ASSESSMENT AND IMPROVEMENT OF THERMAL CONDITIONS INSIDE PILGRIMAGE TENTS AT MAKKAH, SAUDI ARABIA

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This thesis is submitted in fulfilment of the degree of

Doctor of Philosophy in Architecture

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SEPTEMBER-1993

ABSTRACT

The overheating problem experienced during Islamic pilgrimage in recent years has caused serious thermal discomfort and a number of mortalities among pilgrims coming from various parts of the world to perform the annual event at Makkah in Saudi Arabia. This research aims to investigate the real dimension of thermal discomfort experienced inside the pilgrimage tents. The back bone of this task was the data collected from the field investigations during the Hajj season of 1989, including climatic measurements taken inside the tents for the first time during the Hajj season. The investigations also included a subjective evaluation for internal thermal conditions by the pilgrims from Europe, the Middle East, and South East Asia.

This research also attempts to identify passive and natural cooling guidelines that are applicable to the tent's design. The author tested sets of experiments aimed to measure the thermal effects of some of the natural cooling techniques on pilgrimage tents at Makkah. The research concludes with design guidelines to improve the thermal quality of the pilgrimage tent. The recommended guidelines were based on the experimental results and practical examples of cooling strategies applied to tents in similar hot climates.

ACKNOWLEDGEMENTS

"He who does not thank people, does not thank God- Allah"

The Prophet Mohammad

I am very grateful to many individuals and various establishments in The United Kingdom and The Kingdom of Saudi Arabia for their co-operation and help without which this work would not have been accomplished.

First and foremost I am very indebted to the staff members of the School of Architecture at the University of Newcastle-upon-Tyne, particularly, Mr. Brian Warren for his supervision, concern and help throughout this research. I am also indebted to Prof. John Wiltshire, Head of the School, for valuable advice on statistical analysis and research management; Dr. Steve Dudek for his technical advice and help with the computer; Mr. Steve Lockley, Mr. Sun Ming, and Mr. Steve Armstrong for their generous help with computer problems. My thanks also extend to Mr. Norman Harper who provided me with the chance to teach and learn from the undergraduates, Mr. John Wilson for his photography, and the technichians Mr. Bill Softley and Mr. Jack Murta for their readiness always to help.

I am very grateful to Dr. Andrew Metcalfe and members of the Statistical Department of the University of Newcastle-upon-Tyne for their guidance and help concerning the statistical analysis of this research. I appreciate the co-operation of Dr. J. Steel and Dr. J. Read of the Medical School of the University for their advice concerning the human response to overheat conditions. My thanks are due also to Mrs. M. Billings for proof reading this thesis.

The author extends his deep thanks to King Saud University in Riyadh and Saudi Educational Attache in London for financing my study in the United Kingdom.

The University of Umm Alqura has provided me with great help and support during my field study at Makkah. I express special thanks to the administrative and academic staff members of the College of Engineering and Islamic Architecture and members of the Hajj Research Centre.

Grateful acknowledgement is also made to the Saudi National Guard in Jeddah and Tamimi tent manufacturers in Makkah for supplying me with the tents needed for the experiments. Three establishments to whom I am very grateful are, the establishment of European and Turkish pilgrims, the establishment of Arab Pilgrims and the establishment of South East Asian pilgrims for their excellent co-operation during the field survey and enthusiasm for the research. Thanks are also due to the Saudi Meteorological and Environmental Protection Agency in Jeddah and the Meteorological stations of Makkah and Muna for supplying the author with valuable meteorological data.

I am very grateful to Dr. Sharaf Al-Abdaly, the Deputy Mayor of Makkah, for his kind hospitality during my stay in Makkah.

I would like to express my gratitude to my brother Ahmad who willingly helped in data collection during the field work in Makkah. Also I thank the students of Umm Alqura University who also helped in data collection during the Hajj season of 1989: Mr. Mohammad Alqus, Mr. Hussain Kadah, Mr. Ismail Dampa, Mr. Mohammad Zydan, Mr. Abduallah Helni and Mr. Sheek Omar.

I am very grateful to my parents, my wife and children for their moral support and patience during the course of this research.

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CHAPTER I

INTRODUCTION

1- THE OUTLINE OF THE PROBLEM:

More than one and a half million Muslims, coming from over eighty different nations gather every year during the last month of the Islamic calendar, Dhu'l-Hijjah, in the city of Makkah in Saudi Arabia. This Islamic pilgrimage, the Hajj, is a duty each Muslim strives to fulfil once in his or her lifetime.

It takes about one week to complete the rituals of the Hajj, performed in Makkah and three nearby sites, Muna, Arafat, and Muzdalifa. The pilgrims' stay on these sites is temporary, and tents, therefore, have been the traditional form of shelter, particularly in Muna and Arafat, which together form the largest city of tents on earth.

The climate of Makkah is generally described as hot-dry desert climate and is distinguished with two marked seasons: the hot summer which extends from May to October and the warm winter which occupies the rest of the year (Appendix I). Summer air temperature rises during the day time to mean maximum of 36 to 40°C. During the winter the mean maximum temperature ranges from 26 to 34°C. Night-time mean minima are between 27 to 31°C in the summer and between 18 to 24°C in the winter. The average relative humidity varies from 30% in the summer to 65% in the winter. The rainfall is distributed during the winter time and very rare during the summer. The maximum rain fall is 25mm per annum but flash storms may occur with an average of 157 mm rain in one or two days.

As the Islamic year is based on a lunar calendar- twelve days less than the solar year- the Hajj, in recent years, has been performed during the summer months where dry bulb temperatures range from 35 °C to 50 °C. This gradual change in the timing of the Hajj, coupled with the increasing number of pilgrims, has produced a serious problem of over heating and mortalities among the pilgrims.

To indicate the size of the over-heating problem, the data for mortality, heat stroke and heat exhaustion for ten consecutive years (1980-1989) are summarised in table (1-1). Under the "total death" column is the number of deaths due to various reasons including death caused by heat while "heat death" column includes number of deaths specifically caused by heat. Heat stroke and heat exhaustion reported in the table are the most familiar heat illnesses during the Hajj, heat stroke being the most serious. The cases reported in the table only occurred during the first two weeks of the month of Dul-hijjah. It is clear from figure 1.1 that the number of pilgrims arriving at Makkah varied significantly from one year to another. The number of pilgrims for example increased from nearly two million in 1980 to over 2.5 million in 1983 and decreased the following years to fluctuating around 1.5 million. Figure 1.2 shows a general increase in air temperature and a fall in relative humidity. The average maximum air temperature increased from 39°C in 1980 to 47°C in 1987. By contrast, but perhaps as expected, the average maximum relative humidity decreased from 70% in 1982 to its lowest value of 30% in 1988.

Under such climatic and crowded conditions, there is a greater risk of heat stroke. Figure 1.3 indicates the death rate (per 10000 pilgrims) reported for one decade (1980-1989). Where data on the figure is not shown, no information was available. The more pilgrims at Makkah the higher the number of deaths is expected. In order to compare statistics for different years (regardless of the numbers of pilgrims present), the death rate is expressed as so many per 10000, instead of the actual number of deaths. The death rate reached its maximum of 9 pilgrims per ten thousand (1579 pilgrims in the first two weeks) during 1984 but declined gradually to reach its minimum in 1988 with less than 3 pilgrims per ten thousand (353 pilgrims in two weeks). By contrast, death due only to heat increased gradually from one pilgrim per ten thousand in 1983 (that is 98 pilgrims in two weeks with the rate of 14% of total death) to reach 6 pilgrims per ten thousand in 1985 (that is 960 pilgrims in two weeks and the rate of 88% of total death). An unusual drop of both total death and mortality rate was recorded in 1986, less than for any previous years of the decade. The mortality rate reached only 9% of the total death and the rate per ten thousands was very small (34 pilgrims in two weeks). The mortality rate, however, increased for the following year (1987) to nearly four pilgrims per ten thousands (624 pilgrims in two weeks representing a significant portion of 90% of the total death of the same year). The numbers reported for pilgrims' deaths during the cited years do not include victims of serious accidents and natural disasters.

The total number of heat exhaustion and heat stroke cases treated in Saudi hospitals and health centres during the first two weeks of Dhul-hijjah from 1980 to 1989 is indicated in figure 1.4. The rate of heat exhaustion and heat stroke per 10000 pilgrims increased from 5 pilgrims in 1980 to a maximum of 94 pilgrims in 1985 (that is 14938 pilgrims in two weeks). For the following years, the victims of heat stroke and exhaustion treated in hospitals declined, reaching a minimum of 25 per 10000 pilgrims in 1988 (that is 3520 pilgrims in two weeks). The health ministry of Saudi Arabia has reported that since 1983 heat stroke and exhaustion are the major illnesses during the Hajj. In 1985 and 1986, for example, heat disorders and related illnesses represented 30% of the total number of treated cases during the Hajj (Hazzah, 1989).

Examining the above data, a strong and significant relationship emerges between air temperature and rate of death due to heat. The correlation is reported positive ($R= 0.70$, $p=0.002$) and indicated in the scatter plot in figure 1.5. No significant relationship was found between air temperature or relative humidity on one hand and rate of heat exhaustion on the other. Saudi Meteorological and Environmental Protection Agency (Hadad and Ajlan, 1988) reported a positive relationship between death rate due to heat and increase in air temperature and relative humidity. This relationship, according to the report, is explicit when air temperature exceeds 38°C and relative humidity is above 50%.

The breakdown of death, heat stroke and heat exhaustion rates from 1983-1988 indicated in figures 1.6 and 1.7 indicate when most of the heat distress occurred during the Hajj. The figures indicate that one half to three quarters of the heat casualties are reported between 8th to 13th of the month of Dhul-hijjah. These are the days when pilgrims stay in the Muna valley (8th, and 10th to 13th) and Arafat (9th), and in which pilgrims are provided with tents as the main accommodation. Heat casualties were less during the rest of the days when the pilgrims stayed in Makkah. Heat build-up has caused suffering and death for a considerable number of pilgrims. Khogali (1983) has predicted that the problem of over-heating will continue as long as the pilgrimage falls during the summer, i.e. until the year 2000 (1420H.).

The problem of over-heating raises questions about the indoor environment of the tents. Preliminary measurements conducted by the Hajj research centre of Um-Alqura University in Makkah found that inside temperatures were 1-5^{o}C higher than outside. Al-Yamamah, a popular magazine in Saudi Arabia, published in its August 13, 1986 printed an interview with an engineer, Abdul Alaziz Ghandura, the director-general of the Muna development project in which he stated that pilgrims could not tolerate living in traditional tents because of the hot climate and the enormous concentration of people in Muna. He observed that it was natural for them to live in the shaded and cooler areas along the pedestrian route rather than living in traditional tents, the renting of which they paid for in advance. They also had the advantage of being well supplied with toilets and cold water.

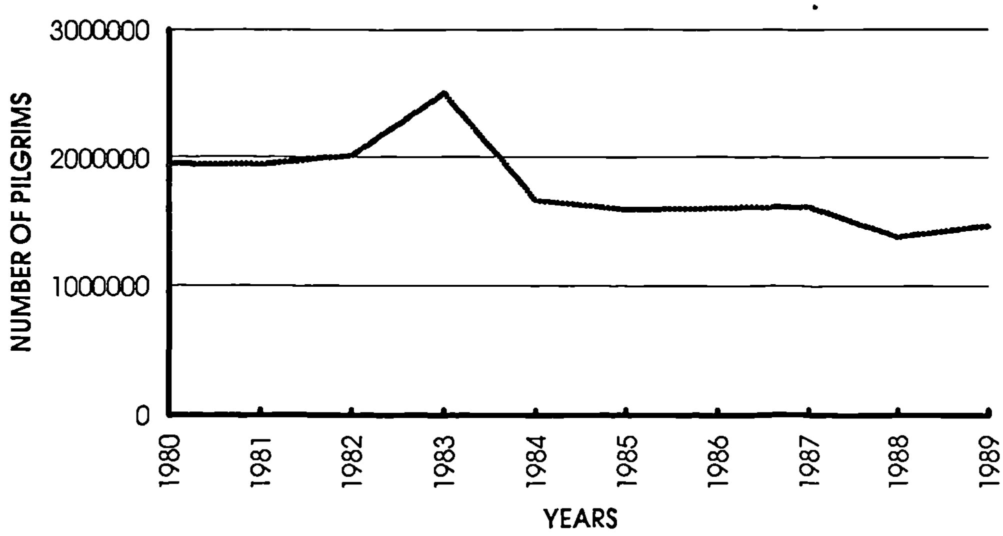

Fig. 1.1: *Number of pilgrims performed Hajj from 1980 to 1989.*

After: Central Department of Statistics, "Total statistical results for Hajj of 1989." Final report to the Saudi Ministry of Finance and National Economy.

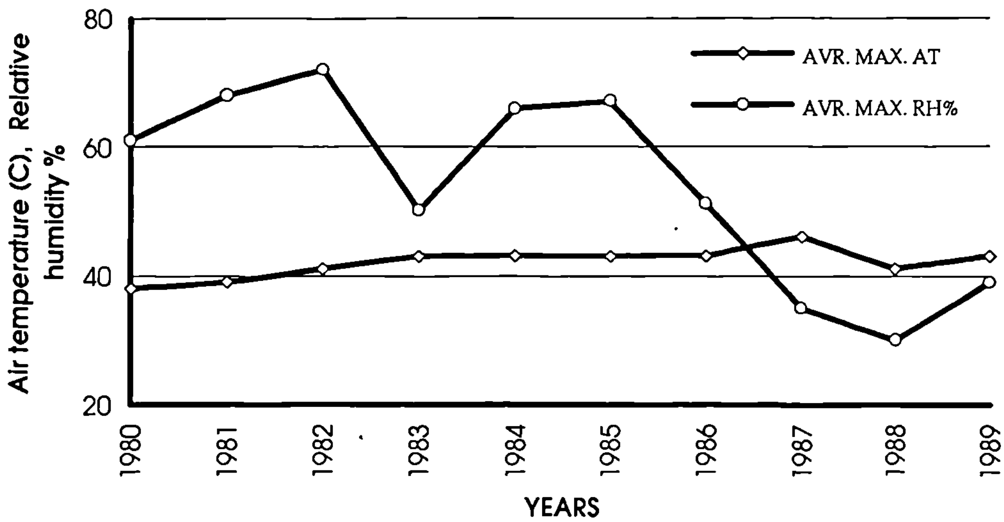

Fig.1.2: *Average maximum air temperatures and relative humidities measured during pilgrimage seasons from 1980 until 1989.*

Hadad, A. and Ajlan, M. "Comparitive study for air temperature and relative humidity and mortality and heat stroke during the period of the Hajj." A report to the Saudi Meteorological and Environmental Protection Agency, unpaginated.

TABLE 1.1:

The number of deaths, heat stroke and exhaustion during the first two weeks of Dul-Hijjah, the month of the pilgrimage.

				TOTAL DEATH		HEAT DEATH		HEAT STROKE & EXHAUSTION	
YEAR	MAX. AT C^0	MAX.RH%	PILGRIMS	NUMBER OF PILGRIMS	PER 10000 PILGRIMS	NUMBER OF PILGRIMS	PER 10000 PILGRIMS	NUMBER OF PILGRIMS	PER 10000 PILGRIMS
1980	38	61	1949643	-	-	85	0.44	1056	5.42
1981	39	68	1943180	-	-	90	0.46	3048	15.69
1982	41	72	2011555	-	-	206	1.02	6714	33.38
1983	43	50	2501706	2154	8.61	306	0.39	7315	29.24
1984	43	66	1664478	1579	9.49	337	2.02	5404	32.47
1985	43	67	1589776	1089	6.85	960	6.04	14938	93.96
1986	43	51	1600475	379	2.37	34	0.21	5935	37.08
1987	46	35	1619224	697	4.30	624	3.85	4668	28.83
1988	41	30	1379556	353	2.56	-	-	3520	25.52
1989	43	39	1466995	-	-	-	-	-	-

Source: Anual reports of Health Ministry of Saudi Arabia, and

Hadad, A. and Ajlan, M. "Comparitive study for air temperature and relative humidity and mortality and heat stroke during the period of the Hajj."

A report to the Saudi Meteorological and Environmental Protection Agency, unpaginated.

Note: (-) data not available.

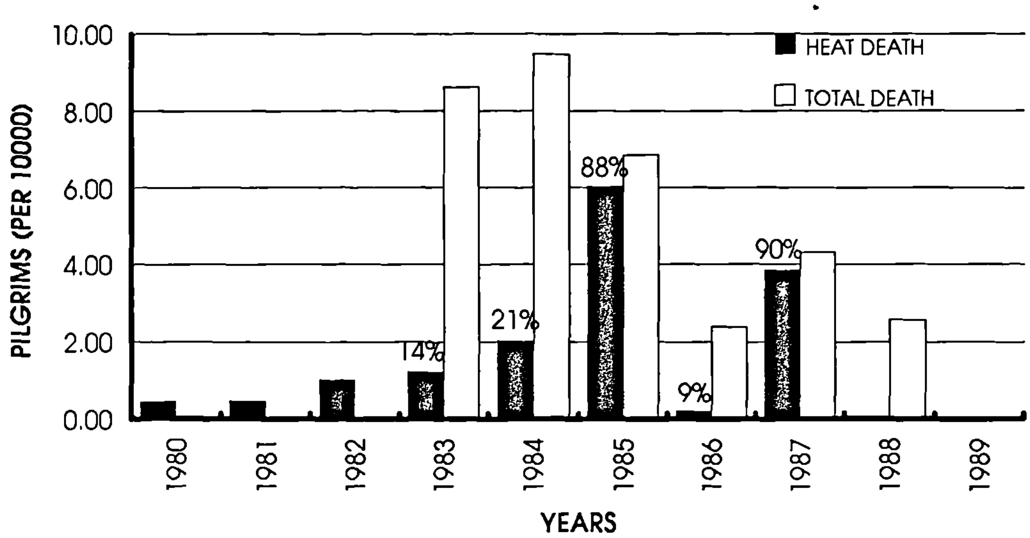

Fig.1.3: *Death and mortality rates per 10000 pilgrims reported for one decade (1980-1989).*

"Chapter five: Health welfare for pilgrims," Annual reports of the Saudi Health Ministry (1980 to 1986).

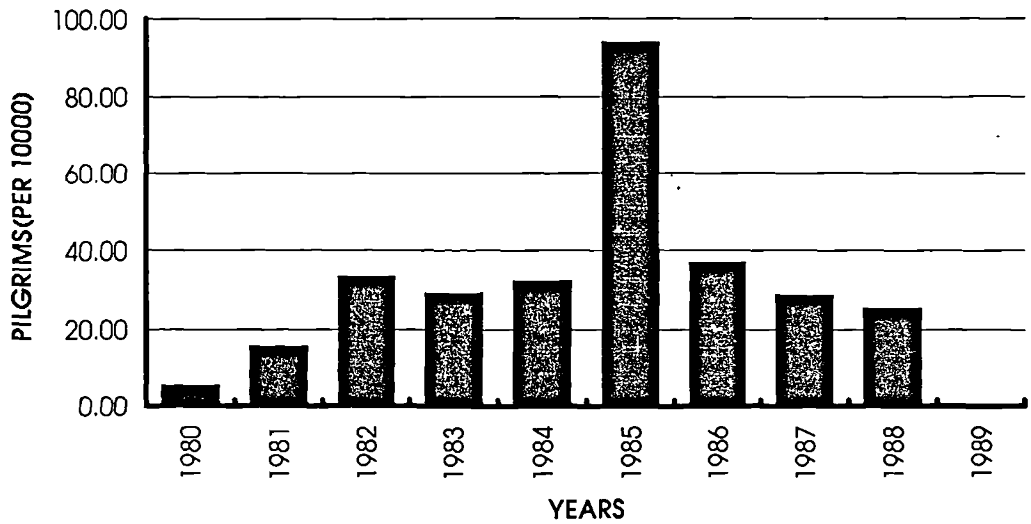

Fig. 1.4: *Rate of heat stroke and exhaustion per 10000 pilgrims reported for one decade (1980-1989).*

"Chapter five: Health welfare for pilgrims," Annual reports of the Saudi Ministry of Health (1983-1988).

TABLE 1.2:

Daily rate of deaths, heat stroke and exhaustion during the first two weeks of Dul-Hijjah, the month of the pilgrimage.

	1983		1984		1985	1986	1987		1988	
DAYS	TOTAL DEATH	HEAT DEATH	TOTAL DEATH	HEAT DEATH	TOTAL DEATH	TOTAL DEATH	TOTAL DEATH	HEAT DECEASE	TOTAL DEATH	HEAT DECEASE
1	*	*	*	*	*	26	*	*	*	*
2	*	*	*	*	*	8	29	81	20	99
3	*	*	*	*	*	12	25	143	9	96
4	*	*	*	*	17	19	24	136	11	79
5	*	*	*	*	24	10	22	109	15	102
6	*	*	*	*	19	14	33	141	15	90
7	23	14	28	10	25	12	21	93	11	100
8	13	6	10	1	56	14	46	126	14	104
9	255	186	107	61	258	25	33	262	20	173
10	86	59	64	36	319	83	47	803	22	293
11	78	26	28	15	153	35	76	886	44	556
12	41	15	33	13	80	44	79	889	29	646
13	*	*	*	*	66	30	105	628	74	842
14	*	*	*	*	42	24	53	135	31	229
15	*	*	*	*	30	20	50	84	28	111
16	*	*	*	*	*	3	54	47	*	*
TOTAL	496	306	270	136	1089	379	697	4563	343	3520

Note (*) no cases reported.

Source: Annual reports of Health Ministry of Saudi Arabia.

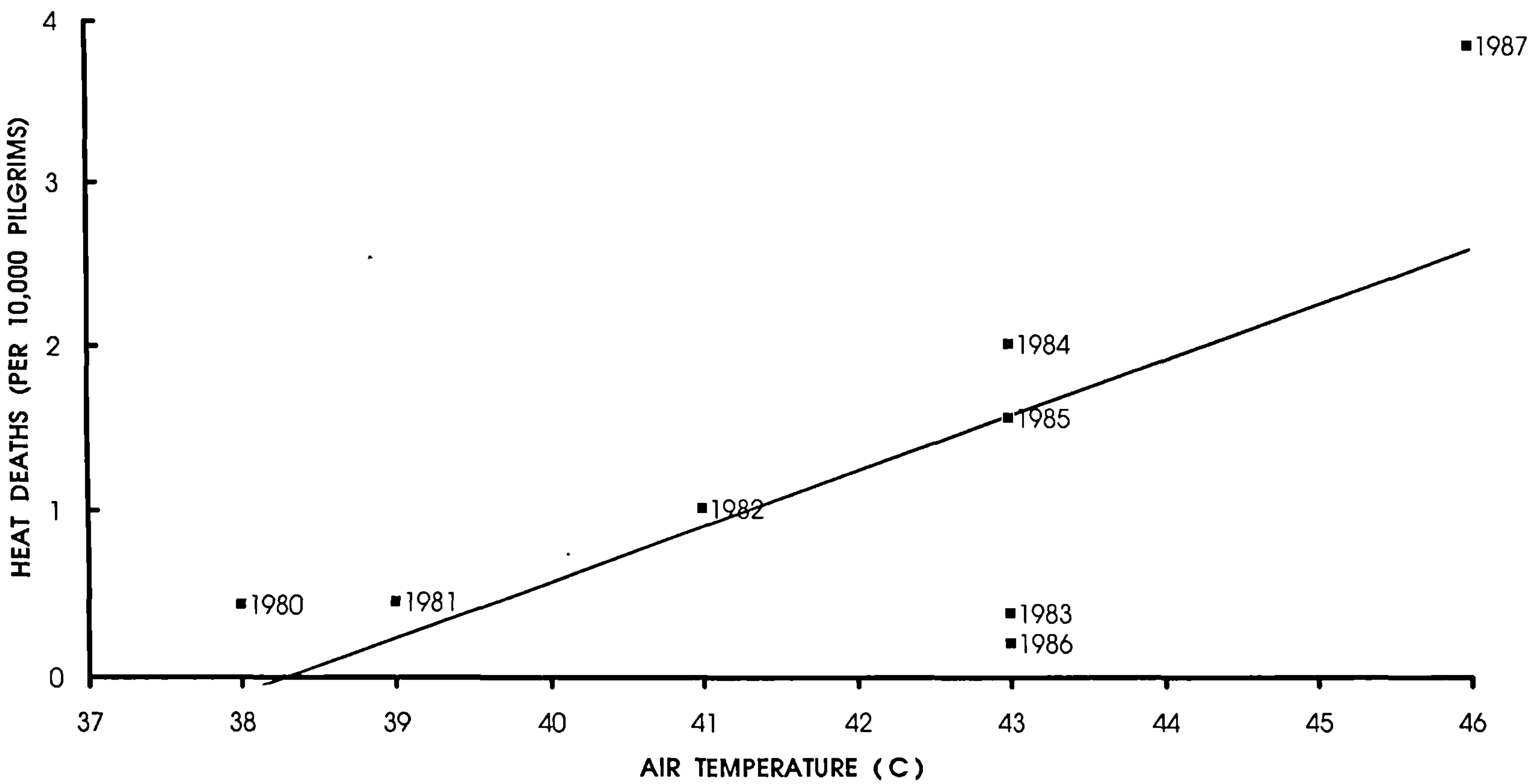

FIG. 1.5: *Correlation between air temperature and reported deaths due to heat from 1980-1987.*

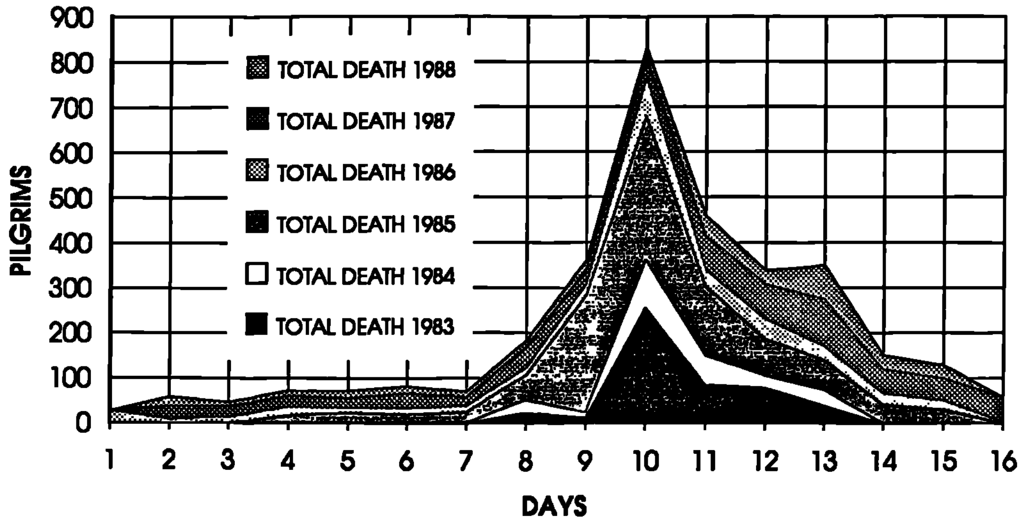

Fig. 1.6: *Daily death cases of pilgrims as recorded during the first two weeks of the month of pilgrimage, Dul-Hijjah, during the years from 1983 to 1988.*

"Chapter five: Health welfare for pilgrims," Annual reports of the Saudi Health Ministry (1983-1988).

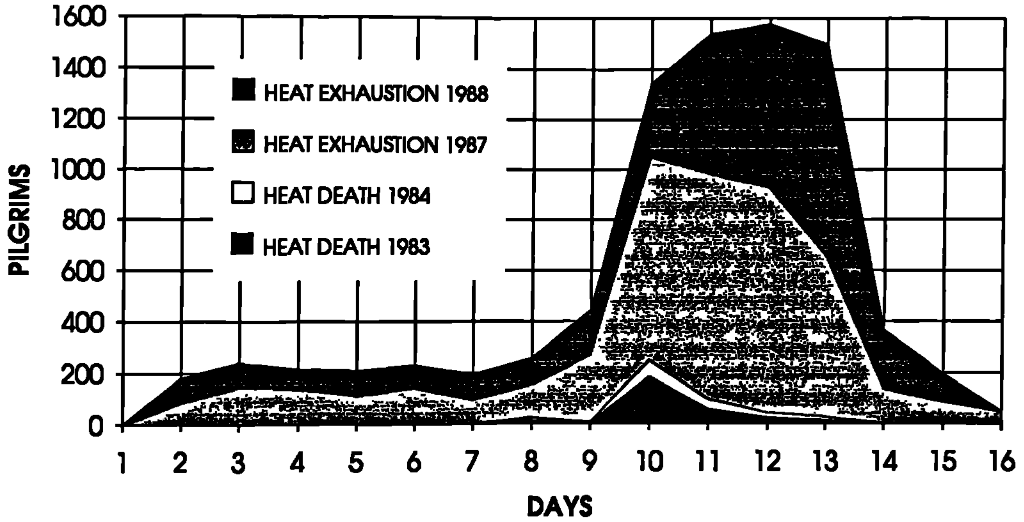

Fig.1.7: *Daily heat exhaustion and mortality among pilgrims as recorded during the first two weeks of the month of pilgrimage, Dhul- Hijjah, during the four years.*

"Chapter five: Health welfare for pilgrims," Annual reports of the Saudi Health Ministry (1983-1988).

2-THE NEED FOR THE STUDY:

The available evidence as presented here raises the serious question of safety inside pilgrimage tents, especially for pilgrims not used to living in the severe summer heat of Makkah. Also worthy of attention is the question of whether the pilgrimage tents, used since the inception of the Hajj, can continue to be employed as suitable shelters. Existing knowledge provided by the Saudi Health Ministry, thermal studies published by the Hajj research centre and independent studies (Sabbagh and Khalifa, 1983 and Zaki et al, 1991) do not sufficiently indicate the real thermal conditions inside the occupied tents during the pilgrimage seasons. Similarly, there is a lack of knowledge concerning the experience of pilgrims living in such an indoor environment, i.e., their subjective evaluation.

It is vital to assess the thermal discomfort and tolerance limits of pilgrims exposed to such heat conditions in the pilgrimage tent. Also, since pilgrims arrive from different climatic zones and vary in sex and age, it is also vital to know the influence of these factors on thermal discomfort. Equally there is a need for design guidelines as how to achieve better thermal conditions inside the pilgrimage tent.

3-THE OBJECTIVES:

The aim of this study is to fulfil three main objectives:

1- To assess the thermal discomfort of pilgrims inside the pilgrimage tents.

2- To investigate the cause of poor thermal conditions by gaining an understanding of the thermal behaviour of the tent.

3- To study passive cooling strategies and develop design guidelines applicable to the tent's design in order to maintain habitable conditions.

4-HYPOTHESES:

(A) Thermal conditions inside pilgrimage tents are worse than the outside shaded climate and contribute to heat-stroke conditions.

(B) Overheating inside the pilgrimage tent is due to:

- The low thermal performance of fabric materials of the tents which cannot protect occupants from the excessive heat of the sun.
- The high density of pilgrims inside the tents add to the internal heat generation, namely the metabolic heat.
- The extensive use of tents causes a lack of ventilation, which prevents a reduction in the internal air temperature.

5-METHODOLOGY:

In order to test the above hypotheses two different methodologies are suggested; a field survey and a series of experiments to test the effect of different configurations.

5.1- FIELD SURVEY:

A field survey was conducted during the pilgrimage season of 1989, in the second week of July. The purpose of the survey was threefold:

(a) To measure the thermal conditions inside and outside occupied full size tents during the Hajj. The important variables to measure for the indoor climate were air temperature, globe temperature, relative humidity, and ventilation rate. The important variables to measure for the outside climate were air temperature, relative humidity, wind speed and solar radiation.

(b) To closely observe how the internal space of the tents was arranged and the initiatives used to reduce the harsh climate.

(c) To establish the subjective evaluation of pilgrims towards heat conditions inside their tents. A questionnaire was designed to include the important variables that affect subjective thermal evaluation such as age, sex and climatic background of the individuals.

The data collected from the survey was then used to assess internal thermal conditions of tents. This was achieved directly through the analysis of users' evaluation and by using the international heat indices developed for hot climates. The data collected during the survey were analysed to examine the interrelationship between three sets of variables, namely the physical measurements of internal thermal conditions of tents, the subjective evaluation of users and the characteristic variables of pilgrims (i.e., age, sex, and climatic background). The analysis tools needed included the SPSS-PC statistical package. The outcome of the field survey should describe the problem of over-heating as it is experienced during the pilgrimage.

5.2- EXPERIMENTS:

Experiments on full-size tents were needed to test the impact of different variables that govern the thermal performance of tents, which in turn could lead to a better design from a thermal point of view. Some of these variables included ventilation rate, colour of the tent, type of tent fabric, height of the tent, shading with a double roof and geometry of the roof. The experimental design comprised two tents: one received no treatment, the control tent, the other received different treatments, the experimental tent. Experiments were conducted to compare the performance of the experimental tent with the control tent for the six variables stated above.

A comparison analysis was needed to study the results of above experiments and the SPSS-PC statistical package was used for this purpose. The aim of the analysis was to examine the relationship between design variables and thermal performance of the pilgrimage tent. The outcome of this work should lead to design guidelines that improve the tent's thermal conditions.

Careful preparation was made before implementing the above mentioned methodologies due to the nature of the Hajj event. The Hajj season is limited to a very short period (about one week), conditions are very crowded, pilgrims speak different languages and are busy performing Hajj rituals. The fear always was that any shortage in preparation or any misfortune could only mean a delay for one more year until the next Hajj season.

6- SCOPE OF THE STUDY:

In this study the site of Muna will be focused upon for Muna accommodates pilgrims for a longer period than other sites of Hajj, and the problem of heat inside tents is more pronounced in this locale as discussed earlier. The scope of investigation for cooling strategies was limited to the passive ones that could be applied to or integrated with the tent's design.

7- STRUCTURE OF THE STUDY:

This study is divided into four main parts. The first part includes two chapters in which this introduction is the first. The second chapter establishes the background that highlights the significance of the Hajj and focuses on the contemporary Hajj. It also describes the accommodation system practised and developed for many years to accommodate the sudden flow of two million pilgrims. This chapter ends the first part of the study.

The second part of the study aims to discuss the site investigation into the environmental conditions of pilgrimage tents. Chapters three to six form the body of this part.

Chapter three discusses the characteristics of the outdoor climate of the Muna valley and the indoor climate of tents as they were measured during the Hajj summer season of 1989. Details of methods and instruments used for the survey were included in this chapter.

Chapter four identifies heat indices by which heat stress can be assessed and ends with assessment for heat loads and thermal discomfort experienced by pilgrims from various climatic backgrounds.

Chapter five discussed in depth the design of the questionnaire that was distributed to pilgrims during the Hajj of 1989. Lessons learned from the experience of designing a questionnaire for people speaking different languages and gathered in such a transition period are discussed in this chapter.

Chapter six analyses data collected from the questionnaire. The analysis uncovered the relationship between subjective thermal evaluation of the tent and the characteristic variables of pilgrims such as age, sex, climatic background and health conditions. The analysis also established the relationship between the subjective thermal evaluation and the physical measurements such as air temperature, relative humidity, globe temperature and air speed measured inside the pilgrimage tent.

Part three investigated improving thermal conditions of the pilgrimage tents. This part includes chapters seven and eight.

Chapter seven describes ten experiments conducted immediately after the Hajj season of 1989. The experimental design and objectives are discussed in details in this chapter. A discussion of experimental results and analysis involved is separately considered in Chapter eight.

The final part of this study comprises chapter nine and an addendum. The ninth Chapter discusses the principles of passive cooling and their meanings in terms of design guidelines for tents. The addendum suggests areas for future studies.

CHAPTER II

BACKGROUND

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CHAPTER II

BACKGROUND

1- INTRODUCTION:

The Arabic word "Hajj" is usually translated as "pilgrimage" which means a journey to a shrine or a holy place. However, the precise meaning is a visit to a person or place, once, or more often, with exertion of efforts. Technically, according to Muslim scholars, Hajj means the visit to Makkah to perform certain rituals and rites (Kari, 1987).

Without becoming involved in the technical details of the significance of the Hajj rituals, Muslims perform the Hajj to express their belief in the creator of the universe (Allah) and to follow the commandment: "*Perform the Hajj and the Ummra for Allah.*"[1] In fact, the Hajj is the fifth of the five pillars of Islam, the remaining four being, testifying to the oneness of God (Allah) and the messenger-ship of the prophet Mohammad; observing the five daily prayers (Salah); paying alms (Zakah) to the poor; and fasting during the month of Ramadan. The fifth pillar, the Hajj, is obligatory once in the lifetime of every Muslim if he or she has the financial and physical means to carry it out.

Not long ago, pilgrims used to travel even from central China or Africa to Makkah on foot without knowing for certain whether they would ever return to their families and friends. This reflects the reality that the Hajj is not only a journey to a holy place but also a declaration of belief in the creator (Allah), and an expression of inspiration and devotion. For many pilgrims, the Hajj is a process of purification and marks the rebirth and continuity of their spirituality. Indeed, the Prophet Mohammed, peace be upon him, stated: "*Those who perform the Hajj in the right manner and with full spiritual and emotional involvement shall come down from Arafat pure as the day his mother gave birth to him.*"[2]

The scale of this religion's gathering is difficult to visualise. It is the largest ever assemblage any where on earth at one time. The rallying of men, women, children regardless of nationality, race or social status symbolises the equality and unity of all human beings in the sight of God (Allah). In this respect, Malcom-X a black American leader who visited Makkah wrote in his own words:

"You may be shocked by these words coming from me. But on this pilgrimage, what I have seen, and experienced, has forced me to re-arrange much of my thought patterns previously held, and to toss aside some of my previous conclusions ... because this is the one religion that erases from its society the race problem....I have never before seen sincere and true brotherhood practised by all colours together, irrespective of their colours....I could see from this, that perhaps if white Americans could accept the Oneness of God, then perhaps, too , they could accept in reality the oneness of man."[3]

Faithful coming from many cultures doing the same rituals, wearing the same simple dress and moving together from one place to another, being peaceful not only with themselves and with each other but also with plants and animals as they are commanded in many verses in the Quran is such a rich experience for such a short period. The Hajj is an experience of faith as well as an experience of international companionship in which people try to understand each other better. Therefore, the Hajj is a turning point in a Muslim's life and its effect remains for years to come and not only limited to the two weeks of the Hajj.

2- SITES OF THE HAJJ:

The Hajj envolves an annual visit to sites in and near Makkah city, located in the western province of Saudi Arabia about 70 kilometres east of Jeddah, the largest Saudi port on the Red sea (Figure 2-1). It is possible for Muslims to complete the pilgrimage in five days but almost every one allows at least two weeks.

An important characteristic of the Hajj is the structured and defined movement of pilgrims from one place to another at specific time intervals for the performing of specific rituals (Figure 2.2). These rituals take place both in Makkah and in three other holy sites outside the city namely Muna, Muzdalifa and Arafat.

Makkah city is the birthplace of Islam and of its prophet, Mohammad and lies in, and is surrounded by rocky hills and valleys. The heat of the desert sun makes the summer time of Makkah the harshest of the Arabian desert. The hottest season of the year extends from May to October and air temperature is recorded near to $50^{o}C$. At the very heart of the city is the sacred mosque that houses in its court yard the Ka'ba. The Ka'ba means the cube, the simplest form of structure, empty inside, which Muslims believe was first built in ancient times, for the worship of God. Every Muslim turns towards the Ka'ba five times each day in prayer, and it is because of the Ka'ba that Makkah is held in such high respect.

The nearest site to Makkah is the valley of Muna, an area of about four square kilometres bounded with ranges of rocky mountains on two sides and is located six kilometres north-east of the holy mosque at Makkah. During the period of the Hajj, Muna houses the largest tent city in the world, with pilgrims staying for three days in the area to carry out a number of Hajj assignments.

At the border with Muna is Muzdalifa, a wide valley enclosed by rocky mountains. Muzdalifa is a transit area for pilgrims to rest on their way back from Arafat, remaining there for only one night, that is, the ninth night of the pilgrimage month. No form of shelter is supplied at this location and pilgrims sleep the night under the bare sky of Muzdalifa.

The furthest site is the plain of Arafat which is located about 20 kilometres east of Makkah, where the pilgrims stay from sunrise to sunset on the ninth day of the pilgrimage month. Tents are erected before the pilgrims' arrival to Arafat and dismantled immediately after their departure at sunset.

Figure (2-1): *The Kingdom of Saudi Arabia*

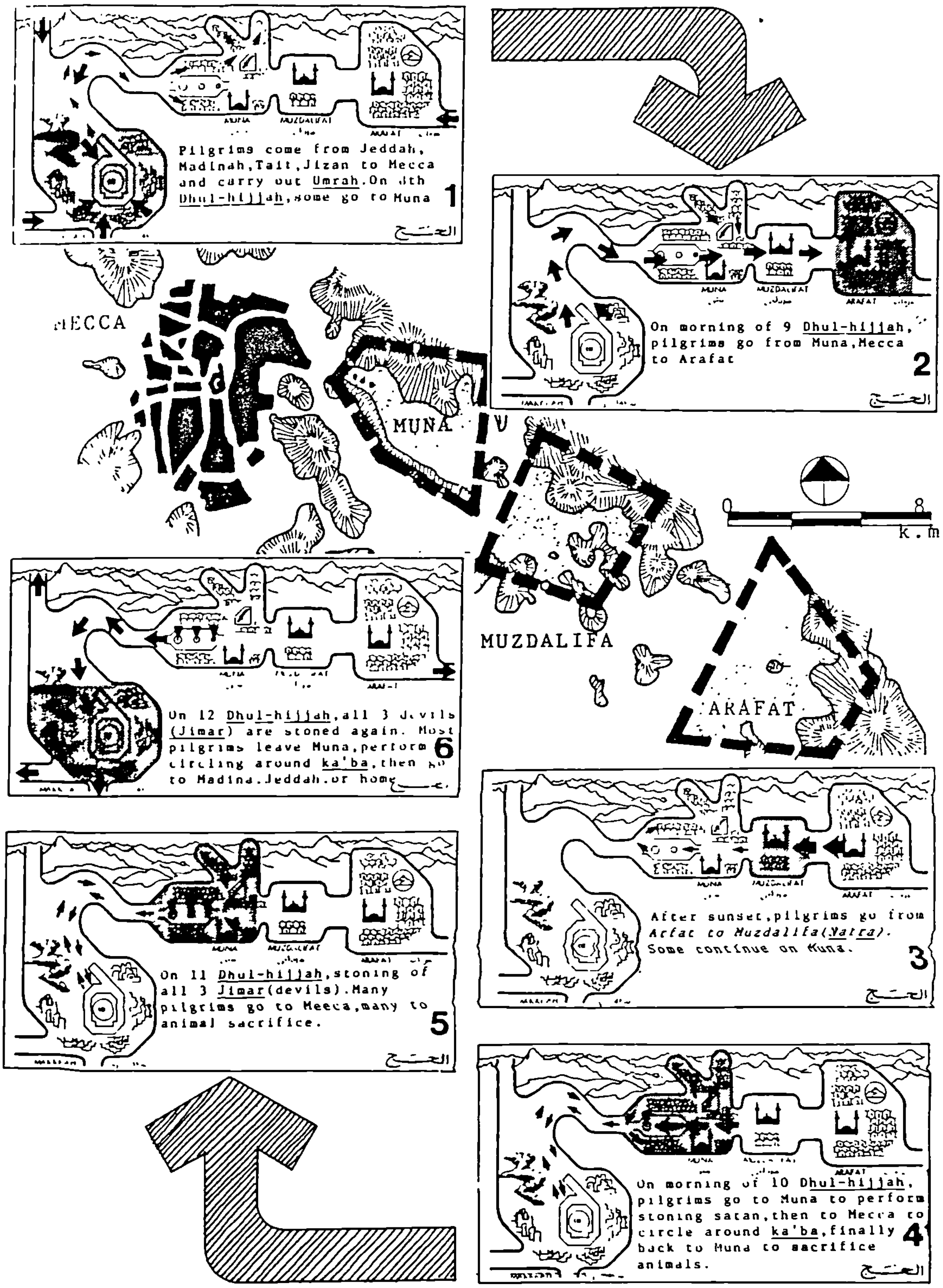


Figure (2-2): Schematic diagram patterns of movement, rituals of the Hajj, and Pilgrimage sites.

After: Bodo Rasch, The Tent Cities of The Hajj, 1980, p.37.

3- THE CONTEMPORARY HAJJ:

The Hajj of today is characterized by an enormous increase in the number of pilgrims which jumped from 600,000 pilgrims in 1960 to 2.5 million in 1983. Since then the number of pilgrims has been temporarily restricted to fluctuate near to 1.5 million. This is to allow for the building of new facilities and infra structures in Makkah city and other sites to serve even more pilgrims. The number of pilgrims predicted for the coming years is estimated to be about three million by the year 2000.[4] This enormous increase is due to the improved ease and frequency of transportation and to the higher living standards of pilgrims in developing Islamic countries and the independence of Muslim countries in central Asia after the collapse of the USSR.

A primary characteristic of the contemporary Hajj is the high density of pilgrims in Makkah and other pilgrimage sites. The density of pilgrims at Muna and Arafat exceeded 5000 pilgrims / ha- twice as high as the highly concentrated population centres, such as Dacca.[5] This means that each pilgrim had about one square metre in which to live.

Because the Islamic year is governed by a lunar calendar and has 354 days, the Hajj passes through all four seasons during a 34-year period. Therefore, another important characteristic of the contemporary Hajj is that since 1982 it has fallen in the summer months and will not move to winter until 2000.[6] The high density of pilgrims and the severe summer conditions in Makkah- both of which produce excessive heat within the pilgrimage tents- are both contributing factors to the growing number of pilgrim fatalities in recent years.

4- PILGRIM ACCOMMODATION AT MUNA:

To house the large number of pilgrims, tents are used, as has been the case since the origin of the Hajj. Today more than 350-400,000 tents are in use; their roofs cover 500-600 hectares in Muna and Arafat together.[7]

A typical layout of the tent's camp in the Muna valley during the seventies would be similar to the plan indicated in figure (2.3), sketched from an aerial photograph. Tents are arranged around one or more large tents which are used for prayers, sermons and meals. Preparation of food is done in an open area close to the tents of the Mutawaf (pilgrims guide), who supervise the camp and provide information for pilgrims and staff. A fresh water supply is often kept in tin drums holding 200-500 litres and distributed over the encampments. For sanitation, a small tent over a can-pit is used as a toilet unit. These units are often outside the camps or otherwise distributed on the boundary.

With the gradual increase of pilgrims arriving to Makkah, and more areas used for bridges, roads and other services, there will be a reduction in the area allocated for accommodation. The total area of Muna is 380 hectares, half of it is mountainous and so cannot be used for tents in any great concentration, and the other half is flat terrain. Yet only 48 percent of the entire flat area of Muna is used for accommodation; the rest is taken up with bridges, mosques, public services, and government agencies.[8] In effect, there are only about 180 hectares to accommodate an average population of two million pilgrims. The average density of population in the Muna tent camps during the 1983 Hajj exceeded 10,000 persons / ha, that is, 10-12 pilgrims per $16m^2$ tent.

As a result, improvements were essential to maximise the use of land available for accommodation. From the administration side, the government organised pilgrims according to their nationalities into specific establishments under the direction of pilgrim guides, creating six different establishments, namely:

1. Arab pilgrims;
2. South Asian pilgrims;
3. Southeast Asian pilgrims;
4. North and South American, European, and Turkish pilgrims;
5. Iranian pilgrims; and
6. African (non Arab) pilgrims.

This administrative arrangement resulted in six distinct residential zones, plus two zones for uncategorized pilgrims who do not follow guides. A further zone is for pilgrims with guides but not yet categorized under any of the six establishments. Government services, such as controlling, policing, and hospitals, including employees and guests, form a separate zone at Muna (figure 2.4).

Camps administered by pilgrim guides are arranged into blocks. Figure (2.5) represents a typical camp arrangement at Muna as observed by the author during the Hajj of 1989. Three toilet units are in the middle of the site, with each unit consisting of 30 toilets. At the end of the units there are water taps for washing and ablutions. Excreta and waste water are collected into a large septic chamber underneath the units, where it is piped to the central treatment plant out of Muna. Cooking and food preparation are near the entrances of the camp and must be built with corrugated steel for safety from fire. For the same reason the camp is fenced with corrugated steel sheets which are mainly painted white. Tents occupy the rest of the area and are arranged into modules, varying in size, depending on the shaded area needed for pilgrims. In the camp represented in figure (2.5), tents are organised into modules consisting of ten tents long by two wide; each module consists of an area of about 300 metres.

The camp's preparation and the erection of the tents are illustrated in sequence in figure (2.6). The first preparatory step is to arrange the site according to the drawing plan provided for it. The underground electrical network is then laid down to supply each tent with one lamp and socket. Once the underground work is finished, the construction of the tents is started. The procedure is very simple. First, vertical metal poles are fixed firmly in the ground along the side walk ways and to a height of two metres above the ground. The vertical poles are reinforced with horizontal metal beams covering the two metre span between the poles. The diameters of poles and beams are no more than ten centimetres. This results in strips each measuring 40x8 m and surrounded with vertical poles reinforced with horizontal bars.

Each strip is then covered with roof canvas, and then the erection is very simple. The tents' roof, each measuring 4x4 m, are first laid down on the ground, and connected with each other by ropes: ten tents long and two tents wide. The far ends of the tents are then anchored with ropes to the horizontal bars at a height of two metres above the ground. The roofs then take their final shape simply by raising the centre wooden poles of each tent. Each wooden pole measures 3.5 m long and 10 cm in diameter and divides into half for easy storage. The side walls are the last component to fix, and are made with the same fabric as the roof but reinforced at metre intervals with bamboo. The current tent used in the Hajj is double skinned with colourful cotton fabric inside and white cotton outside, and are sewn together. Within a week the Muna valley is dominated by white tents forming the largest tent city on earth.

Constructing one large shaded area as described above is useful for pilgrim guides for it is simple, fast, and inexpensive. The price of the standard and widely used tent during the Hajj (1989 price) costs no more than £50 and many can be rented even more cheaply. The reason for the low price is the competition between tent manufacturers to produce large quantities of cheap and low quality tents in terms of their resistance to thermal conditions and multi-use.

The current use of tents, however, is not satisfactory for the pilgrims because the shaded spaces are over crowded, overheated, and poorly ventilated. Moreover, it does not meet the standard of privacy which for Muslims requires complete segregation between sexes.

The overheat problem inside the tents makes some pilgrims choose to sleep in better shaded areas, such as under bridges or the only covered pedestrian walk in the valley. If these areas are crowded then pilgrims build their own shade using recycled materials such as empty boxes, or even their own Hajj dress, as indicated in figure (2.7). Here, pilgrims have decided to stay in their rented tents and use their Hajj dress to form a second internal layer aiming to cut solar radiation to the inside, While others have added a double roof from the outside for the same purpose.

The problem of privacy leads to using fabric partitions to divide the large internal space as indicated in figure (2.8), resulting in poor ventilation and, therefore, intolerable heat. Another serious disadvantage is that the tent's fabric is combustible; in the event of a fire, it is fortunate that the tent is on level ground and pilgrims can easily escape from any side. The solution to this problem is to use flameproof fabrics, which has been achieved by the Hajj Research Centre in Saudi Arabia where a flame proofing chemical was developed. This treatment, however, increases the weight of the tent by 10 to 20 percent and reduces its porosity to air flow.

5- SUMMARY:

To summarise, tents are an essential part of the architecture of the Hajj, not only because of their functional and economical advantages, but also because of their history of usage from the very origins of the Hajj. Such dwellings have developed over the generations to produce an inexpensive shelter that could be built with few skills in a short space of time. From observations made during the Hajj of 1989, there are two important necessities which pilgrims require for their tents. First, there must be protection from the sun for people unaccustomed to temperatures up to and above 50°C- this is a matter of survival. Second, there is need for privacy the achievement of which often restricts ventilation. Both functions are not satisfied properly by the tent camp since pilgrims complain, of the intolerable temperatures inside the tents which exceed the temperatures outside. A solution must therefore be devised to improve the thermal conditions of the pilgrimage tent.

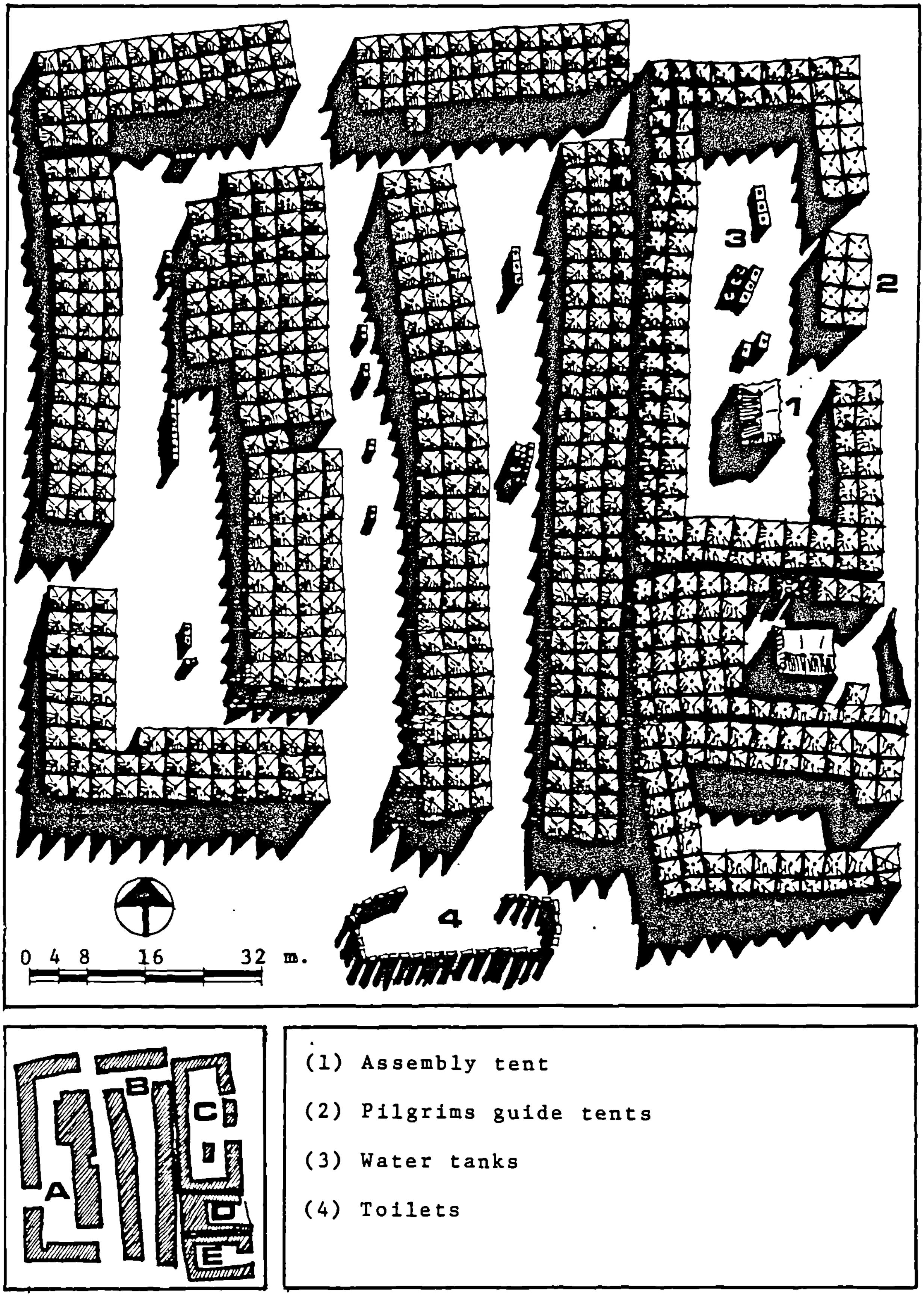
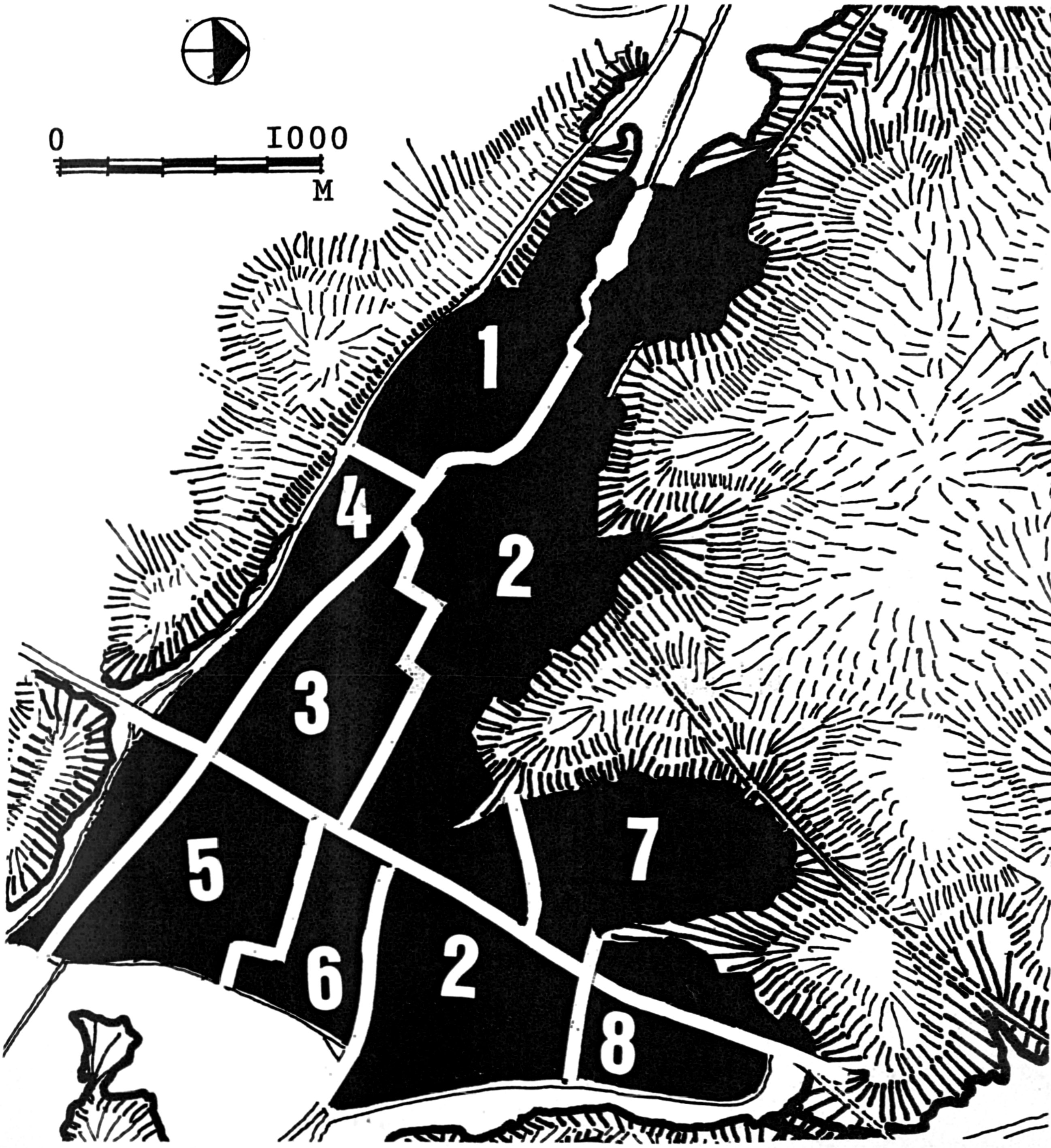


Figure (2-3): *Typical arrangement of tent camps during seventies.*



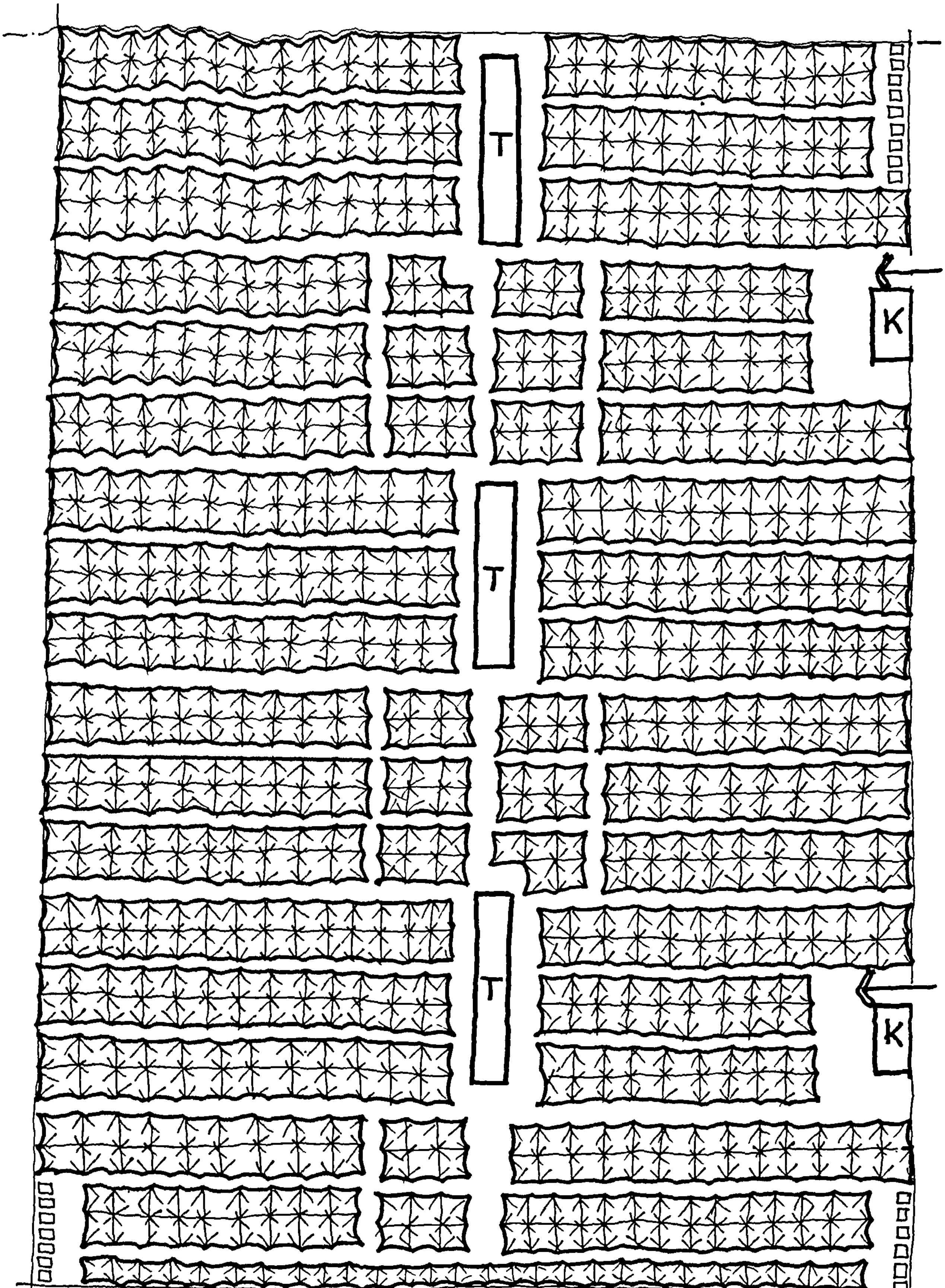
[1] Pilgrims with guides [2] Arab pilgrims [3] South Asian pilgrims

[4] Governmental area [5] Iranian pilgrims [6] African (non Arab) pilgrims

[7] Southeast Asian pilgrims [8] European and Turkish pilgrims

Figure (2-4): *Residential and service areas in Muna valley during the Hajj of 1985.*

After: Hajj Research Centre, 1985 guideline map.



T= Toilets K= Kitchen ◻ = Water tanks = Tent (4x4m)

Figure (2-5): Typical modern arrangement of tents' camp in Muna Valley.

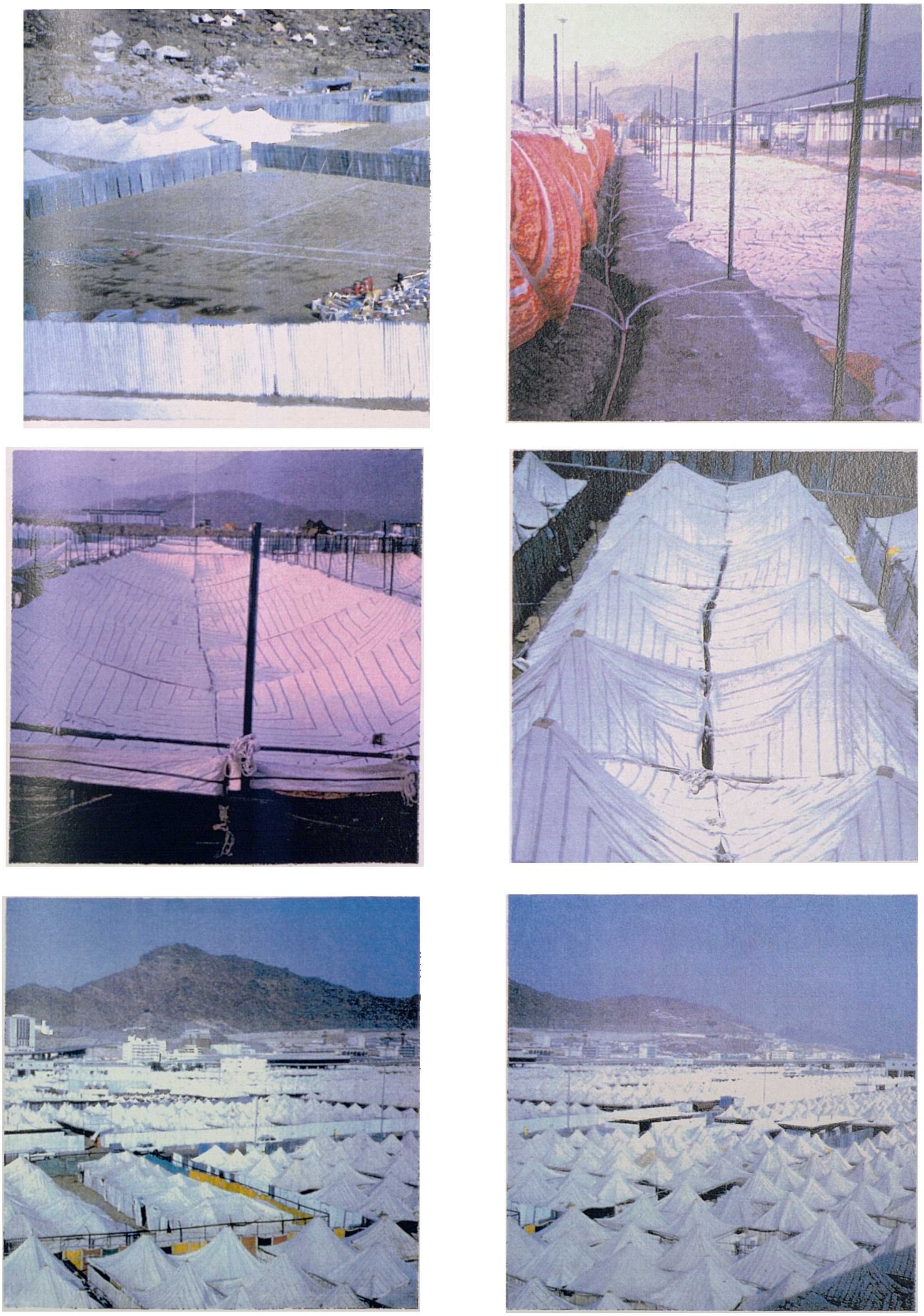


Figure (2-6): Sequence of site preparation and tents' construction in Muna valley.

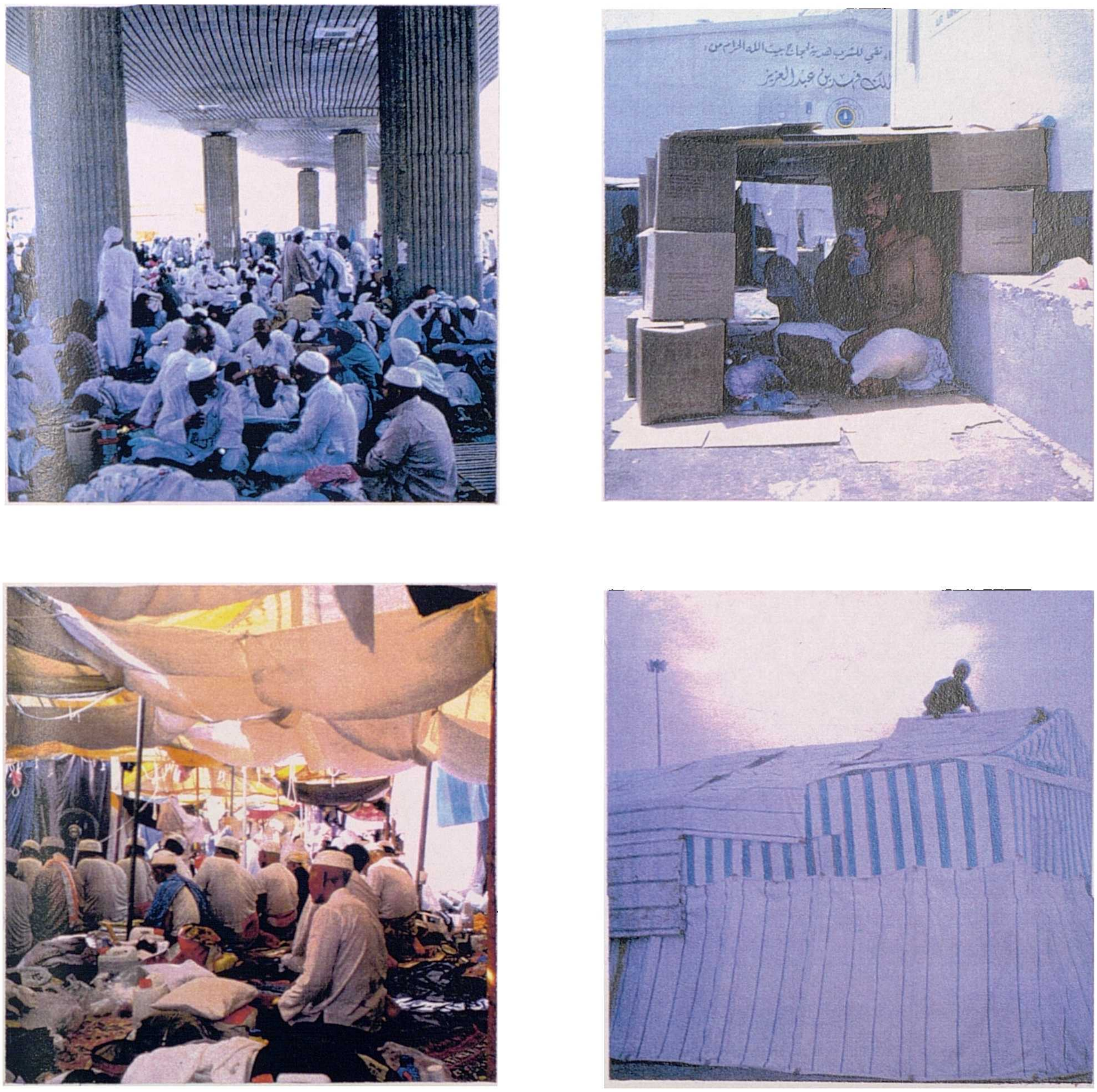


Figure (2-7): *Some of the pilgrims' initiatives to easy the problem of over-heating inside tents.*

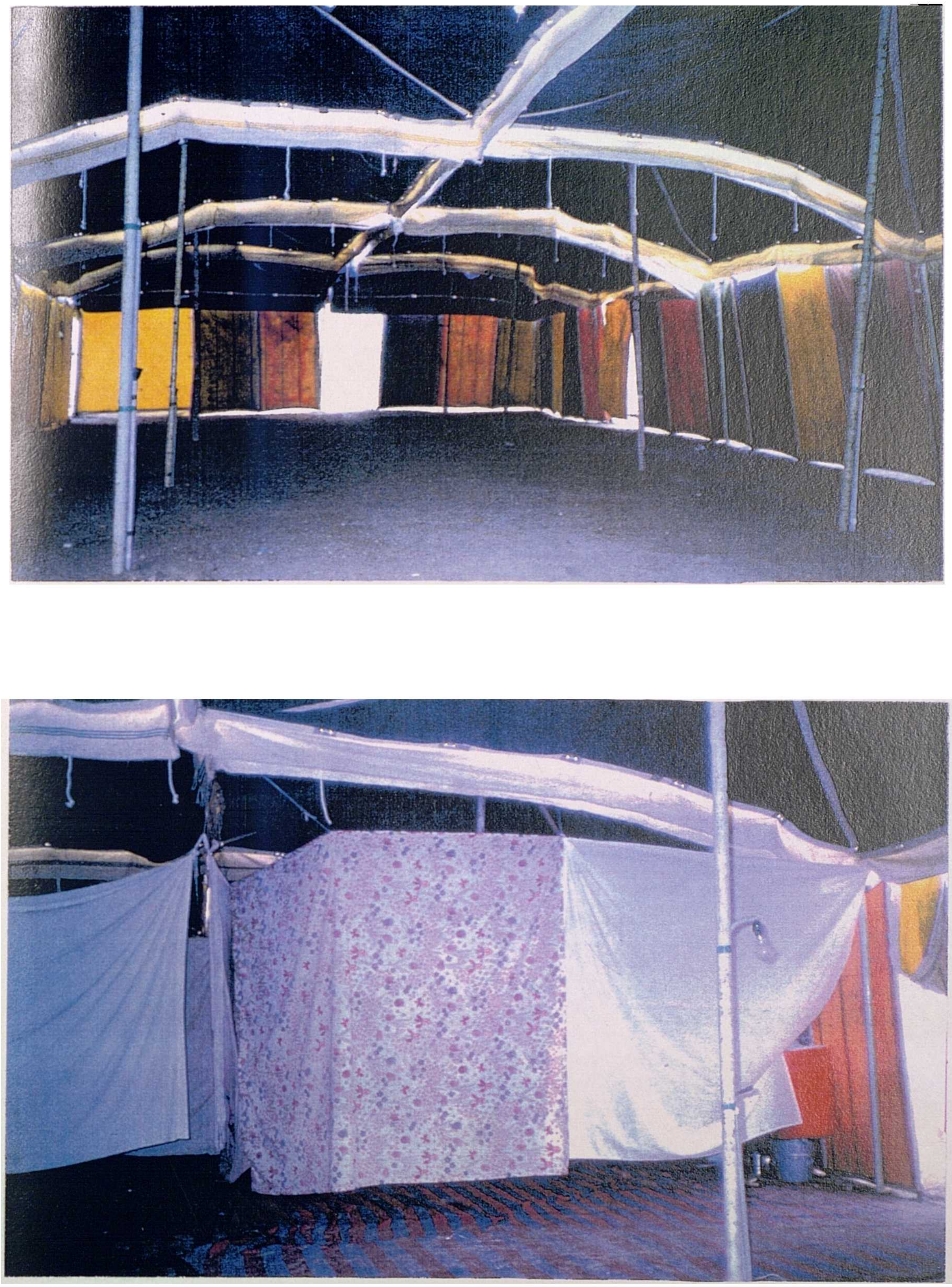


Figure (2-8): *The Pilgrims' arrangement of the internal space of tents for privacy, (a) The internal space before use, (b) The internal space after use.*

END- NOTES

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6- Khojali, M. "Prevention of Heat Stroke: Is it Plausible?" In M. Kojali and J. Hales, editors,. Heat Stroke and Temperature Regulation, Sydney: Academic Press, 1983, pp. 293-301.

7- Rasch, The Tent Cities of The Hajj, p.63.

8-Hajj Research Centre, Land use of Muna Area for 1980,1981, and 1982, Makkah: University of Umm Alqura, 1983, p.2.

CHAPTER III

THERMAL CONDITIONS INSIDE AND OUTSIDE THE PILGRIMAGE TENTS: MEASUREMENTS AND RESULTS

TABLE OF CONTENTS

CHAPTER III

THERMAL CONDITIONS INSIDE AND OUTSIDE THE PILGRIMAGE TENTS: MEASUREMENTS AND RESULTS

1- INTRODUCTION:

This chapter aims to determine the climatic characteristics of the inside and outside environment of the pilgrimage tents during their use in the Hajj. Inside and outside environments of pilgrimage tents were measured during the Hajj period of 1989, the second week of July. The results are presented in this chapter. The tents in Muna are erected for one week and are occupied by large numbers of pilgrims from different nationalities and climates. Before and after the Hajj period the site is empty. Field work in such temporary conditions, therefore, differs from other studies in terms of its planning and preparation. In other cases, built up areas and physical shapes of buildings can be defined, with more time being available for any necessary alterations to field work. In temporary cases, such as in the Muna valley, however, the site is inhabited for only a short time and remeasurement is impossible. Any error in measurements may involve waiting until the following Hajj season, twelve months later. Even then the people, layout, and time variables would be different. Methodology and tools of measurement are presented below, together with the difficulties experienced during the field work.

2- METHODOLOGY:

To achieve the stated objectives it was necessary to measure environmental conditions during the pilgrims' stay in the Muna valley. This occurs during one of the hottest months of the year: from 11th to 15th July 1989. The parameters chosen to quantify the inside environments of pilgrimage tents are: air temperature, relative humidity, globe temperature, and air velocity. The parameters to describe the outside environment are: air temperature, relative humidity, wind speed, wind direction, and solar radiation.

The inside environment was measured at three different camps occupied by pilgrims coming from three different climates: cold, tropical, and hot dry. Pilgrims from Europe and Turkey were selected to represent pilgrims from a cold climate. Pilgrims from Malaysia and Indonesia represented pilgrims from a tropical climate and Arab pilgrims from Egypt and Morocco represented those from a hot climate. However, shortage of instruments made it only possible to measure the inside environments of the two extreme climates, the 'Arab' and 'Europe' camps (i.e. "hot" and "cold").

The first step was to identify the locations of the Arab and Europe camps before they were occupied to install the measuring equipment. This was done with the help of aerial maps produced by the Hajj Research Centre (HRC). Second, permission had to be obtained from local authorities and the camp's administering body to install the instruments and to have access to the camps during their occupation. The criteria used for selecting the tents in which to install the instruments for measuring the **inside** environment were:

(1) The location of the tents had to be in the middle of the camp site, surrounded with tents on all sides. Selected tents were located far away from any humidity sources such as kitchens, toilets, or ablution areas.

(2) The selected Arab and Europe tents had to be similar in size and orientation and made of white cotton fabric which is the most frequently used material and so represents the majority of the tents. Their interior had to be well protected against direct solar penetration through holes or joints between the tents' roofs.

(3) Any uncontrollable parameters such as the number of occupants, type of electrical equipment used inside tents, location of side openings, and pattern of

using the interior space were to be observed. A special form was designed for this purpose (Appendix III).

The criteria for selecting the location of equipment for measuring the **outside** environment were:

(1) The location had to be near to the Arab and the European camps and within a maximum distance of 500 metres.

(2) The location had to be safe from public interference for the security of measuring devices.

(3) The equipment had to be installed at a height to avoid the effects of tall buildings or surrounding tents, particularly for those instruments measuring solar radiation and wind velocity. Minimum height was twice the height of the tent, i.e., not less than 7 metres.

A preliminary experiment was conducted using a tent erected in the Architectural Science Laboratory of Newcastle upon Tyne University. The aim was to become familiar with the operation and recording systems of measuring devices. This step indicated that three sets of instruments were required, one set for measuring the outside environment and two other identical sets for measuring the inside environment. Outside measuring instruments consisted of sensors for air temperature and relative humidity, a solar meter and a wind anemometer. Inside measuring instruments were a globe thermometer, sensors of air temperature and relative humidity, and an air velocity anemometer. With this limited number of measuring sets, it was only possible to use one location to measure the inside environment in Arab and European camps. The measuring position had to be representative of the measured space and so sensors were not to be positioned close to the floor or the ceiling, but preferably at a medium height. Sensors should also not be close to radiation or heat sources such as lighting lamps or cookers. The sensors of each set were attached to a stand at a head level of 1.7 m. above the ground, i.e., the middle of the tent's height. They were connected through separate channels to a data logger. Each stand could then be secured at its place or in the case of the inside measurements attached to the tent poles for safety. The data logged was loaded onto a computer using the Squirrel data manager.

3- LOCATION:

Four sites were selected at Muna valley for the field measurements and are indicated in figure 3.1. The outside environment was measured at two locations. The first site was the meteorological station operated by the Hajj Research Centre (HRC). It is located on the roof of a two-storey building near the Arab camps at a height of 280 meters above sea level. The second site was selected by the researcher to satisfy the criteria established in the methodology section. The second site therefore was on the roof top of Muna mosque at the same height as the HRC meteorological station.

For the inside measurements of the Arab camps, a block of tents was selected from the Moroccan camp as is indicated in figure 3.2. The block consisted of six tents long by two wide with passageways of one metre width around the edges. Each tent measured 4 m by 4 m with a maximum height of 3.5 m at the centre and 1.7 m towards the edges. The total area of the block, therefore, amounted to 192 m^2. Tents in the Moroccan camp were positioned with the long side facing a north-east south-west axis. Tents in this camp were typically made of light cotton fabric of a thickness of approximately 0.001 m from outside and thin translucent cotton material from inside. Electrical equipment inside the block consisted of 9 electrical fans, each 95 watts, and 12 incandescent lamps, each 60 watts. Fans were used for the 24 hour-period and lamps used during the night time. The measuring instruments were mounted on a stand and positioned near the middle of the tent protected from direct solar penetration and light bulbs. Pilgrims had divided the interior with partitions to provide privacy. This use of space is widely practised in Arab camps and partitions come in various sizes and shapes, but generally are made of sheets and parts of the pilgrim's uniform *Ihram*. Tents selected for inside measurements at the Moroccan camp were inhabited by approximately 100 pilgrims.

In the European camps a block of tents was selected to measure the inside environment of tents inhabited with pilgrims from a cold climate. The block, as indicated in figure 2.3, has similar measurements, is built of similar materials, and pitched at a similar orientation to, the one selected from the Arab camps. Electrical equipment consisted of 12 fluorescent lamps, each of 40 watts, which were operated during the night time, and 16 fans each of 75 watts, which were operated 24 hours a day. Unlike the Arab camps, the interiors of the European camps were not divided with partitions. Instead, more openings existed along the side walls of the tents and in some cases no side walls were built at all. The number of pilgrims using the selected site, approx. 60, was less than that observed in the Arab camps.

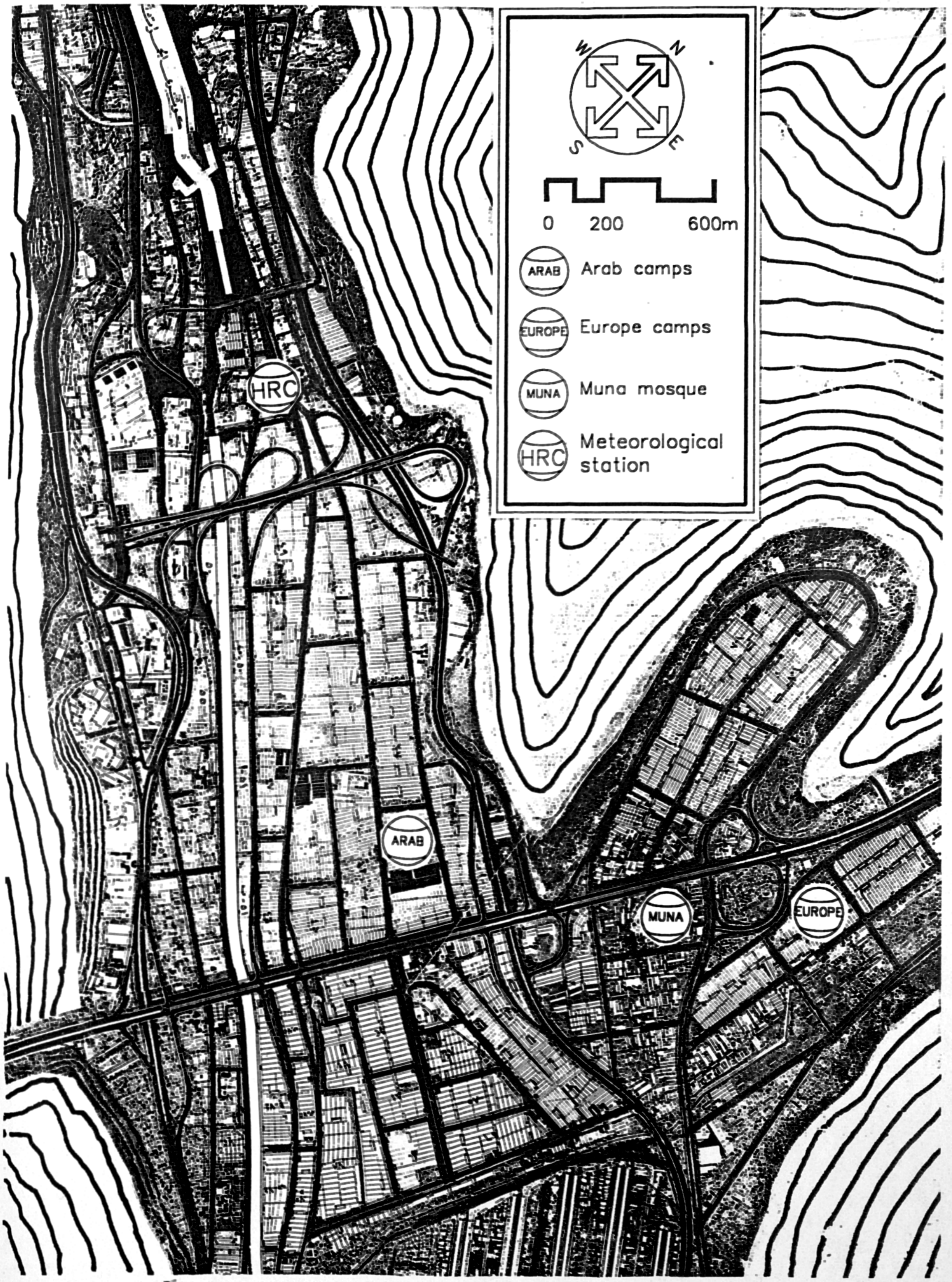


Fig. 3.1: *Locations selected at Muna valley for the measurements of the inside and outside environments*

Hajj Research Centre, 1405 guide-line picture, 1985.

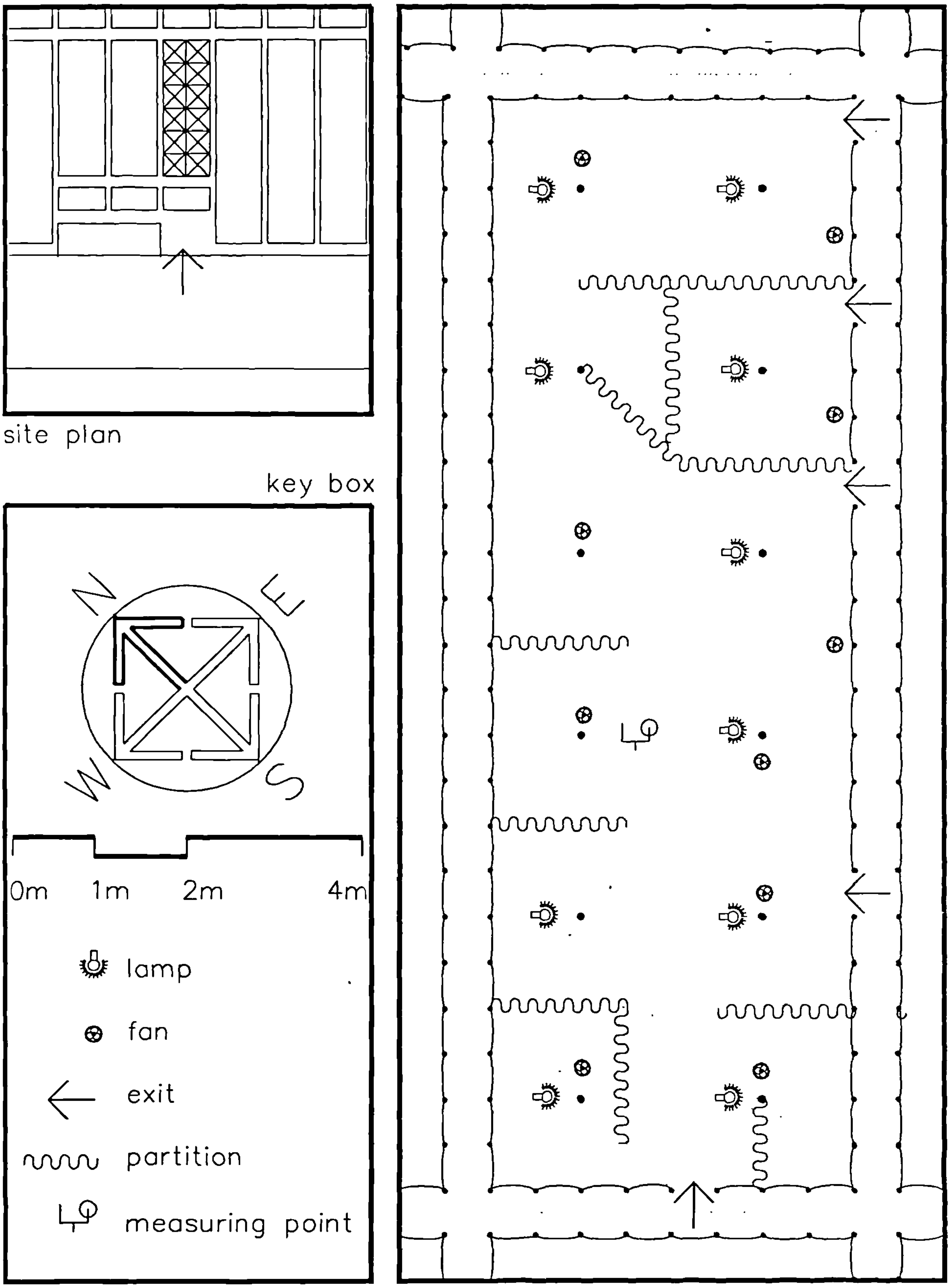


Fig. 3.2: Tents selected for measuring the inside environment at the Arab camp.

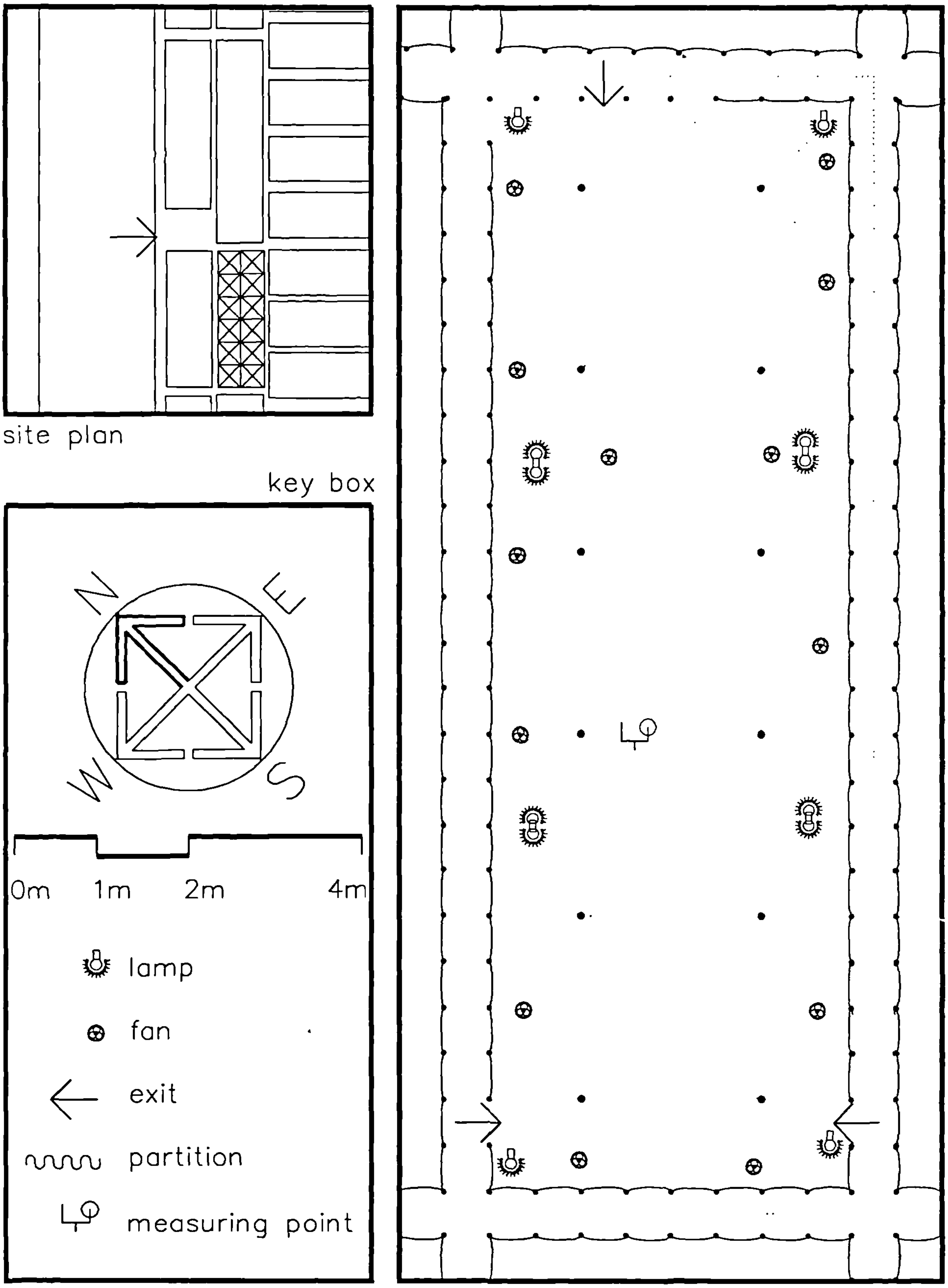


Fig. 3.3: *Tents selected for measuring inside the environment at the European camp.*

4- INSTRUMENTATION:

Instruments used for the measurements were obtained from the Department of Architectural Science at Newcastle University and Umm Alqura University in Saudi Arabia. All instruments used in the field measurements were calibrated with reference to international standards, and are illustrated in figure 3.4.

Air temperature and relative humidity were measured with probes manufactured by VAISALA (HMP 31UT). Similar probes, shielded against solar and thermal radiation, were used to measure the air temperature and relative humidity of the outside environment on the roof of the Muna mosque. The meteorological station of HRC used an aspirated hygrometer to measure dry bulb and wet bulb temperatures. The hygrometer was accommodated inside a Stevenson meteorological screen to reduce the effect of thermal radiation from surrounding surfaces. The reading of the wet bulb temperature is referred to as the psychrometric wet bulb temperature while the reading of dry bulb temperature measures the air temperature. The difference between the dry and wet bulb temperatures is used to provide an indication of the amount of water vapour present in the air. Relative humidity can be read from tables provided with the instrument.

Globe temperature was measured using a globe thermometer- which is a 150 mm diameter, thin-walled copper sphere painted matt black. A thermistor sensor was inserted at the centre of the black sphere, figure 3.4. Mean radiant temperature was derived from the readings of the globe temperature and air temperature using the following formula which is suitable for low air speed.[1]

$$MRT = (GT - 0.6AT) / 0.4 \quad \text{.......} (3.1)$$

Where: MRT= Mean radiant temperature, ^{o}C

GT= Globe temperature, ^{o}C

AT= Air temperature, ^{o}C

A hot wire instrument was available for measuring air speed inside tents. However due to the practical problems of measurements, i.e. the difficulty of locating representative readings which were not influenced by local disturbance, it was decided to abandon the measurements and make the assumption that the air velocity in the tents would be low (i.e. within the range of 0.1- 0.5 m/s). Spot readings during the survey and subsequent measurements obtained from the experiments justified this assumption.

The instrument used for measuring external wind speed was the Porton anemometer, type A100. This instrument needs a battery supply of 12 volts for its operation. The output is read in volts and can be converted to m/s using the following formula[2]:

$$O_m = O_v / 0.203 \quad \text{...(3.2)}$$

Where: O_m= Output in m/s

O_v= Output in Voltage

The meteorological station of the HRC had used the KAHLSICO hand anemometer, type (03AM120) to measure wind speed and direction. The accuracy of the hand anemometer is ±0.5 m/s and direction is better than ±5°. Measurements of free wind velocity were taken at a height of 10 metre both for the HRC and the Muna mosque meteorological stations.

An Eppley Precision Pyranometer, model PSP, was used to measure the total solar radiation intensity on the horizontal plan. The output is read in microvolts and is converted to Watts / m^2 using the following formula[3]:

$$O_w = O_{mv} / 0.009 \quad \text{...(3.3)}$$

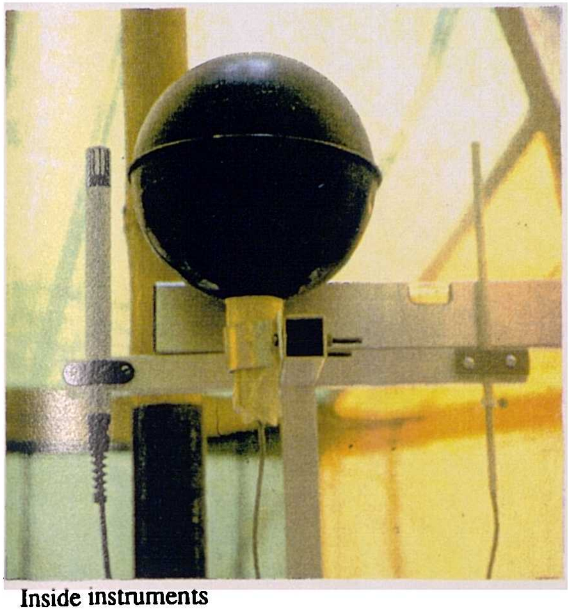
where: O_w= Output in Watts/m^2.

O_{mv}= Output in microvolts.

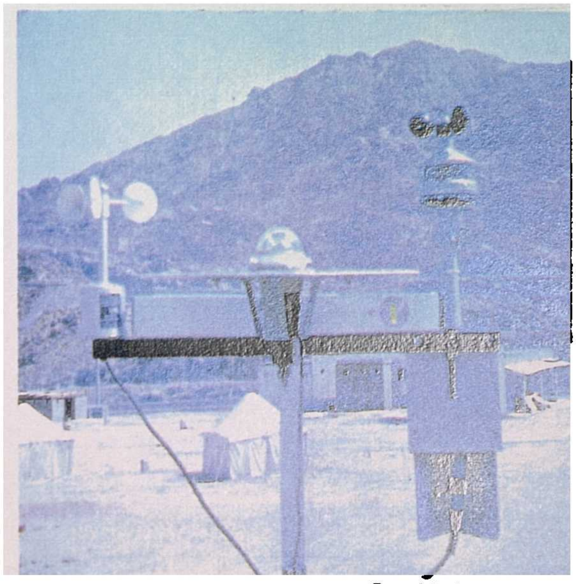
The meteorological station of the HRC had used a Pyrheliograph to measure total solar radiation. Solar radiation is transmitted through a glass dome mounted at the top part of the Pyrheliograph. Change in solar intensity is recorded on a special chart paper (chart # 5-1050-AW weekly) mounted on a cylinder that is mechanically rotated according to the change in time. The area under the inked record is multiplied by the chart constant[4]. Each square inch under the curve of the chart represents 851.61 g-cal / cm^2 to convert this unit to W/m^2 the chart constant is multiplied by 11.634.

Instruments prepared for the outside measurements on the roof top of the Muna mosque were: a Pyramometer for measuring solar radiation, an Anemometer for measuring wind speed and air temperature, and a relative humidity Probe. All were attached to a stand which was firmly fixed to resist any strong wind. Consideration was given to selecting a measuring spot not affected by either shade or wind deflection due to the minarets of the mosque or the parapet of the roof. The stand therefore was located 30 m away from the nearest minaret and 1.7 m above the level of the roof. The Pyramometer was fixed horizontally facing the sky and the probes of air temperature and relative humidity were shielded against solar and thermal radiation. Readings were automatically recorded every hour using a 12-bit micro-data logger which is manufactured by Grant and is known as a squirrel. The squirrel was kept protected from solar radiation and dust inside a wooden box.

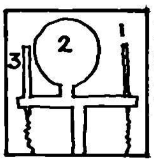
Readings at HRC meteorological station were taken manually every hour throughout the Hajj period and every 30 minute during the hottest hours of the day, 11.00 to 14.00 hrs. The hygrometer which measured dry and wet air temperatures was kept protected from solar and thermal radiation inside a Stevenson screen. An unshaded spot was selected to locate the Pyrheliograph to measure solar radiation.



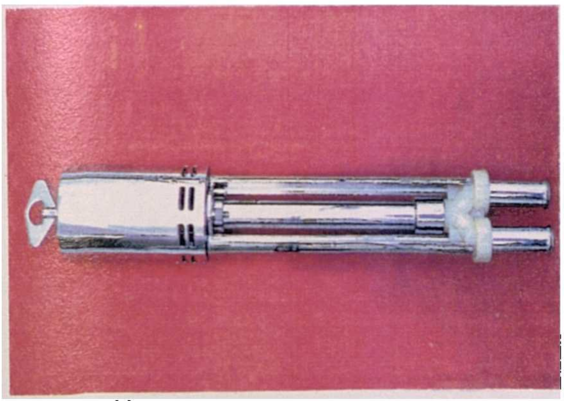
Inside instruments



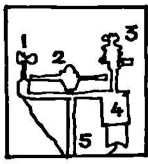
Outside instruments



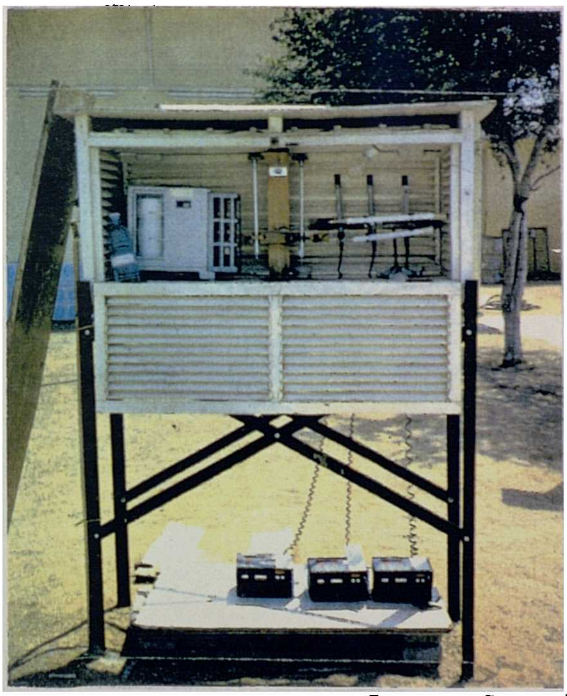
1- Air velocity probe
2- Globe thermometer
3- Air Temp. and RH% probe



Aspirated hygrometer

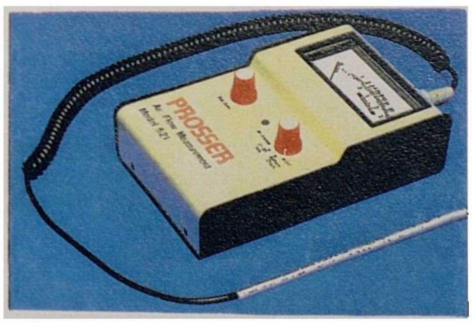


1- Porton anemometer
2- Pyranometer (psp)
3- Hand anemometer
4- Shielded air temp. and RH% probe
5- Stand of 1.7m height



Stevenson Screen

Squirrel



Air velocity meter

FIG. 3.4: Instruments used to measure outside and inside environments during The Hajj season of 1989.

Sensors used to measure the inside environment of pilgrimage tents were attached to a stand set up in the middle of the tents selected from the Arab and European camps. Sensors were located at a head height of 1.7 m and were kept away from any light and radiation sources. Pilgrims were made aware of the purpose of the instruments and requested not to touch them. The probes attached to the stand were to measure air temperature, relative humidity, and globe temperature. The "Squirrel" was used to log readings every hour.

Readings stored in the "squirrel" were downloaded to an IBM / AT computer using a squirrel data manager program. Output data indicated values of measured parameters and the time of measurement.

5- TREATMENT OF MISSING DATA:

One of the difficulties experienced during the investigation of the thermal environment conducted during the Hajj period of 1989 was the data missing relating to the outside environment. Access to the roof of Muna mosque, where instruments for the measuring of the outside environment were located, was impossible during the period of the Hajj which meant the instruments could not be accessed for reading and checking. Even when the Hajj was over it was too late to save the data recorded, for the batteries of the squirrel were flat and logged data exceeded the capability of the squirrel. Measurements of the outside environment, however, were taken at two different locations, but with different instruments. Data collected from the meteorological station of Hajj Research Centre (HRC), during the Hajj period of 1989 were used, therefore, to replace the missing data of the outside environment, and an assessment of the validity of this data had to be made.

The first strategy adopted to replace the missing data was to collect sample measurements to test both instruments used by the HRC and the researcher. The second was to find a relationship between both sets of measurement that could be used to predict the missing data, during the Hajj period. The probes of air temperature and relative humidity used by the researcher, were kept together with the hygrometer used by the HRC, inside the Stevenson screen. Readings of air temperature and relative humidity were recorded manually from the hygrometer and electronically from the probes using the squirrel. Both readings were recorded hourly for a period of 33 hours and are plotted in figure 3.5. The Squirrel readings of air temperature rose slightly from 02.00 to 05.00 hrs in the morning, in comparison with a continual drop in the manual HRC readings. The HRC readings of relative humidity from 20.00 to 01.00 hrs fall gently compared with a sharp drop in the squirrel readings. Readings from the HRC are slightly different from that of the squirrel due to the different methods of recording. For example, a squirrel reading for a particular hour is the average of four readings measured every fifteen minutes during that hour, while the HRC manual measurement is a spot reading of that hour. Manual measurements are possibly inconsistent due to errors resulting from inaccurate readings or the time of taking measurements.

5.1- RETRIEVING AIR TEMPERATURE:

Figure (3.5-a) show the readings of air temperatures recorded by the squirrel and meteorological station of the HRC. From figure (3.5-a) there is clearly a strong correlation between the two sets of data. Initially the correlation was assumed to be linear and investigated on that basis. The equation for the straight line that relates the two sets of readings is:

$$T_{sq} = B_0 + B_1 * T_{hrc} \qquad (3.4)$$

Where: T_{sq}= Squirrel air temperature.

T_{hrc}= HRC Meteorological air temperature

B_0= the intercept.

B_1= The slope.

The SPSS/PC$^+$ Regression procedure is used to calculate the least square's line. Figure 3.6 shows the least square line superimposed on the scatter plot. The regression line describing the relation between the squirrel and meteorological data is:

$$T_{sq} = 5.03 + (0.85800 * T_{hrc}) \qquad (3.5)$$

Where: T_{sq} = Squirrel air temperature.

T_{hrc} = HRC meteorological air temperature.

The observed data points do not all fall on the straight line but cluster about it. That is because the procedure used in fitting the line is the method of least squares that aims to minimise the sum of squared vertical distance from the data points to the line. The regression line is a useful description of the relationship between two variables. However, the values of the slope and the intercept alone do little to indicate how well the line fits the data. Table in figure 3.6 summarises the parameters that provide an indication of how well the calculated regression line actually fits the data. The Pearson correlation coefficient between the two sets of readings, the R value, is equal to 0.97. This value indicates that there is a fairly strong linear association between the two variables of the squirrel and meteorological readings. The R^2 equals to 0.93 which means that 93% of the variation in the parameter Squirrel (dependent variable) is explained by the linear regression. If there is no linear relationship in the sample, the value of R^2 is zero. If variables are perfectly linearly related, the value of R^2 is one.

By plotting actual squirrel data as the dependent variable against the computed squirrel data as the independent variable, we would be able to validate the linear module. The ideal prediction would be when the linear line passes through the origin, i.e., the intercept equals zero and the slope equals unity. Figure 3.7 is a scatter plotting of the actual squirrel data and the computed squirrel readings using equation (3.5). The formula suggested for the regression line is:

$$T_{sq} = -0.11572 + (1.00310 * T_{csq}) \qquad (3.6)$$

Where: T_{sq} = Squirrel air temperature.

T_{csq} = Computed squirrel air temperature.

It is clear that the intercept value is very close to zero and that the slope is very close to one. This suggests, that the model can be used to retrieve the missing air temperature measured by the squirrel for the outside environment during the period of Hajj.

5.2- RETRIEVING RELATIVE HUMIDITY:

The observed values of relative humidity measured by HRC and by the squirrel are scattered near the regression line in the Scatter plot shown in figure 3.8. This means that the relationship between variables could be explained linearly. The equation of the regression line found by the SPSS/PC+ regression procedure is:

$$R_{sq} = -4.15 + (0.85988 * R_{hrc}) \qquad (3.7)$$

Where: R_{sq}: Squirrel relative humidity.

R_{hrc}: HRC meteorological relative humidity.

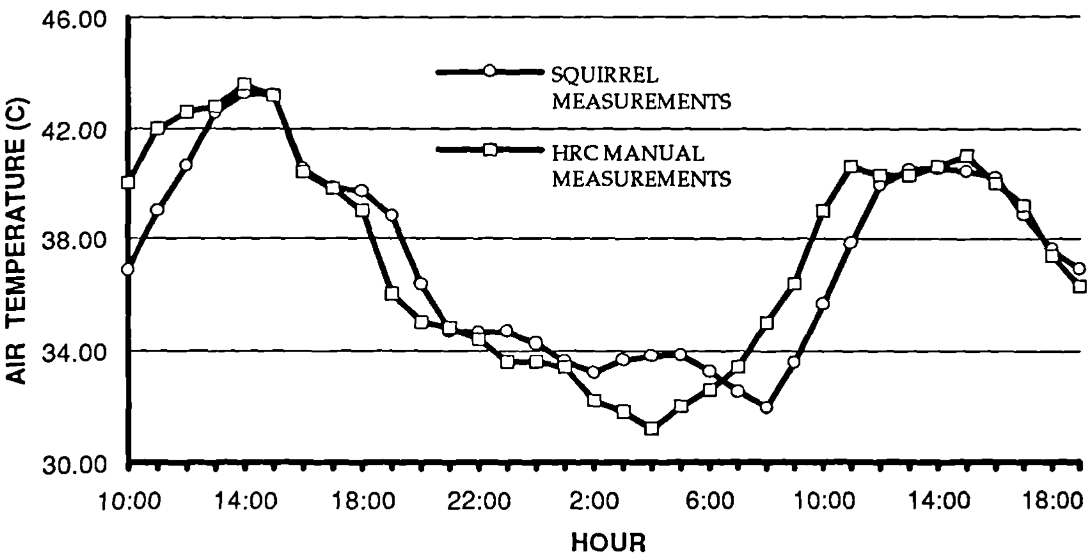
Parameters of how well the calculated regression line fits the data are summarised in the table of figure 3.8. The correlation coefficient, R value, reaches to 0.88; and R^2 value equals to 0.78, which means that 78% of the variation in the dependent variable (squirrel) is explained by the linear regression. To validate the linear model above, a regression analysis is made for the actual squirrel measurements against the calculated squirrel readings using equation (3.7). Results are indicated in figure 3.9. The equation given by the analysis is:

$$R_{sq} = 0.07 + (1.00005 * R_{csq}) \qquad (3.8)$$

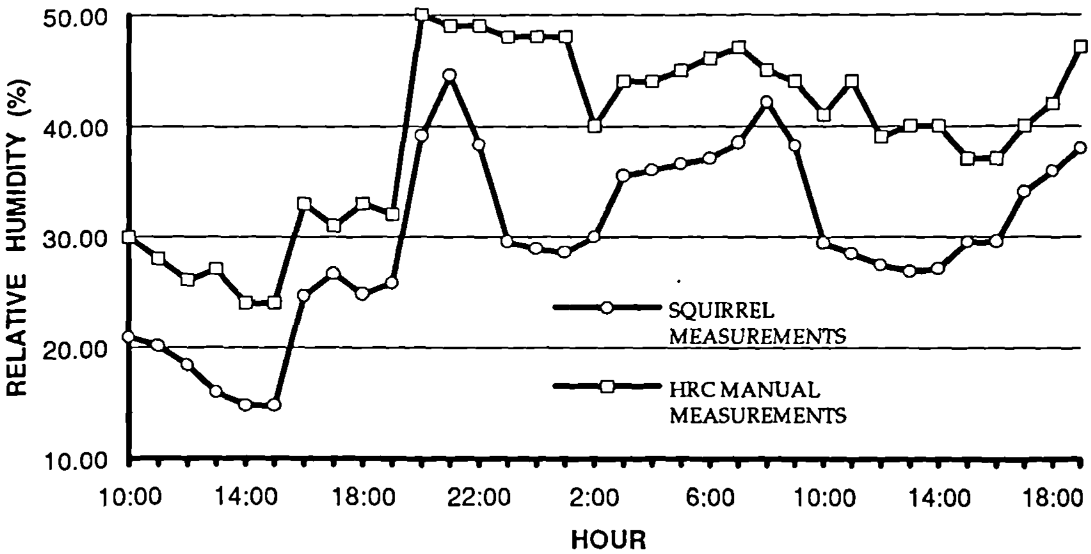
Where: R_{sq}= Squirrel relative humidity.

R_{csq}= Calculated squirrel relative humidity.

The intercept and slope of the equation are close to the ideal values, zero for the intercept and one for the slope. Therefore, the linear model of formula (3.7) can be used to replace missing relative humidity collected by the squirrel for outside environment during the period of the Hajj.

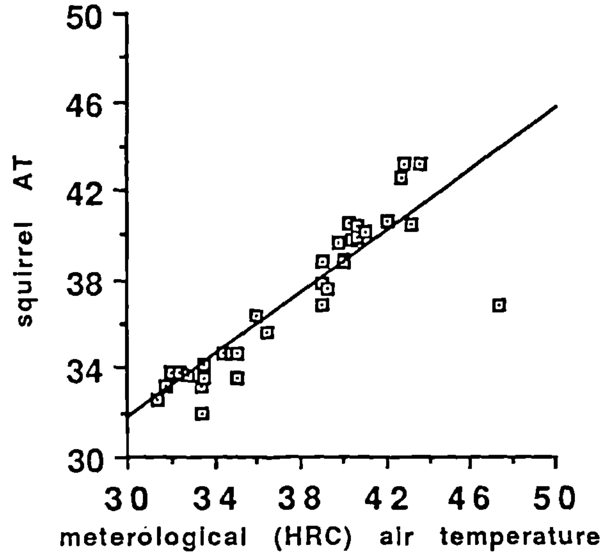


A- Manual and Squirrel readings of Air temperature.



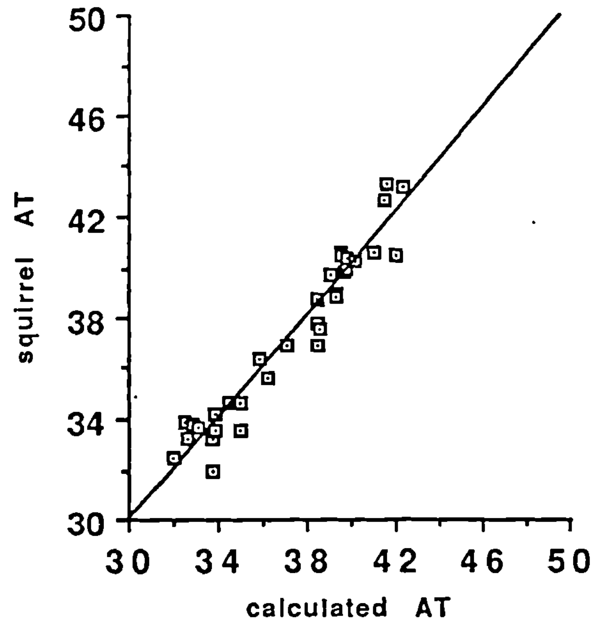
B- Manual and Squirrel readings of Relative Humidity.

Fig. 3.5: *Readings of air temperature and relative humidity measured by squirrel and HRC meteorological station.*



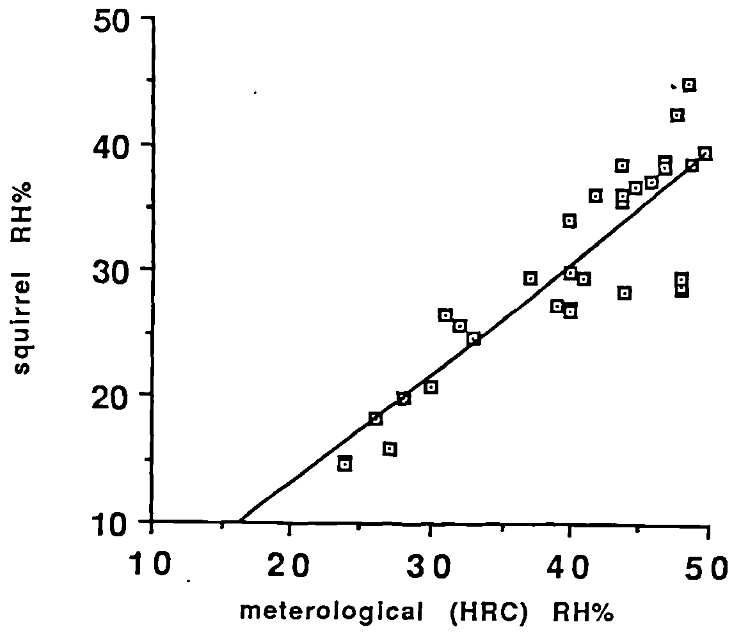
CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
0.96708	0.93524	0.86495	0.0000	5.03653	0.85800

FIG. 3.6: Correlation between readings of air temperature measured by Squirrel and by HRC meteorological station.



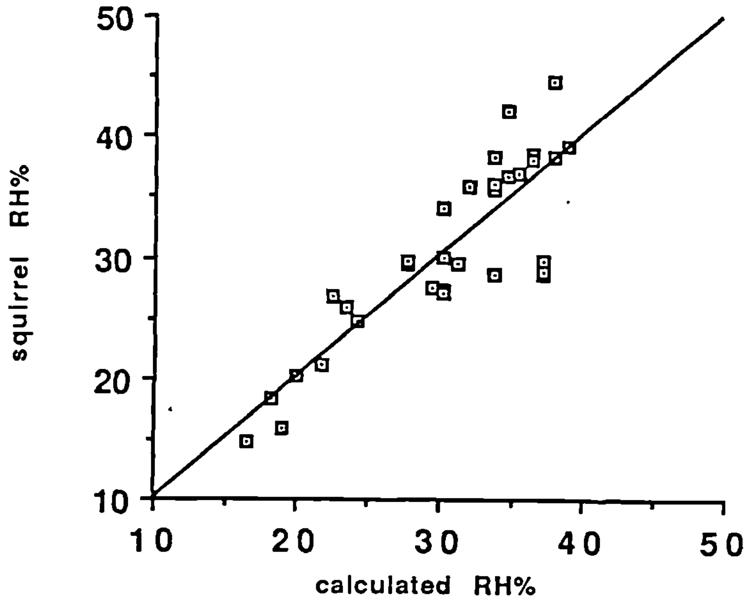
CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
0.96737	0.93581	0.86116	0.0000	-0.11572	1.00310

FIG. 3.7: Correlation between actual squirrel and computed readings of air temperature.



CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
0.87434	0.76446	3.84694	0.0000	0.07399	1.00005

FIG. 3.8: Correlation between readings of relative humidities measured by Squirrel and by HRC meteorological station.



CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
0.88346	0.78051	3.71360	0.0000	-4.15025	0.85988

FIG. 3.9: Correlation between actual squirrel and computed readings of relative humiditty.

6- RESULTS:

The results of environmental measurements taken during the pilgrimage season of 1989 are shown in two figures. Figure 3.10 contains the profiles of measurements for consecutive days for dry bulb, relative humidity, globe temperature, difference between globe and air temperature, and wind speed. By correlation of occupancy patterns with patterns of environmental parameters, it is easier to understand certain behaviour such as change in air temperature and relative humidity. Equally important was to decide when were the crucial times for pilgrims to stay in the tents. Figure 3.10, therefore, shows the occupancy pattern of Moroccan and British pilgrims indicated below each pattern of inside environmental parameters.

It was possible to trace patterns of pilgrims' activity and occupancy inside tents due to the structured and defined movements of pilgrims at specific times to perform specific rituals. Most activities exercised inside tents are sedentary such as reading, chatting, praying, eating, and sleeping. Metabolic heat output for such activities range from 75 to 120 watts for an average healthy man. The maximum occupancy rate for Arab and European pilgrims ranges from 61%-63% respectively. All pilgrims leave Muna to go to Arafat in the early morning of the 9th day of pilgrimage month *DHUL-HIJJAH*, the second day on figure 3.10. Some pilgrims return to Muna on the same night and others wait until the next morning. The most unoccupied time observed during the day occurred between 16.00 hrs. to 19.00 hrs. when pilgrims were out performing their rituals. Most occupancy was observed during night time and early morning. The occupancy rate was also low during the hottest hours of the day from 12.00 hrs. to 16.00 hrs. Figures 3.11 and 3.12 indicate the typical solar radiation pattern and wind direction recorded for the outside environment. The following is the discussion of the environmental results.

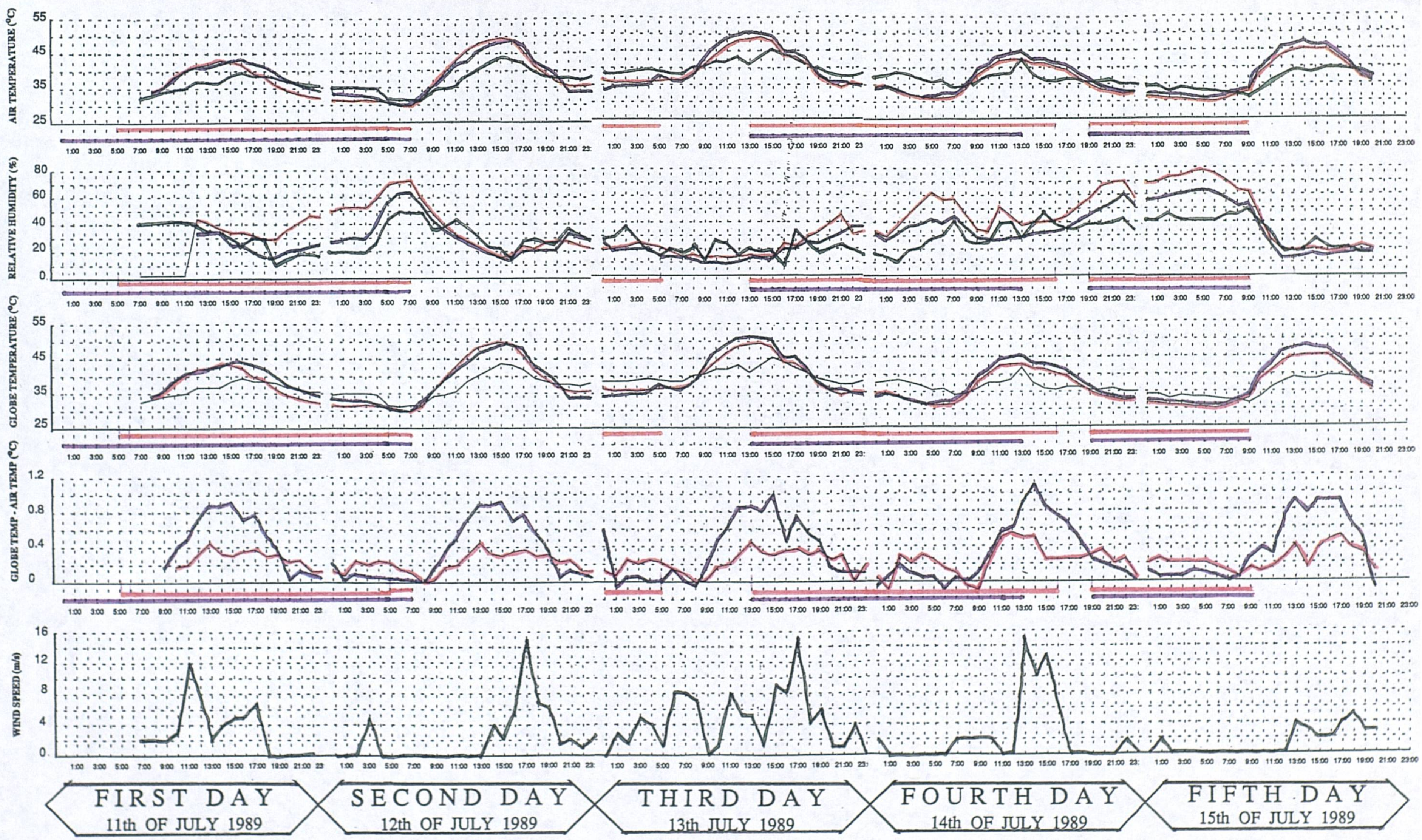


FIG. 3.10: Profiles of Air temperature, Relative humidity, Globe temperature, and wind speed measured for Outside, green colour, European camp, blue colour, and Arab camp, red colour, during the pilgrimage period of 1989.

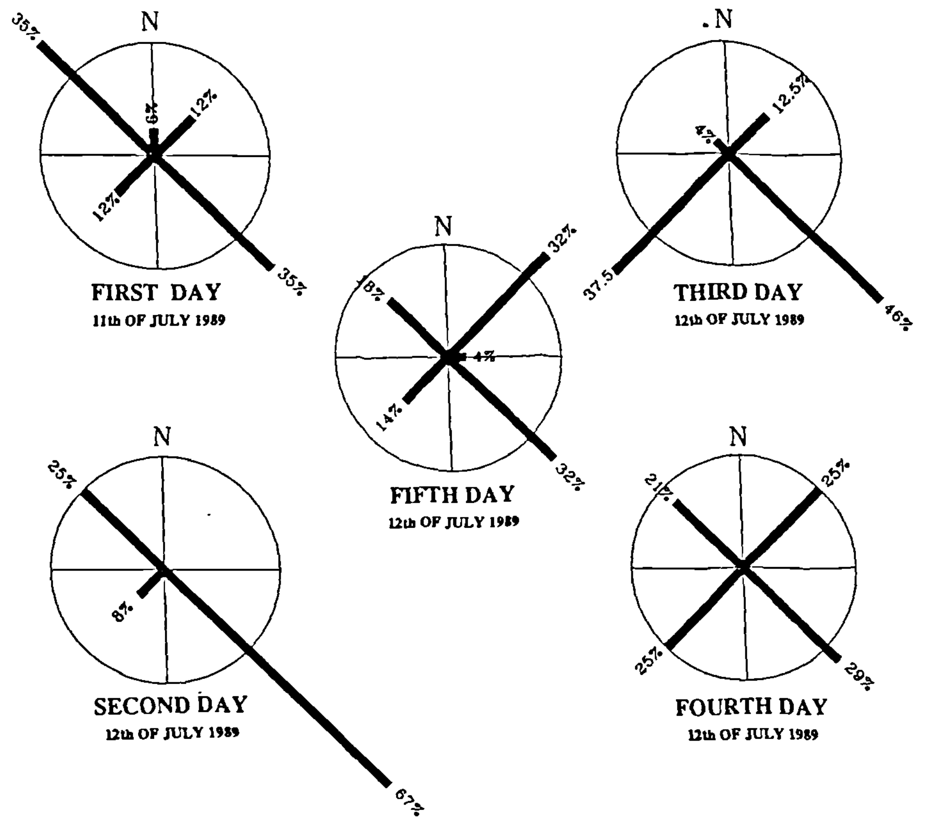


Fig. 3.11: *Patterns of wind direction as recorded during the pilgrimage period of 1989.*

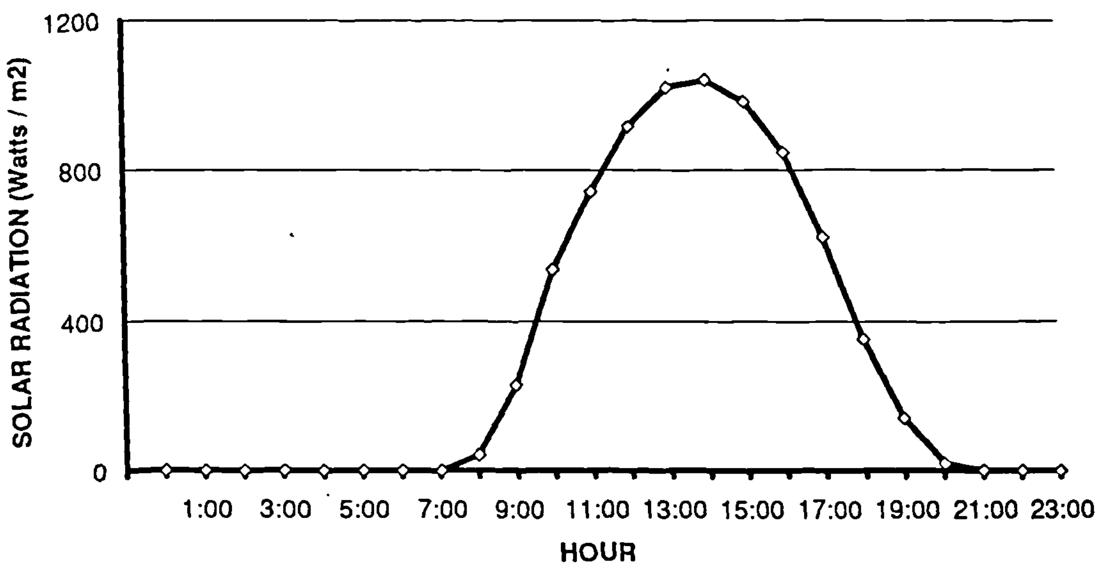


FIG. 3.12: *Typical pattern of direct and diffused solar radiation recorded during the pilgrimage period of 1989.*

6.1-AIR TEMPERATURE:

Internal air temperatures are higher in the European camp than the Arab. Differences in air temperature between the two camps range between less than 0.5 ^{o}C to an average maximum of 1.5 ^{o}C. The minimum difference was observed during the night and early and late hours of the day. The maximum difference occurred from 10.00 hrs. to 14.00 hrs. The only exception to this pattern was the one indicated in figure 3.10 during the second day of measurements. On this particular day pilgrims move to Arafat as part of the Hajj rituals. Tents from the Arab camp were observed to be unoccupied and their side walls were closed while tents from the European camp were unoccupied but left open. Therefore, a lower ventilation rate was expected through the tents of the Arab camp. As a result, internal heat accumulated and air temperatures increased.

During the daytime, indoor air temperature in both camps exceeded outside air temperatures from 8.00 hrs. in the morning to about 19.00 hrs. in the evening, i.e. the period that represents the entire day time. The maximum temperature difference was recorded at 14.00 hrs. by up to 6^{o}C. Little time lag was observed between the two peaks of indoor and outdoor air temperature which meant that indoor air temperature responded quickly to a change in outdoor air temperatures. The peak of indoor air temperature tended to last for four hours, from 12.00 hrs. to 16.00 hrs. The mean maximum recorded is 46 ^{o}C.

The higher air temperatures inside the tents and the short time lag may be associated with several factors. The most important is solar radiation which affects tents in two ways. One which is absorbed at the outside surface and heats the fabric and one which is transmitted to the tent's interior. Tent's fabric transmits up to 10% of solar radiation striking its envelope. This radiation warms the internal surfaces which retransmit long wave radiation. A tent's canvas is opaque to long thermal wave length and heat as a result is trapped[5]. This process of trapping heat is commonly known as the "green house effect." These observations during the day time reflected the low thermal resistance of the tent's fabric and the low capacity to store thermal energy. Higher air temperatures inside the tents may result also from a low ventilation rate inside the tents. The ventilation rate was estimated from 3 to 6 air changes per hour inside pilgrimages' tents based on a moisture balance calculation (example in Appendix IV). The heat input from pilgrims' bodies was less likely to contribute to high internal air temperature. This because the average air temperature of 45 ^{o}C was considerably above the average skin temperature of 29^{o}C which meant that heat loss by convection and radiation could not take place and the heat output was emitted as latent heat and sensible heat loss becomes zero.[6] Latent heat was emitted by means of sweat evaporation and not by radiation or convection. Sweat evaporation therefore had more effect on the internal relative humidity than the internal air temperature.

During the night-time, the air temperatures inside the Arab and Europe camps dropped below the outside air temperature by up to 3.5 ^{o}C at 03.00 hrs. in the morning. This phenomenon appeared immediately after sun set at 19.00 hrs. and lasted until two hours after sun rise at 08.00 hrs early morning. A similar observation was confirmed during the summer time for unoccupied airhouses in England by Croom and Moseley of Bath University (1984-a). They observed that inside air temperature of airhouses was frequently below the outside air temperature by up to 1^{o}C during the night, evening, and morning[7]. Nevertheless, night air temperature inside inhabited pilgrimage tents was expected to be higher than outside because of the heat produced by people sleeping at night. In ideal conditions it may be similar to outside air temperature. At this stage no similar measurements were known to the researcher for inhabited tents to compare results with. Nor was it possible to remeasure the inside and outside environments of the pilgrimage tents to validate the observed results.

A lower inside air temperature compared to outside during the night may be attributed to several interconnective factors. Firstly, at night the cooling by radiation to the sky is probably offset by the reemission of stored energy in the ground which has been subject to solar radiation all day. The tent materials have little thermal mass and therefore cool down quickly and the ground beneath the tents has been shielded from solar radiation during the day. This is a possible reason for the tent temperature dropping below outside at night.

Secondly, the outside measurement was taken approximately 8 metres higher than the inside measurements. At night, the ground surface loses its heat to the clear sky. The temperature becomes, as a result, lower near the ground and the temperature gradient increases with height[8]. The magnitude of air temperature difference measured at 2 and 10 metres high is indicated in figure (3.13-a) for Seville city in Spain, latitude 37.25^{o}N. Clearly, at night the air temperature at 2 metres high is 1^{o}C less than at 10 meters level. In the day the air temperature at 2 meters high is 1^{o}C higher than at 10 meters level. There are no similar measurements found for the Muna valley to correct air temperatures measured at two different heights. It is possible then to assume that the outside air temperature would be similar to inside during the night and lower during the day if they were measured at the same heights.

Thirdly, a lower inside air temperature may also be attributed to error in the substitution process of missing outside measurements during the Hajj. However, statistical analysis explained in the previous section (5.1) shows a very high correlation of 0.96 between manual and electronic readings. This hypothesis is therefore the least likely in explaining the phenomenon of cooler air temperatures inside the tents than outside during the night.

The outside temperature was very hot during the day from midday until 16.00 hrs. The mean maximum was recorded at 40^{o}C. The mean minimum dropped to 33^{o}C from 05.00 hrs. to 08.00 hrs in the morning. In hot dry desert climate the diurnal range is expected to be large but for the Muna valley it was observed as falling between $7^{o}C$ to $12^{o}C$. This characteristic of a narrow diurnal range was also observed for the Hajj seasons of 1983 to 1988[9]. The narrow diurnal range was attributed to the topographic and climatic character of the Muna valley when comparing it with the normally open landscape associated with a hot desert climate. There are several contributory factors for this observation such as:

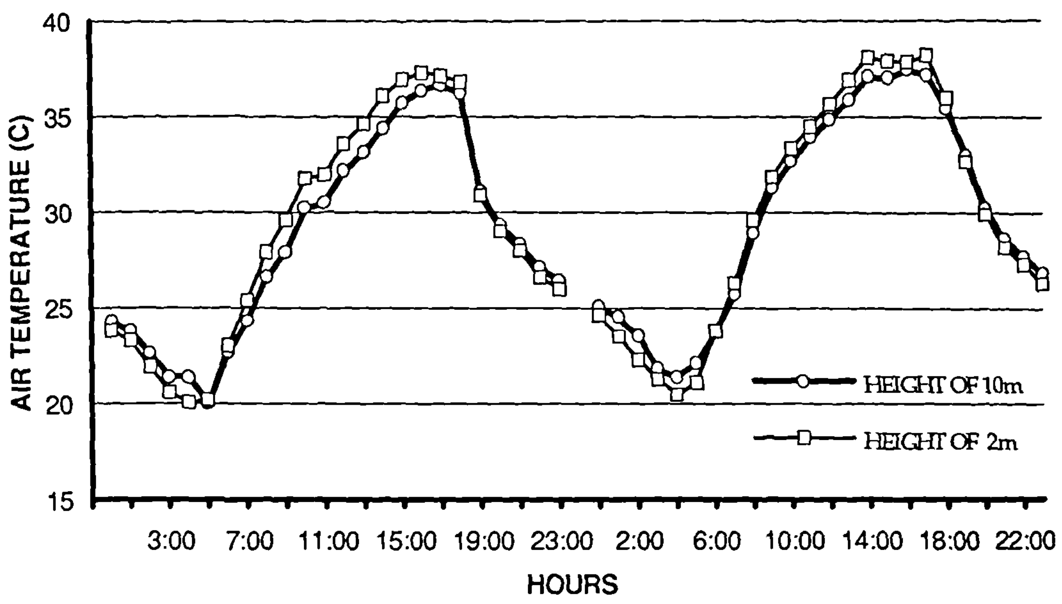
(1) Muna valley is heavily populated and largely covered with tents (as indicated in figure 3.1).

(2) Night temperature was expected to be warm due to a calm wind during the night The section on wind pattern (6.4) provides further information.

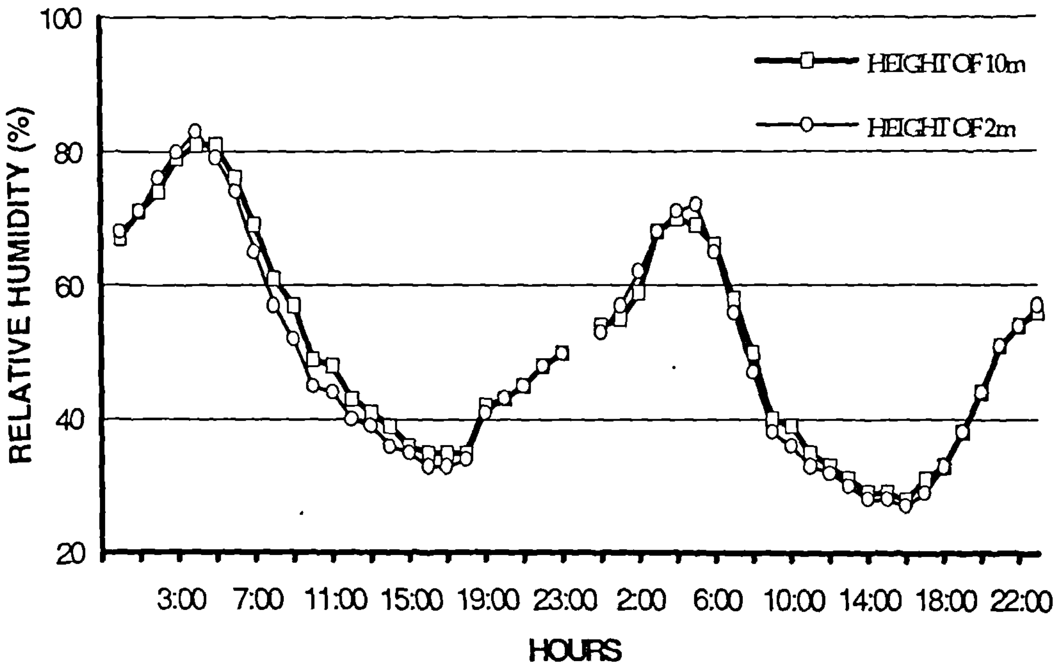
(3) Reduction in night temperature may be due to the reduction of net long wave cooling from surfaces in the middle of the valley due to the reduction of the sky view factor (SVF). Figure 3.14 indicates that the sky view factor was less when a portion of the hemisphere was obscured by tents or other objects. The sky view factor was equal to unity when long wave radiation was emitted to the complete sky hemisphere[10]. Long wave radiation may be also reduced due to the overlying pollution layer which may have resulted from a high concentration of carbon monoxide due to high traffic density during the Hajj.[11]

6.2- RELATIVE HUMIDITY:

The outside relative humidity was measured at a height of 10 metres. No measurements were known to the author for the Muna valley to quantify the difference between relative humidity at 2 m and 10 m high. Vertical measurements of relative humidity at Seville, figure (3.13-b), indicate that relative humidity near the ground is lower during the night and higher during the day. However, the difference in relative humidity between the two heights is small and reaches the maximum of 4%. It is, therefore, reasonable to assume that even when relative humidity was measured at a lower height for the Muna site the same observation between inside



(A) Air temperature.



(B) Relative humidity

Fig. 3.13: *Profiles of air temperature and relative humidity measured at 2m and 10m high for Seville-Spain, latitude 37.25°N*

Relative humidity inside the tents from the Arab and Europe camps follows a comparable pattern and fluctuates in an opposite pattern to the air temperature. Relative humidity declines with the increase of air temperature at 07.00 hrs. and reaches its minimum at 15.00 hrs., at the same hour when air temperature reaches its maximum. Relative humidity reaches its peak of 64% in tents of the Arab camp and 77% in the European camp at 06.00 hrs. This exceeded the humidity measured for the outside environment by 15-28%. Relative humidity inside the tents of the Arab camp is higher than that of the Europe camp which may be attributed to the higher density of pilgrims. There is a strong correlation between the occupation pattern inside the pilgrimage tents and the level of relative humidity. When tents are occupied the level of relative humidity is increased due to sweat released by pilgrims. This was noticed during the night-time when pilgrims were sleeping. On the contrary, relative humidity inside unoccupied tents was lower than outside. This was noticed during the second day from 10.00 hrs. until after mid-night in both Arab and European camps. The higher relative humidity inside the tents may also be affected by the lower ventilation rate especially during the night-time when the outside wind was calm. The ventilation rate inside the tents ranged from 3 to 6 air changes per hour based on the calculation method of moisture balance (see Appendix IV).

Outside relative humidity varied within the narrow range of 21-39% during the day and night. The maximum relative humidity was observed in the early hours of the morning at 07.00 hrs. and the minimum was at 16.00 hrs. in the after noon.

6.3- GLOBE TEMPERATURE:

Globe temperature is a combination of air temperature and the effect of any received or emitted radiation. The difference between globe and air temperatures summarises the pattern of received and emitted radiation which is indicated in figure 3.10 for the European and Arab camps. Radiation was received inside the tents of the Arab and European camps at 08.00 hrs., two hours after sunrise. Radiation gain in tents of the European camp reached its peak from 13.00 hrs. to 15.00 hrs. It dropped in a symmetric shape to its minimum at 20.00 hrs., one hour after sunset. This indicated that the increase in globe temperature was due to solar radiation during the day. Radiation gain inside the tents of the Arab camp was less than the European and reached its peak at 12.00 hrs. midday and its minimum at 22.00 hrs. Less radiation was recorded in the Arab tents during the day may be due to their closed side walls which would reduce diffused radiation from the ground. Radiation heat gain was also recorded during the night time in both Arab and European camps, particularly from 01.00 hrs. to 08.00 hrs. in the morning. This radiation heat gain may be explained as emitted from pilgrims' bodies during their sleep inside the tents. More radiation gain was observed in the tents of the Arab camp than those from the European camp due to a higher occupancy rate inside the former. When tents were not occupied radiation at night was close to zero. The best example of this was the night of the second day from sunset at 19.00 hrs. to 8.00 hrs. the following day.

6.4 WIND PATTERN:

To draw a general pattern for wind direction and speed for the Muna valley would have required more measurements for a longer time. Nevertheless, measurements of wind speed and direction for the Hajj period of 1989 were found to be in general agreement with the HRC measurements for the Hajj seasons of 1981, 1982, and 1983. The results of these measurements are plotted in figure 3.15. The figure shows that wind activity started after sunrise and reached its peak between noon and sunset, i.e. 12.00 hrs. -19.00 hrs. The calm condition represented 64% of the day and occurred mainly during the night and early hours of the morning. The prevailing wind direction was south-east / north-west running along the axis of the valley with an average speed of 3m/s and a maximum of 15 m/s. Wind direction was greatly affected by the mountains surrounding the Muna valley which in turn produced what is called the local wind systems. The exact nature of these local systems depends on the geometry and the orientation of the valley. As a simple explanation, figure 3.16 indicates a section in a valley. During the day, air near the slope surfaces is heated and rises up the slopes to form what is known as anabatic flow. Air near the valley centre falls to form a closed circuit. This local circulation transports heat from the surrounding surfaces and warms the whole valley atmosphere[12]. By night, heat is lost from the ground surface due to long wave radiation. Local circulation is reversed, i.e., cold air gently slides down hill and lifts up again at the centre of the valley. However, the cooling effect is insufficient because of intermittent flow and the slowness speed of night cold circulation[13].

6.5- SOLAR RADIATION:

Figure 3.12 indicates the typical global solar radiation measured at the Muna location (21.25^{o}N) during the Hajj period of mid July, 1989. The sun was quite close to the zenith and produced a very strong solar input. The peak value of solar radiation amounted to 1010 W/m^2. The sky was cloudless and the sun shone almost thirteen hours a day. The angle of the sun altitude was high from 09.00 hrs. to 15.00 hrs and the maximum angle was 89^{o} at noon.

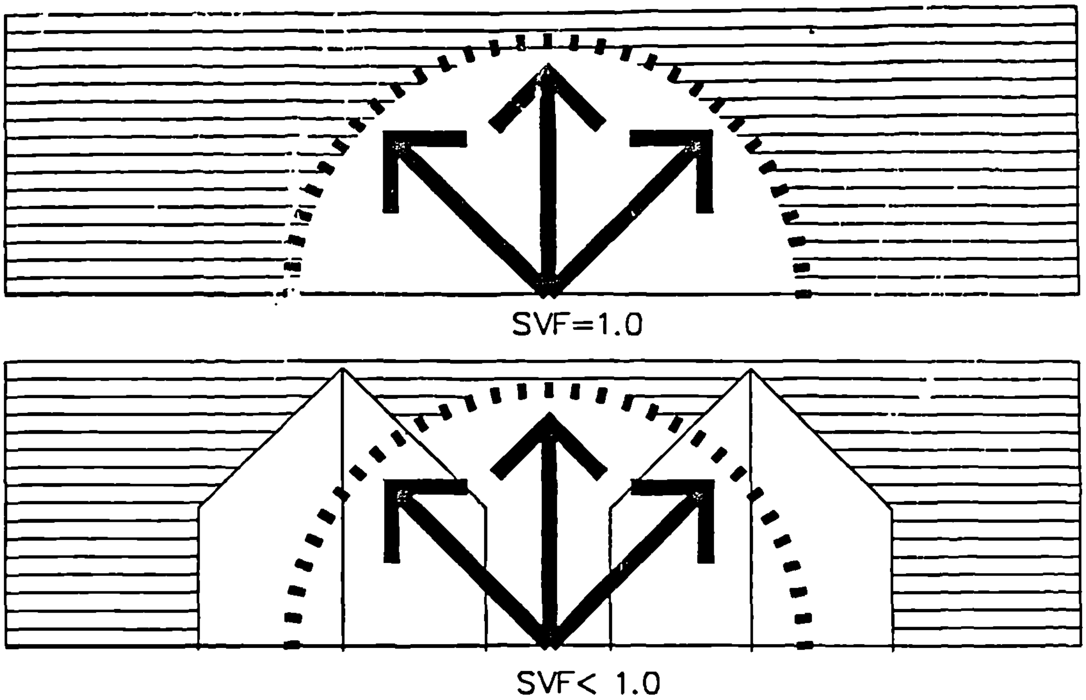


Fig. 3.14: Long wave radiation is reduced due to the reduction of the sky view factor (svf).

After: Oke,T. Boundary layer climates. London: Methuen & Co Ltd, 1978, p.202.

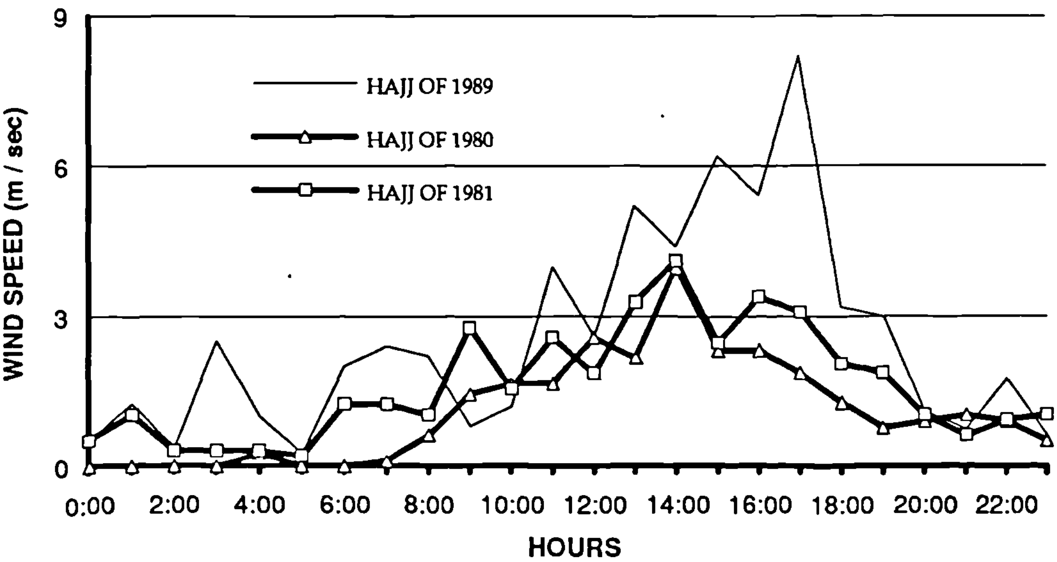
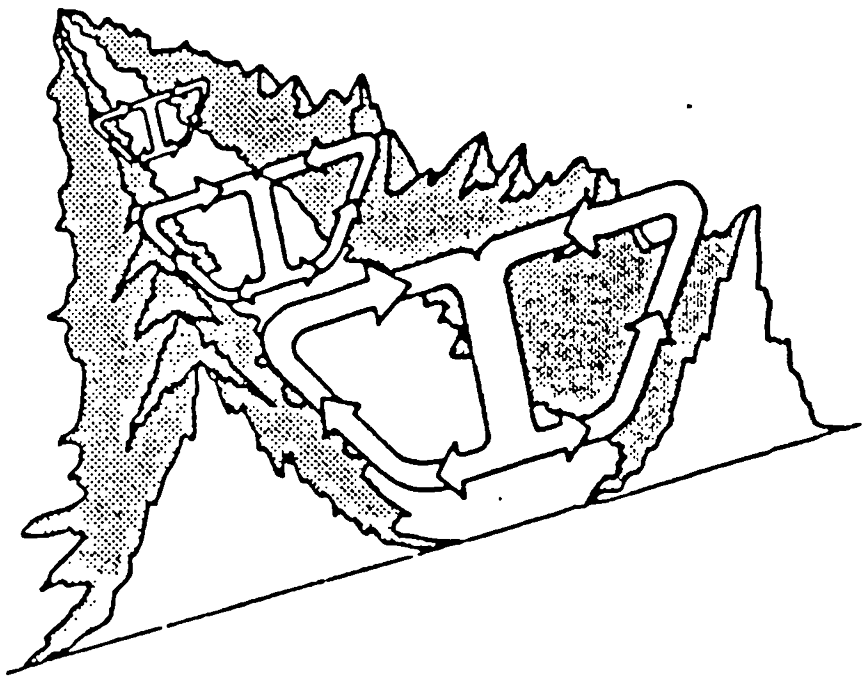
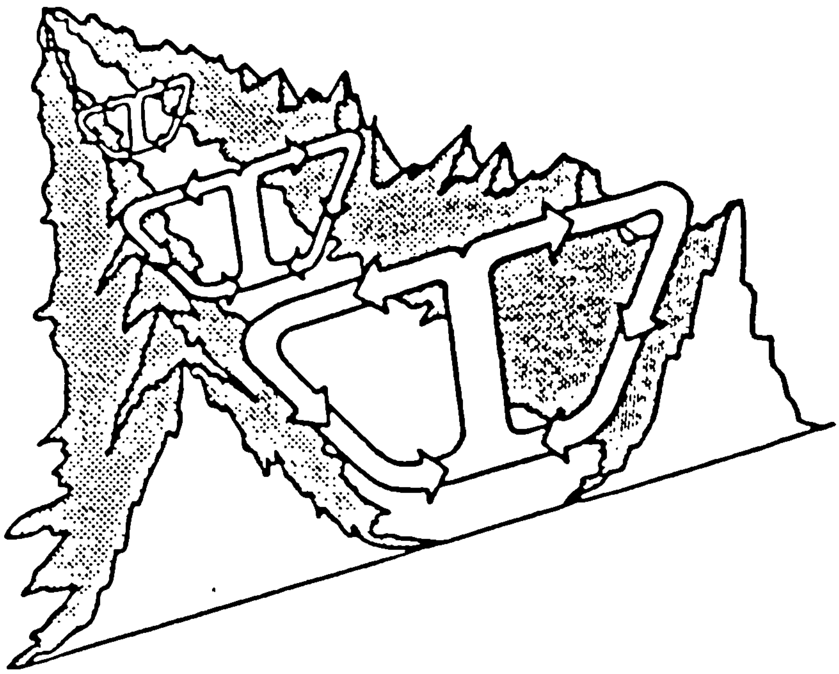


Fig. 3.15: Patterns of wind speed during the Hajj seasons of 1980, 81, and 89.



(A) **During the Day**



(B) **During the Night.**

FIG. 3.16: *The local air movement in a microclimate of mountains during the day and the night.*

Larry, P. <u>Mountains and man: A study of process and environment.</u> Berkeley: University of california press, 1981, p.141.

7- CONCLUSION

An investigation was made during the Hajj period of 1989 to measure the thermal conditions inside and outside pilgrimage tents of the Muna valley. Results have helped to identify several characteristics for the outside environment of the Muna valley and inside environment of pilgrimage tents. The outside environment was characterised as:

(1) The climate of the Muna valley during the summer was classified as a hot dry desert climate. Air temperature extended within a narrow range from 33°C to 40°C and relative humidity ranged from 20% to 40%. The diurnal range was narrow and night air temperature was high due to a reduction in long wave radiation to night sky and low wind speed.

(2) The high solar intensity reached over 1000 Watts/ m^2 and high solar altitude reached an angle of 89° at noon. The sky was cloudless most of the day and the sun shone for 13 hours.

(3) The wind pattern was affected by the topography of the valley. The wind was active during the period between noon and sunset with an average speed of 3 m/s and reached up to 15 m/s at its maximum. However, the wind is stable during the night and early hours of the morning. The prevailing wind direction was south east / north-west, running along the axis of the valley.

The pilgrimage tent as a light weight structure responded quickly to a change in the outside environment. For example, high heat was gained during the day while high heat was lost during the night. Environmental conditions inside the tents, therefore, were characterised as follows:

(1) Extremely hot air temperature ranged from 32-46°C, exceeding outside temperature during day time. The maximum difference ranged at 2-6 °C from mid day to 16.00 hrs.

(2) During the night time, tents lost most of their heat. The inside air temperature was recorded as lower than the outside. However, that may not be the exact case due to differences in heights when measurements were taken. The inside measurement, therefore, may well- equal that of the outside during the night time. More field work is needed to confirm this conclusion.

(3) The inside relative humidity exceeded that of the outside when the tent was inhabited during the night and early morning. The difference was distinguished and was based on the density of occupants. It ranged from 6% to 29% as a maximum recorded from 03.00 hrs. to 07.00 hrs.

(4) The ventilation rate inside tents was low and was estimated to be from 3-6 air change per hour. However, this was well above the minimum required for health safety because of the nature of the tent's fabric and the expected increase of its infiltration rate.

(5) The majority of heat built up inside the tents during the day time was due to the direct transmittance of solar radiation and radiation absorbed and then emitted through the tent's fabric. Heat accumulated during the day and increased the inside air temperature. Heat did not dissipate appreciably due to the low ventilation rate inside the tents. It also collected due to the nature of the tent's fabric that blocked out thermal radiation from being transmitted back during the day, acting in a similar way to the "green house effect".

(6) Heat output from pilgrims' bodies was emitted as latent heat during the day and therefore did not affect air temperature but increased the level of relative humidity. During the night time, however, the body's heat was emitted as latent and sensible heat. A high density of pilgrims inside the tent, therefore, increased the internal air temperature and relative humidity.

Pilgrims from hot and cold climate backgrounds occupy such an environment most of the time. Occupancy rates of tents ranged from 61 to 63% for Moroccan and

British pilgrims. Full occupancy was observed from 19.00 hrs. to 12.00 hrs. with a reduced occupancy rate from 12.00 hrs. to 16.00 hrs. The minimum occupancy rate was observed from 16.00 hrs. to 19.00 hrs. The most crucial period for pilgrims during their stay in the tents was between 12.00 hrs. to 16.00 hrs. when the air temperature recorded was at its maximum.

END-NOTES

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CHAPTER IV

ASSESSMENT OF HEAT STRESS INSIDE THE PILGRIMAGE TENTS

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CHAPTER 1V

ASSESSMENT OF HEAT STRESS INSIDE THE PILGRIMAGE TENTS

1-INTRODUCTION:

The human body maintains its temperature within a narrow range regardless of the relatively wide variations in the external environment. In a hot summer or cold winter normal body temperature, measured as rectal, must always be maintained at 37^{o} C. Deaths may result if the body temperature falls below 36^{o} C or rises above 39.5^{o} C. To maintain the body temperature, internal body heat production should balance heat gains or losses from and to the environment. Such a thermal equilibrium with the environment is one of the primary requirements for health and comfort. Within the wider range of thermal balance, human thermal sensations vary between extremely cold and extremely hot. Similarly comfort sensations vary between comfort and intolerable. Several heat indices have been developed to express thermal and comfort sensations for different climates. This chapter analyses the results of measurements undertaken during Hajj period of 1989 by the use of heat indices. The analysis aims to:

1. Determine the heat stress load of the hot environment on the pilgrim's body,
2. Determine the dangerous limits on a human body that cause suffering as a result of heat disorders and illnesses during the Hajj and,
3. Predict the thermal and comfort sensations for pilgrims exposed to the hot environment of the Hajj.

This chapter is structured to investigate, firstly, the thermal equilibrium between man and his thermal environment. Secondly, discussion is focused on the components of heat stress and the physiological and sensory responses of the human body in order to maintain thermal balance. The final part is designated to evaluate thermal conditions inside pilgrimage tents by testing data collected during the Hajj period of 1989, using heat indices especially developed for extremely hot climates.

2-THERMAL EQUILIBRIUM OF THE HUMAN BODY:

The human body produces energy from the process of oxidation of food elements at a rate depending on the body's activity. This process is known as metabolism. Only a small portion of the energy, 20-25 %, is utilised for mechanical work and the rest is transformed into heat which must be dissipated to the environment.

Thermal equilibrium between the body and the environment is achieved through heat exchange mechanisms which takes place in two forms, dry and wet. Dry heat exchange (sensible) includes convection exchange between the air and the individual and radiation exchange between the surrounding surfaces and the individual. When an individual is in a cold environment, heat is lost by convection to the surrounding air and by radiation to colder objects nearby. When in a hot environment, heat is transferred to the individual by these processes and adds to the heat load. In this case, radiation and conduction work against the maintenance of body temperature.

Wet exchange (latent) is the heat lost from the body by the evaporation of sweat and water in the lungs. Evaporation takes place in two forms: insensible perspiration through the skin and the lungs, and sensible perspiration through secretion of the sweat glands. Evaporation results in the loss of heat from the body at an evaporation rate where 1 gram of water removes about 2.42 KJ of heat.[1] Thus, even when the ambient air and mean radiant temperatures are above the skin temperature the body can lose great quantities of heat.

If thermal equilibrium is maintained, heat gained must be exactly offset by the amount of heat lost from the body to the environment. The heat exchange between the body and its environment can be simply represented by the heat balance equation:

$$M \pm R \pm C - E = \pm S \quad \text{.........} (4.1)$$

Where: M= Metabolic rate

R= Heat exchange by radiation

C= Heat exchange by convection

E= Heat exchange by evaporation

S= Changes of heat stored within the body. S equals zero when thermal equilibrium is maintained and body temperature remains constant.

3- HEAT STRESS:

When man is exposed to a hot environment his body remains under heat stress. Heat stress is defined in general terms as the combination of climatic and non climatic factors that result in large heat gains to the body and restriction of heat loss from the body.[2] Climatic factors include air temperature, humidity, mean radiant temperature, and air velocity. The main non-climatic factors include activity level and thermal resistance of the clothing. To appreciate the effect of the above factors, it is necessary to examine each briefly.

3.1- AIR AND MEAN RADIANT TEMPERATURE:

Air temperature and mean radiant temperature affect the dry heat exchange of the body. A body may lose or gain heat by convection and radiation depending on whether the ambient is colder or warmer than the body surface.

Raising the air temperature and mean radiant temperature results in an increase in skin temperature and sweat rate. The wetness of the skin depends on relative humidity and air velocity. When the humidity level is high and the air velocity is low, the feeling of skin wetness increases with air and mean radiant temperature. When humidity level is low and air velocity is high the skin remains dry even at a high temperature.[3] More seriously, a rise of air temperature can influence the core temperature of the body. When thermal balance is not maintained by the cooling effects of evaporation, the influence of high temperatures is highly prejudicial to survival. Subjectively, the change in air and mean radiant temperature significantly affect thermal sensation and subsequently comfort feeling.[4]

The variation of mean radiant temperature above the air temperature has its impact on human physiology and subsequently thermal discomfort, particularly in hot environments with low humidity and wind velocity. For example, a field study conducted by Macpherson concluded that an increase of one degree Celsius in mean radiant temperature above the air temperature would elevate the sweat rate by 11 g/h and the rectal temperature by 0.065 deg C.[5] Variations of mean radiant temperature in an enclosure may cause discomfort for occupants due to the effect of asymmetry where one side of the body is hot while the other is cold. In most cases asymmetry is small and has little impact on discomfort, but it can be strong when bodies are subjected to radiant heat, such as solar radiation.

3.2- HUMIDITY:

The evaporative capacity of the air determines the cooling efficiency of sweating and subsequently thermal discomfort. The bigger the difference between the vapour pressures of the skin and the ambient air the greater is the evaporative capacity of the air. The vapour pressure of the skin ranges from about 37 mm Hg for a skin temperature of 33° C, in comfortable conditions, to 46 mm Hg for skin temperature of 37° C, in severe heat.[6] The vapour pressure of the environment is an expression of humidity which means the partial pressure of water vapour present in the air.

The boundaries that determine the effect of humidity depend on the overall requirements of evaporative cooling, air velocity, and clothing. Givoni has determined these boundaries at 25° C. At an air temperature range of 20-25° C, the variations in the humidity of the environment do not affect the human body. Vapour pressures of the air in this range are, usually, less than the skin vapour pressure, and cooling efficiency is, therefore, high. Only when humidity is high to the extent that the evaporation level equals sweat secretion and air is almost saturated, do people feel discomfort due to moist skin.[7]

At temperatures above 25° C, the influence of humidity on skin wetness and cooling efficiency becomes gradually more pronounced. At high levels of humidity the process of evaporation is slowed down compared to the levels of sweat secretion. As a result, a larger area of the skin is covered with sweat, especially on the body hair. This wet layer builds up higher resistance to heat flow from the body and a certain quantity of heat may be drawn from the surrounding air and not from the skin. Consequently, the skin has to secrete and evaporate more sweat than that required for cooling and people, therefore, experience discomfort.[8]

In extremely hot environments with high vapour pressure, changes in humidity influence the limits of the tolerance time by restricting the total evaporation and, therefore, affecting the rectal temperature and heart rate.

<u>3.3- AIR VELOCITY:</u>

Air velocity affects human bodies in two ways. Firstly it determines the rate of convection heat exchange. Secondly, it determines the rate of heat exchange by sweat evaporation.

When the air temperature is below skin temperature, i.e., under 35 °C, an increase in air velocity always produces a cooling effect, which increases as the air temperature is lowered. When the air temperature is above the skin temperature, i.e., above 35 °C, the effect of air velocity is more complex. At one hand , the increase in air velocity elevates the convective heat gain and warms the body. On the other hand, an increase in air velocity increases the evaporative capacity and therefore the cooling efficiency. To explain these two opposite effects of air velocity, the following example of wet skin in a hot environment is given. Wet skin feels comfortable with increasing air velocity up to the limit that makes the skin dry. Any increase of air velocity above this limit will make people feel discomfort for it will increase heating by convection. The magnitude of this limit not only depends on ventilation rate but also on other variables such as air temperature, humidity, metabolic rate, and clothing. Givoni recommended 0.25 m/sec as the maximum limit of air velocity for people dressed in light summer clothing and undertaking light activity in a hot environment of 40^{o} C and 10% relative humidity.

3.4- ACTIVITY LEVEL:

When the human body performs a task the metabolic rate increases to provide the energy needed for that task. Only a small portion of the energy is utilised for mechanical work (20- 25%) and the rest is transformed into heat. As a result higher quantities of heat are needed to transfer from the body core to the skin which are then dissipated into the external environment. This is possible by increasing the rate of blood flow and sweat secretion which remove the extra heat to the skin.

3.5- THERMAL RESISTANCE OF CLOTHING:

Clothing protects the human body from cold and hot environments. It reduces the sensitivity of the body to variations in air temperature and velocity. It also interferes in the dry and wet heat exchanges of the human body with its environment. Givoni suggested that the effect of clothing at air temperatures below 35^{o} C is always to reduce the rate of convective and radiative heat loss from the body. At air temperatures above 35^{o} C, human bodies start to lose heat by sweat evaporation. The effect of clothing, therefore, is not straightforward. At such temperatures, clothing reduces radiation and convection heat gain from the environment. On the other hand, clothing reduces the cooling efficiency of sweat evaporation. This is due partly to a reduction of air velocity over the skin and partly because evaporation takes place from the clothing and not from the skin. Another factor which reduces the evaporative capacity is the humidity level of the environment. In the desert climate where the level of humidity is low, adequate evaporation can be maintained even when clothes are worn.[9] But in a very hot and humid climate, such as on beaches, people would feel more comfortable dressed in a swimming costume than in a business suit.

One can conclude that thermal comfort due to clothing in hot environments is determined by the balance between the protection provided against solar heat gain and the reduction in sweat evaporation. In the hot and dry desert climate, for example, protection from solar heat is more important than the reduction in sweat evaporation. High reflectivity and low transmissivity of radiation are the most important characteristics of the clothing of desert dwellers in order to achieve thermal comfort. Full white clothing made of light weight material and loosely fitting is more suitable to wear in a hot arid climate. A study conducted by Harvard and Tel Aviv Universities in 1980, illustrated in figure 4.1, revealed that the white Bedouin robe gains two to three times less solar radiation than the Black robe. However, enhanced convection of air beneath the black robe carries this heat away before it reaches the skin.

4- HUMAN RESPONSES TO HEAT STRESS:

The human body responds to heat stress in several physiological and sensory ways. The main physiological responses include blood flow regulation, raising of the inner body and skin temperatures, and the sweating rate. The main sensory responses include the thermal sensation of excessive heat and the sensation of skin wetness, sensible perspiration. These responses reflect the strain imposed on the body to maintain thermal balance under stress conditions.

4.1 PHYSIOLOGICAL RESPONSE:

The physiological response in the human body under thermal stress ultimately aims to maintain a thermal equilibrium. They are characterised as complex, autonomic, and voluntary systems. They differ in their responses to various changes in the environment. Some are more sensitive to humidity and others to air temperature. Some are more affected by internal heat stress while others to external environmental stress. The following is a discussion of the physiological responses:

4.1.1 BLOOD FLOW REGULATION:

In hot environments, the main task is to increase heat flow from the body to the skin surface where it is dissipated to the environment. The first physiological mechanism which is activated to adjust the rate of heat flow is the regulation of the blood flow. Beneath the skin is a layer known as subcutaneous tissue indicated in figure 4.2. In this layer there is a network of fine blood vessels which can be dilated (vaso-dilation) or constricted (vaso-constriction). Total blood flow is estimated to range from 0.16 liter/m^2/min under Vaso-constriction to 2.2 litre/m^2/min under full Vaso-dilation.[10]

Blood is characterised with having a high heat capacity which enables the blood to carry and transfer large quantities of heat through small changes in its temperature. Blood is also characterised with having a high thermal conductivity which makes the thermal resistance of the subcutaneous layer dependent on its blood content. Vaso-dilation increases the blood flow near the skin surface and, therefore, larger quantities of heat are transported from the body core to the skin surface. Skin temperature as a result is raised and heat loss to the surrounding environment by convection and radiation is increased. An increase in blood flow through the skin is also accompanied by an increase in the heart rate. This is the reason why heart rate is an important physiological mechanism in adjusting the rate of heat loss due to variations in the thermal environment.[11] Vaso-constriction reduces heat transfer to the skin which results in lower skin temperature and less heat loss to the environment.

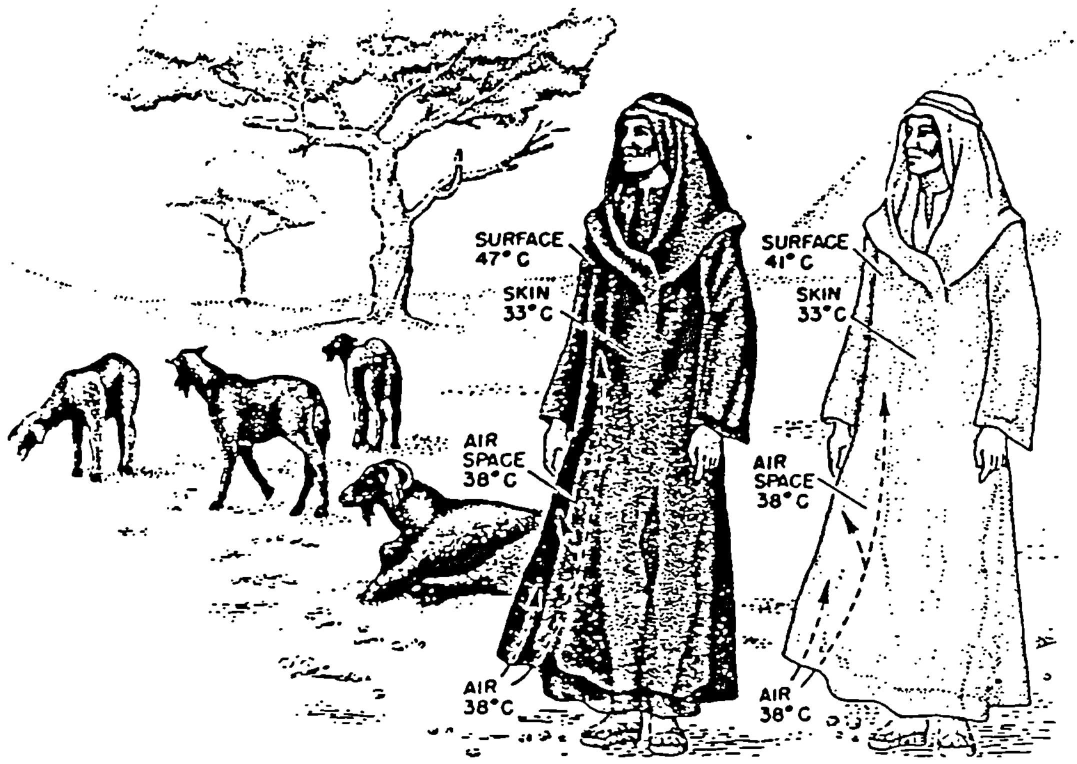

Fig. 4.1: *Measured air and skin temperatures for black and white Bedouin robes.*

A. S hkolink, C. Taylor, V. Finch, and A. Borut, "Why do Bedouins wear black robes in hot deserts ?," Nature, 24 January 1980, 283:375.

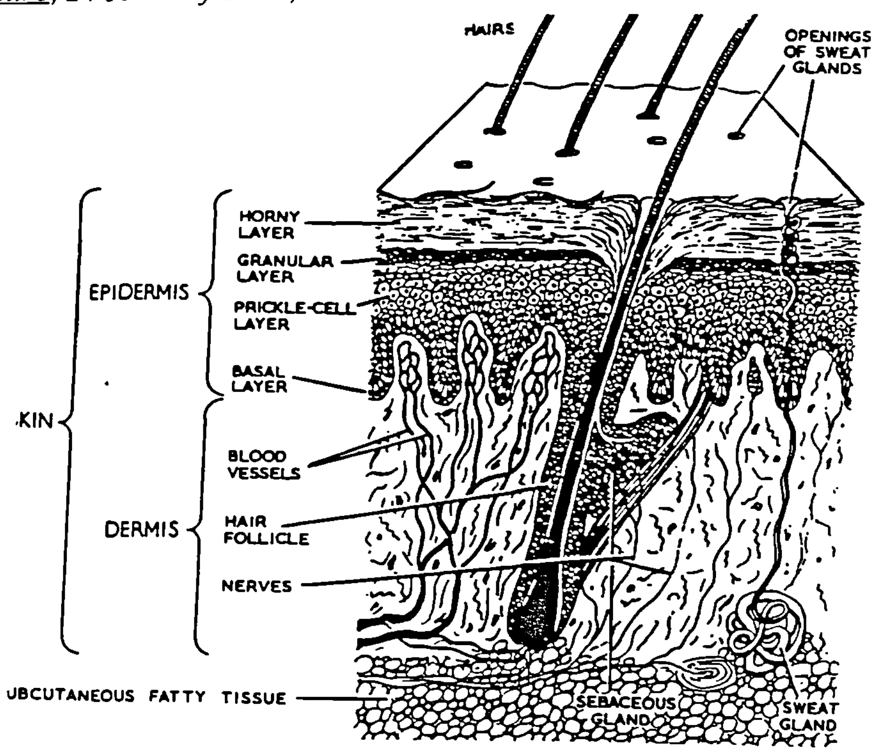

Fig. 4.2: *Section beneath the skin.*

A. Domonkos, Andrews' diseases of the skin. London: W. B. Saunders company 1971.

4.1.2- SWEATING:

In hot conditions the principal mechanism for maintaining heat equilibrium is evaporative cooling by sweating. Sweating takes two forms, insensible through lungs and skin, and sensible through sweat glands which lie deep in the skin and are distributed over all the body, figure 4.2. The latter form starts when the dry heat loss by convection and radiation plus the loss by insensible perspiration falls below the rate of heat production. This is estimated above 28° C for sedentary activity under low humidity and still air.[12] From figure 4.3 evaporative heat loss caused by sweating increases rapidly with ambient temperature. The body can cool itself at a rate of as much as 230 watts by sweating for the severest conditions at 48° C. In more severe conditions, the elevation of the sweat rate is small and not sufficient to maintain a thermal equilibrium.[13]

The rate of sweating is controlled by the need to prevent an excessive rise in body temperature. It is also controlled by the surrounding environment, the duration of the exposure, and the level of activity. For example, the average sweat rate for a man working in a hot environment is estimated to be one litre per hour. This rate is increased to about 2.2 litre per hour when working hard in a very hot environment.[14] The sweat rate, however, is inconsistent with the exposure time to heat stress. Givoni reported a study that recorded a 23% reduction in the sweat rate after the first two hours of exposure and a further reduction of 57% after five hours of exposure.[15]

4.1.3: INNER BODY TEMPERATURE:

The relationship between body temperature and the ambient conditions depends on the metabolic rate and the cooling efficiency of sweating.[16] For example, under mild environmental conditions and with a constant metabolic rate, the normal body temperature is relatively constant at 37° C, rectal. In hot conditions, above 38° C and low relative humidity, rectal temperature is significantly affected by the environmental heat stress and raised above the normal body temperature of 37°C as it is indicated in figure 4.4. This is explained as a result of an imbalance between the sweat rate and the additional environmental heat load.

4.1.4 SKIN TEMPERATURE:

The amount of heat exchanged between the body and its environment depends on the gradient of temperature and of vapour pressure that exist between the skin and its environment. Unlike the internal body temperature, the skin temperature varies considerably over a wide range of 15-42^{o} C. It is also not consistently distributed over the body. The variations between different parts of the body are greatest in cold conditions but in hot environments the skin temperature distribution becomes more homogeneous. Figure 4.4 represents average skin temperatures in relation to air temperature for people resting in a low humidity environment with still air. Below 28^{o} C skin temperature demonstrates a strong relationship with variations in the external temperature, as long as thermal equilibrium is maintained. Within this range skin temperature therefore is considered as an objective measure of the physiological and sensory feeling of cold.[17] Under heat stress conditions, skin is completely wet and no longer in direct correlation with dry air temperature. Instead, skin temperature is stabilized at a level which is determined by the balance between metabolism and the convective and radiative heat gain on the one hand and the heat loss through evaporation on the other hand.

4.1.5-METABOLIC RATE:

The metabolic rate is lowest when the body is at rest in a comfortable environment : estimated approximately as 90 watts. Figure 4.3 indicates the relation between metabolic heat and ambient air temperature. Metabolic rate is high at lower temperatures due to shivering that can double or triple the resting metabolic rate. An increase in the metabolic rate is needed here to maintain the inside body temperature at 37^{o} C; the greatest increase occurring in bodies which are unacclimatized to cold. When the body is acclimatised the increase in the metabolic rate is lower.

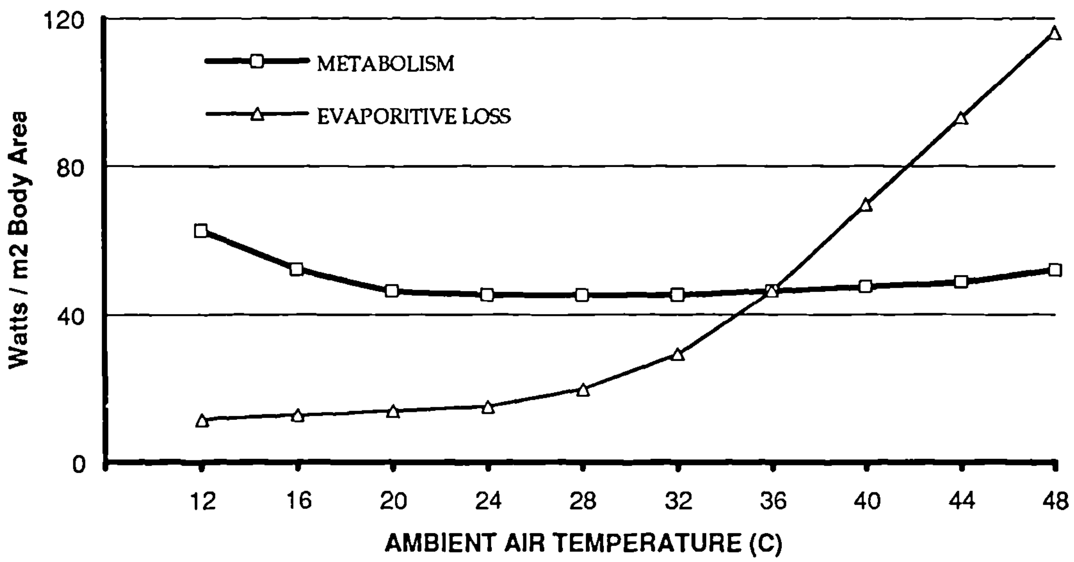

Fig. 4.3: *Relation of evaporation loss and metabolism heat with the ambient temperature for resting subjects in still air and low relative humidity.*

After: Gagge, Hardy ""Comfort and thermal sensations and associated physiological responses at various ambient temperatures." in Environmental Research-1, Academic press Inc., 1967, p.4.

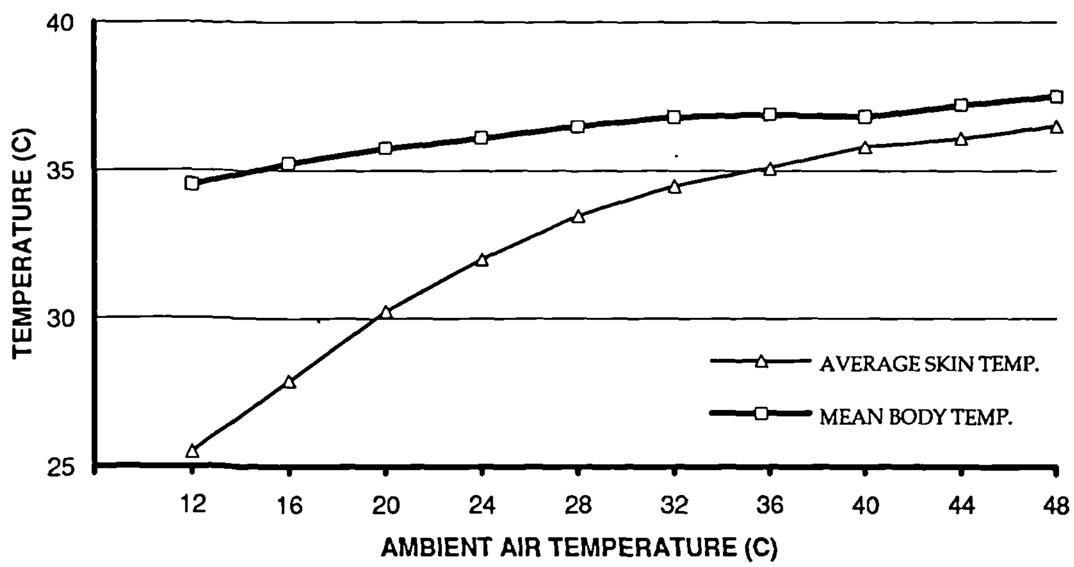

Fig. 4.4: *Relation of the body temperature and the average skin temperature with the ambient temperature for resting subjects.*

After: Gagge, Hardy ""Comfort and thermal sensations and associated physiological responses at various ambient temperatures." in Environmental Research-1, Academic press Inc., 1967, p.4.

Metabolic heat is also increased at the higher temperatures. In other words, when a body is exposed to a hot environment, its metabolic heat production is increased above that at a lower temperature. This increase is due to a combination of the increased blood circulation, sweat gland activity, and a higher temperature of the skin tissues; The increase is greatest among people who are not used to hot climates. Bruce (1960) observed in his study that basal metabolic rate at complete rest was relatively constant in the temperature range from 20-39^{o} C in still air. On sudden exposure to severe heat stress, however, an increase of the metabolism by 25-30 % was recorded for unacclimatized men. Acclimatization, however, greatly reduces this response.[18]

4.2- SENSORY RESPONSE:

Under heat stress a person feels discomfort mainly due to the thermal sensation of excessive heat and sensation of wet skin.[19] Sometimes both sensations can affect discomfort simultaneously, at other times only one sensation may have the dominant affect. A typical example of a single source of discomfort from heat sensation is in the desert climate. Because of the low humidity and the high air temperature of the desert climate people feel hot without sensible perspiration. The simultaneous affect of both sensations is felt clearly in the hot humid climate when one feels hot and at the same time the skin is too moist.

The main environmental conditions which affect the thermal sensation of heat are: air temperature, radiant temperature, and the air velocity over the body. The thermal sensation for heat is experienced when the average skin temperature is raised above 32-33^{o} C, under sedentary activity.[20] The scale for thermal sensation adopted for many environmental studies is described as:

1- Extremely cold.	6- Slightly warm.
2- Very cold	7- Warm.
3- Cold.	8- Hot.

4- Cool. 9- Very hot.

5-.Neutral (comfortable). 10- Extremely hot.

On the other hand sensible perspiration has two limits. The lower limit is when the skin is completely dry and the upper limit is when the whole body and clothing are soaked with sweat. When the evaporation rate is much faster than sweat secretion the sweat evaporates as it emerges from the pores of the skin and the skin is then felt as dry. When the evaporation rate is decreased or sweat rate is increased, sweat spreads over the skin causing discomfort due to the moist skin. It was found that skin wetness can be expressed as a function of the ratio of the required evaporative cooling (E_{req}) which is equal to the total metabolic and environmental heat stress and the evaporative capacity of the air (E_{max}).

5- HEAT INDICES:

From the previous discussion it is recognised that human sensory response is more complicated than just a function of a single environmental factor. All environmental factors affect the human sensory and physiological responses simultaneously and the influence of any one depends on the levels of the other factors. Therefore, it is necessary to combine all the factors in a single scale referred to as "Heat index." Most Heat indices are formulae or nomograms developed on theoretical or empirical grounds and aim to establish which combinations of heat stress components provoke equal thermal strain in the human body.[21] Their main use is either to estimate thermal sensation due to the stress imposed by a wide range of conditions of work and climate, or to estimate the physiological strains in response to those stresses, particularly the response of the sweat rate.

In the past, many attempts have been made to devise a single index that combines all the effects of environmental factors. Between the thirties and the early seventies many thermal studies were undertaken. Early studies are of limited value because one or more of the environmental variables have not been measured and activity level and clo-value is not specified. Such studies have resulted in thermal indices such as: the effective temperature (Yaglou et al), the operative temperature (Gagge et al), the resultant temperature (Nielson), and the equivalent temperature (Dufton and Bedford).

In 1972, Fanger developed a thermal index that combined all the six parameters that effect thermal balance into one index. The thermal index is known as the predicted mean votes (PMV-Index) which is a more widely accepted measure of thermal sensation. In addition, Fanger's work predicted the number of the thermally dissatisfied persons by using the "predicted percentage of dissatisfied" PPD-Index. The PMV - index can be calculated for different combinations of metabolic rate, clothing, air temperature, mean radiant temperature, air velocity and air humidity. However, International standard (7730 - 84) has recommended PMV only for air temperatures ranging from 10^{o} C to 30^{o}C. Gagge (1985), Rohles, Hayter and Milliken (1975) have concluded in their studies that PMV tends to exaggerate true discomfort at low humidity and to underestimate it at high humidities.[22]

Most indices differ in the range of conditions of their application and vary in their experimental methods. As a result, existing indices are useful for their limited range of conditions, but are not universal. Recent research by Givoni has cast doubt on the validity of existing discomfort standards for people in developing hot countries.[23] His doubt is based on the fact that most of the discomfort studies have been developed in the USA and in Europe focusing on people with different levels of acclimatization and expectations of thermal comfort than from people from developing hot countries.

When considering the evaluation of heat stress in the extremely hot climate of MAKKAH, concentration in the following discussion is on the heat indices which are most often used and have the greatest practical advantages in hot climates. The indices considered here fall into two groups. The first group is expressed as a reference temperature and includes the Wet Bulb Globe Temperature (WBGT) and the new Effective Temperature (ET^*). An advantage of this approach is that a single number on the centigrade scale of air temperature serves to specify the net exchange of heat by radiation, convection, and evaporation. The second group is expressed as the rate of sweat loss and includes the Heat Stress Index (HSI), the Index of Thermal Stress (ITS), and the Predicted Four Hour Sweat Rate (P4SR). Sweat loss is a practical measure of the physiological strain experienced in response to a heat stress.

5.1- WET BULB GLOBE TEMPERATURE HEAT INDEX- WBGT:

The WBGT-Index is determined by two simple readings, the wet bulb temperature and the globe temperature. The wet bulb and globe temperatures were selected because their sensors respond to the same environmental factors as a human being such as air and radiant temperatures, air velocity and humidity. The following formula shows the relationship between these environmental parameters without solar load:[24]

$$WBGT = 0.7\ WBT + 0.3\ BGT. \quad (4.2)$$

In direct solar radiation an alternative weighting formula is used:

$$WBGT = 0.7\ WBT + 0.2\ BGT + 0.1\ AT \quad (4.3)$$

where: WBT: Wet bulb temperature

BGT: Black globe temperature

AT: Air temperature

The index sets the permissible exposure limits to ensure that the central body temperature does not rise above 38° C. Limits of heat exposure related to the WBGT index were developed by the National Institute for Occupational Safety and Health in 1972, and by the ESSO research and engineering company with the assistance of Yaglou. All have proposed threshold limit values based on various levels of work. No person should be exposed to thermal conditions beyond those shown in table 4.1. Other threshold limits are proposed based on a work- rest schedule. The threshold limit values are valid for light summer clothing, 0.6 clo, customarily worn by workers when working under hot environmental conditions. The relation between the WBGT temperatures and permissible heat exposure limits is illustrated in figure 4.5. The figure shows that the safety threshold limit is 32^{o} C of the WBGT scale for people performing light work with continuous exposure to a hot environment. Continuous exposure above this limit may cause the person to collapse.

5.2- NEW EFFECTIVE TEMPERATURE- ET^*:

The concept of effective temperature was first introduced in 1923 by Houghton and Yaglou. Effective temperature is simply an index that combines into a single value the effect of dry bulb temperature, wet bulb temperature, and air velocity on the thermal sensations of the human body.[25] Effective temperature, however, has been recognised to overestimate the effects of humidity at low temperature and to underestimate its effects at high temperature. To avoid this distortion and to understand the human thermal response to warm indoor environment, Gagge, Stolwijk, and Nishi suggested in 1971 a new effective temperature or ET^*.

The new ET^* assumes standard factors such as clothing at 0.6 clo, still air movement at 0.2 m/s, a sedentary activity and an exposure time of one hour. The index of effective temperature estimates thermal discomfort based on the concept of "reference environment". "Reference environment" is the test environment where the relationship between the main components of heat stress and heat strain is studied. The "reference environment" is uniform, i.e., its surface temperature is equivalent to the air temperature. Body wetness for people exposed to such an environment is calculated as an indication of the heat strain. Constant skin temperature for different combinations of air temperature and relative humidity is plotted on a psychrometric chart in figure 4.6. The new effective temperature is the dry bulb temperature resulting from the intersection of the wetness slope with a 50% relative humidity curve. The abscissa in figure 4.6 is the operative temperature (T_o) and the ordinate is the ambient vapour pressure (P_a). Curves for 20, 50, 80, and 100 % RH complete the basic chart.

A successful index of human response to a warm environment must indicate thermal sensation and discomfort. Thermal and discomfort sensations are governed by the physiological parameters of the body's skin surface namely mean skin temperature (T_{sk}) and skin wetness (W_{sk}) caused by perspiration. At thermal comfort, skin temperature ranges from 33-34^o C for sedentary activity. Skin wetness (W_{sk}) is the ratio of perspiration to the total skin surface, i.e., E_{sk} / E_{max}. Theoretically skin wetness values change from zero to one. At thermal comfort, skin wetness is zero for sedentary activity, and when extremely hot, wetness value is one.

For warm environments, any index with isotherms parallel to skin temperature serves as a reliable index of temperature sensation.[26] Figure 4.7 illustrates the isotherms for the mean skin temperature and different zones of thermal sensations. Zones of thermal sensation range between the zone of body cooling below 20 ET* and the zone of body heating above 41.5 ET*. Between these extremes, zones of thermal sensation are drawn based on the ASHRAE psychological scale as follows: "neutral and comfort", "slightly warm"; "warm", "hot", "very hot" and "intolerable".

Thermal discomfort closely follows physiological strain, measured by skin wetness. Figure 4.8 illustrates isotherms for warm discomfort on the same psychrometric chart as figure 4.6. The zones of discomfort range from the zone of body cooling below 20^o C ET* and the zone of body heating above 41.5^o C ET*. Between these extremes, zones of thermal discomfort are classified as: "slightly uncomfortable", "uncomfortable", "very uncomfortable" and "intolerable".

The upper and the lower limits of thermal and discomfort sensations are quite similar, i.e., 20^o C ET* and 41.5^o C ET*. Isotherms for thermal and discomfort sensations are coincidental for the neutral comfort and cold discomfort states. Unlike the thermal sensation isotherms in figure 4.7, the ET* isotherm lines in figure 4.8 are affected by a change in humidity. The reason is that both discomfort and ET^* lines are functions of skin wetness,W_{sk}.

Table 4.2 summarises the health and physiological strain as well as the thermal and comfort sensation compared with effective temperature scale ET*. The ASHRAE comfort zone lies between 22° C ET^* and 27° C ET^*. The danger line of heat stroke suggested by ASHRAE roughly coincides with the 34 to 36° C ET^* and for wetness values from 0.40 to 0.50. Deaths from heat stroke plotted in figure 4.8 fall near to the 35 to 36° C ET^* zone, applies to young US soldiers assigned to sedentary duties. For American old people, 65 years old or over, death from heat stroke was noted at 29° C ET^*. The danger line tends to move toward lower values of ET^* as people grow older and less fit.

5.3- THE HEAT STRESS INDEX- HSI:

The value of heat stress index (HSI) is expressed as the ratio of the required evaporation to maintain thermal balance (E_{req}) to the maximum evaporation (E_{max}). The HSI values are plotted in figure 4.9 for different conditions of air and radiant temperature, air speed, humidity, and metabolic rate. The HSI values lie between zero and 200. The value zero represents the absence of heat stress or the comfort zone. The value 100 is the upper limit for thermal equilibrium; the region of body heating is above the 100. The HSI has many advantages, the greatest one being that it makes it possible to calculate the allowable exposure time for a given stress condition. However, the accuracy of the HSI to predict quantitative physiological responses to thermal stress is doubted. The HSI is compared with sweat rate measurements under various climatic conditions.[27] Results (Givoni, 1981) suggested that the HSI overestimates the cooling effect of the wind and the warming effect of humidity. The reason may be due to the fact that the HSI was developed from a theoretical analysis of heat exchange between man and his environment and is, therefore, independent of the physiological response of the individual. For example, a skin temperature is assumed constant at 35^{o} C, and the maximum sweating of an average person is equivalent to 700 watts.

5.4- THE INDEX OF THERMAL STRESS- ITS:

The ITS was developed by Givoni in 1963 as an extension to the heat stress index. This Index is regarded as a biophysical model which describes the heat exchange mechanisms between the body and the environment. The ITS can, therefore, predict physiological strain manifested by sweat rate. Unlike the HSI index, ITS gives a good quantitative prediction of the required sweat rate.[28]

5.5- THE PREDICTED FOUR -HOURS SWEAT RATE INDEX-P_4SR:

This index was developed from experimental data undertaken for the British Royal Navy in 1947. The chart of the P_4SR in figure 4.10 attempts to combine the effect of the metabolic level, clothing, and the climatic factors such as air temperature, radiation, humidity, and air speed. The value of the P_4SR index is based on the total sweat loss during a four hour exposure. However, the P_4SR index is not intended as a prediction of the actual sweat rate, as the name implies, but rather as an index of heat stress. In the view of many researchers, the P_4SR is considered to be the most complicated of heat indices to use but also is the most accurate index of heat stress.[29]

6- SUITABLE HEAT INDEX:

The most suitable index to assess heat stress and thermal discomfort during the Hajj period was the index that:

1. applied to the conditions of the Hajj,
2. was simple to use, and
3. Satisfied the objectives of the analysis of thermal discomfort inside the pilgrimage tents.

TABLE 4.1

Heat exposure limits for working in a hot environment.

NIOSH		ESSO AND YAGLOU		
Time (Minutes)	WBGT C	Light work WBGT C	Moderate work WBGT C	Heavy work WBGT C
20	----	44.44	41.11	37.77
30	38.33	41.66	38.33	35.00
60	34.33	37.77	35.00	32.22
90	33.05	------	-------	------
120	32.22	35.55	32.77	30.00
180	31.11	34.44	31.66	28.88
240	30.55	-------	--------	-------
Continues (8 hours)	------	32.22	30.00	26.66

After: Brief, R. and Confer, R."Environmental measurements and engineering assessment of heat data." <u>Symposium on standards for occupational exposures to hot environments</u>*,Pittsburgh, University of Pittsburgh, 1973, pp.236-39.*

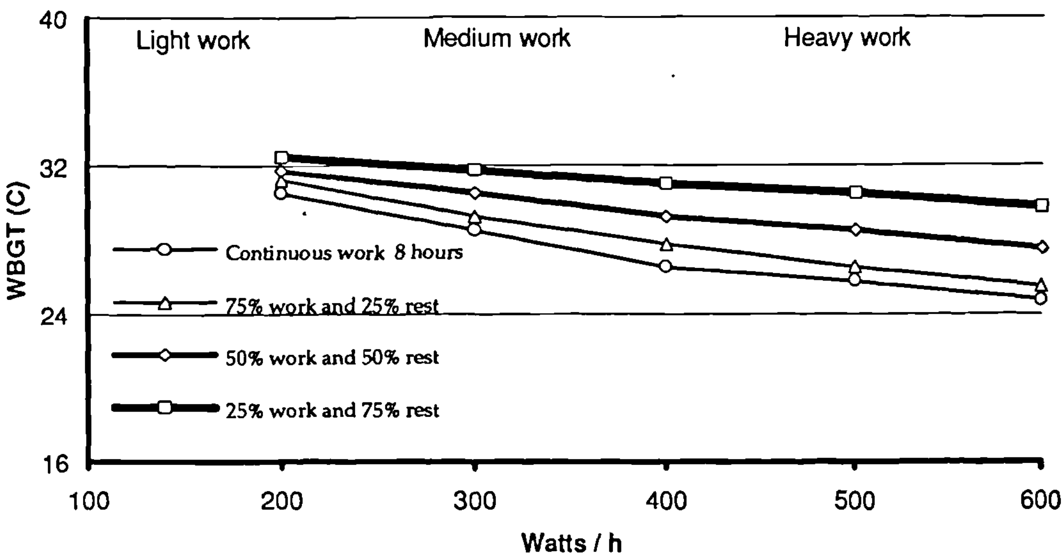

Fig. 4.5: Limits of permissible heat exposure predicted by the WBGT index.

Ashrae, fundamentals handbook,New York: Ashrae, 1985, p. 8-30.

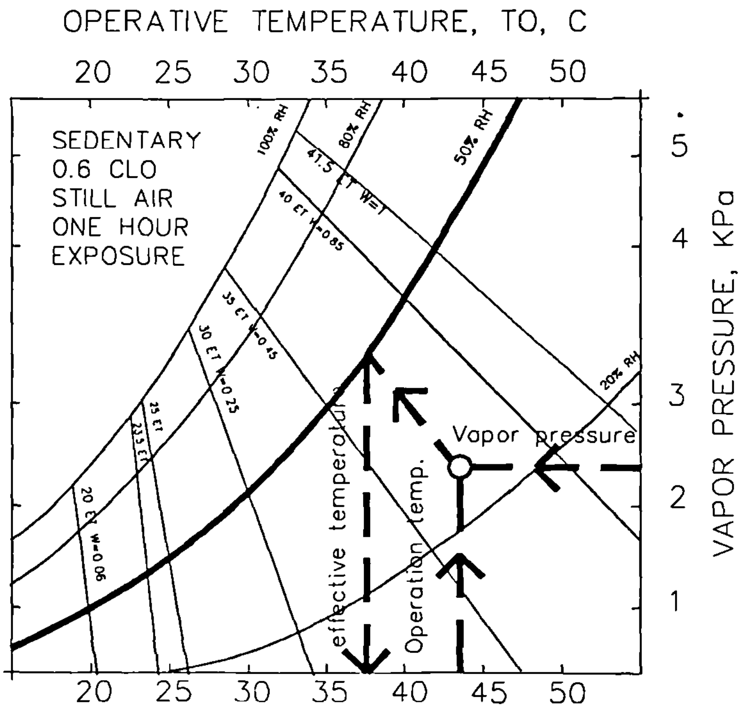

Fig. 4.6: *Psychrometric process to determine Effective temperature (ET^*).*

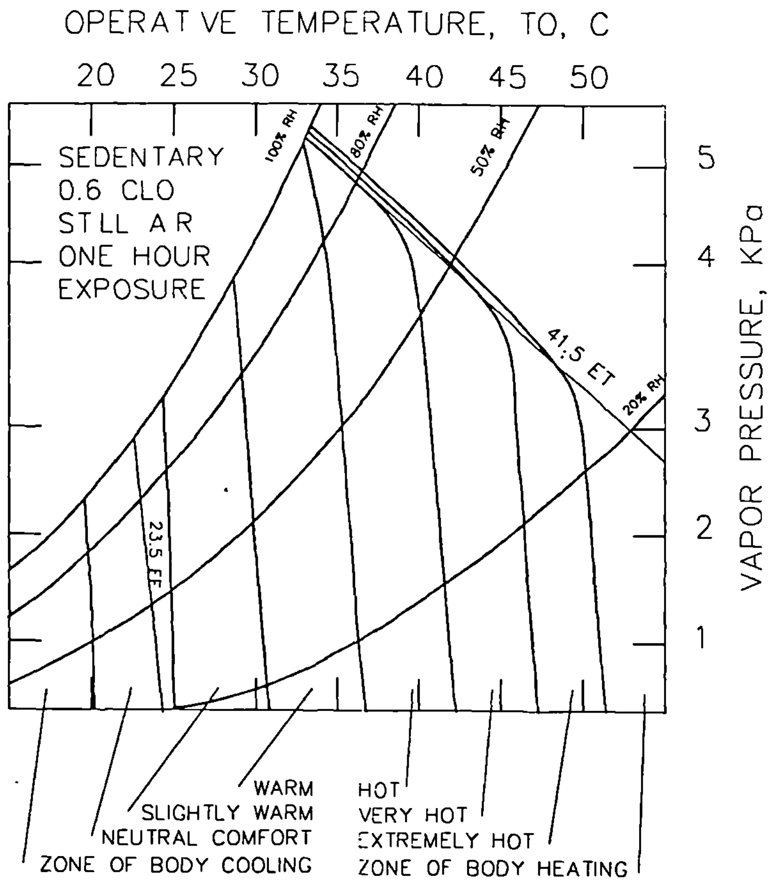

Fig. 4.7: *Psychrometric chart for ET^* with Isotherms for thermal sensation.*

Ashrae, Fundamentals handbook, NewYork: ASHRAE, 1985, P. 8-17.

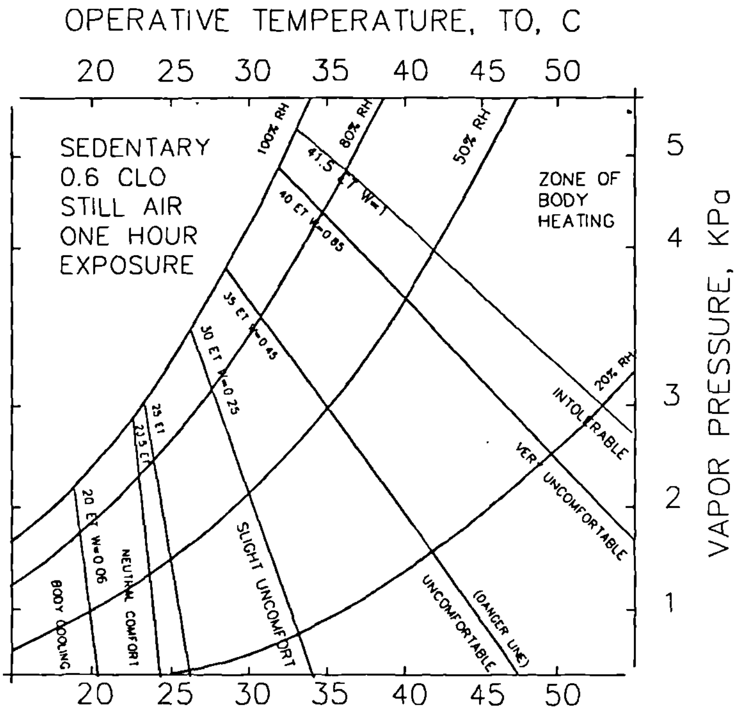

Fig. 4.8: *Pssychrometric chart for ETo* with isotherms for discomfort sensation and the proposed comfort zone and danger threshold.*

Ashrae, Fundamentals handbook,NewYork: ASHRAE, 1985, P. 8-25.

Table 4.2

Scale of ET* and related human sensory, physiological and health responses for prolonged exposures.

ET*	TEMPERATURE SENSATION	DISCOMFORT	REGULATION OF BODY TEMP.	HEALTH
40	Very hot	Limited tolerance very uncomfortable	Failure of free skin evaporation	
	Hot	Uncomfortable		Increasing danger of heat-stroke
35				
30	Warm	Slightly Uncomfortable	Increasing Vasodilation sweating	
	Slightly warm			
25	Neutral	Comfortable	No registered sweating	Normal health
	Slightly Cool		Vasoconstriction	
20	Cool	Slightly uncomfortable	Behavioral changes	
15				Complaints from dry mucosa
	Cold	Uncomfortable	Shivering begins	Impairment
10	Very Cold			peripheral circulation

Ashrae, Fundamentals handbook,NewYork: ASHRAE, 1985, P. 8-26.

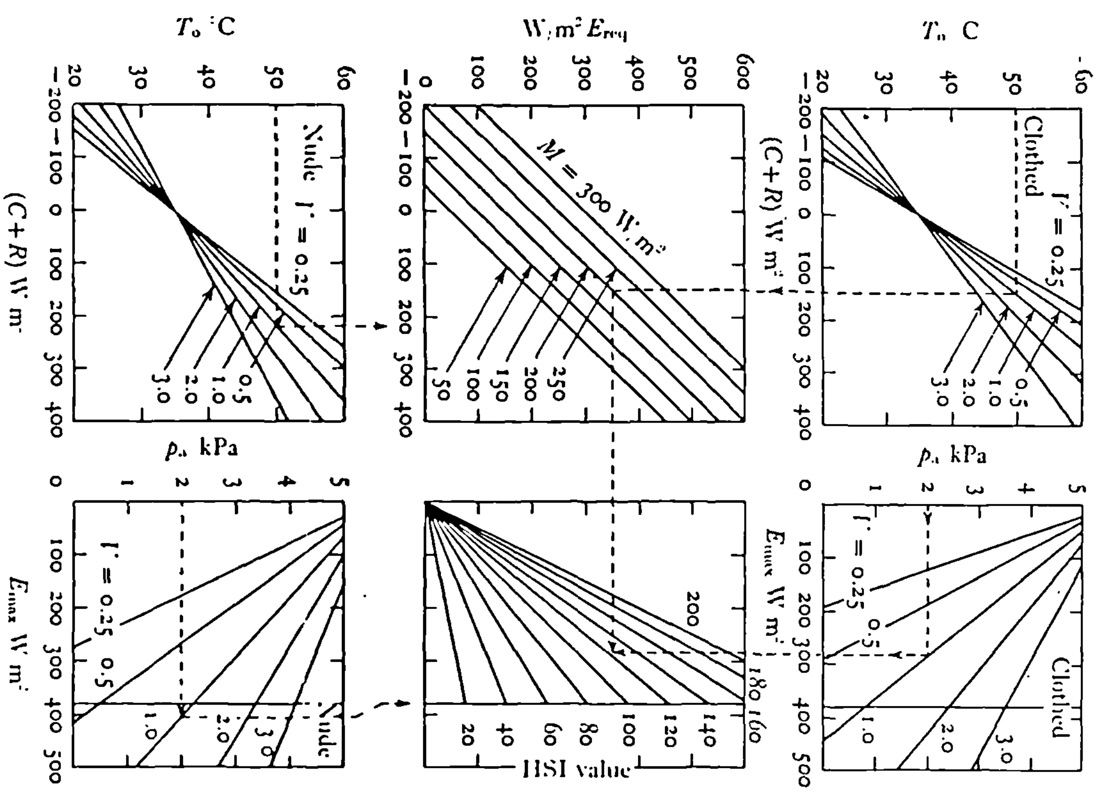

Fig. 4.9: *The heat Stress Index (HSI).*

D. Kerslake, <u>The stress of hot environments</u>, Cambridge: University press 1972, p.225.

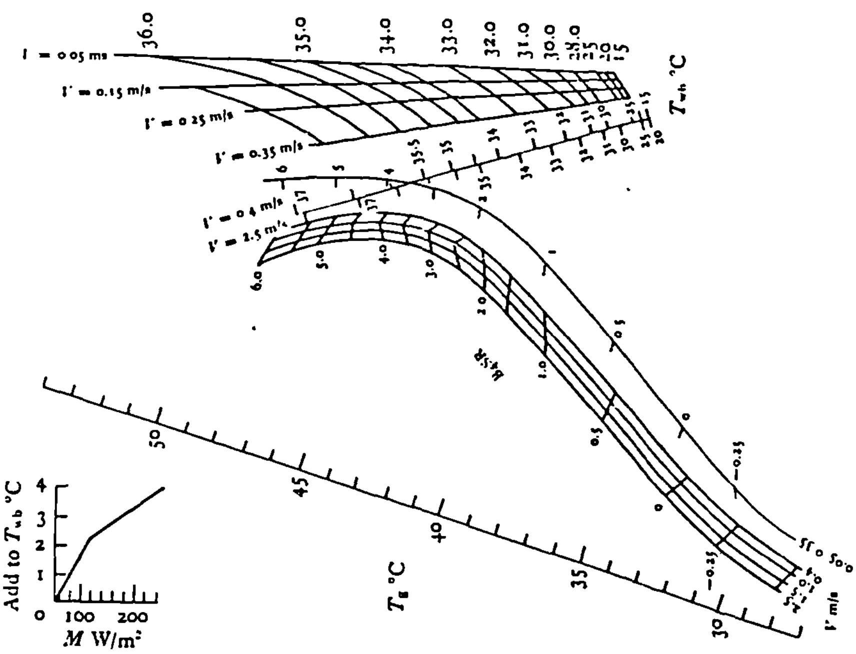

Fig. 4.10: *Chart of the P4SR.*

D. Kerslake, <u>The stress of hot environments</u>, Cambridge: University press 1972, p.234.

All heat indices mentioned previously are reported satisfactory under conditions ranging from comfortable to severe heat stress for people at rest or engaged in light to medium work. Environmental conditions inside pilgrimage tents such as air temperature, relative humidity, and globe temperature were measured during the Hajj of 1989. Pilgrims' activities are light and range between 75- 120 watts for the healthy average adult male. Pilgrims at Makkah wear a simple dress consisting of two pieces of unsown white cloth for men. Women wear a long white dress and cover their heads with a scarf. Hajj uniform is light and estimated from 0.50 - 0.65 clo based on the estimation done for the Saudi national dress. [30]

Environmental conditions during the Hajj, pilgrims' activities, and clothes are all within the range of all the heat stress indices mentioned in this chapter. Some heat indices are more favourable to use because they are simpler in terms of the required calculation such as the WBGT-Index. Some others are more complicated such as P_4SR. Nevertheless, the best heat stress indices are determined by the objectives of the analysis cited earlier at the introduction which were:

1. To determine the heat stress load of the hot environment on a pilgrim's body,
2. To determine the dangerous limits on a human body that cause suffering as a result of heat disorders and illnesses during the Hajj, and
3. To predict the thermal and comfort sensations for pilgrims exposed to the hot environment of the Hajj.

7- THE PREDICTION OF THE HEAT STRESS LOAD ON PILGRIMS:

Figures 4.11 and 4.12 demonstrate the typical hourly heat load on pilgrims exposed to the hot environment of the pilgrimage tents in the Arab and the European camps respectively. The three channels of heat gain and loss namely radiation, convection, and evaporation are calculated using the formulae of the ITS- heat index.[31] The metabolic rate is assumed at the lowest rate of 75 watts per hour. Also assumed is the thermal resistance of pilgrims uniform to fall in the range of 0.50 - 0.65 clo.

Figures 4.11 and 4.12 indicate negative values for heat losses and positive values for heat gain. It can be concluded that for 70% of a 24 hour day, the body can maintain a thermal equilibrium with the environment. This occurs during the night and early hours of the day, from 17.00 hrs to 10.00 hrs the following morning. However, for 30% of the time, from 10.00 hrs to 17.00 hrs which represents most of the daylight hours, heat is continuously gained at a rate sufficient to disturb the thermal equilibrium with the environment and may increase body temperature to a considerable degree of strain. Pilgrims during this time are exposed to thermal conditions which clearly are hazardous to their health. The main components of heat gain are by radiation (42%), by metabolism (40%), and by convection (18%). The required sweat evaporation rate to balance heat gain cannot be achieved simply because it exceeds the maximum evaporation rate that the body can produce. Thermal conditions, therefore, must be altered in some way to enable the human body to maintain a thermal balance.

8- LIMITS OF PERMISSIBLE EXPOSURE TO INSIDE ENVIRONMENT OF PILGRIMAGE TENTS:

The best available recommendation supported by the World Health Organisation suggested that the deep body temperature of people exposed to hot climates should not be permitted to exceed 38° C. A person can not tolerate temperatures above this value and will eventually collapse.

The WBGT - Index has been proven particularly versatile for displaying permissible exposure limits in terms of different combinations of environmental heat and work intensity. The upper limit set by the WBGT- index for continuous exposure and light work in a hot environment is 32° C WBGT.

Figure 4.13 shows the WBGT curve averaged for the duration of measurements. It also indicates threshold limits of three activity levels, above which Pilgrims would be exposed to harmful health conditions. The WBGT curve exceeds the permissible heat limit of light activity from 12.00 hrs mid day to 16.00 hrs for both European and Arab camps. Limits of permissible heat exposure indicated by the WBGT- index are developed and used for acclimatized young military trainees in the United states and in Canada. While critical limits of heat exposure set by the WBGT-index are accepted here as an indication, true permissible limits inside the pilgrimage tent may be lower and vary due to age, sex, and acclimatization. This suggests that a critical period of heat exposure to a hot environment of the pilgrimage tents may be longer by one or two hours. This observation can not be verified from the field data because physiological measurements such as rectal temperatures were not monitored nor can it be confirmed from the available heat stroke records because time and place (e.g. inside or outside tents) were not specified.

9- PREDICTION OF THERMAL AND COMFORT SENSATIONS:

To predict the thermal and comfort sensations, average 24 hour readings of field measurements during the Hajj of 1989 were plotted on the psychrometric chart of the new effective temperature scale. Data were plotted by using operative temperature and vapour pressure. Operative temperature is defined as the temperature that combines the effect of radiation and convection heat exchange. It is calculated using the following formula:[32]

$$T_o = (4.7 * MRT + 3.1 * T_a) / (4.7 + 3.1) \qquad (4.4)$$

Where:

T_o= Operative temperature, ^oC

MRT= Mean Radiant Temperature, ^oC

T_a= Air temperature, ^oC

3.1= Convective heat transfer coefficient acting on resting subject, $w/(m^2 . ^oC)$[33]

4.7= Radiation heat transfer coefficient, w/ $(m^2.^oC)$[34]

Values of vapour pressure are determined from CIBSE tables for properties of humid air.[35]

Figures 4.14 indicates thermal discomfort isotherms and plots average readings for a 24 hour period in the Arab and European camps. The clearly plotted hours fall outside the Ashrae "comfort" zone and are scattered in the "uncomfortable", from 19.00 hrs to 9.00 hrs, and the "very uncomfortable" zones, from 10.00 hrs to 18.00 hrs. The lower limit of "very uncomfortable" sensation was predicted at 10.00 hrs, reaching its peak between 13.00 hrs and 15.00 hrs and falling back to its lower limit near sunset at 19.00 hrs.

Heat stroke deaths are noted as occurring near the line of 35^o C ET and suggested as a danger line by Ashrae. The period from sunset at 19.00 hrs to 9.00 hrs is below the line while the period from 10.00 hrs to 18.00 hrs is above it. This suggests that pilgrims experience an uncomfortable thermal environment during the evening and night time, i.e. from sunset to the early hours of the morning. This represents 62% of the whole day. It also suggests that during most of the daytime, accounting for 38% of the whole day, pilgrims are exposed to very uncomfortable and harmful environment.

Figures 4.15 indicates thermal sensation isotherms and average hourly values of operative temperature and vapour pressure plotted for the Arab and European camps. Clearly, plotting hours are scattered between "warm" and "extremely hot" zones. Most concentration is observed within the warm zone from 20.00 hrs to 9.00 hrs-this represents most of the hours of the darkness and accounts for 54% of the whole 24 hour day. Further concentration is observed within the "very hot" zone from 10.00 hrs in the morning to 13.00 hrs after noon and from 15.00 hrs to sun set at 19.00 hrs. This represent most of the daylight hours and 29% of the whole 24 hour day. The hottest hours of the day, i.e., from 13.00 hrs to 15.00 hrs, fall into the "extremely hot" zone and represents 8.5% of the whole 24 hour day. The remaining 8.5% of the time is located within the "hot" zone and occurs between 9.00 hrs to 10.00 hrs in the morning and from 19.00 hrs to 20.00 hrs in the evening.

It is interesting to notice that the time division of the above analysis of thermal sensation roughly coincides with the local time divisions of daily prayer. Muslims must pray five daily prayers, the starting and the ending times for prayers are according to the sun movement as follows:[36]

1. The time of noon prayer, DUHR, starts when the sun begins decline from its zenith and ends when the size of an object's shadow is equal to the size of the object. DUHR time in Makkah during the Hajj of 1989 is due from 12.25 hrs to 15.44 hrs and coincides with the period characterised as extremely hot zone.

2. The time of afternoon prayer , ASAR, starts when the shadow of an object is the same size as the object and ends just before sunset. This is due from 15.44 hrs to 19.08 hrs and coincides with the period classified as very hot zone.

3. Time of sunset prayer, MAGHRIB, starts just after sunset and ends when the twilight has disappeared. This is due from 19.08 hrs to 20.38 hrs and coincides with the period classified as "hot" zone.

4. The time of the night prayer, ISHA, starts from the disappearance of twilight at 20.38 hrs and ends just before midnight.

5. The time of morning prayer, FAJAR, starts at dawn at 4.11 hrs and ends at sunrise at 5.42 hrs. This period is classified as the "warm" zone based on the effective temperature heat index.

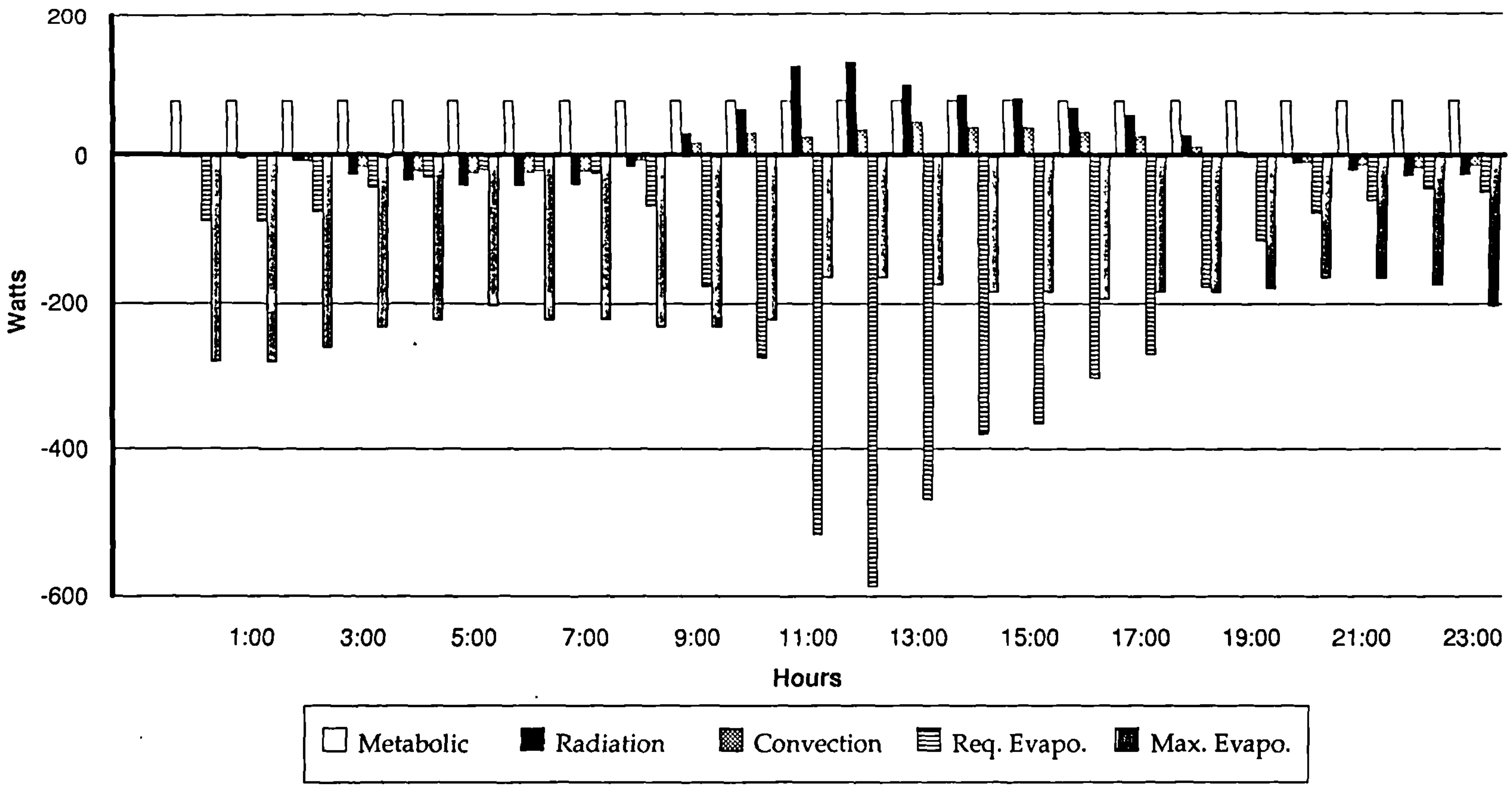

Fig. 4.11 *Hourly heat stress load for a subject exposed to the inside environment of the Pilgrimage tent in the Arab camps, calculated using the ITS- heat index.*

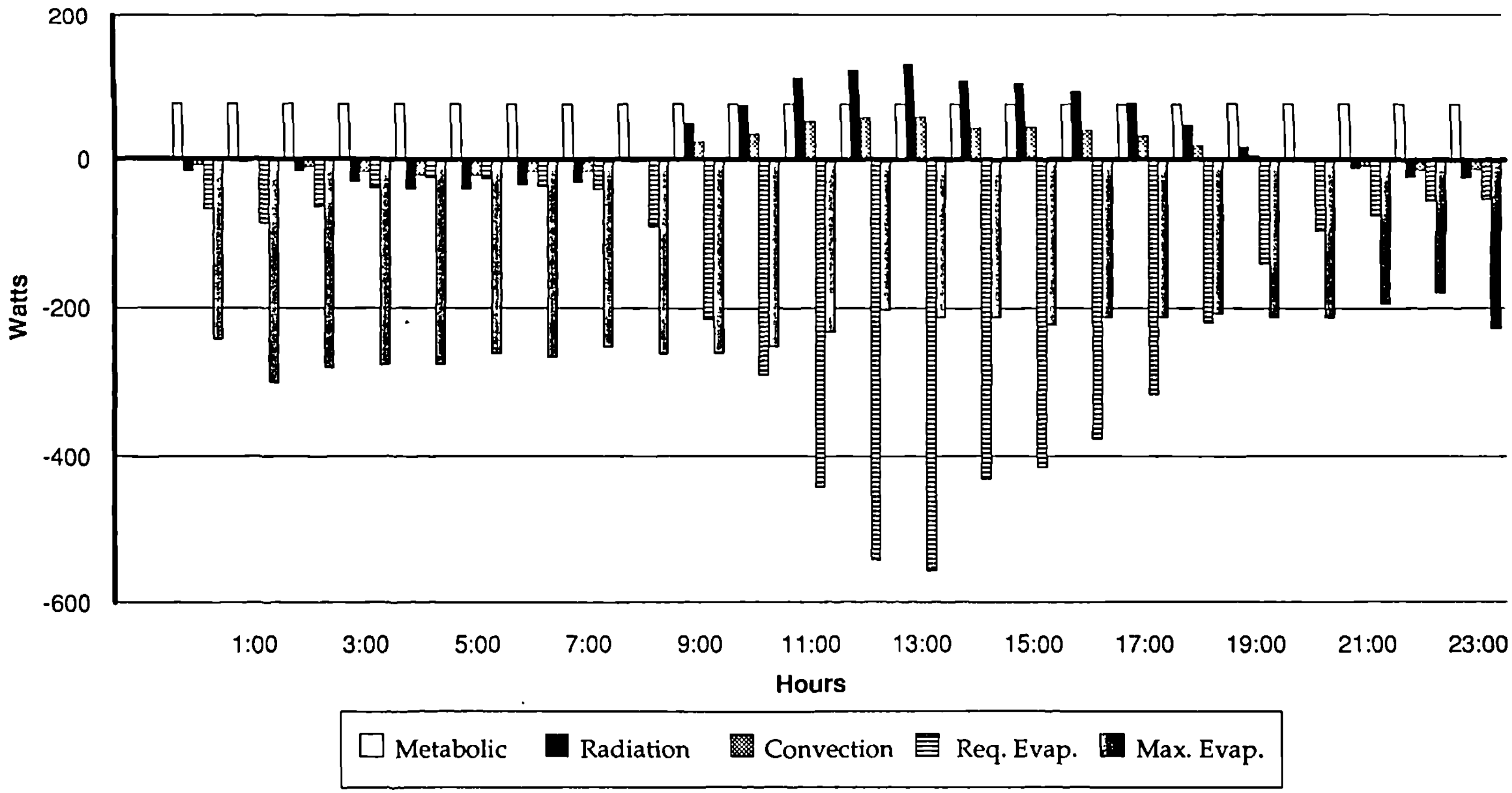

Fig. 4.12 *Hourly heat stress load for a subject exposed to the inside environment of the Pilgrimage tent in the European camps, calculated using the ITS- heat index.*

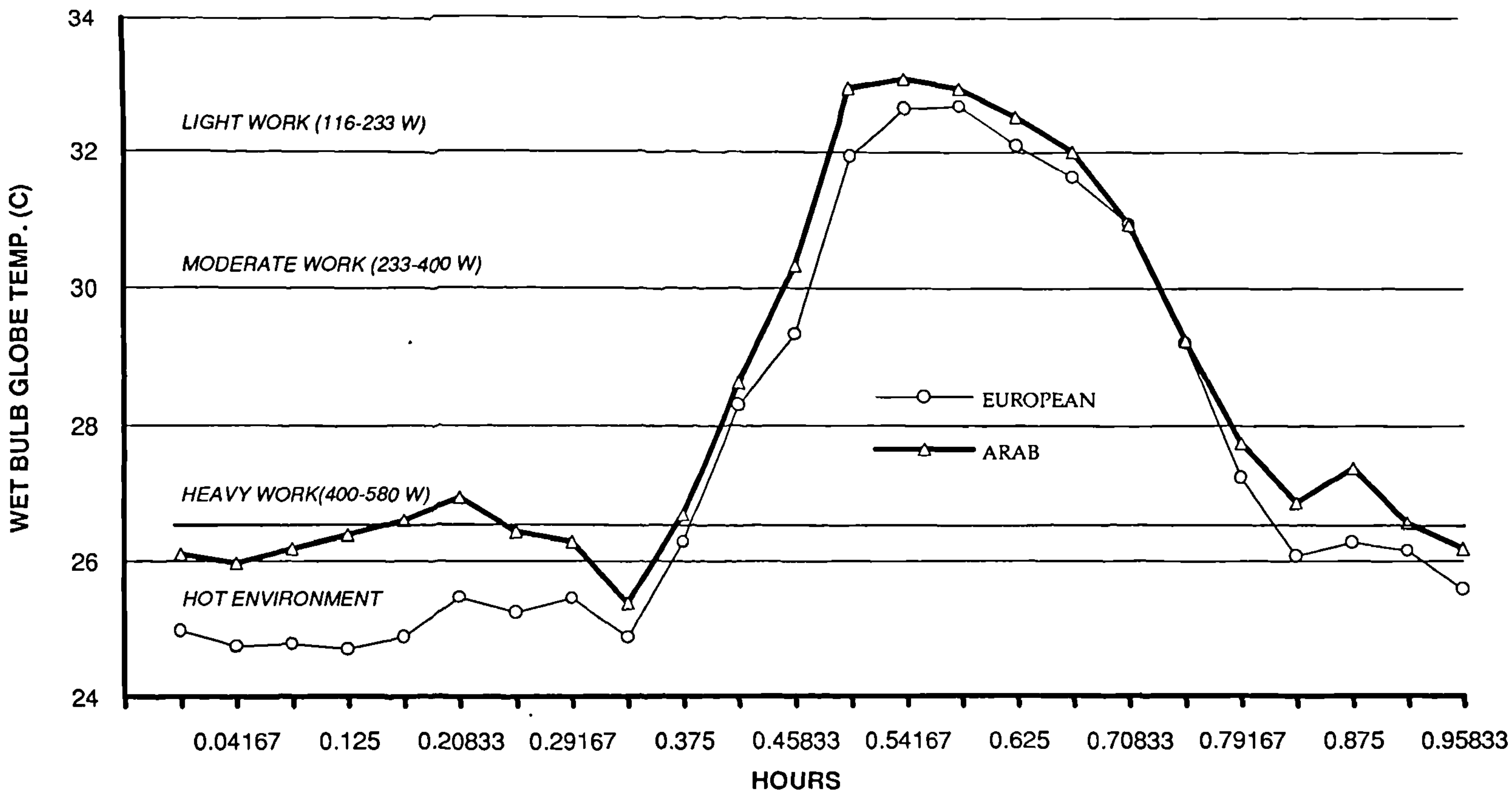

Fig. 4.13: *Average WBGT inside the pilgrimage tent calculated for the Hajj period of 1989 with permissible heat exposure threshold limits for different work levels.*

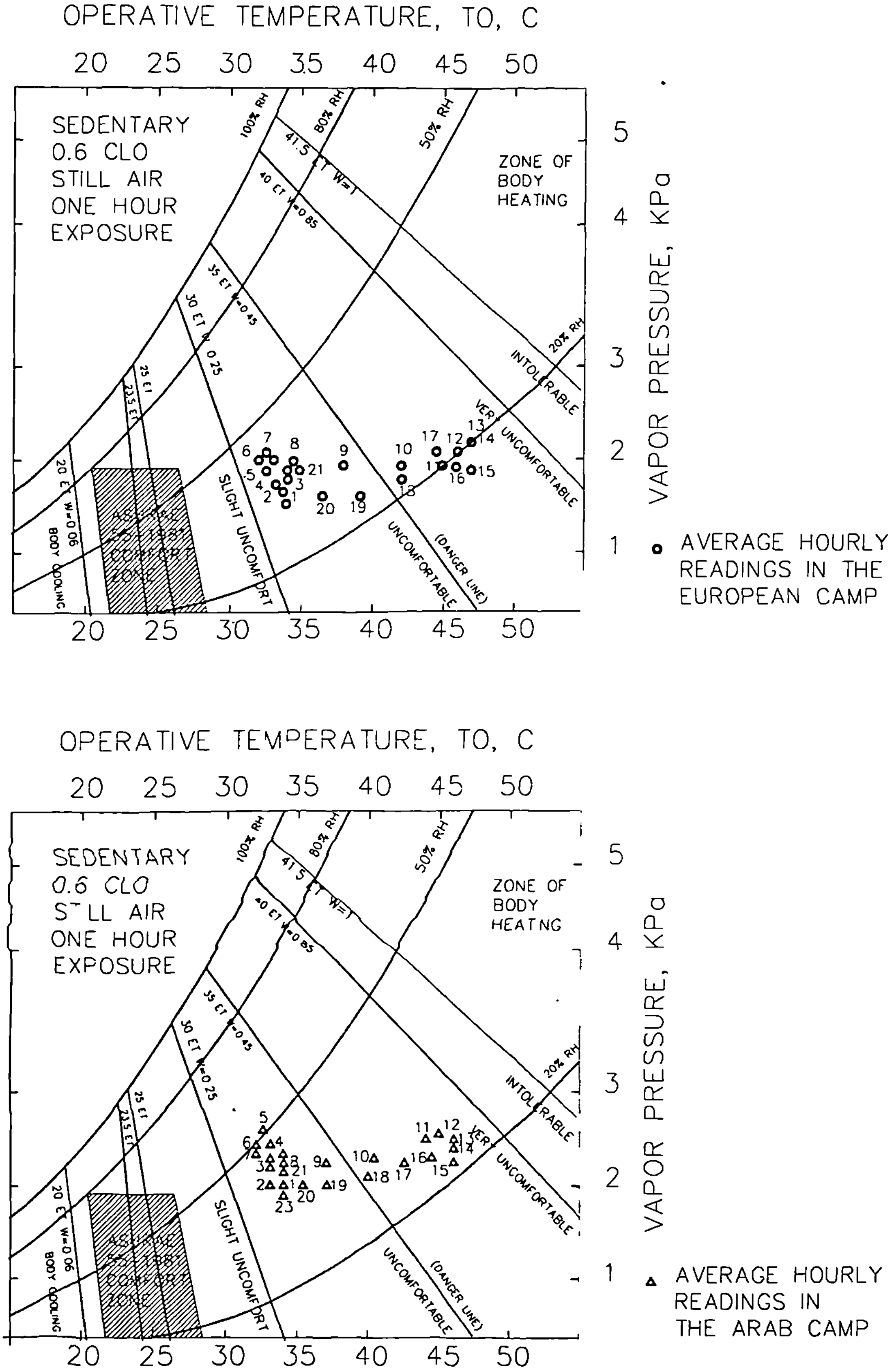

Fig. 4.14: *Analysis of discomfort sensations for subjects exposed to the hot environment of the pilgrimage tents in the European camp and in the Arab camp during the Hajj of 1989.*

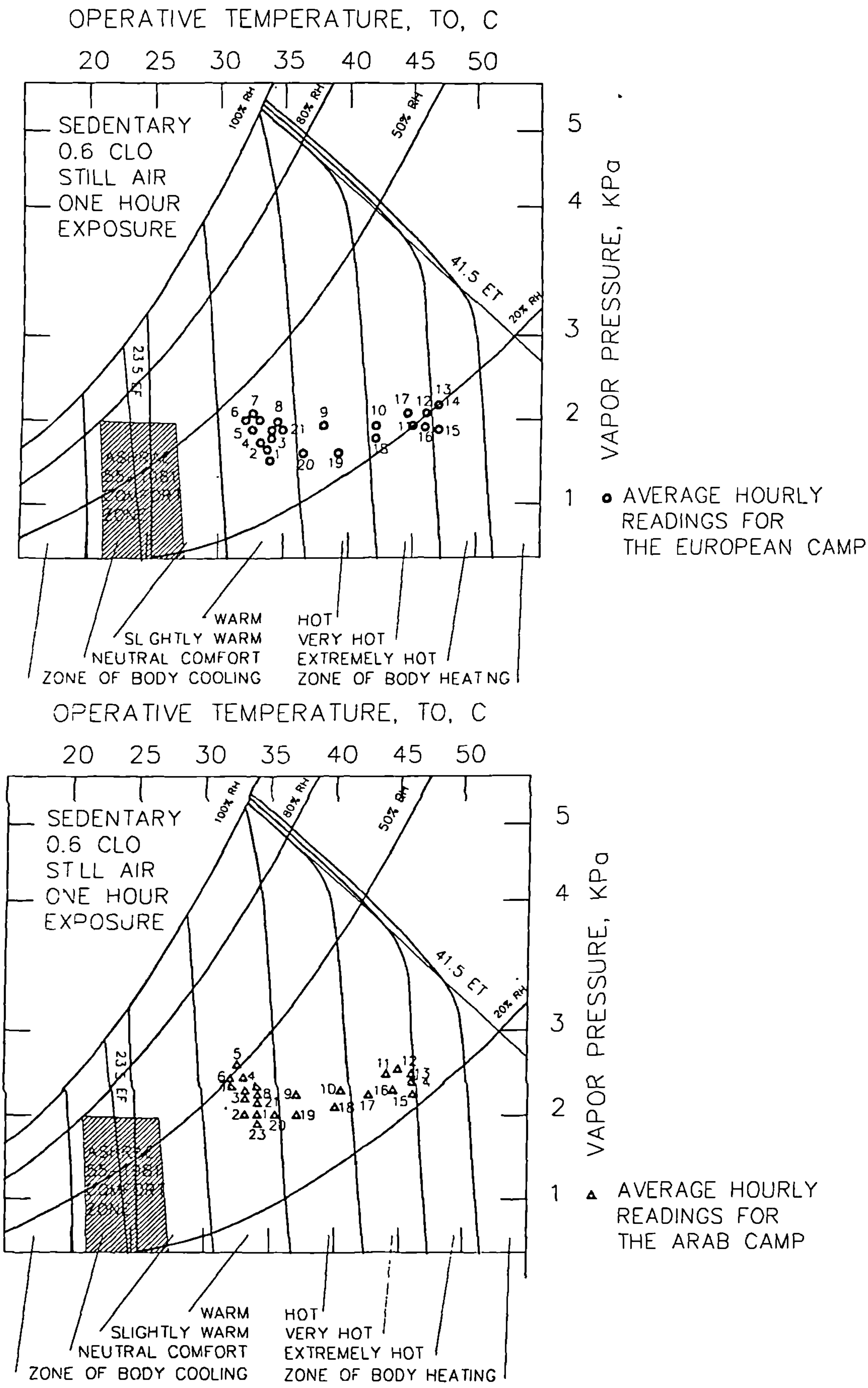

Fig. 4.15: *Analysis of thermal sensations for subjects exposed to the hot environment of pilgrimage tents in the European camp and in the Arab camp during the Hajj of 1989.*

10- CONCLUSION:

Heat stress is imposed on the human body due to many climatic and non climatic factors. Climatic factors include air temperature, relative humidity , mean radiant temperature , and wind velocity. Non-climatic factors include internal heat production and thermal resistance of clothing. Man is endowed with a thermoregulation system that enables the body to respond in several physiological ways to maintain a thermal equilibrium with the environment. The first of these physiological responses is through increasing blood flow in which large quantities of heat are transferred to the outside. The skin surface as a result is increased and heat is dissipated to the outside. The most important physiological response, however, is by sweating which helps to lower body temperature by method of evaporation. When these mechanisms fail to maintain thermal balance, inner body temperature is elevated and the body may collapse as a result.

Man feels discomfort under heat stress due to the sensation of heat on the one hand and the sensation of wet skin on the other hand. Heat indices are used to assess heat stress and thermal discomfort for subjects exposed to the hot environment . Several heat indices are discussed in the previous pages and are used together with the data collected during Hajj period of 1989. The purpose was to assess thermal discomfort and heat stress due to the exposure to the hot inside environment of the pilgrimage tents. Results are summarised in figure 4.16.

The inside environment of the pilgrimage tent is not comfortable. Based on the Ashrae scale of comfort, the inside environment of the pilgrimage tent falls into two categories: "uncomfortable" and "very uncomfortable". From sunset at 19.00hrs to 10.00hrs in the morning it is described as "uncomfortable". This period of time represents 62% of the whole 24 hour day. During this time bodies can maintain thermal equilibrium with the environment without any danger of body collapse due to heat exposure. The remainder of the time, from 10.00hrs to sunset at 19.00hrs (and represents 38% of the whole 24 hour day) is categorised as "very uncomfortable". During this period bodies are continuously gaining heat at a rate that could disturb the thermal equilibrium and may increase the body temperature to dangerous limits. The most crucial time of all, however, is the period from 12.00hrs to 16.00hrs. During this period environmental conditions exceed the permissible limits of 32^{o} C WBGT and the rise of body temperature may reach above 38^{o} C. Pilgrims therefore are exposed to harmful health conditions and their tolerance may vary according to their age, sex, and degree of acclimatization. Based on the use of the ITS index, the main component of heat gain is by radiation. This component represents 42% of total heat gain. The second and third components are by metabolic heat (40%) and by convection (18%).

This study has revealed a correlation between local time divisions of daily prayers at Makkah and the classification of thermal sensations based on the index of the new effective temperature scale. The index predicted the hottest hours of the day from 13.00 hrs to 15.00 hrs as "extremely hot". This period represented 8.5% of the whole 24 hour day and coincided with the local time for noon prayer, DUHR. Thermal sensation during the period from 15.00 hrs to 19.00 hrs was predicted as "very hot". This period coincided with the local time for afternoon prayer, ASAR. Also classified as "very hot" was the time from 10.00hrs and 13.00 hrs. The "Very hot" thermal sensation represented 29% of the whole 24 hour day. Thermal sensation from sunset at 19.00 hrs to 20.00 hrs was "hot" and coincided with sunset prayer, MAGHRIB. Also classified as a "hot" period was the time from 9.00 hrs to 10.00 hrs in the morning which in total represented 8.5%. of the whole 24 hour day. Most of the time (54%) occurring during the hours of darkness and the early hours of the day until 8.00 hrs was classified as "warm".

Most occupation was noticed to occur during the hours of the darkness and the early hours of the day in both the Arab and the European tents. However, during the day Arab pilgrims stayed in their tents even though the inside environment was extremely hot and left only after 15.00 hrs. European pilgrims left their tents mainly in the afternoon and, therefore, were less likely to experience the extreme hot thermal sensation inside the pilgrimage tents.

It has been shown that the measured conditions in the pilgrimage tents are likely to cause not only discomfort but hazardous conditions. The following chapter reinforces the conclusion determining of the subjective impressions of conditions experienced by the pilgrims themselves.

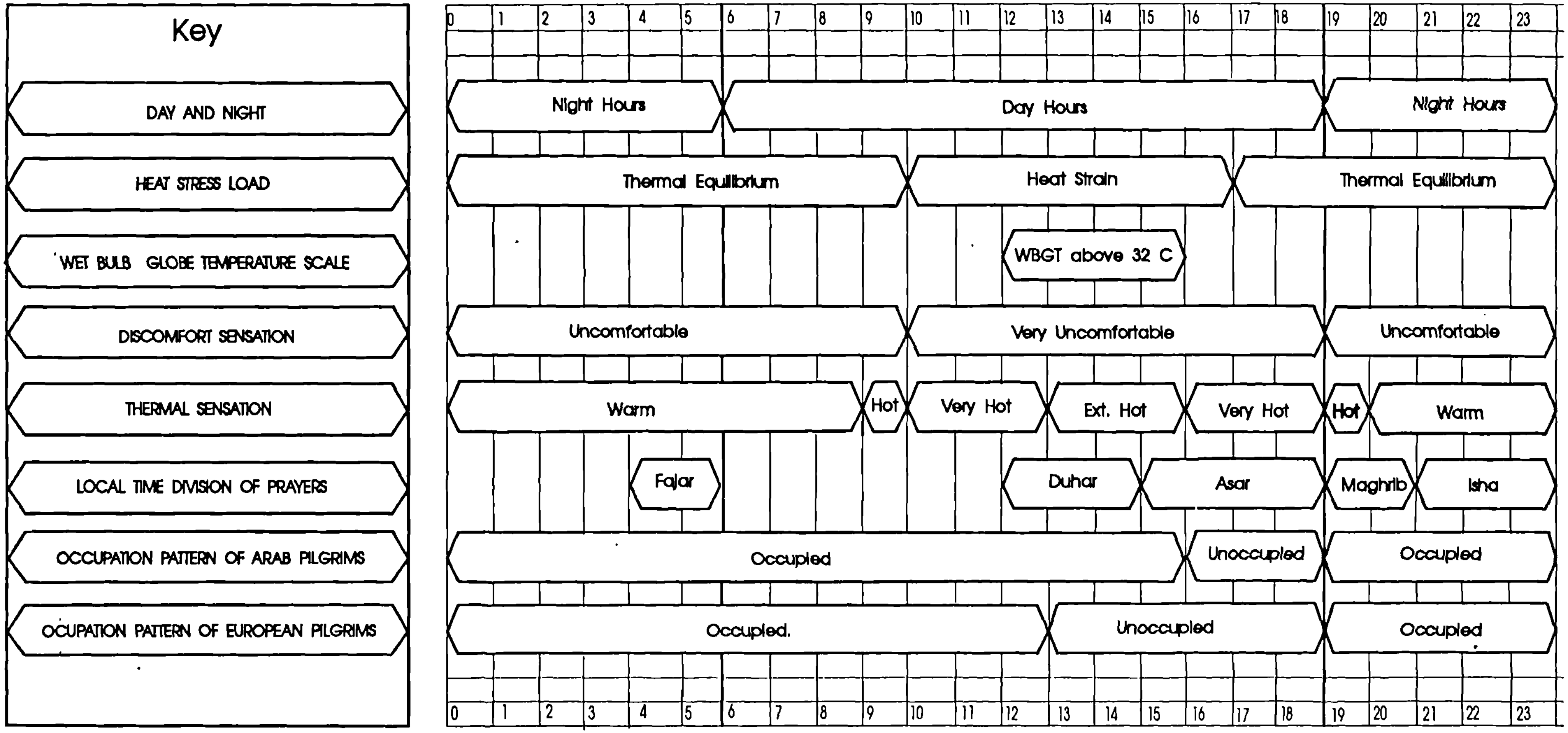

Fig. 4.16: *Summary of the thermal and comfort sensations experienced in the tents, related to the local time of daily prayers and occupation pattern of pilgrims.*

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CHAPTER V

SURVEY DESIGN AND PROCEDURES

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CHAPTER V

SURVEY DESIGN AND PROCEDURES

1-INTRODUCTION:

The results discussed in the previous chapter revealed that pilgrims were exposed to hazardous conditions inside the pilgrimage tent from 12.00 hrs to 16.00 hrs. It was also concluded that thermal sensation ranged from "warm" during the night-time to "extremely hot" during the hottest hours of the day between 13.00 hrs and 14.00 hrs. Such an assessment was based on the use of heat indices which considered both climatic and non climatic conditions. The climatic conditions included air and globe temperatures, relative humidity and wind speed. The non-climatic conditions included clothing and metabolism due to different levels of activities. However, there are many other factors which may have affected heat exchange between man and his environment and which were not included in the heat indices.[1] These factors are such as: age, sex, acclimatization, and physical fitness of individuals exposed to heat stress. Such factors are important to consider in a thermal evaluation of a practical situation such as the Hajj. It is equally important to verify the conclusion derived from the previous chapter by requesting pilgrims to evaluate thermal conditions inside the pilgrimage tents.

A questionnaire was, therefore, designed and distributed during the pilgrimage period of 1989. The main objectives of this survey were:

1. To measure pilgrims' evaluation of the hot environment of the pilgrimage tent and from this identify when environmental problems occurred;
2. To examine differences in thermal evaluation between the "hot", "cold", and "tropical" subgroups; and

3. To analyze factors that directly influenced thermal stress, such as age, sex, health, acclimatization, the experience of living in a hot climate, and the location of subjects inside the tent, and to study which of these factors had the strongest influence on pilgrims' thermal discomfort, and hence possible heat stress problems.

This chapter is structured to assess how these objectives are achieved and how a survey can be designed for a transient gathering lasting for only a few days. Analysis of the survey and results will be discussed in chapter VI. It must be made clear here that the survey and measurements form part of a wider area of research. The intention was not to conduct an exhaustive investigation of the physiological problems arising from extreme conditions. This would be beyond the scope of this research.

2- DESIGN OF THE SURVEY:

The design of the questionnaire has passed through several stages. Having determined the objectives and the parameters to be measured, three other stages remained. The first one was the initial structure and writing of the questionnaire. The second was to pre-test the questionnaire. The third was the constructing and rewriting stage.

The initial design of the questionnaire was to ask pilgrims to repetitively evaluate thermal and ventilation conditions inside the pilgrimage tents at different times of the day. For example, the day was divided into "early morning"," morning", "noon", "afternoon", "evening", "night", and "late night." This design was pretested to examine clarity and the time taken to complete the questionnaire. The first pre-test was made on members of the Islamic Society of the University of Newcastle-upon-Tyne. The society comprises students from Britain and overseas, in a similar mix of people as is expected for the Hajj. The feed back suggested that the repetitive evaluation of the thermal environment was very expensive, labour intensive, and time consuming. Pilgrims were being expected unwillingly to be interviewed repeatedly. Further, more practical difficulties may have arisen when using this survey method. Pilgrims for example may not necessarily be in their tents when the survey forms had to be completed. Pilgrims also may lose their forms if they had to keep them for a long time. The design, therefore, was altered to one of instant thermal evaluation at different hours of the day. Another pre-test was undertaken with pilgrims not in the final sample at Makkah before the Hajj time. The comments of the previous stage had helped to modify the initial format. Some questions were added, others were deleted and others were made simpler and more direct. The comments also suggested some alteration to the language style and to the length of each question.

The final format distributed during the Hajj of 1989 and presented in Appendix II consisted of ten sections; each contained one or more close-ended questions. The following is a description of each section:

(1) The first section was an introduction to the purpose of the survey and detailed information on the location of the camp and the date and time of the questionnaire. This information was to be filled in by the interviewer.

(2) The second section contained background questions on the age, sex, nationality and the type of climate the pilgrim came from. The climate background was assumed "cold" if the pilgrim's country was either Turkey or one of the European countries. It was assumed "hot" if the pilgrim's country was among the Arab countries and tropical if the country was Malaysia or Indonesia. The questions this section aimed to answer were: do people from different climatic zones and different age groups vary in their assessment of discomfort sensation?; do women more than men vary in their discomfort sensation?

(3) The third section was to measure the acclimatization of pilgrims' bodies to the hot climate. The acclimatization process was estimated to be attained within four to seven days following the pilgrim's arrival to Makkah.[2] The question this section

tried to answer was: does acclimatization to a hot climate influence thermal discomfort?

(4) The fourth section was to identify the usual location of each interviewee during the day and the night. It is reasonable to assume that a person's position inside the tent would influence his/ her discomfort due to differences in received radiation and air movement.

(5) The fifth section was an evaluation of privacy. The scale used in this evaluation comprised three levels: "sufficient privacy", "little privacy", and "no privacy." The reason for this was that the more partitions used inside the pilgrimage tent (for reasons of privacy) the worse were the internal thermal conditions likely to be due to reduction of air movement.

(6) The sixth section was to test the precautions taken by pilgrims whilst outside their tents. This was to eliminate cases where heat exhaustion or thermal discomfort may have occurred due to the exposure to heat of the outside environment.

(7) The seventh section was the longest section and tested the health conditions of the pilgrims. This section included questions on pilgrims' weight, heat related illness, and quantity of liquid consumption and disposal during the Hajj. This section was designed to establish a knowledge of the relationship between physiological conditions and the thermal scale used for evaluation.

(8) The eighth section was concerned with pilgrims' previous experiences of the hot environment of Makkah. As the pilgrimage falls in the summer this was measured by the number of pilgrimages performed during the last five years. Pilgrims who performed Hajj within the five years before the survey were considered to be familiar with the hot climate of Makkah. The hypothesis was that pilgrims with previous experience of the hot climate of the Hajj would have a higher expectation and, therefore, more tolerance to a severe climate than pilgrims

visiting Makkah for the first time They may also have accumulated experience of the best measures to take to relieve the conditions.

(9) The ninth section was to survey the type of activities exercised inside the pilgrimage tent. The hypothesis was that the harder the work inside the tents; the worse the thermal evaluation of the tent.

(10)The tenth section of the questionnaire evaluated the internal conditions of the pilgrimage tent. An arbitrary scale was used for each of thermal, ventilation, and perspiration sensations as shown in table 5.1. For the thermal environment of the pilgrimage tent, two scales were used. The first was a scale of six points derived from the ASHRAE scale as follows: "comfortable", "very warm", "warm", "hot", "very hot" and "heat exhausted."[3] The second compares the inside thermal environment of the pilgrimage tent with that of the outside. The scale used for this measurement comprised three levels: "worse than outside", "same as outside", and "better than outside." For ventilation conditions inside the pilgrimage tent, the scale used was based on three points: "good", "satisfied", and "poor." For perspiration sensation , a scale of three points determined the quantity of sweating as follows: " sweating very much", "normal sweating", " little sweating". Pilgrims were asked to make their evaluations at the time of the interview.

The survey was designed to take samples from three subgroups. European and Turkish pilgrims represented the "cold climate" subgroup. Arab pilgrims represented the "hot climate" subgroup while Malaysian and Indonesian pilgrims represented the "tropical climate" subgroup. The three subgroups speak different languages and no one language is common to all. Each group had to be communicated with in their own language. The questionnaire was written first in English and then translated into five other languages: Arabic, French, German, Turkish, and Malaysian. Although questions were identical different languages may have produced different meanings. The translations, therefore, were checked before finally being distributed to the pilgrims. The department of European Languages at

King Saud University checked the French and German translations. The Turkish and Malaysian translations were checked by the Hajj research centre in Makkah. The final form of the questionnaire is presented in Appendix II

In parallel to the questionnaire, an inventory form was designed (Appendix III). The surveyor was required to record heat sources in the tent, such as the number of pilgrims, electrical fans, and light bulbs. Also required was a sketch of the tent's layout, an indication of its orientation, and the location of electrical appliances in the tent. The inventory intended to study, when required, the effect of the tent's layout, orientation, and internal heat sources on the thermal evaluation by pilgrims. For example, to study the effect of orientation on thermal evaluation a comparison can be made between two tents oriented differently, but both being occupied by one particular subgroup, i.e., European, Arab, or South East Asian. The time taken to fill in the inventory was estimated to be 10-15 minutes which was enough to attract pilgrims' attention and make them familiar with the surveyor. On the other hand the inventory helped the surveyor to become familiar with the people inside the tent.

3- SAMPLING PROCEDURES:

Modern surveys employ probability sampling in which each member of the target population has an equal opportunity to be included in the sample.[4] Generally, as long as there is no bias in selecting respondents and the sample is large, the sample will be highly representative of the population.[5]

Three sampling frames were defined to represent the different climate backgrounds: Turkish and European pilgrims for the "cold climate", Arab pilgrims for the "hot climate," and Malaysian and Indonesia pilgrims for the "tropical climate." Three issues were important when considering sampling procedures for a transient event such as the Hajj. The first was where to interview; the second; who to interview; and the third, when to interview.

Table 5.1

Thermal comfort sensation scales

Heat scale (1)	Code
Heat exhaustion	6
Very hot	5
Hot	4
Warm	3
Slightly warm	2
Comfortable	1
Heat scale (2)	
Better than outside	3
Same as outside	2
Worst than outside	1
Ventilation scale	
Good ventilation	3
Satisfied	2
Poor ventilation	1
Perspiration scale	
Very much sweating	3
Normal sweating	2
Little sweating	1

Pilgrims are assembled on the basis of their nationality and grouped into six residential zones as indicated earlier in chapter 2. Each zone is administered by a group of guides (establishment) and is divided into camps. Each camp is administered by one pilgrims' guide office and arranged with several tents. This local administrative system has helped to design a strategy of sampling pilgrims at three different stages. Figure 5.1 summarises the sampling procedures followed for this survey.

The first stage was to decide which camps within each sampling frame were to be selected. Each of the residential zones was indicated on a map which also listed numbers, location and orientation of tents in each camp. Each pilgrims' guide office had a number printed on a separate card. The final selection of camps was drawn randomly from the cards and indicated on the map.

The second stage was to decide which tents from each camp were to be selected. On the detailed map of camps selected in the first stage, tents were numbered and then selected randomly in exactly the same simple sampling procedure as the first stage. On a practical front, some difficulties were faced at this stage. In some camps, the tents' layout on the site was slightly different from those drawn on the map. In other camps the enormous number of tents with similar shapes had caused confusion in locating the selected tents. An effective way to overcome this confusion was to start surveying by marking one's location with a reference figure on the site such as a toilet unit or a light pole.

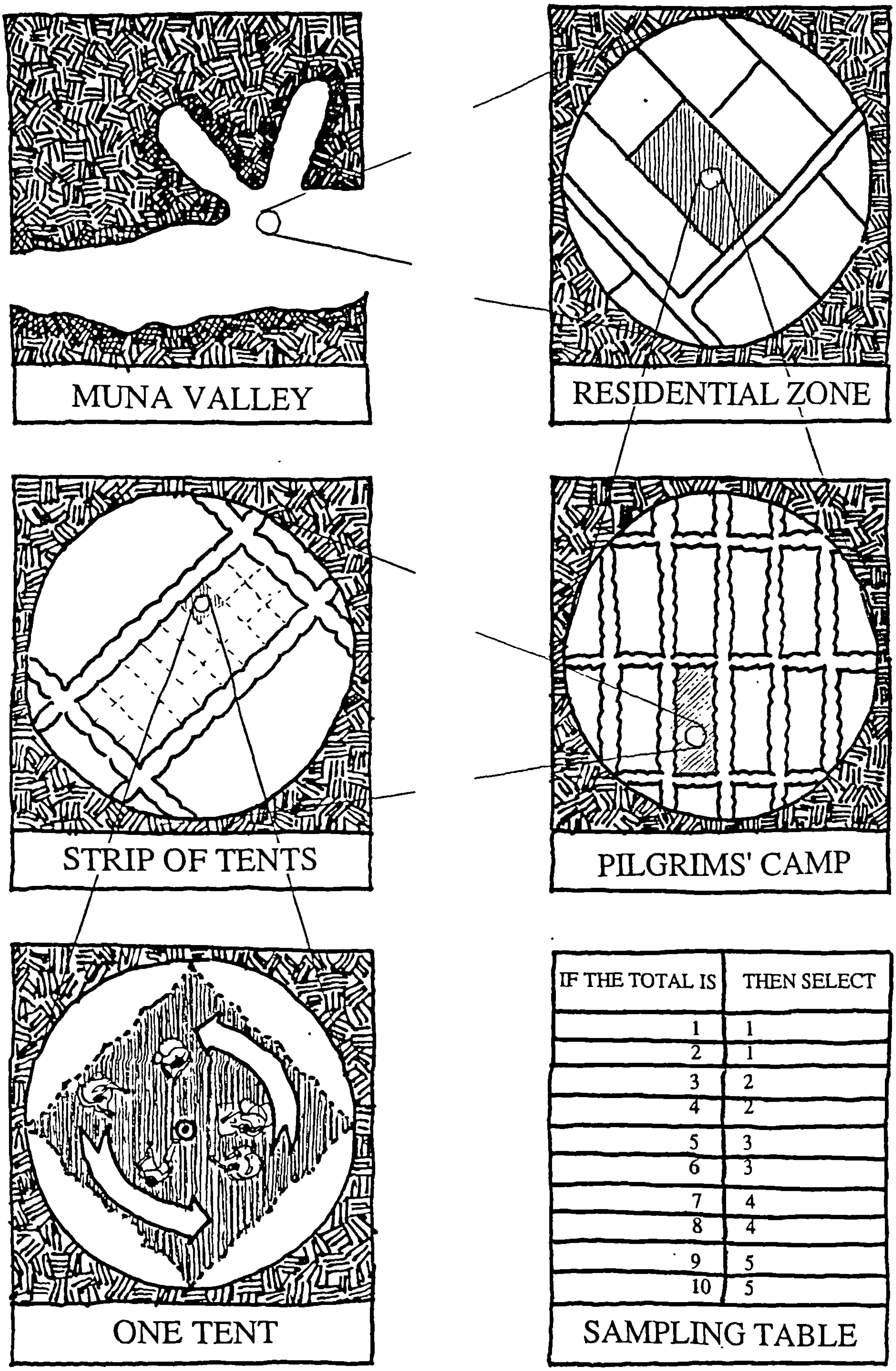
The third stage was to choose the respondents inside each selected strip of tents. Each strip measured two to three tents wide and eight to ten tents long. The method developed for this purpose was to start with the corner tent of the strip and move anti clockwise until the completion of all the tents in the strip. Pilgrims in each tent were to be counted anti- clockwise from the interviewer's right hand side.

Respondents were selected from a selection table reproduced in figure 5.1. Starting from the right hand side is part of Islamic etiquette and pilgrims were familiar with it.

This multi stage sampling procedure required early contact with three headquarters of the pilgrims' guides in Makkah. These were the establishment of pilgrim guides of North American, European, and Turkish pilgrims; the establishment of pilgrim guides of Arab pilgrims; and the establishment of pilgrim guides of South East Asian pilgrims. The contact was necessary to provide an easy access to their camps in Muna during the Hajj time and to provide the necessary maps and list of pilgrims' guide offices.

The time factor was extremely important in conducting this survey. Pilgrims were only allowed to stay three to four days in the valley of Muna according to the Hajj rituals. Each day was structured according to the duties that pilgrims had to perform. On the other hand, the researcher was restricted in not interviewing pilgrims when they were ready to sleep, eating, or just arriving at their tents. The appropriate time for the interview was therefore left to be decided during the Hajj.

The sampling size was determined by: sampling procedure, budget, and the time allowed for the survey. No maximum sampling size was determined in advance but the minimum was estimated at 30 pilgrims a day, (10 from each sampling frame if the researcher alone had to conduct the survey). Because of the nature of the Hajj and the fact it only lasts for a few days, the risk of resampling or the need for more sampling must be ruled out. The decision was made, therefore, to increase the size of the sample as much as possible. Assistance was needed and six overseas students were selected to help in conducting the survey. The resulting sample of pilgrims questioned during the Hajj of 1989 totalled 559 pilgrims.



IF THE TOTAL IS	THEN SELECT
1	1
2	1
3	2
4	2
5	3
6	3
7	4
8	4
9	5
10	5

Fig. 5.1: Sampling procedures developed for the field survey during the Hajj season of 1989.

4- SURVEY ORGANIZATION:

Early communication was made with the following local and academic authorities to facilitate the field survey:

(1) The establishment of pilgrims' guides of Arab pilgrims;

(2) The establishment of pilgrims' guides of Turkish, European, and American pilgrims;

(3) The establishment of pilgrims' guides of South East pilgrims;

(4) The Hajj Research Centre and College of Engineering and Islamic Architecture of the University of Umm Alqura at Makkah.

Offices of pilgrims' guides at the site of Muna valley were all informed well before the Hajj started and requested to assist by visiting their camps during the Hajj and interviewing their pilgrims. The Hajj research centre at Umm Alqura University had provided the researcher with students to help in conducting the survey. Six overseas students were selected on the bases of their language skills to communicate with selected subgroups, previous experience of conducting a survey during the Hajj, and their commitment towards this particular study.

A special training program lasting for one day was then prepared for the assistants. The program consisted of theoretical and practical sessions. Students at the theoretical session were briefed regarding the purpose and the objectives of the study. They were taught the sampling procedures and how to administer the questionnaire. In the practical session, students were divided in two groups to rehearse the sampling procedures. During the Hajj period each assistant was equipped with a set of blank questionnaires of different languages, a set of pencils to be used by pilgrims, inventory forms and a map of the site to be visited indicating the selected tents for sampling. All are packed for easy carrying and movement. Each assistant carried with him a photographed identification card to facilitate visiting the pilgrims' camps. For security reasons names and descriptions of the team were given in advance to the pilgrims' guide offices. For each of the three sampling frames, two students were assigned based on their language skills.

The researcher and assistants had to spend all the days of the Hajj in the Muna valley near to the pilgrims. Accommodation, food, and the workshop area had, therefore, been prepared in the site of Hajj research centre in the valley of Muna. The easiest and quickest way of transport was by foot. Daily meetings were conducted with assistants during the Hajj days to allow for close supervision and controlling the quality of the survey and preparing samples for the following day.

5- DATA COLLECTION:

The initial method of data collection involved distributing the questionnaire among the selected pilgrims and asking them to fill it in immediately and return it complete to the interviewer. Pilgrims in the sample were briefed with the objectives and the use of their answers. Each questionnaire was checked to ensure that answers were complete. This method of data collection had the important advantage of collecting a large sample in a short time with few interviewers. In general, pilgrims were very co-operative in answering the questionnaires. However, some pilgrims were illiterate and unable to fill in the questionnaires. An alternative data collection method was exercised by interviewing pilgrims face to face.

6- DATA MANAGEMENT:

Before the analysis data collected during the field survey of Hajj 1989 was processed in two stages. In the first stage a coding scheme was developed for each question. All respondents' answers were translated into numbers on coding sheets.

The second stage was to transfer numbers on the coding sheets into a computer's memory. This stage was done through the data processing department at the University of Newcastle- Upon- Tyne. Two typists entered the data into the computer. This was done as a precaution to reduce the possible error caused by transferring data.

This completed, data was ready for statistical analysis. The powerful SPSS-PC statistical package was used for the statistical analysis. The package is a powerful tool in performing different statistical analyses such as means, frequency, distribution, cross- tabulation and other statistical analyses. The results of the analysis will be discussed in detail in chapter (VI).

7- PRACTICAL DIFFICULTIES AND FURTHER SUGGESTIONS:

No matter how careful and accurate the preparation was for the field study, one cannot claim an ultimate form for the survey. Practical experience showed that more development work may have been needed and the following are some of the issues which would need to be considered when conducting a similar study:

(1) Some parameters could have been measured more efficiently using a simpler format. The location of respondents inside the tents, for example, could have been marked more easily and directly by including a grid map of tents on each questionnaire. A show card technique might be more useful for thermal evaluation than translating the questionnaire into different languages.

(2) In some camps pilgrims were very co-operative in giving answers to the researcher. In other camps, however, pilgrims expected help in return for their participation in answering the questionnaire. Pilgrims for instance, asked to solve their problems with the pilgrims' guide due to the low quality of service offered by his office. The researcher must be tolerant of these complaints and show sympathy, although it is out of his hands to offer immediate solutions.

(3) Women in the sample were easier to interview whilst in the presence of their husbands or male relatives. Thus, if women have to be included in the survey, a

special sampling procedure would have to be considered. It may be a good alternative to include one or more female interviewers to interview women in their tents.

(4) The time of the survey started at 10.00 hrs and continued until 18.00 hrs. The hottest hours of the day were from 12.00 hrs to 16.00 hrs. Pilgrims during this period were found either sleeping or out of their tents to perform Hajj rituals. In both cases it was difficult to conduct the survey and it was only possible to interview a small number of people.

(5) Embarrassing questions should be avoided. Some pilgrims in this survey were embarrassed to answer questions concerning the quantity of liquid disposal through urine and sweat secretion.

(6) Ambiguous words should not be used. Some Arab pilgrims, for example, found it difficult to elaborate on the word "privacy." "Privacy" to the Arab family may not only mean visual protection from others but may also include protection from noise. The same word may have different meanings for Arab men and Arab women. For example, it may mean protection from mixing with the opposite sex. The risk of different meanings exist when using the approach of different languages. To avoid this risk, the group of pilgrims must have a common language, alternatively, questions can be presented in form of symbols.

(7) Questions which involve technical medical terminology that may be difficult to the average simple pilgrim should also be avoided.

(8) It was difficult for some pilgrims to differentiate between subjective terms used in the scale for thermal evaluation. An example of this is the difference between "very warm" and "warm" or "very hot" and "hot."

(9) The evaluation part of the questionnaire was structured to be answered in two columns. The first column was to instantly evaluate thermal conditions inside the

pilgrimage tents, i.e., when the questionnaire was being completed. The second column was to evaluate the thermal conditions at 22.00 hrs, time for going to sleep. Pilgrims were able to answer the first column easily. However, not many pilgrims were able to recall their thermal experience during the night, when asked the next day. Few pilgrims, therefore, responded to the second column.

END- NOTES

1- C. Leithead and A. Lind, Heat stress and heat disorders. London: Cassell, 1964., p.72.

2- R. Brief and R. Confer, " Environmental measurements and engineering assessment of heat data," in Symposium on standards of occupational exposures to hot environments, Pittsburgh: University of Pittsburgh, 1973, p.236.

3- ASHRAE, " Physiological principles, comfort and health," Fundamentals handbook. New York: American Society of heating, Refrigerating and Air conditioning Engineers, 1985, p. 8.18.

4- B. Bown, J. Krosinick, and H. Weisberg, An introduction to survey research and data analysis, London: Scott, Foresman and Company, 1989., p.35.

5- Ibid., p.51.

CHAPTER VI

ASSESSMENT OF THE THERMAL DISCOMFORT INSIDE THE PILGRIMAGE TENTS

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CHAPTER VI

ASSESSMENT OF THE THERMAL DISCOMFORT INSIDE THE PILGRIMAGE TENTS

1-INTRODUCTION:

Pilgrims from Europe, Arab countries and south east Asia were interviewed during their stay in tents in the Muna valley at Makkah. The purpose of the interview was to evaluate thermal and ventilation conditions inside the pilgrimage tents. A special form for the interview was prepared and climatic measurements were taken inside and outside of the pilgrims' tents. Both the interview method and the process of measuring climatic conditions are discussed in chapters III and V. The investigation of the present study concerns:

(A) Making an assessment of thermal discomfort inside the Arab, European, and south east Asian tents. The purpose is to determine the critical periods relating to pilgrim's discomfort.

(B) Studying which of the personal factors such as age, sex, climatic background, health, physical state and acclimatisation have a dominant influence on thermal discomfort.

(C) Investigating the relationship of climatic factors such as air temperature, globe temperature, relative humidity and others with thermal discomfort. The purpose is to construct a model that can predict thermal discomfort from a set of climatic factors.

This chapter starts with a descriptive analysis of the collected data. The discussion then reveals methods and statistical procedures used for analysis. Two basic issues are then examined. First, to identify significant patterns of thermal, ventilation and perspiration discomfort sensations. Second, to explain any variations of thermal discomfort, by identifying the most important variables which effectively influence thermal discomfort of pilgrims. An attempt is also made to construct a model that describes the relationship between thermal discomfort and the important variables identified earlier. The implication of the survey for design strategies to improve the thermal environment of the tents concludes the discussion of this chapter.

2- DATA COLLECTED:

The investigations were made on pilgrims from "hot", "cold", and "tropical" sub-climates while attending their regular stay inside the pilgrimage tents. The resulting sample of pilgrims questioned during the Hajj of 1989 totalled 559.

Details of each climatic subgroup are summarised in table 6.1. On the first day of the survey, the "tropical" camp was deserted. Pilgrims of this camp did not have, according to their school of thought, *Shaffiee*, to stay in the Muna valley during the first day. Concentration, therefore, was made only on the Arab and European camps: the reason why a greater number of pilgrims were interviewed during the first day compared with other days. On the second day no survey was conducted in any of the three camps as all pilgrims had to leave the Muna valley to the site Arafat. The number of pilgrims interviewed during the first day of the survey was the largest and represented 31% of the total size of the sample. The reason may well be that pilgrims on the first day were not obliged to practice Hajj rituals which meant that pilgrims were more readily available in their tents than on any of the other days. The number of pilgrims interviewed on each of the other three days was fairly evenly distributed at 20%, 24% and 25% respectively. Pilgrims interviewed from Arab camps represented 40% of the sample and from the European camps 43%. Least represented was the tropical camp which consisted of 17% of the sample.

Data from this survey can be classified into three categories. First is the data concerning personal factors such as age, sex, health conditions, weight, physical fitness, last performance of the pilgrimage, activities, and clothing. Second is the climate data measured during the survey inside and outside the tents and includes air temperature, globe temperature, relative humidity, and wind speed. This category also included derived measurements such as wet temperature, wet bulb globe temperature (wbgt), vapour pressure, and enthalpy. Third is the data concerning thermal, ventilation, and perspiration sensations related to internal conditions of the pilgrimage tents.

2.1- PERSONAL DATA:

The age- sex distribution in figure 6.1 illustrates the percentage of each age group in the total population sampled. Pilgrims of the collected sample were grouped into six age groups: "under 20 years old", "21-30 years old", "31-40 years old", "41-50 years old", "51-60 years old" and "above 60 years old." Examination of the sequence of the age columns reveals that it follows a similar pattern in both sexes. The age group "under 20 years old" is narrow, the columns then get taller until it reaches the largest age distribution. The largest age distribution among men is that of the "31-40 years" old representing 22 % of the survey. The largest age distribution among women is that of the "21-30 years" group which represents 6% of the survey. As the population ages, the columns on the graph get progressively shorter at each higher level. The collected sample consisted of 18 % female and 82 % male pilgrims. The sex proportion of the target population during the Hajj of 1989 was revealed as 30% female and 70% male.[1] No detailed statistics were released for Hajj of 1989 to compare the age- sex distribution of this study with that of the true populations during the Hajj. However, the above examination confirms the trend observed in 1983 that the largest age group performing the Hajj was not elderly people but middle aged pilgrims from 26 to 35 years old.[2]

The vast majority, 95 %, of pilgrims in the survey from both sexes had either normal or good health. Only 5 % of the male pilgrims in the survey had bad health.

More than half of the pilgrims included in the survey, 65 %, were of "normal weight." The "underweight" category represented 22 %, most of whom were female. "Overweight" pilgrims represented 11% of the survey, of whom male pilgrims represented the majority.

The physical fitness assessment of about half the pilgrims in the sample was "very fit", 42% were "normal", and 8% were physically "unfit." Most of pilgrims in the sample had performed the pilgrimage at least once before 1989. Over all, pilgrims who had visited Makkah before represented 79% of the sample while 21% were visiting Makkah for the first time.

The major activities practised by both sexes inside each of the three camps were similar. Activities were light involving minimum metabolic heat range from 100-150 watts such as sitting, chatting, or sleeping. Another common element among members of the sample was clothing. Male pilgrims dressed in white in a two piece outfit while women were fully dressed in a light material. The thermal resistance of the pilgrimage dress is estimated to range from 0.50- 0.56 clo.

2.2- CLIMATE DATA:

During the five days of the pilgrims' stay in the tents, air temperature, radiant effects, and relative humidity were measured at intervals for both outside and inside the pilgrimage tents. Figure 6.2 presents the average of the five day's measurements for Arab and European pilgrims. Not enough measurements were taken for Asian camps, the reason why Asian group is not indicated in the figure. Figure 6.2 also gives a summary description of the range and the average of each measurement. More detail discussion of the climatic data is given in chapter III.

2.3- SENSATIONS' DATA:

Figure 6.3 illustrates the distribution of thermal scores for the three groups of pilgrims: Arab, European, and south east Asians. The calculated normal distribution is superimposed on the graph. Also presented is a summary statistics for each of the groups. The scores of thermal sensations vary from "comfort" to "heat exhaustion" and their distribution is close to normal. The mean of Arab's thermal sensation is 4.21 (with a standard deviation of 1.44) and the mode is 'hot'. The rating of European's thermal sensation increases to 'very hot' and the mean is 4.33 (with a standard deviation of 1.26). The mean of thermal sensation of south east Asian is 3.69 (with a standard deviation of 1.21) and the mode is "hot".

Figure 6.4 illustrates the distribution of ventilation sensations for the three groups as well as a statistical summary for each. The score of ventilation ranges from "poor" to "good." The sample of European pilgrims indicated in the figure is close to normal distribution. The rating of European pilgrims concerning ventilation is 'satisfaction'. The samples of pilgrims from Arab and south east Asia are negatively skewed with a general rating of "poor ventilation".

A similar distribution of perspiration sensation is observed for Arab, south east Asian, and European pilgrims. Figure 6.5 indicates that all groups are negatively skewed. The rating of pilgrims in all groups is at the maximum rate of perspiration "very much sweating."

TABLE 6.1

Summary of the sample size of the survey conducted during the Hajj season of 1989.

	COLD CAMP		HOT CAMP		TROPICAL CAMP		TOTAL	
	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN
DAY 1	97	17	50	12	-	-	176	29
DAY 2	-	-	-	-	-	-	-	-
DAY 3	27	2	44	8	22	5	108	15
DAY 4	32	4	27	6	46	15	130	25
DAY 5	39	2	36	7	29	22	135	31
TOTAL	195	25	204	33	97	42	549	100
	220 (40%)		237 (43%)		139 (17%)		559	

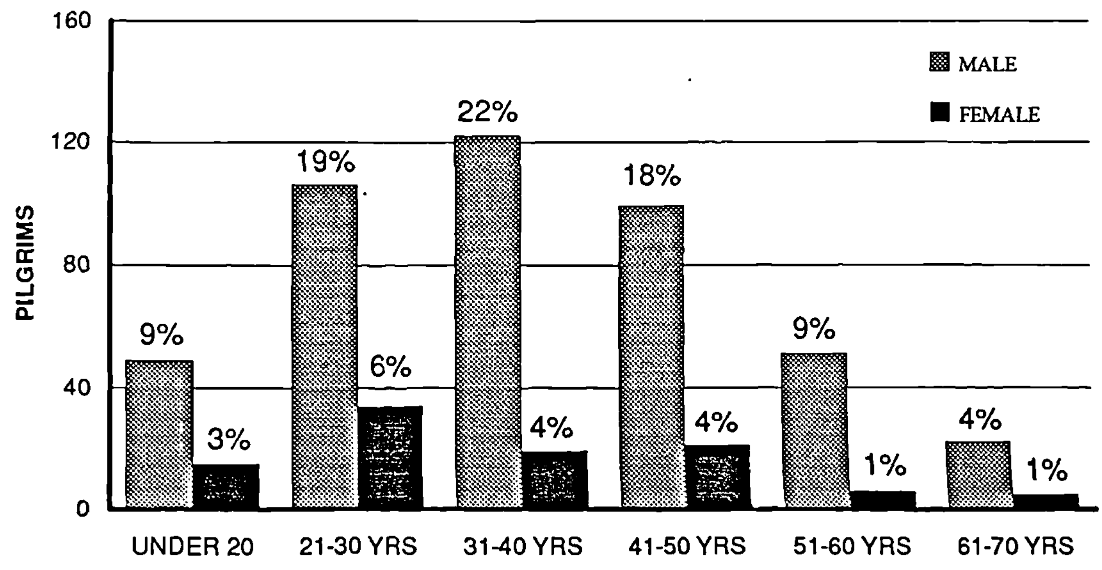
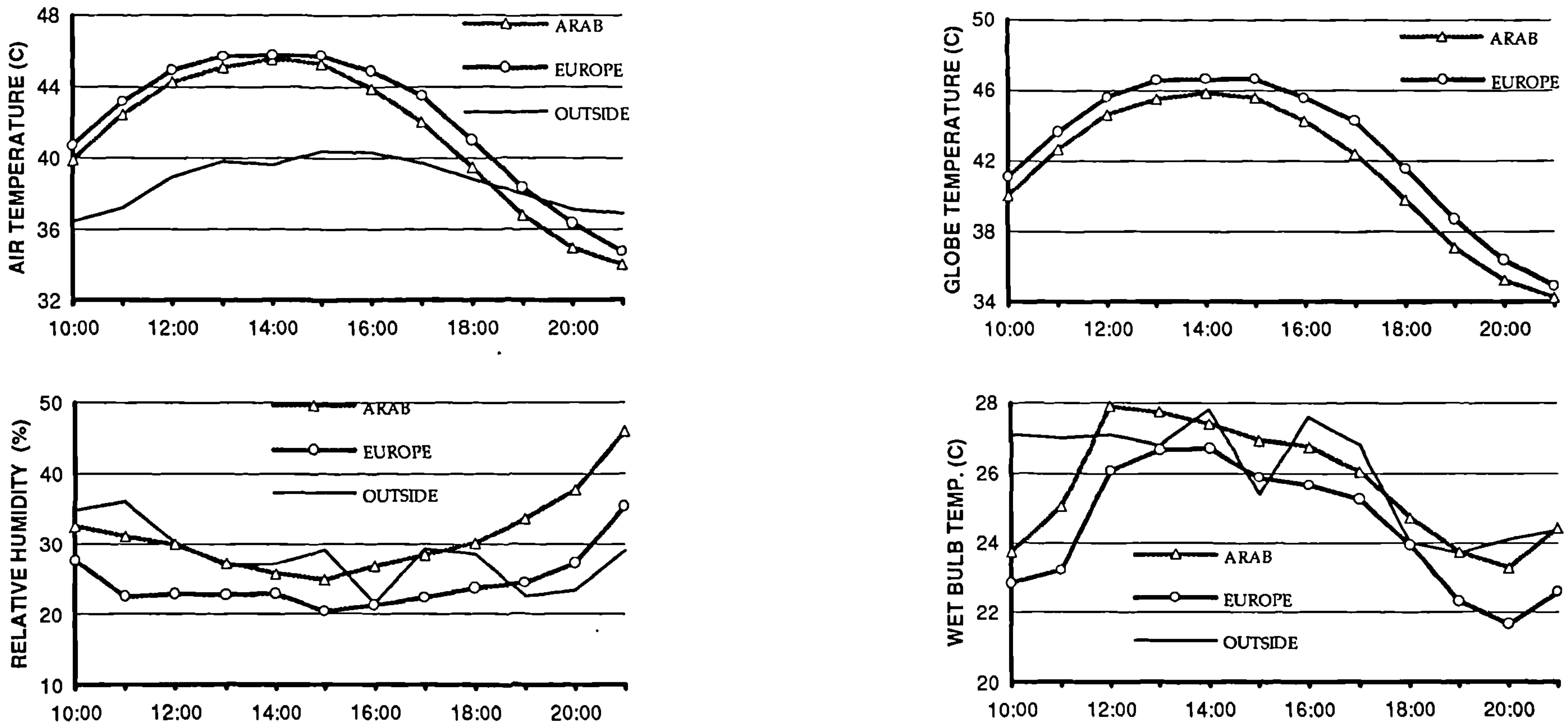
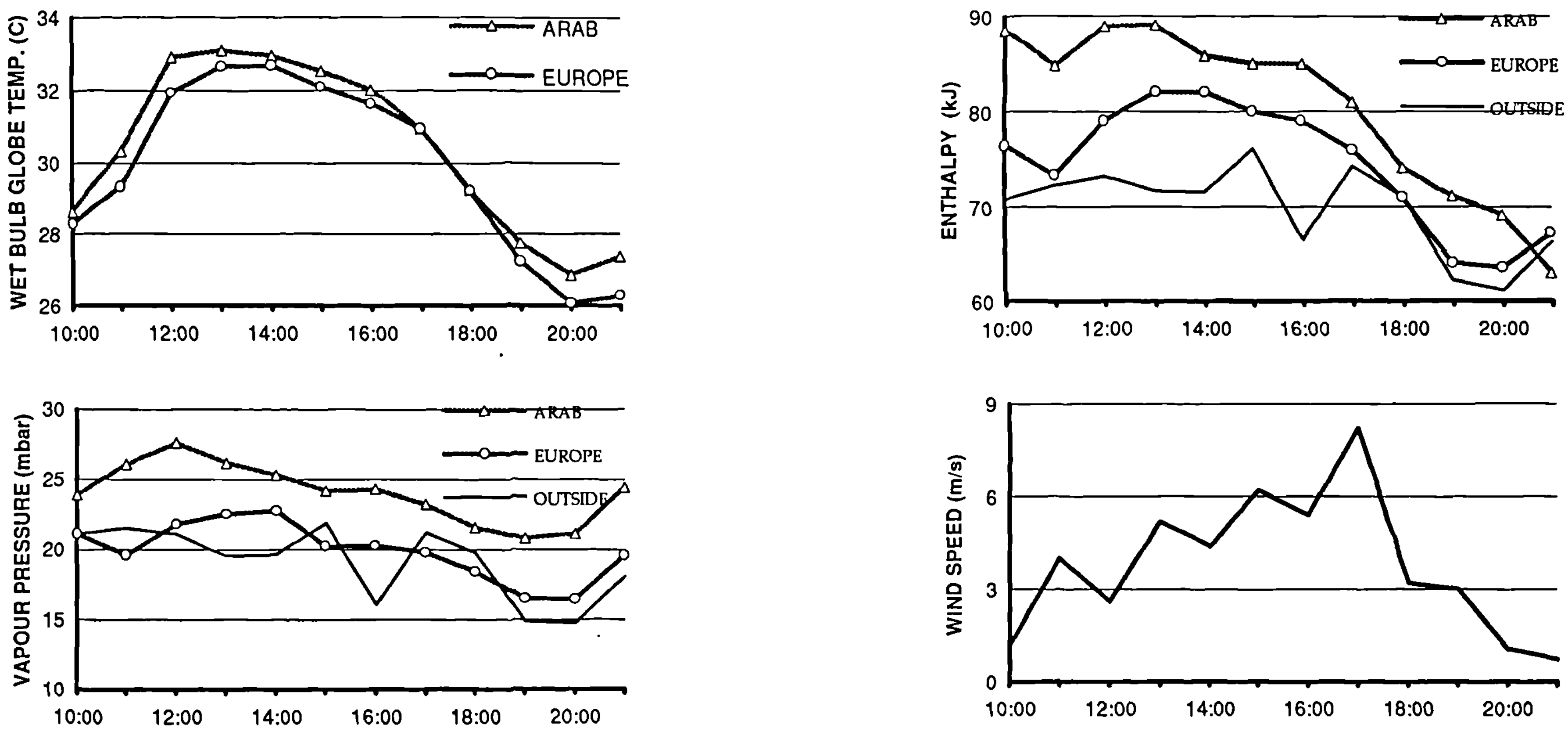


Fig. 6.1: *Age- sex distribution for the total sample.*



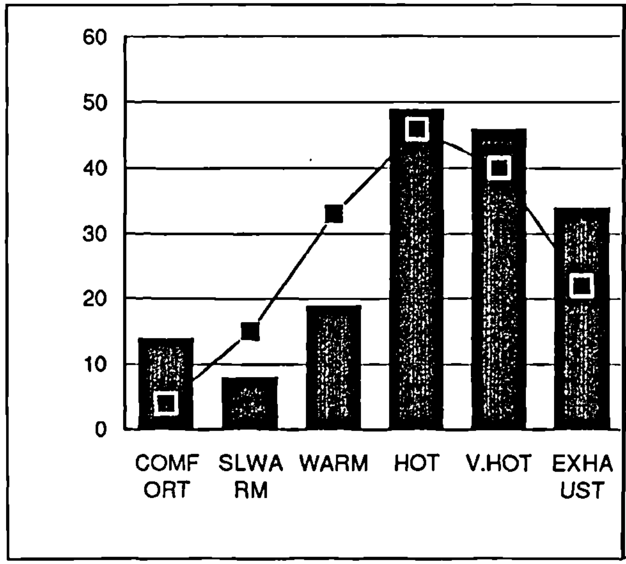
	Air Temperature			Relative Humidity			Globe Temperature			Wet Bulb Temperature		
	MIN	MAX	AVR.	MIN	MAX	AVR.	MIN	MAX	AVR.	MIN.	MAX.	AVR.
ARAB	31.88	45.51	37.16	24.89	57.74	39.26	32.03	45.83	37.38	21.71	27.89	24.47
EUROPE	32.25	45.73	37.97	20.34	44.83	31.25	32.29	46.63	38.09	20.74	26.70	23.05
OUTSID	33.86	40.38	37.18	21.47	38.50	29.13	-	-	-	23.38	27.80	25.09

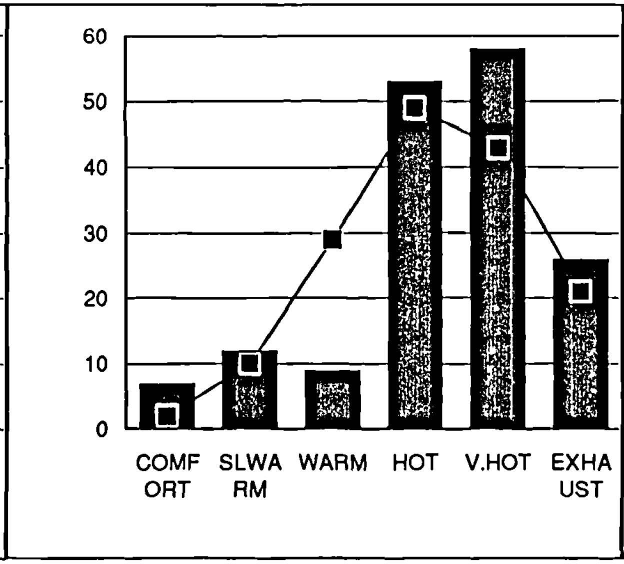
Fig. 6.2.A: Climate graphs for measurements conducted during the Hajj period of 1989.

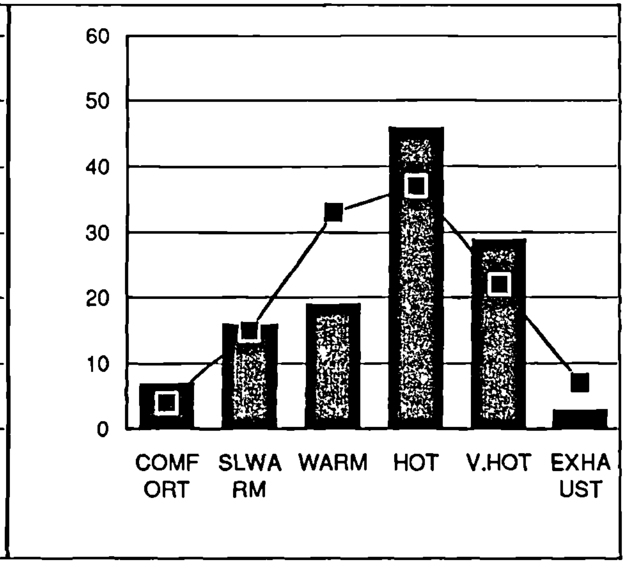


	Wet Bulb Globe Temperature			Enthalpy			Vapour Pressure			Wind Speed		
	MIN	MAX	AVR.	MIN	MAX	AVR.	MIN	MAX	AVR.	MIN.	MAX.	AVR.
ARAB	25.37	33.07	28.35	63.00	89.00	80.45	20.80	27.58	24.06	-	-	-
EUROPE	24.71	32.67	27.56	63.50	82.04	74.48	16.47	22.75	19.91	-	-	-
OUTSID	-	-	-	61.09	76.12	69.77	14.76	21.86	19.12	0.25	8.20	2.54

Fig. 6.2.B: *Climate graphs for measurements conducted during the Hajj period of 1989.*



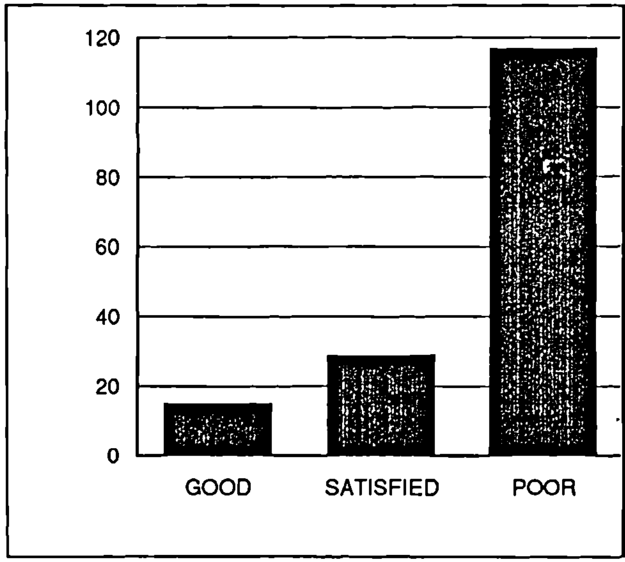


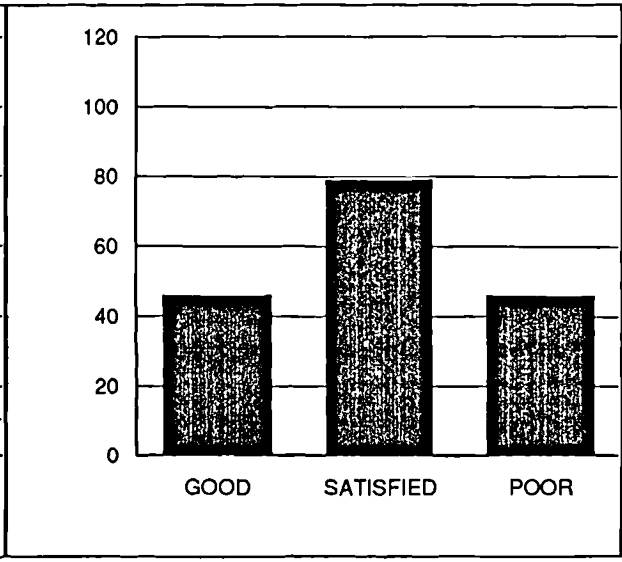


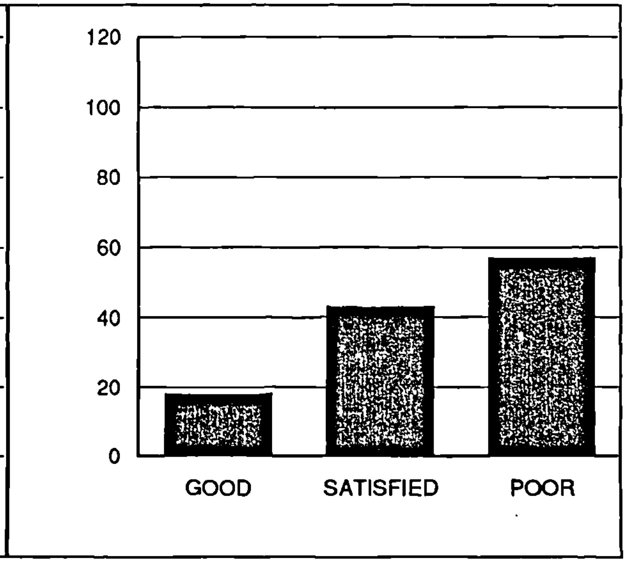
Arab pilgrims | European pilgrims | South East Asian pilgrims

Arab pilgrims				European pilgrims				South East Asian pilgrims			
Mean	4.218	Range	5.00	Mean	4.339	Range	5.00	Mean	3.692	Range	5.00
Mode	4.00	Median	4.00	Mode	5.00	Median	5.00	Mode	4.00	Median	4.00
Std. Err.	0.111	Variance	2.077	Std. Err.	0.099	Variance	1.604	Std. Err.	0.111	Variance	1.476
Std dev.	1.441	Skewness	-0.74	Std dev.	1.266	Skewness	-0.91	Std dev.	1.215	Skewness	-0.55

Fig. 6.3: Distribution of thermal sensation for pilgrims of Arab, European, and south east Asian camps.

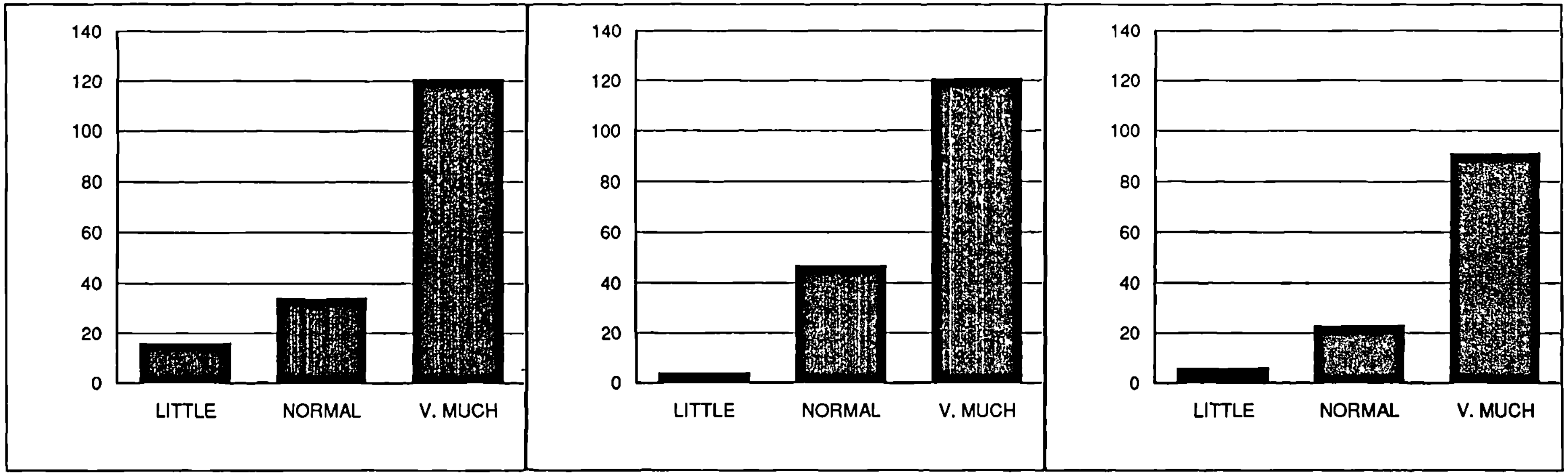






Arab pilgrims				European pilgrims				South East Asian pilgrims			
Mean	2.634	Range	2.00	Mean	2.00	Range	2.00	Mean	2.292	Range	2.00
Mode	3.00	Median	3.00	Mode	2.00	Median	2.00	Mode	3.00	Median	2.00
Std. Err.	0.051	Variance	0.421	Std. Err.	0.056	Variance	0.541	Std. Err.	0.071	Variance	0.612
Std dev.	0.649	Skewness	-1.55	Std dev.	0.736	Skewness	0.000	Std dev.	0.782	Skewness	-0.78

Fig. 6.4: *Distribution of ventilation sensation for pilgrims of Arab, European, and south east Asian camps.*



Arab pilgrims				European pilgrims				South East Asian pilgrims			
Mean	2.614	Range	2.00	Mean	2.680	Range	2.00	Mean	2.708	Range	2.00
Mode	3.00	Median	3.00	Mode	3.00	Median	3.00	Mode	3.00	Median	3.00
Std. Err.	0.050	Variance	0.427	Std. Err.	0.039	Variance	0.266	Std. Err.	0.051	Variance	0.309
Std dev.	0.653	Skewness	-1.45	Std dev.	0.515	Skewness	-1.28	Std dev.	0.556	Skewness	-1.78

Fig. 6.5: *Distribution of perspiration sensation for pilgrims of Arab, European, and south east Asian camps.*

3-METHODS OF ANALYSIS:

In all 559 records collected during the survey, variables were divided into three groups. The first group defined characteristic variables which described pilgrims' ethnic background, age, sex, weight, physical fitness, and experience with the hot climate of Makkah. The second group of variables were those of climate which described all direct and derived physical conditions measured during the survey. The third group included all subjective sensations of pilgrims, i.e., thermal, ventilation, and perspiration. Figure 6.6 summarises the analysis procedures of this study.

The first strategy of analysis was to examine the inter-relationship between subjective sensations and characteristic variables. The aim of the examination was to test homogeneity and differences in subjective sensations due to various characteristics of the groups. The statistical procedure used to test the significance of variations in subjective sensations was the analysis of variance, Anova. The Anova test is a technique for examining differences among three or more independent means.

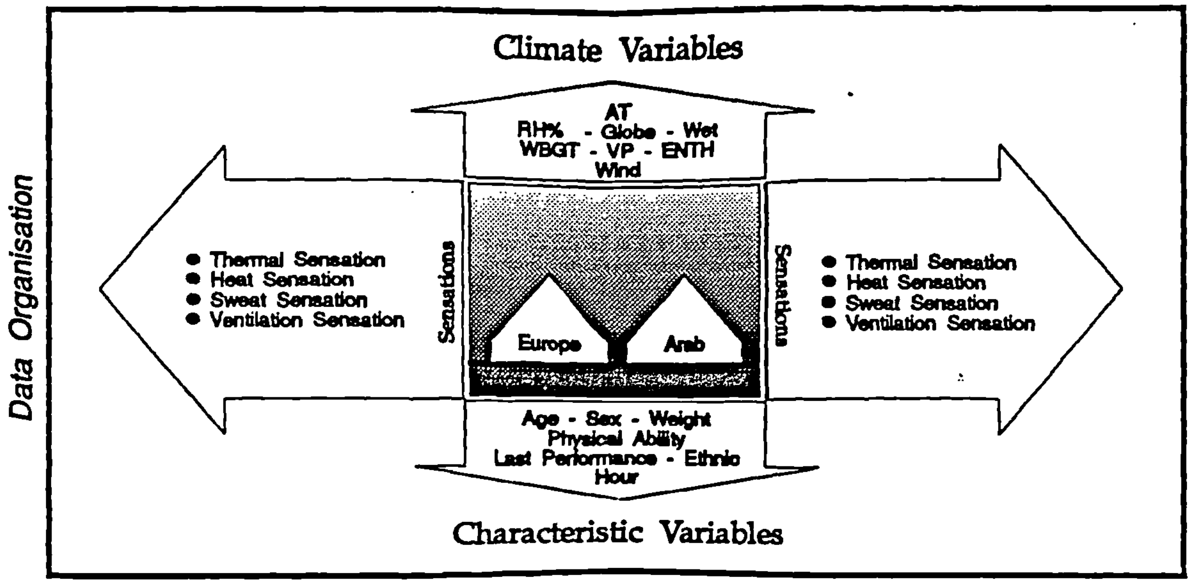
Having decided which significant patterns to consider; the second step was to find various possible explanations for such variations. The best predictors for such variations lay among physical measurements grouped as climatic variables. Multiple regression procedures were needed here to describe the effect of several predictors with significant sensation variables. The significant level chosen for all analysis of this study was .05 level.

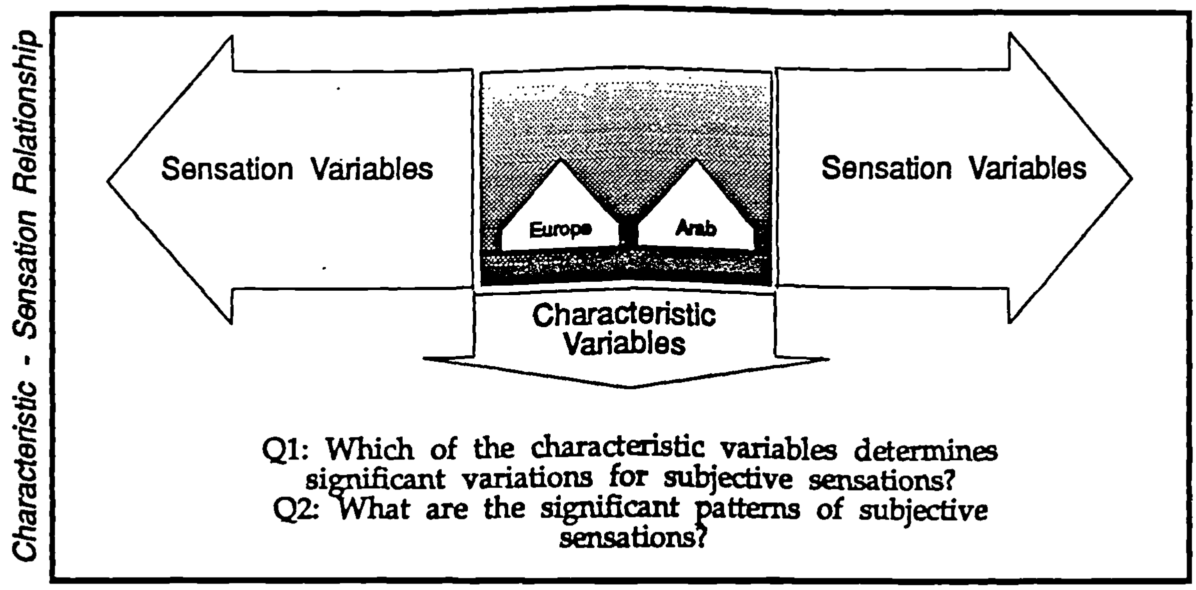
The data collected for Arab and Europe subgroups were analysed while the south east Asian group was excluded. This decision was taken because the Arab and Europe pilgrims formed the largest portion of the survey (84%). Moreover, not enough physical measurement were recorded in the South Asian camps to explain their subjective sensations.

4- SIGNIFICANT VARIATIONS OF SENSATION VARIABLES:

The purpose of the analysis of this section is to identify which of the characteristic variables distinguish significant variations in thermal, ventilation, and perspiration sensations. To examine the effect of many variables it became necessary to use the ANOVA statistical procedure. Results of the ANOVA test for Arab and Europeans are presented in table 6.2. It emerges that different characteristic variables are significant in terms of their main effect on subjective sensations. For example, thermal and ventilation sensation for Arab pilgrims vary significantly at different times of the day, while perspiration sensation of the same group shows no significant variations. European's thermal sensation, on the other hand, is significant due to sex, physical fitness and weight of pilgrims, while perspiration sensation varies significantly due to the weight. Variation of ventilation sensation of European pilgrims is not significant for any of the tested characteristics variables.

However, before making any valid conclusions, one should consider the interaction between characteristic variables which could also affect subjective sensations. A higher order of interaction was suppressed in table 6.2 because of empty cells. Empty cells resulted due to the small number of cases in some categories. To begin looking at the interaction that may exist between variables, empty cells had to be eliminated. To achieve the interaction two possible strategies may be followed. The first is to allow the minimum fluctuation in the sample size to achieve a meaningful interaction between variables. The second maintains the sample at its original size but tests each pair of variables individually rather than collectively. The strategy followed in this research is the latter. Discussion of the significant characteristic variables and their influence on each of the subjective sensations continues under the following sub-headings.





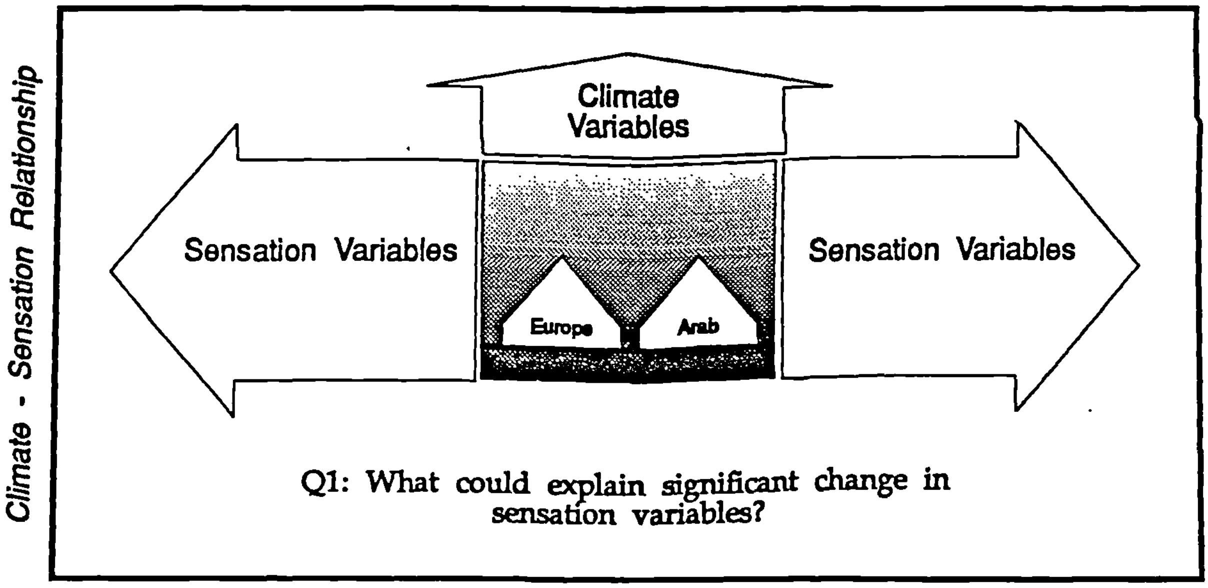


Fig. 6.6: *Summary of the analysis procedures of the survey conducted during Hajj period of 1989.*

TABLE 6.2:
ANOVA results for Arab and European pilgrims

		ARAB PILGRIMS					EUROPEAN PILGRIMS				
	Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F	Sum of Squares	DF	Mean Square	F	Significant of F
THERMAL SENSATION	Main effect	101.137	20	5.057	3.016	**0.000**	40.847	20	2.042	1.204	**0.259**
	Sex	4.632	1	4.632	2.763	**0.099**	8.694	1	8.694	5.123	**0.025**
	Physical fitness	6.573	2	3.287	1.960	**0.144**	11.671	2	5.835	3.439	**0.035**
	Last performance	0.344	1	0.344	0.205	**0.651**	1.780	1	1.780	1.049	**0.307**
	Weight	4.410	2	2.205	1.315	**0.272**	9.283	2	4.642	2.735	**0.068**
	Time (Hour)	73.969	11	6.724	4.011	**0.000**	11.430	11	1.039	0.612	**0.816**
	Age	6.387	3	2.129	1.270	**0.287**	3.916	3	1.305	0.769	**0.513**
	Explained	101.137	20	5.057	3.016	**0.000**	40.847	20	2.042	1.204	**0.259**
	Residual	249.810	149	1.677			249.439	147	1.697		
	Total	350.947	169	2.077			290.286	167	1.738		
VENTILATION SENSATION	Main effect	14.662	19	0.772	2.064	**0.009**	11.800	19	0.621	1.169	**0.291**
	Physical fitness	0.728	2	0.364	0.974	**0.380**	1.218	2	0.609	1.146	**0.321**
	Last performance	0.685	1	0.685	1.832	**0.178**	0.589	1	0.589	1.108	**0.294**
	Weight	1.143	2	0.571	1.529	**0.220**	0.275	2	0.137	0.259	**0.772**
	Time (Hour)	12.314	11	1.119	2.994	**0.001**	7.774	11	0.707	1.331	**0.213**
	Age	0.811	3	0.270	0.723	**0.540**	2.368	3	0.789	1.486	**0.221**
	Explained	14.662	19	0.772	2.064	**0.009**	11.800	19	0.621	1.169	**0.291**
	Residual	52.717	141	0.374			80.200	151	0.531		
	Total	67.379	160	0.421			92.000	170	0.541		
PERSPIRATION SENSATION	Main effect	12.487	20	0.624	1.559	**0.070**	6.661	20	0.333	1.298	**0.189**
	Sex	0.947	1	0.947	2.365	**0.126**	0.850	1	0.850	3.314	**0.071**
	Physical fitness	0.154	2	0.077	0.193	**0.825**	0.247	2	0.124	0.482	**0.619**
	Last performance	0.843	1	0.843	2.105	**0.149**	0.113	1	0.113	0.440	**0.508**
	Weight	0.080	2	0.040	0.100	**0.905**	1.548	2	0.774	3.015	**0.052**
	Time (Hour)	6.305	11	0.573	1.432	**0.164**	3.053	11	0.278	1.082	**0.380**
	Age	1.113	3	0.371	0.927	**0.429**	0.968	3	0.323	1.257	**0.291**
	Explained	12.484	20	0.624	1.559	**0.070**	6.661	20	0.333	1.298	**0.189**
	Residual	60.042	150	0.400			38.752	151	0.257		
	Total	72.526	170	0.427			45.413	171	0.266		

4.1- THERMAL SENSATION:

Results of the ANOVA test applied to the Arab group with two ways of interaction are shown in table 6.3. Thermal sensations vary significantly due to the sex of pilgrims and the time of day. The thermal sensation of both Arab male and female is plotted against the hours of the day in figure 6.7. The table of analysis of variance is attached to the figure. There is statistical evidence that Arab females are less tolerant to heat than Arab males during the early and late hours of the day. Arab females however are more tolerant during the evening from 15.00 hrs to 18.00 hrs. The interaction of sex and time of day appears to be significant. However, the number of females was small compared with male pilgrims (26 females compared with 144 males) and the females' thermal sensation is widely spread between the two ends of the thermal scale. It seems sensible therefore to separate out female pilgrims and focus on variations of the males' thermal sensation.

Results of the ANOVA test applied to the Arab male are presented in table 6.4. Variations in thermal sensation were not significant due to age, weight, or time of the last performance of pilgrimage. On the contrary, variations were significant due to changes of time and perceived physical fitness of pilgrims. Figure 6.8 indicates thermal sensations of both physical fitness categorise together with the ANOVA table. It seems from the graph that "very fit" pilgrims tolerated more heat than "normal fit" pilgrims. This observation is confirmed by the ANOVA test which showed no significant interaction between physical fitness and hour variables. Thermal sensation for each physical fitness category varies significantly at different hours of the day.

Table 6.5 indicates significant results of the ANOVA test applied to the European pilgrims. Two variables emerged as being significant: namely sex and physical fitness of pilgrims. Other variables such as weight, last performance of the pilgrimage, age and hour of the day were not significant. The thermal sensation of both male and female is plotted in figure 6.9 together with results of the ANOVA test. Statistically, the results show significant differences between thermal sensations of European male and female pilgrims. The European female is less tolerant than the male during the hours 11.00 to 17.00 hrs. However, as was the case for Arab females, the number of European females was very small; 19 compared with 146 male. Therefore female pilgrims were excluded from the sample and concentration was made only on males.

Table 6.6 presents results of the ANOVA test applied to male European pilgrims. As in the case of the Arab pilgrims, physically "very fit" pilgrims responded significantly differently from those classified as "normally fit." Figure 6.10 indicates the patterns of thermal sensation of both physical fitness categories together with results of the ANOVA test. Physically "normal fit" pilgrims felt more discomfort in the morning and in the evening from 17.00 hrs to 19.00 hrs. Physically "very fit" pilgrims felt more discomfort from noon until 16.00 hrs. Unlike the Arab pilgrims, the interaction between time and physical fitness is significant. This means that observed variations in both physical categories are due to the dual effect of physical fitness of pilgrims and time of day. Another difference from the Arab pilgrims is that the variation of thermal sensation in relation with the time scale is not significant. Europeans are observed to be less sensitive to variations of heat during the day than Arab pilgrims. The reason may be that Arabs are more acclimatised to a hot climate which enables them to differentiate between thermal conditions at different periods of the day (i.e. before noon, afternoon. etc.).

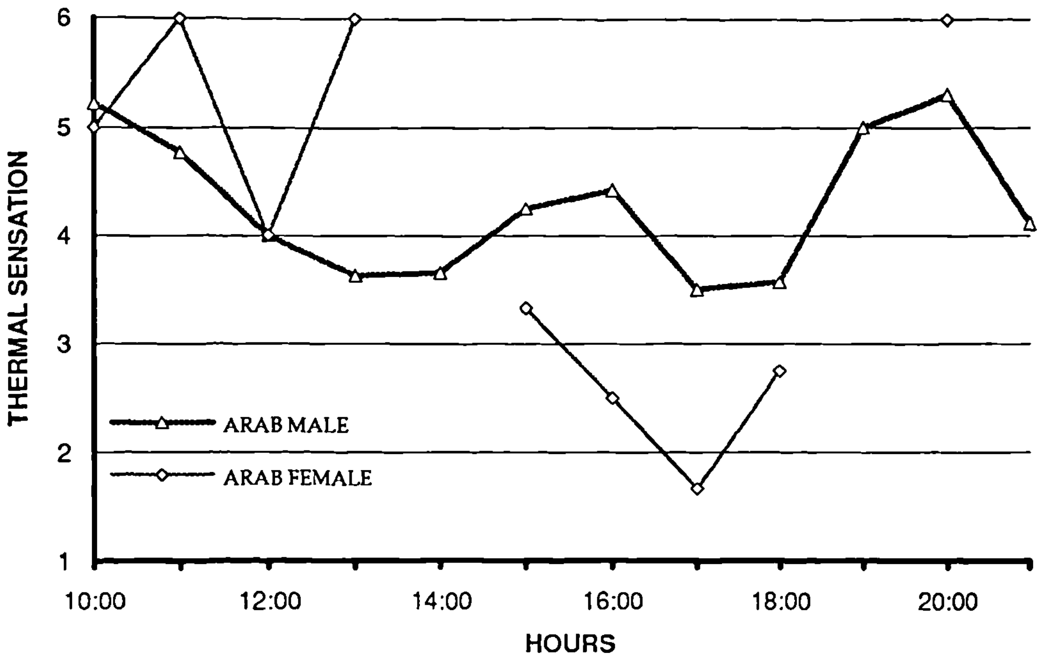
The question that must now be asked is: would thermal sensation of physically "very fit" and "normally fit" Arabs be significantly different from Europeans in corresponding categories? To answer this question the ANOVA procedure was applied to test data of male pilgrims in both groups. Results presented in table 6.7 confirm that variation in thermal sensation due to physical categories of the Arab group is not significantly different from the European group.

TABLE 6.3:
ANOVA results for Arab pilgrims at main and two way interaction levels.

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
Main effect	101.137	20	5.057	3.016	**0.000**
Sex	4.632	1	4.632	2.763	**0.099**
Physical fitness	6.573	2	3.287	1.960	**0.144**
Last performance	0.344	1	0.344	0.205	**0.651**
Weight	4.410	2	2.205	1.315	**0.272**
Time (Hour)	73.969	11	6.724	4.011	**0.000**
Age	6.387	3	2.129	1.270	**0.287**
Explained	101.137	20	5.057	3.016	**0.000**
Residual	249.810	149	1.677		
Total	350.947	169	2.077		
2-Way interaction					
Sex- Physical fitness	2.188	2	1.094	0.538	**0.585**
Sex- Last performance	9.408	1	9.408	4.816	**0.030**
Sex-Weight	3.150	2	1.575	0.768	**0.466**
Sex-Time (Hour)	26.481	8	3.310	2.054	**0.044**
Sex- Age	5.159	3	1.720	0.844	**0.471**
Physical- Last performance	1.381	2	0.690	0.336	**0.715**
Physical- Weight	13.727	4	3.432	1.670	**0.160**
Physical- Time (Hour)	9.350	11	0.850	0.471	**0.919**
Physical - Age	6.112	5	1.222	0.585	**0.711**
Last Performance- Time (Hour)	3.505	10	0.351	0.193	**0.997**
Last performance-Age	0.861	3	0.287	0.139	**0.937**
Weight-Time(Hour)	50.131	20	2.507	1.563	**0.071**
Weight- Age	11.435	5	2.287	1.100	**0.363**
Time (Hour)- Age	40.415	22	1.837	1.082	**0.374**

TABLE 6.4:
ANOVA results for Arab male pilgrims at main and two way interaction levels.

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
Main effect	65.116	19	3.427	2.102	**0.008**
Physical fitness	7.994	2	3.997	2.451	**0.090**
Last performance	0.000	1	0.000	0.000	**0.987**
Weight	3.703	2	1.852	1.136	**0.325**
Time (Hour)	53.035	11	4.821	2.957	**0.002**
Age	4.582	3	1.527	0.937	**0.425**
Explained	65.116	19	3.427	2.102	**0.008**
Residual	202.190	124	1.631		
Total	267.306	143	1.869		
2-Way interaction					
Physical- Last performance	2.884	2	1.442	0.777	**0.462**
Physical- Weight	9.734	4	2.434	1.316	**0.267**
Physical- Time (Hour)	10.497	11	0.954	0.566	**0.853**
Physical - Age	2.359	4	0.590	0.311	**0.870**
Last performance- Weight	2.012	2	1.006	0.529	**0.591**
Last Performance- Time (Hour)	5.481	10	0.548	0.314	**0.976**
Last performance-Age	0.194	3	0.065	0.034	**0.992**
Weight-Time(Hour)	44.658	20	2.233	1.443	**0.118**
Weight- Age	6.087	5	1.217	0.629	**0.678**
Time (Hour)- Age	35.235	21	1.678	1.013	**0.455**



1=COMFORT 2=WARM 3=VERY WARM 4=HOT 5=VERY HOT

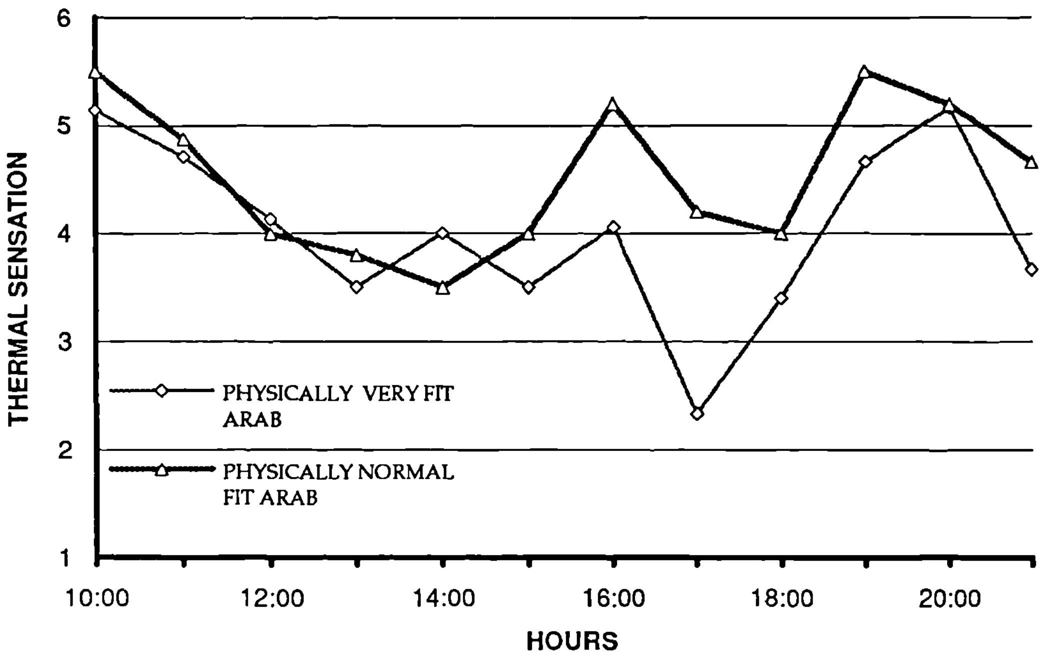
6=EXHAUSTION

* * * ANALYSIS OF VARIANCE* * *

Thermal sensation by sex and hour

Source of variations	Sum of squares	DF	Mean of squares	F	Signif.
<u>MAIN EFFECT</u>	84.369	12	7.031	4.363	.000
SEX	5.057	1	5.057	3.138	.079
HOUR	74.612	11	6.783	4.209	.000
<u>2-WAY INTERACTION</u>	26.481	8	3.310	2.054	.044
SEX-HOUR	26.481	8	3.310	2.054	.044
EXPLAINED	110.850	20	5.543	3.440	.000
RESIDUAL	240.097	169	1.611		
TOTAL	350.947	169	2.077		

Fig. 6.7: Significant thermal sensation for male and female Arab pilgrims.



1=COMFORT 2=WARM 3=VERY WARM 4=HOT 5=VERY HOT

6=EXHAUSTION

* * * ANALYSIS OF VARIANCE* * *

Thermal sensation by physical and hour

Source of variations	Sum of squares	DF	Mean of squares	F	Signif.
<u>MAIN EFFECT</u>	52.883	12	4.407	2.613	.000
PHYSICAL	8.171	1	8.171	4.846	.030
HOUR	47.539	11	4.322	2.563	.000
<u>2-WAY INTERACTION</u>	10.497	11	0.954	0.566	.855
PHYSICAL-HOUR	10.497	11	0.954	0.566	.855
EXPLAINED	63.379	23	2.756	1.634	.040
RESIDUAL	188.856	112	1.686		
TOTAL	252	135	1.868		

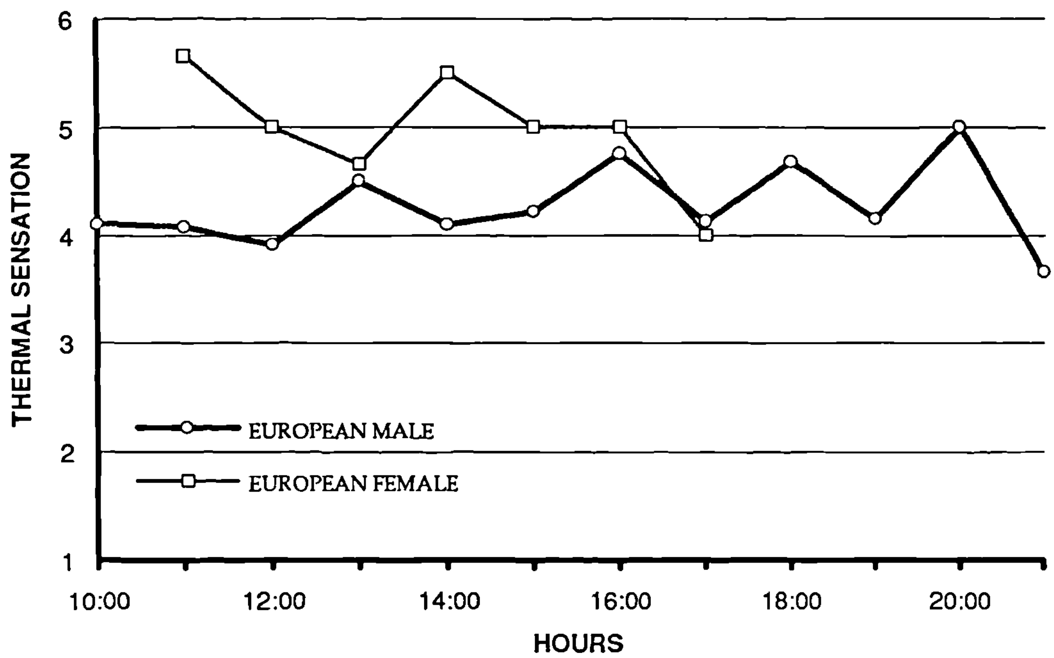
Fig. 6.8: Significant thermal sensation for physically fit categories of Arab male pilgrims.

TABLE 6.5:
ANOVA results for European pilgrims at main and two way interaction levels.

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
Main effect	40.847	20	2.042	1.204	**0.259**
Sex	8.694	1	8.694	5.123	**0.025**
Physical fitness	11.671	2	5.835	3.439	**0.035**
Last performance	1.780	1	1.780	1.049	**0.307**
Weight	9.283	2	4.642	2.735	**0.068**
Time (Hour)	11.430	11	1.039	0.612	**0.816**
Age	3.916	3	1.305	0.769	**0.513**
Explained	40.847	20	2.042	1.204	**0.259**
Residual	249.439	147	1.697		
Total	290.286	167	1.738		
2-Way interaction					
Sex- Physical fitness	4.446	2	2.223	1.344	**0.585**
Sex- Last performance	1.147	1	1.147	0.676	**0.030**
Sex-Weight	7.308	2	3.654	2.224	**0.466**
Sex-Time (Hour)	9.316	6	1.553	0.883	**0.044**
Sex- Age	17.715	3	5.905	3.640	**0.471**
Physical- Last performance	4.496	2	2.248	1.309	**0.715**
Physical- Weight	4.050	3	1.350	0.792	**0.160**
Physical- Time (Hour)	37.825	10	3.783	2.273	**0.919**
Physical - Age	18.372	5	3.674	2.235	**0.711**
Last Performance- Weight	4.550	2	2.275	1.313	**0.997**
Last Performance- Time (Hour)	8.409	11	0.764	0.405	**0.937**
Last performance-Age	11.715	3	3.905	2.270	**0.071**
Weight-Time(Hour)	50.944	14	3.639	2.293	**0.363**
Weight- Age	22.064	6	3.674	2.204	**0.374**
Time (Hour)- Age	46.077	19	2.425	1.402	

TABLE 6.6:
ANOVA results for European male pilgrims at main and two way interaction levels.

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
Main effect	32.702	19	1.721	1.006	**0.459**
Physical fitness	10.885	2	5.442	3.182	**0.045**
Last performance	1.670	1	1.670	0.976	**0.325**
Weight	10.167	2	5.084	*2.972*	***0.055***
Time (Hour)	14.664	11	1.333	0.779	**0.660**
Age	2.330	3	0.777	0.454	**0.715**
Explained	32.702	19	1.721	1.006	**0.459**
Residual	220.654	129	1.710		
Total	253.356	148	1.712		
2-Way interaction					
Physical- Last performance	6.979	2	3.489	2.093	**0.127**
Physical- Weight	3.523	3	1.174	0.702	**0.552**
Physical- Time (Hour)	42.120	9	4.680	3.038	**0.003**
Physical - Age	13.210	5	2.642	1.582	**0.169**
Last performance- Weight	4.236	2	2.118	1.237	**0.293**
Last Performance- Time (Hour)	9.053	11	0.823	0.444	**0.933**
Last performance-Age	5.901	3	1.967	1.131	**0.339**
Weight-Time(Hour)	35.752	13	2.750	1.678	**0.074**
Weight- Age	11.498	4	2.875	1.705	**0.152**
Time (Hour)- Age	32.969	18	1.832	1.027	**0.435**



1=COMFORT 2=WARM 3=VERY WARM 4=HOT 5=VERY HOT

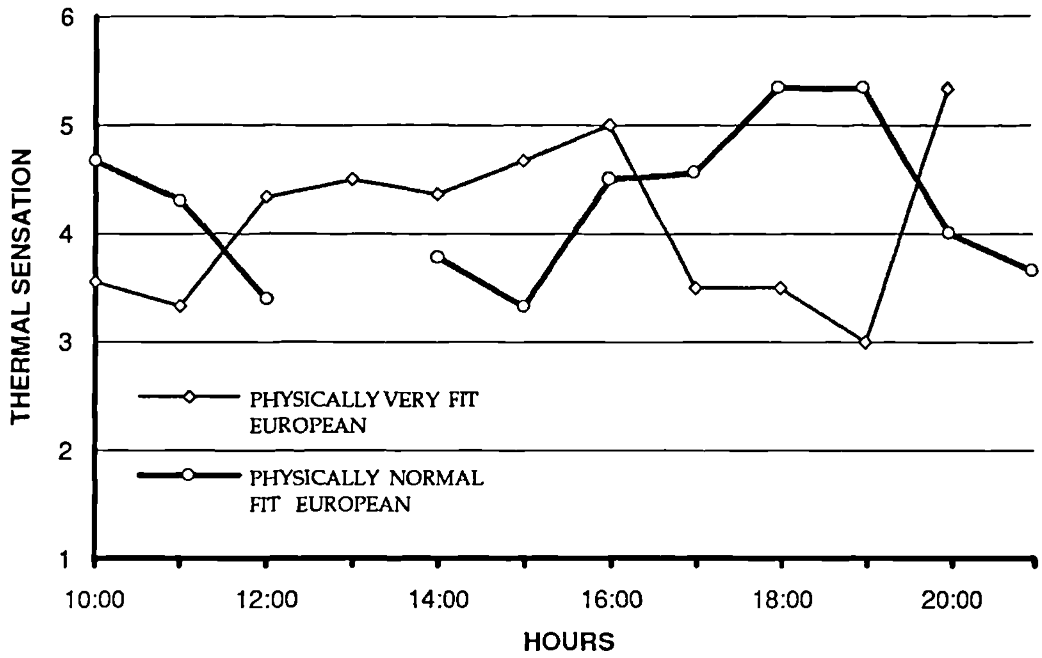
6=EXHAUSTION

*** * * ANALYSIS OF VARIANCE* * ***

Thermal sensation by sex and hour

Source of variations	Sum of squares	DF	Mean of squares	F	Signif.
MAIN EFFECT	18.916	12	1.576	0.896	0.552
SEX	9.029	1	9.029	5.134	0.025
HOUR	7.986	11	0.726	0.413	0.949
2-WAY INTERACTION	9.316	6	1.553	0.883	0.509
SEX-HOUR	9.316	6	1.553	0.883	0.509
EXPLAINED	28.232	18	1.568	0.892	0.589
RESIDUAL	262.054	149	1.759		
TOTAL	290.286	167	1.738		

Fig. 6.9: Significant thermal sensation for male and female European pilgrims.



1=COMFORT 2=WARM 3=VERY WARM 4=HOT 5=VERY HOT

6=EXHAUSTION

* * * ANALYSIS OF VARIANCE* * *

Thermal sensation by physical and hour

Source of variations	Sum of squares	DF	Mean of squares	F	Signif.
MAIN EFFECT	18.012	12	1.501	1.106	0.362
PHYSICAL	5.420	1	5.420	3.992	0.048
HOUR	14.461	11	1.315	0.968	0.478
2-WAY INTERACTION	40.659	9	4.518	3.327	0.001
PHYSICAL-HOUR	40.659	9	4.518	3.327	0.001
EXPLAINED	58.672	21	2.794	2.058	0.008
RESIDUAL	158.854	117	1.358		
TOTAL	217.525	138	1.576		

Fig. 6.10: Significant thermal sensation for physically fit categories of European male pilgrims.

TABLE 6.7:

ANOVA results for Physical fitness categories of Arab and European male pilgrims.

	PHYSICALLY VERY FIT MALE PILGRIMS					PHYSICALLY FIT MALE PILGRIMS				
Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F	Sum of Squares	DF	Mean Square	F	Significant of F
Main effect:	40.451	18	2.247	1.298	**0.198**	43.411	20	2.042	1.204	**0.259**
Ethnic	1.474	1	1.474	0.852	**0.354**	1.844	2	5.835	3.439	**0.035**
Last performance	4.394	1	4.394	2.539	**0.113**	0.924	1	1.780	1.049	**0.307**
Weight	2.214	2	1.107	0.640	**0.529**	3.357	2	4.642	2.735	**0.068**
Time (Hour)	31.538	11	2.867	1.656	**0.090**	32.376	11	1.039	0.612	**0.816**
Age	3.451	3	1.150	0.665	**0.575**	2.098	3	1.305	0.769	**0.513**
Explained	40.451	18	2.247	1.298	**0.198**	43.411	20	2.042	1.204	**0.259**
Residual	242.316	140	1.731			163.228	147	1.697		
Total	282.767	158	1.790			206.639	167	1.738		
2-Way Interaction:										
Ethnic- L. Perform.	0.056	1	0.056	0.031	**0.860**	2.214	1	2.214	1.281	**0.260**
Ethnic- Weight	2.383	2	1.192	0.659	**0.519**	4.924	2	2.462	1.410	**0.249**
Ethnic- Time (hour)	34.447	10	3.445	2.153	**0.024**	14.529	10	1.453	0.893	**0.543**
Ethnic- Age	6.198	3	2.066	1.136	**0.337**	7.651	3	2.550	1.466	**0.228**
L. Perform- Weight	4.776	2	2.388	1.343	**0.264**	0.011	2	0.006	0.003	**0.997**
L. Perform- Time	9.855	11	0.896	0.507	**0.896**	21.853	11	1.987	1.269	**0.254**
(Hr)	9.612	3	3.204	1.804	**0.149**	6.592	3	2.197	1.246	**0.297**
L. Perform- Age	49.915	16	3.120	2.003	**0.017**	53.097	18	2.950	2.228	**0.007**
Weight- Time (hour)	11.287	6	1.881	1.031	**0.408**	12.086	4	3.022	1.741	**0.146**
Weight- Age	22.311	19	1.174	0.645	**0.865**	35.972	22	1.635	1.004	**0.469**
Time (hour)- Age										

4.2- VENTILATION SENSATION:

Results of the ANOVA test applied to the Arab and European groups are indicated in table 6.8. The results show significant differences between Arabs and Europeans and both patterns are indicated in figure 6.11. It can be deduced that ventilation in the Arab camp is poor most of the day but it slightly improved after noon and reached its "satisfactory" limit at 17.00 hrs. It is interesting to observe that the best ventilation conditions coincided exactly with the time when maximum wind speed was reached. The same figure was also recorded for the European's sensation for ventilation conditions in their camp. Ventilation sensations vary near to the satisfactory limit and, therefore, can be generally described as "satisfactory."

The observed differences between Arabs and Europeans might be due to the way each group used their tents. Arabs were concerned mainly with maximum privacy, therefore, tents were divided with partitions and side walls were kept closed. Poor ventilation, therefore, resulted. Ventilation conditions in the European camp were better for no inside partitions existed and side walls were opened.

4.3- PERSPIRATION SENSATION:

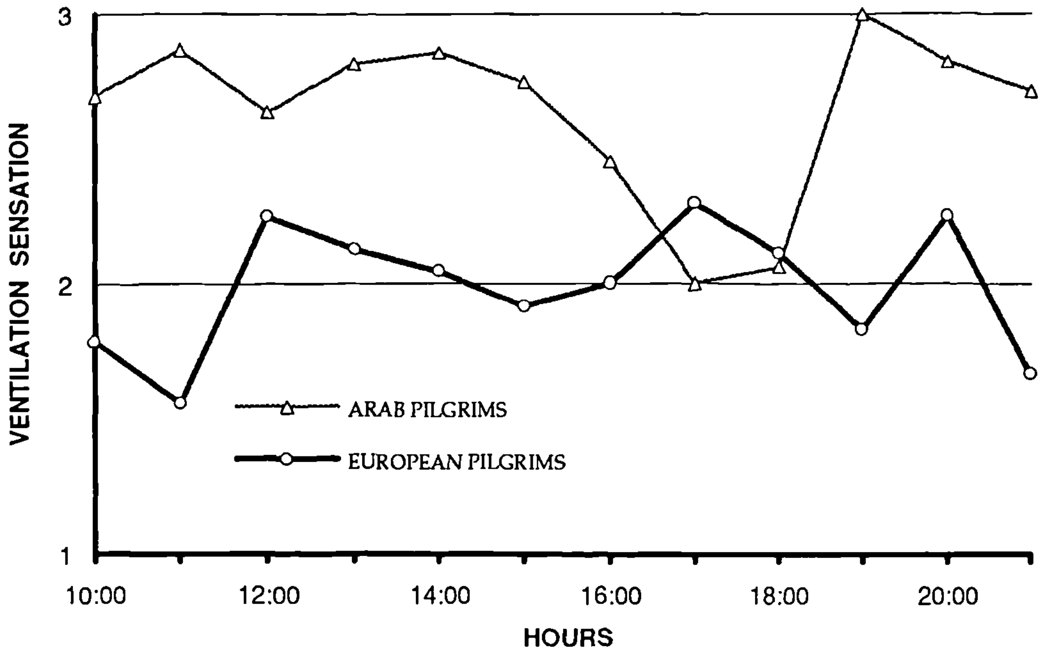
Under such hot conditions in the pilgrimage tents a body normally sweats to dissipate heat. The perspiration sensation varies depending on the evaporative capacity of the surroundings, the higher the rate of evaporation the less the sensation of discomfort. Conversely, the lower the rate of evaporation the greater is the sensation of discomfort. Results of the ANOVA test applied for Arab pilgrims are indicated in table 6.9. The figure indicates that for Arabs, previous experiences of pilgrimages had a significant influence on sweat sensation. Arab pilgrims, therefore, were segregated according to their previous performance of Hajj. The variation of each category in relation to perspiration sensation is represented in figure 6.12. Arabs who had previously performed Hajj sweat less than Arabs who performed Hajj for the first time. The reason might be, though it cannot be confirmed, that pilgrims with previous experience find better ventilated locations inside tents than pilgrims performing Hajj for the first time. Locations are better ventilated either naturally, i.e., near openings or artificially, i.e., near electrical fans.

As for European pilgrims, it seems that the weight variable determined significant variations in sweat sensations as is indicated in table 6.10. The heavier the weight, the more the sensation of sweat. The weight variable is of three categories, namely "under", "normal", and "overweight". Pilgrims of "under" and "overweight" categories were excluded- because of their relatively small number (18 pilgrims of each, compared to the "normal" category of 136 pilgrims.) The perspiration sensation indicated in figure 6.13 is for the European's "normal" weight category. The sensation fluctuates near to the discomfort level "very much sweating."

TABLE 6.8:

ANOVA results for ventilation sensation of Arab and European pilgrims at main and two way interaction levels.

	Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
	Main effect	43.322	21	2.063	4.282	0.000
	Ethnic	29.211	1	29.211	60.636	0.000
	Sex	0.681	1	0.681	1.413	0.235
	Physical fitness	0.714	2	0.357	0.741	0.477
	Last performance	0.159	1	0.159	0.330	0.566
	Weight	0.617	2	0.308	0.640	0.528
	Time (Hour)	6.001	11	0.546	1.133	0.335
	Age	3.551	3	1.184	2.457	0.063
	Explained	43.322	21	2.063	4.282	0.000
	Residual	149.341	310	0.482		
	Total	192.663	331	0.582		
	2-Way interaction					
	Ethnic- Sex	0.058	1	0.058	0.120	0.729
	Ethnic- Physical fitness	0.661	2	0.331	0.681	0.507
	Ethnic- Last performance	0.505	1	0.505	1.045	0.307
	Ethnic-Weight	0.910	2	0.455	0.937	0.393
	Ethnic- Time (Hour)	14.321	11	1.302	2.864	0.001
	Ethnic- Age	0.409	2	0.205	0.426	0.654
	Sex- Physical fitness	0.126	2	0.063	0.107	0.899
	Sex- Last performance	0.310	1	0.310	0.529	0.467
	Sex-Weight	1.253	2	0.627	1.076	0.342
	Sex-Time (Hour)	2.752	9	0.306	0.523	0.857
	Sex- Age	1.440	2	0.720	1.246	0.289
	Physical- Last performance	1.986	2	0.993	1.703	0.184
	Physical- Weight	2.056	4	0.514	0.878	0.477
	Physical- Time (Hour)	21.249	20	1.062	1.946	0.010
	Physical - Age	1.887	4	0.472	0.811	0.519
	Last Performance- Weight	0.355	2	0.178	0.304	0.738
	Last Performance- Time (Hour)	7.235	11	0.658	1.146	0.325
	Last performance-Age	0.280	2	0.140	0.242	0.785
	Weight-Time(Hour)	10.424	21	0.496	0.856	0.648
	Weight- Age	1.397	4	0.349	0.601	0.662
	Time (Hour)- Age	11.762	19	0.619	1.110	0.340



1=GOOD VENTILATION 2=SATISFACTORY 3=POOR VENTILATION

* * * ANALYSIS OF VARIANCE* * *

Ventilation sensation by race and hour

Source of variations	Sum of squares	DF	Mean of squares	F	Signif.
MAIN EFFECT	38.354	12	3.196	7.032	0.000
RACE	29.737	1	29.737	65.42	0.000
HOUR	5.070	11	0.461	1.014	0.433
2-WAY INTERACTION	14.321	11	1.302	2.864	0.001
RACE-HOUR	14.321	11	1.302	2.864	0.001
EXPLAINED	52.675	23	2.290	5.039	0.000
RESIDUAL	139.987	308	0.455		
TOTAL	192.663	331	0.582		

Fig. 6.11: Significant ventilation sensation of Arab and European pilgrims.

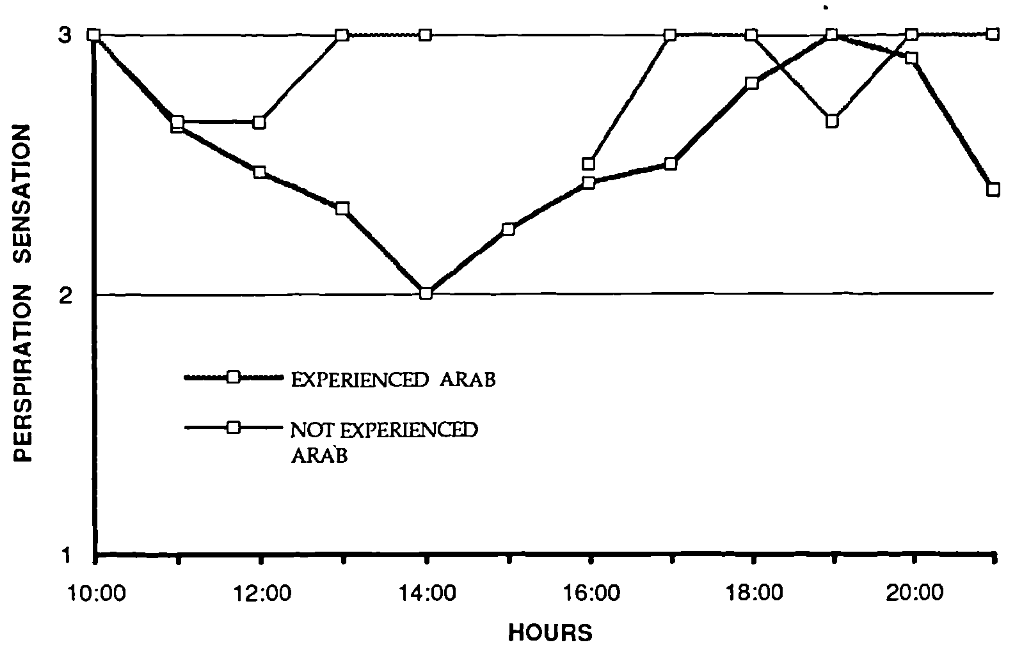
TABLE 6.9:
ANOVA results for Perspiration sensation of Arab pilgrims at main and two way interaction levels.

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
Main effect	12.484	20	0.624	1.559	**0.070**
Sex	0.947	1	0.947	2.365	**0.126**
Physical fitness	0.154	2	0.077	0.193	**0.825**
Last performance	0.843	1	0.843	2.105	**0.149**
Weight	0.080	2	0.040	0.100	**0.905**
Time (Hour)	6.305	11	0.573	1.432	**0.164**
Age	1.113	3	0.371	0.927	**0.429**
Explained	12.484	20	0.624	1.559	**0.070**
Residual	60.042	150	0.400		
Total	72.526	170	0.427		
2-Way interaction					
Sex- Physical fitness	0.729	2	0.365	0.859	**0.425**
Sex- Last performance	0.173	1	0.173	0.421	**0.517**
Sex-Weight	1.172	2	0.586	1.401	**0.249**
Sex-Time (Hour)	4.128	9	0.459	1.163	**0.323**
Sex- Age	0.011	3	0.004	0.009	**0.999**
Physical- Last performance	0.419	2	0.209	0.502	**0.606**
Physical- Weight	2.513	4	0.628	1.487	**0.209**
Physical- Time (Hour)	3.510	11	0.319	0.803	**0.637**
Physical - Age	5.999	5	1.200	3.013	**0.013**
Last Performance- Weight	0.035	2	0.018	0.042	**0.959**
Last Performance- Time (Hour)	2.132	10	0.213	0.520	**0.874**
Last performance-Age	0.317	3	0.106	0.254	**0.858**
Weight-Time(Hour)	11.607	20	0.580	1.527	**0.082**
Weight- Age	0.911	5	0.182	0.424	**0.832**
Time (Hour)- Age	8.456	22	0.384	0.960	**0.518**

TABLE 6.10:

ANOVA results for perspiration sensation of European pilgrims at main and two way interaction levels.

Source of Variation	Sum of Squares	DF	Mean Square	F	Significant of F
<u>Main effect</u>	6.661	20	0.333	1.298	**0.189**
Sex	0.850	1	0.850	3.314	**0.071**
Physical fitness	0.247	2	0.124	0.482	**0.619**
Last performance	0.113	1	0.113	0.440	**0.508**
Weight	1.548	2	0.774	3.015	**0.052**
Time (Hour)	3.053	11	0.278	1.082	**0.380**
Age	0.968	3	0.323	1.257	**0.291**
Explained	6.661	20	0.333	1.298	**0.189**
Residual	38.752	151	0.257		
Total	45.413	171	0.266		
<u>2-Way interaction</u>					
Sex- Physical fitness	0.077	2	0.039	0.143	**0.867**
Sex- Last performance	0.230	1	0.230	0.865	**0.354**
Sex-Weight	0.037	2	0.018	0.071	**0.932**
Sex-Time (Hour)	1.484	7	0.212	0.803	**0.586**
Sex- Age	0.438	3	0.146	0.554	**0.646**
Physical- Last performance	1.057	2	0.529	1.995	**0.139**
Physical- Weight	0.213	3	0.071	0.268	**0.849**
Physical- Time (Hour)	5.572	10	0.557	2.274	**0.017**
Physical - Age	1.797	5	0.359	1.372	**0.238**
Last Performance- Weight	0.358	2	0.179	0.684	**0.506**
Last Performance- Time (Hour)	1.809	11	0.164	0.600	**0.826**
Last performance-Age	0.514	3	0.171	0.645	**0.587**
Weight-Time(Hour)	3.923	14	0.280	1.091	**0.371**
Weight- Age	1.684	6	0.281	1.093	**0.369**
Time (Hour)- Age	6.510	19	0.343	1.351	**0.162**



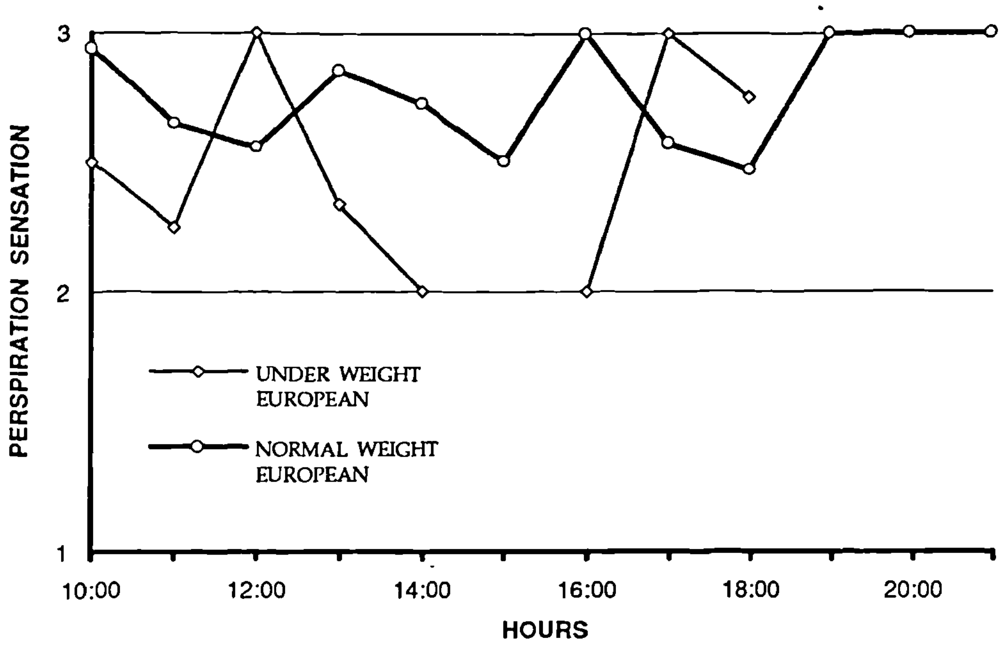
1=VERY LITTLE 2=NORMAL 3=VERY MUCH

* * * ANALYSIS OF VARIANCE* * *

Perspiration sensation by last performance and hour

Source of variations	Sum of squares	DF	Mean of squares	F	Signif.
MAIN EFFECT	9.669	12	0.806	1.964	0.031
LAST PERFORMANCE	1.134	1	1.134	2.763	0.099
HOUR	6.992	11	0.636	1.549	0.120
2-WAY INTERACTION	2.132	10	0.213	0.520	0.874
L. PERFOM. -HOUR	2.132	10	0.213	0.520	0.874
EXPLAINED	11.801	22	0.536	1.307	0.175
RESIDUAL	60.725	148	0.410		
TOTAL	72.526	170	0.427		

Fig. 6.12: Significant perspiration sensation for Arab pilgrims.



1=VERY LITTLE 2=NORMAL 3=VERY MUCH

* * * ANALYSIS OF VARIANCE * * *

Perspiration sensation by weight and hour

Source of variations	Sum of squares	DF	Mean of squares	F	Signif.
MAIN EFFECT	4.505	13	0.347	1.349	0.192
WEIGHT	1.519	2	0.759	2.957	0.055
HOUR	3.066	11	0.279	1.085	0.377
2-WAY INTERACTION	3.923	14	0.280	1.091	0.371
WEIGHT-HOUR	3.923	14	0.280	1.091	0.371
EXPLAINED	8.428	27	0.312	1.215	0.230
RESIDUAL	36.985	144	0.257		
TOTAL	45.413	171	0.266		

Fig. 6.13: Significant perspiration sensation for European pilgrims.

5- THE EFFECT OF CLIMATE ON PILGRIM'S THERMAL DISCOMFORT:

The focus in this section concerns the thermal discomfort of Arab and European pilgrims. It has been established that thermal discomfort is significantly different for the two physically fitness categories of "very fit" and "normally fit." The present analysis attempts to answer two questions. The first is, to what extent variations in thermal discomfort are related to measured climatic variables? The second is, can the values of thermal sensations be predicted from the measured values of climatic variables?

To examine the relationship that may exist between thermal sensation and measured climatic variables, a correlation test was applied. Results for the two physical fitness categories are shown in table 6.11 for Arab pilgrims and table 6.12 for the Europeans. Climatic variables include air temperature, globe temperature, relative humidity, wind speed, wet bulb temperature, wbgt, vapour pressure, and enthalpy. To interpret results of the correlation test, consideration will be given to three pieces of information namely: the strength of the relationship, the direction of the relationship, and the statistical significance of the correlation.

For physically "very fit" Arab pilgrims, it is apparent from the scatter plot in figures 6.14 and 6.15 that thermal discomfort sensation decreases with increasing of dry and wet air temperatures. This contradicts the normal relationship which would expect thermal discomfort to increase linearly with increasing of air temperatures.

From the scatter plot of thermal sensation with relative humidity, indicated in figure 6.16, the relationship appears to be strong and significant ($R=0.67$, $P=0.01$). Thermal discomfort sensation tends to increase linearly with increases in relative humidity. The more humid the Arabs' tents the more discomfort the thermal sensation.

To discuss the above observations, it seems that absolute values of dry and wet air temperatures do not directly determine thermal discomfort of pilgrims. However, their combinations manifested in relative humidity has stronger and more significant influence as is apparent from the statistics in figure 6.16. Relative humidity is in direct relationship with air temperature. It is low when temperature is maximum, in early afternoon, and increases to its maximum during the night. The point made earlier that thermal discomfort increases with increasing air temperature stands true when air temperature is low, for example between 24 - 30°C. There is good evidence that the relationship tends to be different at higher temperatures. Hickish (1955) reports that at temperatures above 24°C the slope of thermal discomfort inclined sharply and then flattened at 30°C. Any further increase of air temperature would give the same thermal discomfort sensation.[3] Similar effect was observed by Ellis (1952) over a range of 25-35°C.[4] The range of conditions encountered then, did not extend to temperatures above 35°C. In this study thermal conditions ranged from 35-50°C. The negative relationship of dry and wet air temperature with thermal discomfort is claimed insignificant. Therefore, the null hypothesis of flattened relationship with thermal discomfort is accepted.

Data shows the significant influence of relative humidity. In hot, extremely crowded, and poorly ventilated environments, similar to that of the Arab camps, relative humidity determines the evaporative capacity of the air and, therefore, the cooling efficiency of sweating. The higher the relative humidity the less the difference between dry air temperature and wet bulb temperature and subsequently the slower the evaporative rate. The less the relative humidity the faster the evaporative rate, and the more pronounced the cooling sensation. This observation agrees with studies by Fanger (1982). Fanger has described the influence of relative humidity in two levels. First when persons are in thermal comfort, 20-25°C, the influence of relative humidity is moderate. Second when the ambient temperature is high, above 35^{o}C, the degree of discomfort can be heavily influenced by the air humidity.[5]

Thermal sensation of the same physical category, "very fit" Arab pilgrims, has a negative relationship with wind speed (R=-0.85, P= 0.00). This relationship is indicated in figure 6.17. The higher the wind speed; the less the thermal discomfort. Under the hot and extremely crowded environments of pilgrimage tents, air temperature exceeded that of the body's skin. Bodies sweat to dissipate heat and the more the evaporative capacity the more the cooling efficiency of sweating. An increase in air movement enhances the evaporative capacity by changing the air immediately near to the body but up to a certain limit. That is when higher air movement causes body heat gain due to an increase in the value of the convective heat transfer coefficient.

The second category of Arab pilgrims is the physically "normal fit." Thermal discomfort of this category is significantly correlated with relative humidity (R=0.68, P=0.01). This positive relationship is indicated in figure 6.16 and is similar to that observed for physically "very fit" Arabs. The scatter plot in figure 6.17 shows a negative relationship with wind speed but not statistically significant. Therefore the null hypothesis of no linear relationship between thermal discomfort of normal Arab and wind speed is accepted. Within the same range of wind speed, "very fit" Arabs are more sensitive to the cooling effect of ventilation than "normal fit" Arabs. This is indicated by the slope values of the regression line of each scatter plot. The slope in the "very fit Arab" scatter plot is deeper than the "normal fit Arab". The reason may be that "very fit" Arabs are normally the more active and therefore sweat more.

Table 6.12 presents the correlation of the two physically fit categories of European pilgrims. Data collected for the European camps do not indicate any significant relationship with climatic variables for any of the physically fit categories. To explain this result one should recall that significant thermal discomfort of

European pilgrims varied within a narrow range on the discomfort scale- that is from "very warm" (point 3 on the scale) to "very hot" (point 5). Discomfort variation from hour to hour was insignificant and Europeans, unlike Arabs, were less sensitive to variations in climatic variables.

This study was not originally intended to establish limits for thermal discomfort. It is interesting, however, to observe that relative humidity in the European camp ranges from 20 to 30% and in Arab camp is extended to 36%. The reason might be in the use of tents in each camp. The side walls of tents in the European camp were kept open while Arabs keep them closed for privacy. A lower density of occupation in tents of the European camp may be another reason. Both ethnics were not very sensitive to a small variation of relative humidity from 20-27%. It was only when relative humidity increased above 27% that the negative relationship emerged significantly with thermal discomfort. Unfortunately this can only be confirmed with Arab pilgrims and not with Europeans, for the range of relative humidity in the European camps did not exceed 30%. This may suggest a threshold of 30% for relative humidity. The exposure of pilgrims beyond this limit may cause severe thermal discomfort.

5.1- PREDICTION OF PILGRIM'S THERMAL DISCOMFORT:

The discussion made earlier concluded that in the high temperature conditions experienced during the Hajj, relative humidity and wind speed were the most important factors that influenced the thermal discomfort of pilgrims. It is thus of interest to learn how variables relate to each other in explaining thermal discomfort and which of the independent variables is more important than the others. The use of regression analysis in this section aims to answer the above questions. The SPSS/PC+ REGRESSION procedure is used to develop a model that predicts thermal discomfort from a set of independent variables. The independent variables include relative humidity, wind speed, air temperature, wet bulb temperature, globe temperature, wbgt, vapour pressure, and enthalpy. The best model is the one that physiologically explains variations of thermal discomfort and statistically is significant.

As a first trial a model was built to explain the difference in thermal discomfort for Arab and European pilgrims. Two indication variables were, therefore, added as independent. The first was ethnic which was assigned a value of (0) for Arab pilgrims and a value of (1) for Europeans. The second was physical fitness which was assigned a value of (0) for physically very fit and a value of (1) for normally fit. This trial ended with a model that could explain 26% of the variations in thermal discomfort with an overall significance of (0.01). The statistic for this model is given in table 5.14 and the equation is given as:

$$\text{Disc} = 1.47 - 0.037(\text{Wind}) + 0.09(\text{Rh}) + 0.31(\text{Phy}) + 0.48(\text{Ethnic}) \qquad (6.1)$$

Where: Disc = Thermal discomfort.

Wind = Wind speed (m/ second).

Rh = Relative humidity (%).

Phy = Physical categories, (0) for physically very fit and (1) for physically normal.

Ethnic= Ethnic of pilgrims, (0) for Arab and (1) for Europeans.

The maximum the above model can explain is only 26% of the discomfort variations and the regression coefficients are not statistically significant. Two other trials were, therefore, performed aimed to explain thermal discomfort of each pilgrims' group separately. For Europeans it seemed no satisfactory model was possible.. Tables 6.13 and 6.14 present different models to predict thermal discomfort of Arab pilgrims. The model which contained both relative humidity and wind speed and is accepted from the physiological point of view is given in the following equation:

$$\text{Disc} = 2.23 - 0.14(\text{Wind}) + 0.08(\text{Rh}) + 0.47(\text{Phy}) \qquad (6.2)$$

Where: Disc = Thermal discomfort for Arab pilgrims.

Wind = Wind speed (m/ second).

Rh = Relative humidity (%).

Phy = Physical categories, (0) for physically very fit and (1) for physically normal.

The model could explain 56% of the variations in Arabs' thermal discomfort and the overall regression of the equation was significant (0.001). However, none of the individual coefficients were significant.

These results observed for equations 6.1 and 6.2, where the overall of the model was significant but the individual coefficients were not, is abnormal. It is so because of the high intercorrelation between relative humidity and wind speed, see table 6.11. High correlation, at more than 0.70, between independent variables often results in multicollinear conditions which make individual coefficients quite unreliable [6]. It seems, therefore, that there is no evidence to build a model which contains all the important climatic independents because all are highly correlated. In the case of the Arab pilgrims, the best predictor of thermal discomfort consisted of two variables, namely wind speed and physical fitness of pilgrims. The equation of the model is given as:

$$\text{Disc} = 5.06 - 0.25(\text{Wind}) + 0.47(\text{Phy}) \quad \text{..} (6.3)$$

Where: Disc = Thermal discomfort for Arab pilgrims.

Wind = Wind speed (m/ second)

Phy = Physical categories, (0) for physically very fit and (1) for physically normal.

The model is accepted from both a statistical and a physiological views. It explains 50% of variations in thermal discomfort of the Arab pilgrims with an overall significance of (0.001). The adjusted R^2 which gives a better fit of the model in the population is (0.48).

Table 6.11:

Correlation matrix of thermal sensation for physically very fit and normal fit Arab pilgrims

Correlation/ ARAB	Thsens of Very Fit	Thsens of Norm. Fit	Air Temper..	RH%	Globe Temper.	Wet Air Temper..	WBGT	VP	Enthalapy	Wind	Dry-Wet
	Thsens of Very Fit		-.4881 p=.064	.6694 p=.012	-.4970 p=.060	-.5577 p=.037	-.5383 p=.044	-.1099 p=.374	-.3139 p=.174	-.8552 p=.000	-.3764 p=.127
		Thsens of Norm. Fit	-.6764 p=.011	.6785 p=.011	-.6809 p=.011	-.7573 p=.003	-.7339 p=.005	-.4699 p=.072	-.6019 p=.025	-.4659 p=.074	-.5346 p=.045
			Air Temper..	-.9170 p=.000	.9998 p=.000	.9257 p=.000	.9779 p=.000	.8174 p=.001	.9534 p=.000	.5922 p=.027	.9501 p=.000
				RH%	-.9186 p=.000	-.8388 p=.001	-.8922 p.000	-.5246 p=.049	-.7563 p=.004	-.7461 p=.004	-8796 p=.000
					Globe Temper.	.9306 p=.000	.9806 p=.000	.8154 p=.001	.9522 p=.000	.5988 p=.026	.9458 p=.000
						Wet Air Temper..	.9843 p=.000	.7705 p=.003	.8902 p=.000	.5699 p=.034	.7616 p=.003
							WBGT	.8154 p=.001	.9359 p=.000	.5939 p=.027	.8639 p=.000
								VP	.9532 p=.000	.1979 p=.280	.7653 p=.003
									Enthalapy	.4145 p=.103	.8995 p=.000
										Wind	.5448 p=.042
											Dry-Wet

Thsens of very fit. = Thermal sensation of very fit Arab pilgrims.

Thsens of norm. fit= Thermal sensation of normally fit Arab pilgrims.

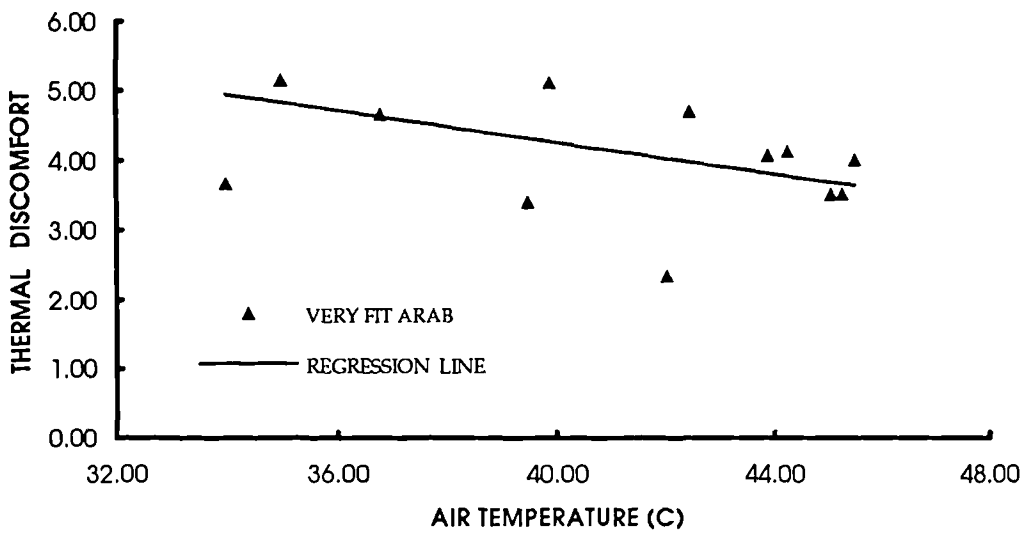
Table 6.12:

Correlation matrix of thermal sensation for physically very fit and normal fit European pilgrims

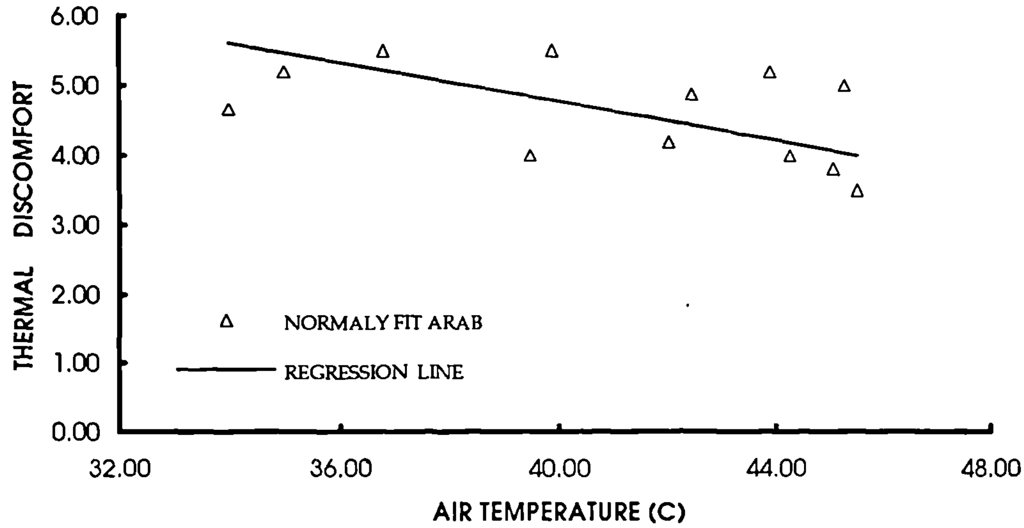
Correlation/ EUP	Thsens of Very Fit	Thsens of Norm. Fit	Air Temper..	RH%	Globe Temper.	Wet Air Temper..	WBGT	VP	Enthalapy	Wind	Dry-Wet
	Thsens of Very Fit		.1830 p=.295	-.1003 p=.385	.1763 p=.302	.3133 p=.174	.2556 p=.224	.1774 p=.301	.1880 p=.290	-.0133 p=.489	.0095 p=.489
		Thsens of Norm. Fit	-.2343 p=.244	-.0811 p=.406	-.2331 p=.245	-.4051 p=.108	-.3280 p=.162	-.5073 p=.056	-.3904 p=.118	.0111 p=.487	-.0757 p=.412
			Air Temper..	-.7964 p=.002	.9997 p=.000	.9361 p=.000	.9791 p=.000	.8516 p=.000	.9593 p=.000	.6430 p=.016	.9195 p=.000
				RH%	-.8020 p=.001	-.7339 p=.005	-.7759 p=.003	-.3638 p=.136	-.5947 p=.027	-.8050 p=.001	-.7453 p=.004
					Globe Temper.	.9408 p=.000	.9818 p=.000	.8469 p=.001	.9566 p=.000	.6538 p=.015	.9137 p=.000
						Wet Air Temper..	.9880 p=.000	.8183 p=.001	.9098 p=.000	.6281 p=.019	.7226 p=.006
							WBGT	.8436 p=.001	.9448 p=.000	.6492 p=.015	.8204 p=.001
								VP	.9650 p=.000	.2911 p=.193	.7595 p=.003.
									Enthalapy	.4785 p=.068	.8689 p=.000
										Wind	.5620 p=.036
											Dry-Wet

Thsens of very fit. = Thermal sensation of very fit European pilgrims.

Thsens of norm. fit= Thermal sensation of normally fit European pilgrims.

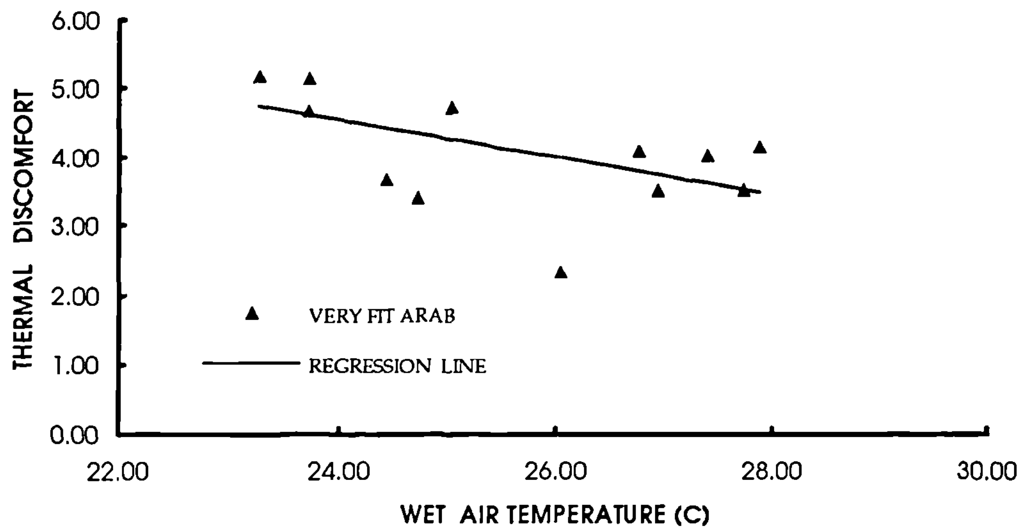


CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
-0.48805	0.23819	0.78321	0.1278	8.91293	-0.11624

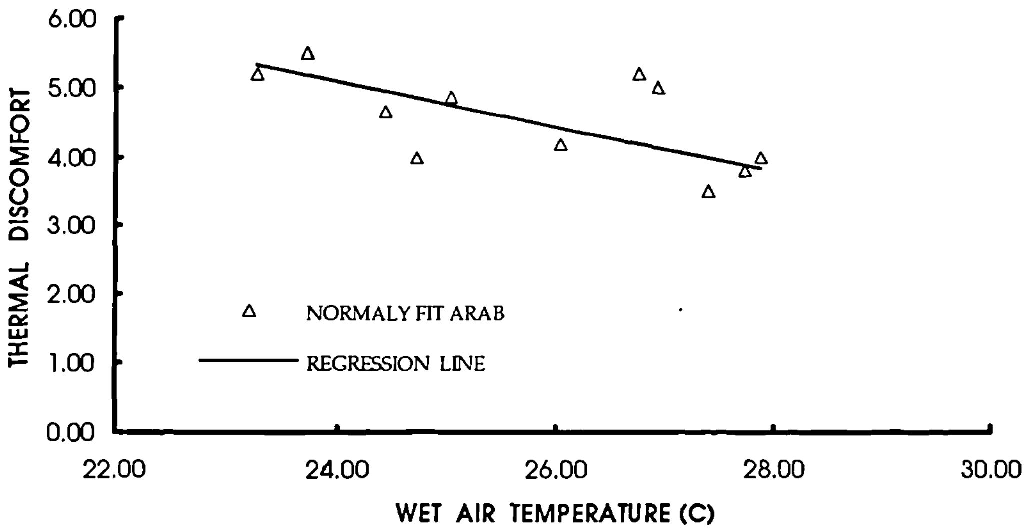


CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
-0.67640	0.45751	0.57283	0.0223	10.35823	-0.13963

FIG. 6.14: *Correlation between air temperature and thermal discomfort of very fit and normally fit Arab pilgrims.*

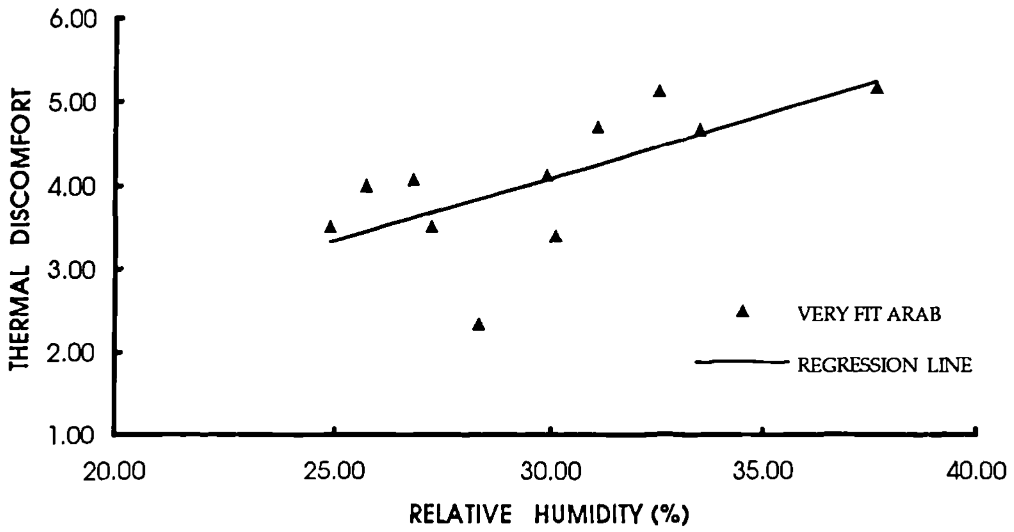


CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
-0.55769	0.31102	0.74483	0.0746	11.16784	-0.27609

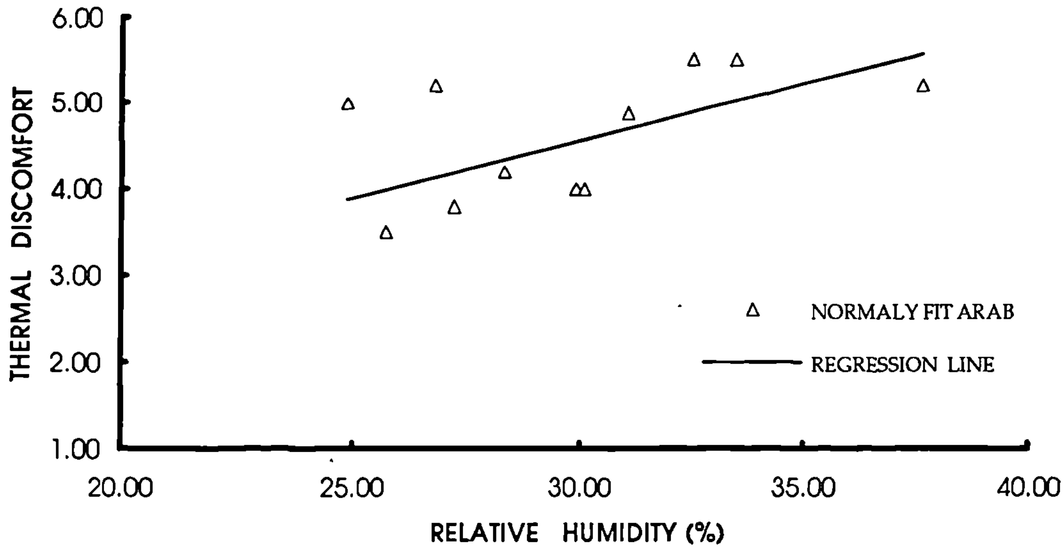


CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
-0.75729	0.57349	0.50792	0.0070	12.89415	-0.32493

FIG. 6.15: Correlation between wet air temperature and thermal discomfort of very fit and normally fit Arab pilgrims.

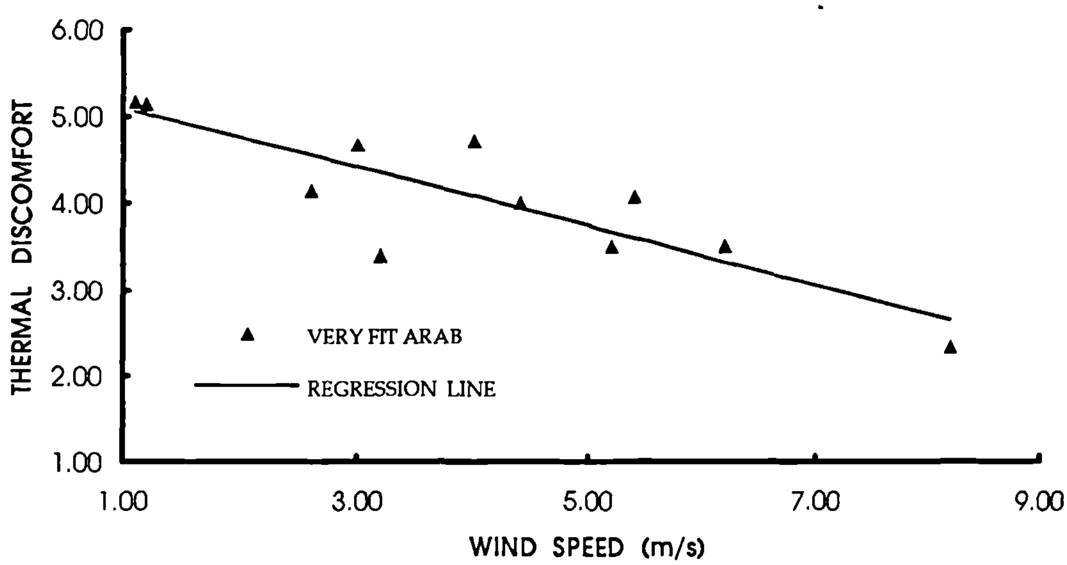


CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
-0.66936	0.44804	0.66666	0.0243	-0.42578	0.15037

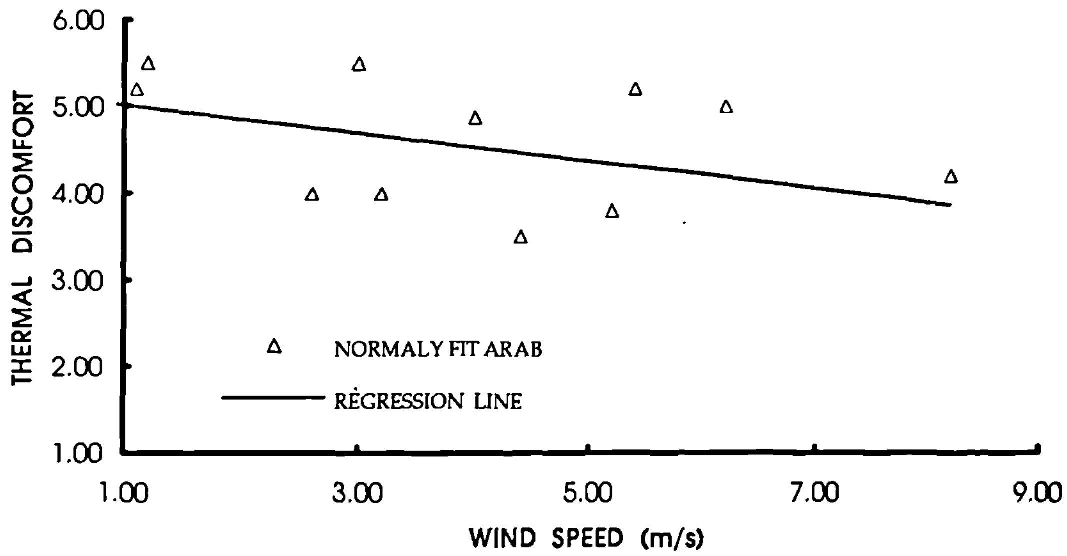


CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
0.67854	0.46041	0.57129	0.0217	0.58669	0.13211

FIG. 6.16 *Correlation between relative humidity and thermal discomfort of very fit and normally fit Arab pilgrims.*



CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
-0.85522	0.73139	0.46506	0.0008	5.43192	-0.33994



CORRELATION	R SQUARED	S.E.OF EST	SIG.	INTERCEPT	SLOPE
-0.46593	0.21709	0.68815	0.1486	5.17437	-0.16052

FIG. 6.17 *Correlation between wind speed and thermal discomfort of very fit and normally fit Arab pilgrims.*

TABLE 6.13:

Statistics for variables in the equation (6.1)

Disc= 1.47-0.037* (wind) + 0.09* (RH) + 0.31* (PHY) +0.48 * (ETHNIC)

MULTIPLE REGRESSION

Multiple R=	0.50640		
R Square=	0.25644		
Adjusted R Square=	0.18018		
Standard Error=	0.68754		
	F= 3.36261		Signif F = 0.0186

VARIABLES IN THE EQUATION

Variable	B	SE B	Beta	T	Sig T
RH	0.09434	0.05226	0.54703	1.805	0.0788
PHY	0.31499	0.20730	0.20981	1.519	0.1367
ETHNIC	0.48943	0.39220	0.32600	1.248	0.2195
WIND	-0.03797	0.07591	-0.10327	-0.500	0.6198
Constant	1.47451	1.80701		0.816	0.4195

TABLE 6.14:

Statistics for variables in the equation (6.2)

Disc= 2.23 - 0.14 (wind) + 0.08* (RH) + 0.47* (PHY)

MULTIPLE REGRESSION

Multiple R=	0.74808		
R Square=	0.55962		
Adjusted R Square=	0.48623		
Standard Error=	0.58309		
	F= 7.62466		Signif F = 0.0017

VARIABLES IN THE EQUATION

Variable	B	SE B	Beta	T	Sig T
WIND	-0.14384	0.09143	-0.36957	-1.573	0.1331
PHY	0.46828	0.24863	0.29460	1.883	0.0759
RH	0.08059	0.05167	0.36636	1.560	0.1363
Constant	-2.23626	1.84137		1.214	0.2403

TABLE 6.15:

Statistics for variables in the equation (6.3)

Disc= 5.06 - 0.25* (wind) + 0.47* (PHY)

MULTIPLE REGRESSION

Multiple R=	0.70719		
R Square=	0.50011		
Standard Error=	0.60466		
	F= 9.50434		Signif F = 0.0014

VARIABLES IN THE EQUATION

Variable	B	SE B	Beta	T	Sig T
WIND	-0.25023	0.06313	-0.64290	-3.964	0.0008
PHY	0.46828	0.25783	0.29460	1.816	0.0851
Constant	5.06900	0.31379		16.154	0.0000

6- CONCLUSION:

This study aims to assess thermal discomfort experienced by pilgrims staying inside tents when visiting Makkah for the annual pilgrimage. The survey was structured to collect samples relating to three climatic zones: a hot climate represented by Arabs, a cold climate represented by Europeans, and a tropical climate represented by south east Asians. In this study, analysis was mainly focused on Arab and European male pilgrims. South east Asian pilgrims represented only a small portion of the data and measurements in their camps were incomplete. Similarly, Arab and European females were excluded from the analysis because of their relatively small numbers. Analysis of samples for Arab and European male pilgrims indicated the following findings:

A. Thermal conditions in both camps were far from being thermally comfortable. The mode of Europeans was "very hot" and experienced extreme discomfort from 10.00- 19.00hrs. The analysis of European pilgrims is in agreement with the prediction made earlier in Chapter IV using heat stress indices. Heat stress indices predicted very uncomfortable conditions from 10.00-19.00 hrs. The mode of thermal sensation of Arab pilgrims was "hot" and the harsh thermal conditions were experienced when tents were crowded from 10.00-12.00 hrs in the morning and after sunset from 19.00-21.00 hrs. Arab pilgrims were more sensitive to variations of thermal conditions than Europeans. For example, Arabs were able to spot the time from 10.00-12.00 hrs as the most uncomfortable period of the day; while Europeans extended this period from 10.00- 19.00 hrs.

B. No significant variations were identified due to differences in ethnic, age, weight, health conditions, or previous experience of the HAJJ. Significant variations in thermal sensation were identified due to the physical fitness of pilgrims. "Very fit" Arabs were more tolerant of heat than "normally fit" pilgrims during the period of the survey from 10.00-21.00hrs. Europeans were different. "Very fit" pilgrims were more tolerant of heat all of the time, except from 12.00-16.00hrs, the time when "normally fit" pilgrims showed more tolerance.

C. Pilgrims experienced extreme thermal conditions ranging from 36-50^{o}C, well above normal comfort conditions. The present study has identified climatic factors that influence thermal discomfort in such a range. It revealed that absolute values of dry and wet air temperatures do not directly determine thermal discomfort. However, their combinations manifested in relative humidity have a stronger and more significant influence on thermal discomfort. Thermal discomfort of pilgrims increases with an increase in relative humidity. In such extreme thermal conditions in the pilgrimage tents, sweat evaporation becomes the primary way of dissipating the body's heat. High relative humidity slows down the cooling efficiency of evaporation and so thermal discomfort is increased. This relationship is pronounced when relative humidity is above 30%; below this limit the effect of humidity alone does not appear to be strongly correlated with discomfort. Wind is the other determining factor which influences thermal discomfort since it would have a direct relationship to air movement within the tent. The higher the wind the higher the internal air movement and the better pilgrims' thermal comfort. An increase in air movement enhances the evaporative capacity by changing the air immediately near to the body. This draws attention to an area which needs further study: that is pilgrims' thermal discomfort during the night. Pilgrims may experience even harsher thermal conditions during the night. At night tents are heavily occupied, wind speed is practically zero, the diurnal range of air temperature is small, and the relative humidity inside the tents reaches as high as 60-70%.

D. The analysis shows that ventilation conditions inside the Arab camp were poor for most of the day but improved slightly when wind speed reached its maximum in the afternoon. Ventilation conditions inside the European camp were better and the mode was "satisfactory." This difference between the two camps was mainly due to how the interior of the tent was used. The closed side walls and partitions used by Arabs for more privacy resulted in poor ventilation conditions. Conversely, open side walls with no partitions resulted in better ventilation conditions in the European camp.

The above findings can be developed to design strategies for improving the thermal environment of tents. The first strategy is to increase ventilation speed inside tents. The outcome of this strategy is to supply tents with fresh and cool air from outside to prevent a reduction of the cooling efficiency of sweating. Existing electrical fans used inside tents would only relocate air from one location to another without a change of air temperature and relative humidity. This does not improve thermal conditions inside tents although the increased air movement would be expected to remove sweat at a greater rate so improving the perception of comfort. The second strategy is to decrease relative humidity inside tents. Sweat secreted from pilgrims' bodies crowded in hot conditions with poor ventilation is a major source of high humidity. The chapters that follow discuss in more detail design strategies to improve the thermal environment of the pilgrimage tents.

END- NOTES

1- Ministry of Finance and National Economy. Summary Statistics for Hajj of 1409 H. Riyadh: Ministry of Finance and National Economy of Saudi Arabia, 1989, p.8.

2- Hajj research centre. General Statistics of Hajj 85. Jeddah: University of Umm Alqura, 1986, p.19.

3- Hickish. "Thermal sensations of workers in light industry in summer. A field study in southern England." The journal of Hygiene, Cambridge: University press, 1955, p.116.

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6- SPSS INC. SPSS/PC+ V2.0 Base Manual. Chicago: SPSS INC, 1988, p.B-223.

CHAPTER VII

EXPERIMENTAL DESIGN

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CHAPTER VII

EXPERIMENTAL DESIGN

1- INTRODUCTION:

This chapter describes the experimental work conducted in the Muna valley during the months of August and September 1989. The chapter is structured to answer the following questions:

- What were the aims of the experimental study?
- What were the cooling strategies to be tested and why?
- How were comparisons between different strategies made and how were such differences measured?
- What precautions were taken to ensure fair comparisons?
- What were the variables to be measured?
- What were the instruments used?
- What difficulties were encountered and lessons learned from such experiments?

1- STATEMENT OF THE OBJECTIVES:

The experimental work described in this chapter aimed to determine design guidelines that would improve the thermal performance of tents at Makkah. To achieve this goal three natural cooling strategies were tested.

First was the ventilation strategy, which included four treatments, namely, minimum cross ventilation, maximum cross ventilation, minimum stack effect and maximum stack effect. Second was the radiation strategy which included treatments such as using heavier materials, a dark colour fabric and double roofing. Third was the form strategy which included increasing the height of the tent, and reshaping the geometry of the tent's roof. The three strategies were selected for they were practical and low cost to use for tents. They also represented the major principals of natural cooling. Due to financial and technical constraints the evaporative cooling strategy was not tested.

From these experiments measurements would be obtained which would enable the thermal effectiveness of the different treatments to be compared and evaluated. The results of these experiments would only apply to tents in hot arid climatic conditions.

2- THE DESIGN OF THE EXPERIMENTS:

Under each of the head strategies, number of experiments were conducted. Each experiment was designed to test the effect of one cooling treatment on the thermal environment of the tents. For example, ventilation strategy included four treatments and therefore four experiments namely to test minimum cross ventilation, maximum cross ventilation, minimum stack effect and maximum stack effect. A total of nine experiments were conducted according to the schedule presented in figure 7.1. For each experiment two tents were used, one the control tent and the other the experimental tent. The control tent was kept untreated throughout the experiments while the experimental tent was configured according to the treatment tested. Each experiment lasted for 72 hours, the time to give three days of weather cycle and reasonable to measure the quick thermal respond of the tent.

A number of dependent variables were measured inside both tents and included air temperature, relative humidity, globe temperature, air movement velocity and wet bulb globe temperature. The latter was established by using the following equation:[1]

$$WBGT = 0.7\, t_w + 0.3\, t_g \quad (7.1)$$

Where:

WBGT = Wet bulb globe temperature.

t_w = Derived Wet bulb temperature from the relative humidity and air temperature.

t_g = Globe temperature.

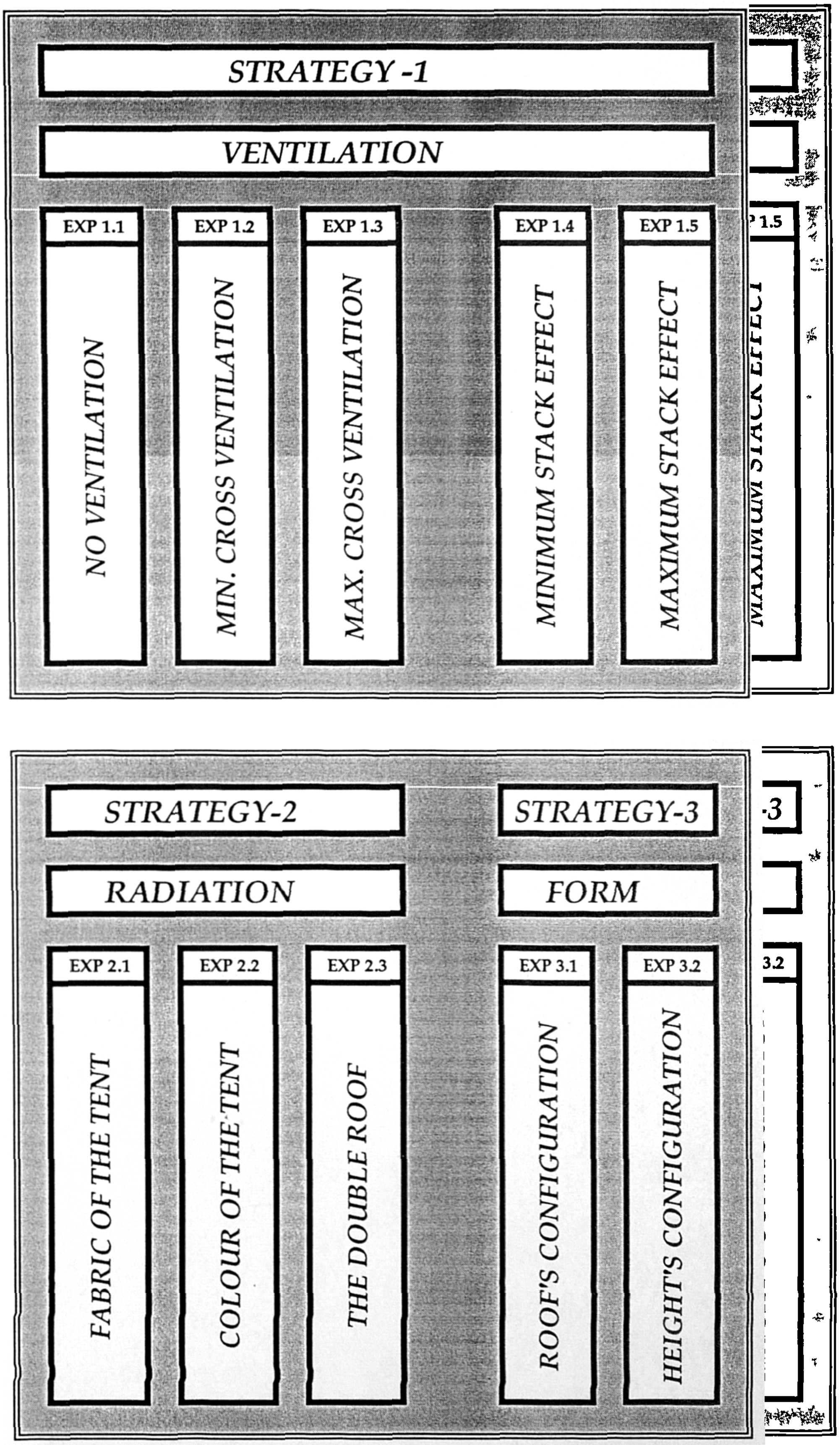


FIG 7.1: *Schematic diagram for ten experiments conducted in Makkah during the summer of 1989.*

The same variables were measured for external conditions in addition to solar radiation and wind speed. The wet bulb globe temperature for external conditions was established using a slightly different equation from above because of the effect of direct radiation from the sun:[2]:

$$WBGT = 0.7\ t_w + 0.2\ t_g + 0.1\ t_a \qquad (7.2)$$

Where:

WBGT = Wet bulb globe temperature.

t_w = Wet bulb temperature.

t_g = Globe temperature.

t_a = Air temperature.

Three natural strategies were tested, each consisting of a number of treatments. The ventilation strategy included two types of ventilation, cross ventilation and stack effect. Experiments regarding this strategy were designed to study the effect of the minimum and the maximum of each ventilation process.

The radiation strategy included three treatments: using a double roof, more closely woven fabric, and a darker colour. The double roof treatment was expected to reduce the solar load on the tent and therefore improve its thermal performance. The more closely woven fabric was expected to reduce solar penetration through the tent and result in a better thermal environment. The dark colour was not a cooling treatment but was tested since it supplied some needed information about the thermal advantages of the white cotton fabric. A total of three comparisons were made as follows: single layer tent with double layer tent, dense woven fabric with spaced fabric and dark colour with light colour. Fabric density and colour were selected on the basis of available materials which were most likely to be used in practice. The darkest available colour was khaki. The lightest density cotton material was that of 8 ounces and the most dense material was that of 20 ounces.

The strategy to study the effect of the tent's form on its thermal performance was also examined. The shapes of the roofs were tested: the pyramid and the flat. The flat roof was expected to receive the most exposure to solar radiation during the day, whilst parts of the pyramid shaped roof were expected to receive solar radiation and others remained shaded. Two different heights were also tested: the standard height of 3.00m and 4.5 m. By increasing the height of the tent it was expected that the thermal performance would improve as air circulation would be more efficient, due to stack effect and the mean air temperature at head height would be reduced.

2.1 EVALUATION OF RESULTS:

External and internal measurements were taken simultaneously at hourly intervals. Of the three sets of measurements (i.e., outside, control tent, and experimental tent) the external air temperature was expected to be the lowest as the outside instruments were shaded and ventilated. In contrast air temperature of the control tent was expected to be the highest as the tent was kept unventilated. The experimental tents would be expected to be between the two extremes. The effectiveness of each treatment, therefore, was measured by the difference between the treated tent and the control tent on the one hand and the treated tent and the outside environment on the other. In other words, the closer the thermal conditions of the experimental tent to that of the control tent the less effective was the treatment. In contrast, the closer the thermal conditions of experimental tent to that of the outside the more effective was the treatment.

2.2- PRECAUTIONS:

In all the experiments, precautions were taken to ensure that differences observed between the control and the experimental tents were due to the applied treatment and not to the interaction of other variables. The precautions taken are listed below:

1- Measurements were taken in the middle of each of the control and experimental tents and at the same height of 1.7 m, i.e. head height.

2- Measurements were taken simultaneously in both tents at hourly intervals.

3- Only good condition tents, with no tears were selected for the experiments.

4- The control and experimental tents had effectively the same dimensions.

5- All side wall openings, gaps between roof and walls and corners were stitched to reduce the effect of ventilation. For the same reason, walls were dug about 0.15m into the ground to eliminate gap.

No people were used in any of the experiments, although metabolic heat was simulated by using light bulbs, which were switched on and off according to the patterns of occupation observed during the pilgrimage of 1989. Most pilgrims occupied their tents in the morning, at noon, and during the night. While least occupation was observed in the evening from 16.00 hr to 20.00 hr. The number and the power of lamps were decided upon based on the density observed during the Hajj (10 pilgrims per tent) and their sedentary activity inside the tent. Ten incandescent lamps therefore were used each had a power of 100 Watts which were operated all day except during the hours of 16.00 hr to 20.00 hr. The light bulbs were sheltered by metal sheets so that the heat produced was scattered and evenly radiated inside the tents, and were located at ground level, 0.5m in from the east and west walls of tents.

3- THE SITE OF THE EXPERIMENTS:

Experiments were conducted at the site of the Hajj research centre in the Muna valley, located on the south-west hillside about 440 m above sea level. At such a height, the site was approximately 80 m above the average lowest point of the valley. The site of the Hajj research centre had several advantages, such as, easy access, large in area, and secure from public interference, and included the services needed to conduct the experiments such as nearly supervision, an electricity supply, office rooms, storage for tents and toilets. No other sites were suitable since they did not offer the same advantages.

Figure 7.2 presents the layout of the tents in the middle of the site. Of three tents erected one was kept unchanged throughout the period of the experiments, While the other two were the experimental tents, one undergoing treatment and the other being prepared for the next experiment. In pitching tents, several precautions were taken. Firstly, all tents were oriented with a wall facing towards the north. Secondly, the tents were pitched at a distance of about 20m from each other to prevent any obstruction to wind flow or shading. Thirdly, tents were pitched away from objects such as water sources, that might have increased ambient relative humidity, reflecting surfaces and heat sources that might have caused extra heat load on the tents, and walls that might have distorted wind speed or direction.

The best location for instruments measuring the outdoor environment was on the top of a storage room near the entrance, approximately 5m away from shade or wind disturbance. Adjacent to the site, to the north-east, was Muna meteorological station that was especially operated during the period of the experiments to measure wind speed and direction.

4- TENTS USED IN THE EXPERIMENTS:

Tents, obtained from the tent market at Makkah were available in different sizes and fabric materials, but the final selection was a square shaped one which is widely used during the Hajj known as the pilgrimage standard tent. The roof was square with one rope in each of four corners and three on each side. The side walls were reinforced at metre intervals with bamboo and stood between 1.60 m and 1.70 m high. A wooden centre pole that was between 2.95 m and 3.20 m long and 0.1 m in diameter divided in half for easy storage. Although the standard dimensions were 4m wide by 4m length, the actual dimensions were less and ranged from 3.70 m to 3.90 m. The tent weighed about 30 kg and collapsed into a bundle 2 m in length and 0.5 m in diameter. The fabric was made of cotton that varied in density. At the local tent market, such variations of density were expressed by the weight of the fabric and ranged from 8 ounces as the lightest and most commonly used to 20 ounces as the heaviest and the most expensive. The fabric of the tents was made of two layers sewn together; the outer layer being made of a white cotton fabric, and the inner layer being made of a translucent thin cotton fabric made of colourful strips of red, yellow, orange, green, and blue.

The erection of the pilgrimage standard tent required two people as is illustrated in figure 7.3. The roof of the tent was first unrolled, stretched out on the ground and tied with the ropes at the four corners. Two parts of the centre pole were then connected and the tent erected. The remaining twelve ropes were anchored and the tent received its final shape by the insertion of the side walls. The erection of the flat roof tent and the higher tent were different and are discussed in section 4.6 and 4.7.. The following seven sections describe tents used in the experiments as they appear in figure 7.4.

4.1 THE CONTROL TENT:

The control tent measured 3.80m in the width, 3.80m in the length, and 2.95m in height and used a cotton fabric that weighed 8 ounces. In all the experiments one control tent was used and kept sealed undergoing no treatment.

4.2 THE VENTILATED TENT:

One tent was used to test the effect of no ventilation, minimum cross ventilation, maximum cross ventilation, minimum stack effect, and maximum stack effect. The tent was identical in size and used the same material as that described for the control tent. Each of the north and south side walls of the experimental tent had two small openings that measured 0.30m by 0.26m which were used as windows in the form of a fabric grille, situated 1.2 m above the ground and were located near the corners of the tent. Each window had an external curtain shutter. The north and south side walls also had two large openings that were used as doors and measured 1m in width by 1.65m in height, and were located in the centre of the tent walls as indicated in figure 7.4.

The treatment of "no ventilation" was the first stage, in which the experiment tent was kept sealed from any ventilation, in exactly the same way as adopted for the control tent and described earlier in the precautions. The reason for this treatment was to detect any significant differences between the experimental tent and the control tent under the same conditions.

Minimum cross ventilation was the second stage of the experiment in which small openings facing north and south were opened. Maximum cross ventilation was the third stage in which the side walls of the experimental tent were dismantled leaving only the roof standing. Minimum stack effect was the fourth stage in which all openings were sealed and continuous strip of 0.2 m for ventilation was left at the bottom edge of the tent. The final stage of maximum stack effect, involved leaving open strip at the bottom of the tent opening and four other vents in the roof. Each of the roof vents was an equilateral triangle that measured 0.25 m, refer to figure 7.4. They were not shaded against solar radiation due to technical difficulties.

4.3 THE TENT MADE WITH DENSER MATERIAL:

The tent of this type had similar measurements to the control tent but the weight of the cotton fabric was 20 ounces.

4.4 THE COLOURED TENT:

The experimental tent used here was a dark khaki colour, the darkest colour available during the experiment (Black was only available for artificial or natural wool but not for cotton). Wool tents were rarely used during the Hajj time and expensive to rent, therefore, they were not within the scope of this study.

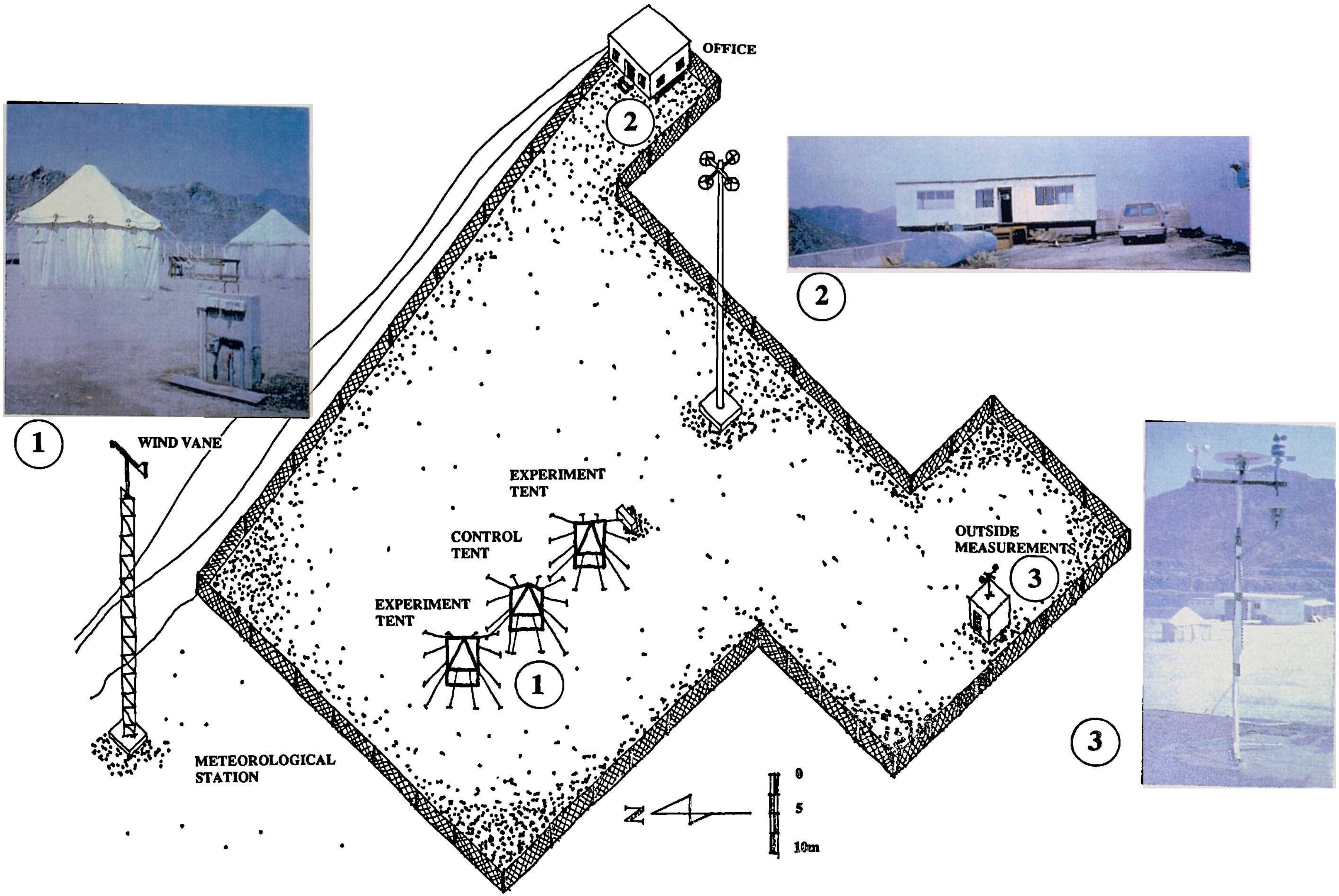


FIG 7.2: The site of the Hajj Research Centre at Muna valley, where exper ments were conducted.

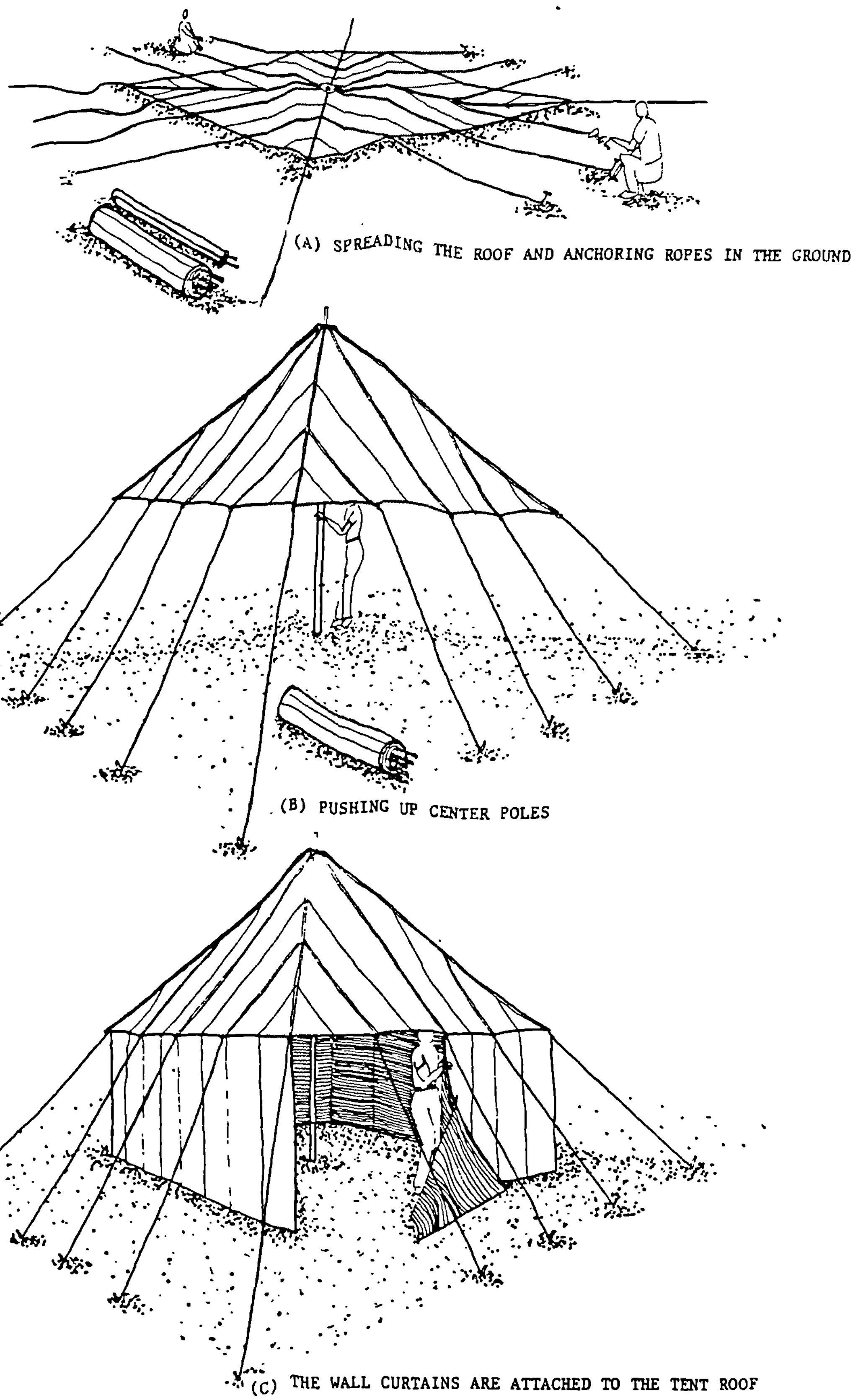


Fig.7.3: *Erecting the square standard tent.*

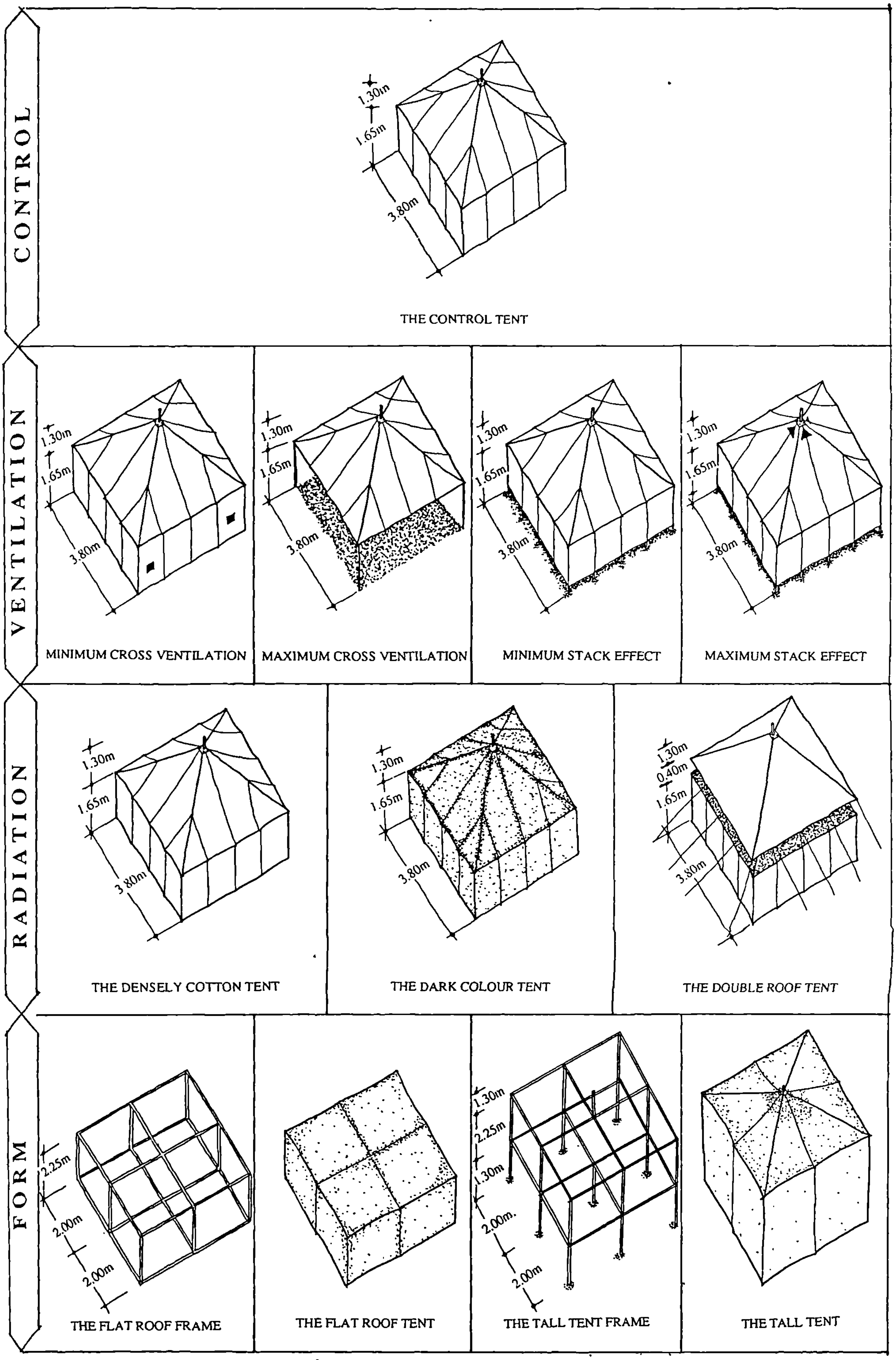


Fig.7.4: Tents used for experiments.

4.5 THE DOUBLE ROOF TENT:

The double roof tent measured 3.8m by 3.8m and the internal height was 2.95m. The roof consisted of two layers, with a gap of approximately 0.4m between each and was made of 8 ounce cotton fabric. To keep a clear gap between the two layers of the roof, the upper layer was stretched from all directions and the edges were supported with wooden spacers each measuring 0.40m in height.

4.6 THE FLAT ROOF TENT:

Since no flat tent was available in the local market, a special cubic frame was made for the experimental tent, designed to equal the volume of the control tent, i.e. $36m^3$. Measurements, therefore, were 4m x 4m with a height of 2.25m. The frame was made of steel tubes each measuring 2m in length and 0.025m in diameter and connected together by steel joints. A total of 18 joints were used, one at each of the eight corners, two at each of the four side walls for reinforcement, and two cross joints at the centre of the upper and bottom sides of the frame. The frame was covered with 8 ounce cotton fabric that was sealed at the corners and joints.

4.7 THE TALL TENT:

The same frame described earlier in the flat roof tent was adjusted to be used for making the tall tent. At the centre of the top side of the frame, a pole of 1.3 m was fixed to extend the height of the roof and to give it the pyramid shape. At the bottom side of the frame, eight legs were fixed to elevate the whole frame as indicated in figure 7.4. The extended legs were made of steel tubes and measured 1.3 m in length. These adjustments increased the height of the tent's apex to over one and half times the normal height, i.e. from 3.00 m to 4.70 m. The lower extended part was covered with 8 ounce cotton fabric and the whole tent was sealed against ventilation by sewing the joints and openings.

5- THE INSTRUMENTS:

Different instruments were used to measure two types of variables, internal and external. The internal variables included air temperature, globe temperature, relative humidity, and air speed. External variables included air temperature, globe temperature, relative humidity, wind speed, and solar radiation. All the instruments used in the field measurements the same instruments illustrated previously in figure 3.4 at chapter three.

5.1 THE INTERNAL MEASUREMENTS:

The probe used for measuring air temperature and relative humidity was an HMP 31 UT-Vaisala. The humidity and temperature sensors were housed at the tip of the probe and protected with a plastic grid. The accuracy reported for air temperature was $\pm$ 0.3 ^{o}C and for relative humidity $\pm$ 2% RH.

A matt black globe thermometer of 150 mm diameter was used to measure the globe temperature, A function of air temperature, mean radiant temperature, and air speed. A thermistor sensor was inserted at the centre of the sphere.

The air flow inside the tents was measured using the Prosser air velocity meter (AVM model 522) which consisted of a heat transfer probe and an analogue meter. The probe housed an electrically heated element exposed to the air for the purpose of measuring the air velocity. The element was very sensitive to heat loss caused by increased air speed. The influence of temperature on the velocity meter was manually compensated. The accuracy of the instrument was $\pm$5 % at high air flow of 5m/sec and $\pm$10% at low air flow of 0.05 m/sec..

The three instruments were mounted on a stand at the middle of the tent and at the head height of 1.7 m. The data for air temperature, relative humidity, and globe temperature were stored in the 12 bit- 1200 series Grant 'squirrel' data logger. Two squirrels were used for logging the data, one for each of the control and the experimental tents, and the readings stored for each hour was the average value of four scanning intervals.

The measurement of the air flow was recorded with a Rustrak model 288 recorder which presented as a series of dots. All recorders were protected against sun and dust by keeping them inside a wooden box outside the tents.

5.2 THE EXTERNAL MEASUREMENTS:

Instruments used for measuring the outside environment were positioned approximately 5 m above the ground. Measurements were taken at hourly intervals and simultaneously with those taken inside the tents.

Solar radiation intensity was measured by the Eppley Precision Pyramometer, model PSP, fixed horizontally facing the sky and away from any shade. A glass dome allowed solar radiation to penetrate through to a thermopile cell giving a voltage output.

Air temperature and relative humidity were measured using the Vaisala probe and shielded against solar radiation.

The outside globe temperature was measured using a globe thermometer similar to that described above for the internal measurements.

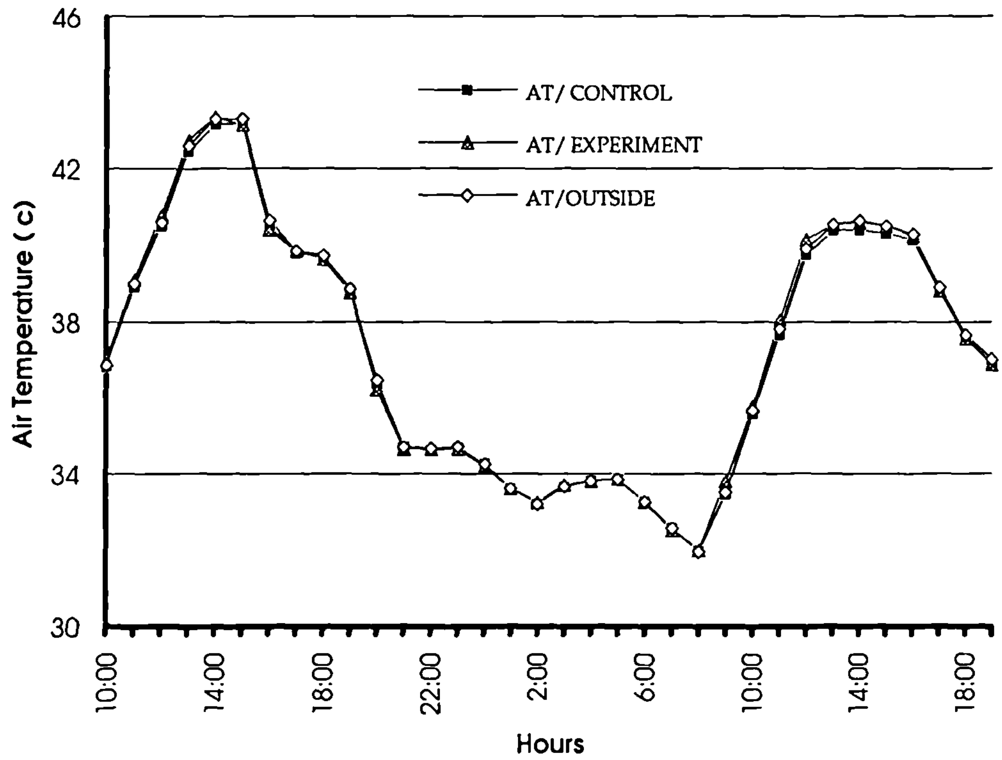
Wind speed was measured using the Porton power supplied anemometer, type A 100 powered by a 12 volts battery. The output was read in volts, and the accuracy of this instrument was ± 0.5 m/s.

Wind direction was determined manually using the KAHLSICO hand anemometer type (03AM120), being supplied with a compass indicator to facilitate alignment with the North. An index on the anemometer indicated the direction on a scale marked with cardinal and intermediate points. The manufacturer's stated accuracy of wind direction was better than $\pm 5^{o}$.

The meteorological station of the Muna valley was adjacent to the site of the experiments and especially operated during the period of the experiments. The station used a wind vane fixed at a height of approximately 20 m above the ground, and produced a continuous record of wind direction which was then presented on chart paper that indicated time and wind direction. The record was used to back up manual readings collected on the site of experiments.

Data from external measurements, except wind direction, were logged using the 1200 series squirrel and stored readings transferred to an IBM-PC computer using a simple transfer/analysis data manager program. The printout indicated real data and the time of measurement.

All the instruments were supplied by the Architectural Science Department of the University of Newcastle-upon-Tyne, and were with reference to international standards. Before commencing the experiments, the readings of the instruments were checked against each other by mounting them together in stevenson screen and collecting records. Figure 7.5 presents readings of air temperature and relative humidity measured for the period of 48 hours. The difference observed was within the calibration of the instruments, i.e., within the tolerance of $\pm$ 3% for the relative humidity and $\pm$ 0.5^{o} for the air temperature.



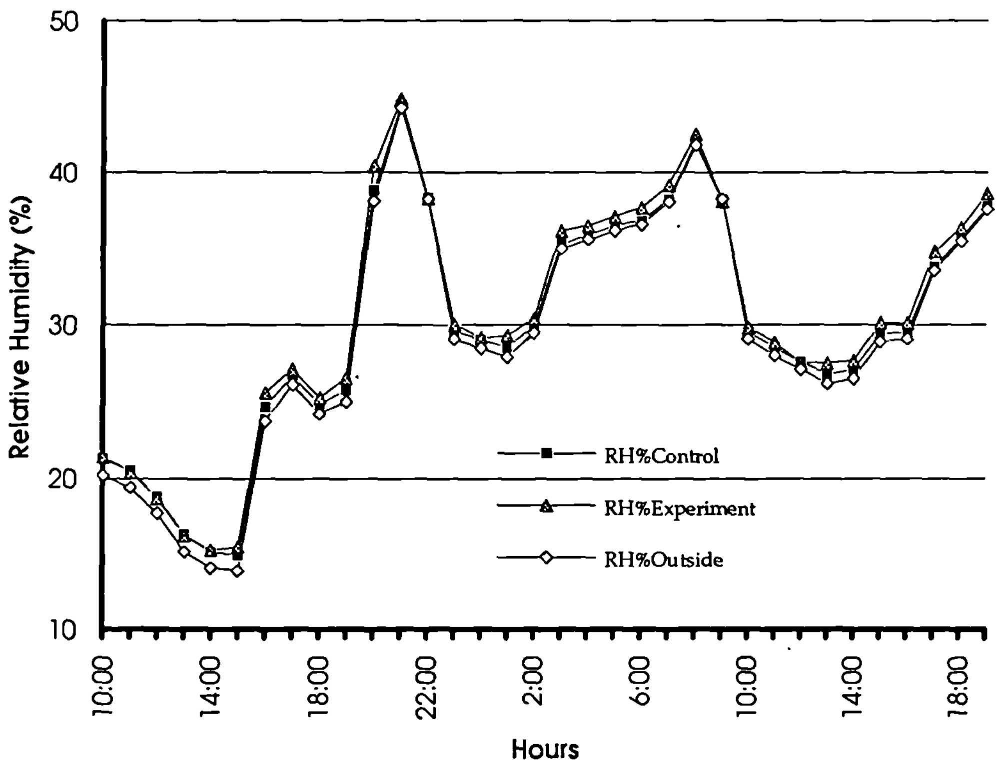


Fig. 7.5: *Typical readings for Air temperature and Relative humidity measured by the three probes used in the experiments.*

6- DIFFICULTIES:

The experiments were only possible to conduct with the kind co-operation of many departments. The Hajj research centre had offered the site of the experiments in the Muna valley. The Saudi National Guard and Al-Tamimi tent manufacturers supplied the tents. All the instruments were supplied by the Department of Architectural Science of the University of Newcastle-upon-Tyne. Meteorological and Environmental Protection Agency had operated their station at Muna during the period of experiments to measure wind direction. The following discussion highlights some of the difficulties experienced and the lessons learned from the field work that are suggested for future studies.

1. Missing one of the three data sets collected for the control tent, the experimental tent, and the outside environment would have invalidated the experiment. In fact, two of the experiments had to be repeated for this reason- the experiments to measure the effect of a dark colour and the roof's configuration on the thermal performance of tents. The unexpected delay of a week involved extra costs of living, labour, and the renting of tents as well as the arrangement for an extension to use the site and the computer service of the Hajj research centre. The missing data could have resulted from an inadequate memory size in the 12 bit squirrel logger used to store the data or from a shortage of power supply when transferring the stored data to the computer. In this respect it is advisable to have a computer facility at the site of the experiments, thus facilitating a speedier process of data transferring and analysis.

2. Due to the requirements of some experiments, special tents had to be made. Two tents were specially made, one as the flat roof tent and the other as the tall tent. In designing the flat roof, consideration was made to ensure there was an equal volume as the standard pyramid roof tent, but in constructing the tent, the

dimensions were cut slightly bigger resulting in the tent being about 8% bigger than originally designed.

3. Light bulbs were used in all the experiments to resemble heat emitted by human bodies, but in such a hot climate the effect was over exaggerated because the heat produced by the lights was emitted as sensible heat while the heat produced by human bodies is both sensible and latent. The latent heat is the heat taken up or liberated depends on the change of state of the water from liquid to vapour or vice versa.[3] The emission of sensible and latent heat depends on air temperatures and the degree of activity. The sensible and latent heat emissions of adult males for sedentary activities are presented in figure 7.6. For sedentary activity at 15^{o}C the latent heat is about 15% and the rest is sensible. For the same activity at 26^{o}C the latent heat increases to about 45% of the total heat emission. In the hot climate, i.e., for limits above that experimented by CIBCE and shown in figure 7.6, the evaporation of sweat is the body's principal method of dissipating heat. Therefore, the latent heat increases to represent the largest portion of heat emission. This means that the real effect of the heat emitted by the human bodies is far less than that emitted by the light bulbs. In general, this would mean slight increase in measured temperatures. The final comparisons between different cooling treatments, however, would not be affected because light bulbs were used simultaneously in both control and experimental tents, and the methodology used eliminated this effect by comparing differences of measurements rather than the actual ones. More about methodology of analysis is discussed in next chapter. For practical difficulties of controlling the amount of latent heat, no attempt was made to simulate latent heat input.

4. Due to the shortage of equipment, only one point was selected in the middle of the tent and at a height of 1.7 m to measure the thermal environment of tents. A more comprehensive picture could have been drawn if measurements were taken at different locations and at different heights. For example, measurements could have

been taken near the edges as well as in the middle of the tent and at different heights, for example at the ankle (0.1 m), the abdomen (1.1 m), as well as head height (1.7m). Ventilation speed could also have been measured at different heights, such as ground and ceiling levels.

In this study three strategies for natural cooling were tested namely radiation, ventilation, and the tent's form. Experiments were planned according to financial and technical constraints, the availability of instruments, time limits and the effort expected by an individual researcher. Due to such limitations other important cooling strategies, such as evaporative cooling was not tested. The output data and discussion for experimental results are the topics of the next chapter.

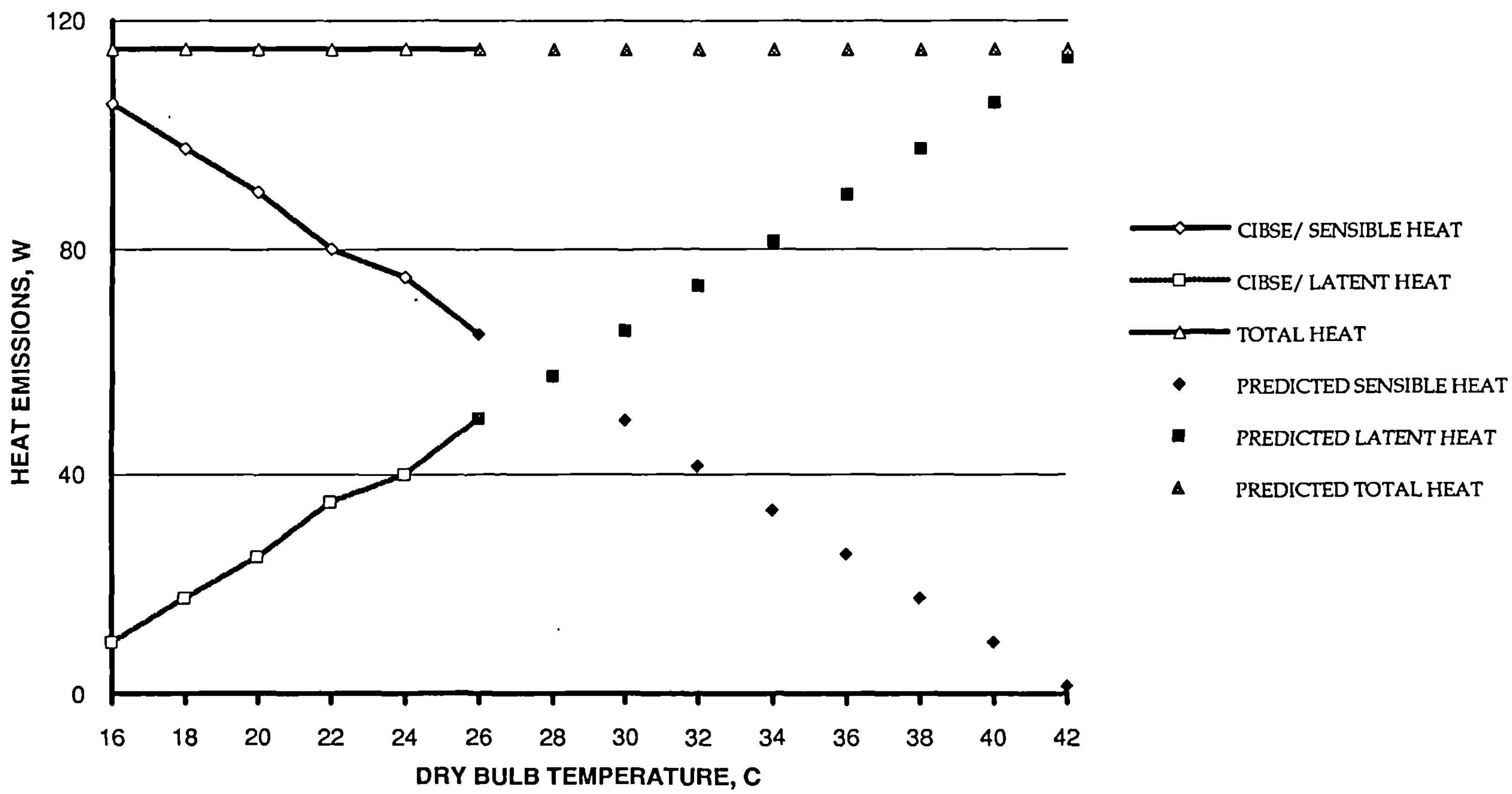


Figure 7.6: *Latent and Sensible heat emission from the human body engaged in sedentary activity*

After: CIBSE, CIBSE Guide, The chartered Institution of Building Services Engineers, London, 1986, pp.A7-3.

END- NOTES

1- Bruel and Kjaer, The automatic way to measure WBGT. Denmark: Bruel and Kjaer.

2- Ibid.

3- Alan Isaacs. Mini dictionary of physics. Oxford: Oxford University Press, 1988, p.166

CHAPTER VIII

THE EFFECT OF THE APPLIED TREATMENTS ON THERMAL CONDITIONS OF TENTS

TABLE OF CONTENTS

CHAPTER VIII

THE EFFECT OF THE APPLIED TREATMENTS ON THERMAL CONDITIONS OF TENTS

1-INTRODUCTION:

The previous chapter presented a review of the methods and equipment used to conduct the field experiments in the Muna valley. The experiments aimed to test different possible treatments in order to achieve better thermal conditions for the tents. The treatments applied fell into three sets:

1- The ventilation set included treatments of maximum and minimum cross ventilation as well as treatments of minimum and maximum stack effect.

2- The radiation set included the treatments of using a double roof, closely woven cotton fabric, and dark colour.

3- The form set included the geometry of the roof and the height of the tents.

This chapter aims to present an analysis and discussion of the results of the experiments. The analysis of the experiments has a twofold aim, first, to compare the different treatments applied as part of the natural cooling methods and second, to recommend which of the treatments applied provided the best thermal conditions.

The chapter starts by identifying methods and statistical procedures used for the analysis. The results are presented in two sections. The first section introduces results of the external measurements that describe the outside conditions for all the experiments. The second section deals with the results of the internal measurements for the control and experimental tents. In each section, the results were presented and their significance discussed.

The analysis of the results presents what happened when different treatments were applied while the discussion attempts to interpret why the particular results were obtained. Results, therefore, are discussed under separate headings according to the treatment of the experimental tents, i.e., ventilation, radiation, and forms. Discussion ended with a comparison of the treatments in terms of their respective performance.

2- METHODS OF ANALYSIS:

Data was collected for experiments that were conducted through a period of two months. The experiments were conducted in sequence and therefore were not subjected to the same weather conditions.

Three important sets of data were identified. First, the data describing the outside thermal conditions. Second, the data describing thermal conditions of the control tent, i.e., the tent with no treatments. Third, the data describing thermal conditions of the experimental tents. The thermal conditions of the control tent represented the reference for comparison of the other treatments. For most of the treatments applied, the control tent represented the worst conditions of all.

The data was analysed on two levels: firstly with respect to each individual treatment carried out (the individual level), and secondly with respect to the results of all the experimental treatments taken as a single group (the group level).

2.1- INDIVIDUAL LEVEL:

The analysis on this level aimed to compare the results of each experiment with that of the control tent and the outside environment. Prior to this the significant level of differences among the three sets of data had to be established to determine whether the results were statistically significant at the 5% level. The appropriate statistical procedure used was the t-test, usually used to examine the difference between the means of two groups and to indicate whether the difference in means is significant or simply apparent.

Analysis on this level was not only concerned with the statistical significance, but also the relationships between the three sets of data: experimental, control and outside. The extent to which the measures were related was determined using the Pearson's product-moment correlation coefficient which is a widely used method.[1]

2.2- GROUP LEVEL:

The comparison between different treatments was not straightforward. Treatments were applied on different days that were not homogeneous. The question arose as to whether the differences between the different treatments were real differences or simply a reflection of the fact that treatments were conducted on different days. To find the answer, the initial analysis step was to test the independence level of internal measurements on the variation of the outside. That is to test the significant level of the relationship between variations of internal measurements and that of the outside. The statistical procedure needed for such analysis is the correlation test. If the independence level was insignificant then different treatments can be directly compared without considering the variation of the outside. If, on the other hand and as normally expected, the independence level was significant then the variation of the outside had to be considered. At such a case, the appropriate statistical procedure to fairly compare treatments with each other was the analysis of covariance, Anova. Anova procedure with covariates eliminates the effect of the outside and adjusts therefore the means of the different treatments.

3- SITE CLIMATE:

The plots in figures 8.1 and 8.2 indicate the outside conditions of air and globe temperatures, solar radiation, relative humidity, and wind speed as had been measured at the site of the experiment. These were measured for the months of August and September 1989. The gaps of data indicated on the plots are either missing data or days when experiments were not conducted. The following sections describe site climate over the period of the experiments:

3.1- AIR TEMPERATURE:

The daily maximum external air temperatures ranged from approximately 38^{o}C to 43^{o}C with an average of 40.5^{o}C. The daily minima ranged from 29^{o}C to 34^{o}C with an average of 31.5^{o}C. The maximum and the minimum values of air temperature were recorded at 16.00 hrs and at 8.00hrs in the morning respectively. For a hot dry climate the diurnal range is very great: 17 to 22 degC but for the Muna Valley the range was small from 6 to 12 degC [2]. This small diurnal range is a distinguishing characteristic of the Muna valley and confirmed by measurements taken during the pilgrimage time of 1989, discussed earlier in chapter 3.

3.2-GLOBE TEMPERATURE:

The globe temperature was influenced by wind speed and air and mean radiant temperature. The average maximum temperature was 48^{o}C during the day with a difference of 7^{o}C above air temperature. The average minimum was 29^{o}C during the night with a difference of 2.5^{o}C below that of air temperature. The diurnal range, therefore, was larger than that observed for air temperature, reaching 19^{o}C, due to the effect of solar radiation during the day and radiant long wave during the night. An approximate estimation of mean radiant temperature from air and globe temperatures would give 55.5^{o}C during the day and 26.5^{o}C at night.

3.3- SOLAR RADIATION:

The intensity of solar radiation was measured on a horizontal plane for the months of August and September. Solar intensity reached its highest level of 1100 watts / m^2 at 14.00 hrs. when the sun's altitude was 81^{o}. The sun shone for an average of 11.5 hours per day and sky conditions were clear for all the days of the experiments.

3.4- RELATIVE HUMIDITY:

As the sun rose, air temperature increased and relative humidity rapidly decreased. The mean minimum was 16% rh recorded during the day, while the mean maximum was 40% during the early hours of the morning. Relative humidity varied significantly throughout the days of the experiments. For example, the maximum relative humidity recorded at the site was 80% at the beginning of September. Towards the end of September the minimum relative humidity dropped to 1%. As can be observed from the figures, relative humidity was negatively related to air temperature as would be expected. It was also negatively related to wind speed during the month of August and the first half of September. During the second half of September, the relationship with the wind was reversed, the increase in the wind speed the more the relative humidity. These two patterns of relationships with wind speed are explained by the prevailing wind direction. During the month of August and the first half of September, the wind was dry, blowing from the north and north-east. The wind during the second half of September was humid because it blew from the sea direction, i.e. west and north-west.

3.5- WIND SPEED:

The wind speed varied significantly during the days of the experiments. The daily maximum wind speed ranged from less than 1 to 7 m/sec. The wind was generally slight during the night and started to increase rapidly at 8.00hrs in the morning, reaching an average daily maximum of 3.5 m/sec around 18.00 hrs, after which it slowly decreased to very slight at midnight. The predominant wind direction was from the north and north-east during the months of August and the first half of September and west to north-west during the second half of September. During the period of the experiments, the wind carried no noticeable dust or sand, a further indication of the generally low wind speed.

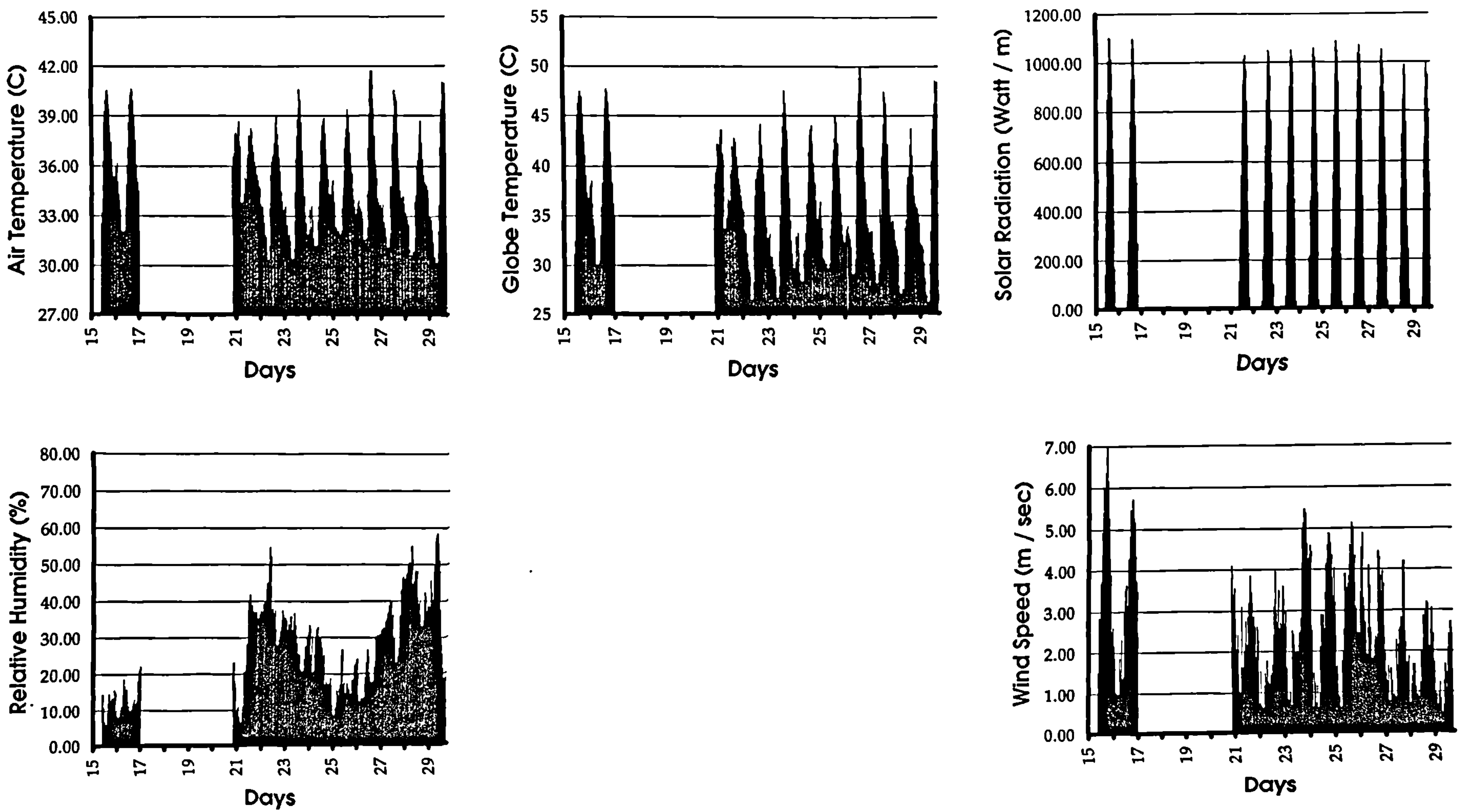


Fig 8-1: *Outside thermal conditions during the month of August*

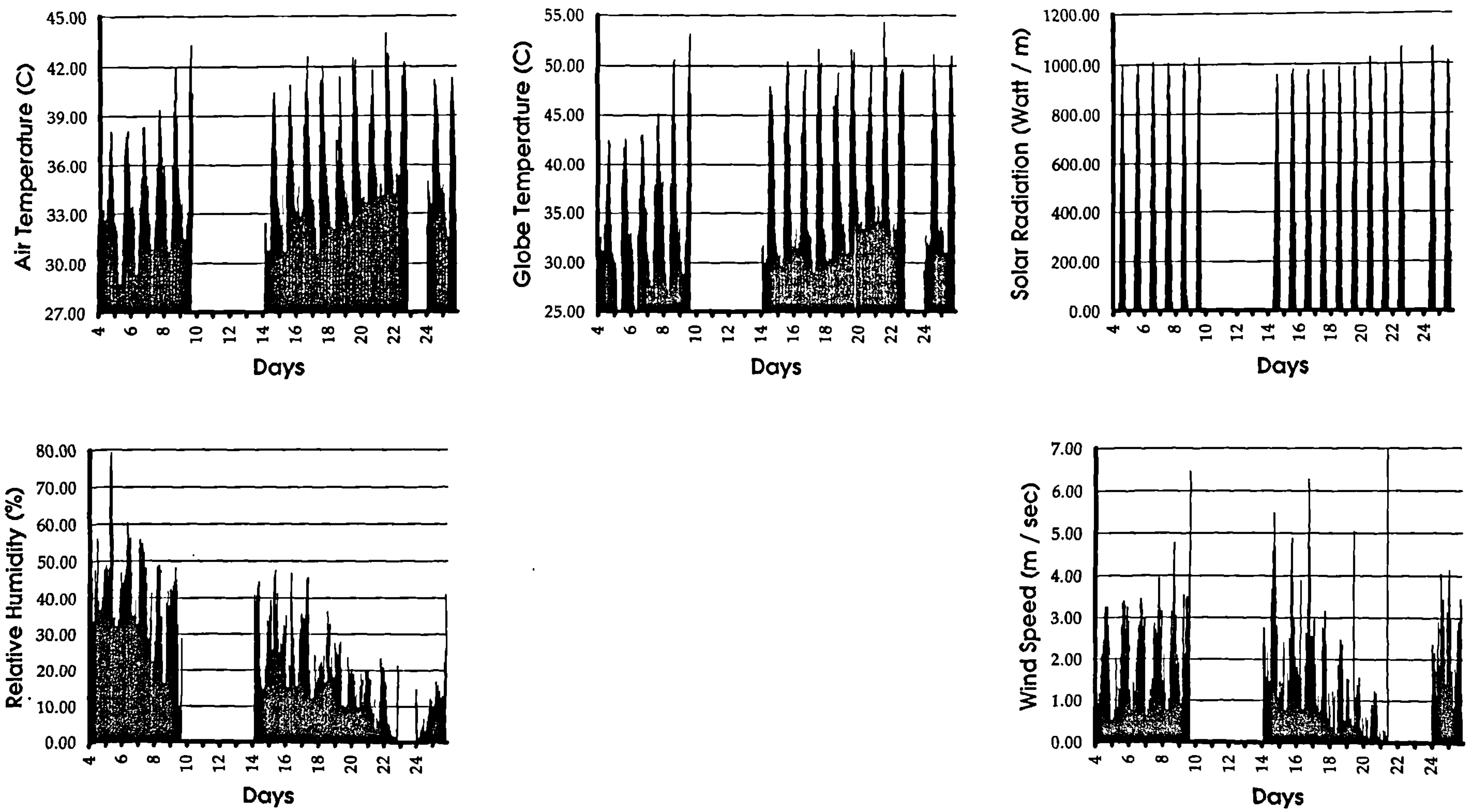


Fig 8-2: *Outside thermal conditions during the month of September.*

3.7- VARIATION OF OUTSIDE MEASUREMENTS:

It was essential at this stage to test the daily variation of outside measurements for two reasons. Firstly, if the variation was significant then outside conditions were not homogeneous and, therefore, must be considered when comparing the results of experiments. Secondly, if the variation was insignificant then it was reasonable to consider homogeneous outside conditions. For this purpose the analysis of variance (Anova) was applied to the data of outside conditions. Table 8.1 summarises the results of the Anova test. The table is divided according to the major divisions of the experiments, i.e., ventilation, radiation, and form.

Solar intensity had shown no significant variations throughout the days of the experiments. The outside globe temperatures were not significantly different for two of the experimental groups namely the ventilation and form groups. However, outside globe temperature varied significantly for the radiation experimental group. The outside air temperature was homogeneous in one set of experiments, the form group. Variation of outside temperature was significant for the other two sets, ventilation and radiation. Other outside measurements such as relative humidity and wind speed varied significantly during the experimental days.

In conclusion only one climatic variable was homogeneous for all the experiments, that was solar intensity. Globe and air temperature of outside conditions were homogeneous for some groups and significantly different for others. Relative humidity and wind speed varied significantly throughout all the experimental days. With the exception of solar intensity, outside variables had to be considered for any evaluation of treatments applied.

4- INTERNAL CLIMATE OF TENTS:

The averages of internal measurements for the control and experimental tents are plotted in figures 8.3 and 8.4 for all the experiments. The average measurements for outside conditions are superimposed for easy comparisons with internal and external conditions. The graphs are for air temperature, globe temperature, relative humidity, and ventilation speed. The following section presenting the results identifies the general patterns of internal climatic variables for both the control and experimental tents. The influence of individual treatments on tents is discussed separately.

4.1- AIR TEMPERATURE:

The maximum air temperature of the control tent ranged from 53°C to 58°C while the range for the experimental tents was wider and extended from 46°C to 60°C. This was obviously due to the different treatments applied to the experimental tents while the control tent remained unchanged for the period of the experiments. The range of minimum temperature remained within 8°C for both groups of tents regardless of different treatments applied to the experimental tents.

Internal air temperatures for the control and experimental tents fluctuated simultaneously with outside air temperature and with hardly any time lag. During the day, maximum internal air temperatures in the experimental tent exceeded the outside temperature by a range varying from 4°C to 22°C. The range was narrower for the control tent and varied from 13°C to 17°C.

After sunset the outside temperature reduced down to its minimum at 8.00 hrs, just before sun rise. During the same hours internal temperatures dropped to a level below or equal to the outside. However, the fall was interrupted by a sudden rise at about 23.00hrs- one hour after light bulbs were turned on. The light bulbs were used to simulate occupants' body heat. The rise continued until it reached its maximum between 2.00 hrs and 4.00 hrs. Internal air temperatures then dropped again to reach their minimum before sunrise at 8.00 hrs.

TABLE 8.1:

Summary of significant variations among the outside measurements, identified by using Anova test.

	OUTSIDE AIR TEMPERATURE									
	EXP 1.1	EXP.1.2	EXP. 1.3	EXP.1.4	EXP.1.5	EXP.2.1	EXP 2.2	EXP. 2.3	EXP. 3.1	EXP 3.2
EXP1.1: NO VENTILATION	-									
EXP1.2: MIN CROSS VENT.		-			*					
EXP1.3: MIN STACK EFFECT			-		*					
EXP1.4: MAX STACK EFFECT				-	*					
EXP1.5: MAX CROSS VENT.		*	*	*	-					
EXP2.1: 20 OZ COTTON						-	*			
EXP2.2: COLOUR						*	-	*		
EXP2.3: DOUBLE ROOF							*	-		
EXP3.1: ROOF'S CONF.									-	
EXP3.2 HEIGHT CONF.										-

	OUTSIDE RELATIVE HUMIDITY									
	EXP 1.1	EXP.1.2	EXP. 1.3	EXP.1.4	EXP.1.5	EXP.2.1	EXP 2.2	EXP. 2.3	EXP. 3.1	EXP 3.2
EXP1.1: NO VENTILATION	-	*	*	*	*					
EXP1.2: MIN CROSS VENT.	*	-		*	*					
EXP1.3: MIN STACK EFFECT	*		-	*	*					
EXP1.4: MAX STACK EFFECT	*	*	*	-	*					
EXP1.5: MAX CROSS VENT.	*	*	*	*	-					
EXP2.1: 20 OZ COTTON						-	*	*		
EXP2.2: COLOUR						*	-	*		
EXP2.3: DOUBLE ROOF						*	*	-		
EXP3.1: ROOF'S CONF.									-	*
EXP3.2 HEIGHT CONF.									*	-

	OUTSIDE GLOBE TEMPERATURE									
	EXP 1.1	EXP.1.2	EXP. 1.3	EXP.1.4	EXP.1.5	EXP.2.1	EXP 2.2	EXP. 2.3	EXP. 3.1	EXP 3.2
EXP1.1: NO VENTILATION	NO TWO									
EXP1.2: MIN CROSS VENT.	GROUPS ARE									
EXP1.3: MIN STACK EFFECT	SIGNIFICANTLY									
EXP1.4: MAX STACK EFFECT	DIFFERENT									
EXP1.5: MAX CROSS VENT.										
EXP2.1: 20 OZ COTTON						-	*			
EXP2.2: COLOUR						*	-	*		
EXP2.3: DOUBLE ROOF						*		-		
EXP3.1: ROOF'S CONF.									-	
EXP3.2 HEIGHT CONF.										-

	OUTSIDE WIND SPEED									
	EXP 1.1	EXP.1.2	EXP. 1.3	EXP.1.4	EXP.1.5	EXP.2.1	EXP 2.2	EXP. 2.3	EXP. 3.1	EXP 3.2
EXP1.1: NO VENTILATION	-				*					
EXP1.2: MIN CROSS VENT.		-		*	*					
EXP1.3: MIN STACK EFFECT	*	*	-	*	*					
EXP1.4: MAX STACK EFFECT		*	*	-	*					
EXP1.5: MAX CROSS VENT.	*	*	*	*	-					
EXP2.1: 20 OZ COTTON						-	*	*		
EXP2.2: COLOUR						*	-	*		
EXP2.3: DOUBLE ROOF						*		-		
EXP3.1: ROOF'S CONF.									-	*
EXP3.2 HEIGHT CONF.									*	-

	OUTSIDE SOLAR RADIATION									
	EXP 1.1	EXP.1.2	EXP. 1.3	EXP.1.4	EXP.1.5	EXP.2.1	EXP 2.2	EXP. 2.3	EXP. 3.1	EXP 3.2
EXP1.1: NO VENTILATION	NO TWO									
EXP1.2: MIN CROSS VENT.	GROUPS ARE									
EXP1.3: MIN STACK EFFECT	SIGNIFICANTLY									
EXP1.4: MAX STACK EFFECT	DIFFERENT									
EXP1.5: MAX CROSS VENT.										
EXP2.1: 20 OZ COTTON						-				
EXP2.2: COLOUR							-			
EXP2.3: DOUBLE ROOF								-		
EXP3.1: ROOF'S CONF.									-	
EXP3.2 HEIGHT CONF.										-

	OUTSIDE WBGT									
	EXP 1.1	EXP.1.2	EXP. 1.3	EXP.1.4	EXP.1.5	EXP.2.1	EXP 2.2	EXP. 2.3	EXP. 3.1	EXP 3.2
EXP1.1: NO VENTILATION	-	*	*		*					
EXP1.2: MIN CROSS VENT.	*	-		*						
EXP1.3: MIN STACK EFFECT	*		-	*						
EXP1.4: MAX STACK EFFECT		*	*	-	*					
EXP1.5: MAX CROSS VENT.	*			*	-					
EXP2.1: 20 OZ COTTON						-	*	*		
EXP2.2: COLOUR						*	-	*		
EXP2.3: DOUBLE ROOF						*	*	-		
EXP3.1: ROOF'S CONF.									-	*
EXP3.2 HEIGHT CONF.									*	-

* = Significant variation

The rapid drop of internal temperature during the night and the simultaneous peak with the outside temperature during the day reflected the very fast response to variations in outside environment. Internal temperatures were higher than external temperatures during the day for two reasons. Firstly the translucent nature of the tent's fabric increased solar gain during the day. The tent's fabric transmitted short wavelengths inwards but restricted the longer wavelengths of radiation outwards. Secondly no ventilation was permissible for the control tent but took place in the experimental tents. As a consequence, heat was trapped and a higher air temperature resulted in the control tent. A lower internal air temperature during the night was due to the high emissivity of the fabric and to the effect of radiation to clear night skies.

4.2- GLOBE TEMPERATURE:

Air speed inside the tents was very low, less than 0.1 m/s, which meant that there was very little forced convective heat exchange between the globe thermometer and the air. The measurements of air temperature and globe temperature were always very close from which it is concluded that the mean radiant temperature, MRT, is approximately close to readings of globe temperature. This implied that most of the heat build up inside the tents was mainly due to radiation. During the day, radiation was received mainly through two channels, direct transmission through the tent's fabric and radiation released due to heat absorbed by the fabric. During the night, wall and roof surfaces were cold due to radiation heat loss to the night sky. The maximum globe temperature was recorded at 16.00 hrs and reached 1°C above the internal air temperature. The night globe temperature recorded 0.2°C below the outside temperature. Globe temperatures followed the same general patterns as for air temperature.

4.3- RELATIVE HUMIDITY:

The minimum relative humidity for the inside of the control and experimental tents varied within the range of 1-30%, 3-15% respectively. The minimum range was recorded during the day time and the lowest figure generally occurred between 16.00 and 17.00hrs.. Internal and external relative humidity, then, sharply increased for the following 5 to 7 hours before reaching their first peak. At this point three patterns of relative humidity were identified. First, that relative humidity continued to rise slowly until it reached its maximum around 8.00 hrs. Examples of this pattern were the results from the experiment of maximum stack effect and the experiment concerning the tent's height. Second, that relative humidity dropped gradually to reach its minimum during the day such as that seen with the experiment of maximum cross ventilation. The majority of experiments, however, followed the third identified pattern where relative humidity dropped slightly at approximately 23.00 hrs but increased again to reach its maximum around 8.00 hrs, the average drop being about 10%. The average maximum relative humidity for outside, inside the control tent and inside the experimental tents varied from 22-58%, 25-54%, and 25-58% respectively.

Variations of internal relative humidity were mainly dependent on and positively related to variation of outside relative humidity. Outside relative humidity exceeded the internal relative humidity during the day by an average of 8%. Internal relative humidity, however, started to exceed that of outside from 20.00 hrs to 21.00 hrs. At this point the internal relative humidity could be either above, below, or equal to the outside relative humidity depending on the treatments of the experimental tents. The three patterns were in accordance with the treatments applied for each experiment. The difference between internal and external relative humidity was dependent on the ventilation allowed in the tent. More ventilation inside the tents resulted in less of a difference between internal and external relative humidity.

4.4- INTERNAL AIR SPEED:

The openings and windows of the control tent was sealed, preventing ventilation during the period of the experiments. Contrary to the pattern of outside wind speed, air movement inside the control tent increased during the night and decreased during the day. The maximum speed recorded at 0.1 to 0.25 m/sec during the night and ventilation was calm during the day. This suggested that the inside ventilation of the control tents was not responding greatly to any variation of outside wind. This phenomenon occurred when tents were not ventilated or poorly ventilated. In such cases the use of light bulbs as a model for human heat had a significant impact on ventilation speed inside the tents. During the night, large temperature gradients were expected between areas adjacent to the light bulbs, at the lower level of the tent, and the areas adjacent to the tent's cold surfaces at the higher levels. This increased the air movement due to convection. During the day, indoor air was easily affected by the inner warm surfaces of the tent. As a result, indoor air was more homogeneous in term of gradient temperature and, therefore, less air movement and calm speed was observed.

For the experimental tents, there was no common pattern for ventilation speed. Various patterns resulted depending on the internal and external conditions and the cooling treatments applied for each experiment. When the experimental tents were either not ventilated or poorly ventilated, a similar pattern to that described earlier for the control tent was observed. However, the range of speeds was lower, i.e. less than 0.15 m/sec. When the experimental tents were ventilated, the maximum air speed increased to fall within a range of 0.5 to 1.3m/sec, air speed responded to outside active wind during the day and continued to be active during the night mainly due to the effect of the heat from the light bulbs.

4.5- VARIATION OF INTERNAL MEASUREMENTS:

Before further discussion or deriving more conclusions, it was important to test significant variations of the measurements presented earlier. The reason for this step was to be totally confident that variations and differences observed earlier between control tents, experimental tents, and the outside were real and not due to errors or chance. Errors in such measurements could have arisen from using different instruments, or using different tents for the experiments.

A summary of the significant levels, using the t-test analysis, is presented in tables 8.2 for air temperature, globe temperature, relative humidity and ventilation speed. A comparison was made of the mean scores of the three groups: control tents, experimental tents, and outside. It is important to emphasise that differences examined here are between individual treatments and the control (i.e., the individual level). A comparison between the different treatments (i.e., the group level) are discussed separately in section 5.4 of this chapter.

Some treatments have shown strong evidence that there are significant differences between the control and outside groups of measurements. Some others showed that the difference was not large enough to reach statistical significance. Results are discussed accordingly in the following section.

5-DISCUSSION:

The ventilation set included experiments with no ventilation, minimum and maximum stack effect, and minimum and maximum cross ventilation. The radiation set included experiments with closely woven cotton fabric, dark colour, and double roof. The form set included two roof styles: a pyramid shape and a flat roof and two heights: 3.5m and 4.65m.

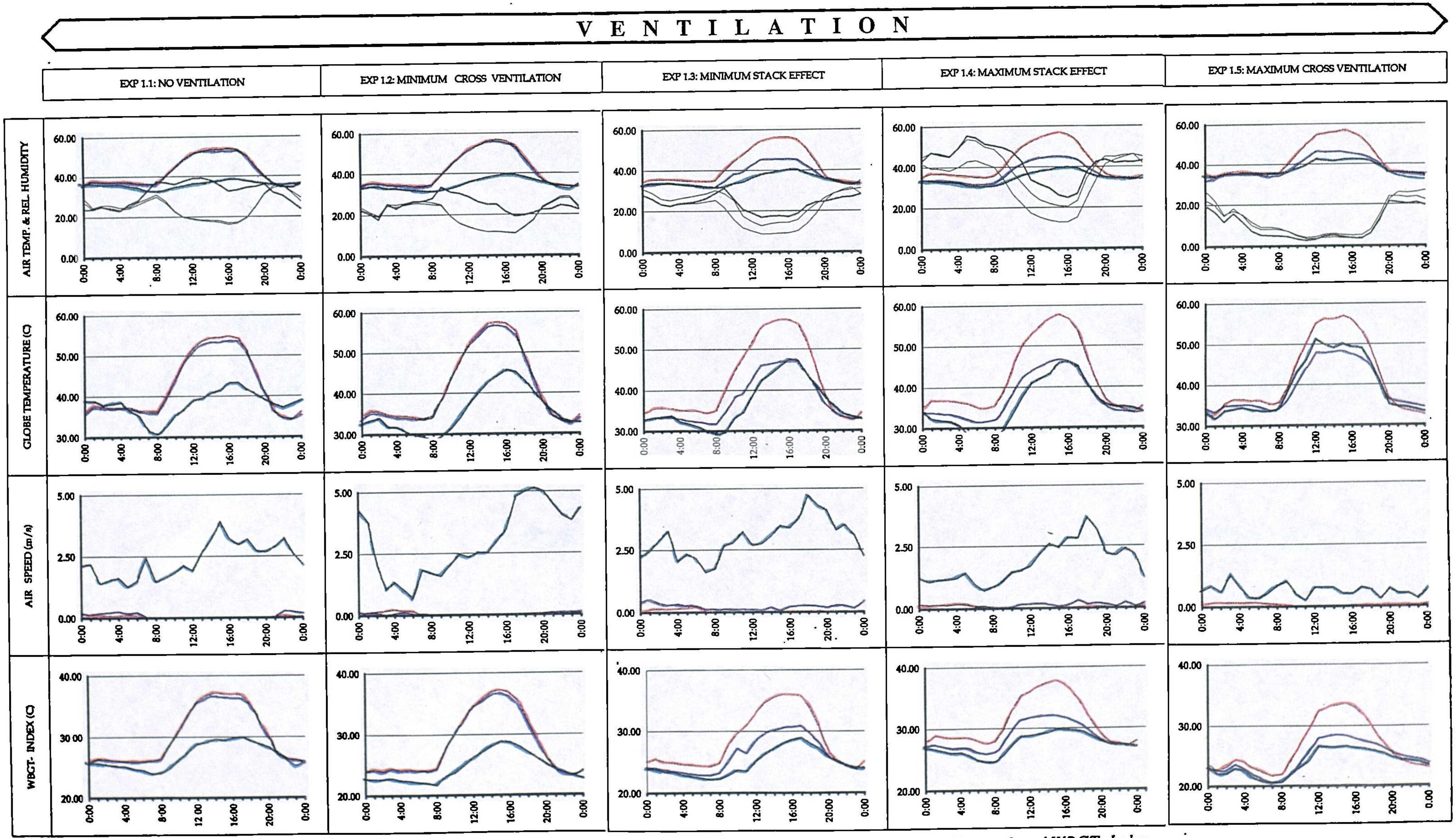


FIG. 8.3: *Profiles of Air temperature, Relative humidity, Globe temperature, Air speed, and WBGT- Index measured for control tent, red colour, experimental tent, blue colour, and outside, green colour.*

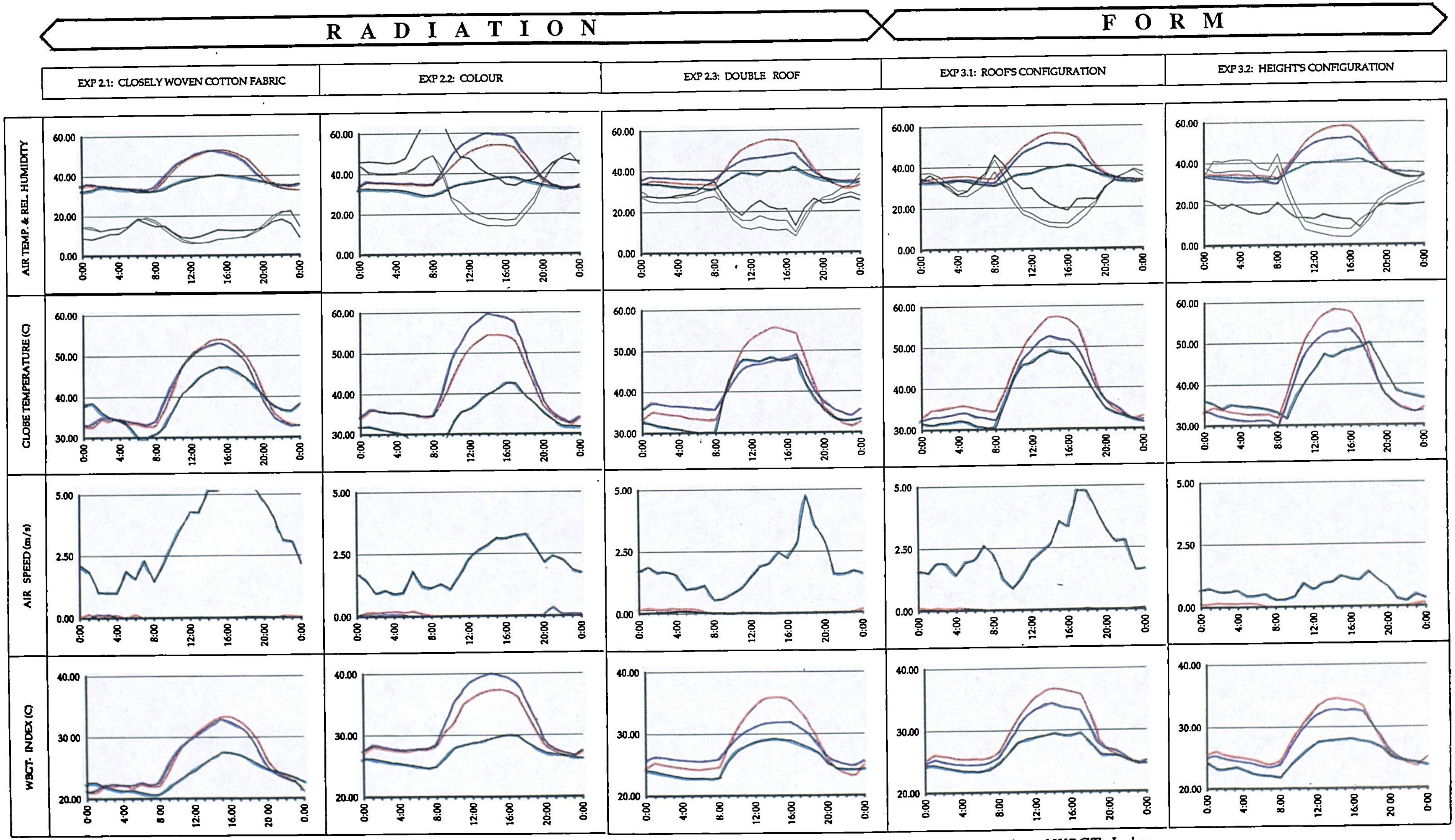


FIG. 8.4: *Profiles of Air temperature, Relative humidity, Globe temperature, Air speed, and WBGT- Index measured for control tent, red colour, experimental tent, blue colour, and outside, green colour.*

TABLE 8.2:

A summary of significant variations among three groups of data: control, experimental and outside.

	VENTILATION SET					RADIATION SET			FORM SET	
	EXP 1.1	EXP 1.2	EXP 1.3	EXP 1.4	EXP 1.5	EXP 2.1	EXP 2.2	EXP 2.3	EXP 3.1	EXP 3.2
AIR TEMP.	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * # -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -
GT	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * # -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E * -; O # # -
RH%	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * # -	C -; E * -; O * * -	C -; E # -; O * * -	C -; E # -; O # # -	C -; E * -; O * * -	C -; E # -; O # * -	C -; E * -; O * * -	C -; E * -; O * * -
A.SPEED	C -; E * -; O * * -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E # -; O * * -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E # -; O * * -	C -; E * -; O * * -
WBGT	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -	C -; E * -; O * # -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E # -; O * * -	C -; E * -; O * * -	C -; E * -; O * * -

C= CONTROL TENT, E= EXPERIMENTAL TENT, O= OUTSIDE, (*)= SIGNIFICANT VARIATION, (#)= INSIGNIFICANT VARIATION

5.1- THE VENTILATION SET:

The internal air temperatures of the experimental tents fluctuated between air temperatures recorded for the control tent and the outside. The control tent was kept unventilated and recorded the highest air temperatures during the day. The maximum air temperature for the control tent ranged from 54 to 57°C, recorded between 15.00 and 17.00 hrs. The control tent, therefore, had the worst thermal conditions with respect to air temperature in the group. The outside maximum air temperature of this group ranged from 38-42°C also recorded between 15.00 and 17.00 hrs. The outside air temperature of this group, therefore, had the best possible natural thermal conditions of this group.

The air temperature of the experimental tents was nearer to that of the outside conditions when more ventilation was introduced as expected. Similarly when ventilation was poor or not permitted, the temperature was nearer to that of the control tent. The unventilated tents had a maximum air temperature 16°C higher than that of the outside. This difference was reduced to only 4°C when maximum cross ventilation was permitted inside the tent. Moreover, the difference between the mean score of the fully cross ventilated tent and outside was not significant according to the t-test shown in Table 8.2.

The globe temperature inside the tents with little or no ventilation was higher than the outside globe temperature mainly due to higher air temperatures in the tents. The average difference reached about 10°C. The introduction of ventilation resulted in the internal globe temperature being lower or no more than 0.5°C higher than that of the outside. The maximum drop in internal globe temperature was observed when maximum cross ventilation was permitted. This small difference between the internal globe temperature and that of the outside was insignificant according to the t-test.

Based on the results of this group, the maximum cross and stack ventilation were able to lower the globe temperature to levels similar to that of the outside. The reason for the large reduction in internal globe temperature with high ventilation is due to the reduction in internal air temperature combined with the shading effect of the tent. The internal radiation would also be reduced due to the lower internal surface temperature.

Since no moisture gains were introduced into the tents, the moisture content of the air in the tents was always the same as that of the outside air. Ventilation rate therefore makes no difference and any difference in relative humidity between inside and outside is purely as a result of temperature difference. The relative humidity recorded for the tent with open side-walls and maximum cross ventilation, was not significantly different from the unventilated tent, i.e., the control tent even though the control tent had a higher temperature. The reason for this is that relative humidities were in any case very low (around 10%) and at these values changes in temperature only make a small difference.

It was clearly demonstrated by this group of experiments the importance of both vertical and cross ventilation in reducing air temperature. However, it was not possible at this stage to say which way was the best, as it was not known whether the reduction in air temperature was due to the treatment itself or due to conducting the experiments on different days. This is what the section (5.4) aims to determine.

5.2- THE RADIATION SET:

The second group of experiments was concerned with the radiation effect and included treatments such as using a more densely woven material, double roof, and dark colour. The temperature of the tent for this group ranged from 32-54^{o}C. The average minimum difference compared to the outside was 1^{o}C and the average maximum difference was 14^{o}C. The minimum temperature was recorded at 08.00 hrs and the maximum at 14.00 -15.00 hrs. The experimental tents varied in their range and behaviour according to the treatments applied.

5.2.1- FABRIC MATERIAL:

The difference gained by using a heavy weight cotton material (20 ounces) was insignificant in relation to the lightweight cotton fabric (8 ounces). It was interesting however to notice that the rate of increase in air temperature inside the heavy weight tent was slower during the hours from 8.00-12.00 noon. Air temperatures were similar for both tents from 12.00hrs to 15.00hrs. The decrease in temperature in the lightweight control tent, was faster than the heavy weight experimental tent. This remained the case until about 22.00 hrs. As the maximum air temperatures were recorded as the same for both tents, so the minimum air temperatures were also the same from 22.00 hrs to 8.00 hrs.

The same observation as for air temperature could also be made for globe temperatures measured for both tents. Relative humidity was negatively related to air temperature. Therefore, the decrease of relative humidity was slower in the experimental tents (20 oz.) from 08.00 hrs to 12.00 hrs and faster from 18.00 hrs to 22.00 hrs. Relative humidity for both tents was the same from 12.00 hrs to 18.00 hrs. Using 20 oz cotton fabric had no significant impact on the internal air velocity which remained below 0.2 m/sec.

The behaviour of the "heavy weight" tent compared with that of the "lightweight" tent is as one would expect, with the heavy weight tent exhibiting a time lag with respect to temperature change. On the one hand it has an advantage in slowing the rate of heat gain. Yet on the other hand, it has the disadvantage of slowing the rate of heat loss to the outside of the tent. This may have resulted due to different thermal properties of the 20 oz cotton fabric. For example, it may permit less translucence but be more heat absorptive, being more densely woven, the 20 oz fabric was less porous and permeable than the 8 oz fabric.

5.2.2- COLOUR OF THE TENT:

Internal temperatures of the dark coloured tent exceeded that of the light coloured tents by a maximum of $6^{o}C$. As a result of the higher air temperature inside the dark tents, the relative humidity was lower than the white tent by a maximum of 5%. The globe temperature inside the dark tent was $5^{o}C$ above that of the white tent during the day but similar during the night. As for the rate of air movement, no significant difference was observed between the two tents.

Different colours have different coefficients of absorption and reflection. As the colour of the fabric gets darker the surface becomes greatly heated on exposure to the sun due to its high absorptivity and low reflection of radiation. This absorbed heat in turn was released to the inside and the outside by means of radiation and convection. As the colour of the fabric gets lighter the surface becomes less heated because of its optimum reflectiveness and low rate of absorption. Air temperatures of both tents were similar during the night. Emissivity, which is important when considering heat loss is almost always high, regardless of the colour of the tent fabric. This meant that black and white fabrics were equally cooled at night by radiation to the cooler outside environment.

5.2.3- DOUBLE ROOF:

The double roof comprised an outside layer which provided shade for the inner layer. The use of the double roof tent resulted in lower air temperatures during the day, the maximum difference being $7^{o}C$. During the night, however, it was the single roof tent that had the advantage of a lower air temperature by at least $3^{o}C$. The advantage of lower air temperature inside the double roof during the day was however offset by higher air temperature during the night. This explained why mean scores of air temperature appear insignificant in Table 8.2. A similar reason may have explained why mean scores of the globe temperature and relative humidity for both tents appeared insignificantly different from each other. Globe temperature was

7^oC less in the double roof tent during the day. At night the double roof tent maintained a globe temperature at least 2.5^oC higher than the single roof tent. Relative humidity of the single roof tent exceeded the double roof tent by a maximum of 9%. The double roof tent, however, was more humid during the night by at least 2%. The maximum air speed inside the single roof tent was twice as much as for the double roof tent. Although the maximum value did not exceed 0.2 m/sec.

The double roof tent was effective in reducing the maximum air temperature because the heat transfer to the inside the double roof tent was less compared to the single roof tent. The internal space of the tent is influenced by the underside surface temperature of the roof. The single roof tent is directly exposed to solar radiation. Hence, the underside surface is considerably heated causing appreciable radiant heat load to the interior space. The introduction of a further layer of material and the formation of an air space in the roof results in the double roof having a lower thermal transmittance (U value) than the single roofed tent. Being better insulated, the double roof tent has a lower rate of heat transfer to the inside during the day which results in a lower air temperature.

Heat build-up during the day was primarily lost through long wave radiation during the night. The double layer of the tent placed a restriction on radiative cooling at night. This explained the increase of night temperatures inside the double roof tent above that of the single roof.

5.3- THE FORM SET:

This set contains two treatments. First is the geometry of the roof which tests thermal performance of a flat roof tent in relation to a tent with the convential pyramid-like roof. Second is the height of the tent that tests thermal performance of 4.65m height in comparison with the tent of 3.5m.

5.3.1-GEOMETRY OF THE ROOF:

The geometry of the roof affected the thermal behaviour of the tent in several ways. It determined the amount of solar radiation incident on the roof. The surface normal to the sun's rays intercepted the greatest amount of heat. However, two important factors needed to be considered when examining the geometry of the roof: orientation of the slope and the surface area exposed to radiation. For example, the pyramid roof had four sloping facades each of which was oriented towards a different geographical direction and therefore received various amount of radiation during the day. Incident roof collected more solar radiation in the morning and afternoon. The horizontal roof received more heat, however, at noon.

To illustrate the above effect, the total irradiance falling on to the sloped and flat tents was estimated and presented in table 8.3. Total irradiance was determined based on the calculation procedures described in CIBSE guide[3]. The calculation included the influence of direct, diffused and ground reflected radiation. Particular attention was given to radiation gain from 9.00 to 15.00 hrs since it represented the hottest period of the day. On average, the pyramid roof received 21% less radiation than the horizontal roof while vertical walls received 24% less than that of the flat tent. This was similar to the portion of the surface area in each tent. Due to the change in the configuration, the vertical walls of the flat tent had to be larger to give the same volume as the pyramid tent. For both tents, almost half of the total radiation was received by the vertical walls and the other half was received by the roofs.

The above argument so far would expect there to be less radiation received, therefore, better thermal conditions for the pyramid tent than the flat roof. Results in figure 8.4 however show the contrary, i.e., better thermal conditions for the flat roof tent. Air and globe temperatures were lower by a maximum of 5°C during the day and an average of 3°C at night. Relative humidity results confirms temperature measurements, during the day, relative humidity was higher in the flat roof tent by a maximum of 6%. At night relative humidity was also higher but with an insignificant value of 2%. The ventilation difference between the two forms of tents was insignificant and remained stable, below 0.1 m/sec.

The author suspected that the better performance for the flat roof tent was solely due to the geometry of the tent's roof. Due to the leakier nature of tents, infiltration rate became significantly important in heat exchange. The available data was insufficient to accurately calculate the infiltration rate. However, it was reasonable to assume that the infiltration rate was positively related to the surface area of the tent. That is to say the infiltration rate was not similar for both tents, as the total surface area of the flat roof tent was larger than the pyramid tent. Although both tents were made taut, due to technical difficulties the horizontal tent comprised a larger area in that it was constructed of more joints and connections than originally designed. Under such circumstances it was difficult to offer a fair comparison between the two forms and future experiments will be needed with careful attention being paid to the infiltration rate.

5.3.2- HEIGHT OF THE TENT:

Increasing the height of the tent's apex to 4.65 m resulted in better thermal conditions during the day compared to the conventional height of 3.5m. Air and globe temperatures were lower by a maximum of 5°C during the day and by a minimum of 2°C during the night. Relative humidity reached an average of 4% higher than the control tent. Ventilation speed in both tents remained below the level of 0.2m /sec. Differences in relative humidity and air speed were statistically significant but were not great enough to affect the comfort sensation to any extent.

Increasing the height of the tent inevitably involved an increase in the volume of air and an increase of the surface area of the material. Controlled experiments to study each effect separately were not a practical proposition.

TABLE 8.3:

Calculated solar radiation intensity (direct and diffused) falling into walls and roofs' surfaces of flat and sloped roof tents.

	FLAT ROOF TENT							SLOPED ROOF TENT									
Time	Flat Roof	Flat Roof	North Wall	East Wall	South Wall	West Wall	Total Wall	North Roof	East Roof	South Roof	West Roof	Total Roof	North Wall	East Wall	South Wall	West Wall	Total Wall
	w/m2	w	w/m2	w/m2	w/m2	w/m2	w	w/m2	w/m2	w/m2	w/m2	w	w	w	w	w	w
6:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00	170	2720	67.5	547.5	112.5	67.5	7314	153.9	393.9	176.4	50	3871	621	5037	1035	621	7314
8:00	415	6640	141.3	771.3	266.3	141.3	12144	369.4	684.4	431.9	75	7804	1300	7096	2450	1300	12144
9:00	635	10160	201.3	786.3	401.3	201.3	14628	85	853.8	661.3	85	8426	1852	7234	3692	1852	14628
10:00	810	12960	252.5	687.5	512.5	252.5	15686	100	932.4	844.9	100	9886	2323	6325	4715	2323	15686
11:00	925	14800	283.8	518.8	583.8	283.8	15364	105	932.6	965.1	105	10539	2611	4773	5371	2611	15364
12:00	965	15440	293.8	293.8	608.8	293.8	13708	105	849.8	1007	849.8	14059	2703	2703	5601	2703	13708
13:00	925	14800	283.8	283.8	583.8	518.8	15364	105	105	965.1	932.6	10539	2611	2611	5371	4773	15364
14:00	810	12960	252.5	252.5	512.5	687.5	15686	100	100	844.9	932.4	9886	2323	2323	4715	6325	15686
15:00	635	10160	201.3	201.3	401.3	786.3	14628	85	85	661.3	853.8	8426	1852	1852	3692	7234	14628
16:00	415	6640	141.3	141.3	266.3	771.3	12144	369.4	75	431.9	684.4	7804	1300	1300	2450	7096	12144
17:00	170	2720	67.5	67.5	112.5	547.5	7314	153.9	50	176.4	393.9	3871	621	621	1035	5037	7314
18:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The improvement in the thermal conditions of the taller tent is probably due to two main reasons. Firstly one would expect the taller tent to exhibit a smaller variation of temperature with the height and therefore at the measurement point of the experiments, the same for each tent, a lower temperature would be expected in the taller tent. Secondly, the temperature gradient and tent height are together responsible for the stack effect which tends to induce cooler air into the tent at the lower levels. Since the taller tent has a bigger surface area of porous fabric than the normal tent it is expected that the ventilation rate would be increased which provides increased cooling. At night, one may expect the temperature gradient to be reversed due to radiation cooling to the top of the tent.[4]

Sabbagh and Khalipha (1983) reported that the height of the tent plays an important role in advancing the mechanism of convection and replacing it with cool outside air through the tent fabric. In this respect increasing the height of the tent is essential in keeping hot air away from the occupants' level.

5.4- AN EVALUATION OF THE TESTED COOLING TREATMENTS:

The experiments were designed to compare different treatments for natural cooling. The effect of the individual treatment on thermal conditions of the tents was measured by the difference between the control and experimental tents. The control tent, also called "reference" tent, received no treatment. The experimental tents which received the treatments are referred to as "treated" tents. The lower the temperature in the experimental tent comparing with that of the control tent the better the thermal conditions. Thermal conditions were measured using the index of wbgt. The wbgt-index was selected for it combined the effect of the same environmental factors as a human being experiences when exposed to a hot environment (i.e. air and radiant temperature, air velocity, and humidity). The wbgt-index has also been used in an International Standards Organisation standard (ISO 7243-1982) to evaluate hot environments.

Figure 8.5 presents the correlation test between the two variables measured for each experiment. The horizontal axis is the outside wbgt. The vertical axis is the wbgt difference between the control and the experimental tents. Inspection of the data suggests that correlation coefficients are all positive and range from weak to very strong. The relationship is weak, 0.38, when the height of the tent was increased and very strong, 0.96, when the roof of the tent was doubled. Correlation coefficients for other treatments fell within the range of strong to very strong, i.e. from 0.55 to 0.84. Regression lines are superimposed for each plot. Different regression lines have different slopes. The higher the slope the better the thermal conditions of the experimental tents, i.e., due to the treatment applied. The lower the slope the less effective was the treatment in improving thermal conditions. It is interesting to notice that the vertical axis also has negative values. That is because the wbgt of the reference tents exceeded, at some times and for some treatments, that of the experimental tents.

To elaborate on this, three patterns can be identified. The first pattern is when all the values were negative . The only example of this is when the tent was dark coloured. Clearly the performance of the coloured tent was the worst of all.

The second pattern is when all the values were positive. The set of ventilation experiments demonstrates this clearly; thermal conditions were better when ventilation was permitted.

For the previous two patterns, Δwbgt in both the reference and experimental tents came closer during the night and diverged during the day. This made the applied treatments most effective during the day and less effective during the night.

The third pattern is when some values were positive and other values negative. Two clear examples represent this pattern: when the tent's roof was doubled, and when the tent's material was more dense. The negative values were observed during night hours from sunset to sunrise. It means, for instance, that double roof or thicker materials can be of great advantage during the day when protecting the tent's envelope from the sun. It is not so during the night where it will reduce the heat loss.

As discussed earlier in the methods of analysis, one question must be first addressed before attempting any comparison between different treatments. That is whether the wbgt differences between different treatments were real differences or simply a reflection of the fact that treatments were conducted on different days. The initial analysis step was to find the independence level of internal measurements on the variation of the outside.

From the analysis presented in figure 8.5, clearly the Δwbgt, Y-scores, were significantly dependent on the outside wbgt. Because treatments were applied on different days, some values of the outside wbgt were low for some treatments and other values were high. This is clearly seen from regression plots in figure 8.5. The next step was to set out an analysis of covariance to adjust the means of different treatments so they could be fairly compared with each other in order to eliminate the effect of the outside wbgt. Since the results of the tent geometry experiment were not conclusive they have not been included in the overall comparison.

Table 8.4 comprises four sections that summarise the analysis for the applied treatments. Section (A) analysed the relation between Δwbgt and the outside wbgt in the absence of treatments. There seemed to be a significant linear relationship between the two variables. This means using the outside wbgt as a covariance is useful and may explain more of the variation in Δwbgt. Section (B) is an analysis of variance for Δwbgt, Y-variable. Section (C) is an analysis of variance for outside wbgt, X-variable. From examining the analysis of variance it is clear that there were significant differences both for Δwbgt and the outside wbgt. The introduction of the covariance in section (D) had not affected the significance of the treatment effects. In other words, the difference between treatments is real and not due to the conducting of experiments on different days.

Applied treatments are listed in order according to their "adjusted means" in table 8.5 for three periods: day only, night only and day and night together. The list for the three sections shows the top, i.e. the best, three treatments to be the ones connected with ventilation namely: "min stack ventilation", "maximum cross ventilation", and "maximum stack ventilation".

The list suggests that "min stack ventilation" was a better treatment than the "maximum stack ventilation" during the day time. The tent with the maximum stack ventilation treatment used unshaded openings in the roof. This allowed for the penetration of solar radiation and hence increased the heat load inside the tent. More evidence is given in Section (c) of the table. In the absence of solar radiation during night time, the "maximum stack ventilation" is classified to be more effective than the "minimum stack ventilation" and attained the best of all treatments.

The list in sections (a and b) also suggests that "minimum stack ventilation" is a better treatment than the "maximum cross ventilation". Although maximum cross ventilation allowed for more ventilation, it also permitted indirect and reflected radiation from the ground and surrounding surfaces. This probably explains why the "minimum stack ventilation" treatment is superior to the "maximum cross ventilation" treatment during the day time.

The tent made of more dense cotton fabric, 20 oz, had shown a better performance than the double roof tent during the day time. Indeed, the double roof tent is shown near the bottom of the list in sections (a) and (c) but near the top in section (b). The double roof was a very effective treatment during the day, for it protected the tent's envelope from solar radiation and therefore it appears near the top in section (b). During the night, however, the double roof blocked internal heat from escaping by radiation to the night sky and therefore it appears at the bottom of section (c). It is because of these opposing characteristics that it appears toward the bottom of section (a).

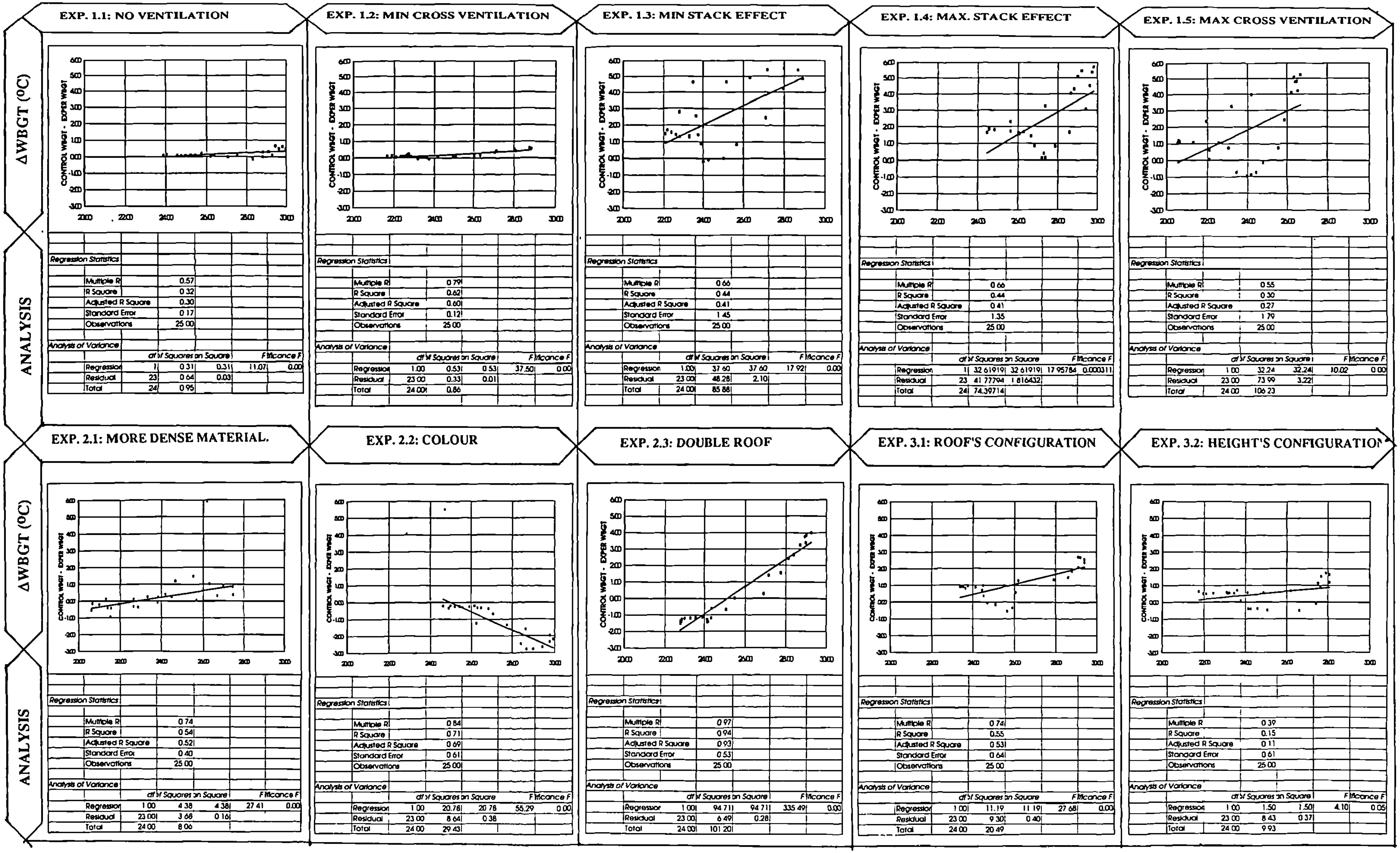


Fig 8.5: Statistics and relationship between outside WBGT (x-axis) and Δ WBGT between experimental and control tents (Y-axis) for all experiments.

TABLE 8.4:

Summary of statistical analysis used to test significant variations among different cooling treatments

Multiple R	0.25567		
R Square	0.06537		
Adjusted R Square	1.72185		
Analysis of Variance			
	DF	Sum of Squares	Mean Square
Regression	1	46.24036	46.24036
Residual	223	661.14216	2.96476
F = 15.59665	SIGNIF F= 0.0001		

Section A: Regression analysis of A wbgt, dependent, with outside wbgt, independent.

Source of variation	Sum of Squares	Df	Mean Square	F	Signif F
Covariates	46.24	1	46.24	30.594	0.00
WBGT of Outside	46.24	1	46.24	30.594	0.00
Main Effects	336.188	8	42.024	27.804	0.00
Experiments	336.188	8	42.024	27.804	0.00
Explained	382.428	9	42.492	28.114	0.00
Residual	324.954	215	1.511		
Total	707.383	224	3.158		

Section D: Analysis of variance *for* A *wbgt* with outside wbgt.

Source of variation	Sum of Squares	Df	Mean Square	F	Signif F
Main Effects	290.445	8	36.306	18.8	0.00
Experiments	290.445	8	36.306	18.8	0.00
Explained	290.445	8	36.306	18.8	0.00
Residual	416.938	216	1.93		
Total	707.383	224	3.158		

Section B: Analysis of variance for A wbgt, Y- Variable.

Source of variation	Sum of Squares	Df	Mean Square	F	Signif F
Main Effects	396.297	8	49.537	11.347	0.00
Experiments	396.297	8	49.537	11.347	0.00
Explained	396.297	8	49.537	11.347	0.00
Residual	942.975	216	4.366		
Total	1339.273	224	5.979		

Section C: Analysis of variance for the outside wbgt, X- Variable.

TABLE 8.5:

Multiple Classification Analysis for three periods of the day.

A- Day and night time.

Category	Number	Unadjusted mean	Adjusted mean
1- Minimum stack effect	25	2.446	2.656
2- Maximum cross ventilation.	25	1.746	2.226
3- Maximum stack effect	25	2.446	1.836
4- More dense material (20 oz).	25	0.156	0.706
5- Increasing the height.	25	0.506	0.666
6- Minimum cross ventilation	25	0.186	0.466
7- Double roof	25	0.386	0.326
8- No ventilation	25	0.176	-0.284
9- Dark color	25	-1.164	-1.694
Grand mean=0.766	Multiple R Squared= 0.541	Multiple R= 0.735	

B- Day time only.

Category	Number	Unadjusted mean	Adjusted mean
1- Minimum stack effect	12	4.079	4.319
2- Maximum cross ventilation.	12	3.519	4.019
3- Maximum stack effect	12	3.879	3.429
4- Double roof	12	2.109	1.859
5- Increasing the height.	12	2.298	0.939
6- More dense material (20 oz).	12	0.269	0.789
7- Minimum cross ventilation	12	0.269	0.449
8- No ventilation	12	0.289	-0.101
9- Dark color	12	-2.111	-2.571
Grand mean=1.459	Multiple R Squared= 0.838	Multiple R= 0.915	

C- Night time only

Category	Number	Unadjusted mean	Adjusted mean
1- Maximum stack effect	15	1.212	1.362
2- Maximum cross ventilation.	15	0.232	1.142
3- Minimum stack effect	15	1.092	1.062
4- Dark color	15	-0.358	0.248
5- Minimum cross ventilation.	15	0.082	0.182
6- More dense material (20 oz).	15	0.102	0.164
7- Increasing the height.	15	0.182	0.142
8- No ventilation	15	0.102	0.032
9- Double roof	15	-1.098	-1.118
Grand mean=0.172	Multiple R Squared= 0.634	Multiple R= 0.796	

Contrary to the previous example of the "double roof" is the "dark colour tent". At the very bottom of the list during the day and as expected is the dark tent that shows a negative mean and represents the worst treatment. Dark colour was not significant as a treatment during the night because of the similar emissivity to the light colour.

It is apparent from sections (b and c) of table 8.5 that increasing the height of the tent is more effective during the day than the night. The greater difference between inside and outside globe temperatures during the day than the night is expected. This may result in greater stratification effect during the day than the night and therefore increasing tent's height is more effective treatment during the day than the night.

6-CONCLUSION:

Different cooling strategies were applied for the pilgrimage tent including ventilation, radiation, and form configuration. Their effects on thermal performance of tents were tested and discussed in the previous sections. The main findings are summarised below:

1- Ventilation is the best of all cooling strategies tested in this study. It was demonstrated the importance of ventilation both cross and stack effect in reducing air temperature during the day and the night.

2- In providing cross ventilation during the day, one precaution must be considered, that is, to prevent the effect of indirect and reflected radiation from the ground and surrounding surfaces. Similarly, in providing the stack ventilation by means of the tent's roof, shade must be provided and the roof's vents should not allow for penetration of solar radiation.

3- Radiation strategy had shown opposite effects during the day and the night and must, therefore, be applied carefully. For example, the double roof protected the tent's envelope from solar radiation during the day and hence lower air temperatures were achieved. This made the double roof to be only second to the ventilation treatments during the day time. During the night time however the double roof obstructed internal heat from escaping to the night sky, hence, high air temperatures were recorded. This classified double roof to be the last and rather undesirable to apply.

4- The heavy weight tent had the advantage of slowing the rate of heat gain yet it had the disadvantage of slowing the rate of heat loss to the outside of the tent. The difference gained by using a heavy weight tent (20 oz) during the day was insignificant in relation to the performance of 8 oz.

5- The dark colour fabric absorbed the maximum amount of solar radiation and appeared as the worst of all treatments during the day time. During the night, however, the thermal performance of the dark colour was not significantly different from the light colour since emissivity of both colours approached the same value.

6- Increasing the height of the tent's apex to 4.65m resulted in better thermal conditions compared to the conventional height of 3.5m. Increasing the height of the tent is essential in keeping hot air away from the occupants' level. To this end result of height's configuration does not indicate whether the same improvement can be obtained with lesser height. This would need proper measurements at different heights which were not possible during the field work due to the shortage of instruments.

7- Internal temperatures within tents are determined by the effect of two factors: heat flow across the tent's envelope, and ventilation. Future study of testing the thermal effect of cooling strategies on tents should consider measurements of surface temperature and ventilation speed at various locations inside tents.

END- NOTES

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2- 2-Koenigsberger, Ingersoll , Mayhew, and Szokolay. Manual of tropical housing and building. London: Longman, 1980, p.27.

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CHAPTER IX

PRINCIPLES AND DESIGN GUIDELINES FOR NATURAL COOLING

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CHAPTER IX

PRINCIPLES AND DESIGN GUIDELINES FOR NATURAL COOLING

1- INTRODUCTION:

The aim of this chapter is intended to determine design criteria to serve as guidelines to treat the over heating problem experienced during the Hajj. It should be established that the aim of this study is not to provide comfort so much as to relieve discomfort. Various passive and active techniques were available to improve the environmental conditions for the hot arid climate. This chapter focuses on passive cooling treatments suitable for the temporary nature of Hajj accommodation.

This chapter begins by examining the passive cooling principles, which include protection from solar radiation, and the use of ventilation and evaporation and explains the role they play in easing the harsh climate of the Muna valley. The limitation and the maximum potential for each one is also considered. Design guidelines are presented in two sections, one for the indoor climate and the other for the outdoor climate and are differentiated because each requires different cooling treatments. The basis for the design guidelines arose out of the experimental study conducted by the author on tents during the summer of 1989 and other thermal studies, including the latest work conducted for Expo'92 at Seville in Spain.

2- GENERAL COOLING PRINCIPLES RELATING TO THE MUNA VALLEY:

The climatic conditions in the Muna valley are severe in terms of overheating and it is necessary to design the tents so as to minimise overheating problems.

Three essential climate control principles can act passively to minimise the overheating problems, namely; solar heat control, ventilation, and evaporation.

2.1- PROTECTION FROM SOLAR RADIATION:

The sky conditions in the Muna valley are clear and total solar radiation reaches over 1000 W/m^2 during the summertime on a horizontal plane and becomes a major contributor to thermal discomfort. Direct exposure of the human body to such intense radiation can result in heat disorder or total collapse of the body, depending on the body's level of acclimatisation and length of exposure.

Any attempts to block radiant exchanges, both short and long waves, must be given immediate attention as many authors, for example Givoni and Szokolay, have considered it essential to drastically reduce all radiant interchange before implementing any further cooling strategies. According to the ITS thermal index, used earlier in Chapter 4, radiation heat exchange represented about 45% of the total heat gain to the tent during most of the daytime. To improve the thermal conditions inside the tents, a further reduction in radiation is essential, and can be achieved by three strategies: shading, orientation, and insulation.

2.1.1- SHADING:

To achieve good shading it is necessary to consider the materials and geometry of the shading device. As far as tent materials are concerned shading is unlikely to be perfect and two major aspects which must be considered are heat transfer to the inside of the tent by radiation and convection from the underside of the material and transmission of some radiation directly through the material when it is not completely opaque. Reradiation and convection depends on the temperature of the underside of the material which in turn is a function of the reflectivity and absorbtivity. To avoid the overheating of the covering's underside, materials must be selected of low absorbtivity and high reflectivity and a reduction of the total area exposed to radiation must be aimed for. Materials used must be as opaque as possible to ensure a low level of direct solar transmission through the material. The shape of the shading devices must be such as to assure that the shadow cast completely covers the occupied space.

2.1.2- ORIENTATION:

The effectiveness of tents as shading devices must take into account a number of factors relating to the orientation:

(a) The need for solar radiation: While solar radiation penetrating the occupied areas during the summertime is unwanted, higher solar intensity may be welcomed during the wintertime. The season during which the Hajj takes place slowly changes from year to year and tents must be designed for both summer and winter conditions. The sun in the Muna valley during the summer is high the most of the day, for example, at midday on June 21 the sun is only 0.5^{o} off the vertical and it is the summer conditions that causes the major problems.

(b) The position of the surface in relation to the sun: The intensity of solar radiation on a surface depends on the surface's orientation and its angle of incidence to the sun. Values of solar intensity at different orientations for the Makkah location are tabulated and can be obtained directly from published solar data (such as IHVE, 1971). From these tables and the solar geometry the radiation on different facades can be determined. The east and west vertical facades receive the maximum intensity of solar radiation, where the east facade is more exposed in the morning and the west facade in the afternoon. The vertical northern facades receive the least solar radiation, because though exposed to the sun, the angle of incidence is such that the sun's rays are almost tangential to the surface of the facade before and after midday. In the early morning the angle of the sun's altitude and intensity was low. The southern wall was slightly affected by the sun at noon but with low intensity since the angle of declination was high. The tent's surface tilting east receives more direct solar radiation at noon while the tilted surface to the west receives more radiation after midday.

According to measurements conducted by Zaki et al (1991) for the tent's roof, eastern tilted facades received, in total, 39% more radiation than those tilted to the west. The tilted surface facing south received the maximum solar radiation, for this orientation was exposed to the sun for most of the day. It was established that a southerly orientation was the best direction for collecting solar radiation while a northerly orientation received the least radiation.

Generally speaking, the best orientation is when the east and west facade areas are minimised and north and south areas maximised. This provides valuable information regarding the arrangement of groups of tents.

2.1.3- INSULATION:

Insulation is an attempt to control heat transfer by increasing the thermal resistance of a wall or roof and reducing, as a result, heat flow from the outside to inside. The procedure however, of adding an insulation layer to the tent's fabric is discouraged for two reasons. Firstly, any insulation of occupied tents although reducing heat flow from the outside to inside during the day would also tend to increase the heat build up inside the tent. In this regard, Sabbagh and Khalifa (1983) conducted an experiment in which a tent's roof was insulated with a layer of 0.025 m glass wool sandwiched between two paper sheets covered with aluminium foil. The results in figure 9.1 indicate a higher air temperature through the day and night for the occupied and insulated tent. The insulation layer would reduce the infiltration and the radiation transmitted through the fabric and therefore *contributed to the high air* temperature measured inside the tent. The number of occupants was also an explanation for this result, for where there were more than three occupants, the insulated tent was warmer than the uninsulated one, and the heat generated inside the tent (mainly metabolic) continuously built up without it being removed through the insulated tent fabric.[1] The second reason of discouraging the use of the insulation layer is it expensive in cost and adds weight and thickness to the tent's fabric, adding to the burden of storing and transportation.

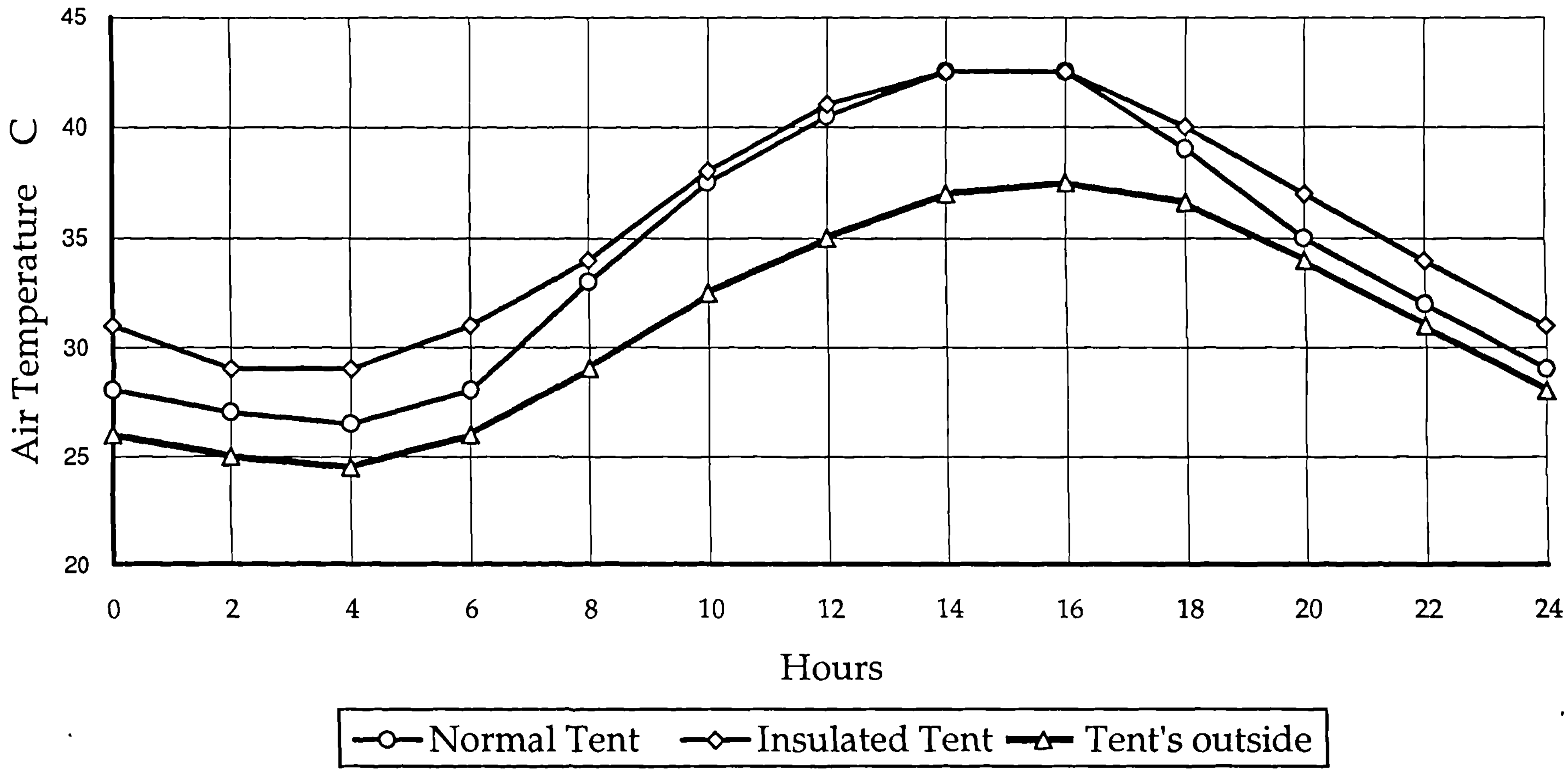


FIG. 9.1: *Effect of insulation on the air temperature inside the tent.*

After: Sabbagh and Khalifa. "Improving the design of tents for better thermal comfort," Jeddah, 1981, p.182

2.2- VENTILATION;

The measured indoor air temperatures of tents in the Muna valley exceeded those of the outside by an average maximum of 6°C. The simplest strategy for improving the thermal conditions inside the tents, therefore, is to increase the indoor ventilation rate. From the experiments discussed in Chapter 8, when the tent was cross-ventilated, the indoor air temperatures closely followed the ambient air temperature.

On the other hand, measured indoor and outdoor temperatures still tended to be above the skin temperature during day time. A common opinion argues that when such conditions occur high air speed is not important or even desirable, as it can increase the body's heat gain. Experience in hot arid climate (Givoni, 1991-a) suggests that even with an air temperature of about 40°C, a high air speed actually reduces discomfort by reducing the wetness of the skin, i.e., the perspiration of the skin evaporates and heat is lost from the body. As a result, the skin temperature is lowered but also the air in contact with the skin is saturated. This ambient air needs to be removed by ventilation otherwise the process of evaporation will be reduced and the feeling of discomfort will increase.

To enhance natural air movement on the skin, two processes can be applied. In the first, differences in wind velocity produce a pressure differential across the tent that results in air flowing from the higher to the lower air pressure region. In the second process, air is warmed, causing convection with the warm air rising and being replaced by cool air. The rate of airflow caused by the second process is determined by the difference in the level of openings, with greater airflow resulting from greater differences in the heights of the openings.

Although increasing air movement is desirable, upper limits of air speed must be determined and many attempts have been made to determine the upper limits, (Ashrae, 1985) and (Givoni, 1991-a). Experiments have produced different results.

The Ashrae guide specifies 0.8 m/s as the highest indoor speed allowed. However, Givoni was critical about the application of the Ashrae air speed limits to hot climates. He sees the Ashrae limit of 0.8 m/s as "*Too restrictive when dealing with providing comfort in unconditioned building in countries with hot summers.*"[2] Givoni and Arens suggested, therefore, that air speeds of 1.5 to 2 m/s were considered as comfortable in hot climates. However, they agreed that the continuous exposure to higher air speeds may be unpleasant. On the basis of this argument, it is reasonable to assume 2 m/s as the upper tent internal speed limit for the hot climate of the Muna valley.

2.3- EVAPORATIVE COOLING:

The hot arid valley of Muna is characterised by summer day time temperatures above 36^{o}C and a low level of relative humidity. Under the local climate conditions, ventilation alone would not maintain the indoor daytime temperature at an acceptable level and other passive cooling principles, such as evaporative cooling, would need to be applied during the very hot hours.

The energy consumed in the process of water evaporation can be utilised in two different ways in order to cool the tents. One way is by direct evaporative cooling of air that is then introduced to the indoor space. This would increase the moisture content in the air and lower the air temperature near to, or equal to, the wet bulb temperature. This is normally achieved when air is in contact with sprayed water or evaporated water vapour from wet surfaces. The moist, but cool air, when in contact with wet skin evaporates the sweat from the skin surface. Heat loss associated with this process makes the body feel cool. This cooling effect is highest when air velocity is high and the skin surface wet, and lowest when the air is saturated and moving slowly. When the air is saturated the evaporation rate is reduced and sweat accumulates on the skin causing thermal discomfort.

The second way is by indirect evaporative cooling where a given element of the structure serves as a heat sink and absorbs the heat, thus the indoor temperature can lowered without elevating the indoor humidity. In conventional buildings the process of indirect evaporation has long been exploited by providing a shaded pond over the roof, where the ceiling then acts as a passive cooling element for the space below. A roof pond will not be used in this study for it is impractical for light weight structure of the tents.

3- LIMITATION OF COOLING PRINCIPLES:

The described cooling strategies for the Hajj environment are not intended to achieve thermal comfort conditions similar to that experienced in air conditioned interior spaces, for three reasons. Firstly, it is virtually impossible, from a physical point of view, to achieve such an aim by means of passive technologies. Secondly, such an aim is not economically viable by means of conventional techniques. Thirdly, pilgrims are from different climatic backgrounds that may require different standards of comfort. Consequently, the aim of the cooling strategies is to soften the harsh climatic conditions, rather than to achieve thermal comfort.

The potential effect of ventilation, and direct and indirect evaporative cooling on human comfort may best be illustrated in figure 9.2. The figure is a conventional psychometric chart on which boundaries of comfort zones are suggested for the application of three cooling options: ventilation, direct and indirect evaporation in addition to a comfort zone with still air. Each of the four climatic boundaries is presented separately as indicated in figure 9.2 and specified in terms of an average maximum temperature and humidity level. The chart was recently developed by Givoni (1991-a) to apply to hot climate countries and is known as the building bio-climatic chart, BBCC.

Plotted on the same chart is the typical climatic condition for an occupied pilgrimage tent during the Hajj season. Hourly readings plotted on the figure were taken from the field study conducted during the summer of 1989 by the author. Examining the four sections of figure 9.2, clearly climatic conditions inside the pilgrimage tent were outside the boundaries demarcated as comfort zones (sections b, c, and d of figure 9.2). However, the application of cooling principals makes the gap narrower between the plotted hourly thermal conditions inside the tent and the boundaries of comfort zones. The widest gap is when ventilation cooling principal is applied and the narrowest gap is when indirect evaporation is utilised. Thus it is concluded that the application of natural cooling principles is essential to soften the harsh climatic conditions, but will not be able to provide total thermal comfort.

4- DESIGN GUIDELINES:

Design guidelines are the means and ways by which an individual cooling principle or an interaction of different strategies can be implemented for better thermal comfort during the Hajj. Minimising the heat stress of pilgrims involves design guidelines at two levels: the indoor level and the outdoor (or the urban) climate level. The indoor climate was the one experienced inside the pilgrimage tents while the outdoor climate was the one experienced outside the tent and included pedestrian walkways, streets and open spaces. Although the aim in both areas was the same, the design guidelines for one space may not be the most appropriate for the other. Distinguishing between cooling treatments applied to the two climates is a common approach of many thermal studies (Givoni, 1991-a) and (Alvariz etal, 1991). According to such studies the most important factor of thermal balance in indoor space is the convective heat exchange, in which radiation heat exchange becomes less important. Air temperature, therefore, is always the parameter on which operations are mostly concentrated. On the other hand thermal balance in the outdoor space is more affected by incident radiation upon the occupant and the convective component becomes less important. Effective blocking of incident radiation, therefore, is the primary treatment for outside conditions.

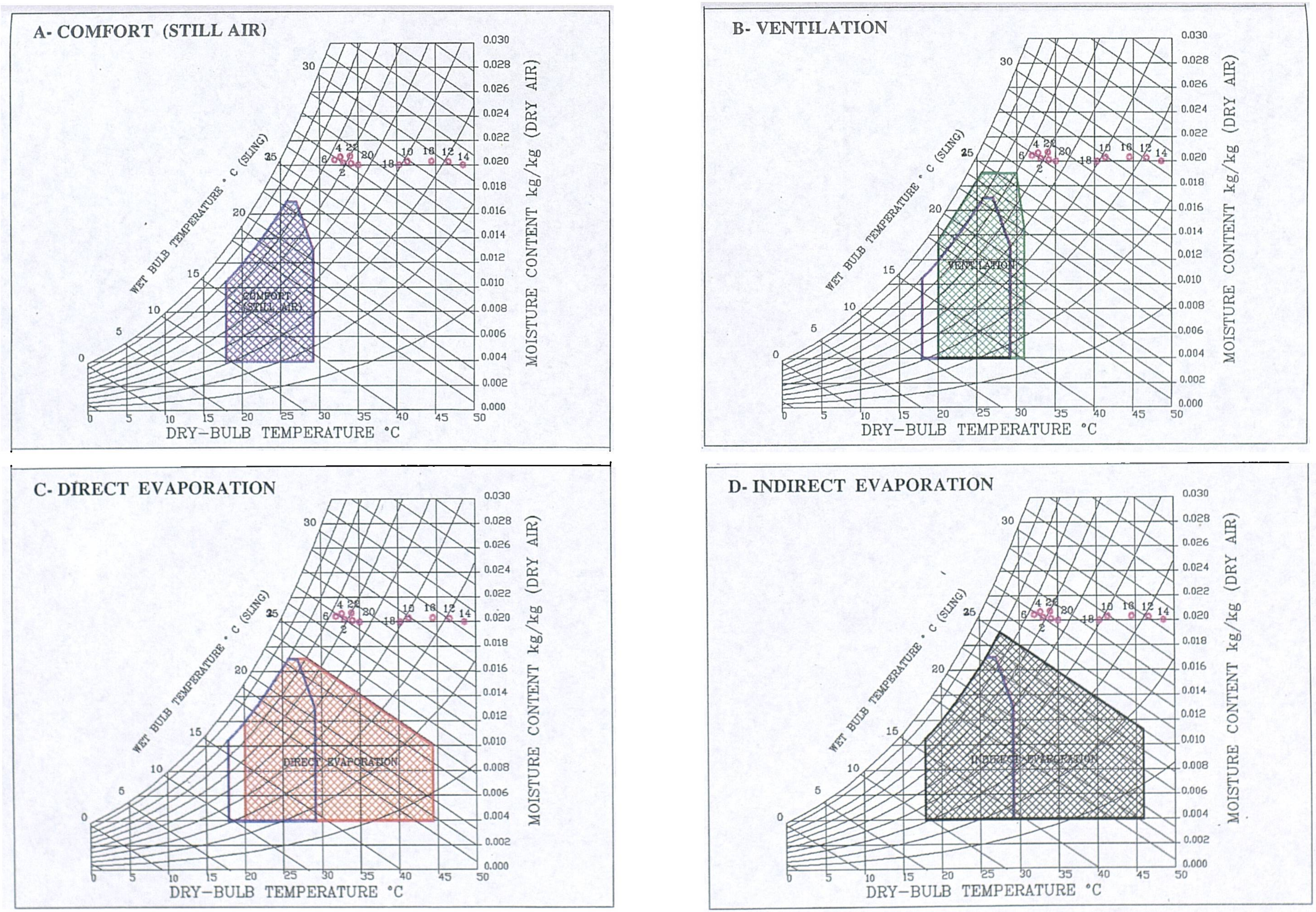


FIG. 9.2: *"BBCC" chart indicates boundaries of the comfort zone, ventilation and evaporation cooling principals applied for the hot climate. Plots on the chart are the hourly average thermal conditions inside the pilgrimage tent.*

4.1- DESIGN GUIDELINES FOR THE INDOOR CLIMATE:

The structural framework of this section is to discuss design guidelines according to the tent's major components, namely: the roof, the side walls, the ground, and the air between them. The tent's components are presented according to their importance and under each, one or several design guidelines are suggested.

4.1.1- THE ROOF:

The roof is the most important element of the tent since it is the most exposed to solar radiation. By carefully treating the roof, thermal performance can be improved.

4.1.1.1- ROOF MATERIALS:

The most widely used fabric of the tents during the Hajj is *made of 8 oz cotton*, owing to its low price compared with other materials. One of the serious shortcomings of this fabric is that it allows direct transmission of a large amount of solar heat. The exact transmittance factor of this particular fabric is unavailable but by comparison with other cotton samples measured in laboratories in Japan and Germany, the transmittance of the 8oz cotton fabric is estimated to be between 0.15-0.20.[3] Such a high transmittance coefficient has a direct and considerable effect on heat gain inside the tents. As established in many references (Croom, 1984-a) the transmission coefficient is a major component of solar heat gain and is calculated according to the following formula:[4]

$$G = \tau + \alpha/2 \qquad \text{9-1}$$

Where: G= Solar gain factor

τ = Transmission coefficient.

α = Absorption coefficient.

Another serious disadvantage of the cotton canvas is its inflammable character. Technical information has reported that even after the removal of an igniting flame, the cotton fibre itself continues burning with black smoke that often causes death from poisoning, and sadly many pilgrims have lost their lives because of this factor.[5]

Excessive heat gain through the existing cotton fabric and its inflammable nature justifies the need to improve or to search for a fabric which overcomes these defects. The Fibres from which fabrics are produced can be classified according to their broad general source, natural and man-made as presented schematically in figure 9.3.

Traditionally tents are made of animal fibres, such as wool, or vegetable fibres such as cotton. Unlike cotton fabric, the surface of wool is water resistant, and its interior is highly absorbent. According to Hyde (1988), wool absorbs as much as 30% of its weight without feeling wet to the touch, whilst cotton absorbs only 8%. Wool is able to release as much heat as 27 calories from a single gram of wool fabric when it goes from dry to wet.[6] Wool is also known as a good insulator against heat and cold. These characteristics may explain the good thermal performance of the Bedouin wool tent observed by Faegre (1979). The presence of water and protein in wool fibres make it naturally flame resistant, and when ignited, it burns slowly. A wool blanket for instance is an effective way of smothering a flame. Natural wool however is heavy and very expensive, and this is reflected in the cost of renting a wool tent (which is 200 times the price of a cotton tent according to 1989 prices). The high price and heavy weight are sufficient reasons to consider wool fabric impractical for the pilgrimage tent.

Man-made fibres however can be woven in to membranes that can be used for the tent's fabric. Table 9.1 summarises the advantages and disadvantages of such membranes widely known in the industry today. The shortcomings of some membranes, particularly of their high flammability, have led to the development of coated fabric systems. These combine additional coating films to the flexible fabric material to satisfy most of the required performance constraints.

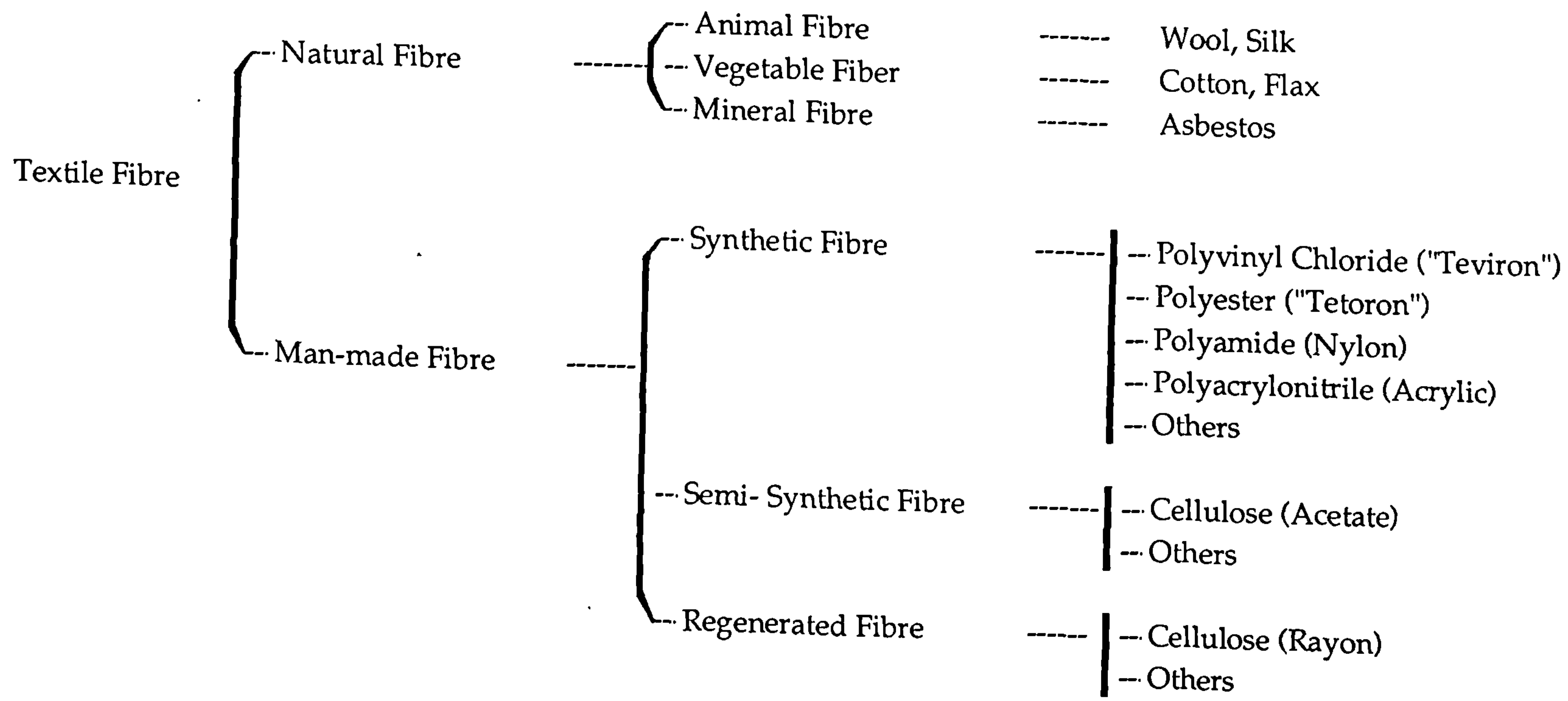


FIG. 9.3: Schematic diagram of textile fibres.
Teijin Limited, Technical Information, Japan: Teijin limited, 1982, p.2.

TABLE 9.1

Properties of selected flexible membranes

The Fabric materials	Disadvantages	Possible treatments and Advantages.
Nylon fibres (e.g. Kevlar)	Sensitive to ultra-violent degradation.	
Polyester fibres	High flammability	Can overcome by coating with a flame resistant polymer Silicon tie-coatings.
Glass fibres	Poor abrasion resistance flexural strength is weak.	When coated with Silicon, the fabric has less deterioration of quality and requires easy maintenance.
PVC		Low cost and need treatments with fire retardants.
Polyurethane	Only fair resistance to weather, corrosion, and fire	
Fluoropolymers such as Polytetra-Fluoroethylene (PTFE)		Excellent weathering and fire resistant. Coated PTFE with glass have a life span of 25-50 years.
Teflon (Du pont's trademark)		Non adhesive to dirt hence is self cleaning.
Teviron		Outstanding flame and chemical resistant properties.

Source: D. Croom and P. Moseley. "Environmental Design of Airhouses," London: The Institution of Structural Engineers, 1984, p.p. 213-15.

It is not the scope of this study to specify a particular fabric material for tents in the Muna valley as this needs further research and experimental work. Instead the study suggests the following guidelines to assist selection from different materials:

1- SOLAR ABSORPTION:

The value of having a low solar absorption coefficient is twofold. High absorption values lead to high internal surface temperatures and consequently uncomfortable mean radiant temperature conditions inside the tent. Absorbed radiation also causes "photo degradation" in plastic films and as a result they become weak and brittle.

2- REFLECTIVITY:

The reflectivity of the fabric to solar heat is of great importance for it reduces the heat gain on the surface. As an example, the surface of white cotton fabric reflects up to 70% of the incident solar radiation. This amount of reflectivity is reduced to only 20% when the colour is dark, e.g., dark green, as dark colours absorb more radiation and reflect and transmit less. Emissivities of both the fabrics are almost alike regardless of the colour. A fabric treated with aluminium has a higher reflective surface than the white fabric, but has lower emissivity. Despite this fact the white fabric is the most favourable because the heat loss from the white fabric by emission is many times that of the aluminium.[7] In use the fabric loses some of its brightness, and becomes covered in dust thus reducing its reflectivity. Studies for Expo'92 in Spain have concluded that dust reduces the reflectivity and changes the absorbtivity from 0.25 to 0.36%.[8]

3- TRANSMITTANCE TO SOLAR RADIATION:

In order to reduce the thermal effect of solar radiation, the fabric is required to prevent solar radiation being transmitted to inside. However, an acceptable amount of translucence is also desirable for natural light. From an architectural point of view, the quality of natural light determines the character and the atmosphere of the environment. Diffused, evenly flat and graduated light provided through the tent's fabric is seen as one of the top quality of lighting. The balance between good quality lighting and heat gain by transmission is essential but cannot be determined quantitatively without further studies and experimental work. Until such studies are conducted one can consider as a starting point a maximum transmissivity level of 5%, based on the outcome of studies undertaken at Expo92 at Seville in Spain.

4-HIGH TRANSMITTANCE TO LONG WAVE RADIATION:

Fabrics that do not transmit long wavelength radiation cause a greenhouse effect, resulting in thermal discomfort particularly during the night-time when maximum occupancy is expected. The roof fabric should be highly transparent to infrared radiation and highly reflecting to solar radiation. A significant reduction of air temperature was reported (Addeo etal, 1980) when polyethylene film was used as a covering material for a large extent of land. Polyethylene film is highly reflective to solar radiation and also highly transparent to long wave radiation especially in the range 8-13 μm.

5-FLAME RESISTANCE:

Fabrics are generally flammable in their original form but vary in terms of their ignition temperature. To raise the ignition temperature, the fabric is often coated with a flame retardant or treated with a flame resistant polymer or silicon rubber during manufacture. Other ways of treatment may exist, yet, any process should not negatively affect the thermal or physical properties of the fabric. The final product should also not produce any toxic gas when ignited.

6-STRENGTH OF THE FABRIC:

The fabric should be resistant to tearing and tensile stress in use. The fabric should also be tough enough to resist damage caused by folding, hooking, dismantling, storing and reusing.

7-AGE OF THE FABRIC:

The fabric should not show any remarkable change in its quality or deterioration by corrosion with the passage of time either under normal use or during storage. Fabrics that are easily corroded by moulds and dirt are very difficult to maintain and, therefore, do not last. Fabrics which do not attract dirt maintain their whiteness for a longer time.

8-COST OF THE FABRIC:

Existing administrative rules determine how much the pilgrims pay for the use of the tents. Since most pilgrims arrive from economically poor countries, the Hajj administration has made the cost very low, 100 SR (£17) for each tent per person (price at 1989). The fabric is the major cost of the tent's structure, therefore, fabrics proposed for better thermal and safety performance must also be economically sound and competitive.

4.1.1.2-GEOMETRY OF THE ROOF:

The shape of the roof is also of considerable importance in a sunny climate. A flat roof receives solar radiation continuously throughout the day, at a rate that increases in the early morning and decreases in the late afternoon due to changes in the angle of the sun.

Pitching or arching the roof has several advantages over a flat structure. Firstly, the height of part of the interior is increased providing a space far above the heads of the inhabitants for the warm air which rises or is transmitted through the roof. Experiments which involved changing a tent's height, discussed earlier in chapter 8, concluded that it was important to maintain the height above 4m. Such a height, besides keeping hot air away from the occupants' level, would also enhance the mechanism of convection.

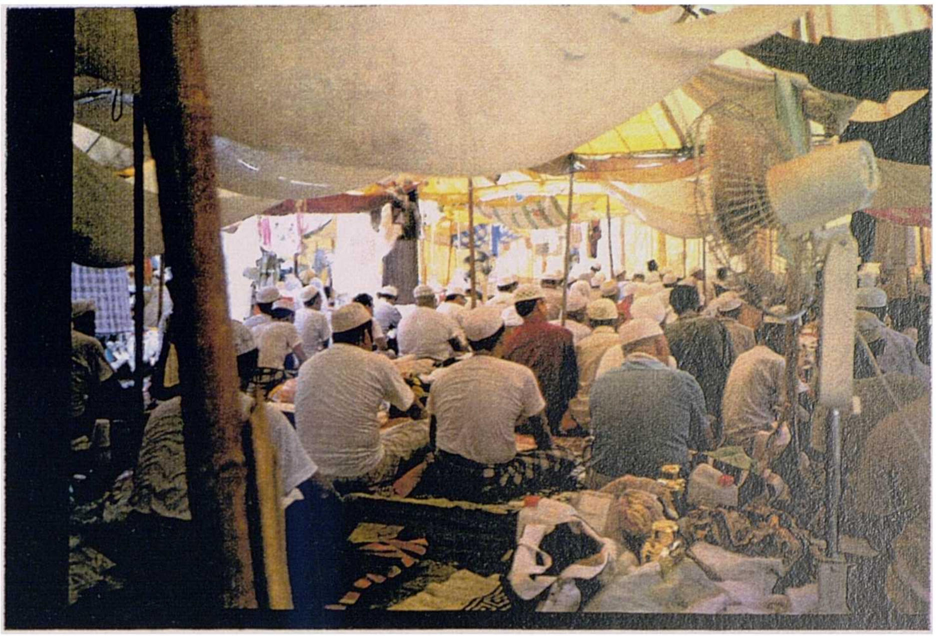
Secondly, the total surface area of the roof is increased with the result that the solar radiation is spread over a larger area and the average heat increase of the roof and heat transmission to the interior is reduced. Results of experiments concerning geometry discussed earlier in chapter 8, revealed that the pyramid roof received 21% less solar radiation than the horizontal roof of the same size.

Thirdly, when parts of the roof are shaded and others are not, radiation exchange took place between the two surfaces which result in lower air temperature inside tents. The rate of radiation exchange between the two surfaces depends on the difference between their surface temperature. When tents' roofs are attached to each other in a repetitive pattern, the shaded side would still receive reflected solar radiation from the sunlight sides of attached roofs. The strong reflected solar radiation would reduce the differences between surface temperatures of the sunny and shaded sides of the tent, that would result in lower radiation exchange between the two surfaces.

4.1.1.3- DOUBLE ROOF:

A double or shaded roof, is a technique which aims to shield a tent's roof from direct sunlight, improves the thermal performance of tents. Tents with double roofs were traditionally used by the military when serving in hot climates. In his study about tents, Sugar (1979) observed that tents with double roofs were much cooler than the other tents that were almost unbearable during the summer months.[9]

Double roofs were primitively constructed during the Hajj where pilgrims used their Hajj uniform, two white pieces of cloth, to form an internal second layer under the tent's roof,. Tents with multi layers were also constructed as indicated in figure 9.4.



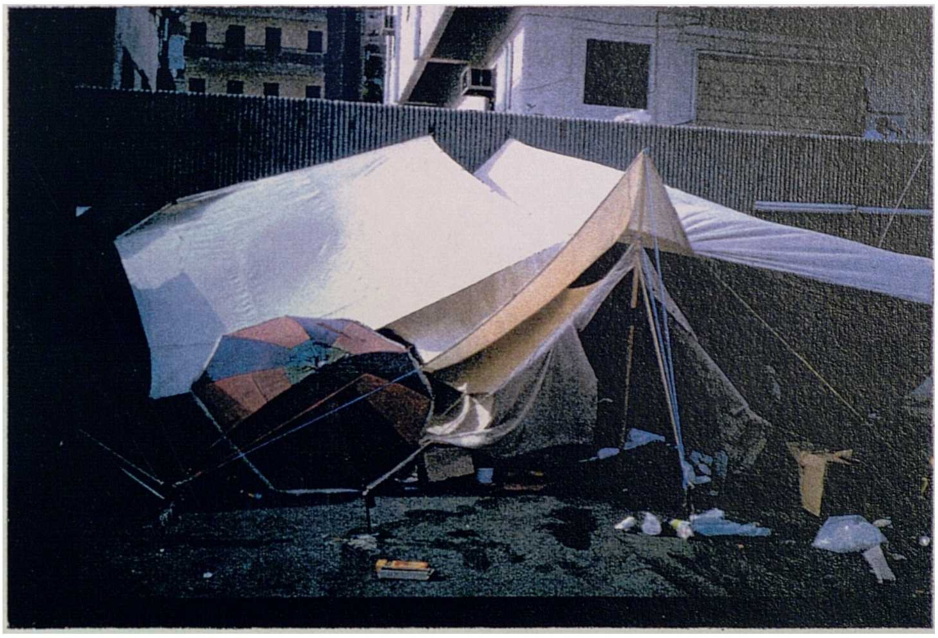


FIG. 9.4: *Primitive use of double and many layers to provide protection from extreme heat experienced during the Hajj.*

The author tested the thermal performance of two full scale tents, one with a double roof and the other without. The double shaded roof had a lower air temperature during the day, a reduction of about 7^{o}C. The single roof tent, however, was better during the night and a 3^{o}C difference was recorded. During the night, heat transfer from the shaded tent to the surrounding area was not appreciable and the double roof blocked heat from escaping. Recent work in Saudi Arabia (Zaki et al 1991) measured heat flux experimentally for a tent's roof. The roof was half shaded with a canopy and the other half was exposed to the direct weather conditions. Results are shown in figure 9.5 in which the double layer has appreciably reduced heat flux during the day. The percentage reduction in daily heat rate was between 46-49%. This study confirms the observation made earlier regarding the better performance of a single roof tent during the night. Heat flux through the single shaded half was faster than the shaded half, from midnight to sunrise.

Heat removal is accomplished when air between the roof and ceiling is properly ventilated, otherwise unchanged air could have a direct effect on the convective heat transfer from the upper to bottom layers. This effect is increased when the roof covering is darker, thinner, and has a higher thermal conductivity. When conditions are reversed, the effective cooling due to ventilation may be negligible.[10] The air gap recommended for good ventilation between two layers should range from 0.3 to o.5 m.

In terms of passive means to reduce heat flow rate, providing double layers emerges as inexpensive, effective and a simple arrangement during the Hajj. The poor thermal performance of a double roof during the night can be improved, such as removing the double layer during the night or providing roof vents that can be opened and shut from inside.

4.1.1.4- MOVABLE ROOF:

During the day the solar radiation is the major source of thermal discomfort. The immediate cooling action, therefore, is to reduce the sun's effect by shading and using double roof. When night falls the main heat sources are internal, generated from bodies and electrical fans. Covering treatments might block heat emission from tents during the night. Such a conflict between thermal performance during the day and the night was observed for measurements conducted for two types of tents, double roof tents and tents with single and heavy cotton fabric (20 ounces). The measurements and detailed discussions are presented in chapter 8.

When such a conflict occurs, it is suggested that the tent's roof be removable. During the hot hours, the tent's fabric can be closed, protecting the space from solar penetration, and in the evening, or even in the late afternoon hours, the panels could be opened and heat can be easily radiated to the sky.

The roof can be opened and closed without involvement of any form of complicated technology, as simple devices have been developed throughout the Middle East and southern Europe. In southern Spain, for example, court yards and pedestrian ways are covered with steel cables in a module of about 2 m wide, through which a strip of canvas can easily be supported as indicated in figure 9.6. The opening and closing mechanism can be simply controlled by pulling canvas strips forward and backward.

4.1.1.5- IRRIGATED ROOF:

Radiation must either be transmitted through a surface, reflected from it or be absorbed. Transmitted radiation through the fabric directly adds to the heat load on pilgrims and the portion absorbed directly affects the elevation of surface temperature which when heated above the skin temperature, 32°C, becomes a source of radiant heat gain.

The surface temperature of the tent's fabric would normally exceed that of the ambient air. A recent study in Saudi Arabia (Zaki et al 1991) has measured the roof's surface temperature for a tent made of cotton fabric and concluded that peak surface temperature of eastern and western roofs reached 50°C. The difference observed between the fabric's surface temperature and the outside air temperature ranged from 10°C to 15°C. This range was recorded during the day from 10.00 to 16.00 hrs.

Clearly under such conditions, in order to reduce the thermal discomfort of pilgrims, the surface temperature of the fabric must be reduced to below 32°C during peak outdoor conditions. The solution proposed here is to control surface temperature by irrigation and cooling in this case would be due to evaporation.

Irrigation of the roof is an old cooling strategy practised in traditional thatched roof houses in Japan. When rain water is soaked up by thatched roofs, it is evaporated by strong solar radiation. As a result, the surface temperature becomes much lower and the occupants experience a lower air temperature.

The principal of irrigated roofs was recently applied to tents covering the rest areas at the Expo site in Seville, Spain. Micronizers, which produce a fine water mist, were distributed along the tent's roof and used to irrigate the external surface of the roof. Figure 9.7 shows the bioclimatic rotunda where the irrigated roof was first applied. Results presented in figure 9.8 illustrate a reduction of the surface temperature in the range of 16°C which can be realised due to irrigation of the roof.

Irrigation was controlled so as to achieve a reduction in covering temperature without forming water film on the surface. The designers confirmed that cooling was not due to water temperature but to its evaporation.[11] The water used for the system is claimed to be very little compared with the reduction achieved in surface temperature. According to the studies at Expo 92, the maximum water flow rate required for the system was $6m^3/h$ for every 1000 m^2. An additional advantage of the irrigation system is the fact that the covering is kept clean and a lower absorption of solar radiation is obtained.

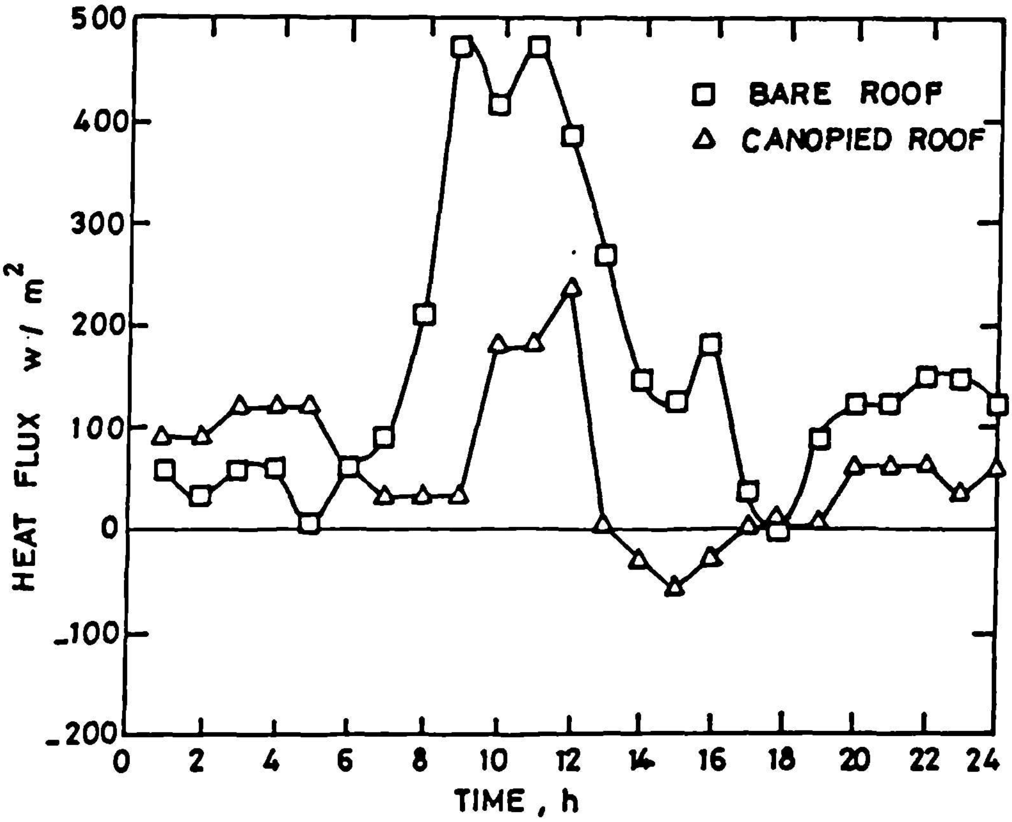


FIG. 9.5: *Heat flux for shaded and unshaded areas of tent's roof.*

G. Zaki etal. "A study of reducing heat load on tents due to solar insolation," Energy and Buildings, 1991, 17:13

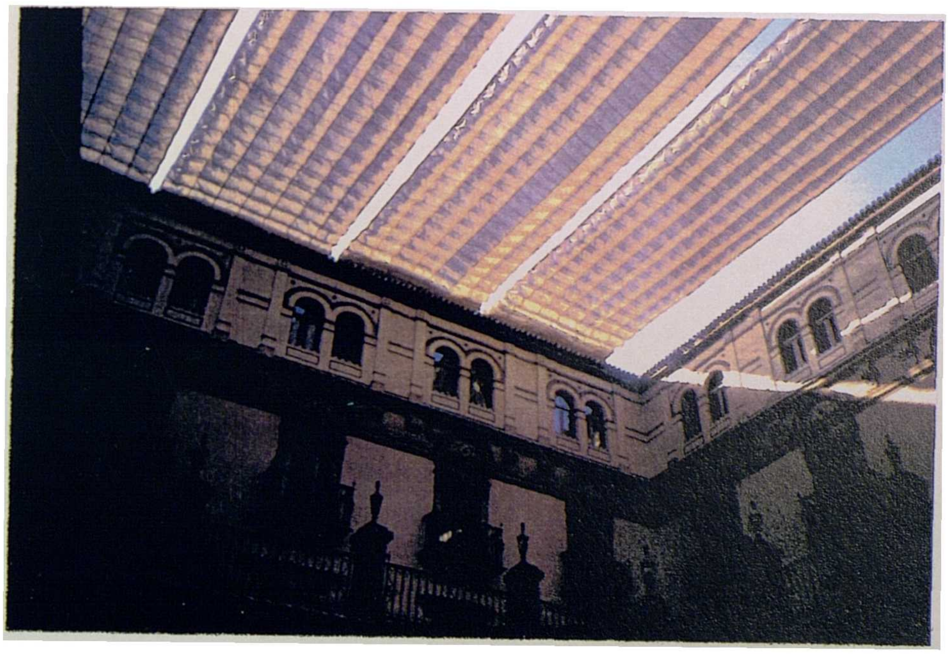


FIG 9.6: *Movable canvas roof to shade courtyard, Spain.*

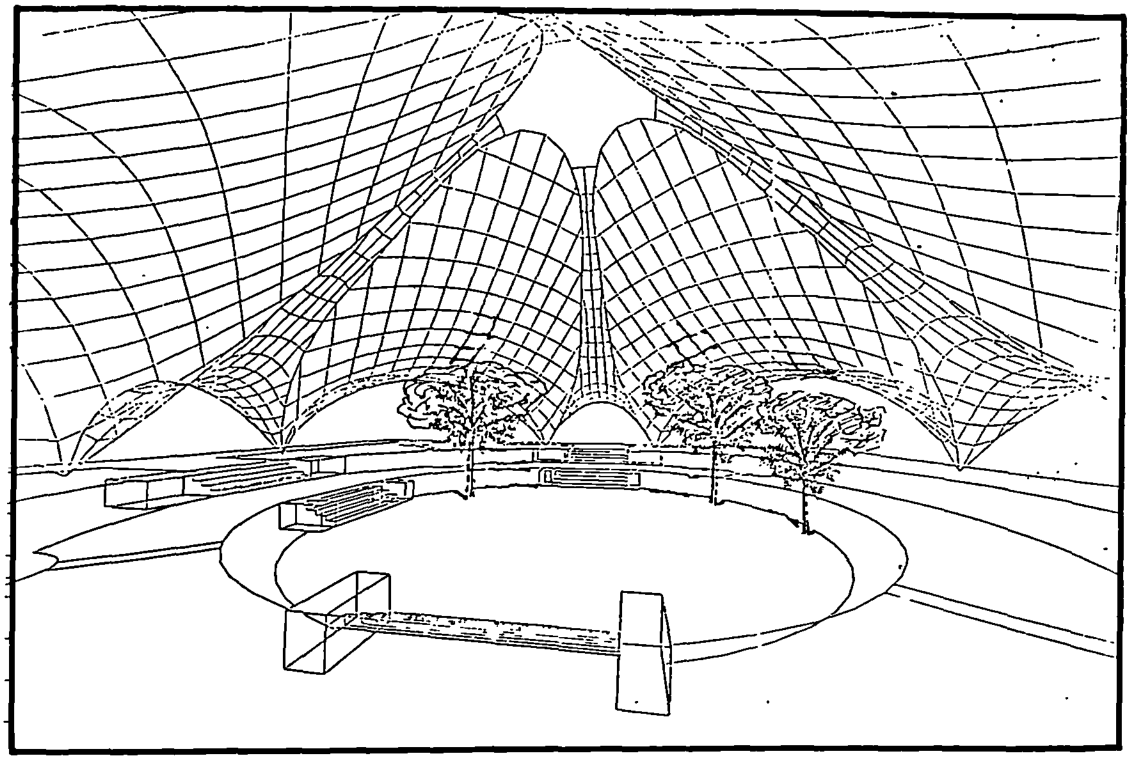


FIG. 9.7: *Bioclimatic rotunda: an experimental tent designed for Expo'92 at Seville, Spain.*

R. Velazquez etal. Climatic control of outdoor spaces in expo'92. Seville: Publication centre, Sociedad Estatal, 1991,p.20.

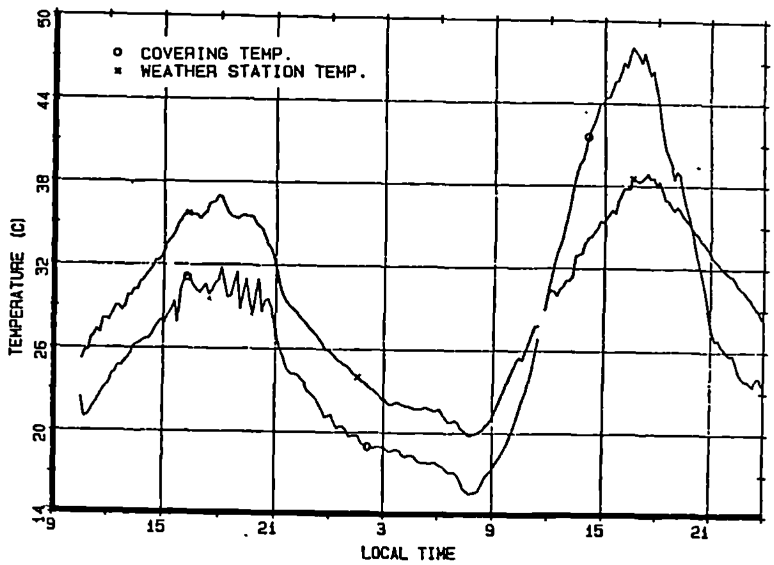


FIG. 9.8: *Covering temperature with and without irrigation*

R. Velazquez etal. Climatic control of outdoor spaces in expo'92. Seville: Publication centre, Sociedad Estatal, 1991,p.22.

In order to apply the irrigated roof to pilgrimage tents, two factors must be considered. Firstly since water is scarce in the Muna area, the quantity of water needed to operate the system must be carefully estimated. On the basis of that estimation together with a cost analysis of water consumption, the decision should be made concerning the use of irrigated roof in comparison with other cooling treatments. Secondly, fabrics used for this treatment must have stability of finished size under irrigation conditions. Natural fabrics shrink when absorbing water. Cotton, for example, shrinks by 10 to 20 % of its original size. Industrial fabrics are water resistant and, therefore, maintain their original size when treated with water.

4.1.1.6- ROOF VENTS:

A large amount of heat is built up inside the pilgrimage tent and it is necessary to provide the facility to evacuate hot air from the interior space and replace it with fresh and cooler outside air. The hot air tends to move and accumulate near the top centre of the roof and using vents in the roof enables hot air to escape and enhance air circulation inside the tents. According to experiments conducted by the author, tents supplied with roof vents have shown an increase in air movement in comparison with tents with no roof vents. The increase is estimated at 120% during the night time and during the day air speed increased from practically zero to an average of 0.12 m/s. Another study on tents (Sabbagh and Khalifa 1983) claimed 100% increase in average velocity when using roof vents.

Three precautions should be considered, when providing roof vents: the height of the tent, the distribution of the vents, and the protection of vents from direct solar penetration. The existing height of the pilgrimage tent, 3.0m at the centre, may not be enough to introduce air by means of a chimney effect. By increasing the height of the ventilation path, i.e. the vertical distance between the outlet openings at the roof and the inlet openings at side walls, thermal force can be used effectively for natural ventilation. This study recommends a height above 4.00 m based on the experimental results discussed earlier for a tent's height.

The best location for roof vents is where the hot air accumulates near to the upper most part of the tent. Roof vents must be protected against solar radiation and possible rain penetration. When a double roof is used, it is suggested that vents for both layers are provided in a way that vents of the upper layer always remain in a higher position than vents of the lower layer, figure 9.9. This distribution follows the natural upward escape path of hot air and guarantees that the upper roof layer provides shading for vents of the lower one, allowing no direct solar radiation to penetrate inside.

4.1.2- AIR SUPPLY FOR TENTS:

The main concern of this study has always been to provide tents of the Muna valley with natural ventilation during the day, and more importantly during the night. The Muna valley has strong winds during the daytime but the winds usually subside in the evenings. The average maximum inside air speed recorded during the summer of 1989 was 0.5 m/s for the daytime and 0.1m/s for the night. The massive use of tents in such a dense valley of the Muna would result in tents screening each other, consequently, the wind's velocity at street level would be reduced. Given this situation, inlets and outlets provided at the street level would not effectively promote a tent's ventilation. Furthermore, natural cross ventilation was very difficult to provide, for the span covered by tents (more than 40 m) was large enough to reduce the pressure difference between the leeward and the windward side to the minimum.[12] The situation can be handled, however, by catching the free, strong and cool wind from high above the street level through a "wind tower" and channelling it down to the interior of the space below.

4.1.2.1- WIND TOWER:

Wind towers are devices traditionally popular in several hot arid and hot humid climates of the Middle East, Pakistan and Afghanistan. While the concept of catching wind is practised more for buildings at permanent settlements, the same concept is also practised for tents. The Cyrenaican Bedouins in north Africa, were among the first who used wind catchers in tents. The design was very primitive and consisted of an opening at the tent's roof that could be opened and closed from the inside as indicated in figure 9.10. Wind towers are known in Persian as "Bad-gir" and in Arabic as "Malqaf"; both names practically mean wind catcher.[13] There are different sizes, shapes, heights, and designs traditionally developed for the wind tower; some of which are presented in table 9.2. The "Malqaf" for example is usually located in such a way that the venting tower is oriented in the direction of the prevailing wind, so that when wind blows, the air is forced down and escapes through outlets provided below, figure 9.11. When the wind blows in the opposite direction, the negative pressure in front of the tower creates a suction that pulls air up from below. The "Bad-gir" on the other hand is designed to catch breezes from any direction. This is achieved by providing louvered openings on all faces of the tower that allow wind to flow horizontally through the top of the tower. This creates a suction zone at the top of the tower causing air to be pulled up from the space below. When the wind is not blowing, the "Bad-gir" acts as a chimney and the hot air is still evacuated.

Air channelled down the tower can be cooled utilising thermal mass of its walls and the principle of evaporation. During the day, the outside hot air comes into contact with the tower walls that retain cool surfaces from the previous night. The air, therefore, becomes cool and is pulled down towards the building space. By adding the water element to the wind tower, air is cooled through evaporation. The Egyptians practised this method by hanging water jars in the air passageways.

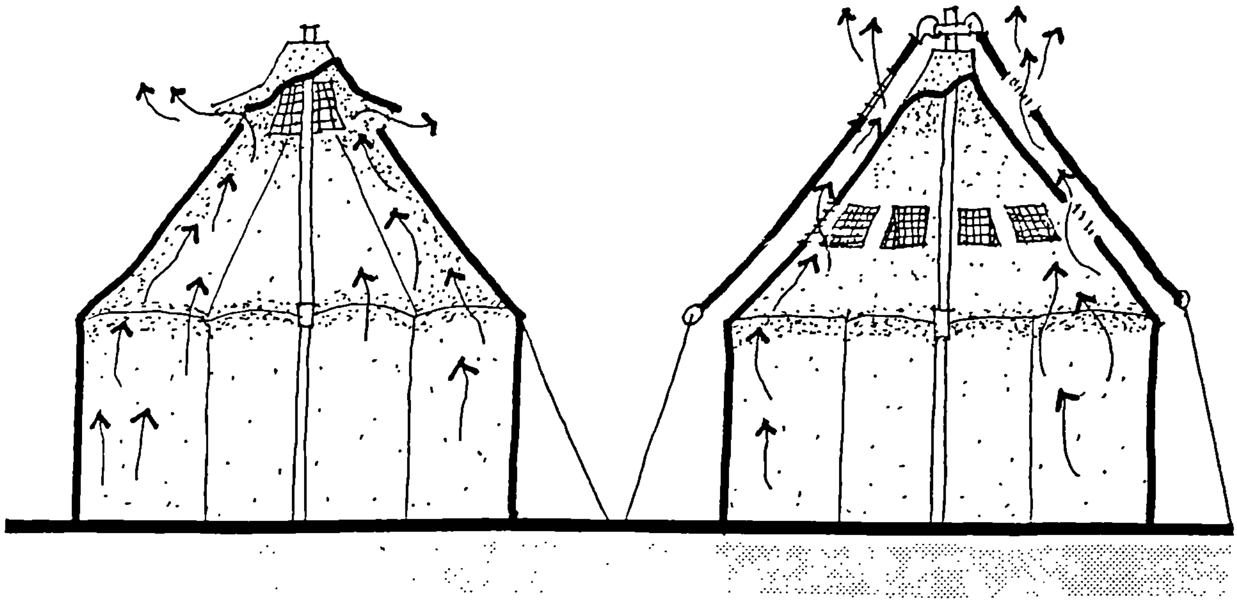


FIG. 9.9: *Different treatments for roof's vents*

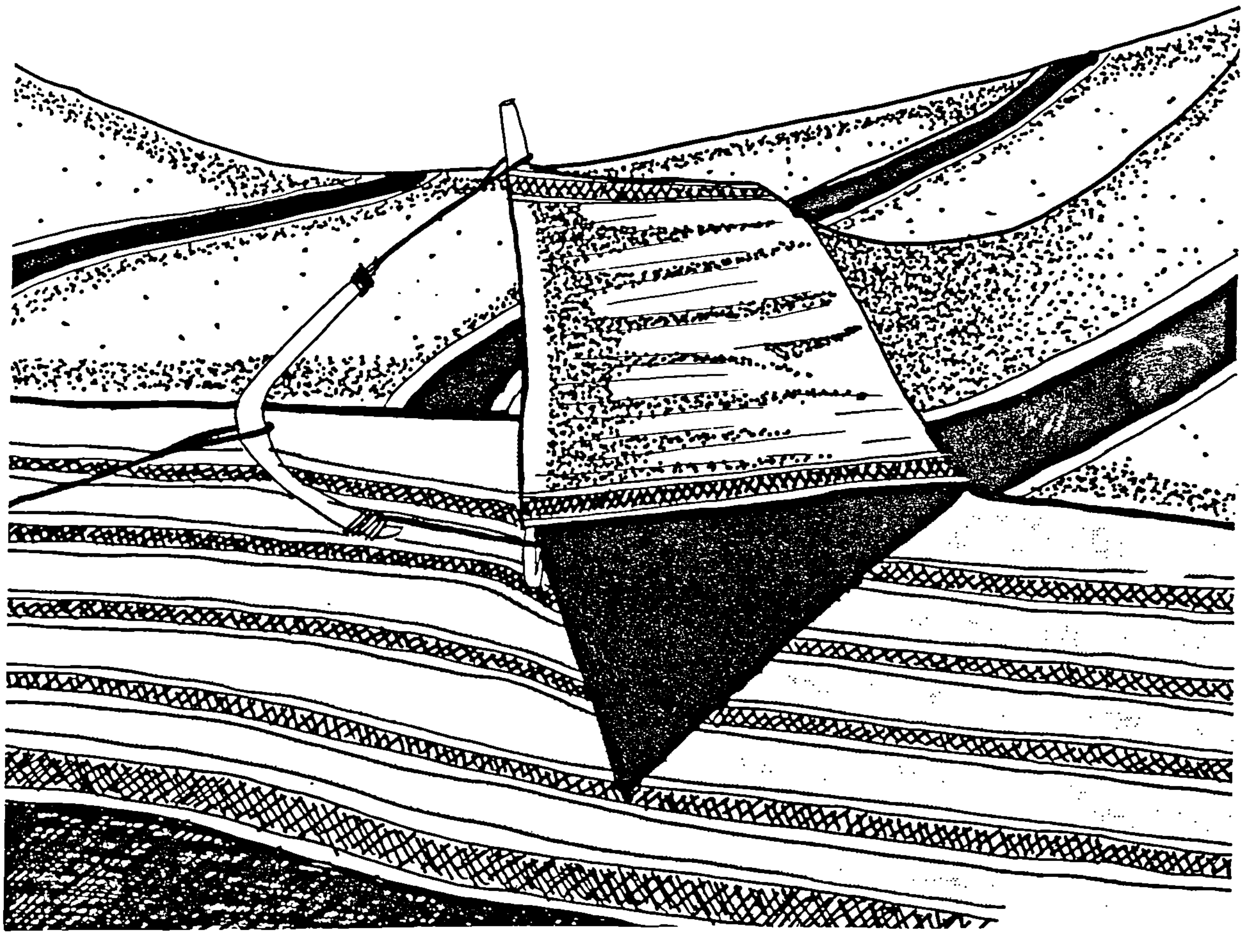


FIG. 9.10: *A tent in Cyrenaica, with Wind catcher built into the tent cloth.*

TABLE 9.2

A comparison between various types of traditional wind towers with respect to climate

	CLIMATIC ASPECTS		DESIGN ASPECTS OF WIND TOWERS						
	Climate Region	Wind Direction	Cross sections	Dimensions m	Height m	Orientation to Wind	Concept of flow	Top end shape	Use of evaporation
Afghanistan	semi-Hot arid	North	Square	1x1 m	1.5 above the roof	Normal	Uni-Direction	Inclined with 30°	No
Egypt	Hot Arid	North East	Rectangular	--	3m above the roof	Normal	Uni-Direction	Inclined with 30°	Sometimes
Iraq	Hot Arid	North West	Rectangular	0.5x 1.5 m 1.20 x .60 m	1.8 to 2.10	Normal	Uni-Direction	Inclined with 45°	Sometimes
Iran	Hot Arid Hot Humid	North East North North West	Square Rectangular Hexagonal	0.4 x 0.8 m	7x11 m 8x15 m	Diagonal	Dual Direction	Flat	Sometimes
Gulf Area	Hot Humid	--	Square	4x4 m	8x15 m	Diagonal	Dual Direction	Flat	No
Pakistan	Hot Humid	South West	Square	1x1 m	Up to 5 m	Diagonal	Uni direction	Inclined with 45°	No

Source: K. Al-Megren. "Wind towers for passive ventilation cooling in hot-arid regions," Unpublished Ph.D. dissertation, University of Michigan, 1987, p.53.

The potential of evaporation cooling in wind towers has been fully utilised in different forms. Hassan Fathi, an architect, author and expert in traditional cooling technology in the Middle East, has developed a simple technique to enhance evaporative cooling in wind towers consisting of panels of wet charcoal covered by a metal mesh suspended within the tower shaft (figure 9.12).

Bahaduri (1985) introduced a rather more complicated development to the traditional Iranian wind tower. The new design, figure 9.12, includes a grid of long ducts made of fire-clay, known for its high thermal energy storing capability. A spraying water system is added to the top part of the tower to ensure uniformly wetted surfaces of the clay ducts.

The environmental research laboratory at the university of Arizona has developed a cooling tower that is today widely commercialized in hot arid climates. The new system is operated by air passing through evaporative cooler pads. The system indicated in figure 9.13 claimed 15-20^{o}C drop in air temperature (Yoklic, 1991).

The three developments described above have all claimed great potential for evaporative cooling and a great reduction in air temperature. However, no indication was given to the quantity of water needed to operate the system, nor how the system would be maintained through the year. The best cooling system using a wind tower must consider the scarcity of water in hot arid areas.

The latest and the major application of wind towers was that developed for Expo'92 at Seville. Wind towers covered with a white fabric made of PVC dominated the scene of rest areas and the European avenue at the site. Figure 9.14. Wind towers of the Expo were designed to consume the minimum amount of water and provide the maximum potential for evaporative cooling. The wind tower used fogging devices known as micronizers as a cooling source, and are distributed along the tower in different sections creating an artificial fog according to a pre-planned time schedule.

The evaporation of the droplets cools the air passed through the tower. The use of a controlled fog system instead of the system of continuous water flow has two advantages. Firstly, it minimises the air pressure losses in order to obtain a good efficiency under both still air and wind conditions. Secondly, with fine regulation capability the cooling capacity can be maximised while preventing people from getting wet because of non evaporated water droplets.

Wind towers are undoubtedly excellent ventilators and can provide a sufficiently large number of air changes per hour to make them well worth considering as part of the natural air circulation system for the densely grouped tents of Muna. When wind is active during the day the tower supplies the space below with air flow cooler and stronger than the air at street level. When wind is calm during the night the tower acts as a chimney evacuating hot air from the space below. By placing a fan at the top of the tower air can be blown down all the time if needed. However, the cost and the noise resulting from the use of a fan can be avoided when natural ventilation alone is provided.

The air flowing through the wind tower can be further cooled by evaporation. The fog cooling system designed for wind towers used for the Expo 92 at Spain provided the maximum potential of evaporative cooling and at the same time only required a minimum amount of water. The system of such wind towers sounds economic, simple, and efficient and a viable proposition for the tents of the Muna valley. However, further studies are needed to explore the following:

1- A control strategy for water consumption suitable for the climate of the Muna valley and the possibility of reducing water consumption by utilising water remaining after ablution (Ablution water is the water used to wash face, hands, and feet before Islamic prayer).
2- Height, form, size, orientation of openings, and distribution of wind towers among the tents.

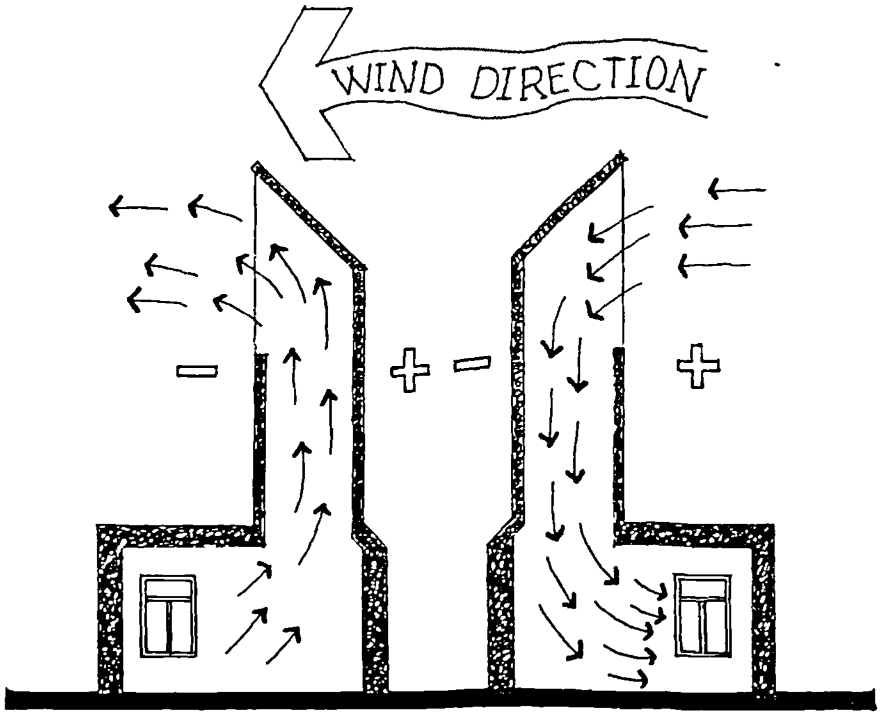


FIG. 9.11: *Schematic illustration of air circulation in the Malqaf, a passive ventilation system used in the Middle East.*

M. Melargno. Wind in Architectural and Environmental Design, N.Y: Van Vo Strand Co., 1982, p.339.

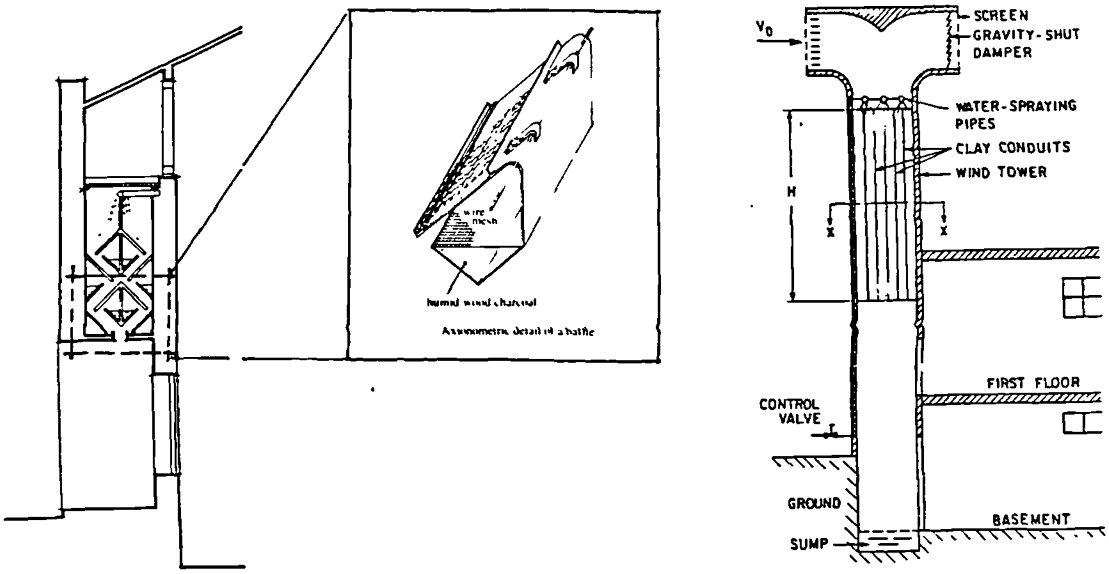


FIG. 9.12: *Two cooling teqniques developed for the wind tower. (a) by Hassan Fathy and (b) by Mehdi Bahadori.*

H. Fathi. Natural Energy and Vernacular Architecture. Chicago: The university of Chicago Press, 1986, p.125. and M. Bahadori. " Passive and Low Energy Cooling," England, 1986, p. 150.

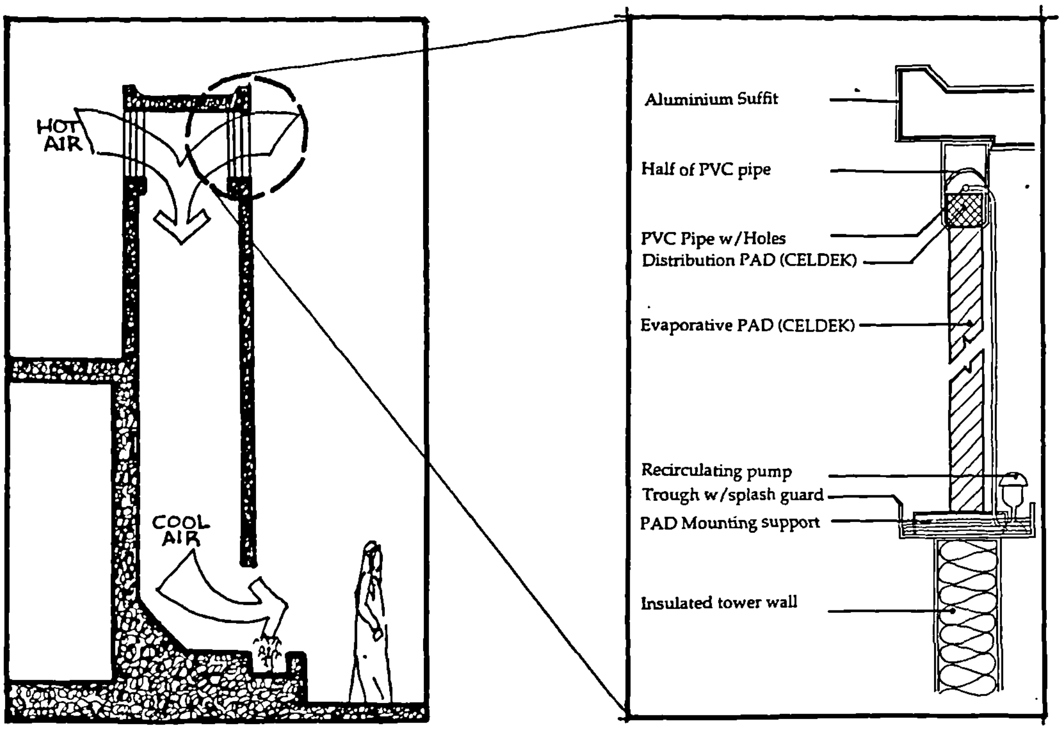


FIG. 9.13: The cool tower developed by the University of Arizona.

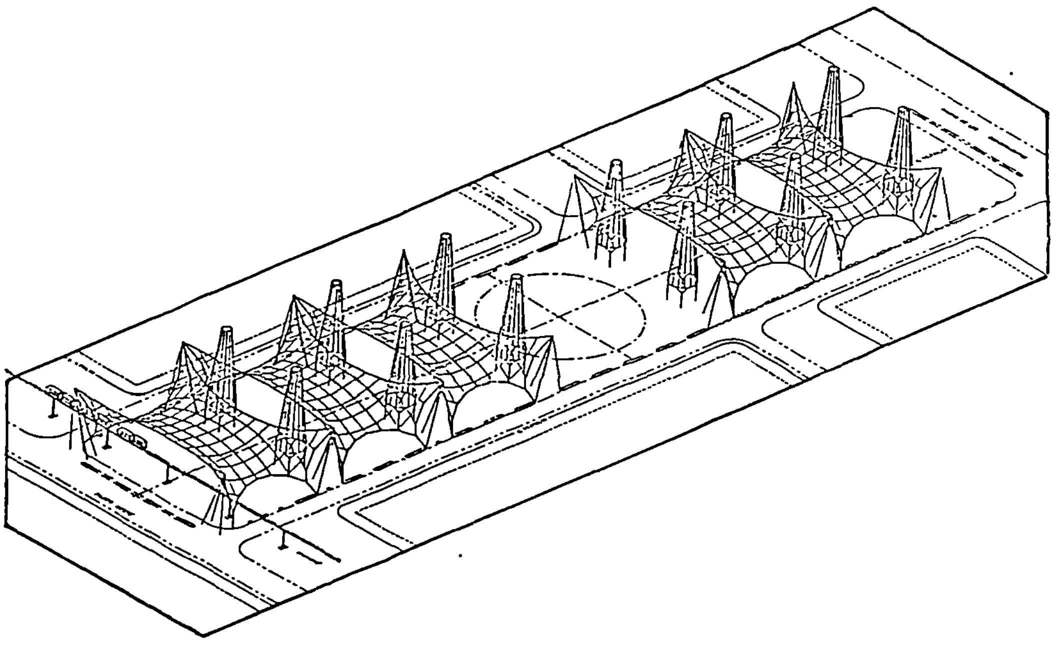


FIG. 9.14: The cool towers in the European avenue of Expo'92 at Seville, Spain.

S. Alvarez etal. The Bioclimatic Rotunda in Expo'92 (Seville), Seville: Universidad de Seville, 1990, p.32.

Wind towers can be built as self supporting structures with tents covering the space between to form one open space around the bottom of the towers. In this case the tower's skeleton would stand up through the year and only be covered with light weight fabric when used. Alternatively, a wind tower can be integrated with a tent design and made as a supporting structure for the tent. Apart from a climate regulator, a wind tower can also serve as a land mark, or light tower.

4.1.3- SIDE WALLS:

The tent's sidewalls are one source of direct and indirect penetration of solar radiation and the main barrier through which outside air can penetrate. Unwanted infiltration of air and solar radiation through the tent's sidewalls should be controlled in order to maintain low air temperature for the interior space.

Solar penetration through walls can be controlled by using different shading devices. The south and north sidewalls receive less direct solar radiation than the east and west walls and could be shaded by a small roof overhead. The eastern facade is exposed to the sun only from sunrise to noon, and the exposure of the western facade is only between noon and sunset, yet they both receive the maximum intensity of solar radiation because the sun's rays are directly focused on these two surfaces during the period when solar intensity is at its maximum.

As the south and north sidewalls receive the minimum of solar intensity and penetration, it is recommended, therefore, to maximise the north and south facades and to maximise the openings through them. The east and west facades should be minimised and should not have openings. To enhance solar protection for the tent's sidewalls, walkways around them should be shaded.

The application of wet or vegetation barriers can effectively cool the outside air before it enters the occupied area, but they may be impractical for use during the Hajj, as vegetation needs time to grow before the Hajj and even if allowed to grow they would only be used for a few days. The wet barrier is impractical for it may cause noise and increase relative humidity.

4.1.4- THE GROUND:

Areas allocated for tents were raised about one metre above street levels and filled with earth. The earth possess a large thermal storage capacity and therefore absorbs a significant amount of solar heat during the day. The amount of solar heat absorbed by the earth depends on the intensity of solar radiation, orientation of the ground slope, the reflectivity of the surface and any shading. The large amount of heat absorbed by the earth results in elevation of its surface temperature. In summer time, the daily average surface temperature of the earth is estimated to be above the average of the ambient air.[14] During the night the earth releases the heat back to the outside by long wave radiation and convection, hence a heat balance is established and the average earth surface temperature is lower than that of the ambient air. The nightly average surface temperature of the ground would be lower than the average air temperature.

The ground can serve as a natural cooling source by lowering its surface temperature. This is achieved by shading the ground from direct solar heat, changing the reflectivity(albedo) of the ground surface, controlling irrigation to increase its evaporative cooling, or a combination of all.[15]

Tents provide shading over large areas of ground, while unused areas can be shaded with free hanging canvas, plants, or pebbles (gravel).

Since they have different reflectivity, white painted asphalt was compared with black asphalt. Results (Givoni, 1981) demonstrated an average of 7^{o}C lower surface temperature for the white painted asphalt.

Water evaporation from the ground can be effective in reducing the earth's surface temperature. However, when shading and irrigation are applied, evaporation becomes more effectively utilised in cooling the ground surface. [16]

When the earth is cool enough, the ground can be utilised for cooling the interior of the tents, coupled with more active procedures, such as installing air pipes in the soil and a ventilation system that circulates the internal air of tents down through the underground soil and back again to the tents. The cooler earth mass serves as a heat sink to cool the air before it enters the tent. This active method of cooling should be applied only under two conditions. First, when all other passive and natural actions have been exhausted. Second, when it would not conflict with the existing infrastructure in the valley.

Due to the absence of optical properties of the earth used in the Muna valley, this study is unable to recommend a particular ground surface without further investigations.

4.2- DESIGN GUIDELINES FOR THE OUTDOOR CLIMATE:

The rituals to be performed during the Hajj required mass movements within the Muna valley or to other locations outside the valley, thus exposing pilgrims to the outdoor climate for most of the time. Some of the rituals were performed during the hottest hours of the day, i.e., from 11.00 hr to 14.00 hr, while some others were permissible during the cooler hours after sunset.

Pilgrims using the outdoor space of the Muna Valley were exposed to different environmental stresses. The first and the most important was the intense solar radiation coupled with high air temperature, exceeding 40°C, that resulted in high heat stresses during the summer. The second was the high glare resulting from the strong direct and reflected sunlight. The third was the high level of pollution resulting mainly from vehicles. With an exception of one shaded pedestrian area, the existing outdoor spaces, including streets, walkways and other open areas in the valley, were not protected against environmental stresses. The only means of protection against solar radiation was by using an umbrella which some individuals failed to use.

The main objective of the following design guidelines was to moderate heat stresses imposed by the climate on pilgrims staying outdoors. To focus mainly on heat stress of the outdoor climate, the following strategies should be considered:

(1) Providing shade in the streets and pedestrian walkways;

(2) Securing adequate ventilation for the outdoor environment; and.

(3) Providing means for evaporative cooling.

Cooling the outdoor climate is a subject that has recently developed and no known studies have been conducted particularly for the Muna valley. However, in the light of many general studies carried out for urban cooling in hot arid climate such as Givoni (1991-b), Cook (1991), Alvarez etal (1991) one can initiate discussions at outdoor level. This study focuses on two cooling options at the urban climate level: the streets' layout and vegetation. Both options were considered permanent when applied.

4.2.1- THE STREETS' LAYOUT AND ORIENTATION:

The width and direction of urban streets affects the impact of solar exposure and ventilation. Such a relationship between the streets' layout and urban climate conditions has been a subject extensively studied by many investigators, such as Chandler (1971) and Givoni (1989). Knowles (1981) has compared different street orientations and concluded that streets running north-south have better shading conditions in summer and better light conditions in winter than east-west streets. A street grid in diagonal orientation, i.e., NE-SW and NW-SE was found to be a preferable pattern from solar exposure. It provided more shade in summer and more sun exposure in winter. In respect to the streets' width, narrow streets reduce the sun's penetration and, therefore, are better shaded. Wide streets on the contrary allow more solar radiation and need, therefore, trees and other features to provide enough shading for pedestrians.

Givoni's studies concerning streets' layout and their impact on urban ventilation noted that streets running parallel or lying at a small angle to the direction of the wind create abstract free passageways through which the prevailing winds can penetrate. In this case, the air flow encounters less resistance from buildings on the sides of the streets, therefore, improving general urban ventilation. When streets are perpendicular to the wind direction, the prevailing wind flows above the buildings causing relatively low air currents at the street level. This secondary air current is caused by the friction of the wind blowing above the buildings and against buildings lining the streets. Under these conditions, the ventilation of urban space is hardly affected by the width of the streets.

Sometimes it is difficult to propose streets' layout that maximises shading and at the same time provides good ventilation conditions: a balance, therefore, must be achieved. General speaking, in hot dry regions protection from the sun is more important than ventilation.[17] The urban ventilation aspect as related to street layout in hot dry climate is secondary because during daytime hours high air speed is not needed outdoors for the air temperatures would be above the body temperatures resulting in convective heat gains.

The main objectives related to the streets' layout in the Muna valley are twofold. First, to provide maximum shade in summer for pedestrians and second to ensure minimum solar exposure of tents along the streets.

Streets running parallel to the SE-NW or NE-SW directions have been established earlier as the best orientations that provide maximum shade in summer and maximum solar radiation in winter. The streets in the Muna valley, therefore, should preferably be laid out parallel with or perpendicular to the long axes of the valley, that is a SE-NW direction.

The orientation of the streets determines the orientation of individual plots the land is divided into, and consequently the orientation of the tents. This means that the main facades of plots along a street running from east to west are facing south and north. To minimise the effect of the hot sun, rows of tents are preferably laid out facing north and south. In the summer, the angle of the south sun is quite high at midday, so that a porch, overhang or similar device will provide an effective protective screen for the occupied spaces inside. The north face has no direct sun exposure. If a north or south direction can not be achieved due to the layout of the streets, then the NE- SW or NW-SE facades are the next option. Facades opening to the east or to the west should be minimised and if possible avoided for they allow solar radiation to penetrate inside the tents for most of the day.

4.2.2- VEGETATION:

The use of trees is well appreciated for their aesthetic values, but they are useful in many other ways: providing shade, reducing temperatures, and influencing wind movements, moisture level, pollution level and acoustic and visual pollution.

1- PROVIDING SHADE:

Deciduous trees provide shade in the summer, when it is needed, and facilitate heating by solar radiation during the winter, when it is most desirable. Most of the solar energy falling on the trees is absorbed by the plants' leaves and only a little is reflected. The absorbing and reflecting efficiency depends on colour, texture, density and size of the leaves and canopy. Plants' leaves have a very high absorption coefficient for solar radiation (about 0.8). This largely absorbed heat, instead of raising the temperature of the leaves, is partly converted to latent heat in the process of evapo-transpiration of water from the leaves. As a result of the cooling process the air near the shaded ground is cooler than the air near the unshaded ground. Furthermore, as a result of the lower temperature, the long wave radiation from the leaves is lower than from the surrounding surfaces, and therefore, people using the green areas experience a lower radiant heat load.

2- REDUCING AIR AND SURFACE TEMPERATURES:

The shading caused by the vegetation, and the moisture released through respiration result in low air and surface temperatures. A field measurement recently carried out at large and small green areas of Kumamoto city in Japan (Saito etal, 1991) concluded that there was a close relationship between air temperature distribution and the distribution of greenery. As indicated in figure 9.15, the cooling effect is noticeable even with a small covering percentage. The measured surface temperature, using remote-sensing data from an aeroplane, shows about 15-20^{o}C lower temperatures than that of the surrounding areas.

3- INCREASING MOISTURE LEVEL:

Evaporation of water from the leaves causes a significant cooling effect that manifests itself in lower air temperatures, and at the same time higher humidity. As a quantitative example, a mature tree is able to produce 400 litres daily through the transpiration process alone. The cooling effect of such a quantity is equivalent to the effect of 5 small cooling units working for 20 hours a day.[18]

4- CONTROLLING WIND MOVEMENT:

Trees and shrubs can be used as barriers from unwanted dusty wind as well as to filter air from dust or slowing wind speed. Trees can also be used to direct desirable streams of the air particularly when temperature conditions are stable, and so are suitable for forming path ways through which fresh air can be channelled into the Muna valley.

5- CONTROLLING POLLUTION LEVEL:

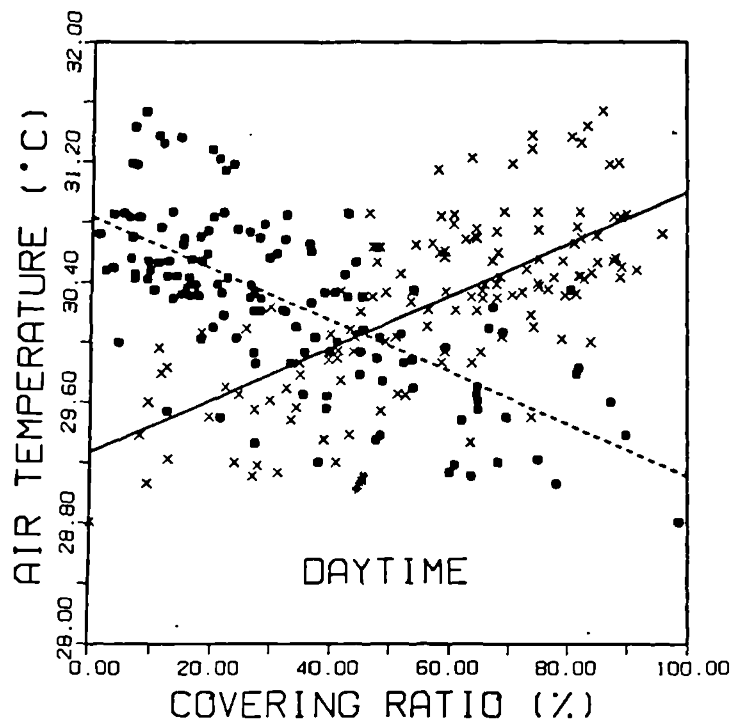
Measurements of air pollution for the Muna valley detected a high concentration of sulphur dioxide, ammonia, suspended particulate, dustfall rates, photochemical oxidants and carbon monoxide. For example, the study (Nasrallah, 1983) reported that dust fall rates were increased three fold during the Hajj period compared with those recorded after the Hajj. It also reported that concentrations of sulphur dioxide and suspended particles were high enough to create health problems for pilgrims with a previous record of chest disease. The author identified vehicles as the main source of pollution and recommended that their numbers be reduced during the Hajj.[19]

Harmful gases emitted by automobiles can also be filtrated by trees. It has been found, for example, that 20,000 trees planted along an avenue in Los Angeles were able to achieve a significant daily reduction of 90 lb of harmful concentrated ozone per day.[20] Trees have a direct influence on air pollution through various ways:

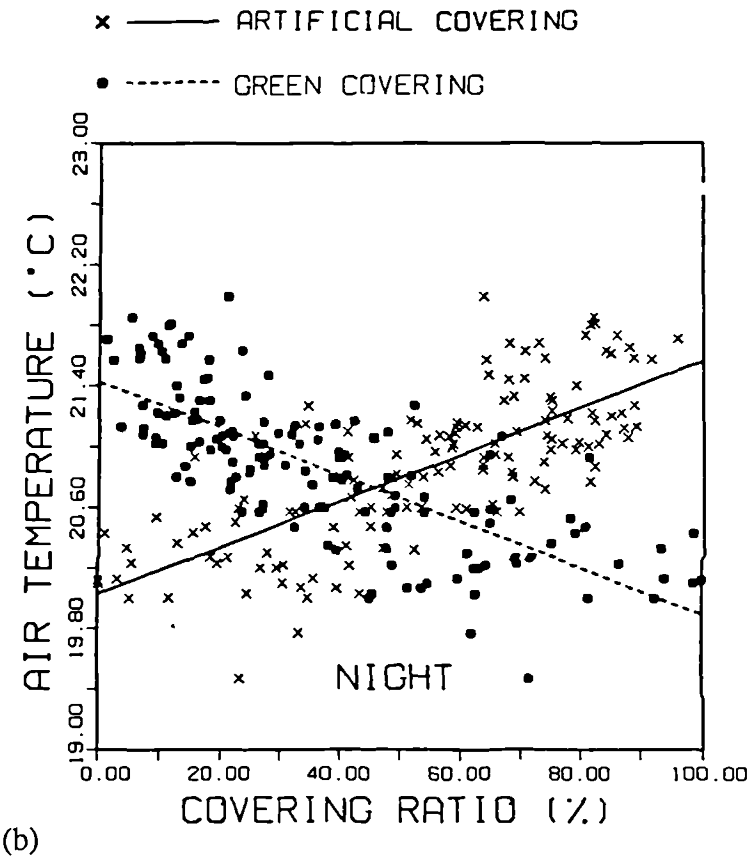
1- Trees increase the oxygen percentage and decrease the carbon dioxide through the photosynthesis process. It is reported, for example, that an area of 25 m^2 of plants leaves produce enough oxygen for one person a day.[21]
2- Trees absorb carbon dioxide during the day and produce it during the night. The Co2 production, however, is only 20-30% of the absorbed Co2, according to some studies.[22]
3- Trees cause a large volume of air to drop its dust by holding or absorbing them with their leaves.

6- CONTROLLING ACOUSTIC AND VISUAL NOISE:

The noise of vehicles can be effectively reduced by using trees, as they are able to reduce the sound by diffusing, reflecting and absorbing. For good and effective noise reduction, trees should be densely planted in wide zones. The zone needed to reduce the noise from motor ways, for example, is required to range from 8-10 metres. Tamarix aphylla (Tamarisk) was able to reduce noise by 4 dB when planted in a strip 6.0 m wide.



(a)



(b)

FIG. 9.15: *Relationship between air temperature and covering ratio of vegetation. (a) Daytime and (b) night time.*

I. Saito etal. "Study of the effect of Green Areas on the Thermal Environment in an Urban area," Energy and Buildings, 1990/91, 15:495.

Trees are effective in reducing the reflected glare from the sun and the shiny surfaces of automobiles and corrugated metal walls used as boundaries for the pilgrimage camps. Trees are also a practical way to hide an unwanted scene in the valley.

The advantages and benefits of planting trees in the Muna valley are visible and countless. However, some questions need to be answered: what type of trees should be planted in the valley?, On what basis should they be distributed?, How to maintain them ? and For what cost?. Answers to these questions are not straight forward and are worth considering as a separate subject for research. To suggest guide lines for urban trees in the Muna valley, many factors and issues must be considered, such as climate, topography, environment, soil conditions and water resources. A collective experience of different specialities is needed before reaching any conclusive recommendations.

The following discussion focuses on urban trees from two levels, planning and individual. Emphasis should be made here that recommendations suggested for each level are only general and not final, and that further studies are required to reaching final conclusions on design, species to be used, irrigation methods, maintenance programmes and management of urban trees.

4.2.2.1- THE PLANNING LEVEL:

The need for a comprehensive planning policy regarding urban trees is essential since vegetation can make a large contribution to improve the microclimate. The area suggested for study extends from Makkah to Arafat in the south, a strip 25 km long and an average of 3 km in width, figure 9.16. The area includes three sites of the Hajj, namely: the Muna valley, Muzdalifa (an attached site to Muna from the south), and Arafat (a plain sited about 10 km south of Muna). In the mid eighties a well received project was launched to plant 30,000 trees on the plain of Arafat. However, no attempts were made to investigate the cooling effects of urban trees on the plain of

Arafat. Similarly no data was available on the water quantities needed for irrigation or on the principles of planting out the trees. The effect of trees on the microclimate of Arafat needs to be studied and evaluated over a period of time to establish some basic guidelines that could be extended to the rest of the area.

The restricted area of the Muna valley and its heavy use does not allow space for the provision of extensive green areas. However, adjacent areas to the north and to the south of the valley, Muzdalifa, can be extensively planted with trees. The fact that the two sites are attached to the Muna valley at either end, together with the fact that the prevailing wind direction is along the main axis of the valley suggests the use of tall trees. Using tall trees, such as palms at the two ends of the valley would enable air to be channelled from the higher levels to the lower levels, reducing the air temperature before it finally approaches the Muna valley, figure 9.16.

4.2.2.2- THE INDIVIDUAL LEVEL:

Trees in the Muna valley can be planted along streets and walkways. Although selecting the right type of tree is very complicated and needs separate study and analysis, some basic guidelines are suggested below.

1- Trees must resist the harsh climatic conditions of the Muna valley and be drought resistant.
2- Trees must resist the pollution levels in the valley during the busy time of the Hajj; and
3- Trees must grow quickly. One disadvantage of using trees is that they take time to grow before being functional.

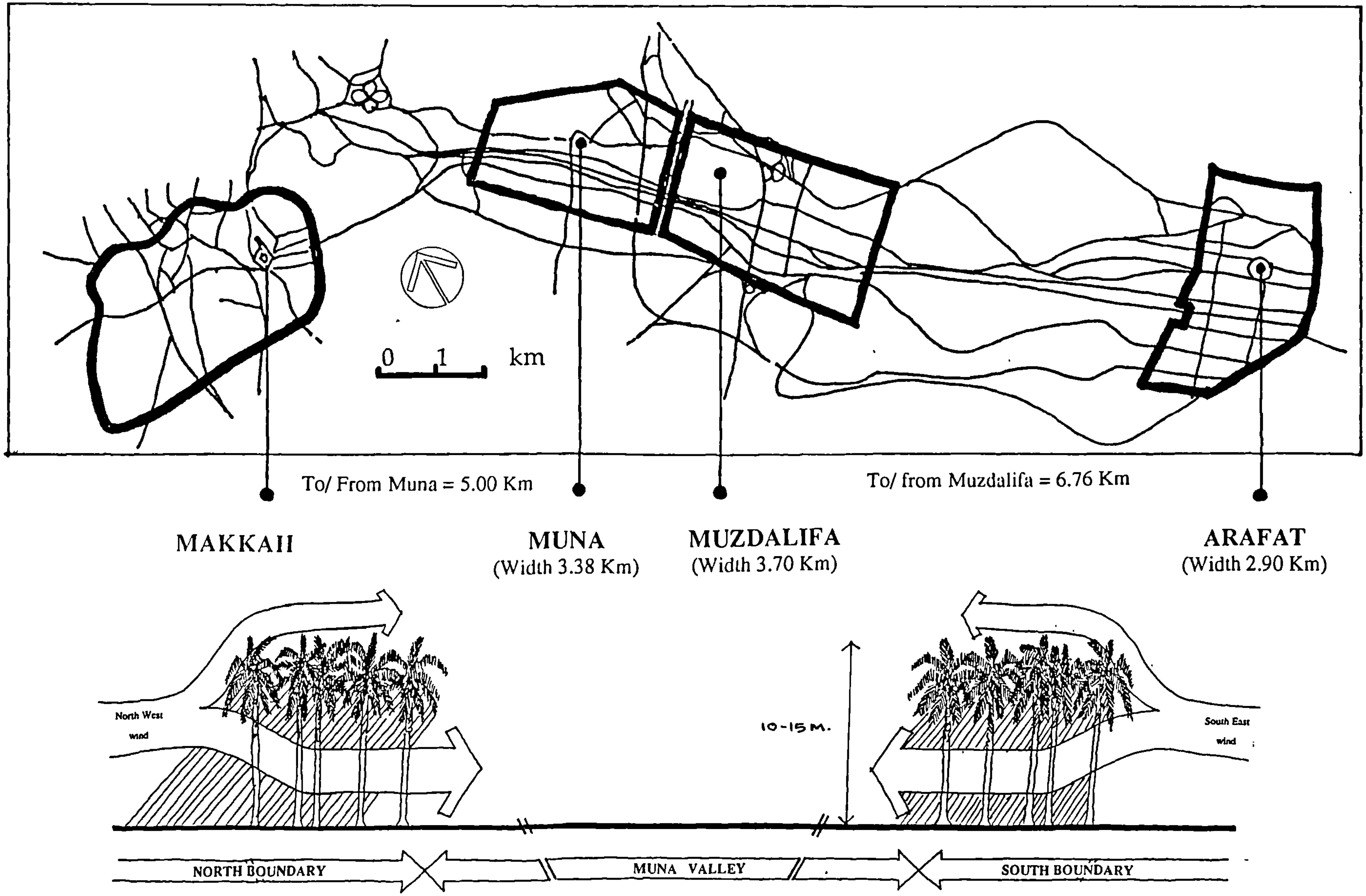


Fig. 9.16: *Longitude section for the Valley of Muna and Muzdalifa indicating height of trees proposed for the area.*

5- SUMMARY OF GUIDE LINES

In this chapter the principles of providing more comfortable conditions both inside and outside the tents have been presented. Clearly there are many approaches that can be made and further research is necessary in some cases to assess their relative performance. It seems that the blocking of direct radiation is the start of any cooling strategies suggested for alleviating the heating problem during the Hajj, followed by the reduction of air temperature by ventilation and evaporation. The following is a summary of design guidelines discussed throughout this chapter:

5.1 TENT'S FABRIC:

The tent's fabric forms the first line of defence against solar radiation and should satisfy the following criteria:

(a) Low solar absorptivity.

(b) High solar reflectivity. The colour of the fabric determines to great extent this characteristic and the white colour is therefore recommended.

(c) Low transmittance to short wave radiation. An adequate amount of translucence, initially estimated at 5% level, is however desirable for natural light.

(d) High transmittance to long wave radiation to prevent heat build up during the night hours.

(e) Resistance to flame.

(f) Resistance to tearing and tensile stress when used.

(g) Resistance to corrosion and deterioration when in use or during storage.

(h) Economically sound and competitive in their cost.

5.2- TENT'S ROOF:

5.2.1. The pitched roof receives less solar radiation than the horizontal one of the same size and therefore is preferable to use during the Hajj.

5.2.2. The use of the double roof has shown a significant reduction during the day time. The reduction of heat during the day also depends on the ventilation conditions between the inner and the upper layer of the tent's roof. To ensure a proper ventilation between the two layers the air gap recommended for good ventilation should range from 0.3 to 0.5 m. However, double roof should be removed during the night time for it forms a barrier against heat loss and results in poor thermal conditions.

5.2.3. A moveable roof is suggested to use when a conflict occurs between thermal performance during the day and the night such as that observed with the double roof tent and the tent made of heavy fabric. During the hot hours of the day, the tent's roof can be closed protecting the interior space from solar penetration. In the evening, or even in the late afternoon the roof could be opened and heat can be easily radiated to the sky.

5.2.4. High surface temperature of cotton's fabric of the tent's roof approached 50^{o}C during the peak hours of the day and exceeded the outside air temperature by 10-15^{o}C and becomes a prime source of thermal discomfort. The surface temperature therefore must be reduced to below the skin temperature, 32^{o}C, and the technique suggested for reduction is to use a water spray to lower surface temperature by evaporation. The decision for using an irrigation roof must be made after careful estimation of water consumption needed for the irrigation and cost analysis balanced with comfort gain and duration of use. Irrigation system is not recommended for use with natural fabrics since they shrink with water. Industrial fabrics such as PVC are more suitable for they are water resistant.

5.2.5. Roof vents enable hot air to escape and enhance air circulation inside the tents. Naturally the vents should be located where the hot air is accumulated near the top centre of the tent. To facilitate the function of roof vents, vertical distance between the inlet and the outlet should be increased. A height above 4m is recommended for the pilgrimage tent. Such a height, besides keeping hot air away from the occupant's level, would also enhance the mechanism of convection. Vents should be protected from direct solar penetration by providing shading to the roof tents.

5.3- TENT'S WALLS:

South and north walls receive less direct solar radiation than the east and west walls and could be shaded by a small roof overhead. East and west walls however need an extensive vertical and horizontal shading along walkways surrounding them. This can be achieved by maintain the width of walkways to its minimum so vertical walls shade each other. Opening should be maximised through south and north side walls and should be avoided through east and west facades.

5.4- TENT'S GROUND:

The adjacent ground to the tent can serve as a natural cooling source by lowering its surface temperature. This is achieved by shading the ground from direct solar heat, changing the reflectivity of the ground surface, controlling irrigation to increase its evaporative cooling or a combination of all. Shading devices can range from free hanging canvas, plants and pebbles (gravel).

5.5- TENT'S AIR SUPPLY:

Tents might be ventilated by the use of wind towers catching the free, strong and cool wind from high above the street level and channelling it down through the wind tower to the interior of the space below. The air channelled through the tower can be further cooled by using water spray distributed along the height of the tower and operated according to a pre planned time schedule to guarantee the maximum cooling capacity while preventing people from getting wet because of non evaporated water droplets. In order to obtain a good efficiency under both still air and wind condition, water spray should be operated in a way not to minimise the air pressure difference between inlet and outlet of the tower. The structure of the wind tower should be simple and covering materials can be made of materials such as PVC.

5.6- TENT'S LAYOUT:

The tents' layout should keep rows of tents facing north and south since these orientations receive less direct solar penetration and can be shaded in the summer with simple overhang shading device. The second best orientation is NE-SW or NW-SE facades.

5.7- CLIMATE CONTROL OF THE OUTDOOR SPACES:

5.7.1. The streets in the Muna valley should preferably be laid out parallel with or perpendicular to the long axes of the valley that is SE-NW direction. This would provide maximum shade in summer for pedestrians and at the same time facilitate good ventilation conditions since the prevailing wind direction is along the axes of the valley.

5.7.2. Vegetation can make a large contribution to improve the micro climate of the Muna valley. An area of 25 km long and an average of 3 km in width was suggested for future planning and vegetation study. Planting tall trees such as palm trees in areas adjacent to the Muna valley from the north and the south would channel air down to the street's level of the Muna valley. No specific trees were suggested for the Valley but general criteria were given: such as: resistant to the drought season and harsh climate of Muna valley, resistance to pollution levels, and rapid growth.

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CHAPTER X

FUTURE STUDIES

During the course of this study thermal conditions of pilgrimage tents were examined. The study reveals that pilgrims experienced a very serious thermal condition near the border of heat stroke and beyond the safety limits set by the international standards (ISO 7243) during the peak hours of the day.

In view of the large and sudden flux of pilgrims in short time combined with the harsh climate of the pilgrimage site, the Hajj authority has largely invested in building heat stroke centres and training Doctors and nursing staff to treat heat stroke cases during the Hajj. However more efforts are needed to prevent the problem of overheating before it occurrs by means of improving the design of pilgrimage tents and the micro climate of the Muna valley.

During the course of this research many cooling guidelines were suggested for both indoor and outdoor climates but to implement these guidelines in practice and on a large scale, there is a need for a pilot study to be set up as experimental support for testing and evaluating the different system designs for climatic treatments. The pilot study is suggested to carried out in two phases before reaching any general recommendations for large scale implementation:

Phase-1 (Design): This phase aims to integrate the cooling design guidelines suggested in this research with other developments concerning tent structure and electrical networks needed for lighting and other services. The aim is to develop a tent design that conforms to the guidelines, which is simple to use, and would be used as a prototype with a view to further improvement and development.

Phase-2 (Evaluation): To evaluate both qualitatively and quantitatively the behaviour of the various techniques tested. This stage should involve climatic measurements for indoor and outdoor climates and measured variables should include air temperature, radiant temperature, surface temperature, relative humidity, air speed and solar radiation. Measurements should supply enough data to decide:

(1) The optimum configuration for an individual cooling technique that provides the best thermal effect, for example the optimal size of a wind tower and the optimal height of the tent. This would include essentially the inter-relationship between different configurations of the passive technique and the thermal performance of tents.

(2) The best method of integration and combinations of the applied cooling techniques in term of cooling performance, aesthetic values, cost and simple technology.

This study clearly foresee the possibility of upgrading the tent design so that it continues to be the major form of accommodation during the Hajj. Opportunity should be given to develop the existing system of tent structure, stemming any move to substitute the tents with more permanent structures.

Although many possibilities were suggested to soften the harsh climate of the Muna Valley, these still need further exploration and more data should be collected regarding their performance and the best configuration to use. These areas include:

(1) The effective size, location and distribution of roof vents.

(2) The optimum height of the tents to maintain satisfactory ventilation by stack effect.

(3) There is a need to decide the effective size, height and proper location of wind towers suggested earlier for tents. Also there is a need to know the distribution method for large scale implementation, such as with the tents of the Muna valley and with the pedestrian walks of the valley. A wind tower was suggested to be a self-supportive structure, but it would be worth considering the improvement of its design to act as a structure of support for the tent's roof. If this is further developed

so as to have the roof moveable at night, the overheating problem inside the tent at night would be reduced if not eliminated, depending on the clearness of the night sky. When the tent roofs are opened at night, the interior heat built up during the day, in addition to that which is expected at night due to metabolic function, would be radiated to the night sky and a lower temperature would result. During the day, roofs would protect the interior from the sun's heat.

(4) To determine the most economic use of a water spray system for evaporative cooling suggested for tent's roof and wind tower. Also, to determine the best governing scheme for using water spray in regard to the outside climate, the inside climate of the tent and thermal comfort of pilgrims. Worth exploring also is the feasibility of reusing ablution water in evaporative cooling, as large amounts of water are consumed by pilgrims before performing the Islamic prayers.

(5) The focus of this study was on the thermal effect of the individual passive technique. It would be worth studying the thermal effect on the collective scale, i.e., the inter-relationship between various techniques in order to decide the best combinations in terms of cooling performance, aesthetic values, cost and simple technology.

(6) Apart from the cooling strategies for pilgrimage tents which were the prime concern of this research, it would be worth considering the improvement of the tent's structure by using, for example, a simple cable technique to support the tent's roof instead of the existing use of a wooden central pole. This would provide greater interior space to utilise from functional and aesthetical points of view. Consideration could also be given to providing a permanent solution to the electricity network that pilgrim guides have to lay down under the ground every Hajj season. Solving this problem may include providing a permanent underground network or even permanent ducts which could then be wired according to the needs of the pilgrim guides.

(7) Several planning decisions have to be made concerning the upgrading of the Muna valley and adjacent areas, including Arafat and Muzdalifa, in terms of

the distribution of trees, species suitable for each area, a maintenance and management scheme, and cost analysis. Decisions have to be made also regarding the irrigation methods and estimated water consumption for planting the Muna valley. Irrigation and landscape studies suggested for Muna and the adjacent areas can reap the same benefits of the successful experience of planting 30,000 trees at Arafat.

In parallel with the measurements and design development work it is suggested that theoretical modelling studies are undertaken in order to attempt to produce predictable algorithms which can be used for assessing tent designs.

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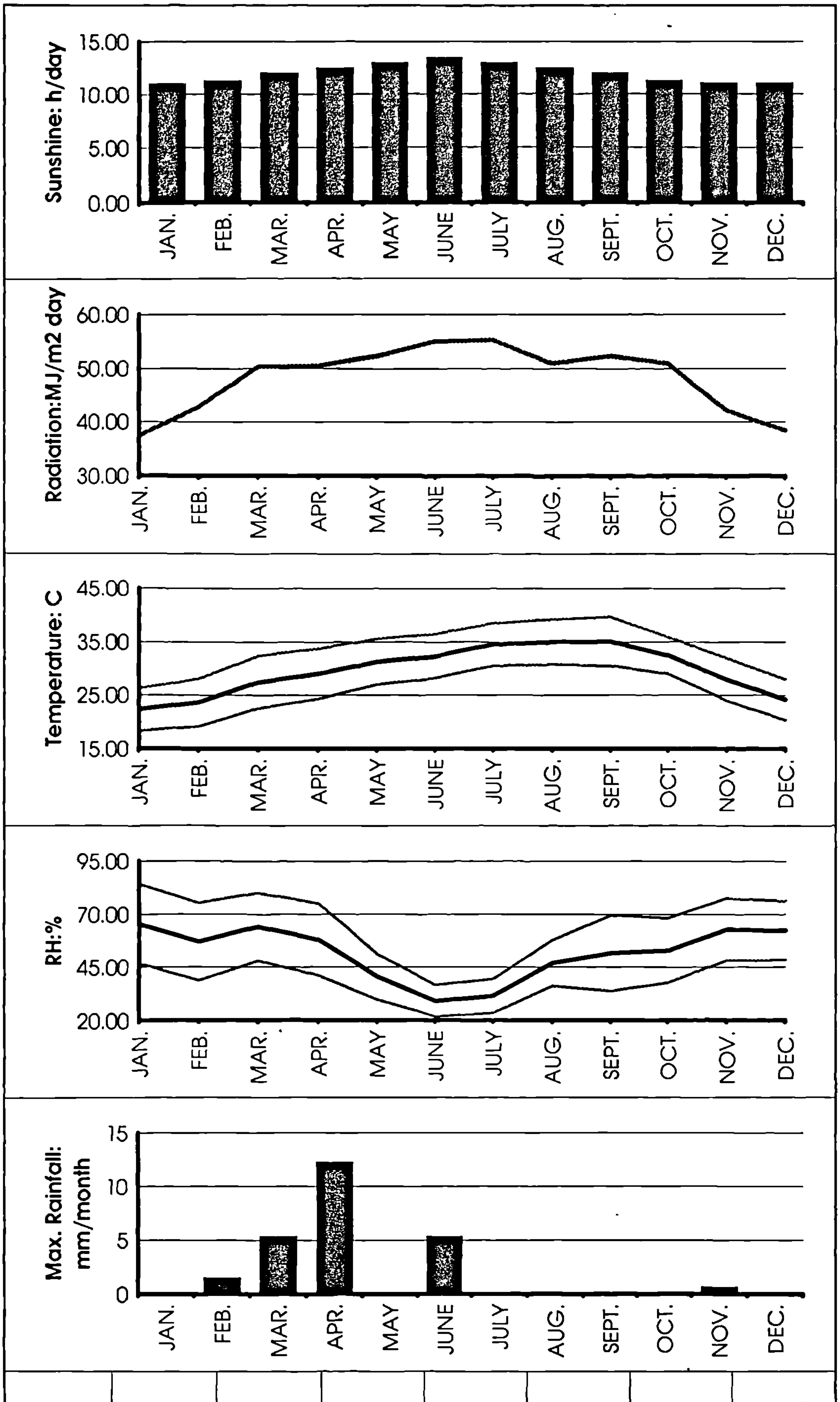
Appendix-I

CLIMATE DATA FOR MUNA.



Climate graph (Muna: Saudi Arabia)- for the year of 1986.

Appendix-II

THE QUESTIONNAIRE FORM

QUESTIONNAIRE

Dear HAJJI: This questionnaire is part of an investigation to improve thermal performance of tents. Please fill it accordingly and we will collect it from you. Thank you for your co-operation.

1- Name of TAWAFA establishment:..............................Office no:....

2- Date :....../ 7/ 1989 (.../12/1409 H.)

3- Age:............Years.

4- Sex: Male [] Female []

5- Nationality:..

6-Which part of your permanent residential country?

State / Province / Area:...

7- How long have you been in Makkah?

Less than three days [] More than three days []

8-How long have you been living in TENT since you arrived in Muna?

Less than one day [] More than one day []

9- Where do you normally spend your time and when?

	Noon(12-16)	Night / Sleeping time
A- Near the middle	[]	[]
B- Near an open side wall	[]	[]
C- Near a closed side wall	[]	[]
D- Near an electrical fan	[]	[]
E- Near an air conditioner	[]	[]
F- Outside tent	[]	[]
G- Outside tent in shade	[]	[]

10- How do you evaluate privacy inside tent? (please tick only one choice)

Sufficient privacy [] Little privacy [] No privacy []

11- What means of transportation do you use most when go outside your tent?

Please tick only one:

Normal Bus	[]
Air conditioned bus	[]
Walking	[]
Others:(Please specify)................	

12- While you are outside the tent, do you consider any of the following protections form the sun? (please tick the appropriate)

White umbrella	[]
Black umbrella	[]
Walk in the shade	[]
Cover the head	[]
Never use a protection	[]

13- How do you describe your physical condition? (Please tick only one choice)

Good [] Satisfactory [] Bad []

14- How do you describe your weight? (Please tick only one choice)

Under weight [] Normal weight [] Over weight []

15- Have you suffered from any of the following?

	Yes	No	Don't Know
Fever	[]	[]	[]
Weakness	[]	[]	[]
Fatigue	[]	[]	[]
Headache	[]	[]	[]
Nausea and Vomiting	[]	[]	[]
Dry mouth and tongue	[]	[]	[]
Diarrhoea	[]	[]	[]
Muscle cramp	[]	[]	[]
Bleeding (nose)	[]	[]	[]

16- How much liquid do you drink per day? (Please encircle the appropriate)

	Litre / day											
Water	0	1	2	3	4	5	6	7	8	9	10	11
Natural Juices	0	1	2	3	4	5	6	7	8	9	10	11
Soft drinks	0	1	2	3	4	5	6	7	8	9	10	11
Others (Specify)	0	1	2	3	4	5	6	7	8	9	10	11

17- How often does your body sweat per day? (Please tick only one choice)

Little [] Normal [] Very much []

18- How often do you urinate per day? (Please tick only one choice)

Little[] Normal [] Very much []

19- Have you performed Hajj in previous years?

Yes [] What year.................................. No []

20- Are you thermally (Please tick only one choice per column)

	Now	Night / Sleeping time
Comfortable	[]	[]
Slightly warm	[]	[]
Warm	[]	[]
Hot	[]	[]
Very Hot	[]	[]
Heat exhausted	[]	[]

21- How do you compare Heat inside tent with it outside? (Please tick only one choice per column)

	Now	Night / Sleeping time
Worst than outside.	[]	[]
Similar.	[]	[]
Better than outside.	[]	[]

22- How do you evaluate ventilation inside tent ? (Please tick only one choice per column)

	Now	Night / Sleeping time
Poor	[]	[]
Fair	[]	[]
Good	[]	[]

23- What activity have you been engaged just before filling your evaluation?

(Please tick only one choice)

Performing Hajj rituals	[]	Eating	[]
Sleeping	[]	Praying	[]
Seated	[]	Cooking	[]
Reading	[]	Walking from outside	[]
Writing	[]	Others	[]
Chatting	[]		

24- What is the time of evaluation?

Hours..Day / Night

25-Have you filled this form:

By yourself [] With assistant []

THANK YOU FOR YOUR CO-OPERATION

Appendix-III

THE INVENTORY FORM

نـمـوذج مـلاحـظـات

١ـ اسـم المـلاحـظ : .... التاريخ: /١٢/١٤٠٩هـ

المواقف: /٧/ ١٩٨٩م

٢ـ اسـم مؤسـسـة الطوافة : .... مكتب رقم:.........

٣- موقع المكتب \ رقم قطعة الارض:...............................

٤- عدد الخيام في الموقع :....................................

٥- ماهي نوعية الخيام تحت الملاحظة؟

خيام صفوف	( ) مقاس الوحده:.......*........متر
خيام تهويه صناعيه	( ) مروحه \ مكيف فريون \ مكيف صحراوي
خيام تهويه طبيعيه	( )
خيام ضد الحريق	( )
خيام غير معالجه ضد الحريق	( )
خيام بيضاء	( )
خيام ملونه	( ) فضلا ذكر لونها :............
خيام ذات سقفين	( )
خيام ذات سقف مستوي (شراع)	( )
خيام ذات سقف شديد الميول	( )
خيام ذات فتحات بالسقف	( ) فضلا ذكر مساحتها:............
خيام ذات فتحات سفليه	( ) فضلا ذكر أرتفاعها:............

أخري (أذكرها) :........................

٦-حجم الخيام تحت الملاحظه ؟

الطول \ .... او عدد الخيام ....* طول كل خيمه.......متر

العرض \........ او عدد الخيام ....* طول كل خيمه.......متر

الأرتفاع \........متر

٧- كم عدد الحجاج داخل الخيام تحت الملاحظـه ؟

العـدد:..................شخص

٨ـ ماهى نوعية قماش الخـيام تحـت الملاحـظة ومن كم طبقة مصـنوع؟

	قـطـن	صـوف	نايلون	أقمشـة أخـرى (أذكرها)
طبقة واحـدة	.... ( )	........( )	........( )	.... / ....
طـبـقـتـيـن	.... ( )	........( )	........( )	.... / ....
ثـلاث طـبقات	.... ( )	........( )	........( )	.... / ....

٩- هل يوجد جدران خارجيه (تيازير) علي محيط الخيام تحت الملاحظه؟

جهه واحده ( ) جهتين ( ) ثلاث جهات ( ) الاربع جهات ( )

لايوجـد ( )

١٠ـ هل يوجـد قواطع (حـواجـز) داخـل الخـيمة ؟

نـعـم ( ) لا يوجـد ( )

أذا أجـبت بنعم فضـلا أجب على التـالى:ـ

١١ـ ما حـجـم القواطـع (تقريبا) ؟

الطـول/....(متر) أو عددالاعمدة....* المسافة بين عمودين/...(متر)

الارتفاع المتوسـط/....(متر)

١٢ـ مانوع القواطع (من أى مادة مصـنوعة):......................

١٣ـ حـدد مواصـفات أرضـية الخـيمة: (الرجـاء أخـتيار واحـد فقط)

أرضـية ترابية.................. ( )

أرضـية ترابية مغطاة بالسـجاد... ( )

١٤ـ هـل انقطع التيار الكهربائى ؟

نعم ( ) لا ( )

١٥ـ ا/اذا أجبت بنعم الرجاء ذكرمتى كان ذلك وكم من الوقت استغرق؟

انقطع التيار الكهربائى من الساعة صباحا/مساء وحتى الساعة

١٦ ـ الأجهزة المستخدمة داخل الخيمة :

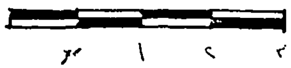
فيما يلي بيان بأسماء الأجهزة المستخدمة في الطبخ ، الاضاءة ، التبريد ، أو التسلية والتي يوفرها المطوف داخل الخيمة . رجاء اختيار وملء المناسب .

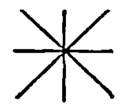
	النوع	معدل القوة الكهربائية (وات)	عدد القطع	وقت التشغيل (ساعة)	
الاضاءة	فلورسنت			نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
	تنجستن			نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
الطبخ	غلاية			نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
	آلة صنع القهوة			نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
	. . . .			نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
	. . . .			نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
	. . . .			نهار	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦
				الليل	٧ ٨ ٩ ١٠ ١١ ١٢ ١ ٢ ٣ ٤ ٥ ٦

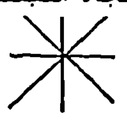
	النــــــوع	معـدل القوة الكهربائية (وات)	عـدد القطـع	وقــت التشغيـــل (ساعـــة)
تسلية	تلفزيـــون	. . . .	. . .	نهـار ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
				الليـل ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
	. . . .	. . . .	. . .	نهـار ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
				الليـل ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
ميكانيكيـة	مروحـــة	. . . .	. . .	نهـار ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
				الليـل ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
	مكيـف فريـون	. . . .	. . .	نهـار ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
				الليـل ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
	مكيـف صحـراوى	. . . . . .	. . .	نهـار ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
				الليـل ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
	. . . . . .	. . . . . .	. . .	نهـار ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
				الليـل ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
تهويـة	. . . . . .	. . . . . .	. . .	نهـار ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦
				الليـل ٧ ٨ ٩ ١٠ ١١ ١١ ١ ٢ ٣ ٤ ٥ ٦

١٧ - فضلا ، ارسم موقع الخيام تحت الدراسة في الفراغ التالي : -

مفتاح
مكيف فريون
مكيف صحراوى
اضاءة
عمود
قواطع :

مقياس الرسم


اتجاه الشمال


اتجاه القبلة


المناقشـــــــــــــــة	الملاحظـــــــــــــــة

Appendix-IV

CALCULATION OF AIR CHANGE PER HOUR

Calculation of ventilation rate using metabolic and water vapour as tracer: Steady State.

The following data were obtained from the measurements conducted during the pilgrimage season of 1989. The data were selected for a period when air temperature was fairly constant so as to ensure that variations in relative humidity were due to the change in moisture content and not to the change in air temperature. The period selected therefore was between 2.00 hrs and 5.00 hrs of the fifth day of measurements as indicated on figure 4.10 in Chapter 4. The following table summarises the data used for calculation:

	European camps		Arab camps		Outside air	
	RH%	AT (C^o)	RH%	AT (C^o)	RH%	AT (C^o)
At 2.00hrs	58%	31.7	72.5%	30.8	39%	33.5
At 5.00hrs	63%	30.9	77.6%	30.2	38%	32.5
Moisture Content	0.0178 Kg / Kg		0.021 Kg / Kg		0.0134 Kg / Kg	
Volume of tents	576 m^3		384 m^3		-	
No of Pilgrims	180		120		-	
Latent heat for sedentary activity.	68 Watts / person					

The ventilation rate may be determined from the following equation for steady- state conditions (CIBSE, 1986):

$$v = \frac{Q_1}{(g_{max} - g_a)\,\rho_a l_e}$$

Where:

v = flow rate of air	m^3/s
Q_l = rate of latent heat gain	W
g_{max} = maximum permissible moisture content of the internal air.	kg/kg
g_a = moisture content of external air.	kg/kg
ρ_a = density of air	kg/m^3
l_e = specific latent heat of evaporation of water	j/kg

__(A) European camp- Steady state__

$$v = \frac{180 * 68}{(0.0178 - 0.0134) * 1.127 * 2430 * 1000} = 1.015\ m^3/s.$$

$$v = \frac{1.015 * 3600}{576} \approx 6.34\ AC/H.$$

__(B) Arab camp- Steady state:__

$$v = \frac{120 * 68}{(0.021 - 0.0134) * 1.127 * 2430 * 1000} = 0.39\ m^3/s.$$

$$v = \frac{0.39 * 3600}{384} = 3.65\ AC/H.$$