of thermal comfort in building design may reduce the need for air conditioning and increase the possibilities for achieving comfort by using simple passive cooling and heating technique.

On the other hand such finding go to the heart of the "constancy" and variable models of thermal comfort. It is unlikely that the neutral temperature will be the same world-wide and that people will use various means at their disposal to improve their comfort condition. The constancy model can help design a building to comfort requirements for the occupants and the variable theory can be used to identify the means by which occupants will make adjustments to achieve comfort equilibrium.

This thesis included three main parts. First was a literature review on climatic and housing design in Iran (Chapters two and three) and a literature review on the theory of thermal comfort and some case studies of thermal comfort (Chapters four and five). In Chapter two a general outline of Iran's situation and climate and in particular the climate of Ilam were given. An understanding of climate is important because of the relationship between climate and housing design and also between both and indoor comfort conditions. In Chapter three the climatic consideration in the traditional and contemporary housing design was considered. In spite of suitable or unsuitable housing design in Iran some actions by people were noted in this chapter which showed that people use numerous strategies to achieve thermal comfort.

The importance of thermal comfort studies has been recognised for a long time and is still acknowledged as is evidenced by the continued pursuance of comfort in present day. Thus Chapter four undertook the necessary background review of thermal comfort for a well based field survey. From various case studies in the Chapter five it is clear that the neutral temperatures varied according to different places and climatic regions but in all there was a good relationship between indoor temperature and neutral temperature as well as between outdoor temperatures and neutrality. However the main point which is noted by Humphreys [1994] is "a thermal comfort field study can give an accurate estimate of the thermal environment linked by particular people in a particular building at a particular time"

The second part of this thesis described four separate field surveys in Ilam. In Chapter six the results of two field studies in traditional and contemporary housing during hot and cool seasons were presented. Both studies showed there was no significant difference in the neutral temperature between the two types of housing (less than 0.5°C) as well as between male subjects and female subjects (also about 0.5°C). The neutral temperature for the indoor subjects and outdoor subjects differed by about 0.5°C showing some of the difference is accounted for by changes in the clothing worn. It seems the seasonal changes in the neutral temperature (about 7°C) is attributed to changes in clothing and changes in mean indoor air velocity. The results of Chapter six showed that both air velocity and relative humidity had a measurable effect on thermal sensation.

A simple linear regression gave findings for comfortable conditions of the subjects: the neutral temperature for the hot season subjects was approximately 28°C and for cool season subject was 21°C. More than 80% of Ilam people were comfortable at range of about 24°C to 31.5°C during the hot season and at range of 17.5°C to 24°C in the cool season. These results were in line with results of two other field studies, which were presented in Chapter seven. There is no significant difference between neutral temperature of low-income subjects and other subjects, not only in terms of neutral temperature and acceptability but also in terms of some adaptive behaviour. Chapter seven also showed the results of a systematic study of some adaptive behaviour which was quite usual behaviour for people in Iranian housing especially in the hot regions. Moving from one place to another according to environmental condition in a sample courtyard house was a good example of adaptive behaviour.

Finally in the third section of this thesis a comparative analysis between results of this study and other studies in thermal comfort were discussed. Good agreement was found between the findings of this study and other field studies in terms of relationships between indoor air temperature and neutral temperature and between outdoor temperature and neutral temperature and some actions to achieve comfort. The results when compared with Fanger's study [1972] revealed no match between predicted mean vote (PMV) and actual mean vote (AMV) for Ilam subjects.

The temperatures which Ilam people will find comfortable are predicted from the equation:

$$T_n = 17.3 + 0.36\ T_{om}$$

As a main finding the use of passive cooling and heating system to achieve and improve comfort condition is enough for housing design in Ilam.

9.2 Limitation of this study

1- The surveys were done for two seasons only and it would be better to do a survey covering the whole year in order to get the fuller picture

2- The study is limited to the geographical area of Ilam

3- Just naturally- ventilated housing was used

4- The results are from courtyard housing and may differ for other types of housing, such as high-rise housing, workplaces or educational buildings

9.3 Further research

Some suggestion for future research could be as follows:

1- In the present study a longitudinal survey represented only a small part of the work. It is important for assessing the impact of longitudinal surveys on the accuracy of the results that this kind of survey be repeated on a larger scale in Ilam

2- As mentioned above the data were only for hot and cool periods, so a survey for the whole year data would be desirable

3- There is a difference in thermal comfort during night- time and day- time. It seems there is a need for an investigation of thermal comfort study during night-time

4- The importance of clothing as an adaptive measure for thermal comfort has been shown in this study. More research should be done on "dynamic" clothing values that vary over short periods of time and place in response to adaptive behaviour

5- Computer models of thermal comfort should attempt to integrate the adaptive processes seen in this and other surveys.

References

Abdulshukor, A. (1993) *Human Thermal Comfort in Tropical Climate.* Ph.D. Thesis, University College London, London.

Adolph, (1947) Referenced by Miles (1955)

Angus, T. A. (1968) *The Control of Indoor Climate*. Pergamon Press, UK

ASHRAE Standard 55-66 (1966) *Thermal Comfort Conditions.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York.

ASHRAE Standard 55-1981 (1981) *ASHRAE Standard Thermal Environmental Conditions for Human Occupancy.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

ASHRAE Standard 55-1992 (1992) *Thermal Environmental Conditions for Human Occupancy.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

ASHRAE Handbook (1993) *Fundamentals (S.I).* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

Atkinson, G. A. (1953) An introduction to tropical building design. *Architectural Design*, April, pp 268-271

Atkinson, M. (1962) *A consideration of vegetation, landscaping and micro-climatic conditions for building comfort* M. Arch. Thesis, university of Melbourne.

Auliciems, A. (1977) Thermal comfort criteria for indoor design temperatures in the Australian winter, *Architectural Science Review*. **20**, pp. 86-90.

Auliciems, A. (1981) Towards a psycho-physiological model of thermal perception, *International Journal of Biometeorology*. **25**, pp. 109-122.

Auliciems, A. and R. de Dear (1986) Air-conditioning in Australia I - human thermal factors, *Architectural Science Review*. **29** no. 3, pp. 67-75.

Auliciems, A. and Szokolay, S. V. (1997) *Thermal Comfort.* PLEA Notes: note 3, Department of Architecture, The University of Queensland, Brisbane.

Bahadori, N. B. (1973) A feasibility study solar heating in Iran, Journal of Solar Energy, 15, pp 3-26

Bahadori, N. B. (1979) Natural cooling in hot arid regions, in *Solar Energy Application in Buildings*, Edited by A. A. M. Sayigh, Academic press, INC.

Baker, N. (1987) *Passive and Low Energy Building Design for Tropical Island Climates.* The Commonwealth Secretariat, London.

Baker, N. (1988) Passive building design in warm climates. *Building Technical File.* **22**, pp. 45-53, July 1988.

Baker, N. and M. Standeven (1996) Thermal comfort for free-running buildings, *Energy and Buildings.* **23**, pp. 175-182.

Baker, N. V. (1993) Thermal comfort evaluation for passive cooling- a PASCOOL task, *Proceedings of the Third European Conference on Architecture.* Florence, May 1993, pp. 103-106.

Bansal, N. K., S. N. Garg and S. Kothari (1992) Effect of exterior colour on the thermal performance of buildings, *Building and Environment*, **27**, pp.31-37

Bedford, T. (1936) *Warmth Factor in Comfort at Work.* Medical Research Council, Industrial Health Research Board, report **76**, HMSO, London.

Benzinger, T. H. (1979) The physiological basis for thermal comfort, *Indoor Climate.* Danish Building Research Institute, Copenhagen, pp. 441-476.

Berglund, L. G. and R. R. Gonzalez (1978) Application of acceptable temperature drifts to build environments as a mode of energy conservation, *ASHRAE Transactions.* **84** pt. 1, pp. 110-121.

Brager, G. S., M. E. Fountain, C. C. Benton, E. A. Arens and F. S. Bauman (1994) A comparison of methods for assessing thermal sensation and acceptability in the field, *Thermal Comfort: Past, Present and Future.* Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 17-39.

Brager, G. S. and R. J. de Dear (1998) Thermal adaptation in the built environment: a literature review" *Energy and Buildings.* **27**, pp. 83-96.

Brobby (1987) Referenced by Baker (1987)

Brodal (1950) Referenced by Miles (1955)

Bunn, R.(1993) Fanger: face to face, *Building Services.* June, pp. 25-28.

Bunn, R. (1995) Editorial- King's new clothes in thermal shock *Building Services.* February 1995, pp. 3.

Busch, J. F. (1990) *From Comfort to Kilowatts: an Integrated Assessment of Electricity Conservation in Thailand's Commercial Sector.* PhD Dissertation submitted to University of California at Berkeley. 1990.

Busch, J. F. (1992) A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand *Energy and Buildings.* **18**, pp. 235-249.

Cena, K. (1994) Thermal and non-thermal aspects of comfort surveys in the homes and offices. *Thermal Comfort: Past, Present and Future.* Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993.

Chan, D. W. T., J. Burnett, R. J. de Dear and S. C. H. Ng (1998) A large-scale survey of thermal comfort in office premises in Hong Kong, *Field Studies of Thermal Comfort and Adaptation.* ASHRAE Technical Data Bulletin. **14**, no.1, pp.76-84.

Chow, W. K. and W. Y. Fung (1994) Investigation of the subjective response to elevated air velocities: climate chamber experiments in Hong Kong, *Energy and Buildings.* **20**, pp.187-192.

Chung, T. M. and W. C. Tong (1990) Thermal comfort study of young Chinese people in Hong Kong, *Building and Environment.* **25** no. 4, pp. 317-328.

Consolazio, C. F., L. R. Matoush, R. A. Nelson, J. B. Torres and G. J. Isaac (1963) Environmental temperature and energy expenditures, *J. Appl. Physiol.* **18**, pp 65-68

Cornel, P. H. (1957) Architecture in the tropics, Proc, Symp. on *Design for Tropical Living*, Durban

Davies, A. D. M. and M. G. Davies (1995) The adaptive model of thermal comfort: patterns of correlation *Building Services Engineering Research and Technology.* **16** no. 1, pp. 51-53.

De Dear, R. J. and A. Auliciems (1985) Validation of the predicted mean vote model of thermal comfort in six Australian field studies, *ASHRAE Transactions.* **91** pt 2, pp. 452-466.

De Dear, R. J., H. N. Knudsen and P. O. Fanger (1989) Impact of air humidity on thermal comfort during step-changes, *ASHRAE Transactions.* **95** pt. 2, pp. 336-350.

De Dear, R. J, K. G. Leow and A. Ameen (1991a) Thermal comfort in the humid tropics- part I: climate chamber experiments on temperature preferences in Singapore *ASHRAE Transactions.* **97** pt. 1, pp. 874-879.

De Dear, R. J., K. G. Leow and A. Ameen (1991b) Thermal comfort in the humid tropics part II: climate chamber experiments on thermal acceptability in Singapore *ASHRAE Transactions.* **97** pt. 1, pp. 880-886.

De Dear, R. J., K. G. Leow and S. C. Foo (1991c) Thermal comfort in the humid tropics: field experiments in air conditioned and naturally ventilated buildings in Singapore, *International Journal of Biometeorology.* **34**, pp. 259-265.

De Dear, R. J. (1994) Outdoor climatic influences on indoor thermal comfort requirements, *Thermal Comfort: Past, Present and Future.* Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 106-132.

De Dear, R. J. and M. E. Fountain (1994) Field experiments on occupant comfort and office thermal environments in a hot-humid climate, *ASHRAE Transactions.* 100 pt. 2, pp. 457-475.

De Dear, R. J. and G. S. Brager (1998) Developing an adaptive model of thermal comfort and preference, *Field Studies of Thermal Comfort and Adaptation.* ASHRAE Technical Data Bulletin. **14** no. 1, pp. 27-49.

Denyer, S. (1978) *African Traditional Architecture*, London, Heinmann.

Doherty, T J and E Arens (1988) "Evaluation of the physiological bases of thermal comfort models" *ASHRAE Transactions.* **94** pt. 1, pp. 1371-1385.

Donham, D. (1960) The courtyard house as a temperature regulator, *The New Scientist*, **8**, pp. 663-666

Donnini, G., J. Molina, C. Martello, D. H. C. Lai, H. K. Lai, C. Y. Chang, M. Laflamme, V. H. Nguyen, F. Haghighat (1997) Field study of occupant comfort and office thermal environments in a cold climate, *ASHRAE Transactions.* **103** pt. 2, pp. 205-220.

Ellis, F P (1952) Thermal comfort in warm, humid atmospheres observations in a warship in the tropics, *Journal of Hygiene.* Cambridge. **50**, pp. 415-432.

Ellis, F P (1953) Thermal comfort in warm and humid atmospheres-observations on groups and individuals in Singapore, *Journal of Hygiene.* Cambridge. **51**, pp. 386-404.

Ehlers, E. (1986) *Fundaments of a Geographic Demography*, Sahab geographic and cartographic institute, Tehran, Iran

Etzion, Y. (1990) The thermal behaviour of non-shaded closed courtyards in hot arid zones, *Architectural Science Review*, **33**, pp 79- 83

Evans, M. (1980) *Housing, Climate and Comfort.* Architectural Press, London.

Fathy, H. (1986) *Natural energy in vernacular Architecture-* Principles and examples with reference to hot arid climates, Chicago. University Press.

Fanger, P. O. (1970) *Thermal Comfort.* Danish Technical Press, Copenhagen.

Fanger, P. O., J Hojbjerre and J. O. B. Thomsen (1977) Can winter swimming cause people to prefer lower room temperatures? *International Journal of Biometeorology.* **21** no. 1, pp. 44-50.

Fanger, P. O. (1992) Don't get too comfortable, *Building Services.* November 1992, pp. 15.

Fanger, P. O. (1993) Fanger: face to face, *Building Services.* Interviewed by Bunn (1993).

Fanger, P. O. (1994) How to apply models predicting thermal sensation and discomfort in practice. *Thermal Comfort: Past, Present and Future.* Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 11-16.

Fanger, P. O. (1995) Letters- Energy and the human factor, *Building Services.* May 1995, pp. 11.

Fisher, W. B. (1968) *The Cambridge History of Iran,* **1**, Cambridge, The University Press

Fishman, D. S. and S. L. Pimbert (1982) The thermal environment in offices, *Energy and Buildings.* **5**, pp. 109-116.

Fisk, D. J. (1981) *Thermal Control of Buildings.* Applied Science Publishers, London.

Fountain, M., G. Brager and R. de Dear (1996) Expectations of indoor climate control, *Energy and Buildings.* **24**, pp. 179-182.

Fountain, M. E. and C. Huizenga (1996a) *WinComf©: a WINDOWS™ 3.1 Thermal Sensation Model- Users manual.* Environmental Analysis, Berkeley, California.

Fountain, M. E. and C. Huizenga (1996b) A thermal comfort prediction tool" *ASHRAE Journal.* **38** no. 9, pp. 39-42, September 1996.

Fountain, M. E. and C. Huizenga (1997) A thermal sensation prediction tool for use by the profession, *ASHRAE Transactions.* 103 pt. 2, pp. 130-136.

Fox, R. H., P. M. Woodward, A. N. Exton-Smith, M. F. Green, D. V. Donnison and M. H. Wicks (1973) Body temperatures in the elderly: a national study of physiological, social and environmental conditions. *British Medical Journal.* **1**, pp. 200-206.

Gagge (1937) Referenced by Auliciems and Szokolay (1997)

Gagge, A. P., G. M. Rapp and J. D. Hardy (1964) Mean radiant and operative temperature for high-temperature sources of radiant heat. *ASHRAE Transactions.* **70**, pp. 419-424.

Gagge, A. P., J. A. J. Stolwijk and Y. Nishi (1971) An effective temperature scale based on a simple model of human physiological regulatory response, *ASHRAE Transactions.* **77** pt. 1, pp. 247-262.

Ghasemi, M. (1996) *Effects of Culture*, Tarbiat Moallem Press, Ilam, Iran

Ghiasy, M. (1991) *The Kordish Architecture*, no. 3, Ilam cultural office

Givoni, B. (1962) Influence of ceiling on thermal condition in dwelling houses in Beer-Sheva, *Building Research Station*, Technion. Research paper 10

Givoni, B. (1976) *Man, Climate and Architecture.* 2nd edition, Applied Science Publishers, London.

Givoni, B. (1992) Comfort, climate analysis and building design guidelines *Energy and Buildings.* 18, pp. 11-23.

Givoni, B. (1993) Referenced by Givoni (1998)

Givoni, B. (1994) *Passive and Low Energy Cooling of Buildings*, New York, Van Nostrand Reinhold

Givoni, B. (1998) *Climate Considerations in Building and Urban Design*, New York

Goromosov, (1963) Referenced by Humphreys (1976)

Glickman, N., T. Inouye, S. E. Telser, R. W. Keeton, F. K. Hick and M. K. Fahnestock (1947) Physiological adjustments of human beings to sudden change in environment, *ASHVE Transactions.* **53**, pp. 327-356.

Goulding, J. R., J. O. Lewis and T. C. Steemers (1992) *Energy Conscious Design: a Primer for Architects.* B T Batsford, London.

Gonzalez and A. P. Gagge (1973) Magnitude estimates of thermal discomfort during transients of humidity and operative temperature. *ASHRAE Transactions*, **79** pt 1, pp 89-96

Gotz (1986) The presentation of climatic data must be related to the design process, *Climate and Human Settlements Integrating Climate into Urban Planning and Building Design*, Nairobi, UNEP

Griffiths, I. D. and D. A. McIntyre (1974) "Subjective response to overhead thermal radiation" *Human Factors.* **16** no. 4, pp. 415-422.

Griffiths, I. D. and D. A. McIntyre (1975) The effect of mental effort on subjective assessments on warmth *Ergonomics.* **18** no. 1, pp. 29-33.

Griffiths, I. D. (1990) *Thermal Comfort in Buildings with Passive Solar Features.* Report ENS35-090-UK, Department of Psychology, University of Surrey. (Report to the Commission of the European Community).

Haldane (1905) Referenced by Auliciems and Szokolay (1997)

Hariry M. and V. Millany (1985) *Climatic Classification of Iran*, Tehran University, Tehran, Iran

Hashemi R. (1996) The Iranian building design, Abady **12**, pp. 8-14

Hardy, J. D., J. A. J. Stolwijk and A. P. Gagge (1971) *Man- Comparative Physiology of Thermoregulation.* Vol. 2, pp. 327-380, Academic Press, New York and London.

Heidari, S. (1996) Climatic consideration and building design in Ilam, *Paick*, March, no **4**, pp 6-9

Heijs, W. (1994) The dependent variable in thermal comfort research: some psychological considerations, *Thermal Comfort: Past, Present and Future.* Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 40-51.

Hensel, H. (1973) "Temperature reception and thermal comfort" *Architectural Science Physiology.* **27**, pp. 359-370.

Hensel, H. (1981) *Thermoreception and Temperature Regulation*, Academic Press, London.

Hensen, J. L. M. (1990) Literature review on thermal comfort in transient conditions, *Building and Environment.* **25** no. 4, pp. 309 - 316.

Hickish, D. E. (1955) Thermal sensations of workers in light industry in summer: a field study in Southern England. *Journal of Hygiene.* Cambridge**53**, pp. 112-123.

Hoppe, P. (1988) Comfort requirements in indoor climate. *Energy and Buildings,* 11, pp 249-257

Howell, W. C. and P. A. Kennedy (1979) Field validation of the Fanger thermal comfort model *Human Factors.* **21**, pp. 229-239.

Houghten, F. C. and C. P. Yaglou (1923) Determining lines of equal comfort, *ASHVE Transactions.* **29**, pp. 163-176.

Humphreys, M. A. (1970) A simple theoretical derivation of thermal comfort conditions, *J.I.H.V.E.,* August. **38**, pp 95-98

Humphreys, M. A. and J. F. Nicol (1970) An investigation into thermal comfort of office workers, *Journal of the Institution of Heating and Ventilating Engineers.* **38**, pp. 181-189.

Humphreys, M. A. (1972) Clothing and comfort of secondary school children in summertime, *Proceedings CIB Commission W45 Symposium-Thermal Comfort and Moderate Heat Stress.* HMSO, London.

Humphreys, M. A. (1976) Field studies of thermal comfort: compared and applied, *Building Services Engineer,* **44**, pp. 5-27.

Humphreys, M. A. (1978a) Outdoor temperatures and comfort indoors" *Building Research and Practice.* **6** no. 2, pp. 92-105.

Humphreys, M. A. (1978b) The thermal comfort of young children at school in summertime, Building Research Establishment CP 17/78.

Humphreys, M. A. (1978c) The influence of season and ambient temperature on human clothing behaviour, *Proceedings of the International Climate Symposium.* Copenhagen.

Humphreys, M. A. (1992) Thermal comfort requirements, climate and energy, *Renewable Energy: Technology and the Environment.* Proceedings of the 2nd World Renewable Energy Congress, Reading, 13-18 September 1992, pp. 1725-1734.

Humphreys, M. A. (1994) Field studies and climate chamber experiments in thermal comfort research, *Thermal Comfort: Past, Present and Future.* Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 52-72.

Humphreys, M. A. and J. F. Nicol (1998) Understanding the adaptive approach to thermal comfort, *Field Studies of Thermal Comfort and Adaptation.* ASHRAE Technical Data Bulletin. **14** no. 1, pp. 1-14.

Humphreys, M. A. (1999) *The Relationship Between Scales of Comfort and Scales of Warmth*, UK Thermal comfort group meeting, University of Sheffield, Sep.

Humphreys, M. A. and J. F. Nicol (1999) *Some Effects of Measurement Error and Formulation Error on the Statistical Behaviour of Indices of Thermal Comfort in Field Studies*, U.K. Thermal Comfort Group Meeting, Cornfield, Sep.1998.

Hunt, D. R. G. and M. I. Gidman (1979) *Thermal Comfort in Dwellings*, Report of 45 home pilot survey, January 1978, BRE note, no. 9/79, UK

Hunting, E. (1951) *Principles of Human Geography*. 6th edition, John Wiley and Sons, New York

Iranian National building code (1993) *Ministry of Housing and Development*, Iran

ISO 7730 (1994) *Moderate Thermal Environments- Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort.* 2nd edition, International Organization for Standardization, Geneva, Switzerland.

Jitkhajornwanich, J (1999) *Expectation and Experience of Thermal Comfort in Transitional Spaces*, Ph.D Thesis, University of Sheffield

Kassmai, M. (1992) *Climatic Classification of Iran*, Building and Housing Research Center, Tehran, Iran.

Kimura, K, S Tanabe and T Iwata (1994) Climate chamber studies for hot and humid regions, *Thermal Comfort: Past, Present and Future*. Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 88-105.

Kinnear, P R and C D Gray (1997) *SPSS for Windows Made Simple*. 2nd edition, Psychology Press, East Sussex.

Koenigsberger, O H, T G Ingersoll, A Mayhew, and S V Szokolay (1973) *Manual of Tropical Housing and Building*. Longman, London.

Konya, A (1980) *Design Primer for Hot Climates*. Architectural Press, London.

Koppen, W (1936) Referenced by Trewartha (1968)

Kwok, A. G. (1998) Thermal comfort in tropical classrooms, *Field Studies of Thermal Comfort and Adaptation*. ASHRAE Technical Data Bulletin. 14 no. 1, pp. 85-101.

Ladell (1954) Referenced by Miles (1955)

Langkilde, G, K Alexandersen, D P Wyon and P O Fanger (1973) "Mental performance during slight cool or warm discomfort" *Actes du Colloque International du C.N.R.S.*, 15 Quai Anatole France, F 75700-Paris.

Limb, M (1992) Technical notes- an infiltration and ventilation glossary *Air Infiltration and Ventilation Centre.* **36**, May 1992.

McIntyre, D. A. (1970) *Radiant Heating and Comfort.* Capenhurst, Chester, UK Electricity Council Research Centre Note N305, September, 1970.

McIntyre, D. A. and I. D. Griffiths (1972) Subjective response to radiant and convective environments, *Environmental Research.* **5**, pp. 471-482.

McIntyre, D. A. and I. D. Griffiths (1974) Changing temperatures and comfort, *Building Services Engineer.* **42** no. 8, pp. 120-122.

McIntyre, D. A. and I. D. Griffiths (1975) Subjective responses to atmospheric humidity, *Environmental Research.* 9, pp. 66-75.

McIntyre, D. A. and R. R. Gonzalez (1976) Man's thermal sensitivity during temperature changes at two levels of clothing insulation and activity, *ASHRAE Transactions.* **82** pt. 2, pp. 219-233.

McIntyre, D. A. (1977) Sensitivity and discomfort associated with overhead thermal radiation *Ergonomics.* **20** no. 3, pp. 287-296.

McIntyre, D. A. (1978) "Seven point scales of warmth, *Building Services Engineer.* 45, pp. 215-226.

McIntyre, D. A. (1980) *Indoor Climate.* Applied Science Publishers, London.

McIntyre, D. A. (1982) Chamber studies- reductio ad absurdum ?" *Energy and Buildings.* **5** no. 2, pp. 89-96.

Malama, A. (1997) *Thermal Comfort and Thermal Performance of Traditional and Contemporary Housing in Zambia.* Ph.D. Thesis, University of Sheffield.

Mallick, F. H. (1996) Thermal comfort and building design in the tropical climates, *Energy and Buildings.* **23**, pp. 161-167.

Markus, T. A. and E. N. Morris (1980) *Buildings, Climate and Energy.* Pitman Publishing Limited, London.

Mayer, E. (1993) Objective criteria for thermal comfort, *Building and Environment*, 28, no 4, pp 399-403

Miles, S. (1955) *The Adaptation of the Human Body to Warm Climates*, Thesis, Sheffield University

Miller, G. A. (1956) The magical number seven, plus or minus two. *Psychological Review*, **63**, pp 81-97

Mohsen M. A. (1978) *The Thermal Performance of Courtyard Houses*. Ph.D Thesis, University of Edinburgh.

Mubarak, A. (1888) Cario, Bulaq press, 1. Pp85-86

Nevins, R. G., F. H. Rohles, W. Springer and A. M. Feyerherm (1966) "Temperature-humidity chart for thermal comfort of seated persons" *ASHRAE Transactions*. **72** pt. 1, pp. 283-291.

Nevins, R. G. and P. E. McNall Jr (1973) ASHRAE thermal comfort standards *Building Research and Practice*.**1** no. 2, pp. 100-104.

Nicol, J. F. (1972) An analysis of some observations of thermal comfort in Roorkee, India and Baghdad, Iraq, *Annals of Human Biology*. **1** no. 4, pp. 411-426.

Nicol, J. F. and M. A. Humphreys (1973) Thermal comfort as part of a self-regulating system *Building Research and Practice*. **1** no. 3, pp. 174-179.

Nicol, J. F. (1992) Time and thermal comfort *Renewable Energy: Technology and the Environment*. Proceedings of the 2nd World Renewable Energy Congress, Reading, 13-18 September 1992, pp. 1848-1853.

Nicol, J. F. (1993) *Thermal Comfort- A Handbook for Field Studies toward An Adaptive Model*. School of Architecture, University of East London, London.

Nicol, J. F., G. N. Jamy, O. Sykes, M. A. Humphreys, S. Roaf and M. Hancock (1994) *A Survey of Thermal Comfort in Pakistan*. Final report, July 1994, School of Architecture, Oxford Brookes University, Oxford.

Nicol, J. F. and I. Raja (1996) *Thermal Comfort, Time and Posture*. School of Architecture, Oxford Brookes University, Oxford.

Nicol, J. F. and Roaf, S. (1996) New Comfort Standard for Pakistan, *Energy and Buildings*, **23**, pp 169-174

Olesen, S. and P. O. Fanger (1971) Can man be adapted to prefer a low ambient temperatures? *Proceedings of the 5th International Congress for Heating, Ventilating and Air-Conditioning*. Copenhagen, pp. 27-40.

Olesen, B. W. (1982) Thermal comfort, *Technical Review*, **2**, Denmark

Olgyay, V. (1963) *Design with Climate*. Princeton University Press, Princeton, New Jersey.

Oseland, N. A. (1992) Thermal comfort or complaisance? *Building Services*. July 1992, p 51.

Oseland, N. A. (1993) UK design rules OK? *Building Services*. **15** no. 6, pp. 28-29.

Oseland, N. (1994a) A. review of thermal comfort issues and their relevance to future design guidelines and standards. *Thermal Comfort: Past, Present and Future*. Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 218-245.

Oseland, N. A. (1994b) A comparison of the predicted and reported thermal sensation vote in homes during winter and summer. *Energy and Buildings*. Vol. 21, pp. 45-54.

Oseland, N. A. and M. A. Humphreys (1994) Trends in thermal comfort research, Garston, BRE Report, BR266

Oseland, N. A. (1995) Predicted and reported thermal sensation in climate chambers, offices and homes" *Energy and Buildings*. **23**, pp. 105-115.

Oseland, N. A. (1998) Acceptable temperature ranges in naturally ventilated and air-conditioned offices, *Field Studies of Thermal Comfort and Adaptation*. ASHRAE Technical Data Bulletin. **14** no. 1, pp. 50-62.

Parsons, K. C. (1993) *Human Thermal Environments*. Taylor and Francis, London

Parsons, K. C. (1994) Thermal comfort standards: past, present and future, *Thermal Comfort: Past, Present and Future*. Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 184-197.

Parsons, K. C. (1995) ISO standards and thermal comfort: recent developments, *Standards for Thermal Comfort*. Chapman & Hall, London, pp. 97-105.

Rapoport, A. (1969) *House Form and Culture*. Prentice-Hall, New Jersey.

Raw, G. J. and N. A. Oseland (1994) Why another thermal comfort conference? *Thermal Comfort: Past, Present and Future*. Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 1-10.

Revenue operation (1994) *History of War*, Ministry of Jahad, Tehran, Iran

Rohles, F. H. and R. G. Nevins (1971) The nature of thermal comfort for sedentary man *ASHRAE Transactions*. **77** pt. 1, pp. 239-246.

Rohles, F. H. and R. G. Nevins (1973) Thermal comfort: new directions and standards. *Aerospace Medicine*. **44**, pp. 730-738.

Rohles, F. H., G. A. Milliken, D. E. Skipton and I. Krstic (1980) Thermal comfort during cyclical temperature fluctuations. *ASHRAE Transactions.* **86** pt. 2, pp. 125-140.

Saini, B. S. (1962) Housing in the hot arid tropics, *Architectural science Review,* **5**, no 1 pp 3- 6

Saini, B. S. (1973) *Building Environment*, Sydney, Angus and Robertson.

Saini, B. S. (1982) Climate and built environment studies in Universities- an Australian experience, *Energy and Building.* **5** no. 1, pp. 63-68.

Saremi A. (1998) The new housing design. Art and Architecture. Tehran. **12**, pp23-29

Schiller, G. E., E. A. Arens, F. S. Bauman, C. Benton, M. Fountain and T. Doherty (1988) A field study of thermal environments and comfort in office buildings, *ASHRAE Transactions.* **94** pt. 2, pp. 280-308.

Sharma, M. R. and S. Ali (1986) Tropical summer index - a study of thermal comfort of Indian subjects, *Building and Environment.* **21** no. 1, pp. 11-24.

Shapiro, Y. and Y. Epstein (1984) Environmental physiology and indoor climate- thermoregulation and thermal comfort, *Energy and Buildings* 7, pp 29-34

Tanabe, S., K. Kimura and T. Hara (1987) Thermal comfort requirements during the summer season in Japan, *ASHRAE Transactions.* **93** pt. 1, pp. 564-577.

Tanabe, S. and K. Kimura (1994) Effects of air temperature, humidity, and air movement on thermal comfort under hot and humid conditions, *ASHRAE Transactions.* **100** pt. 2, pp. 953-969.

Tavassoli, M. (1973) *Urban Structure and Architecture in the Hot Arid Zone of Iran*, Tehran University, Faculty of Fine Arts, Tehran. Iran

Tavassoli, M. (1980) City Planning in the Hot Dry Climate of Iran. Van Nostrand Reinhold, New York.

Trewartha, G. T. (1968) *An Introduction to Climate*, Mc Graw- Hill. New York, London

Vernon and Warner (1932) Referenced by Auliciems and Szokolay (1997)

Wang, X. L. and F. K. Peterson (1992) Estimating thermal transient comfort, *ASHRAE Transactions.* **98** pt. 1, pp. 182-188.

Watson, D. (1981) *Analysis of Weather Data for Determining Appropriate Climate Control Strategies Architectural Design*, Proc. Of the International Passive and Hybrid Cooling Conference, Miami Beach. Haisley R., editor. Florida, U.S.A., Solar Energy Association.

Webb, C. G. (1959) An analysis of some observations of thermal comfort in an equatorial climate" *British Journal of Industrial Medicine*. **16**, pp. 297-310.

Wilson, A. T. (1930) *A Bibliography of Persia*, Oxford, UK

Wilson, M. and J. F. Nicol (1994) Tolerated noise levels in the UK and Pakistan and simultaneous thermal comfort *Renewable Energy: Climate Change, Energy and the Environment*. Proceedings of the World Renewable Energy Congress, Reading, 11-16 September 1994, pp.1006-1008.

Woolard, D. (1980) *Thermal Habitability in the Solomon Islands*. PhD Thesis, University of Queensland.

Wyonn, D. P. (1994) Assessment of human thermal requirements in the thermal comfort region *Thermal Comfort: Past, Present and Future*. Proceedings of a conference held at the Building Research Establishment, Garston, 9-10 June 1993, pp. 144-156.

Yaglou, C P (1927) "The comfort zone for man ..." *Journal of Industrial Hygiene*. **9**, p 251.

Zandjani, H. (1998) Iran through history, *Abadi*, **27**, **28** pp. 15-22

Appendix A

Instrumentation in the field surveys

Humidity and Temperature sensors- Skye Data Hog SDL

Humidity sensor

Measurement range	:	0- 100% Rh
Operating temperature	:	-20°C to +70°C
Capacitance	:	typically 500pf at 25°C and 75% Rh
Limit temperature	:	-40°C to +140°C
Pressure	:	0.04 to 30 Bars
Time response	:	typically 10s between 10 and 75% Rh for 90% of the step
Linearity deviation	:	typically 2.5% Rh between 10 and 90% Rh
Hysteresis	:	better than 0.5% Rh
Reversible drift	:	1 day at 97% Rh maximum of 2% Rh
Stability	:	1 week at 97% Rh maximum of 3% Rh
Accuracy	:	better than 2%

Temperature Sensors

Measurement range	:	-20°C t0 +70°C
Accuracy- PRT's	:	standard units to BS 1904 DIN 43760 (1/3rd DIN) max. error at 0°C = +0.05°C (1/5th & 1/10th DIN available to order)
Accuracy- thermistors	:	standard Fenwal type 10 K ohms at 25°C -curve matched. Accuracy 0.2°C max. error over 0°C to 60°C

Air Flow Meter- Solomat MPM 500e

Multifunction Environmental Instrument

Usage conditions	:	-0°C/ 50°C (<80% Rh)
Storage conditions	:	-20°C/ 65°C without battery
Average	:	the average of a continuous set of measurements can be calculated by the processor.
Powering	:	battery type of 9 volt pp3

Hotwire Probe 228MS/GN (Air Speed Measurement)

Range / Resolution	:	0.10 / 40.00 m/s
Accuracy	:	2% rdg ± 0.15 m/s
Temperature range	:	-10°C/ 70°C

Appendix B

Metabolic rates of different activities

ISO 7730- 1994

Activity		*Metabolic rates*	
		W/m²	*met*
Reclining	Sleeping, Lie down	*46*	*0.80*
Seated, relaxed	On chair, on carpet / Passive work	*58*	*1.0*
Sedentary activity	Or seated on armchair, standing	*70*	*1.2*
Standing, light activity	Cooking slowly or washing slowly	*93*	*1.6*
Standing, medium activity	Cooking or washing	*116*	*2.0*
Walking level			
2 km/h	Or Gardening slowly	*110*	*1.9*
3 km/h	Or Weave, gardening	*140*	*2.4*
4 km/h		*165*	*2.8*
5 km/h		*200*	*3.4*

Appendix C

Clothing insulation

Description	*Local name*	*Winter*		*Summer*	
		Male	*Female*	*Male*	*Female*
Chadr	*Ghatrae*	**0.69**	**0.69**	**0.50**	**0.50**
Shalwar	*Jafy*	**0.34**	**0.34**	**0.29**	**0.29**
Sleeved shirt	*Joumae baldar*	**0.33**	**0.33**	**0.33**	**0.33**
Sweater	*Bleese*	**0.28**	**0.28**	-	-
Sleeveless shirt	*Joumae biball*	-	-	**0.25**	**0.25**
Vest	*Jelighae*	**0.10**	**0.10**	**0.10**	**0.10**
Jacket	*Jacate*	**0.52**	**0.52**	**0.44**	**0.44**
Dress	*Joumae*	-	**0.59**	-	**0.59**
Skirt	*Daman*	-	**0.41**	-	**0.41**
Socks	*Jiroo*	**0.03**	**0.03**	**0.03**	**0.03**
Sandals	*Sarpaii*	**0.03**	**0.03**	**0.03**	**0.03**
Shoes	*Kosh*	**0.03**	**0.03**	**0.03**	**0.03**
Shalwar-Kamees	*Jafy ve riah*	**0.87**	-	**0.67**	-
Trousers	*Shavall*	**0.30**	**0.30**	**0.21**	**0.21**
Scarf	*Ban sary*	**0.15**	**0.15**	**0.15**	**0.15**
Head wear	*Sarvan*	**0.10**	**0.10**	**0.10**	**0.10**
Shorts	*Zeer shavall*	**0.12**	**0.12**	**0.12**	**0.12**
Singlet	*Zeer joma*	**0.04**	**0.04**	**0.04**	**0.04**
Trousers/ Short	*Zeer shavally*	**0.06**	**0.06**	**0.06**	**0.06**
Light, summer jaket	*Yaghah haft*	**0.25**	**0.25**	**0.25**	**0.25**
Coat	*Coater*	**0.60**	**0.60**	**0.40**	**0.60**
Mantoo*	*Mantoo*	-	**0.87**	-	**0.67**

* Mantoo is like Shalwar– Kamees but for women

Appendix D

Questionnaires

Date : ....../ .... / 1998
Time : ....
Place : ....
Gender : ....

Age : ....Year
Weight : ....kg
Height : .... cm

Please make a mark "√" in the box which relates to your feeling:

How do you feel at this moment?

Cold	*Cool*	*Slightly cool*	*Neutral*	*Slightly warm*	*Warm*	*Hot*

Would you like to be:

Cooler	*No change*	*Warmer*

How do you feel at this moment in terms of air flow?

Still	*Just right*	*Breezy*

How do you feel at this moment in terms of relative humidity?

Dry	*Just right*	*Humid*

What clothes are you wearing at this moment?

Chader		Mantoo		Coat		Dress	
Shalwar		Skirt		Trousers		Light Jaket	
Shalvar-Kamees		Sleeveless Shirt		Sleeved Shirt		Trousers Short	
Scarf		Head wear		Shorts		Singlet	
Vest		Sweater		Jacket		Socks	
Shoes		Sandal					

What activity did you do in the last 15 minutes?

General state of health?

Good		Normal		Poor	

Date : ....../ .... / 1998

Time : ....

Gender : ....

Age : .... *Year*

Height : .... *cm*

Weight : ....*kg*

Please make a mark "√" in the box which relates to your feeling:

How do you feel at this moment?

Cold	*Cool*	*Slightly cool*	*Neutral*	*Slightly warm*	*Warm*	*Hot*

You are in the (at least from 10 minute ago):

Room/Kitchen	*Ayvan*	*Courtyard*	*Basement*	*Other*

What clothes are you wearing at this moment?

Chader		Mantoo		Coat		Dress	
Shalwar		Skirt		Trousers		Light Jaket	
Shalvar-Kamees		Sleeveless Shirt		Sleeved Shirt		Trousers Short	
Scarf		Head wear		Shorts		Singlet	
Vest		Sweater		Jacket		Socks	
Shoes		Sandal					

What activity did you do in the last 15 minutes?

Date : ....../ ..../ 1999
Time : ....
Place : ....
Gender : ....

Age : .... *Year*
Weight : ....*kg*
Height : .... *cm*

Please make a mark "√" in the box which relates to your feeling:

How do you feel at this moment?

Cold	*Cool*	*Slightly cool*	*Neutral*	*Slightly warm*	*Warm*	*Hot*

Would you like to be:

Much cooler	*A bit cooler*	*No change*	*A bit warmer*	*Much warmer*

What clothes are you wearing at this moment?

Chader		Mantoo		Coat		Dress	
Shalwar		Skirt		Trousers		Light Jaket	
Shalvar-Kamees		Sleeveless Shirt		Sleeved Shirt		Trousers Short	
Scarf		Head wear		Shorts		Singlet	
Vest		Sweater		Jacket		Socks	
Shoes		Sandal					