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"Bioclimatic Approach to Building Design in the Ar-Rihahd Region in Saudi Arabia (Hot Arid)"

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

BIOCLIMATIC APPROACH TO BUILDING DESIGN IN AR-RIHADH REGION IN SAUDI ARABIA (HOT ARID)

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Abstract

By reviewing the literature , there are differen' attempts of determining the suitable systematic methodology for adapting the design of a building to the human requirements and climatic conditions. In this paper, each method will be discussed briefly and apply each one in Ar-Riyadh region of Saudi Arabia with taking into account the limitations for each techniques. Consequently , these methods will be combined to select the most appropriate design strategies in the mentioned region. The methods which will be exhibited in this paper are the most important in terms of the bioclimatic concept of building design accuracy (so far). It has been taken into consideration in presenting these methods, the development of the bioclimatic concepts of building design since 1950.

KEYWORDO

Biocilmatic Design; Psychrometric Chart; Thermal Comfort; Thermal Mass; Strategy;

1.1. Olgyay's Bioclimatic Chart:

Olgyay brothers in 1950's proposed the climatic chart as a method of determining human requirements and satisfactory building design principles in relation to the climate [1,2].The bioclimatic chart shows the relationships of different climatic elements to each other. In the chart, the Y-axis represents dry-bulb temperature and the x-axis represents relative humidity. In addition,the human thermal comfort shown as a zone in the middle of the chart (fig. 4.1) where the other climatic elen.ents (mean radiant temperature,wind speed,solar radiation,and evaporative cooling) around it are indicated by means of curves in which they show the necessary corrective measures to restore the feeling of comfort at any point outside the comfort zone.In the middle, it can be seen clearly that the winter comfort zone lies a little lower of the summer comfort zone. The lower area of the comfort zone is the area where sunshine is required.In the other hand, shading is needed in the area above the indicated limit line.At temperature above the comfort zone, the wind speed required to restore comfort which is shown in relation to humidity. In case of the ambient conditions are hot and dry, the evaporative cooling is necessary for comfort as indicated.

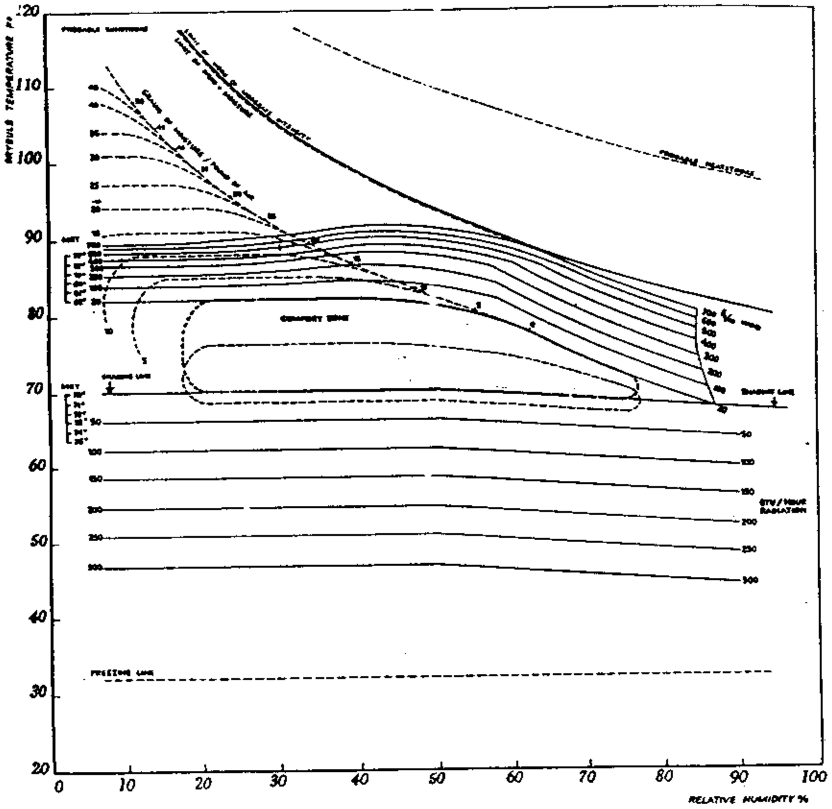


Fig. 1. The Bioclimatic Chart Proposed by The Olgyay Brothers [2]

Some steps should be followed for using Olgyay's bioclimatic chart in determining the appropriate human requirements in order then to be transferred to a building design which satisfy these requirements.

__First__ : collecting the local climatic data such as temperature,wind,radiation and humidity.

__Second:__ putting the climatic data in tables on an annual basis,then a series of charts showing annual distribution of the climatic elements should be constructed.

__Third__ : plotting of the tabulated data on air temperature and humidity on bioclimatic chart. As mentioned, the lower limit of the comfort zone (70° F) is known as the 'underheated' period where irradiation is required. The area above the limit is the 'overheated' period in which shading from solar radiation is necessary. After the climatic type is determined and , from the other variables shown on the chart ,the comfort requirements of ventilation,evaporative cooling,shading or solar radiation can be evaluated.

__Fourth__: design criteria and factors can then be determined accordingly such as the building forms and orientation, the location, size and shading of openings and proportion of the solid to the void, etc.

__1.2. Limitation of Olgyay's method__ :

Although Olgyay's method was the first attempt of incorporating the climatic conditions into building design, the method has some constraints.First of all, the chart is based only on outdoor climatic conditions. In other words, some limitations in analyzing the indoor physiological requirements in the building would be expected [3]. Second, it 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 day.As an illustration , in hot-dry areas where the difference in the daily temperature (maximum and minimum) is about 17°C ,and relative humidity is about 45% and by plotting these figures on Olgyay's bioclimatic chart, comfort is not achievable during the day,unless evaporative cooling is provided or the indoor wind velocity is very high.In this example, the analysis are limited only to the outdoor climatic conditions and not including indoor climatic conditions and the building structure itself as a related factors.By employing the indoor climatic conditions and building structure, the comfort could be easily achieved in the mentioned example such as selecting appropriate materials and shading devices.

__1.3 Application of Olgyay's method in Ar-Riyadh region__

Bioclimatic chart for Ar-Riyadh region is shown in fig.2.4 in which the plotted lines represent the hottest and coldest months from the average daily maxima and average daily minima data of both dry-bulb temperature and relative humidity. It can be observed that in case of the summer (hottest months),comfort

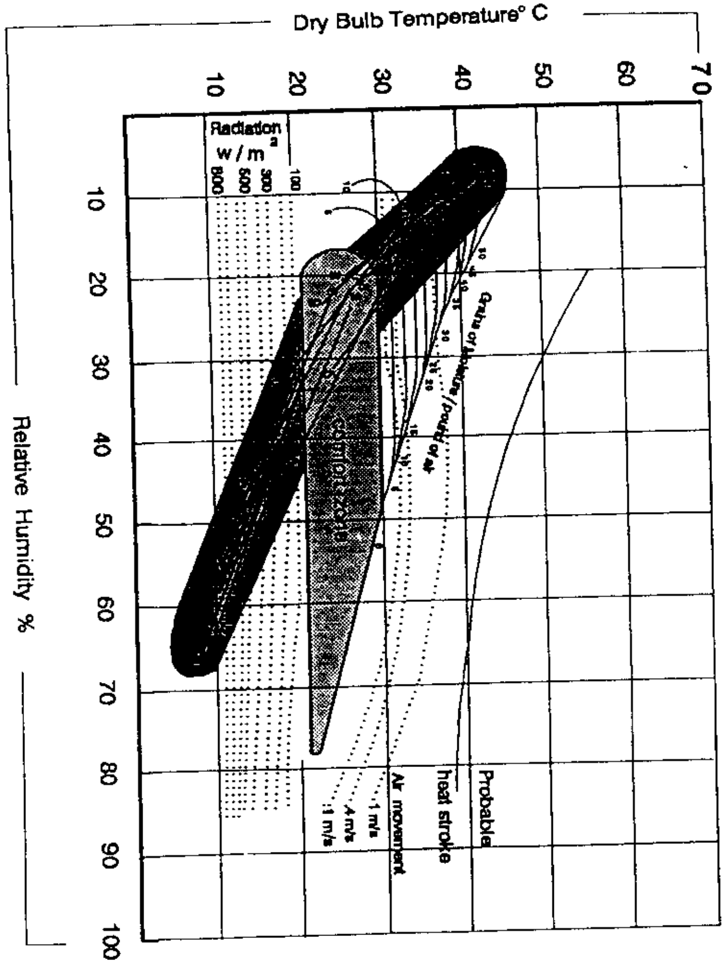


FIG. .2. APPLICATION OF OLGYAY' BIOCLIMATIC CHART ON AR-RIYADH

can be achieved when shading is to be employed. In addition, the case of Ar-Riyadh region as it is clear from the chart for the summer season, the temperature is high and the relative humidity is low. As a solution of this case , the winds are of little help. The most effective tool in order to fight high temperature is evaporative cooling. The dotted lines indicate grains of moisture per pound of air needed to reduce temperatures to the level at the upper comfort perimeter. For example, in July (the hottest month), the grains of moisture per pound of air is 45 in order to bring the high temperature and relative humidity to the upper limit of the comfort zone.

In the other side, radiation is necessary in the winter (Dec,Jan,Feb,March) to counteract lower dry-bulb temperatures. The amount of W/m^2 needed by 'solair' action to restore the sensation of comfort for outdoor conditions only, is shown by the parallel lines below the comfort zone. For example, in the month of January, the radiation needed is more than 800 W/m^2 for the purpose of bringing the outdoor conditions to the lower limit of the comfort zone. However, there is no enough solar radiation in that month.

Having said that, Olgyay's bioclimatic chart is appropriate for outdoor conditions in hot-humid climate only because there is no any consideration to the building structure and materials in which the consideration of them would lead to a better solutions.

2.1 Givoni's building bioclimatic chart

Because the limitations mentioned in Olgyay's bioclimatic chart , Givoni in 1969 developed his building bioclimatic chart. The format which Givoni proposed is the familiar psychrometric chart, which is useful for engineering purposes. On the psychromatric 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 and vapour pressure of the ambient air plotted on a psychromatric 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 (1979) and several other contributors (Milne and Givoni, Arens et al ,1986) [4]. As an illustration, if the ambient climatic conditions were 28°C and 50%, this falling just inside the limit of 'ventilation effectiveness' (fig. 4.3). So, Givoni's bioclimatic chart represents a guideline tool for choosing the appropriate design strategies for a specific climatic conditions. In addition, Givoni used the psychrometric chart as the base to define the comfort zone and sketched out the probable extent of outdoor conditions under which certain passive control techniques can be ensure indoor comfort [5].

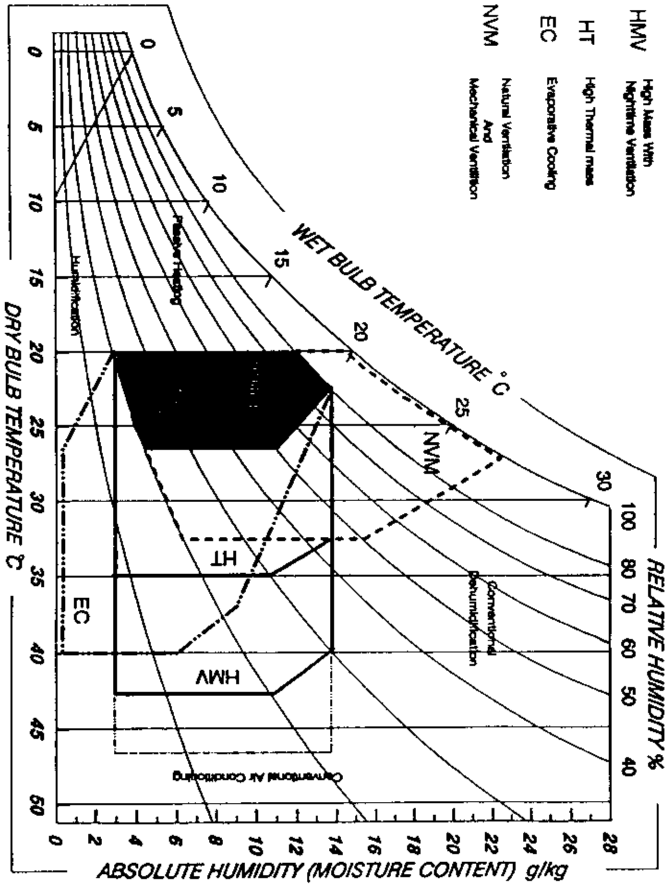


Fig. .3.The building bioclimatic chart proposed by Givoni [14].

2.2 Limitation of Givoni's building bioclimate chart

In spit of the fact that Givoni's bioclimatic chart has been passed through several modifications and improvements, it has some limitations. In 1981 ,Watson [6], discussed the limitations of Givoni's bioclimatic analysis. He stated that Givoni's bioclimatic chart is used more in residential building structures which are free of internal heat gains. He added that some assumptions have 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 of medium to high thermal resistance with white exterior surfaces. The other limitation in Givoni's assumptions is the thermal mass effectiveness which based on the assumption that all windows are closed during the day time, the indoor air and the indoor vapour pressure is 2mm higher than the outdoor. Other building features such as opening surfaces and shading have been described. Watson mentioned some other limitations regarding the collected data from weather stations which is not necessarily represent the climate of their respective regions. He stated that some other information which effect the climate and has not been taken int consideration during the collection of the data such as dust and chemical pollutants ,can compromise the desirability of ventilation as a cooling strategy. Microclimatic conditions such as proximity to bodies of water can significantly alter temperatures and humidity which can be a limitation for other methods as well.

2.3 Application of Givoni's bioclimatic chart in Ar-Riyadh

The building bioclimatic chart for Ar-Riyadh city has been drawn (fig. 4.4) based on the hottest and coldest months July and Dec. respectively. It can be distinctly noticed from the chart that during summer period, the comfort can be attainable entirely by passive means such as evaporative cooling and high thermal mass with night time ventilation. In the other hand ,the case of winter months, small part of it is in the comfort zone ,but large part is under cool period. However, in case of Ar-Riyadh the designer has the challenge to incorporate conflicting winter and summer comfort requirements into a single design. The most dominant strategy in this case is thermal mass (with small openings) which can be a reasonable solution to provide a suitable time lag in which the heat can not reach inside of the building during the daytime in summer, and acts as heat storage advise for the cool nights in winter. This strategy can be employed by the selection of appropriate material along with proper orientation and other passive design strategies such as evaporative cooling etc.

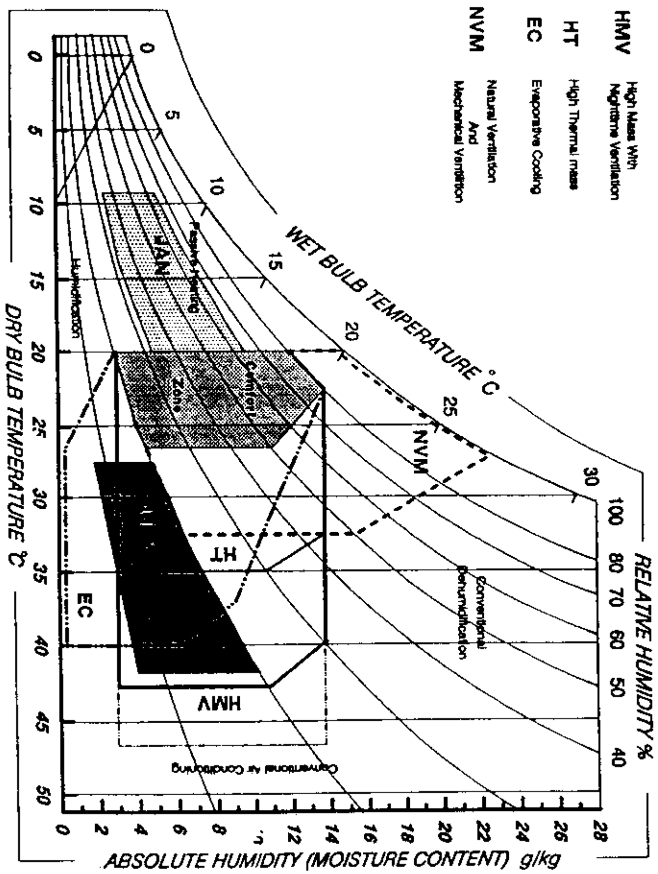


Fig. .4.Application of Givoni' building bioclimatic chart on Ar-Riyadh

3.1 Mahoney's Tables

Another method of determining the human comfort requirements and satisfactory building design principles was developed by Carl Mahoney. It consists of a simple set of tables for recording and analyzing climatic information and driving from it appropriate specifications for the layout ,orientation, shape and structure of the building [7].

In this approach , the climatic data such as dry bulb temperature, relative humidity ,precipitation and wind ,are classified into groups as described below;

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

Similarly the monthly mean maxima and 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 limit 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 described below ;

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 (DR less than 10°C).

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

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

Arid indicators :

A1 : Need for thermal storage. 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 = 1or 2 and when the diurnal range is above 10°C).

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

These tables are followed by the sketch 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 subject :

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

At this stage , recommendations for the various size 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.

3.2 Limitation of Mahoney's Tables

Mahoney's tables are reasonable approach in determining the human comfort requirements and satisfactory building design recommendations. However, the human comfort limits indicated in the table are quite vary depending on people ,age and cultural differences. In addition, some other data are not considered such as dust ,chemical pollutant which can compromise the desirability of other design recommendations. It can be agreed that these limitations are applicable to the previous methods . However, Mahoney's tables are a systematic approach to the design recommendations which are more elaborated than the previous methods in term of different building details.

3.3 Application of Mahoney's tables in Ar-Riyadh city

The climatic data for Ar-Riyadh city is recorded in Mahoney's tables (tables 4.1,4.2,4.3,4.4). It can be noted from the tables that Ar-Riyadh city is hot and dry with monthly mean range more than 11.4 °C. The result of the analysis (table 4.5,4.6) are summarised in the following table :

Element	Recommendations
Layout	1- Building oriented on east-west axis to reduce exposure to sun. 2-Compact courtyard planning.
Spacing	Compact planning.
Air movement	Double-blanked rooms with temporary provision for air movement or no air movement required.
Openings:	
Size:	Very small openings, 10% - 20% of wall surface area.
Position:	In north and south walls at body height on windward side, but including openings in internal walls (towards the courtyard).
Protection:	No indication in the tables.
Walls and floors	Heavy external and internal walls, over 8 hours time -lag.
Roofs	Heavy roofs ; over 8 hours time lag.
Outdoor sleeping	Space for outdoor sleeping required.

4.1. Human thermal comfort

To develop a single parameter that represents the physiological and sensory response of the body under various environmental and physical conditions, a large number of indices have been developed (eg. effective temperature , resultant temperature , and heat stress index etc.). One of these has been attempted by Givoni in the 1970's. This approach is based on determining the heat production and exchange between the human body and its environment to achieve thermal equilibrium.

Location	Ar-Riyadh
Longitude	46.4° E
Latitude	24.4° N
Altitude	600m

TABLE .1 Air Temperature (Deg Celsius)

	J	F	M	A	M	J	J	A	S	O	N	D	Highest / Lowest	AMT / AMR
Monthly mean max.	20.2	24.1	27.7	33.3	38.4	41.6	42.6	42.3	39.8	34.3	27.8	21.8	42.6	25.7
Monthly mean min.	8.8	10.1	14.9	20	24.4	26.4	27.5	27	24.1	19.2	14.3	10	8.8	33.8
Monthly mean range	11.4	14	12.8	13.4	13.9	15.2	15.1	15.4	15.7	15.1	13.5	11.9		

Monthly mean range =(month.mean max. - month.mean min.)

A.M.T. = Annual mean temperature = (highest + lowest) / 2

A.M.R. = Annual mean range = highest - lowest

TABLE .2 Humidity,Rain and Wind

Relative humidity: %

	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max. a.m.	65.7	54.3	51.2	40.2	30.8	20.2	20	20.7	23.8	32.7	47.9	61.8
Monthly mean min. p.m.	32	23.8	24	17.3	13	8.5	8.7	9.3	9.8	14	22.7	31.5
Average	48.9	39.1	37.6	28.8	21.9	4.4	14.4	15	16.8	23.4	35.3	46.7
Humidity group	2	2	2	1	1	1	1	1	1	1	2	2

Rain and wind

	J	F	M	A	M	J	J	A	S	O	N	D	*Total*
Rainfall, mm	4	4	21	22	13	3	0	0	0	0	10	13	90
Wind, prevailing	SE	SE	SE	NE	NE	N	NW	N	NW	NW	NW	SE	
Wind, secondary													

Comfort limits

		TEMP. OVER 20 °C		TEMP. 15-20 °C		TEMP. BELOW 15 °C	
		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	23-39	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

Diagnosis: C	J	F	M	A	M	J	J	A	S	O	N	D	AMT
Monthly mean max.	20.2	24.1	27.7	33.3	36.4	41.6	42.6	42.3	39.8	34.3	27.8	21.8	25.7
Day comfort: upper	31	31	31	34	34	34	34	34	34	34	31	31	
Day comfort: lower	25	25	25	26	26	26	26	26	26	26	25	25	
Monthly mean min.	8.8	10.1	14.9	20	24.5	26.4	27.5	27	24.1	19.2	14.3	10	
Night comfort: upper	24	24	24	25	25	25	25	25	25	25	24	24	
Night comfort: lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress: day	C	C	-	C	H	H	H	H	H	H	-	C	
Thermal stress: night	C	C	C	-	-	H	H	H	-	-	C	C	

TABLE .4 Indicators

Indicators		J	F	M	A	M	J	J	A	S	O	N	D	Totals
Humid:	H1													0
	H2													0
	H3													0
Arid:	A1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	12
	A2					✓	✓	✓	✓	✓	✓			6
	A3	✓	✓		✓								✓	4

Indicators total from table 2					
H1	H2	H3	A1	A2	A3
0	0	0	12	6	4

TABLE .5. Recommended specifications

Layout

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0-10			✓	1	Orientation north and south (long axis east-west)
			11, 12		5-12			
			11, 12		0-4	✓	2	Compact courtyard planning

Spacing

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
11, 12							3	Open spaces 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

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
3-12							6	Rooms single banked,permanent provision for air movement
1, 2			0-5					
1, 2			6-12			✓	7	Double banked rooms, temporary provision for air movement
0	2-12							
0	0, 1					✓	8	No air movement required

Openings

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0, 1		0		9	Large openings, 40-80%
			11, 12		0, 1	✓	10	Very small openings, 10-20%
Any other conditions							11	Medium openings, 20-40%

Walls

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0-2				12	Light walls, short time-lag
			3-12			✓	13	Heavy external and internal walls

Roofs

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0-5				14	Light, insulated roofs
			6-12			✓	15	Heavy roofs, over 8 h time-lag

Out-door sleeping

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
				2-12		✓	16	Space for out-door sleeping required

Rain protection

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
		3-12					17	Protection from heavy rain necessary

Indicators total from table 2					
H1	H2	H3	A1	A2	A3
0	0	0	12	6	4

TABLE .6. Detail recommendations

Size of opening

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0, 1		0		1	Large: 40-80%
			0, 1		1-12		2	Medium: 25-40%
			2-5					
			6-10				3	Small: 15-25%
			11, 12		0-3	✓	4	Very small: 10-20%
			11, 12		4-12		5	Medium: 25-40%

Position of openings

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
3-12						✓	6	In north and south walls at body height on windward side
1-2			0-5					
1-2			6-12			✓	7	As above, openings also in internal walls
0	2-12							

Protection of openings

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
					0-2		8	Exclude direct sunlight
		2-12					9	Provide protection from rain

Walls and floors

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
			0-2				10	Light, low thermal capacity
			3-12			✓	11	Heavy, over 8 h time-lag

Roofs

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
10-12			0-2				12	Light, reflective surface, cavity
10-12			3-12				13	Light, well insulated
0-9			0-5					
0-9			6-12			✓	14	Heavy, over 8 h time-lag

External features

H1	H2	H3	A1	A2	A3	✓	No.	Recommendation
				1-12		✓	15	Space of out-door sleeping
		1-12					16	Adequate rainwater drainage

The factors which effect this heat exchange have been classified into primary and secondary factors. The primary factors are metabolic rate, air temperature , mean radiant temperature, air movement, vapour pressure, clothing type and material fit while the secondary factors are stated to be clothing temperature , air motion beneath clothing, skin temperature ,sweat rate, wetness of skin and clothing, and cooling efficiency of sweating. It is assumed that each one of the primary factors can vary independently of the others and usually these variations will cause changes in several of the secondary features. All these factors lead to a quantity called the 'Index of Thermal Stress' (I.T.S). The range of the factors covered by the I.T.S. is :

Air temperature	: 20 to 50°C
Vapour pressure	: 5 to 40 mmHg
Air velocity	: 0.10 to 3.5 m/s
Solar radiation	: Whole range 600 Kcal/h
Metabolic rate	: 100 to 600 Kcal/h
Clothing	: Semi nude ,light summer clothing Industrial or military overalls.

The basic formula described for the exchange of heat (Q) between the body and its environment is ;

$$M \pm R \pm C - E = Q$$

Wher M = Metabolic rate.
R,C,E = The radiative convective and evaporative heat exchanges respectively.

The quantities R,C and E have been evaluated by the use of coefficients that are derived from various physiological and physical experiments [3].

Humphreys in 1978 [8,9] and Auliciemes in 1982 [10] came up with the **thermal neutrality** equations of the human body. It was defined as the temperature at which the person feels thermally neutral (comfortable). These investigations were based on experimental works when people were thermally tested under different conditions. The results of these experiments were then analyzed by using the regression analysis. Hemphreys shows that
94% of the neutral temperature is associated with the variation of outdoor mean temperature. For free running buildings, the regression equation was found to be :

$$Tn = 11.9 + .534\ Tu$$

Where **Tn** = The predicted neutral temperature,
Tu = The mean outdoor temperature for the months in question.

Based on Humphreys' equation and the climate of Ar-Riyadh, the calculation is made and the predicted neutral temperatures are 30.5°C and 20.3°C .

Another calculation is made by using a slightly different empirical correlation function developed by Aulciems :

$$Tn = 17.6 + .31\ Tu$$

Which produces 28.4°C (summer) and 22.5°C (winter). Both calculations have been based upon two values, the mean temperature of the three hottest months and the mean temperature of the three coldest months [11] fc Ar-Riyadh city.

Fig.4.5 illustrates that the thermal neutrality is a function of the prevailing climatic conditions.

Fanger [12] derived the equation that explain heat balance between the human body and the surrounding environment. The equation is :

$$(M/A_{Du})(1-\eta) - 0.35\,[43 - 0.061\,(M/A_{Du})(1-\eta) - P_a] - 0.42\,[(M/A_{Du})(1-\eta) - 50] - 0.0023\,(M/A_{Du})(44-P_a) - 0.0014\,(M/A_{Du})(34-t_a) = 3.4D10^{-8}\, f_{cl}[(t_{cl}+273)^4 - (t_{mrt}+273)^4] + f_{cl}h_c(t_{cl}-t_a).$$

Where :

M = Metabolic rate.
A_{Du} = DuBois area:surface area of the human body.
η = External mechanical efficiency of the human body.
P_a = Partial pressure of water vapour in ambient air.
t_a = Air temperature.
f_{cl} = Ratio of the surface area of the clothed body to the surface area of the nude body (clothing area factor).
t_{cl} = Mean temperature of outer surface of clothed body.
t_{mrt} = Mean radiant temperature.
h_c = Convective heat transfer coefficient.

The most important points in the general comfort equation are that the human thermal comfort is function of the following variables :

1. Environmental factors such as air temperature (t_a), ambient humidity (P_a), air velocity($\underline{v}$) ,and the mean radiant temperature of the environment (t_{mrt})

2. Body insulation factors which are function of clothing (f_{cl}) and the proportion of the skin covered by clothing.

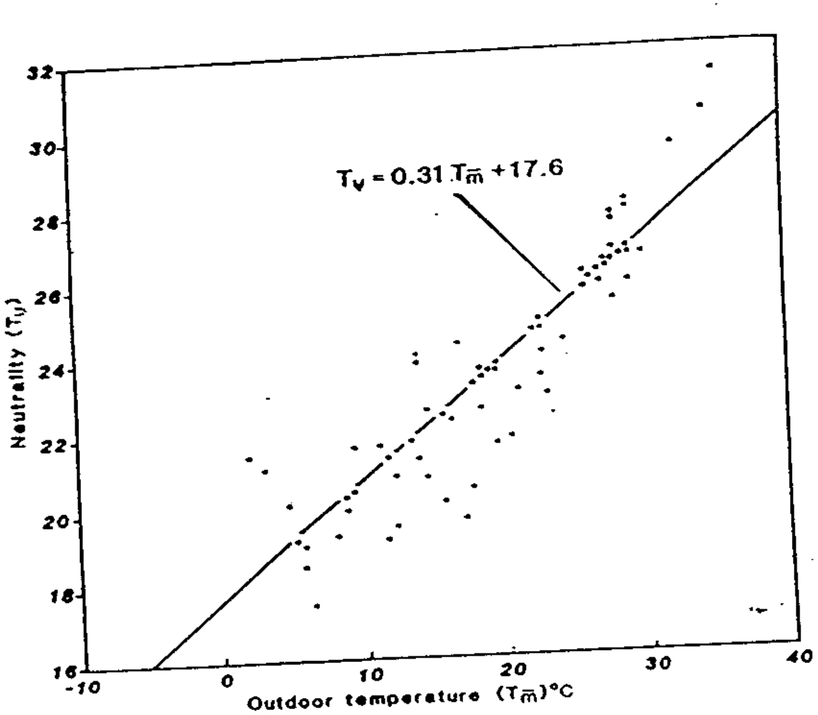


Fig. .5 Correlation of Outdoor Mean Temperature and Thermal Neutrality [9]

3. The human activity level (M/A_{Du}), the mechanical efficiency of the activity (η), and the air flow induced by the activity (v).

4.2 Limitations of the human thermal comfort studies

Among other limitations such as the discomfort /stresscaused by a certain level of noise , glare due to the solar radiation , dust , and other factors etc. , the Givoni's , Humphreys's and Fanger's methods did not provide a clear picture (compered to the bioclimatic chart) of the passive building design re· ›mmendations for achieving human comfort inside the buildings.

5.1 Szokolay and the Control Potential Zones (CPZ)

Based on the previous studies of Olgyay;s (1953) bioclimatic chart , Givoni's (1969) psychrometric chart , Humphreys'(1978) with Au'iciem's (1981) studies on thermal neutrality, Szokolay's contributions (1986,1987)[13] and ASHRAE standard effective temperature (SET), Szokolay (1990) [5] was to bring these separate strands of thought together in order to produce a system of climate analysis , establishing the comfort zone and to propose an accurate definition of the 'Control Potential Zones' (CPZ) of the various passive control techniques (fig. 4.6).

Szokolay (1986) shows three comfort zones to suit different types of climate: average, lowest and highest (fig. 4.7). These zones are based on thermal neutrality correlated with the outer mean temperature (Tum, as

Tn = 17.6 + (.31 D Tum) (Aulciems regression equation)

With the provision that :

1. 18.5 (Tn) 28.5°C.

2. The width of comfort zone is " 2 K at 50% RH level.

3. The humidity boundaries are based on ASHRAE standard 55-81 which set the lower and upper limits in such terms as 4-12 g/kg moisture content (absolute humidity [AH]).

4. Relative humidity should not exceed the 90% RH curve.

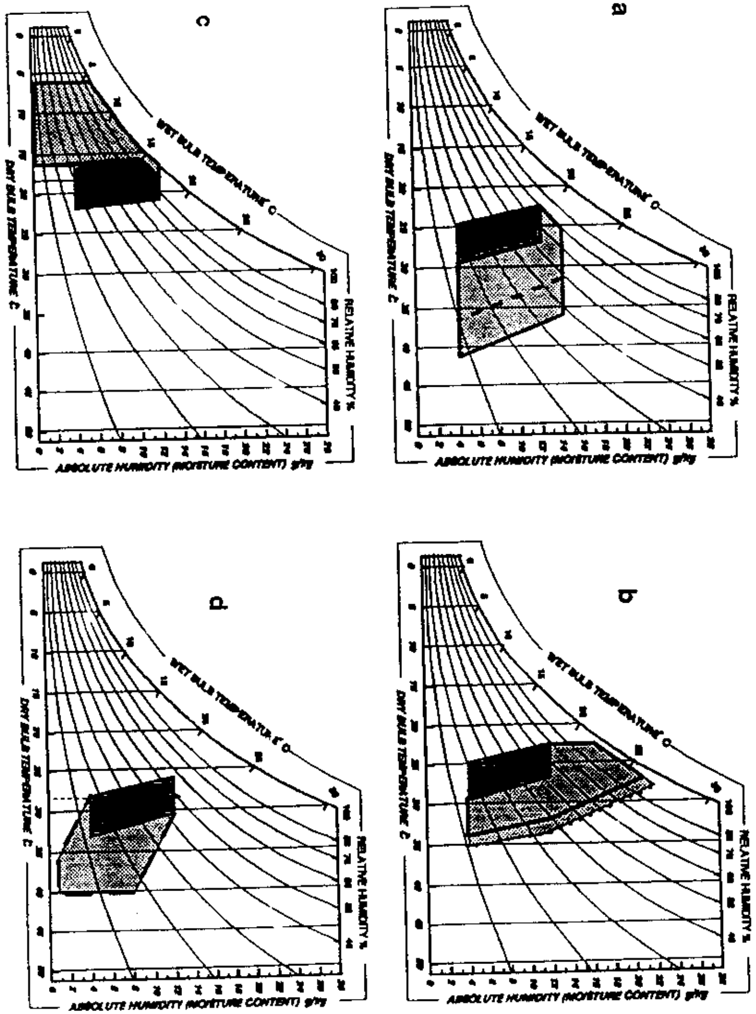


FIG .6 (CPZ) FOR a) MASS EFFECT b) AIR MOVEMENT
c) PASSIVE SOLAR HEATING d) EVAPORATIVE COOLING [5].

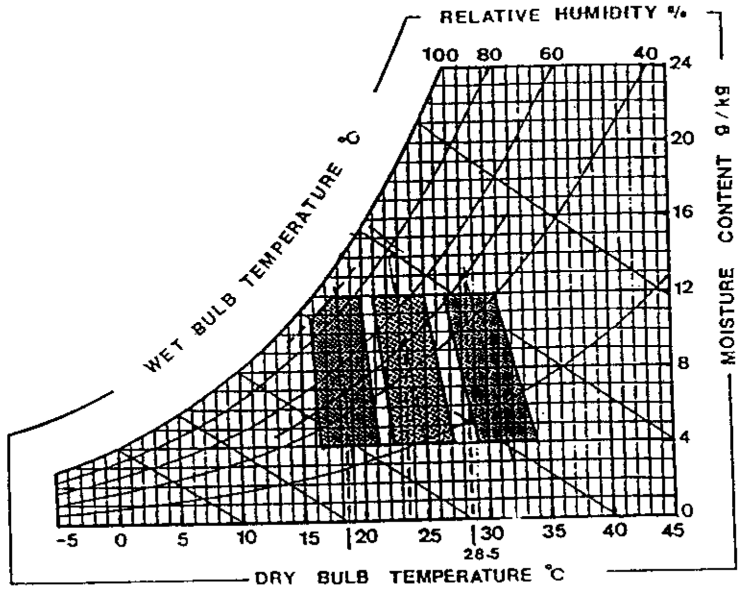


Fig. .7. Lowest,Average and Highest Position of The Comfort Zones [5].

5. The centre line of the comfort zone is drawn through the above Tn point taken on the 50% RH curve, with slope of

.025 D (Tn - 14) for each g/kg vertical distance.

He recommends a neutrality temperatu e for hot , dry climates , where the outdoor mean temperature is 35°C or more ,of 28.5°C with an annual comfort range of 26.5°C to 30.5°C . This zone is valid for lightly clothed people doing sedentary work.

5.2 Application of the Control Potential Zones (CPZ) on Ar-Riyadh

According to the relevant studies for Ar-Riyadh [14], it appears that thermal neutrality in Ar-Riyadh is likely to be 28.5°C in summer and 20.5°C in winter. Similar values can be obtained from equations by Auliciems and Humphreys as mentioned. Based on the thermal neutrality in Ar-Riyadh, other conditions should be applied as mentioned to form the Control Potential Zc ıe (CPZ) in Ar-Riyadh (fig. 4.8).

From psychrometric chart (fig. 4.8) it can be seen that the lines of June ,July and August extend beyond the comfort zone on the right side, indicating overheating. They are located below the comfort zone and are quite long , further indicating that the humidity ratio is very low and there are large diurnal variations.

In the other side and by looking at the lines for December , January and February on the same psychrometric chart , they extend beyond the winter comfort zone to the lift side and are quite long , indicating large diurnal variations. Therefore , the climate can be classified as underheated during winter.

According to the Control Potential Zones (fig. 4.8), the passive control strategies which may provide a solution to the climatic problems of Ar-Riyadh are:

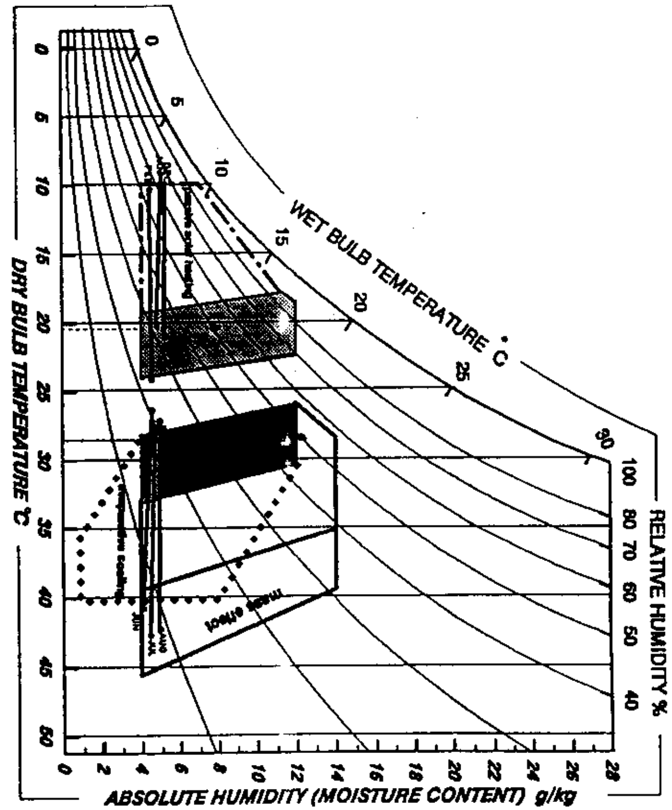
1. Thermal mass effect.

2. Mass effect with night ventilation.

3. Evaporative cooling.

4. Passive solar heating.

FIG. .8.APPLICATION OF CONTROL POTENTIAL ZONE (CPZ) ON AR-RIYADH.



6. Thermal mass as a dominant passive strategy in Ar-Riyadh

6.1 Strategy selection Approach:

A comparison between the four main methods (Olgyay , Givoni , Mahoney, and Szoklay) has been done (Table 4.7) as an approach to determine the most effective and dominant strategy to use in Ar-Riyadh. The comparison of these methods has been constructed based on the application of each method on Ar-Riyadh. Each method is divided into two columns. The firstcolumn represents the condition of thermal comfort (overheated ,cold or comfortable) and the second column contains the appropriate strategy which should be used as a solution to bring the condition to a comfortable atmosphere.

By looking to the table , Olgyay' method has four main strategies (fig.4.9). 37.4% represents that there is no need to use any strategy because the condition is located within the comfort zone. Other than that , ·entilation and evaporative cooling are the most used strategies during the year (29.2%).

In this method , the active energy strategy has been added because in the case of Ar-Riyadh , some times during the year
need solar radiation in which there is no adequate solar radiation in these times of the year. So the only solution to overcome this condition is to use active systems to bring this condition to comfort condition.

In the case of Givoni' method, four main strategies are used (evaporative cooling, passive heating , comfortable and thermal mass with night ventilation)(fig. 4.10). It has been noted that the thermal mass is the most used strategy during the year (31.25%) (fig. 4.11).

While in the Mahoney method , three strategies are applied (thermal mass and storage, outdoor sleeping, and heating). It has been recognised that the thermal mass and storage is also the most effective strategy (58.3%) (fig. 4.12) to use in the condition of Ar-Riyadh.

Finally, in Szoklay' method, there are four main strategies used to bring the climatic condition in Ar-Riyadh as much as possible to the comfort condition (fig. 4.13). It can be considered that the thermal mass is the most dominant strategy to use in Ar-Riyadh (23%)(fig. 4.14).

Table .7 comparison between the four methods

MONTHS \ METHODS			OLGYAY' METHOD		GIVONI' METHOD		MAHONEY METHOD		SZOKLAY METHOD		REMARKS
			CONDITION	STRATEGY	CONDITION	STRATEGY	CONDITION	STRATEGY	CONDITION	STRATEGY	
1	JAN.	DAY	c	Radiation	-	-	c	Thermal Mass (Storage) + Heating	c	Passive Heating	
		NIGHT	c	Radiation + Active	c	Solar Passive Heating	c		-	-	
2	FEB.	DAY	-	-	-	-	c	Thermal Mass (Storage) + Heating	c	Passive Heating	
		NIGHT	c	Radiation + Active	c	Solar Passive Heating	c		-	-	
3	MAR.	DAY	-	-	H	Thermal Mass Evapora. Cooling	-	Thermal Mass (Storage)	c	Passive Heating	
		NIGHT	c	Radiation + Active	c	Solar Passive Heating	c		-	-	
4	APR.	DAY	H	Evaporative Cooling Ventilation	H	Thermal Mass Evapora. Cooling	c	Thermal Mass (Storage) + Heating	H	Thermal Mass Evapora. Cooling	
		NIGHT	c	Radiation	-	-	-		-	-	
5	MAY	DAY	H	Evaporative Cooling Ventilation	H	Thermal Mass Evapora. Cooling	H	Thermal Mass (Storage) + Outdoor Sleeping	H	Thermal Mass Evapor. Cooling	
		NIGHT	-	-	-	-	-		-	-	
6	JUN	DAY	H	Evaporative Cooling Ventilation	H	Thermal Mass Evapora. Cooling	H	Thermal Mass (Storage) + Outdoor Sleeping	H	Thermal Mass	
		NIGHT	-	-	H	Thermal Mass Evapora. Cooling	H		-	-	
7	JULY	DAY	H	Evaporative Cooling Ventilation	H	Thermal Mass Evapora. Cooling	H	Thermal Mass (Storage) + Outdoor Sleeping	H	Thermal Mass	
		NIGHT	-	-	H	Thermal Mass Evapora. Cooling	H		-	-	
8	AUG.	DAY	H	Evaporative Cooling Ventilation	H	Thermal Mass Evapora. Cooling	H	Thermal Mass (Storage) + Outdoor Sleeping	H	Thermal Mass	
		NIGHT	-	-	H	Thermal Mass Evapora. Cooling	H		-	-	
9	SEP.	DAY	H	Evaporative Cooling Ventilation	H	Thermal Mass Evapora. Cooling	H	Thermal Mass (Storage) + Outdoor Sleeping	H	Thermal Mass Evapora. Cooling	
		NIGHT	-	-	-	-	-		-	-	
10	OCT.	DAY	H	Evaporative Cooling Ventilation	H	Thermal Mass Evapora. Cooling	H	Thermal Mass (Storage) + Outdoor Sleeping	H	Thermal Mass Evapora. Cooling	
		NIGHT	c	Radiation	c	Solar Passive Heating	-		-	-	
11	NOV.	DAY	-	-	H	Thermal Mass Evapora. Cooling	-	Thermal Mass (Storage)	H	Thermal Mass Evapora. Cooling	
		NIGHT	c	Radiation + Active	c	Solar Passive Heating	c		-	-	
12	DEC.	DAY	-	-	-	-	c	Thermal Mass (Storage) + Heating	-	-	
		NIGHT	c	Radiation + Active	c	Solar Passive Heating	c		c	Passive Heating	

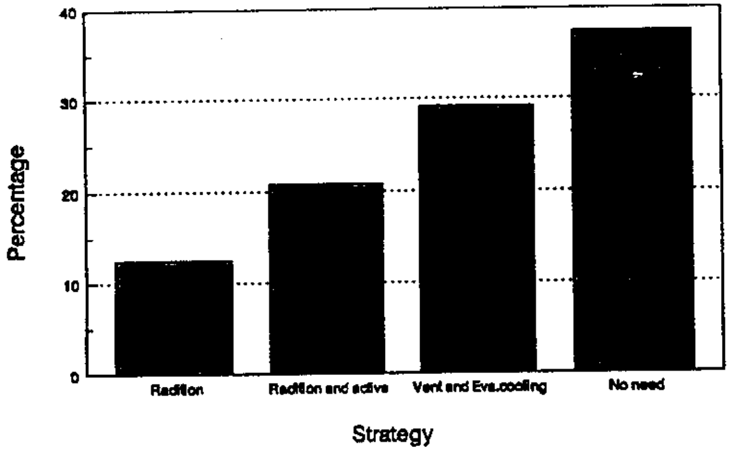


Fig. .9 Application of Olgyay' method on Ar-Riyadh

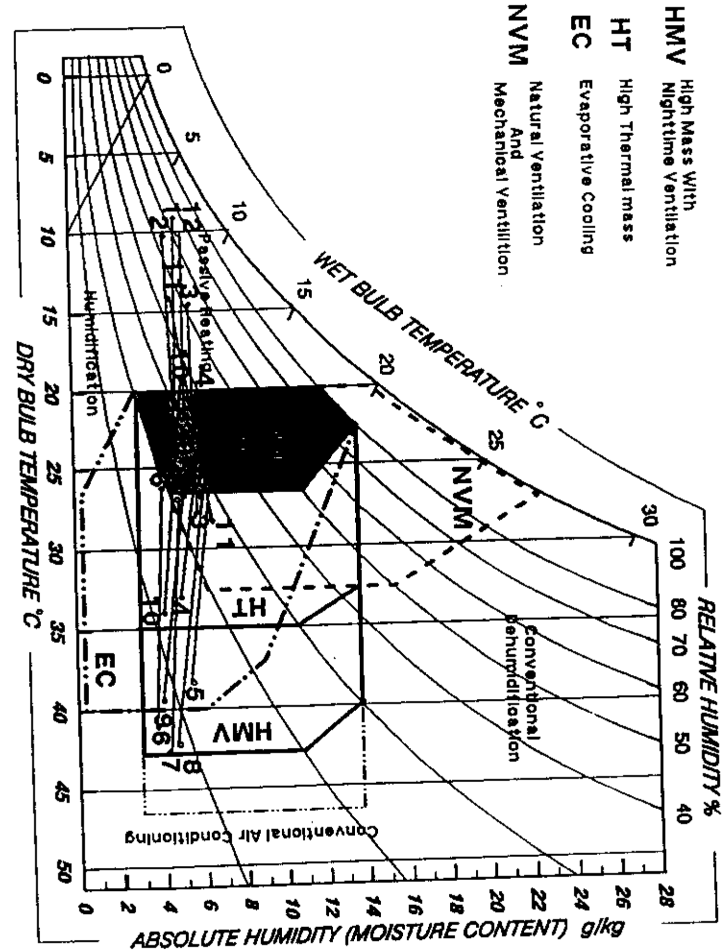


Fig. .10. Application of Givoni' method on AR-Riyadh

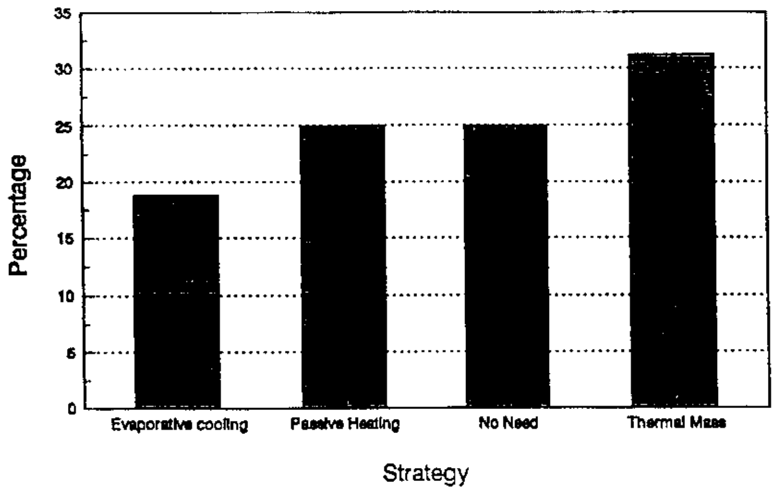


FIG. .11. Application of Givoni' Method on Ar-Riyadh

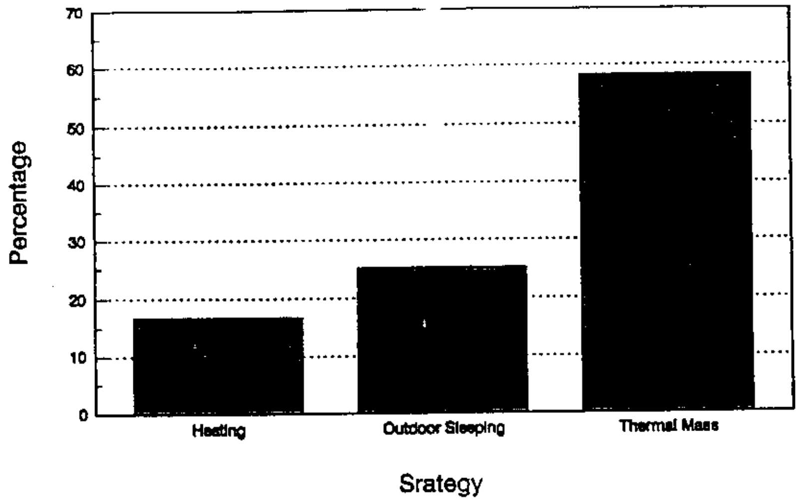


Fig. .12 Application of Mahoney' Method on Ar-Riyadh

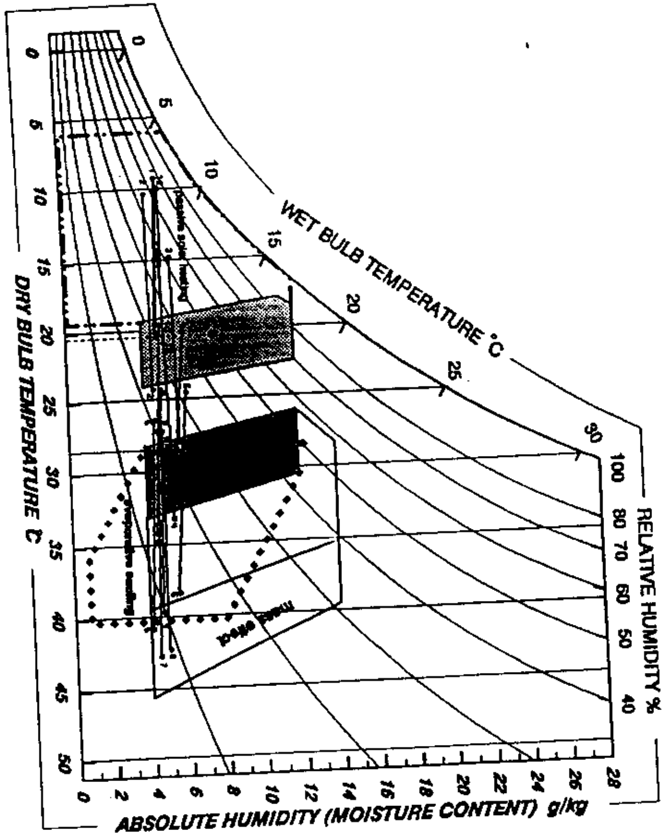


FIG. .13.APPLICATION OF CONTROL POTENTIAL ZONE (CPZ) ON AR-RIYADH.

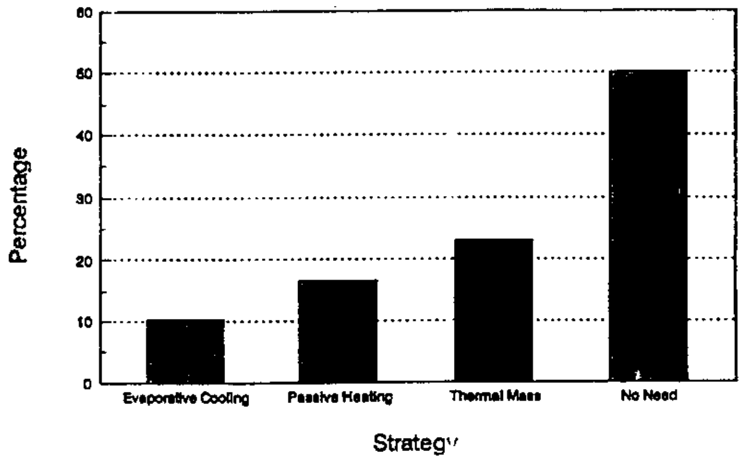


Fig. .14. Application of Szoklay Method on Ar-Riyadh

7. Conclusion

According to the analysis of outdoor climate, the bioclimatic chart , building psychrometric chart , Mahoney Table, the Control Potential Zones, and the application of these techniques in Ar-Riyadh region ,it can be concluded that using the building bioclimatic chart (CPZ) and combine it with Mahoney Table recommendations, comfortable indoor conditions in the building design of Ar-Riyadh region can be hopefully achieved with the following passive cooling strategies:

1. By combining nihgt natural ventilation and evaporative cooling effects.

2. By designing the buildings with compact courtyards to provide shade and thermal control on the external surfaces of the important rooms, with following other design details mentioned in Mahoney Table except the one of sleeping outdoor,because in the present, it is not socially acceptable any more.

3. By using high thermal mass building materials in which by using this strategy, the challenge to incorporate conflicting winter and summer comfort requirements into a single design is minimized. This strategy represents the most dominant and appropriate in such a climate where there is quite big differences between day and night temperatures (11.4 - 14°C in the winter and 13 - 15.7°C in the summer) . Thermal mass with other strategies can be the solution to provide a suitable time lag for not allowing the heat to penetrate inside the building during the day in summer, and act as heat storage material for the cool nights in winter.

According to the comparison table which has been established based on the climatic data and four main methods ,one important point has been noted which is the thermal mass is the most effective and dominant strategy to use in Ar-Riyadh where the individual monthly lines in the building psychrometric chart are quite long , which indicates large diurnal temperature variations. It has been observed this point from three methods (Givoni , Mahoney, and Szoklay) and not from Olgyay method, because the building structure with indoor climatic conditions have not been taken into account (as mentioned in the previous discussion), so Olgyay' method can be neglected in the case of Ar-Riyadh to a certain extant. However, by looking over Olgyay' strategies again, it seems that there is one missing strategy in order to apply his method for indoor conditions and for the case of Ar-Riyadh. The missing strategy is good buffer element and storage which in other words is the thermal mass and storage which is available in the rest of the methods.

The other methods are more or less the same in the strategies but in different techniques such as outdoor sleeping in Mahoney' method and night ventilation in Givoni and Szoklay methods. However, outdoor sleeping is culturally not acceptable at present.

The differences come in the thermal comfort limits which are vary from method to another depends up on the experiments and tests established for different places and cultures.

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