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Climate-Responsive Design: A Comparative Study using Mahoney Table Across Diverse Indian Climates

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Abstract: This research paper undertakes a comparative analysis of design guideline recommendations derived from the Mahoney Table across five diverse and distinctive climates according to the Koppen classification of world climates. Mahoney Table is a key analytical tool which aids architects in designing structures that are in harmony with local climates. By leveraging the insights gleaned from the Mahoney Table, architects can tailor design strategies to suit the specific climatic characteristics of each region. This approach not only optimizes building performance but also reduces reliance on mechanical heating or cooling systems, thereby promoting sustainability and environmentally conscious design practices
Keywords: Mahoney table, Koppen classification, Thermal comfort

I. INTRODUCTION

Mahoney Table has been a cornerstone in architectural practice since its inception in 1971. This was developed by Carl Mahoney in collaboration with John Martin Evans and Otto Konigsberger. Mahoney Table furnishes architects with region-specific data and recommendations, facilitating the creation of buildings that effectively respond to the nuances of their surroundings. It encompasses various microclimatic parameters such as air temperature, humidity levels, wind velocity, solar radiation levels providing a comprehensive framework for informed decision-making.

Architects can utilize this data to optimize building orientation, window placement, shading devices, insulation, and natural ventilation systems, thereby enhancing thermal comfort and energy efficiency.

The Köppen climate classification, developed by German climatologist Wladimir Köppen in the early 20th century, is one of the most widely utilized systems for categorizing the world's climates.. This classification system categorizes climates based on the combination of temperature, precipitation, and seasonal variations in temperature and precipitation.

The necessity of the Koppen classification lies in its ability to provide a systematic and comprehensive framework for understanding and comparing the climates of different regions. By organizing climates into distinct categories, it allows for easier communication and interpretation of climatic data. This is particularly valuable for various fields including agriculture, ecology, urban planning, and architecture.

The classification system delineates five primary climate categories as follows:

A. Tropical (Megathermal)

These regions maintain consistently warm temperatures of 18°C or higher throughout the year and receive abundant precipitation year-round, without a distinct dry season. Subcategories further specify variations in precipitation patterns

A Temperature> 18°C throughout the year. High precipitation throughout the year	Af: Tropical Rainforest Climate	All 12 months have average precipitation exceeding 60 mm
	Am: Tropical Monsoon Climate	The driest month has precipitation less than 60 mm but more than 4% of the total annual precipitation
	Aw: Tropical Savanna	The driest month has precipitation less than 60 mm and less than 4% of the total annual precipitation

Table 1: : Characteristics of Tropical Climate

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B. Dry/Arid

These regions experience minimal precipitation relative to temperature.

To determine the threshold, calculate the product of the average annual temperature in Celsius multiplied by 20. Then, apply one of the following adjustments:

a) If 70% or more of the total precipitation occurs during the spring and summer months, add 280.

b) If 30%–70% of the total precipitation occurs during the spring and summer months, add 140.

c) If less than 30% of the total precipitation occurs during the spring and summer months, add 0.

Given India's location in the northern hemisphere and considering meteorological data from the past 10 years, the period from May to October is deemed most suitable for analysis. Subcategories are delineated according to variations in temperature.

B Low precipitation levels relative to temperature	BW: Desert Climate	BWh: Hot Desert Climate	Annual precipitation is less than 50% of the threshold, and the average annual temperature exceeds 18 °C
		BWk: Cold Desert Climate	Annual precipitation is less than 50% of the threshold, and the average annual temperature is below 18 °C
	BS: Semi-arid Climate	BSh: Hot Semi-arid Climate	Annual precipitation is 50% or more of the threshold, and the average annual temperature exceeds 18 °C
		BSk: Cold Semi-arid Climate	Annual precipitation is 50% or more of the threshold, and the average annual temperature is below 18 °C

Table 2: : Characteristics of Dry/Arid Climate

C. Temperate (Mesothermal)

These regions encounter mean temperatures ranging from 0°C to 18°C in their coldest months and temperatures surpassing 10°C in their warmest months. Subdivisions are identified based on variations in summer temperatures.

C Coldest month's average temperature > 0 °C Hottest month's average > 10 °C	Cf : Without dry season	Cfa : Humid subtropical Climate	At least one month with an average temperature exceeding 22 °C At least four months with average temperatures above 10 °C
		Cfb: Temperate oceanic Climate	All months with average temperatures below 22 °C At least four months with average temperatures above 10 °C
		Cfc: Subpolar oceanic Climate	1 to 3 months with an average temperature above 10 °C
	Cw : With dry winter	Cwa: Monsoon influenced humid subtropical Climate	At least one month with an average temperature exceeding 22 °C At least four months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter
		Cwb:Subtropical highland Climate	All months with average temperatures below 22 °C At least four months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter
		Cwc: Cold subtropical highland	1 to 3 months with an average temperature above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter
	Cs : With dry summer	Csa: Hot-summer Mediterranean Climate	At least one month with an average temperature above 22 °C At least four months with average temperatures exceeding 10 °C Precipitation in the wettest month of winter is more than three times the precipitation in the driest month of summer Precipitation in the driest month of summer is less than 40 mm
		Csb: Warm-summer Mediterranean Climate	All months with average temperatures below 22 °C At least four months with average temperatures above 10 °C Precipitation in the wettest month of winter is more than three times the precipitation in the driest month of summer Precipitation in the driest month of summer is less than 40 mm
		Csc: Cold-summer Mediterranean Climate	1 to 3 months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter Precipitation in the wettest month of winter is more than three times the precipitation in the driest month of summer Precipitation in the driest month of summer is less than 40 mm

Table 3: : Characteristics of Temperate Climate

III. CONTINENTAL (MICROTHERMAL)

The mean temperature during the coldest month falls at 0°C or lower, with warm summers prevailing. Subdivisions are categorized according to differences in summer temperatures.

D At least one month average temperature < 0 °C At least one month average temperature >10 °C	Df : Continental Humid	Dfa : Hot-summer humid continental Climate	At least one month with an average temperature exceeding 22 °C At least four months with average temperatures above 10 °C
		Dfb : Warm-summer humid continental Climate	All months with average temperatures below 22 °C At least four months with average temperatures above 10 °C
		Dfc : Subarctic Climate	1 to 3 months with average temperatures above 10 °C
		Dfd : Extremely cold subarctic Climate	The coldest month has an average temperature below −38 °C 1 to 3 months with average temperatures above 10 °C
	Dw : Continental dry winter	Dwa : Monsoon-influenced Hot-summer humid continental Climate	At least one month with an average temperature exceeding 22 °C At least four months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter
		Dwb : Monsoon-influenced Warm-summer humid continental Climate	All months with average temperatures below 22 °C At least four months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter
		Dwc : Monsoon-influenced Subarctic Climate	1 to 3 months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter
		Dwd : Monsoon influenced Extremely cold subarctic Climate	The coldest month has an average temperature below −38 °C 1 to 3 months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter
	Ds : Continental dry summer	Dsa : Mediterranean-influenced Hot-summer humid continental Climate	At least one month with an average temperature exceeding 22 °C At least four months with average temperatures above 10 °C Precipitation in the wettest month of winter is more than three times the precipitation in the driest month of summer The driest month of summer has precipitation less than 30 mm
		Dsb : Mediterranean-influenced Warm-summer humid continental Climate	All months with average temperatures below 22 °C At least four months with average temperatures above 10 °C Precipitation in the wettest month of winter is more than three times the precipitation in the driest month of summer The driest month of summer has precipitation less than 30 mm
		Dsc : Mediterranean-influenced Subarctic Climate	1 to 3 months with average temperatures above 10 °C Rainfall in the wettest month of summer is at least 10 times greater than in the driest month of winter Precipitation in the wettest month of winter is more than three times the precipitation in the driest month of summer The driest month of summer has precipitation less than 30 mm
		Dsd : Mediterranean-influenced Extremely cold subarctic Climate	The coldest month has an average temperature below −38 °C 1 to 3 months with average temperatures above 10 °C Precipitation in the wettest month of winter is more than three times the precipitation in the driest month of summer The driest month of summer has precipitation less than 30 mm

Table 4 : : Characteristics of Continental Climate

D. Polar/Ice Cap

These regions maintain average temperatures below 10°C throughout the year. Subcategories further delineate differences in summer temperatures.

i. ET: Tundra Climate
ii. EF: Ice Cap Climate

E Throughout the year average temperature < 10 °C	ET : Tundra Climate	The average temperature of the warmest month is between 0 °C and 10 °C
	EF : Ice cap Climate	All 12 months have average temperatures below 0 °C

Table 5: : Characteristics of Polar/ Ice Cap Climate

E. Study Area

This paper undertakes a comparative analysis of recommendations derived from Mahoney Table for five Indian cities: Bangalore (Karnataka), Mangalore(Karnataka), Jodhpur (Rajasthan), New Delhi (NCR) and Ooty (Tamil Nadu). Following are the locational details and climatic datas spanning from 1991 to 2021 sourced from Climate-Data.org.

City	Latitude				Longitude				Altitude (meters)			
Bangalore	12.9716° N				77.5946° E				Approximately 920 meters			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Temperature (°C)	27.4	29.6	32.1	32.8	31.2	27.5	26.4	26.1	26.7	26.4	25.7	25.8
Min. Temperature (°C)	14.6	16.1	18.7	20.8	21	20.2	19.8	19.4	19	18.4	16.7	15.1
Mean range (°C)	12.8	13.5	13.4	12	10.2	7.3	6.6	6.7	7.7	8	9	10.7
Rainfall (mm)	4	7	16	45	131	126	134	137	125	147	65	23
Humidity (%)	56%	46%	41%	51%	65%	76%	78%	79%	78%	78%	72%	65%

High	AMT
32.8	23.7
14.6	18.2
Low	AMR

Table 6: Climatic Data of Bangalore

Banglore's temperature variation is seen from 14.6°C to 32.8°C and average annual temperature is greater than 18°C, Bangalore will come under category B. With 70% or more of the total precipitation falling during the spring and summer months, as per the calculations for the threshold mentioned before, Bangalore falls under the BSh category, which signifies a hot semi arid climate.

City	Latitude				Longitude				Altitude (meters)			
Mangalore	12.9141° N				74.8560° E				Sea level to approximately 30 meters			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Temperature (°C)	30.4	31	31.4	31.7	30.6	27.6	26.8	26.8	27.6	28.6	29.8	30.4
Min. Temperature (°C)	22.4	23.4	25.1	26.4	26.2	24.9	24.3	24	24	24.3	23.9	22.8
Mean range (°C)	8	7.6	6.3	5.3	4.4	2.7	2.5	2.8	3.6	4.3	5.9	7.6
Rainfall (mm)	4	2	17	55	219	704	705	486	244	232	79	19
Humidity (%)	69%	70%	72%	75%	79%	89%	90%	89%	88%	85%	78%	70%

High	AMT
31.7	27.05
22.4	9.3
Low	AMR

Table 7: Climatic Data of Mangalore

Mangalore's average temperature is above 18°C throughout the year. Since, precipitation of the driest month is less than 60 mm and it experiences heavy rainfall during monsoon, Mangalore falls under the Am category, which signifies a tropical monsoon climate

City	Latitude				Longitude				Altitude (meters)			
Jodhpur	26.2389° N				73.0243° E				Approximately 231 meters			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Temperature (°C)	23.7	27.1	32.9	38.2	40.3	38.6	34.4	31.9	34.2	34.9	30	25.4
Min. Temperature (°C)	9.6	12.4	17.6	23	27	28	26.5	25	24.7	21.2	16	11.2
Mean range (°C)	14.1	14.7	15.3	15.2	13.3	10.6	7.9	6.9	9.5	13.7	14	14.2
Rainfall (mm)	3	5	2	3	5	27	122	105	42	8	1	0
Humidity (%)	41%	34%	25%	20%	28%	43%	62%	73%	56%	35%	36%	41%

High	AMT
40.3	24.95
9.6	30.7
Low	AMR

Table 8: Climatic Data of Jodhpur

Jodhpur's temperature variation is seen from 9.6°C to 40.3°C and average annual temperature is greater than 18°C, Bangalore will come under category B. With 70% or more of the total precipitation falling during the spring and summer months, as per the calculations for the threshold mentioned before, **Jodhpur falls under the BWh** category, which signifies a hot desert climate.

City	**Latitude**				**Longitude**				**Altitude (meters)**			
New Delhi	**28.6139° N**				**77.2090° E**				**Approximately 216 meters**			
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Max. Temperature (°C)	20	23.5	29.8	36.7	39.6	38.2	33.7	32.3	32.2	31.8	27.4	22.2
Min. Temperature (°C)	7.7	10.6	15.2	21	25.3	27.6	26.6	25.8	23.9	19.2	14.2	9.3
Mean range (°C)	12.3	12.9	14.6	15.7	14.3	10.6	7.1	6.5	8.3	12.6	13.2	12.9
Rainfall (mm)	23	33	20	14	20	74	208	183	99	13	5	8
Humidity (%)	67%	60%	47%	29%	32%	46%	71%	77%	71%	55%	54%	61%

High	**AMT**
39.6	23.65
7.7	31.9
Low	**AMR**

Table 9: Climatic Data of New Delhi

Delhi's coldest month's (December) average temperature is above 0 °C. Considering the conditions that atleast one month's average temperature is greater than22 °C, and at least four months average temperature is more than 10 °C. Delhi comes under Category C Classification. From the data, it is clear that rain in the July is more than 10 times rain of the driest month of winter, hence **Delhi comes under the category Cwa** which signifies Monsoon influenced humid subtropical Climate with dry winters.

City	**Latitude**				**Longitude**				**Altitude (meters)**			
Ooty	**11.4064° N**				**76.6932° E**				**Approximately 2,240 meters**			
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Max. Temperature (°C)	20.6	21.6	22.9	23.4	22.8	20.7	20.0	20.0	20.5	20.1	19.7	20
Min. Temperature (°C)	10.6	11.2	12.7	14.4	15	14.7	14.1	14.0	13.6	13.4	12.6	11.6
Mean range (°C)	10	10.4	10.2	9	7.8	6	5.8	6	6.9	6.7	7.1	8.4
Rainfall (mm)	24	27	49	92	171	209	206	186	146	207	139	58
Humidity (%)	67%	58%	57%	67%	78%	84%	85%	85%	82%	84%	81%	73%

High	**AMT**
23.4	17
10.6	12.8
Low	**AMR**

Table 10: Climatic Data of Ooty

Ooty's coldest month's (December) average temperature is above 0 °C . Since All months average temperatures is approximately equal or less than 22 °C , and at least four months average temperature is greater than10 °C, **Ooty comes under the category Cfb** which signifies Temperate oceanic climate.

All the above areas of study have distinctive climatic characteristics because of their difference in elevation, urbanisation level, proximity to water bodies like river, ocean etc. These factors influence microclimates by moderating temperatures, increasing humidity levels, and affecting local wind patterns. The prevailing wind refers to the most frequent or dominant direction from which the wind blows over a specific timeframe, which may be months or seasons. On the other hand, the secondary wind direction is the direction from which the wind blows less frequently but still has a notable impact on the local climate and weather patterns. Following tables show the monthly change in prevailing and secondary wind direction of the areas of study .

Bangalore	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prevailing	NE	NE	NE	NW	NW	W	W	W	W	NW	NE	NE
Secondary	S	S	S	SE	SE	NE	NE	NE	NE	SE	S	S

Table 11: Monthly wind direction of Bangalore

From January to May, northeast winds prevail, influenced by the northeast monsoon from the Bay of Bengal, while southeast secondary winds may result from local topography. During June to September, southwest monsoon winds from the Arabian Sea prevail, with northeast secondary winds due to monsoon dynamics. From October to December, northeast winds return, with south secondary winds possibly influenced by regional weather systems. These variations align with the general understanding of Bangalore's climate and monsoon patterns.

Mangalore	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prevailing	NE	NE	NE	NW	NW	W	W	W	W	NW	NE	NE
Secondary	S	S	S	SE	SE	NE	NE	NE	NE	SE	S	S

Table 12: Monthly wind direction of Mangalore

From January to May, northeast winds prevail due to the northeast monsoon from the Bay of Bengal, bringing dry conditions. During June to September, southwest monsoon winds from the Arabian Sea dominate, bringing heavy rainfall. October to December sees a return to northeast winds as the northeast monsoon wanes. These patterns influence local climate and weather conditions in Mangalore.

Jodhpur	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prevailing	NW	NW	NW	W	W	SW	SW	SW	SW	W	NW	NW
Secondary	N	N	N	NE	NE	NW	NW	NW	NW	NE	N	N

Table 13: Monthly wind direction of Jodhpur

From January to March, northwest winds prevail, likely influenced by regional weather patterns. April to September sees prevailing winds from the west, possibly due to the influence of the summer monsoon. October to December returns to northwest winds, likely influenced by post-monsoon conditions. These wind patterns impact Jodhpur's climate and weather variability throughout the year.

New Delhi	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prevailing	NW	NW	NW	W	W	SW	SW	SW	SW	W	NW	NW
Secondary	N	N	N	NE	NE	NW	NW	NW	NW	NE	N	N

Table 14: Monthly wind direction of New Delhi

From January to March, northwest winds prevail, likely influenced by cold air masses from the northwest. April to September sees prevailing winds from the west, possibly influenced by the approaching summer monsoon and the flow of air masses from the Arabian Sea. October to December returns to northwest winds, influenced by post-monsoon conditions.

Ooty	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prevailing	NW	NW	NW	W	W	SW	SW	SW	SW	W	NW	NW
Secondary	N	N	N	NE	NE	NW	NW	NW	NW	NE	N	N

Table 15: Monthly wind direction of Ooty

From January to May, northwest winds prevail, possibly influenced by regional weather patterns. June to September sees prevailing winds from the west, likely influenced by the onset of the southwest monsoon. October to December returns to northwest winds, possibly influenced by post-monsoon conditions

As per the series of table devised by C Mahoney (as mentioned below), we find that considering the relative humidity (RH), humidity groups are suggested. According to Average Mean temperature (AMT) and various humidity groups, comfort level temperatures are prescribed. Comparing the day comfort limits with the mean maxima and the night comfort limits with the mean minima we establish the nature of thermal stress as **H** (Hot), **O**(Optimal) and **C**(Cold).

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If average RH	Humidity Group
Below 30%	**1**
30-50%	**2**
50-70%	**3**
Above 70%	**4**

Comfort Level						
Humidity group	**AMT**					
	Over 20		**15-20**		**Below 15**	
	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

Applicable when:	**Indicator**	**Thermal stress**		**Rainfall**	**Humidity Group**	**Monthly mean range**
		Day	**Night**			
Air movement essential	H1	H			4	
		H			2,3	Less than 10
Air movement desirable	H2	O			4	
Rain protection necessary	H3			Over 200mm		
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				

Table 16: Comfort Level chart with respect to humidity group (top) Indicator factor(bottom)

Studying Monthly Mean Maximum temperature, Monthly Mean Minimum Tempertaure, Rainfall and Relative Humidity of these cities and comparing it with the Humidity group parameters, Comfort Level Chart and Humid/ Arid Indicators, we conclude to following diagnosis :

Bangalore												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Humidity Group	3	2	2	3	3	4	4	4	4	4	4	3
Rainfall (mm)	4	7	16	45	131	126	134	137	125	147	65	23
Monthly mean	27.4	29.6	32.1	32.8	31.2	27.5	26.4	26.1	26.7	26.4	25.7	25.8
Day comfort upper	29	31	31	29	29	27	27	27	27	27	27	29
Day comfort lower	23	25	25	23	23	22	22	22	22	22	22	23
Monthly mean	14.6	16.1	18.7	20.8	21	20.2	19.8	19.4	19	18.4	16.7	15.1
Night comfort upper	23	24	24	23	23	21	21	21	21	21	21	23
Night comfort lower	17	17	17	17	17	17	17	17	17	17	17	17
Thermal Stress Day	O	O	H	H	H	H	O	O	O	O	O	O
Thermal Stress Night	C	C	O	O	O	O	O	O	O	O	C	C
Monthly mean range	12.8	13.5	13.4	12	10.2	7.3	6.6	6.7	7.7	8	9	10.7
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H1						1						
H2							1	1	1	1	1	
H3												
A1	1	1	1	1	1							1
A2		1	1									
A3												

High	AMT
32.8	23.7
14.6	18.2
Low	AMR

	Total
H1	1
H2	5
H3	0
A1	6
A2	2
A3	0

Mangalore												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Humidity Group	3	3	4	4	4	4	4	4	4	4	4	3
Rainfall (mm)	4	2	17	55	219	704	705	486	244	232	79	19
Monthly mean	30.4	31	31.4	31.7	30.6	27.6	26.8	26.8	27.6	28.6	29.8	30.4
Day comfort upper	29	29	27	27	27	27	27	27	27	27	27	29
Day comfort lower	23	23	22	22	22	22	22	22	22	22	22	23
Monthly mean	22.4	23.4	25.1	26.4	26.2	24.9	24.3	24	24	24.3	23.9	22.8
Night comfort upper	23	23	21	21	21	21	21	21	21	21	21	23
Night comfort lower	17	17	17	17	17	17	17	17	17	17	17	17
Thermal Stress Day	H	H	H	H	H	H	O	O	H	H	H	H
Thermal Stress Night	O	H	H	H	H	H	H	H	H	H	H	O
Monthly mean range	8	7.6	6.3	5.3	4.4	2.7	2.5	2.8	3.6	4.3	5.9	7.6
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H1	1	1	1	1	1	1			1	1	1	1
H2							1	1				
H3					1	1	1	1	1	1		
A1												
A2												
A3												

High	AMT
31.7	27.05
22.4	9.3
Low	AMR

	Total
H1	10
H2	2
H3	6
A1	0
A2	0
A3	0

Jodhpur												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Humidity Group	2	2	1	1	1	2	3	4	3	2	2	2
Rainfall (mm)	3	5	2	3	5	27	122	105	42	8	1	0
Monthly mean	23.7	27.1	32.9	38.2	40.3	38.6	34.4	31.9	34.2	34.9	30	25.4
Day comfort upper	31	31	34	34	34	31	29	27	29	31	31	31
Day comfort lower	25	25	26	26	26	25	23	22	23	25	25	25
Monthly mean	9.6	12.4	17.6	23	27	28	26.5	25	24.7	21.2	16	11.2
Night comfort upper	24	24	25	25	25	24	23	21	23	24	24	24
Night comfort lower	17	17	17	17	17	17	17	17	17	17	17	17
Thermal Stress Day	O	O	O	H	H	H	H	H	H	H	O	O
Thermal Stress Night	C	C	O	O	H	H	H	H	H	O	C	C
Monthly mean range	14.1	14.7	15.3	15.2	13.3	10.6	7.9	6.9	9.5	13.7	14	14.2
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H1							1	1	1			
H2												
H3												
A1	1	1	1	1	1	1				1	1	1
A2				1	1	1				1		
A3												

High	AMT
40.3	24.95
9.6	30.7
Low	AMR

	Total
H1	3
H2	0
H3	0
A1	9
A2	4
A3	0

New Delhi												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Humidity Group	3	3	2	1	2	2	4	4	4	3	3	3
Rainfall (mm)	23	33	20	14	20	74	208	183	99	13	5	8
Monthly mean	20	23.5	29.8	36.7	39.6	38.2	33.7	32.3	32.2	31.8	27.4	22.2
Day comfort upper	29	29	31	34	31	31	27	27	27	29	29	29
Day comfort lower	23	23	25	26	25	25	22	22	22	23	23	23
Monthly mean	7.7	10.6	15.2	21	25.3	27.6	26.6	25.8	23.9	19.2	14.2	9.3
Night comfort upper	23	23	24	25	24	24	21	21	21	23	23	23
Night comfort lower	17	17	17	17	17	17	17	17	17	17	17	17
Thermal Stress Day	O	O	O	H	H	H	H	H	H	H	O	C
Thermal Stress Night	C	C	C	O	H	H	H	H	H	O	C	C
Monthly mean range	12.3	12.9	14.6	15.7	14.3	10.6	7.1	6.5	8.3	12.6	13.2	12.9
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H1							1	1	1			
H2												
H3							1					
A1	1	1	1	1	1	1				1	1	1
A2				1	1	1						
A3												1

High	AMT
39.6	23.65
7.7	31.9
Low	AMR

	Total
H1	3
H2	0
H3	1
A1	9
A2	3
A3	1

Ooty												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Humidity Group	3	3	3	3	4	4	4	4	4	4	4	4
Rainfall (mm)	24	27	49	92	171	209	206	186	146	207	139	58
Monthly mean	20.6	21.6	22.9	23.4	22.8	20.7	20	20	20.5	20.1	19.7	20
Day comfort upper	28	28	28	28	25	25	25	25	25	25	25	25
Day comfort lower	21	21	21	21	20	20	20	20	20	20	20	20
Monthly mean	10.6	11.2	12.7	14.4	15	14.7	14.1	14	13.6	13.4	12.6	11.6
Night comfort upper	21	21	21	21	20	20	20	20	20	20	20	20
Night comfort lower	14	14	14	14	14	14	14	14	14	14	14	14
Thermal Stress Day	C	O	O	O	O	O	O	O	O	O	C	C
Thermal Stress Night	C	C	C	O	O	O	O	C	C	C	C	C
Monthly mean range	10	10.4	10.2	9	7.8	6	5.9	6	6.9	6.7	7.1	8.4
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H1				1								
H2					1	1	1	1	1	1		
H3						1	1					
A1	1	1	1									
A2												
A3	1										1	1

High	AMT
23.4	17
10.6	12.8
Low	AMR

	Total
H1	1
H2	6
H3	2
A1	3
A2	0
A3	3

	H1	H2	H3	A1	A2	A3
Bangalore	1	5	0	6	2	0
Mangalore	10	2	6	0	0	0
Jodhpur	3	0	0	9	4	0
New Delhi	3	0	1	9	3	1
Ooty	1	6	0	2	0	3

Table 17 : Diagnosis of Bangalore, Mangalore, Jodhpur, New Delhi and Ooty (above) Summary (below)

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						Tropical Savanna Climate	Tropical Monsoon Climate	Hot Semi-arid Climate.	Monsoon influenced humid subtropical Climate with dry winters.	Subtropical highland Climate with dry winter		
						Aw	**Am**	**BSh**	**Cwa**	**Cfb**		
H1	**H2**	**H3**	**A1**	**A2**	**A3**	*Bangalore*	*Mangalore*	*Jodhpur*	*New Delhi*	*Ooty*		
Layout												
			0-10			√	√	√	√	√	**1**	**Orientation north and south (long axis east-west)**
			11,12		05-'12							
					0-4	√	√	√	√	√	**2**	**Compact courtyard planning**
Spacing												
11,12											**3**	**Open spacing for breeze penetration**
02-.10							√	√	√		**4**	**As 3, but protection form hot and cold wind**
0,1						√				√	**5**	**Compact lay-out of estates**
Air movement												
03-.12							√	√	√	√	**6**	**Rooms single banked, permanent provision for air movement**
1,2			0-5									
			06-.12			√					**7**	**Double banked rooms, temporary provision for air movement**
0	02-.12											
	0,1											**No air movement requirement**
Size of openings												
			0,1		0		√				**8**	**Large openings, 40-80%**
			2-.5		1-.12					√	**9**	**Medium openings, 25-40%**
			6-.10			√		√	√		**10**	**Small opening - 15-25%**
			11,12		0-.3							**Very small opening 10-20%**
					4-.12							**Medium openings, 25-40%**

Position of openings												
3-.12							√	√	√		**11**	**In north and south walls at body height on windward side**
1-.2			0-.5							√		
			6-.12			√					**12**	**As above, openings also in internal walls**
0	2-.12											
Protection of openings												
					0-2	√	√	√	√		**13**	**Exclude direct sunlight**
			2-.12				√				**14**	**Provide protection from rain**
Walls and floors												
			0-2				√			√	**15**	**Light walls, Low thermal capacity, short time-lag**
			03-.12			√		√	√		**16**	**Heavy external and internal walls. Over 8 hour lag time**
Roofs												
10-.12			0-2									**Light, reflective surface, cavity**
			3-.12				√				**17**	**Light, well insulated**
0-9			0-5							√		
			6-.12			√		√	√		**18**	**Heavy roofs, over 8 h time-lag**
Out-door sleeping												
				1-.12		√		√	√		**19**	**Space for out-door sleeping required**
Rain protection												
		3-.12					√				**20**	**Protection from heavy rain necessary**
		1-.12					√		√			**Adequate rainwater drainage**

Table 18 : Recommendation for Bangalore, Mangalore, Jodhpur, New Delhi and Ooty

IV. DISCUSSION

A. Layout

1) Buildings in all the Indian cities studied should be oriented along an east-west axis. This orientation optimizes sun exposure, helps regulate indoor temperatures, and minimizes direct heat gain from the sun.
2) Compact courtyard planning, a feature of traditional Indian architecture, remains effective. Centrally located courtyards provide ventilation, natural light, and social interaction spaces while ensuring privacy and protection from external elements.

B. Spacing

1) Incorporate open spaces to facilitate the flow of breeze.
2) In Jodhpur, New Delhi, and Mangalore, design considerations should include protection from cold or dusty hot winds.
3) Compact planning is advised for Bangalore and Ooty, where minimal air movement is needed.
4) For most cities, use single-banked rooms with windows on the north and south walls to ensure effective cross-ventilation.
5) In Bangalore, double-banked rooms are feasible as long as there is adequate cross-ventilation.

C. Size of Openings

1) In Mangalore, where thermal storage is required for less than one month and there is no cold season, large openings covering 40 to 80% of the wall area are suitable.
2) In Ooty, where thermal storage is needed for over one month and a cool season is present, medium openings covering 25 to 40% of the wall area are advisable.
3) In New Delhi, Jodhpur, and Bangalore, where thermal storage is required for 6 to 10 months, small openings covering 15 to 25% of the wall area are appropriate.

D. Position of Openings

1) In cities such as New Delhi, Mangalore, Jodhpur, and Ooty, where air movement is crucial for three months or more and thermal storage is required for less than six months, position openings to direct the breeze towards the occupants, ideally with a north-south orientation. However, prioritize wind direction over solar orientation when needed.
2) In Bangalore, where thermal storage is needed for more than six months, double-banked rooms with sufficient openings in internal walls are recommended. In this scenario, prioritize north-south solar orientation over wind direction.

E. Protection of Openings

1) With the exception of Ooty, all these cities experience cool seasons lasting no more than two months. Therefore, buildings should be designed to block solar radiation throughout the year.
2) In Mangalore, where rainfall exceeds 200 mm for more than six months, ensure that openings are protected from rain penetration.

F. Walls and Floors

1) When thermal storage is needed for two months or less, use lightweight materials such as hollow blocks or bricks with over 40% voids, thin solid walls (e.g., 50 mm dense concrete), or sheeted walls enclosing a cavity with reflective outer surfaces. Roofs:
2) When thermal storage is required for more than two months, use heavy materials such as solid bricks, blocks, concrete, or adobe with a thickness of about 300 mm. If insulated on the outside, a reduced thickness of up to 100 mm is also adequate.
3) In climates with air movement needs (H1) for 10 to 12 months and thermal storage requirements over three months (e.g., Mangalore), or with air movement needs for less than nine months and thermal storage requirements under five months (e.g., Ooty), a light but well-insulated roof is essential. Aim for an overall U-value not exceeding 0.8 W/m²°C, achievable with an external reflective sheet, a cavity, and a ceiling with at least 25 mm of insulation and a reflective top.
4) In all other cases, use a massive roof with a time lag of eight hours or more.

G. Outdoor Sleeping

1) In Bangalore, Jodhpur, and Delhi, allocate space for outdoor sleeping due to the A2 indicator being one or more. This space is often located on the roof, which should be finished to endure foot traffic.Rain Protection:

2) In cities with heavy rainfall, even for one month a year, special roof drainage provisions are necessary. In New Delhi and Mangalore, care must be taken to protect from rain, and stagnant water should be avoided to prevent mosquito breeding.

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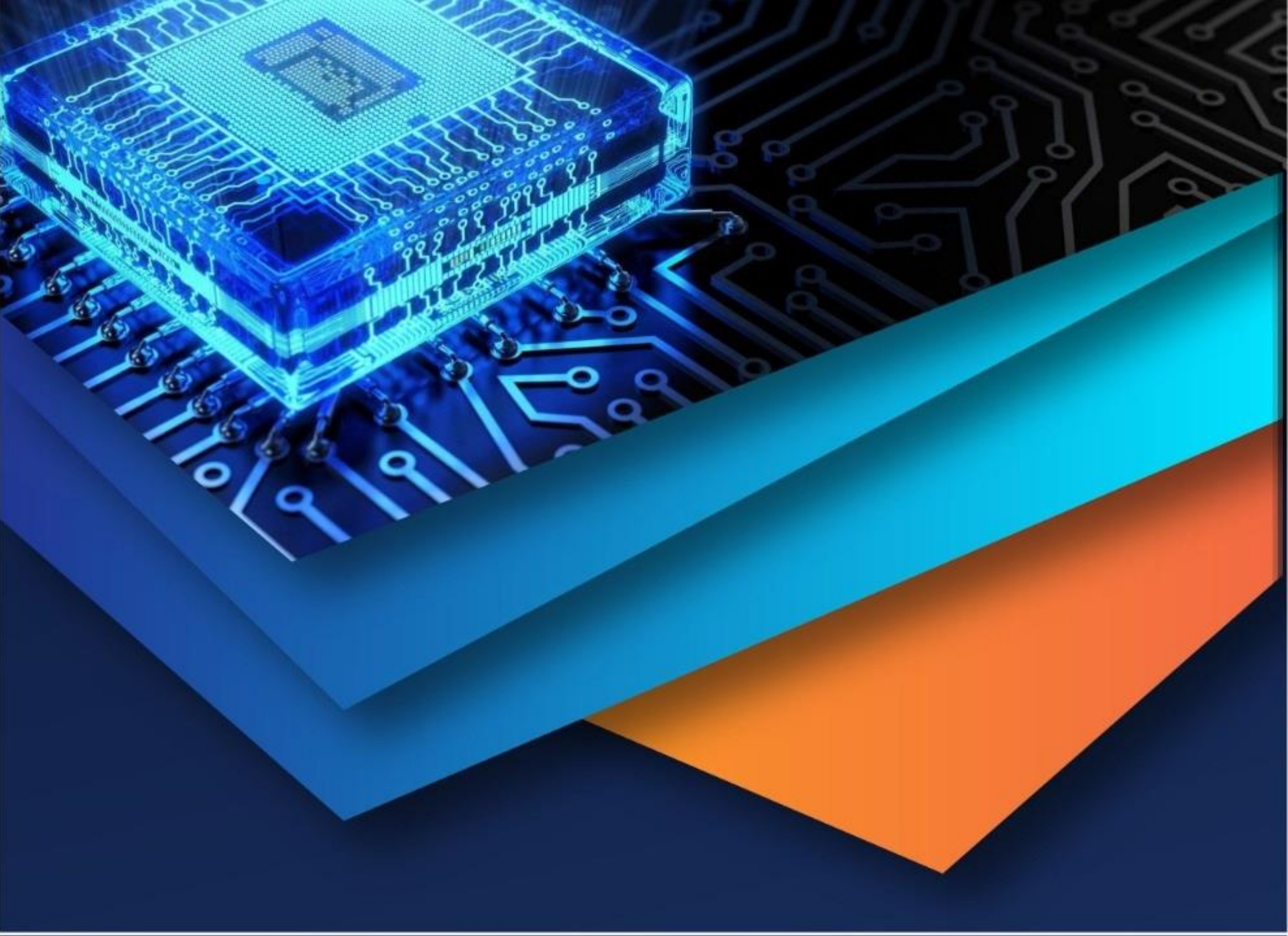

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