INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR.704 - 21

Workshop on Materials Science and Physics of Non-Conventional Energy Sources

(30 August - 17 September 1993)

"Design for Comfort in Residential Baharaini Buildings"

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These are preliminary lecture notes, intended only for distribution to participants.

DESIGN FOR COMFORT IN RESIDENTIAL BAHRAINI BUILDINGS

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ABSTRACT

This paper is an attempt to study the appropriate building design in order to a achieve indoor thermal comfort by passive means. Different methods were used, but all of them agreed on the same result, that natural ventilation, dehumidification and light thermal mass are the best design strategies that should be followed in building design in Bahrain.

Introduction

The primary aim of good building design in any climate is to achieve a satisfactory thermal environment suitable for the performance of various human activities. The indoor environment should appropriate for its purpose and pleasant to inhabit. It must not hinder work and pleasure activities, physically or mentally, and it should contribute towards a person's health and well being. Unfavourable climatic conditions may result in stress on body and mind and cause discomfort, loss of efficiency and eventually lead to degradation of health.

There for, it is imperative to establish the environmental conditions that must prevail indoors in a hot climate in order to maintain thermal comfort.

Thermal Comfort

According to ASHRAE's 55-74 standard [1], human thermal comfort is a condition of the mind which expresses satisfaction with environment. This means that a person must feel thermally neutral, preferring neither warmer nor colder surroundings. Since people are not alike, it is impossible to satisfy everyone at the same time.

Bahadori [2] defined thermal comfort in negative terms as "the conditions at which there is no sensation of thermal discomfort from cold, heat, excessive skin witness or dryness, air stuffiness, or air moving at high speeds". Fanger [3] stated that one may be try to create the optimal thermal comfort so that "man's intellectual, manual and perceptual performance is in general highest".

The energy released by oxidation processes in the human body per unit time, or the metabolic rate (M) is sometimes partly converted to external mechanical power (P), but it is mainly lost from the body as heat (H) so that M=P+H. When there is no external work, the metabolic rate is equal to the heat lose from the body; M=H. As the extent of physical activity increases so does the rate of the heat loss from the body.

Fanger [3] and Givoni [4] state that the body has constantly to lose heat. Without this the body temperature would go up and death would result. The rate of heat loss depends primarily on the degree of physical activity. Although the loss of heat is necessary for survival, it alone does not guarantee thermal comfort. To be comfortable, the body has to lose the necessary amount of heat, while maintaining the following conditions:

- skin temperature should be kept within the limits specified for each part of the body.

- skin wetness due to sweating, and dryness due to too much moisture loss, should be avoided.

- air motion around the skin should be maintained at an acceptable level to avoid stuffiness or draught.

Although human comfort can be influenced by psychological factors it has a physical/psychological basis, the thermal balance between the body and its environment. This involves keeping the internal temperature of the body within a certain range, regardless of the relatively wide variation in the external environment. The conditions under which such a balance is achieved, and the state of the body when it reaches its equilibrium, depend on the combination of two variables, environmental and individual.

Fanger [3] and Szokolay [5] showed that, although air temperature is the most important factor in determining thermal comfort, it is not the only one. Heat exchange on the body's surface is influenced by four environmental and four individual factors. Comfort and discomfort depend on their joint effect. They are:

Environmental

1- air temperature (around the body).
2- humidity (water vapour pressure in ambient air).
3- mean radiant temperature (indoor radiation in relation to the body).
4- relative air velocity (around the body).

Individual

1- activity level.
2- thermal resistance of clothing.
3- body shape.
4- food and drink.

Scales Of Comfort

Comfort can be monitored via different locations connecting the human body to the environment. Some scientists prefer to take skin temperature as an indicator of thermal comfort because the skin is supposed to be the system that adjust the body temperature to thermal surroundings. Skin temperature varies according to the area of skin measured. The skin of toes may be at 27°C, that of upper arms and legs at 31-32 °C, with forehead temperatures near 34 °C [6]. An average is taken as 33.5 °C [7]. Body temperatures can be taken as a measure in the extreme thermal stress. The body core temperature is very sensitive and should be maintained in a very narrow range. Beyond this range, body fever signs start to appear and a person might reach a critical condition.

Due to the several variables affecting human comfort within buildings, it is hard to express such comfort by a single variable. This led to the introduction of indices that combine variables in some sort of relation. Few indices included all the variables affecting comfort. Depending on the circumstances surrounding the measurements of human thermal response, some of them can be more usable than others.

Thermal indices can categorised as: (1) Those concerned with human bodies within the reasonable comfortable levels and (2) Those concerned with human bodies under maximum level of both ends of thermal stress to determine human tolerance at such extreme levels.

Comfort indices were developed through time since the turn of this century. The more recent, of course are the most accurate and more applicable to a variety of conditions. There are many comfort indices, the most well known are effective temperature, corrected effective temperature, equivalent temperature, equivalent warmth, operative temperature, resultant temperature, equatorial comfort index, globe temperature and predicted mean vote of the body heat balance equation.

Comfort Zone in Bahrain

Fanger [8] carried out an extended experiment to find the preferred temperature surrounding the human body. 1296 subjects were involved in separate observations in order to determine the degree of warmth-coolness felt by humans. The scale used in the survey was a seven point scale. 4 being the preferred temperature for comfort, 5, 6, 7 as slightly warm, warm, and hot, 3, 2, and 1 as slightly cool, cool and cold respectively.

The change in temperature was related to a fixed state of light clothing, low air movement, and sedentary activity. Although there was no complete agreement on people's preferences as to exact ratings to the different points in the scale, a conclusion was made that the preferred temperature was 26.1 °C for males and 25.5 °C for females.

Humphreys [9,10] and Auliciemes [11] came up with the thermal neutrality equations for the human body. These investigations were based on experimental work when people were thermally tested under different conditions. The results of these experiments were then analysed by using regression analysis. Humphreys showed that 94% of the neutral temperatures is associated with the variation of outdoor mean temperature. For free running buildings, the regression equation was found to:

$$Tn = 11.9 + 0.534\ Tu$$

Where

Tn is the predicted neutral temperature

Tu is the mean outdoor temperature for the months in question

Auliciems came up with a similar equation, but with different slope:

$$Tn = 17.6 + 0.31\ Tu$$

Based on the above equations, the predicted neutral temperatures for Bahrain based on the hottest and coldest three months are in the range of , 26-28.1 °C for summer and 22-24 °C for winter. Those values are not far away from the thermal neutrality points suggested by Fanger, taking into account the acclimatisation of the Bahraini people to the hot climate and different clothing costumes.

Cooling And Heating Requirements For Bahrain Using The degree - Day Method

One way of estimating the cooling and heating requirements at any location is the degree-day method. The degree day term is a purely climatic concept, which can visualised as the annual cumulative time-weighted temperature deficit (heating degree-days) or surplus (cooling degree-days). A reference temperature is set and every days mean outdoor temperature is compared with this reference temperature. The differences are added for every day to give the annual number of degree-days. The reference temperatures selected for this work are 18.3 °C for winter and that is according to the American Society of Heating , Refrigeration and Air Conditioning (ASHREA), and 26 °C for summer. The out come of this calculation will be classified as humid and dry, taking 50% as neutral point of humidity.

Table 1

Month	Cooling Degree-Days (humid)	Cooling Degree-Days (dry)	Heating Degree-Days (humid)	Heating Degree-Days (dry)
January	--	--	37	--
February	--	--	9	--
March	--	--	--	--
April	--	--	--	--
May	102	25	--	--
June	153	51	--	--
July	196	52	--	--
August	211	32	--	--
September	174	24	--	--
October	83	7	--	--
November	--	--	--	--
December	--	--	--	--
Total	919	191	46	--

The above table shows very clearly that Bahrain requires almost no heating , while , the cooling requirements are very high, and it also shows that excess heat and high humidity are the main problems in Building design in Bahrain. This method may not be as theoretically precise , but it is considered by many to be of more value for practical use .

Bioclimatic Approach To Building Pre Design Strategies

Bioclimatic charts facilitate the analysis of the climatic characteristics of a given location from the viewpoint of human comfort, as they present on a psychrometric chart the current combination of temperature and humidity at given time. They can also specify building design guidelines to maximise indoor comfort conditions. All such charts are structured around the comfort zone.

The Bioclimatic Chart Of Olgyay

Vector Olgyay [12] was the first to develop a bioclimatic diagram, called the "Bio Climatic Chart", Fig. 1. The chart has relative humidity as the abscissa and temperature as the ordinate. Comfort ranges for still air conditions, for summer and for winter, are plotted on the chart. The temperatures below the lower limit of the comfort range are defined as "underheated" conditions and above it as "overheated" conditions. The ability to extend the summer comfort range to higher temperatures and humidities with

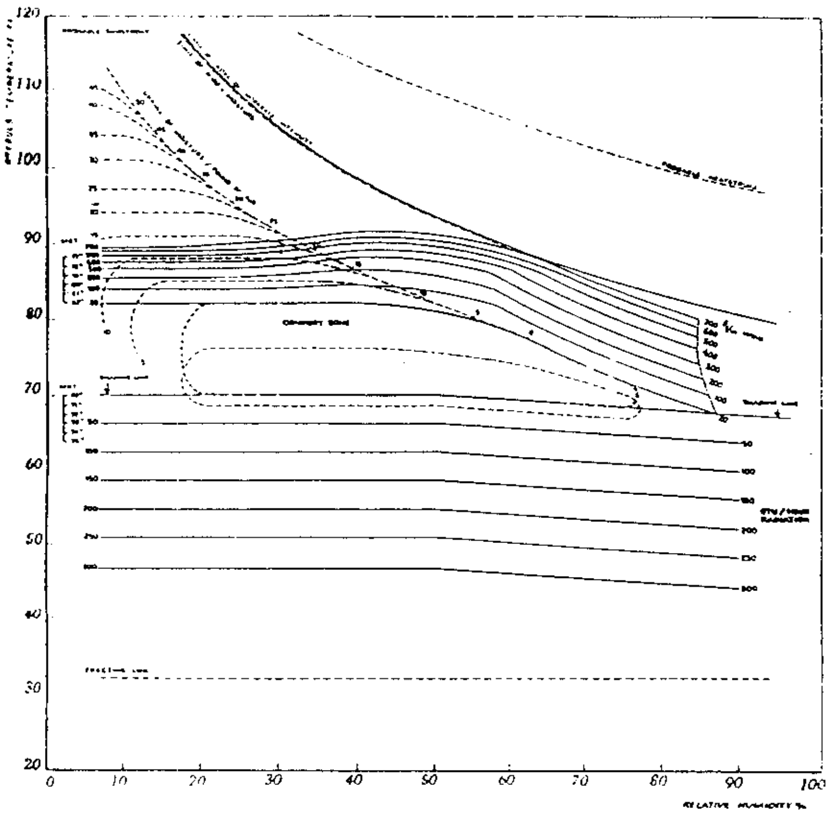

Fig. 1 Olgyay's Bioclimatic Chart (1)

increasing wind speeds, and the ability to lower the air temperature by water evaporation, are also plotted on the chart.

Givoni [4], pointed out that one of the main constraints of Olgyay's chart, that it is based on outdoor climatic conditions, i.e. some limitations in analysing the indoor physiological requirements in the building would be expected.

This chart can be applied only on hot humid regions where there is no high range fluctuations between indoor and outdoor conditions and ventilation is essential during the day.

Olgyay bioclimatic chart for Bahrain is shown in Fig. 2, in which the plotted lines represent the average daily maxima and minima for both dry-bulb temperature and relative humidity for each moth of the year. It can be observed that in case of the summer, comfort can be achieved partially by introducing air movement of about 1 m/s for the hottest months.

In the other side, radiation is necessary in the winter to counteract lower temperatures, as in February for example a radiation of about 500 W/m^2 is required to bring the outdoor conditions to the lower limit of the comfort zone.

<u>The Building Bioclimatic Chart</u>

The building bioclimatic chart (BBCC) was developed by Givoni [4] to address the problems associated with the Olgyay's chart. It is based on the indoor temperature in buildings instead of on the outdoor temperatures, Fig. 3.

The format proposed by Givoni is the familiar psychrometric chart. On the psychrometric chart, he overlaid boundaries defining the limits of the passive cooling strategies to create thermal comfort in the interiors of buildings in given climatic conditions. In other words, the chart combines different temperature amplitudes

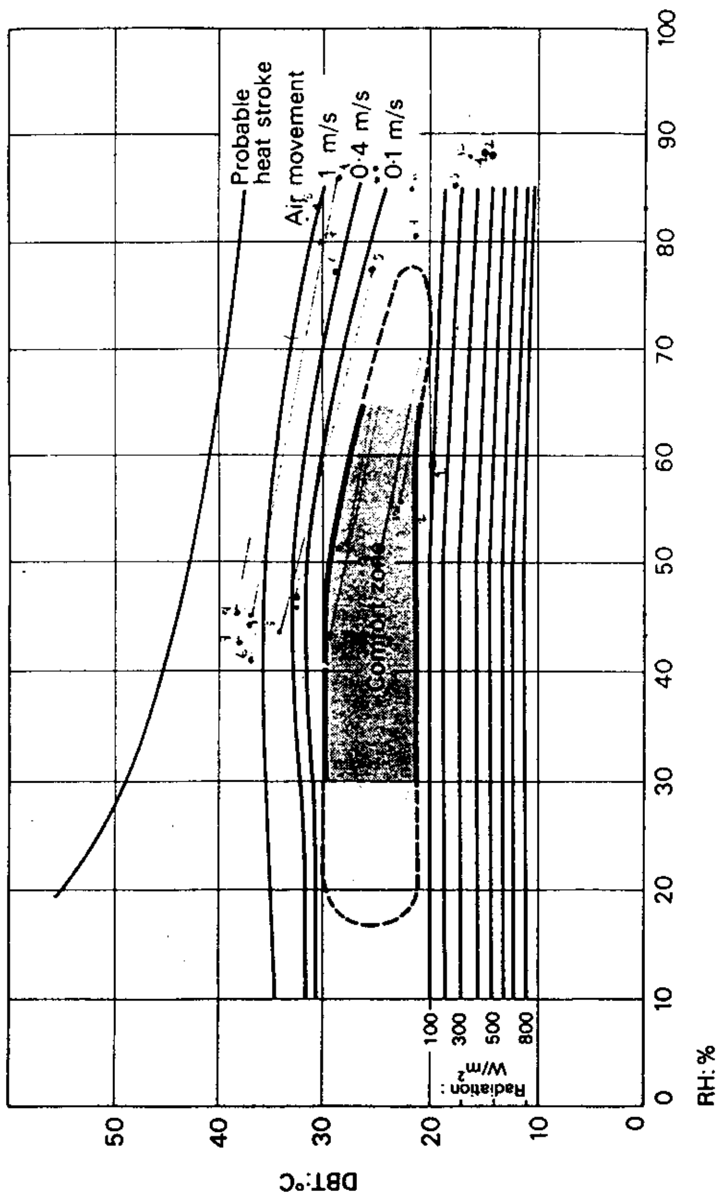

Fig. 2 Application Of Olgyay's Bioclimatic Chart On Bahrain

and vapour pressure of the ambient air plotted on a psychrometric chart and correlated with specific boundaries of passive cooling techniques overlaid on the chart. These boundaries or parameters were initially defined by Givoni on the bases of field measurements of test buildings, and they have been updated subsequently by Givoni and several other contributors.

In addition, Givoni used the psychrometric chart as the base to defined the comfort zone and sketched out the probable extent of outdoor conditions under which certain passive control techniques can ensure indoor comfort.

In spit of the several modifications and improvements, Givoni's chart has some limitations, as Watson [13] showed. He stated that Givoni's chart is used more in residential building structures which are free of internal heat gains. He added that some limitations such as the upper boundary of the ventilation effectiveness zone is based on the assumption that the indoor mean radiant temperature and vapour pressure are nearly the same as these in the external environment. So, this needs a building structure of relatively low mass and a medium to high thermal resistance with white exterior surfaces.

The application of Givoni's bioclimatic chart to Bahrain is shown in Fig.4, for the hottest and coldest moths (August and January). This figure show distinctly that dehumidification and ventilation are the two building passive design strategies that should be followed in Bahrain to achieve thermal comfort inside buildings at summer, while in winter some passive heating is required and this could be obtained by letting solar radiation into buildings.

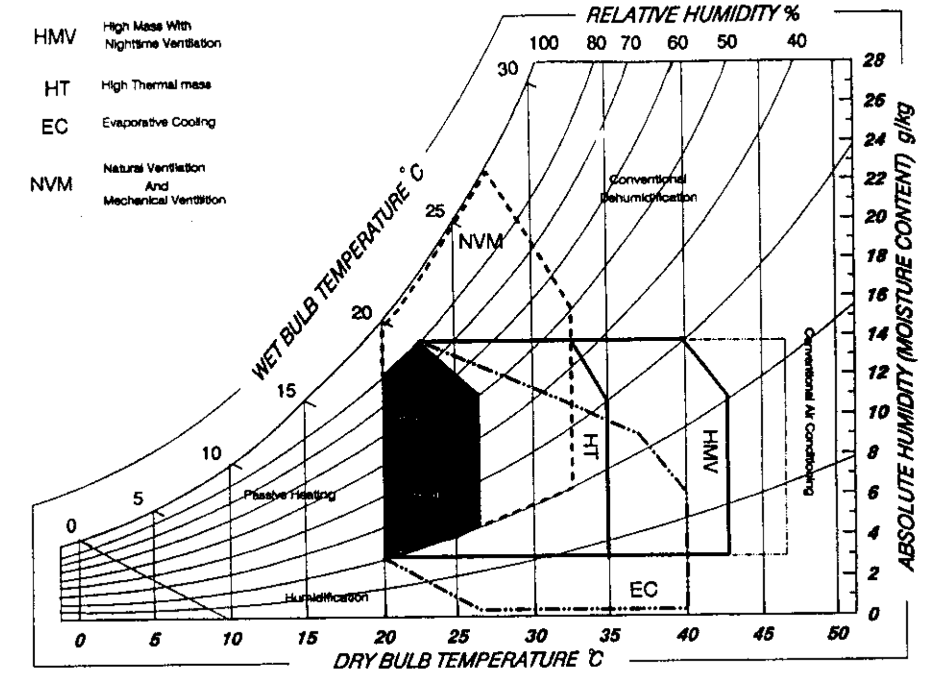

Fig. 3 Givoni's Bioclimatic Chart

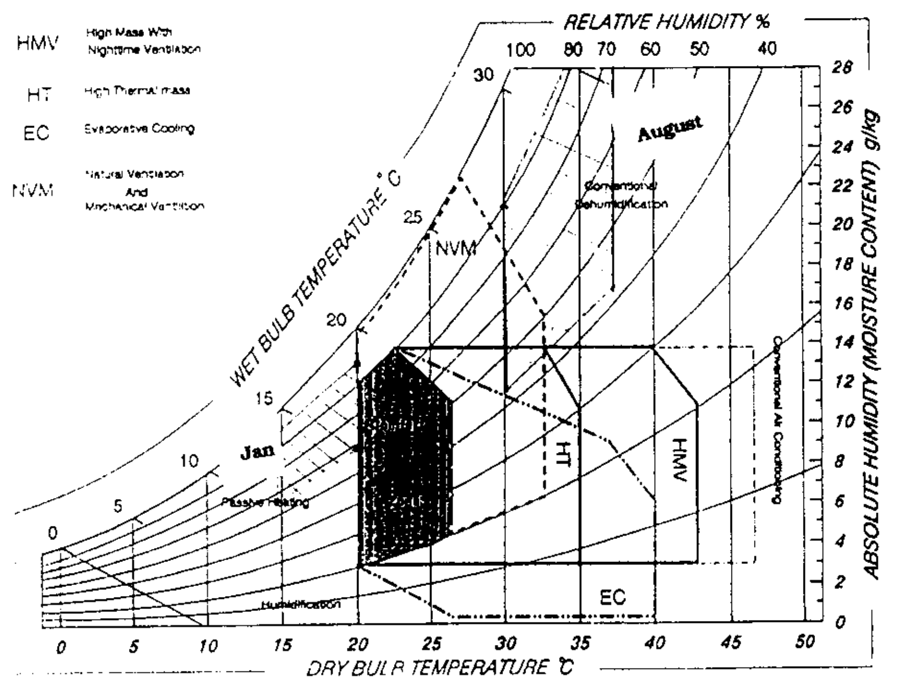

Fig. 4 Application Of Givoni's Bioclimatic Chart On Bahrain

Pre Design Recommendations Of Mahoney Tables For Bahrain's Climate

Carl Mahoney developed a method for determining the human comfort requirements and satisfactory building design principles. It was first published by the United Nations Centre For Housing, Building And Planning [14] and was intended for composite climates but can be used for the diagnosis of any climate.

It consists of a simple set of tables for recording and analysing climatic information and deriving from it the appropriate specifications for the layout, orientation, shape and structure of buildings.

The first set of these tables are used to record the required meteorological data, such as dry bulb temperature, precipitation, wind and relative humidity, which is classified into groups as shown below;

Average Monthly Relative Humidity	Humidity Group
Below 30%	1
30% to 50%	2
50% to 70%	3
Above 70%	4

Similarly the monthly mean maxima and the monthly mean minima of the site in question are compared to the day and night comfort limits for each individual month, according to the annual mean ranges given in table 3 respectively (i.e. maxima with the day comfort limits and minima with the night comfort limits). The classification is established as follows;

Above comfort limit ------------------------------------	H
Within comfort limit ------------------------------------	-
Below comfort limit ------------------------------------	C

In the next step, the humidity and comfort classifications are compared for each month to establish humidity and arid indicators as follows;

Humidity Indicators :

H1 : Indicates that air movement is essential. It applies when high temperature (day thermal stress=H) is combined with high humidity (HG=4) or when the high temperature (day thermal stress =H) is combined with moderate humidity (HG=2 or 3) and a small diurnal range (i.e. less than 10 °C).

H2 : Indicates that air movement is desirable. It applies when temperature within the comfort limit (day thermal stress = -) is combined with high humidity (HG=4).

H3 : Indicates that precautions against rain penetration are needed. Problem may arise even at low precipitation figures, but will be inevitable when rainfall exceeds 200 mm per month.

Arid indicators :

A1 : Need for thermal storage mass. This applies when a large diurnal range (10 °C or more) coincides with moderate or low humidity (HG=1,2 or 3).

A2 : Indicates the desirability of outdoor sleeping space. It is needed when the night temperature is high (night thermal stress=H) and the humidity is low (HG=1 or 2). It may be needed also when nights are comfortable outdoors but hot indoors as a result of heavy thermal storage (i.e. day=H, night= -, humidity group=1 or 2 and when the diurnal range is above 10 °C).

A3 : Indicates winter or cool - season problem. These occur when day thermal stress= C.

TABLE 2

Location	Bahrain
Longitude	50° 37' E
Latitude	26° 16' N
Altitude	2 m

Air temperature °C

	J	F	M	A	M	J	J	A	S	O	N	D	High	Amt
Monthly mean max.	20	21	24.5	29	34	36.5	37.5	37.5	36.5	32.5	27.5	22	37.5	26
Monthly mean min.	14	15	17.5	21.5	26.5	29	30.5	30.5	28.5	25	21	16	14	23.5
Mean range	6	6	7	7.5	7.5	7.5	7	7	8	7.5	6.5	6	Low	Amr

mean range =(monthly mean max.-monthly mean min.)

Amt = Annual mean temperature =(highest+lowest)/2

Amr = Annual mean range = highest-lowest

Relative humidity %

	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max.	88	88	85	81	78	77	80	83	86	86	85	87
Monthly mean min.	59	55	49	43	43	41	42	45	45	47	52	56
Average	74	72	67	62	60	59	61	64	66	67	69	72
Humidity group	4	4	3	3	3	3	3	3	3	3	3	4

Rain and wind

Total

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Rainfall mm	17	13.5	13.5	8	1.5	-	-	-	-	0.5	4	14.5	72.5
Prevailing wind	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	
Secondary wind	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	

		AMT over 20 °C		AMT 15-20 °C		AMT below 15 °C	
Comfort limits		Day	Night	Day	Night	Day	Night
Humidity group:	1	26-34	17-25	23-32	14-23	21-30	12-21
	2	25-31	17-24	22-30	14-22	20-27	12-20
	3	23-29	17-23	21-28	14-21	19-26	12-19
	4	22-27	17-21	20-25	14-20	18-24	12-18

TABLE 3

Diagnosis: °C	J	F	M	A	M	J	J	A	S	O	N	D	ATM
Monthly mean max.	20	21	24.5	29	34	36.5	37.5	37.5	36.5	32.5	27.5	22	26
Day comfort: upper	27	27	29	29	29	29	29	29	29	29	29	27	
lower	22	22	23	23	23	23	23	23	23	23	23	22	
Monthly mean min.	14	15	17.5	21	26.5	29	30.5	30.5	28.5	25	21	16	
Night comfort : upper	21	21	23	23	23	23	23	23	23	23	23	21	
lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress: day	C	C	-	-	H	H	H	H	H	H	-	-	
night	C	C	-	-	H	H	H	H	H	H	-	C	
Indicators													totals
Humid: H1					•	•	•	•	•	•			6
H2												•	1
H3													0
Arid: A1													0
A2													0
A3	•	•											2

TABLE 4: Recommended specifications

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
6	1	0	0	0	2

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
								Layout
			0-10				1	Orientation north and south (long axis east-west)
			11, 12		5-12			
					0-4		2	Compact courtyard planning
								Spacing
11,12							3	Open spacing for breeze penetration
2-10						•	4	As 3, but protection from hot and cold wind
0,1							5	Compact lay-out of estates
								Air movement
3-12						•	6	Rooms single banked, permanent provision for air movement
1, 2			0-5					
			6-12				7	Double banked rooms, temporary provision for air movement
0	2-12							
	0,1						8	No air movement requirement
								Openings
			0,1		0		9	Large openings, 40-80%
			11, 12		0,1		10	Very small openings, 10-20 %
Other conditions						•	11	Medium openings, 20-40%
								Walls
			0-2			•	12	Light walls, short time - lag
			3-12				13	Heavy external and internal walls
								Roofs
			0-5			•	14	Light, insulated roofs
			6-12				15	Heavy roofs, over 8 h time - lag
								Out - door sleeping
				2-12			16	Space for out -door sleeping required
								Rain protection
		3-12					17	Procession from heavy rain necessary

TABLE 5
Detail recommendations

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
6	1	0	0	0	2

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
								Size of opening
			0,1		0		1	Large: 40-80 %
					1-12	•	2	Medium: 25-40 %
			2-5					
			6-10				3	Small: 15-25 %
			11, 12		0-3		4	Very small: 10-20 %
					4-12		5	Medium: 25-40 %
								Position of openings
3-12						•	6	In north and south walls at body height on windward side
1-2			0-5					
			6-12				7	As above, openings also in internal walls
0	2-12							
								Protection of openings
					0-2	•	8	Exclude direct sunlight
		2-12					9	Provide protection from rain
								Walls and floors
			0-2			•	10	Light low thermal capacity
			3-12				11	Heavy, over 8 h time - lag
								Roofs
10-12			0-2				12	Light, reflective surface, cavity
			3-12			•	13	Light, well insulated
0-9			0-5					
			6-12				14	Heavy, over 8 h time - lag
								External features
				1-12			15	
		1-12					16	Heavy, over 8 h time - lag

These tables are followed by the design recommendations in which the design requirements of a building can be derived. The recommendations for the form of the building are grouped under the following eight subjects:

Layout - Space - Air movement - Openings
Walls - Roofs - Rain protection - Outdoor spaces

At this stage, recommendations for the various sizes and protection of openings, layout planning, positioning, glazing, natural light and prevention of glare, along with the type of external walls, roofs and floors, could be indicated.

Application of Mahoney's Tables in Bahrain

The climatic data for Bahrain were fitted in Mahoney's tables (tables 2,3,4 and 5), and after going through the whole analysis, the following recommendations were suggested :

1. Buildings should be well spaced to allow for breeze penetration, but buildings and planting should also be planned to give protection against dusty winds either hot or cold.
2. Rooms should be single banked with windows in the north and south walls.
3. Medium sized openings should be used (from 25% to 40% of the area of the north and south walls). These openings should be protected from direct sunlight.
4. External walls should be light with a small heat capacity (i.e. short time - lag), but the internal walls should be heavy.
5. A light but well insulated roofs should be used.

The very clear thing from the above recommendations that natural ventilation followed by thermal mass(light walls and roofs) are main building design strategies which should be followed in order to achieve thermal comfort in buildings in Bahrain .

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