Bio-climatic Design Strategies for Buildings in Delhi, India

Ar. Abdul Halim Babbu[1], Ar. Mohd. Firoz Anwar [2]

[1] Associate Professor, Department of Architecture, Jamia Millia Islamia, New Delhi-110025, India

[2] Associate Professor, Department of Architecture, Jamia Millia Islamia, New Delhi-110025, India

Abstract— **Building sector plays a vital role towards energy efficiency and energy conservation. In India, building sector accounts almost 35% of the country's energy consumption. Building sector has been growing rapidly and is expected to increase five folds from 2005 to 2030. This rapid growth presents a challenge as well as an opportunity to design energy efficient buildings and to conserve energy for sustainable development. Energy usage in buildings has been increasing with climate change. Bioclimatic design has enormous potential in minimizing energy usage in buildings and minimizing carbon dioxide emissions. New Delhi being the capital city has witnessed tremendous building construction activities in and around the city. This paper focuses on various bioclimatic design strategies for building design in a composite climate like Delhi. Number of factors which affects thermal comforts i.e. temperature, humidity, rainfall, wind etc has been analyzed to arrive at performance specifications. To address the seasonal requirements which are often contradictory in composite climate, a weighing system, known as Mahoney Table has been used to assess the relative importance of conflicting requirements. The objective of the study is to devise different characteristics of architectural components i.e. layout of the building, spacing, air movement, size of the openings, position of openings, protection of openings, thermal capacity and insulation of walls, roofs and external features of buildings in Delhi.**

Keywords— **Bio-climatic design, Thermal comfort, Energy Efficiency, Sustainable development, Mahoney Table**

I. INTRODUCTION

Building sector plays a vital role towards energy efficiency and energy conservation. Due to rapid urbanization and population growth, India has tremendous opportunity in building sector which presently accounts almost 35% of the country's energy consumption. Building sector has been growing rapidly and is expected to increase overall constructed area approximately five folds from 21 billion square feet in 2005 to 104 billion square feet by 2030. This is a challenge as well as an opportunity for the building sector in India. As the building sector will grow, the amount of greenhouse gases emissions will also be more.

As per report "India: Green house Gas Emissions 2007", India ranks 5th in aggregate GHG emission in the world, behind USA, China, EU and Russia in 2007. Even the Current rate of GHG emission would cause further warming of the globe and would create many problems and challenges in future. There is a serious need to control the greenhouse gas emission. India has been addressing the climate change through its national policy. United Nations has also been supporting global efforts to address climate change through its various policies.

Since, building sector consumes a significant amount of energy; there is need in building sector to integrate energy efficiency and energy conservation for sustainable development. Energy can be conserved to a great extent with the use of Bio-climatic design strategies.

Orientation of building plays a vital role in achieving energy efficiency of the building. With proper orientation of the building, the total solar radiation received by the building can be minimized in summer and maximized in winter for composite climate like Delhi. Composite climate are neither consistently hot nor dry, nor warm and humid, which pose difficult task for the designers, as set of solutions for one season may not be satisfactory for the other season.

The objective of this paper is to critically analyze all the parameters which affect thermal comfort and to formulate design standards for the composite climate. Finally, this paper aims to provide detailed recommendation for climate responsive energy efficient building design in terms of layout, spacing, air movement, size of the openings, positions of the openings, protection of the openings, specifications of walls, floors, roofs and other external features of the building.

For the purpose of systematic analysis of various climatic data, and to arrive at the detailed building component specifications, Mahoney table has been used. Mahoney table is a series of tables devised by C Mahoney. Initial part of the table records essential climatic data and identifies humidity group. Next table is used for the diagnosis of the climatic data and provides thermal stress and humidity indicators. Last two tables provide specifications of various components of the building.

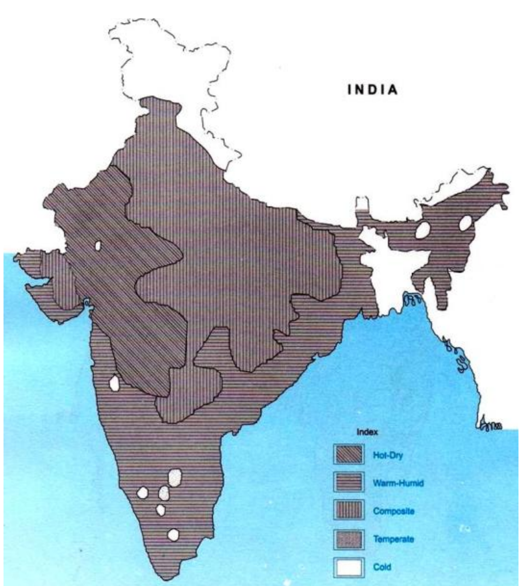
II. CLIMATIC ZONES OF INDIA

As per IS 372-1978 "Guide for Heat Insulation of Non-Industrial buildings", India has been divided into four climatic zones i.e. (1) Hot and Arid Zone (2) Hot and Humid Zone (3) Warm and Humid Zone (4) Cold Zone. Some discrepancies were reported later on in this zoning and Central Building Research Institute (CBRI), Roorkee was entrusted with the task of carry out research for new climatic classification. The research was primarily based on two climatic factors which mainly affect thermal comfort i.e. air temperature and humidity. The aim was to find out extremes of these two factors that are likely to cause discomfort. As per the recent studies carried out, India has been divided into four climatic zones. i.e (1) Hot Dry(2)Warm Humid (3) Cold (4) Temperate and one sub-group i.e. Composite. A place has been assigned to one or other climatic zones if defined climatic conditions prevail there for more than six months, otherwise it has been placed under composite zone. Table –1 shows recent climatic zones and its characteristics.

Table-1 Climatic zones and its characteristics

Climatic Zone	Mean Monthly Maximum Temperature (^{o}C)	Mean Monthly Relative Humidity (%)
Hot Dry	Above 30	Below 55
Warm Humid	Above 30	Above 55
	Above 25	Above 75
Temperate	Between 25-30	Below 75
Cold	Below 25	All Values

Each climatic zone does not have same climate throughout the year. If the climate of a particular place matches with the characteristics of a particular climatic zone for more than six months, the place may be assigned to that particular zone. Few cities like Banglore, Ahmedabad and Pune which present comfortable climate for greater part of the year conforms to temperate climatic zone, though it has been observed that there is no specific region under temperate climatic zone. Fig 1 shows the climatic zones of India.



Source: CBRI, Handbook

III. AN OVERVIEW OF DELHI CLIMATE

The geographical location of Delhi is 28o 35' N latitude and 77o12'E longitude. It is located at an altitude of 216 meter above mean sea level. Delhi is situated on the banks of Yamuna River. The climate of Delhi is extreme. Winter begins in late November or early December. In winter, it is very cold and the average temperature can vary from 5o C to 22o C. By early January, the minimum temperature is close to 0o C and the maximum temperature is in single digit. Summer arrives in early April and continues up to late June, with maximum temperature in the month of May which is 45o C or even more. The average temperature varies from 25o C to 45o C in summer. Monsoon season starts in the late June or first week of July. Though the temperature drops below 40o C in the month of July but because of high level of humidity this season is uncomfortable. August is the wettest month. Mean rainfall is 232.5 mm in the month of August and the mean annual rainfall is 762mm. Autumn season starts by mid October marked with warm days and pleasant nights. Maximum temperature drops below 30o C and minimum temperature drops below 20o C and there is a gradual fall in average temperature. The wind is generally from one or two direction. Most often the wind is out of the west and north-west. Sometimes it is out of the east but it is least often out of south and north.

A particular season does not prevail for more than six months in Delhi and therefore Delhi is placed in a Composite climate. Composite climates are neither consistently hot and dry nor warm and humid. The main consideration for the designer in the composite climate is to create balance between conservation of heat in the winters and exclusion of heat in summer.

Table-2 Climatic Data of Delhi

Year/ months	Temperature		Humidity (%)		Rainfall (mm)
	Mean Min (^{O}C)	Mean Max (^{O}C)	Mean Max (A.M)	Mean Min (P.M)	
January	7.6	20.5	87	38	19.3
February	10.4	23.9	76	29	22.1
March	15.6	29.6	69	26	15.9
April	21.3	36.3	52	19	13.0
May	25.8	39.5	46	20	31.5
June	27.9	39.2	56	31	82.2
July	27.4	35.4	81	56	187.3
August	26.6	34.1	90	66	232.5
September	25.0	34.1	87	53	129.8
October	19.1	32.8	80	34	14.3
November	12.9	28.2	80	31	4.9
December	8.3	23.1	86	38	9.4

Source: India Metrological Department

IV. THERMAL COMFORT ANALYSIS

A. Mahoney Tables

Mahoney table is a series of tables devised by C Mahoney which is a very good tool for the purpose of climatic data analysis. The initial part of the table records the location, longitude, latitude and altitude of the place. Table 3 shows the geographical location of Delhi.

Table-3 Location of Delhi

Location	Delhi
Longitude	77 ^{0} 12' E
Latitude	28 ^{0} 35' N
Altitude	216 m AMSL

.

Monthly mean maximum temperature and monthly mean minimum temperature data from the metrological department of each month is recorded in the respective line in the table 4. Monthly mean range is calculated by subtracting the monthly mean minimum values from monthly mean maximum values. The monthly mean range for each month is entered in the respective lines. Highest mean and lowest mean temperatures during the twelve months are entered on the right side of the table. Annual mean temperature (AMT) is calculated by adding the highest mean temperature and lowest mean temperature values and dividing it by two. The same is entered in the respective box marked AMT. Annual mean range is calculated by subtracting the lowest mean minimum from highest mean maximum values and the same is entered in to the field marked AMR.

Table-4 Air temperature: °C

Months	J	F	M	A	M	J	J	A	S	O	N	D		High	AMT
Monthly mean max.	20.5	23.9	29.6	36.3	39.5	39.2	35.4	34.1	34.1	32.8	28.2	23.1		39.50	23.55
Monthly mean min.	7.6	10.4	15.6	21.3	25.8	27.9	27.4	26.6	25.0	19.1	12.9	8.3		7.60	31.90
Monthly mean range	12.9	13.5	14.0	15.0	13.7	11.3	8.0	7.5	9.1	13.7	15.3	14.8		Low	AMR

Table-5 Relative humidity %

Months	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max. (A.M)	87	76	69	52	46	56	81	90	87	80	80	86
Monthly mean min. (P.M)	38	29	26	19	20	31	56	66	53	34	31	38
Average	62.5	52.5	47.5	35.5	33.0	43.5	68.5	78.0	70.0	57.0	55.5	62.0
Humidity group	3	3	2	2	2	2	3	4	3	3	3	3

Table-6 Rain & Wind

Months	J	F	M	A	M	J	J	A	S	O	N	D		Total
Rainfall, mm	19.3	22.1	15.9	13.0	31.5	82.2	187.3	232.5	129.8	14.3	4.9	9.4		762.20
Wind, prevailing	W	W	W	W	W	W	E	W	W	W	W	W		
Wind, secondary	NE/SE	NE	NE	NW	NW	NW	SE	SE	NW	N	N	N		

Procedure for tabulating table 5 is as follows.

i. From metrological record, enter the monthly mean maximum (early morning reading) and monthly mean minimum (afternoon reading) of relative humidity in the respective lines.
ii. Calculate the average relative humidity and enter the values into third line.
iii. Establish the humidity group of each month (1, 2, 3 and 4) according to the following categories as defined in Fig.2

Fig 2

Humidity group:1	If average RH: BELOW 30%
2	30-50%
3	50-70%
4	Above 70%

Table-7 Diagnosis

Months	J	F	M	A	M	J	J	A	S	O	N	D	AMT
Monthly mean max.	20.5	23.9	29.6	36.3	39.5	39.2	35.4	34.1	34.1	32.8	28.2	23.1	23.55
Day comfort: upper	29	29	31	31	31	31	29	27	29	29	29	29	
lower	23	23	25	25	25	25	23	22	23	23	23	23	
Monthly mean min.	7.6	10.4	15.6	21.3	25.8	27.9	27.4	26.6	25.0	19.1	12.9	8.3	
Night comfort: upper	23	23	24	24	24	24	23	21	23	23	23	23	
lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress: day	C	O	O	H	H	H	H	H	H	H	O	O	
night	C	C	C	O	H	H	H	H	H	O	C	C	

Fig. 3

		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 7 is primarily used for the diagnosis of the climatic data.

Procedure for tabulating table 7 is as follows.

i. Enter the monthly mean maximum temperature and monthly mean minimum temperature values from table 4.
ii. Find the upper and lower comfort limit for the day and night of each month on the basis of Fig 3, as defined by the "annual mean temperature (AMT), and "humidity groups "and enter these values in the lines 2, 3, 5 and 6 respectively.
iii. Compare the day comfort limits with mean maximum and night comfort limits with mean minimum and establish the nature of thermal stress by entering the following symbols in last two lines.

H- Hot if mean is above limit
O- (Comfort) if mean is within limit
C-(Cold) if mean is below Limit

Table-8 Indicators

Indicators	J	F	M	A	M	J	J	A	S	O	N	D	Total
Humid: H1							*	*	*				3
H2													0
H3								*					1
Arid: A1	*	*	*	*	*	*				*	*	*	9
A2				*	*	*							3
A3	*												1

Fig. 4

Applicable when: Meaning	Indicator	Thermal Stress Day	Thermal Stress Night	Rainfall	Humidity Group	Monthly mean range
Air movement essential	H1	H			4	
		H			2,3	Less than 10°C
Air movement Desirable	H2	O			4	
Rain protection necessary	H3			Over 200mm		
Thermal capacity necessary	A1				1,2,3	More than 10°C
Out-door Sleeping desirable	A2		H		1,2	
		H	O		1,2	More than 10°C
Protection from cold	A3	C				

Mahoney table defines six indicators in Fig.4. First three are humid indicators i.e. H1, H2 & H3 and next three are arid indicators A1, A2 &A3.
Procedure for tabulating table 8 is as follows.

i. Check the monthly mean range, humidity group, rainfall from table (4, 5 & 6) and thermal stresses values from the table 7 and place a tick mark in the line of appropriate indicator.
ii. In the last column, write the total number of ticks corresponding to a particular indicator.

Procedure for tabulating table 9 is as follows.

i. Transfer the indicators total from table 8 to the first line of table 9.
ii. Place a tick mark against the specification item in the same line corresponding to the indicator values.

Table-9 Recommended Specifications

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
3	0	1	9	3	1

H1	H2	H3	A1	A2	A3		No.	Specification
								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%

Any other conditions						*	11	Medium openings, 20-40%
		3-12					17	
								Walls
			0-2				12	Very small openings, 10-20%
			3-12			*	13	Medium openings, 20-40%
								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	Protection from heavy rain necessary

Table-10 Detailed Recommendations

Indicator totals from table 2					
H1	H2	H3	A1	A2	A3
3	0	1	9	3	1

Size of openings

			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	Space for out-door sleeping
		1-12				*	16	Adequate rainwater drainage

The combined recommended specifications from table 9 & table-10 are tabulated in the table 11 which shows the design recommendation for energy efficient buildings in Delhi.

Table-11 Design recommendations for Delhi

Parameters	Recommendations
Layout	Building orientation north and south (long axis east –west) to reduce solar radiation incident on the wall
Spacing	Open spacing for breeze penetration but protection from the hot and cold wind
Air movement	Rooms shall be single banked with permanent provision for air movement
Size of Openings	Small- 15-25%
Position of openings	In north and south walls at body height on windward side
Protection of openings	Exclude direct sunlight
Walls	Heavy, over 8 hour time lag
Roofs	Heavy, over 8 hour time lag
Outdoor sleeping	Space for outdoor sleeping required
External features	Adequate rain water drainage required

IV. CONCLUSIONS

In Delhi climate, buildings should be oriented in such a way that its longer axis should remain in east-west direction. In this orientation, the walls will receive less solar radiation in summer and more solar radiation in winter in comparison to other orientations. This orientation minimizes the heat load in summer and is a very effective passive cooling strategy. The walls should be thicker having time lag over 8 hours. Cavity walls or composite walls are also very helpful in controlling the heat transfer from outside to inside the building. When the air movement is necessary, the advantage of prevailing breeze should be taken by grouping the buildings in relation to the wind direction. Fenestrations should be made on the walls perpendicular to the wind direction. Direct sunlight must be excluded from the fenestration and window shades should be designed in such a way so that it cuts the summer sun but permits winter heat inside the building. Roofs should also be properly insulated so as to minimize heat transfer from the roof to the inside of the building. Provision of adequate rainwater drainage is also essential in this climate.

REFRENCES

[1]. Koenigsberger O.H, Ingersoll T.G., Alan Mayhew and Szokolay S.V. "Climate Design: Manual of Tropical Housing and Building", Orient Longman Limited, 1975
[2]. Ishwar Chand, Bhagava P.K, The Climatic Data Handbook", Tata McGraw Hill Publishing Company Limited, 1999
[3]. Arvind Krishnan, Nick Baker, Yannas and Szokolay, S.V. "Climate responsive Architecture, A design handbook for energy efficient buildings". Tata McGraw-Hill Education, 2001
[4]. Energy conservation building code (ECBC) 2007 from http://www.sgcindia.in/pdf/ECBC_final_May_2007.pdf
[5]. Olgay, V and Olgyay, A. Design with climate: bioclimatic approach to architectural regionalism: Some chapters based on cooperative research with Aladar Olglay", Princeton University Press, 1963
[6]. India Metrological Department website, http://www.imd.gov.in