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Bioclimatic Design Strategies Recommendations for Thermal Comfort in the North Region of Cameroon: A Mahoney's Table-Based Approach

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Abstract: The building sector accounts for about 70% of energy consumption in Cameroon. Despite the existence of a national policy, strategy and action plan for energy efficiency, residential and administrative buildings in Cameroon are designed with insufficient consideration to local climatic conditions leading to poor thermal performance of buildings and increasing reliance on mechanical cooling systems to maintain acceptable indoor thermal comfort. This work focuses on the bioclimatic design of buildings in the North Region of Cameroon which is characterized by high temperature and intense solar radiation. The main objective is to aid architects in designing structures that are in harmony with local climates. The study relied on climatic data of the city of Garoua, head-quarter of the North region, collected on the NASA website for a period of 10 years (2015-2024) and this data was evaluated by Mahoney's tables. The results show that in Garoua, buildings should have elongated shapes in the East-West direction with medium-sized windows (25 to 40%) placed to the north and south, thick walls (more than 8 h phase shift time), light roofs with insulation and open-air spaces for sleeping at night.
Keywords: Bioclimatic design; Cameroon; North Region; Thermal comfort; Mahoney's Tables.

I. INTRODUCTION

Global energy needs are increasing (about 1.6% per year over the last two decades), especially those of developing countries whose growth is well above 3% [1]. Faced with the double global challenge posed by the risks of fossil fuel shortages and their effects on climate change, the governments involved in the Kyoto Protocol have multiplied actions in the electricity production sector in order to develop renewable, clean and inexhaustible sources of energy [2]. But the desire to develop renewable energy sources alone would not be enough to provide a sustainable solution if it is not coupled with a strategy to reduce energy consumption. The building sector, one of the world's largest energy consumers, is a prime target for reducing consumption [3]. In Cameroon, energy consumption in the building sector represents a share of 70% of final energy [4]. Among the causes of this high consumption are the use of precarious air conditioning equipment to make the indoor environment comfortable and the absence of references that include the notion of energy or the environment in addition to the structural stability of buildings. Thus, two main ways of improving the energy performance of buildings are possible: improving the efficiency of energy equipment (heating, cooling, lighting, household appliances, etc.) or improving the performance of the building envelope [3]. The latter solution is the easiest to implement in the context of developing countries. Indeed, these countries have a low level of industrialization that does not allow them to develop sophisticated equipment that meets international standards.

Adapting the design of buildings to their climatic context in order to make the best possible use of available environmental resources becomes inevitable [5,6]. This building design approach, called bioclimatic design, is a global approach to all the elements of the architectural study: orientation, openings, room distribution, choice and implementation of materials, atmospheres, needs, etc. [7]. It is most often defined as a practice used to adapt buildings to the climatic conditions of a given location according to the needs and expectations of the occupants, while optimizing energy consumption [8, 9, 10, 11, 12, 13]. Architects and engineers have rarely implemented it during the building design process and one reason is believed to be the long duration of climate analyses. The objective of this work is therefore to propose to the actors of the buildings sector, necessary recommendations concerning the architectural elements of the design of buildings in the North Region. The study will be based on Mahoney's tables and the site chosen is the city of Garoua, head-quarter of the North Cameroon Region.

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II. MATERIAL AND METHOD

A. Material

1) Situation of the Region

The North Region, known until 2008 as the North Province, is one of the ten Regions of Cameroon located at 8° 30' North latitude and 14° 00' East longitude, whose capital is Garoua. It was born from the break-up in 1983 of the first province of the North, which included the three provinces of Adamawa, the North and the Far North. It comprises four divisions (Bénoué, Faro, Mayo-Louti, Mayo-Rey) as shown in Figure 1. With an area of 66090 km^2, the North Region had a population of 3,753,485 souls in 2023, representing 13.0% of the total population of Cameroon [14].

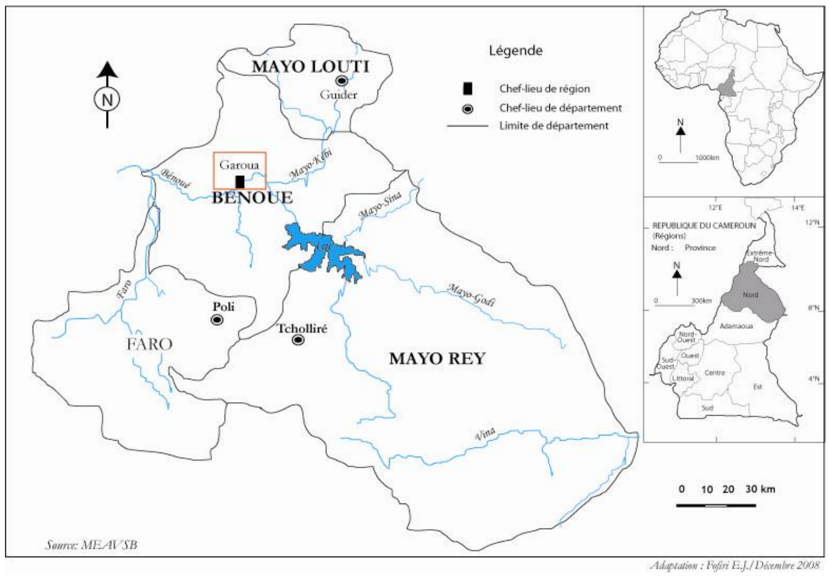

Fig.1 Map of the North Region

2) General information on the climate of the North Region of Cameroon.

The North Cameroon Region belongs to the Sudano-Sahelian tropical climate type characterized by:

- A rainy season that runs from April to October with an average annual rainfall of 767.24 mm;
- A dry season that runs from November to March with average maximum temperatures reaching 40.8°C;
- Intense solar radiation throughout the year with an average of 5.71 Kwh/m2/d.

3) Equipment

This work required:

- A file of meteorological data downloaded from the NASA website from Retscreen Expert over a period of 10 years (2015-2024);
- Mahoney's Tables;

B. Method.

The methodology first consisted of collecting meteorological data of the city of Garoua, followed by presenting the characteristics and knowledge of the main climatic parameters that must be taken into account in the design of buildings in the context of the site and finally, evaluation of the climatic performance of buildings is carried out using Mahoney's tables.

III. RESULTS

A. Analysis of the climatic parameters of the city of Garoua.

The climatic parameters determining the thermal response of buildings are mainly solar radiation, air temperature, air humidity, wind. However, additional factors (precipitation, sky temperature, and ground temperature) may be included in order to further elaborate climatic conditions. In the context of this work, only precipitation was taken into account.

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1) *Sunshine in Garoua:* The average daily irradiation data presented in Figure 2 show that the city of Garoua is among the sunniest in Cameroon with an average daily irradiation of 5.71 Kwh/m^2/d. The analysis of this figure shows that the months of February, March and April are the sunniest with a maximum of sunshine in April (6.20 Kwh/m^2/d) and the months of July, August and September are the least sunny with a minimum of sunshine in August (4.75 Kwh/m^2/d).

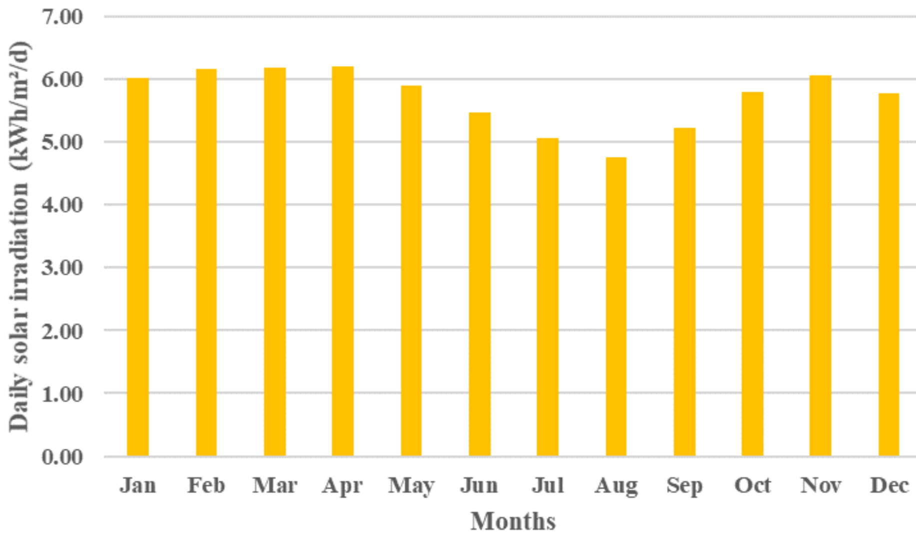

Fig.2 Average monthly sunshine in the city of Garoua

2) *Temperature:* Figure 3 shows the monthly variations in air temperature in Garoua. August is the coldest with an average high temperature of 29.07°C and an average minimum temperature of 22.44°C, while the temperature range is 6.63°C and the average temperature is 25.52 °C. On the other hand, March is the warmest, with an average maximum temperature of 40.79°C and an average minimum temperature of 25.58°C, while the temperature range is 15.21°C and the average temperature is 32.90°C.

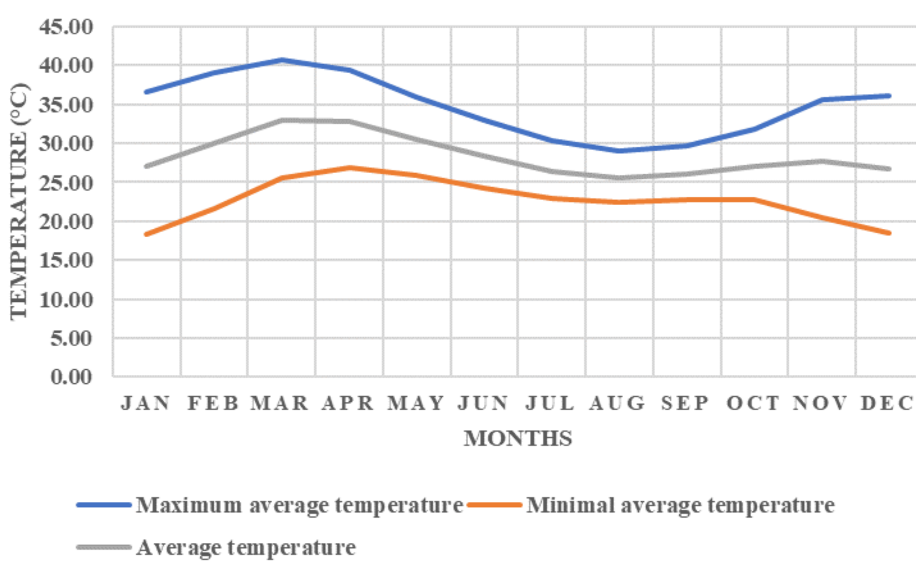

Fig.3 Changes in outdoor air temperature for the period 2015 to 2024

3) *Relative humidity of the air:* The average relative humidity is average throughout the year, its annual average is 52.33%. The maximum value of the relative humidity is recorded during the month of August (84.13%) while the minimum value is recorded during the month of February (15.35%) as shown in Figure 4.

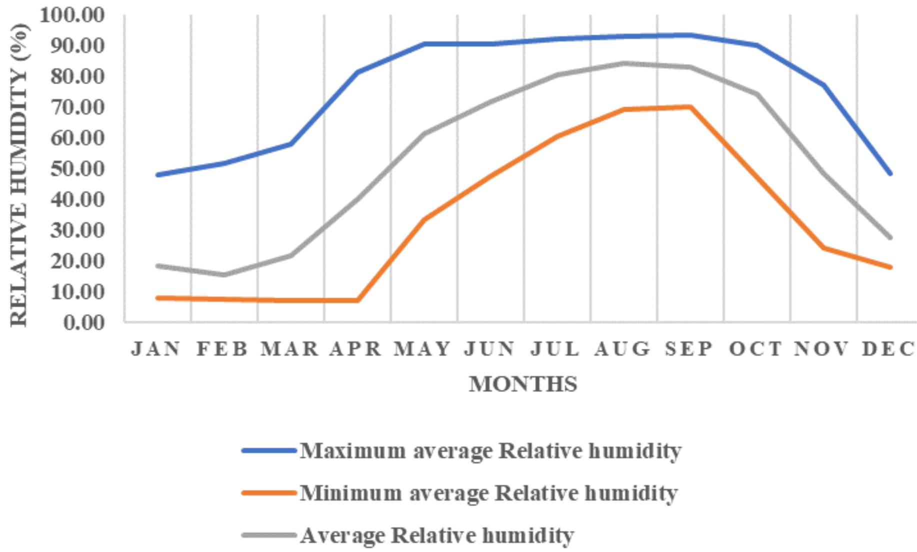

Fig.4 Changes in relative humidity for the period 2015 to 2024

4) *The wind:* Figure 5 shows that the winds are light to moderate, their speeds vary from 1.81 m/s (the minimum value recorded during the month of September) to 4.24 m/s (the maximum value recorded during the month of February). In the rainy season, the prevailing winds come from the west and southwest, bringing the most significant humidity and rainfall. On the other hand, in the dry season, the prevailing winds generally come from the northeast, often associated with the harmattan which brings dry and cool air.

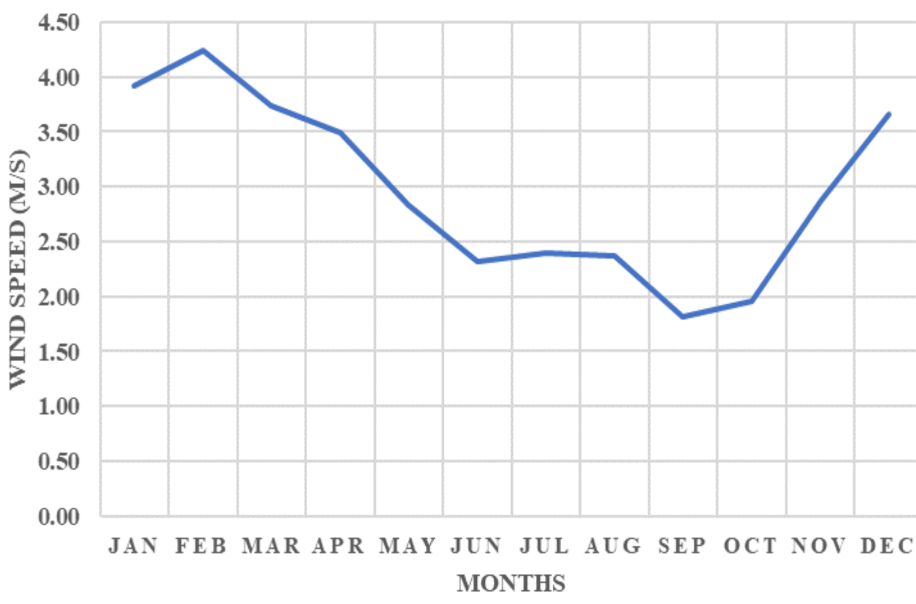

Fig.5 Changes in wind speed in Garoua from 2015 to 2024

5) *Precipitation:* The city of Garoua is considered among the least rainy in Cameroon, with an annual total of 920.6 mm. Figure 6 shows that the months of July, August and September are the rainiest (more than 64%) with a maximum of precipitation during the month of August (206.58 mm). December, January and February are the driest (0.6%) with zero rainfall during the month of January (0.00 mm).

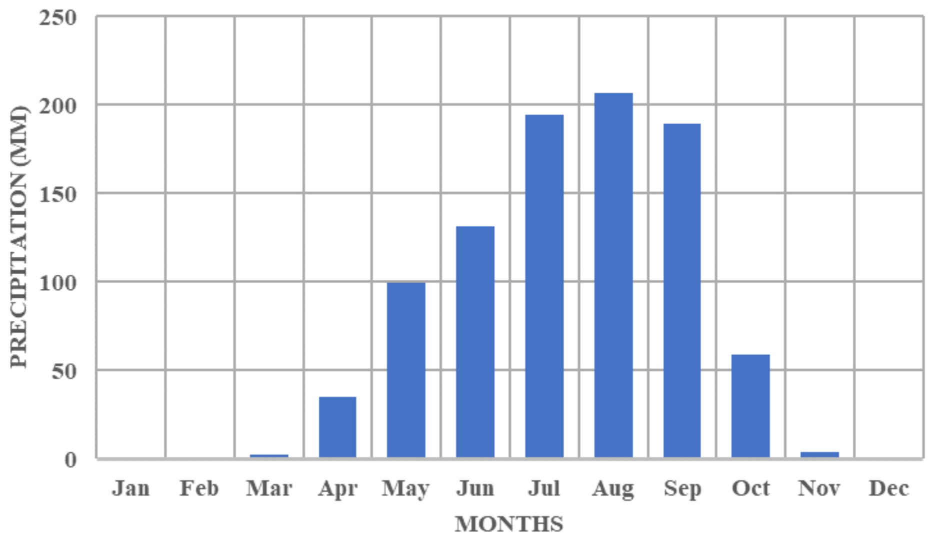

Fig.6 Precipitation changes for the period 2015 to 2024

B. Bioclimatic measures recommended by the Mahoney tables for the city of Garoua

1) Geographical coordinates

TABLE I
Geographic Coordinates

Location	Garoua
Latitude	9°18'N
Longitude	13°24'E
Altitude	240 m

2) Temperature (°C)

TABLE II
Monthly Average Temperatures

Month	Jan	Feb	Mar	apr	may	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	36,61	39,07	40,79	39,43	35,93	32,95	30,37	29,07	29,67	31,90	35,65	36,16
Tmin	18,32	21,58	25,58	26,86	25,85	24,18	22,99	22,44	22,73	22,75	20,41	18,42
Tmoy	27,00	29,95	32,90	32,87	30,56	28,30	26,42	25,52	26,06	27,11	27,63	26,77

Mean annual temperature = ∑ Mean monthly temperatures / 12 = 28.41°C

3) Relative humidity (%)

TABLE III
Humidity Group

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Relative humidity	18.53	15.35	21.78	39.88	61.15	71.85	80.35	84.13	82.83	74.10	48.35	27.55
Humidity group	1	1	1	2	3	4	4	4	4	4	2	1

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Humidity Group	Relative humidity
1	HR: < 30%
2	RH: 30-50%
3	HR: 50-70%
4	RH: > 70%

4) Precipitation (mm)

TABLE IV.
Annual Precipitation Rate

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly precipitation	0	0,15	2,08	34,86	99,59	130,95	194,43	206,58	189,19	58,48	4,07	0,30
Annual precipitation rate	920.6 mm											

5) Wind (m/s)

TABLE V
Wind Speed

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind speed	3,92	4,24	3,74	3,50	2,84	2,32	2,40	2,37	1,81	1,95	2,87	3,66

6) *Comfort limits:* The comfort limits are defined from the Annual Average Temperature (TMA) and the humidity group (GH).

TABLE VI
Comfort Limits

Humidity Group	TMA> 20°C		15°C<TMA<20°C		TMA<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

7) Temperature diagnosis.

TABLE VII
Temperature Classification In Relation To Comfort Limits

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	36,61	39,07	40,79	39,43	35,93	32,95	30,37	29,07	29,67	31,90	35,65	36,16
LCJS	34	34	34	31	29	27	27	27	27	27	31	34
LCJI	26	26	26	25	23	22	22	22	22	22	25	26
CTJ	H	H	H	H	H	H	H	H	H	H	H	H
Tmin	18,32	21,58	25,58	26,86	25,85	24,18	22,99	22,44	22,73	22,75	20,41	18,42
LCNS	25	25	25	24	23	21	21	21	21	21	24	25
LCNI	17	17	17	17	17	17	17	17	17	17	17	17
CTN	O	O	H	H	H	H	H	H	H	H	O	O

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H (Hot): if the monthly temperature is above the comfort limits;
O (comfortable): if the monthly temperature is within the comfort limits;
C (Cool): if the monthly temperature is below the comfort limits;
LCJS: Upper Day Comfort Limit; LCNS: Superior Night Comfort Limit;
LCJI: Lower Day Comfort Limit; LCNI: Lower Night Comfort Limit;
CTJ: Thermal comfort during the day; CTN: Thermal comfort at night.

8) *Indicators*

TABLE 1.
Mahoney Indicators

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
H1	0	0	0	0	V	V	V	V	V	V	V	0	7
H2	0	0	0	0	0	0	0	0	0	0	0	0	0
H3	0	0	0	0	0	0	0	0	0	0	0	0	0
A1	0	V	V	V	0	0	0	0	0	0	V	V	5
A2	0	V	V	V	0	0	0	0	0	0	0	0	3
A3	0	0	0	0	0	0	0	0	0	0	0	0	0

C. *Recommendations*

1) *Specific recommendations*

TABLE V
Specific Recommendations

Indicator					
H1	H2	H3	A1	A2	A3
7	0	0	5	3	0

<table>
<tr><td colspan="8"></td><td>Site plan</td></tr>
<tr><td></td><td></td><td></td><td>0-10</td><td></td><td></td><td rowspan="2">V</td><td rowspan="2">1</td><td rowspan="2">North and south orientation (along the east–west axis)</td></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">11-12</td><td rowspan="2"></td><td>5-10</td></tr>
<tr><td>0-4</td><td></td><td>2</td><td>Compact site plan with inner courtyard</td></tr>
<tr><td colspan="8"></td><td>Spacing between buildings</td></tr>
<tr><td>11-12</td><td></td><td></td><td></td><td></td><td></td><td></td><td>3</td><td>Wide spacing allowings for the penetration of breezes.</td></tr>
<tr><td>2-10</td><td></td><td></td><td></td><td></td><td></td><td>V</td><td>4</td><td>Wide spacing allowing the penetration of breezes, but with protection against hot and cold winds.</td></tr>
<tr><td>0-1</td><td></td><td></td><td></td><td></td><td></td><td></td><td>5</td><td>Compact site plan.</td></tr>
<tr><td colspan="8"></td><td>Air Movement</td></tr>
<tr><td>3-12</td><td></td><td></td><td>0-5</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">V</td><td rowspan="2">6</td><td rowspan="2">Single rooms, permanent air supply</td></tr>
<tr><td rowspan="2">1-2</td><td rowspan="2"></td><td rowspan="2"></td><td>6-12</td></tr>
<tr><td></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">7</td><td rowspan="2">Double rooms, permanent air supply.</td></tr>
<tr><td rowspan="2">0</td><td>2-12</td><td></td><td></td></tr>
<tr><td>0-1</td><td></td><td></td><td></td><td></td><td></td><td>8</td><td>Air movement not recommended</td></tr>
<tr><td colspan="8"></td><td>Windows</td></tr>
<tr><td></td><td></td><td></td><td>0-1</td><td></td><td>0</td><td></td><td>9</td><td>Wide: 40% to 80%</td></tr>
<tr><td></td><td></td><td></td><td>11-12</td><td></td><td>0-1</td><td></td><td>10</td><td>Very small: 10% to 20%</td></tr>
<tr><td colspan="3">No conditions</td><td></td><td></td><td></td><td>V</td><td>11</td><td>Medium: 20% to 40%</td></tr>
</table>

								Walls
			0-2				12	Light walls, short phase shift time.
			3-12			V	13	Thick exterior and interior walls.
								Roofing
			0-5			V	14	Lightweight roofs.
			6-12				15	Thick roofs, phase shift time more than 8 hours.
								Outdoor space
				2-12		V	16	Open air space to sleep at night.
								Rain protection
		3-12					17	Protection from the rain necessary.

2) *Detailed recommendations*

TABLE VI.
Detailed Recommendations

Indicator					
H1	H2	H3	A1	A2	A3
7	0	0	5	3	0

								Window Dimensions
			0-1		0		1	Wide: 40% to 80%.
					1-12	V	2	Average: 25% to 40%.
			2-5					
			6-10				3	Small: 15% to 25%.
			11-12		0-3		4	Very small: 10% to 20%
					4-12		5	Medium: 20%-40%.
								Window Placement
3-12						V	6	To the north and south of the wall facing the wind.
1-2			0-5					
			6-12				7	High openings in interior walls.
0	2-12							
								Window protection
					0-2	V	8	Exclude direct solar radiation.
		2-12					9	Plan for rain protection.
								Walls and floors
			0-2				10	Lightweight, low heat capacity.
			3-12			V	11	Thick, more than 8 hours phase shifting time.
								Roof
10-12			0-2				12	Lightweight, reflective surfaces, cavity.
			3-12			V	13	Lightweight, with insulation.
0-9			0-5					
	2-12		6-12				14	Massive, more than 8 hours of phase shift.
								Exterior elements
				1-12			15	open air space to sleep at night.
		1-12					16	Adequate rainwater drainage.

IV. RECOMMENDATIONS

Based on the results of the analysis, the following recommendations are made to promote the integration of bioclimatic design into construction practices in the North Region of Cameroon:

1) Buildings should be elongated in the East-West direction, with large spacings between buildings allowing the penetration of breezes, but with protection from hot and cold winds;
2) Single rooms with permanent air supply
3) The windows should have an average size of 25% to 40%, be placed north and south facing the wind and protected from solar radiation;
4) Roofs must be light and insulated;
5) Walls and floors should be thick with a phase shift time of more than 8 hours;
6) Open air spaces must be for sleeping at night.

V. CONCLUSION

Bioclimatic design is currently a major challenge in the building sector, both for the quality of the interior environments and for the energy and environmental impacts. A bioclimatic analysis to define recommendations to be followed when designing buildings in the North Region was carried out based on Mahoney's tables. The objective is to minimize the demand for air conditioning in buildings while valuing natural energy resources of the environment. The analysis made it possible to propose the appropriate orientation of buildings, an adapted design of walls, roofs, openings, and floors. However, bioclimatic design alone is not enough to reduce heat exchange between the indoor environment and outdoor spaces. It is necessary to complete these results with a study of suitable materials in the context of the North Region and to carry out experimental studies on real buildings to confirm the proposed solutions in order to integrate the recommendations into the building standards for North Cameroon and promote the emergence of a more comfortable habitat, more energy-efficient.

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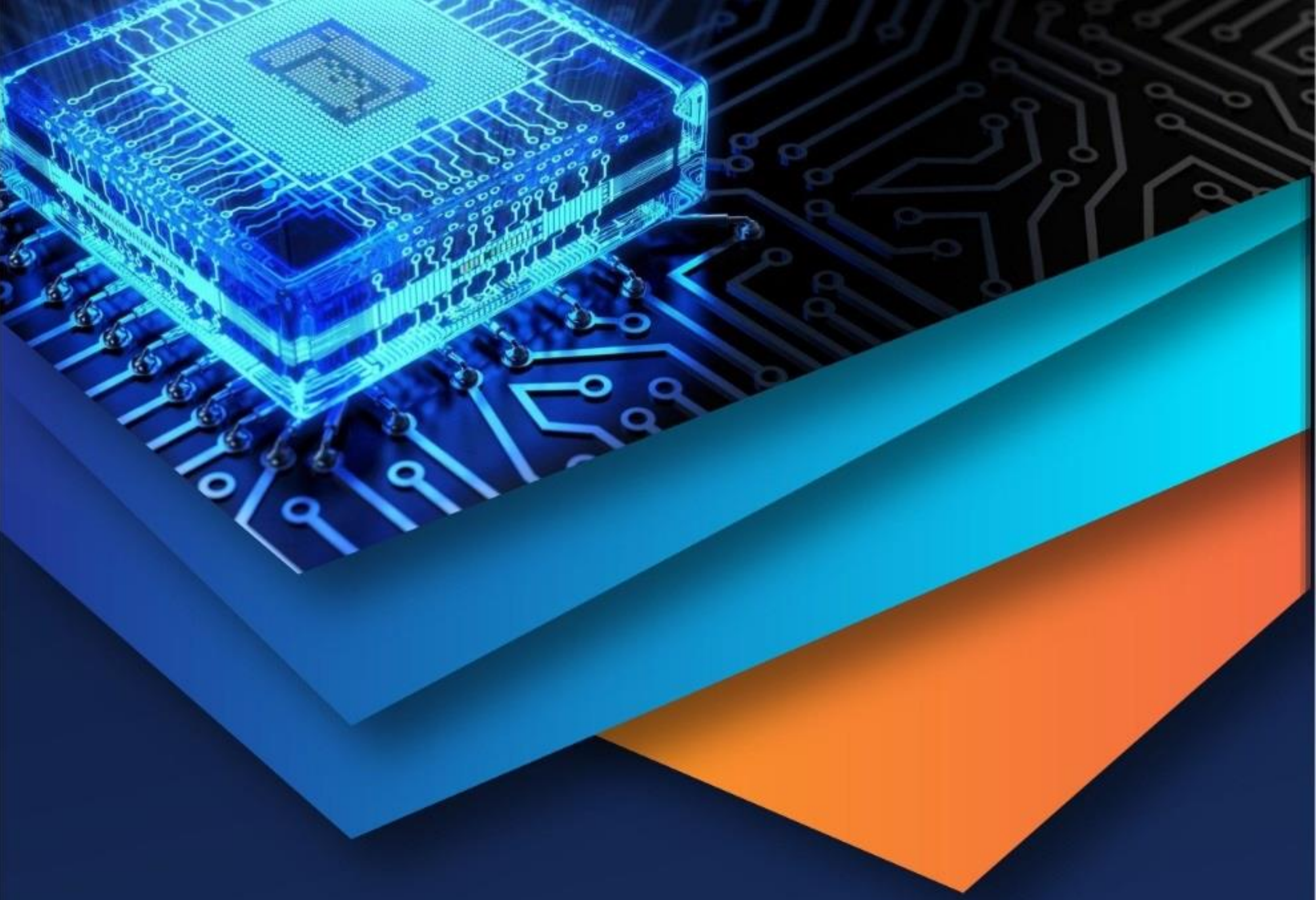

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