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Bioclimatic Building Design Guidelines For Lucknow City: Use Of Various Climate Analysis Methods

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Abstract*: Vernacular Architecture of Lucknow is the outcome of centuries of optimisation of material use, construction techniques and climate considerations. In contrasts modern buildings of Lucknow are being built with little or no consideration of climate which increases the buildings appetite for energy. This paper aims to investigate the design strategies for energy efficiency and thermal comfort specific to contemporary buildings of Lucknow. Bioclimatic Chart, Psychometric chart, Degree Days and Mahoney's Table are used to analyse the climate of Lucknow in order to formulate the building design guidelines. These guidelines will provide appropriate information at project design stage which would help architect in making better use of natural resources, reduction of operational energy and maintaining indoor thermal comfort by the use of passive solar techniques.
Keywords:building materials, energy efficiency, climate, comfort, vernacular architecture

I. INTRODUCTION

Climate is defined as an integration in time of the physical states of the atmospheric environment, characteristics of a certain geographical conditions. [1] Buildings should be designed to accomplish best possible indoor climatic environment to attain human comfort. Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.[2] The term 'Bioclimatic Architecture' was coined by Victor Olgyay in the early 1950s and fully explained in his book, Design with Climate (1963). He synthesizedelements of human physiology, climatology and building physics, with strong advocacy of architectural regionalism and of designing in sympathy with the environment.[3] Therefore, he may be considered as the instigator of Sustainable Architecture.

Sustainability can be best understood by the Vernacular Architecture of a place, which utilizes limited resources to achieve maximum comfort in collaboration with climate responsive construction techniques evolved with time. In contrary construction methods have changed greatly in last two and three decades with the advent of new materials and advancement in building technologies. HVAC system (Heating Ventilation and Air Conditioning) is one of them that ease heating and cooling in the building therefore architects and designers choose to ignore the fundamental aspect such as climate to maintain indoor comfort conditions.

Lucknow lies in the composite climate zone according to NBC (National Building Code) which is characterized by extreme temperatures in summers and winters. For this reason high thermal mass and low window wall ratio is preferable, but contemporary architects rarely address this concept and designed buildings with high window wall ratio and low thermal mass which increases the building's appetite for energy. Vernacular and bioclimatic architecture could be the source of inspiration for them to increase comfort with lesser use of energy.

II. CLIMATE OF LUCKNOW

The study is focused on Lucknow city the capital of Uttar Pradesh, located between 26.30 & 27. 0 North and 80.30 & 81.13 East at an altitude of approximately 128m measured from the sea level. Lucknow covers an area of 3,244 sq.km. [4]

Lucknow has a composite climate with cool, dry winters with mean monthly minimum temperature of of 5 degree Celsius in winters from mid-November to February and dry, hot summers with thunderstorms from late March to June, marked by mean monthly maximum temperature of 45 degree Celsius in ummers(Fig.1) Moreover there are about 4-6 days of heat wave when the maximum temperature of a day rises to 4-6 Celsius above normal values in summer and the temperature may fall to 3-4 degree Celsius for a

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few days when the cold winds from the Himalayan region makes the winters chilly.[5] Annual diurnal range of temperature is high i.e. 19.4 degree Celsius a result days are hot and nights are comparatively cold.

The rainy season is from July to September when the city gets an average rainfall of 990.1 millimeters from the south-west monsoon winds and about 75% of the precipitation is experienced during the months of June, July, August and September. (Fig.4) Therefore humidity is high in monsoon and low in summers. The prevailing wind direction of Lucknow is westerly and the average wind speed is 1.87m/s. [4]

The length of the day in Lucknow varies over the course of the year. The shortest day is December 21, with 10 hours, 27 miutes of daylight; the longest day is June 21, with 13 hours, 50 minutes of daylight. (Fig. 4) The annual direct solar radiation in Lucknow is approximately 1646 kWh/m², i.e. the daily average of 4.51 kWh/m². Moreover annual global horizontal solar radiation is around 1814 kWh/m², i.e. the daily average of 4.97 kWh/m². [4]

III.CLIMATIC ANALYSIS TO ACHIEVE THERMAL COMFORT

Thermal comfort can be defined as that condition of mind that expresses satisfaction with the thermal environment. Evaluating the human comfort condition is a complex process because there are large variations, both physiologically and psychologically, from person to person therefore it is difficult to satisfy everyone in a space.[3]

All climatic parameters in combination form the thermal index to express their effect on man. In this study Bioclimatic Chart [5], Psychometric chart [6], Degree Days [7] and Mahoney's Table [1] are used to analyse the comfort conditions and climate of Lucknow to formulate the building design guidelines in response to it. These design strategies would include natural ventilation, daylight, passive heating and cooling techniques forming bioclimatic architecture of Lucknow.

A. Bioclimatic chart

V Olgyay has constructed a bioclimatic chart on which the comfort zone is defined in terms of dry bulb temperature (DBT) and relative humidity (RH), but simultaneously it is shown by additional lines showing how this zone could be pushed up by the presence of air movement and by the presence of radiation.[5] Bioclimatic chart is very effective for the analysis of thermal comfort as it not only gives the relationship between temperature and humidity but also reveals strategies to achieve comfort conditions. Climatic data of Lucknow for each months is plotted on bioclimatic chart to investigate the comfort condition and passive strategies to achieve thermal comfort. (Fig-2). Lines are plotted by taking mean monthly minimum BDT with AM (ante meridiem) relative humidity and mean monthly maximum DBT with PM (post meridiem) relative humidity, thereafter inferences from bioclimatic chart showing passive techniques to achieve indoor thermal comfort conditions are shown in Table-2.

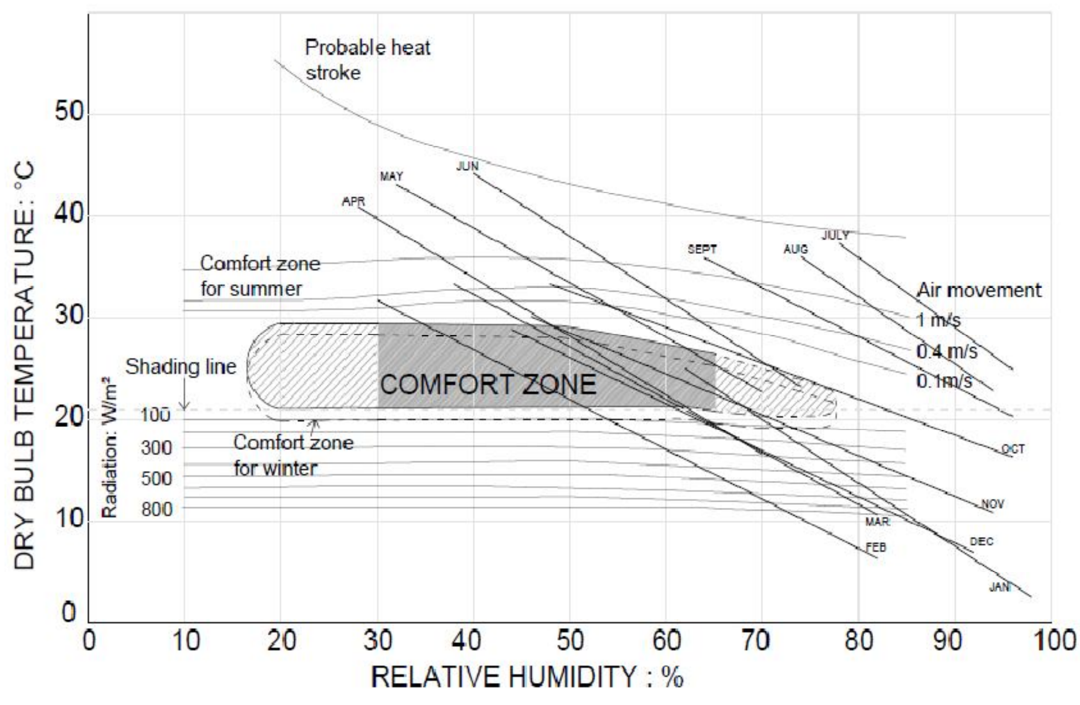

Figure 1: Bioclimatic Chart for Lucknow

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TABLE I
INFERENCES FROM BIOCLIMATIC CHART

Month	Comfort	Radiation needed	Shading needed	Air movement needed	Prevailing wind directions
January	20%	60%	10%	×	WNW
February	30%	30%	25%	10%	NW
March	30%	5%	50%	12%	NW
April	25%	×	85%	40%	E
May	5%	×	100%	90%	E
June	×	×	100%	100%	E
July	×	×	100%	100%	E
August	×	×	100%	100%	N
September	×	×	100%	100%	WNW
October	×	×	80%	90%	W
November	30%	25%	20%	×	N
December	35%	50%	10%	×	NW

It is apparent from the Chart that days of April and May and nights of February, March and November are comfortable. Moreover wind movement of speed 1 to 2 m/s and shading of windows could make hotter months May , June, July, August, September and October comfortable. As a result in combination with wind direction and shading devices opening position can be decided in building. Furthermore in January, February, November and December by the intake of solar radiations, colder months can be made comfortable.

However, there is limitation of Bioclimatic chart as it only indicates passive techniques related to wind movement and solar radiation hence psychometric chart is used for further analysis to accomplish more design strategies for indoor comfort.

B. Psychometric Chart

ThePsychometric chart was proposed by Givoni in 1976, shows the relationship of dry bulb and wet bulb temperature, absolute humidity, relative humidity and vapour pressure of moist air. [6] Moreover, different zones are marked in the chart depending on the properties of air, suggesting design strategies to achieve thermal comfort. These zones are as follows

1) Comfort Zone
2) Evaporative Cooling zone
3) High Thermal Mass/ thermal mass with night flush zon
4) Ventilation z
5) Window shading zon
6) Passive solar heating zone
7) Conventional heating or cooling zone

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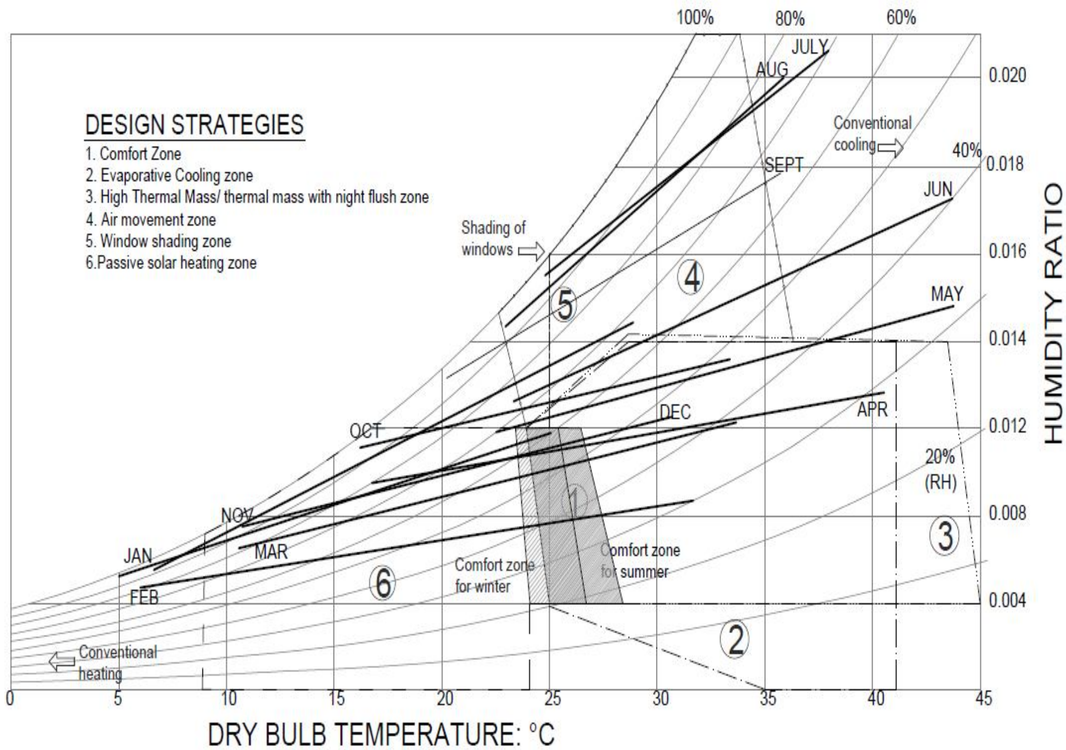

Figure 2: Psychometric Chart for Lucknow

TABLE II
INFERENCES FROM BIOCLIMATIC CHART

Design Strategies	Comfort	Evaporative cooling	High thermal mass	Ventilation	Shading of windows	Passive solar heating	Conventional heating or cooling
January	5%	x	x	×	x	80%	15%
February	10%	10%	10%	×	15%	70%	10%
March	15%	20%	20%	×	20%	65%	x
April	15%	65%	65%	×	70%	20%	x
May	x	70%	80%	90%	90%	x	10%
June	×	×	×	90%	90%	x	40%
July	×	×	×	90%	95%	x	20%
August	×	×	×	90%	99%	x	10%
September	×	×	×	90%	99%	x	x
October	×	×	20%	70%	55%	x	x
November	20%	x	10%	×	30%	60%	x
December	10%	x	x	20%	10%	70%	10%

Same as Bioclimatic chart, climatic data of Lucknow was mapped on Psychometric chart (Fig. 2) and then percentage hours of each month that lies in the different zones of suggested design strategies calculated.[6]. Passive heating is recommended in January, February, November and December as temperature is below comfort level moreover in June, July, August, September and October, ventilation is recommended with shading of windows because high temperature and high humidity. Furthermore, thermal mass and window shading is suggested in March April and May due to the reason of hot and dry weather condition. Conventional cooling is needed in the months of May, June and July to maintain room temperature at comfort level since humidity and temperature both are

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high and passive techniques could not fulfil the cooling demand. Same in the month of January, February and December when DBT is below 9 degree Celsius, conventional heating is needed to maintain indoor comfort.

C. Heating Degree Days and Cooling Degree Days

According to ASHRAE (90.1), Heating degree days base 65°F (HDD65) and Cooling degree days base 50°F (CDD50) are calculated from readings of outside air temperature. For any one day, when the mean temperature is less than 65°F, HDD65 is the difference between outside mean temperature of that day and 65°F whereas when the mean temperature is more than 50°F; CDD50 is the difference between outside mean temperature of that day and 50°F. [7] The annual HDD65 and CDD50 for Lucknow is 375 and 9552 respectively (Fig-3). CDD50 is very high therefore the energy required for cooling would be much more than the energy required for heating. Consequently, the design strategies that reduces the cooling load would be more helpful than the design strategies reducing the heating load. [8]

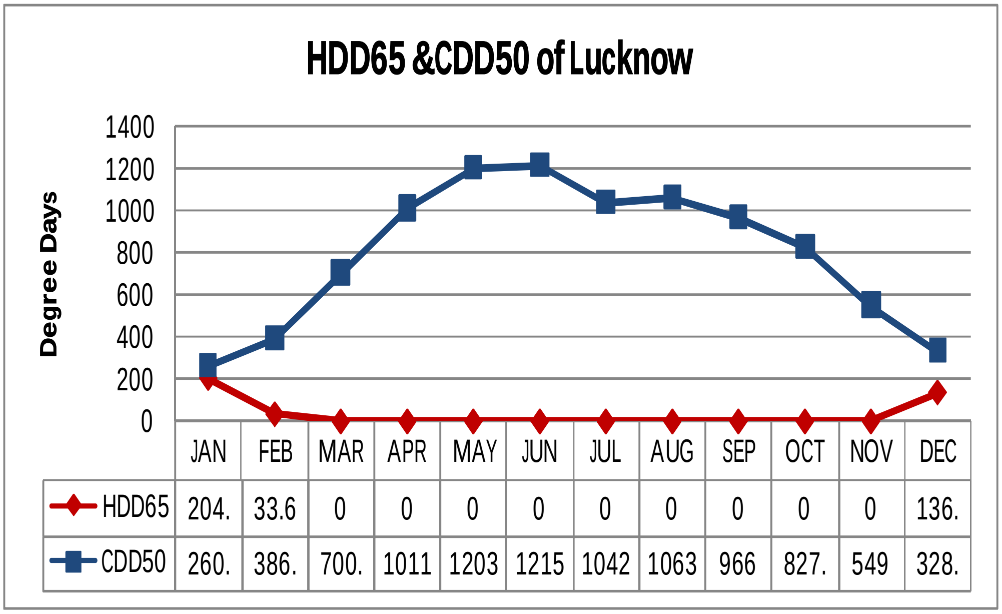

Figure 3: HDD65 and CDD50 for each month of Lucknow [8]

D. Mahoney's Table

From the above chart it is apparent that The seasonal requirements in composite climate of Lucknow are contradictory therefore a weighting system must be used to assess the relative importance of conflicting requirements. Furthermore the system must take into account the duration and severity of the various climatic factors. Based on such a system, a series of following tables have been derived by 'C Mahoney' [1]-

Table1- records the most essential climatic data.
Table2- facilitates a diagnosis of the climate.
Table3- translates into performance by giving sketch design recommendations.
Table4- illustrates the detailed recommendation for bioclimatic building design.

The climatic analysis with recommended specifications resulting by Mahoney's table for the climate of Lucknow are shown in Fig-4. Temperature, humidity and all other climatic data is shown in Table -1 of Manoney'stable, moreover, relative humidity is classified under four groups. This classification was used in combination with temperature variations to define thermal comfort limits which are also linked to annual mean temperature (AMT). AMT of Lucknow is 25.25 that lies in group where AMT is indicated above 20°C. Furthermore this is used with four humidity groups to define thermal stress comfort limits. The mean temperature is graded into four categories of temperature indicators, i.e., O for Comfort, H for Hot and C for Cold for mean temperatures within, above and below the thermal stress comfort limit, respectively. It indicates the indoor condition or the level of thermal stress, for both day and night, that is imparted to the occupant of the building. [8]

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TABLE 1: Data Input

Location	LUCKNOW
Longitude	26.82°N
Latitude	80.93°E
Altitude	128m

Air temperature °C

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	High	AMT
Monthly mean max.	25	31.7	33.3	40.9	43.1	44.2	37.3	36	35.9	33.3	30.1	28.8	44.2	25.25
Monthly mean min.	5	6.3	10.6	16.6	22.7	23.2	24.9	22.8	20.3	16.3	10.8	6.9	5	19.4
Monthly mean range	20	25.4	22.7	24.3	20.4	21	12.4	13.2	15.6	17	19.3	21.9	Low	AMR

Relative Humidity %

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Monthly mean max.(AM)	98	82	82	70	70	74	96	94	96	96	94	92
Monthly mean min.(PM)	62	30	38	28	32	40	78	74	64	48	46	44
Average	80	56	60	49	51	57	87	84	80	72	70	68
Humidity group	4	3	3	2	3	3	4	4	4	4	3	3

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

Other climatic data

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
Rainfall, mm	20.2	16	10	5	18.4	122.9	269.9	255.3	211.5	40.9	7.4	12.6	990.1	Total
Wind speed (m/s)	1.3347	2.382	2.318	2.7447	2.0703	1.9051	1.6324	1.5003	2.4701	0.7294	0.8568	2.4599		
Wind, prevailing	WNW	NW	NW	E	E	E	E	N	WNW	W	N	NW		
Wind, secondary	W	W	W	ENE	ENE	ENE	N	E	W	N	ENE	WNW		
Sunshine hours (per day aveg)	10.65	11.27	12.12	12.82	13.5	13.83	13.65	13.07	12.13	11.5	10.82	10.45	12.151	Mean
Global Hor. Solar rad. (kWh/m²)	3.24	5.13	5.51	6.76	6.82	6.61	4.56	4.57	4.59	4.46	3.73	3.65	4.97	Mean
Direct Nor. Solar rad.(kWh/m²)	3.6	6.86	5.62	6.84	5.8	5.2	1.65	1.86	2.97	4.1	4.36	5.26	4.51	Mean

Comfort limits
Humidity groups

	AMT over 20 °C		AMT 15-20 °C		AMT below 15 °C	
	Day	Night	Day	Night	Day	Night
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 2: Temperature and Humidity Diagnosis

Diagnosis °C	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AMT
Monthly mean max.	25	31.7	33.3	40.9	43.1	44.2	37.3	36	35.9	33.3	30.1	28.8	25.25
Day comfort: upper	27	29	29	31	29	29	27	27	27	29	29	29	
lower	22	23	23	25	23	23	22	22	22	23	23	23	
Monthly mean min.	5	6.3	10.6	16.6	22.7	23.2	24.9	22.8	20.3	16.3	10.8	6.9	
Night comfort: upper	21	23	23	24	23	23	21	21	21	23	23	23	
lower	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress: day	O	H	H	H	H	H	H	H	H	H	H	O	
night	C	C	C	C	O	H	H	H	O	C	C	C	

Indicators

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

H = Hot
O = Comfort
C = Cold

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Humid: H1							√	√	√	√			4
H2													0
H3							√	√	√				3
Arid: A1		√	√	√	√	√					√	√	7
A2													0
A3	√												1

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TABLE 3: List of Recommended Specifications

Indicator Totals from Table 2					
H1	H2	H3	A1	A2	A3
4	0	7	6	1	0

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

TABLE 4: List of Detailed Specifications

H1	H2	H3	A1	A2	A3		No.	Specification
								Size of Opening
			0,1		0		1	Large openings, 40-80%
			0,1		1 to 12		2	Medium openings, 25-40%
			2 to 5				2	Medium openings, 25-40%
			6 to 10			√	3	small openings, 15-25%
			11,12		0-3		4	Very small openings, 10-20%
			11,12		4 to 12		5	Medium openings, 250-40%
								Position of Openings
3 to 12						√	6	In north south wall at body height on windward side
1 to 2			0-5			√	6	In north south wall at body height on windward side
1 to 2			6 to 12				7	As above, opening also in internal walls
0	2 to 12						7	As above, opening also in internal walls
								Protection of openings
					0-2	√	8	Exclude direct sunlight
		2 to 12				√	9	Provide Protection from rain
								Walls and floors
			0-2				10	Light, low thermal capacity
			3 to 12			√	11	Heavy, over 8hr time lag
								Roofs
10to12			0-2				12	Light, reflective surface, cavity
10to12			3 to 12				13	Light, well insulted
0-9			0-5				13	Light, well insulted
0-9			6 to 12			√	14	Heavy, over 8hr time lag
								External features
				1 to12		√	10	Space for out seating
		1 to 12				√	11	Adequate rainwater drainage

Figure 4: Mahoney's Table for Lucknow

After diagnosis of temperature and humidity as stated above, remedial actions are recommended in table-3 and 4 of the Mahoney's Table by following that Architect or designer could attain indoor thermal comfort. These recommended design strategies are grouped under eight headings of layout, spacing, air movement, openings, walls, roofs, outdoor sleeping and rain protection requirements is summarised below:

1) Layout: Orientation north and south (long axis east-west)
2) Spacing: Open spacing for breeze penetration but protection form hot and cold wind
3) Air movement: Rooms single banked with permanent provision for air movement.
4) Openings: Recommended Window to Wall Ratio (WWR) 15-25% in north and south wall at body height on windward side. Moreover direct sunlight should be excluded with proper protection from rain.
5) Walls: Heavy external and internal walls with over 8 hours time lag.
6) Roofs: Heavy roofs with over 8 hours time-lag.
7) Outdoor sleeping: Space for out seating and sleeping
8) Rain protection: Protection from rain with adequate rainwater drainage.

Apart from all the above methods used for analysis of climate, learnings from Vernacular Architecture might be helpful in creating climate responsive building design guidelines.

IV. VERNACULAR ARCHITECTURE OF LUCKNOW

Vernacular Architecture that is evolved with time, (many years or even centuries) takes into consideration the optimised use of resources, the actives in and around the dwelling, the social organisation of the household and climate of that place.[8]

A traditional house in Lucknow is simple rectangular building with shared walls have one or two courts with a single bay of rooms around it opening to narrow shaded streets within dense built contexts. Moreover walls of these houses are very thick, made of lakhori brick, surkhi lime and their roofs have been made of timber joists or jack arches. Furthermore, roofs are high, courtyard facing windows and ventilators on exterior wall facilitates ventilation of the room at daytime and night as well. Thick walls acting as a thermal mass, do not allow heat to transfer into interiors as a result rooms remain cool in summer, stores heat at daytime and dissipate at night making nights comfortable in winter. Low percentage of recessed openings on exterior walls further reduces the heat transfer with adequate daylight into the interior from windows in courtyard facing walls shaded by verandah.(Fig. 5) Therefore vernacular houses of Lucknow were found to be thermally comfortable in the varying seasons of the region due to diverse multiple passive strategies adopted by them to counter the extremities of outdoor conditions.[10]

As stated above building material and its thickness plays an important role in the thermal comfort in the traditional building but in contrast with the advent of new materials and easy construction techniques older materials and techniques lost their significant. In next section new materials and construction methods are discussed that create same effect of thermal comfort as in traditional buildings.

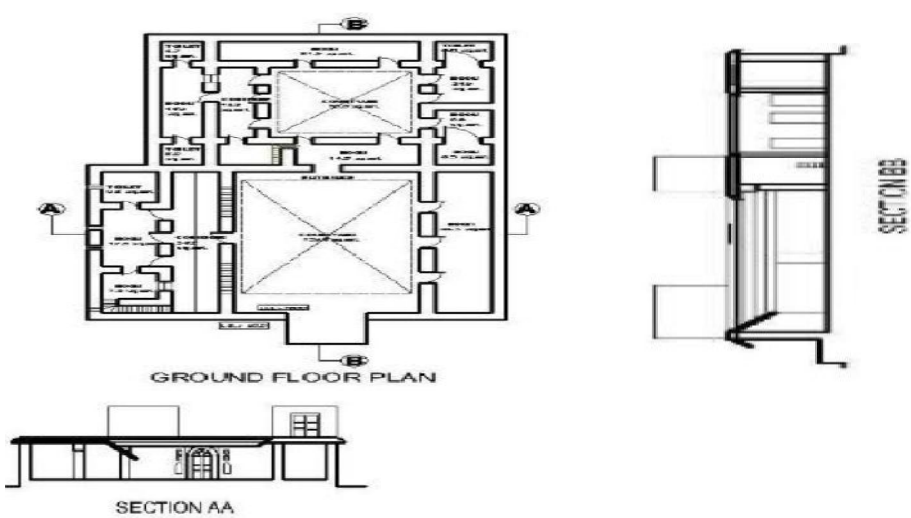

Figure 5: Arrangement of courtyard in Vernacular Houses of Lucknow [10]

V. BUILDING MATERIALS

High thermal mass is recommended for walls and roofs with 8 hours time lag in the Mahoney's Table for Lucknow. Consequently very thick walls and roofs must be required which is uneconomical in today's scenario due to high property rates and construction cost. This can be solved by the use of insulating materials over or between the wall and roof surfaces. Rockwool, glass fibre, expanded polystyrene slab, extruded polystyrene slab and polyurethane foam are commonly used insulating materials. As per Energy Conservation Building Code (ECBC), recommended U Value of wall assembly, roof assembly and fenestrations for 24 hour use building and for daytime use building are given in Table -4. U-value of 0.440 is recommended for wall assembly andU-value of roof assembly should be 0.261 and the R-value 2.10 for 24-hour use building and 0.409 and the R-value 2.10 for daytime use building. Glazing of fenestrations should have U-value of 3.3 and Solar Heat Gain Coefficient (SHGC) should be maximum 0.25 for WWR greater than 40% and 0.20 for WWR between 40-60% [11]

TABLE 1
PRESCRIBED REQUIREMENTS FOR BUILDING ENVELOPE IN COMPOSITE CLIMATE BY ECBC.[11]

	Hospitals, call centers (24- hour)		Other Buildings (Daytime)	
	Maximum U-factor of the overall assembly (W/m²-K)	Minimum R-factor of the overall assembly (W/m²-K)	Maximum U-factor of the overall assembly (W/m²-K)	Minimum R-factor of the overall assembly (W/m²-K)
Wall	U-0.440	R-2.10	U-0.440	R-2.10
Roof	U-0.261	R-3.5	U-0.409	R-2.10
	Maximum U Factor	WWR ≤40% Maximum SHGC	40%<WWR≤60% Maximum SHGC	
Fenestration	3.3	0.25	0.20	

VI. SHADING DEVICES

Bioclimatic chart, Psychometric chart and Mahoney's table suggests the shading of windows almost throughout the year through March till October. Sun path diagram of Lucknow is used to create shading mask with the help of shading protractor for the months in which shading of windows is required. (Fig-6) From this shading mask we get horizontal shading angle and vertical shading angle. (Fig-7) North have only morning and evening sun that can be shaded by approximately 400mm vertical fins. Maximum sun is in south direction, shading mask is created so that it shades the summer sun and allows the winter sun to come in. For that purpose overhang with small fins would work. Designing of shading devices for east and west direction is most difficult task, the sun rays are almost vertical and the intensity of radiation is also high. Therefore, vertical fins designed for that directions are almost parallel to window.

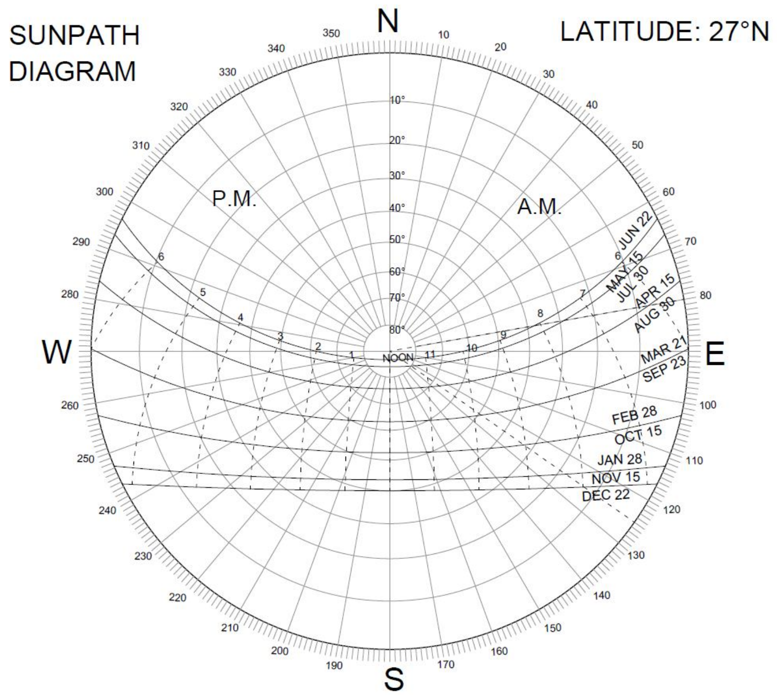

Figure 6: Sun path diagram of Lucknow (www.jaloxa.eu/resources/daylighting/docs/sunpath_27_north.pdf)

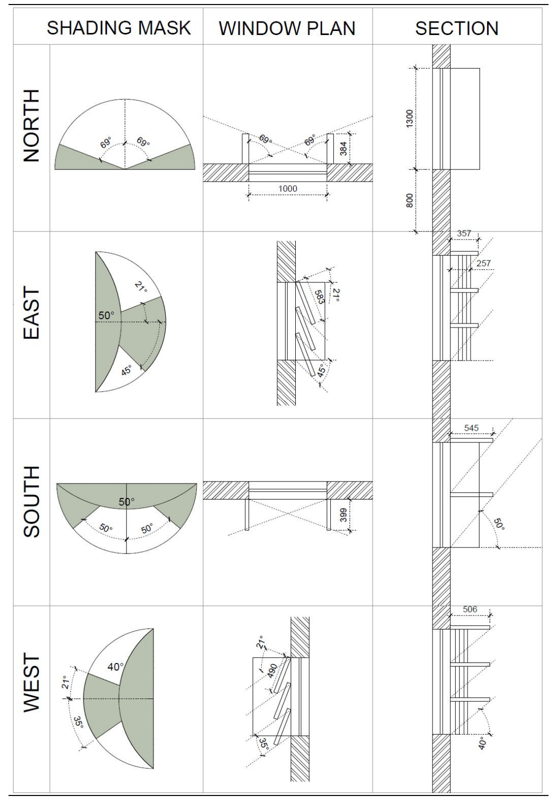

Figure 7: Shading devices for North, East, South and West direction of openings in building at Lucknow.

VII. BIOCLIMATIC BUILDING DESIGN GUIDELINES

Designing a building according to climate has multifold benefits, firstly it enables the use of natural energy, secondly reduces the operational energy demand and lastly but not the least improves the thermal comfort hence the user satisfaction. the following Bioclimatic design guidelines has been formulated on the basis of results from climate analysis and the study of Vernacular Architecture of the Lucknow city.

A. Orientation

Results from bioclimatic, psychometric chart and degree days suggest the reduction of heat gain inside the building. For that reason orientation should be in north south direction (east-west axis) that is also recommended by Mahoney's table, as high altitude sun can be easily cut by small overhang and low altitude sun can be allowed to enter.

B. Layout

Compact planning or singly banked rooms around medium sized courtyard is recommended by Mahoney's table moreover vernacular Architecture of Lucknow also educate the same. Compact planning with use of shared walls, heat transfer into the interiors can be minimised due low surface area to volume ratio. Courtyard with singly banked rooms facilitates the ventilation as well as shades the windows opening towards court. Moreover, it provides the open space in the interior that can utilised for seating at evening in summers and at daytime in winters.

C. Openings

Window to wall ratio recommended by Mahoney's table is 15-20% to minimise heat gain with adequate daylight inside the building. From sun path diagram it is visible that sun rays are at almost 90 degree in the east and west direction hence very difficult to shade, therefore maximum openings should be in north and south direction.

D. Shading of window

Bioclimatic and psychometric chart suggest shading of windows in the months from March till October. Consequently shading mask can be created on sun path diagram on the months to be shaded in different directions as discussed above in section 6. Hence shading devices should be designed according to the direction of placement of windows in building. Shading devices cut the direct solar radiations and thus reduces the heat gain.

E. Ventilation

Results from a above climate analysis recommends ventilation in the months of June, July, August and September which have high temperature, humidity and receives 80% of the total yearly rainfall. Air movement facilitates the evaporation of sweat in this humid weather and thus creates the cooling sensation in the human body. Moreover direction of wind in these months is between east and north east direction henceforth openable windows should be there in direction of east and north east and also in the opposite direction of the room to facilitate cross ventilation. Furthermore singly banked rooms facing courtyard also facilitates cross ventilation in days and nights both as it create air pressure difference.

F. Thermal Mass

Thick wall and roofs are recommended by psychometric chart and Mahoney's table as it acts as thermal mass and restricts and stores heat at day time and dissipates at night. This help in maintaining the temperature at comfort level as diurnal range of temperate is high in Lucknow. This phenomenon is also noted in the traditional buildings of Lucknow which makes them comfortable in all seasons. Contrary to this, thin walls and roofs are used in contemporary buildings due to high land rates and have uncomfortable indoor conditions in summer and winter both as a result conventional heating and cooling techniques are used to create comfortable environment. This can be solved by using insulation in walls and roofs as discussed in section-5 to attain desired time lag for heat to transfer.

G. Passive solar heating

Bioclimatic and psychometric chart advise passive solar heating in the months of January, February, November and December. This can be done effortlessly by providing windows in the south direction with optimum shade to cut summer sun and allow winter sun.

H. Protection from rainfall

Lucknow receives heavy rainfall in four months of the year, so rain protection is necessary. Windows should be protected by projection and roofs by giving proper drainage system or by making slant roof with gutter. Moreover plinth should be raised and surface drainage should be maintained properly so that rainfall does not damage the building.

VIII. CONCLUSION

Bioclimatic building design guidelines have been framed using the results from bioclimatic chart, psychometric chart, degree days, Mahoney's Table and learning from Vernacular Architecture of Lucknow. These recommendations would help the designer in providing innovative and specific design solutions to maintain indoor comfort. Moreover, these guidelines will provide appropriate information at project design stage which would help architect in making better use of natural resources, reduction of operational energy and maintaining indoor thermal comfort by the use of passive solar techniques. Furthermore, the methodology used in this paper would help the architecture students to learn the specific way for doing the analysis of climate.

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