



Revue des Matériaux & Energies Renouvelables

Journal home : www.cu-relizane.dz

ISSN : 2507-7554

E- ISSN : 2661-7595



Assessment of thermal comfort in some public buildings in the sudano-sahelian area of Cameroon during the so-called "cold" period (harmattan season)

Lissangadi Mounouna Dapsia¹, Ahmat Tom², Noël Djongyang^{1*}

¹ Department of Renewable Energy, National Advanced School of Engineering of Maroua, University of Maroua, PO Box 46 Maroua, Cameroon

² Department of Energy Engineering, University Institute of Technology, University of Ngaoundere, PO Box 455 Ngaoundere, Cameroon

ABSTRACT

This paper deals with adaptive thermal comfort in public buildings in the Sudano-Sahelian zone of Cameroon during the harmattan season. In-situ data measurements were taken in various buildings according to the type of landforms (mountain and plain). A quantitative sociological survey was also conducted on the thermal sensation of the occupants. The Predicted Mean Vote and Predicted Percentage of Dissatisfied comfort indexes were evaluated as well as the Actual Mean Vote, and the Actual Percentage of Dissatisfied. Results showed that the operative temperatures and the relative humidity determined on the basis of the Actual Mean Vote were respectively 20.09 °C and 30.35 % (in the Mountains), 20.92 °C and 61.94 % (in plains). The operative temperatures of the comfort zone in the mountain area were between 14.20 °C and 22.45 °C while the operative temperatures of the comfort zone in the plain zone are between 17.5 °C and 24.3 °C. Occupants testified indoor "thermal unacceptability" especially for public administrations and schools.

Article history:

Received 11 July 2020

Received in revised form 31 July 2020

Accepted 20 August 2020

Keys word: Public buildings; Sudano-Sahelian zone; Thermal comfort; Harmattan season; Thermal acceptability; Neutral operative temperature

Copyright © 2020 - All rights reserved

1. Introduction

Most of the time, buildings are just considered as a shelter. Therefore, some aspects related to internal thermal comfort are not taken into account in the architectural design; consequently, they may not be well adapted for some specific areas.

Thermal comfort is defined according to the ASHRAE standard 55 as the condition of the mind which expresses satisfaction with the thermal environment [1]. As such, it will be influenced by personal differences in mood, culture and other individual, organizational and social factors. Based on the above definition, comfort is not a state condition, but rather a state of mind. The definition of thermal comfort leaves open as to what is meant by condition of mind or satisfaction, but it correctly emphasizes that the judgment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other factors [2]. It has an impact on intellectual performance [3]. It is also a key parameter for a healthy and productive workplace (shopping centres, administrative offices, worship places, etc.). Thermal comfort standards determine the energy consumption by a building's environmental systems; therefore, they play an important role in building sustainability. Hence, it is essential to think of adopting public buildings suitable for the climate

* Corresponding author. E-mail address: noeldjongyang@gmail.com

of the Sudano-Sahelian zones, in order to improve the level of their thermal comfort. Thermal comfort depends on parameters like air temperature, relative air humidity, air speed, metabolism, clothing, etc. These parameters are used to determine the thermal sensation based on the objective method (Fanger model) [4]. The thermal sensation is also determined by the subjective approach (the occupants' vote) [5].

Numerous studies based on the thermal comfort of occupants in buildings have been carried out; eg. Ionnou and Itard [6] carried out in-situ measurements of thermal comfort in 30 residential habitats in the Netherlands and compared with existing results from the literature. They proceeded with quantitative (temperature, relative humidity, etc.) and qualitative (thermal sensation and perception, clothing, measurements taken during the last half hour regarding comfort and energy consumption, etc.) measurements. The results obtained showed that the PMV model underestimates the thermal comfort of the tenants in houses. They also showed that clothing, metabolic activity, age and sex have no influence on the neutral temperature and that it is the speed air, adaptation and psychological expectations which are the explanatory factors for the difference in neutral temperature between habitats. Castaño et al. [7] studied the optimization of the thermal comfort of buildings under the natural ventilation regime (with focus on the facades), in order to obtain sufficient comfort levels, low energy consumption in offices subject to the Mediterranean climate. This work was based on thermal modelling and simulation for a full year and without air conditioning installation. It consisted in analysing the situation of thermal comfort inside buildings by calculating the percentage of hours of thermal comfort. The results obtained attested that the combination of natural stimulation (facade) controlled with air conditioning systems constitutes the most suitable design solution in a Mediterranean climate. In the same context, Rijal et al. [8] provided an adaptive model specifically applicable to Japanese homes and clarified the adaptation mechanism (physiological and behavioural) of the occupants. For this, thermal measurements and surveys on thermal comfort were carried out in the living room and bedrooms of 120 dwellings, including 244 residents, each with an air conditioning unit and a fan from the Kanto region of Japan from 2010 to 2014. The results obtained showed that residents are generally satisfied with the thermal environment of their homes, and that the temperature in free operating mode is around 27.6 °C in summer and 17.6 °C in winter. They also showed that an adaptive relationship between the indoor comfort temperature and the outdoor air temperature could be a useful way to estimate the comfort temperature and provide information on control strategies. Finally, they concluded that different adaptation mechanisms (behavioural adaptation, psychological adaptation) contribute significantly to the adaptive model. Roumaissa et al. [3] studied the correlation between architectural typologies of middle-school buildings and the thermal comfort of users in an area with a hot and arid climate in Algeria, more precisely in Bishar. Questionnaire surveys and in-situ measurement campaigns were carried out. The results attested that in hot weather, whatever the plan, the temperature of the rooms remains high and this is valid for the four cardinal orientations. They also found that there is a strong correlation between the ambient temperature and the thermal sensation of the students and finally that the typology of the central corridor plan offers conditions more favourable to thermal comfort. In Cameroon, Kemajou and Mba [9] worked on obtaining thermal comfort in the habitat by a judicious choice of materials in hot areas. They proceeded by thermal simulation based on the Pleiades + Comfie software and carried out a comparison between local and modern materials. The results of this study have shown that better thermal comfort is obtained with local materials based on passive methods (architectural forms, orientation, size of openings, etc.) in line with architectural habits.

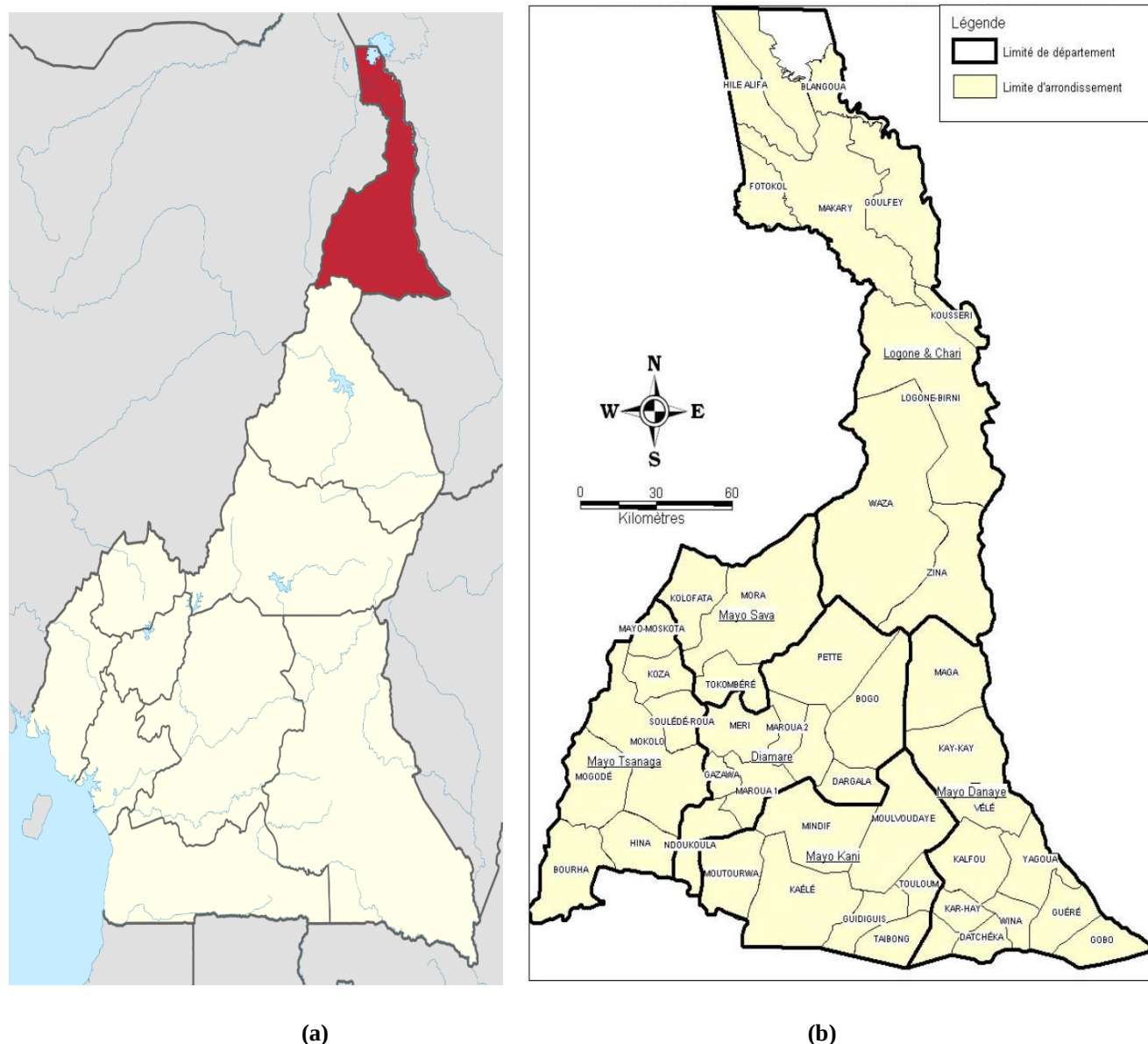
Most of the studies encountered in the literature are limited in the study of thermal comfort to the determination of the neutral temperature and yet relative humidity plays a key role in thermal sensation [10-21]. In this paper, in addition to neutral temperature, we also look at the influence of neutral relative humidity on thermal comfort.

If the climate is generally quite mild in the equatorial climatic region of Cameroon, this is not the case in the Sudanese and Sudano-Sahelian climatic zones which experience peaks of temperature alternating between very hot and very cold. But generally, the climate is hot thus making cold periods particularly difficult to support by the local population. This is why it is this particularly cold period which draws our attention in this work. In this paper, we will be interested in determining the different indexes of thermal comfort (PMV, PPD, AMV, APD), and the correlations existing between them in different types of public buildings and then estimating the neutral temperature and relative neutral humidity in the two types of relief (mountain and plain) during the "cold" period. This study will allow to develop passive (architectural applications) and / or active (use of air conditioning) methods in order to optimize thermal comfort and energy consumption in public buildings in the Sudano-Sahelian zone.

2. Study area

Cameroon is situated between latitude of 2°N to 13°N, longitude of 9°E to 17°E and covers a land area of about 475 442 km² (fig. 1). An equatorial climate with four seasons (two dry and two rainy) is found in the southern part and Atlantic

Ocean coasts with approximately 3 890 mm of precipitation per year. Abundant rainfall occurs from April to November, and practically throughout the year in the south-west mountains (approximately 10 000 mm per year). The climate tends to be of the sahelian type as one leaves the southern to the northern part of the country with two seasons (one dry and one rainy). The dry season lasts from October to April (700 mm of precipitation per year in the central plateau) and the north-west is semi-arid (380 mm of precipitation per year). Three main climatic regions are found: the southern equatorial region, which extends from 2°N to nearly as far as latitude 6°N; the Sudanese region, wet and tropical, extending from 7°N to a little beyond 10°N; the sudano-sahelian region (10 - 13) °N, dry and tropical [10].



(a) (b)
Figure 1– Cameroon map (a) outlining Far-North Region (b)

The mean outdoor temperatures vary between 25°C in the south, 21.1°C in the central plateau and 32.2°C in the north. Two climatic regions are concerned by the Harmattan wind; a cold-dry wind blowing from November to January: the Sudanese and the Sudano-Sahelian regions. The called wind dries skin, splits and wounds lips and feet, the atmosphere is foggy reducing solar radiation, low temperatures occur [10]. The study was conducted in the Far North region of Cameroon (Fig. 1). The sites chosen took into account the relief (because of some specific microclimates related to landform). We opted for mountain and plain sites. The mountainous site is made up of the following localities: Mokolo (10.7425° N, 13.8042° E), Roua (10° 47' 18" N, 14° 01' 05" E), Hina (10°22'7" N, 13°51'21"), Bourrha (10.3396° N, 13.5625° E), Mogode (10.6070° N, 13.5697° E), and Mozogo (10.9624° N, 13.9042° E). The plain sites are the localities of : Koza (10.8683° N, 13.8825° E), Minawao Refugees Camp (10.5514° N, 13.8646° E), and Maroua (10.5925° N, 14.3210° E). At each site we studied three types of public buildings: administrative offices (public administration), primary and secondary schools (schools), and hotels. The study was conducted from December 26, 2019 to March 02, 2020 during working hours (10 am-2pm).

3. Methodology

The research is based on the adaptive approach which consists of two approaches:

- The objective method, which consists of taking in-situ measurements using technical instruments (measurements of ambient temperature, relative humidity, air speed, brightness, etc.) in the various buildings ;
- The subjective method, which consists of conducting quantitative or qualitative sociological surveys by questionnaire on the thermal comfort of the occupants. A questionnaire was therefore developed and administrated to the occupants in parallel with the in-situ measurements.

3.1. The Objective Method

It is based on the measurement of objective variables (ambient air temperature inside and outside, relative humidity inside and outside, air speed) according to the standard ISO 7730. We used two environmental multimeters (Digital Multimeter PM 8229 and Velleman DEM900) (figure 2).

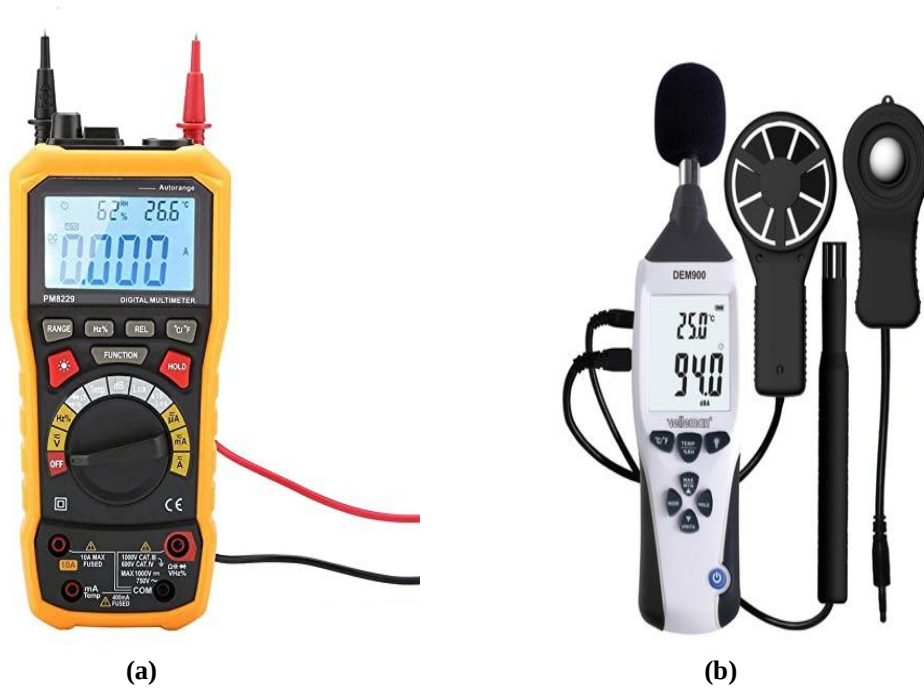


Figure 2– Materials used during in-situ measurements : (a) Digital Multimeter PM 8229, (b) Velleman DEM900

The values collected allowed to calculate PMV (Predicated Mean Vote) and PPD (Predicated Percentage of Dissatisfied) of Fanger based on the following formulas and equations:

$$M = 0.303 \exp(0.036M) + 0.028 \exp(0.028M) + W + 3.05 \times 10^{-8} \{733 + 6.99M + W\} + P_v + 0.42 \times 10^{-5} M + 58.15 \times 1.7 \times 10^{-5} M + 5867 + P_v + 0.0014M + 34 + T_a + 3.96 \times 10^{-8} f_{cl} \quad (1)$$

With:

M = activity + metabolic rate (W / m²),

W = external work (W),

I_{cl} = thermal resistance of clothes,

T_{cl} = fraction covered by clothes,

T_a = air temperature (°C),

T_r = average radiant temperature (°C),

P_v = partial pressure of water vapor (Pa),

h_c = convective heat transfer coefficient (W / m².K),

V_a = air speed (m / s).

$$T_{cl} = 35.7 - 0.028 (M - W) - \{3.96 \times 10^{-8} \times f_{cl} [(T_{cl} + 273)^4 - (T_r + 273)^4] + f_{cl} h_c [T_{cl} - t_a]\} \quad (2)$$

$$h_c = \max(2.38(T_{cl} - t_a)^{0.25}, 12.1\sqrt{V_a}) \quad (3)$$

$$T_{cl} \begin{cases} 1.00 + 1.290I_{cl} & \text{if } I_{cl} < 0,078 \\ 1.05 + 0.645I_{cl} & \text{if } I_{cl} > 0,078 \end{cases} \quad (4)$$

$$P_v = \frac{HR}{100} \exp \left(23.3265 - \frac{3802.7}{T_a + 278.18} - \frac{472.68}{T_a + 278.18} \right)^2 \quad (5)$$

$$PPD = 100 - 95 \exp (-0.03353PMV^4 - 0.2179PMV^2) \quad (6)$$

In the current study, we used $M = 70 \text{ W / m}^2$ (person sitting in mental work), $I_{cl} = 1 \text{ clo}$ (clothing for the cold period) and $W = 0$.

Regarding the radiant temperature (T_r), we used the Nagano formula :

$$T_r = 0.99T_a - 0.01 \quad (7)$$

and the operative temperature

$$T_{op} = aT_a + (1 - a)T_r \quad (8)$$

with $a=0.5$ if $V_a \leq 0.2$ $a=0.6$ si $0.2 \leq V_a \leq 0.6$ $a=0.7$ if $0.6 \leq V_a \leq 1$

3.2. The subjective method

We established 143 questionnaires for the mountain sites and 112 for the plain sites, which makes a total of 255 questionnaires, all of "longitudinal" type. The questionnaire consisted of six sections, three of which related to thermal comfort: general personal information (age, sex, activity, clothing); Site (mountain, plain); Thermal comfort of the space (thermal sensation, thermal preference).

4. Results and discussions

4.1 Indoor environmental parameters

Table 1 and 2 presents respectively the data recorded during in-situ measurements, and the PMV and PPD indexes calculated according to the Fanger model. One could see that the maximum operating temperature (T_{op}) is 37°C , recorded in Public Administration buildings in the Mountainous area (Bourrha) and the minimum operating temperature (T_{op}) is 23.1°C recorded in the plain area (Hotel Sahel of Maroua). Maximum relative humidity (H_r) is 34% and minimum is 5%. The maximum speed is 0.09 m/s recorded in the plain area (Minawao Refugee Camp) and the minimum is 0.01m/s. These values of indoor air velocity are within those recommended by the ASHRAE that it should not be greater than 0.15 m/s. From the relative humidity values, one could remark that the weather is very dry. The values of the relative humidity are far from those prescribed by the ASHRAE guidelines which recommend a relative humidity (RH) of 30 to 60 percent. This could explain the following phenomena encountered on the area : dry skins (particularly lips), eye irritation, static electricity in air, and some respiratory diseases. Table 2 shows that whatever the type of relief, the feeling of discomfort is felt by the occupants.

4.2 Actual Mean Vote (AMV).

Table 3 presents the Actual Mean Votes recorded during the measurement campaign. It could be seen that for the public administration, the AMV were $\bar{x} 0.84$ and $\bar{x} 1.27$ respectively for the mountain and plain areas while for the Schools, the AMV were $\bar{x} 1.22$ and $\bar{x} 0.82$ respectively for the mountain and plain areas. In the hotels, these values were $\bar{x} 0.95$ and $\bar{x} 0.40$ respectively for the mountain and plain areas. For the public administration, the Actual Percentage of Dissatisfied (APD) were 19.9 % and 38.73 % respectively for the mountain and plain areas while for the Schools, the APD were 36.23 % and 19.18 % respectively for the mountain and plain areas. In the hotels, these values were 24.06 % and 8.33 % respectively for the mountain and plain areas. These results confirm the overall tendency "cold" felt by the occupants during the harmattan season.

Table 1- Average values of measured data

Site	Type of Building	T _{in} (°C)	Tr (°C)	Air speed (m /s)	T _{op} (°C)
Mountainous area	Public administration	max : 37.2	max : 36.8	0.03	max : 37.0
		min : 27.3	min : 27.0	0.03	min : 27.0
		mean : 32.0	mean : 31.6	0.03	mean : 31.8
	Schools	max : 35	max : 34.6	0.02	max : 34.8
		min : 31.2	min : 30.8	0.01	min : 31.0
		mean : 33.5	mean : 33.1	0.015	mean : 33.3
	Hotel	max : 30.9	max : 30.6	0.03	max : 30.7
		min : 29.7	min : 29.4	0.03	min : 29.7
		mean : 30.4	mean : 30.0	0.03	mean : 30.2
Plain area	Public administration	max : 28.4	max : 28.1	0.03	max : 28.2
		min : 23.1	min : 22.8	0.03	min : 22.9
		mean : 24.5	mean : 24.2	0.03	mean : 24.3
	Schools	max : 27.9	max : 27.6	0.09	max : 27.7
		min : 26.5	min : 26.2	0.03	min : 26.3
		mean : 27.2	mean : 26.9	0.03	mean : 27.05
	Hotel	max : 23.6	max : 23.3	0.02	max : 23.4
		min : 23.3	min : 23.05	0.02	min : 23.1
		mean : 23.4	mean : 23.1	0.02	mean : 23.2

In-situ measurement period: December 26, 2019 - March 02, 2020, Schedule: 10 am-2pm (work hours)

Table 2- Fanger PMV and PPD calculation table

Site	Type of Building	T _{in} (°C)	Tr (°C)	Air velocity (m/s)	T _{op} (°C)	Calculated PMV	Calculated PPD (%)	Observations
Mountainous area	Public administration	max : 37.2	max : 36.8	0.03	max : 37.0	max : 5.91	max : 100	Discomfort
		min : 27.3	min : 27.0	0.03	min : 27.0	min : 4.00	min : 99	
		mean : 32.0	mean : 31.6	0.03	mean : 31.8	mean : 4.88	mean : 100	
	Schools	max : 35	max : 34.6	0.02	max : 34.8	max : 5.46	max : 100	Discomfort
		min : 31.2	min : 30.8	0.01	min : 31.0	min : 4.77	min : 100	
		mean : 33.5	mean : 33.1	0.015	mean : 33.3	mean : 5.15	mean : 100	
	Hotel	max : 30.9	max : 30.6	0.03	max : 30.7	max : 4.75	max : 100	Discomfort
		min : 29.7	min : 29.4	0.03	min : 29.7	min : 4.34	min : 100	
		mean : 30.4	mean : 30.0	0.03	mean : 30.2	mean : 4.43	mean : 100	
Plain area	Public administration	max : 28.4	max : 28.1	0.03	max : 28.2	max : 4.20	max : 99	Discomfort
		min : 23.1	min : 22.8	0.03	min : 22.9	min : 3.35	min : 99	
		mean : 24.5	mean : 24.2	0.03	mean : 24.3	mean : 3.59	mean : 99	
	Schools	max : 27.9	max : 27.6	0.09	max : 27.7	max : 4.55	max : 100	Discomfort
		min : 26.5	min : 26.2	0.03	min : 26.3	min : 3.60	min : 99	
		mean : 27.2	mean : 26.9	0.03	mean : 27.05	mean : 3.54	mean : 99	
	Hotel	max : 23.6	max : 23.3	0.02	max : 23.4	max : 2.60	max : 95	Discomfort
		min : 23.3	min : 23.05	0.02	min : 23.1	min : 2.57	min : 94	
		mean : 23.4	mean : 23.1	0.02	mean : 23.2	mean : 2.59	mean : 95	

In-situ measurement period: December 26, 2019 - March 02, 2020, Schedule: 10 am-2pm (work hours)

Table 3- AMV calculation table (Actual Mean Vote) = measured PMV***I- Mountainous area***

Public administration	ASHRAE Scale Point	-3	-2	-1	0	1	2	3
	Respondents	6	14	30	5	12	0	2
	Total number of respondents	69						
	AMV	-0.84						
	APD(%)	19.9						
School	ASHRAE Scale Point	-3	-2	-1	0	1	2	3
	Respondents	20	6	14	0	13	0	2
	Total number of respondents	55						
	AMV	-1.22						
	APD(%)	36.23						
Hotel	ASHRAE Scale Point	-3	-2	-1	0	1	2	3
	Respondents	1	3	13	0	1	0	1
	Total number of respondents	19						
	AMV	-0.95						
	APD(%)	24.06						

In-situ measurement period: December 26, 2019 - March 02, 2020, Schedule: 10 am-2pm (work hours)

II-Plain area

Public administration	ASHRAE Scale Point	-3	-2	-1	0	1	2	3
	Respondents	5	10	4	1	6	0	0
	Total number of respondents	26						
	AMV	-1.27						
	APD(%)	38.73						
Schools	ASHRAE Scale Point	-3	-2	-1	0	1	2	3
	Respondents	8	13	20	15	7	0	3
	Total number of respondents	66						
	AMV	-0.82						
	APD(%)	19.18						
Hotel	ASHRAE Scale Point	-3	-2	-1	0	1	2	3
	Respondents	0	1	13	1	4	0	1
	Total number of respondents	20						
	AMV	-0.40						
	APD(%)	8.33						

In-situ measurement period: December 26, 2019 - March 02, 2020, Schedule: 10 am-2pm (work hours)

4.3. Thermal satisfaction

The data collected permitted to assess the thermal satisfaction of the occupants according to the type of landform.

♦ In the mountain area

In mountain areas, the percentage of thermal satisfaction was 68.11 % in public administration buildings, while in educational institutions, the votes indicated a satisfaction percentage of 49.08 %. Occupants of hotels votes indicated a satisfaction percentage of 73.66 %.

♦ In the plain area

In plain areas, the percentage of thermal satisfaction was 42.29 % in public administration buildings, while in educational institutions, the vote indicates a satisfaction percentage of 63.62%. Occupants of hotels votes indicated a satisfaction percentage of 90 %.

One could therefore remark that for the two cases, the hotels are areas where we have the highest percentage of satisfaction. This could be justified by the fact that more passive techniques might have been taken into account in these cases. In fact, these areas were the most frequented tourist areas in North-Cameroon before the advent of Boko Haram terrorists and the COVID-19 health crisis. Architectural techniques were automatically integrated into most hotel establishments.

4.4 Thermal acceptability

The data collected permitted to assess the thermal satisfaction of the occupants. Results are presented in figure 3.

♦ In the mountain area

In mountain areas (Fig 3-a), the percentage of thermal acceptability was 47.8 % in public administration buildings, while in educational institutions, the vote indicates an acceptability percentage of 36.3 %. Occupants of hotels votes indicates an acceptability percentage of 78.9 %.

♦ In the plain area

In plain areas (Fig 3-b), the percentage of thermal acceptability was 57.6 % in public administration buildings, while in educational institutions, the vote indicates an acceptability percentage of 60.6 %. Occupants of hotels votes indicates an acceptability percentage of 42.2 %.

The above results shows that no type of building satisfies the conditions of ASHRAE 55-81 which stipulates that the acceptance rate for thermal comfort must exceed 80%, hence no building is considered thermally "acceptable".

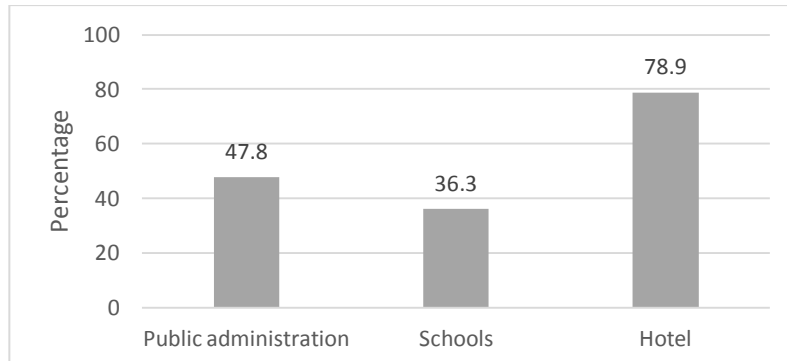


Figure 3a- Thermal acceptability (Mountainous area)

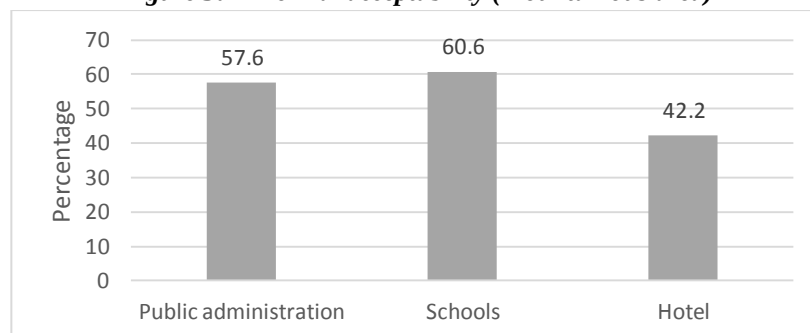


Figure 3b- Thermal acceptability (Plain area)

4.5. Thermal preference

Thermal preference was assessed directly from the questionnaire using the McIntyre's scale of thermal preference through the question "At the present time, would you prefer warmer (+1), no change (0) or cooler (-1) environment ?" Various distributions of respondents' votes are presented in figure 4.

In mountain areas (Fig. 4-a) and in the plains (Fig. 4-b), the general tendency of the occupants' preferential judgments is for "neutral" (neither hot nor cold). This is to say that the majority aspire for optimal thermal comfort.

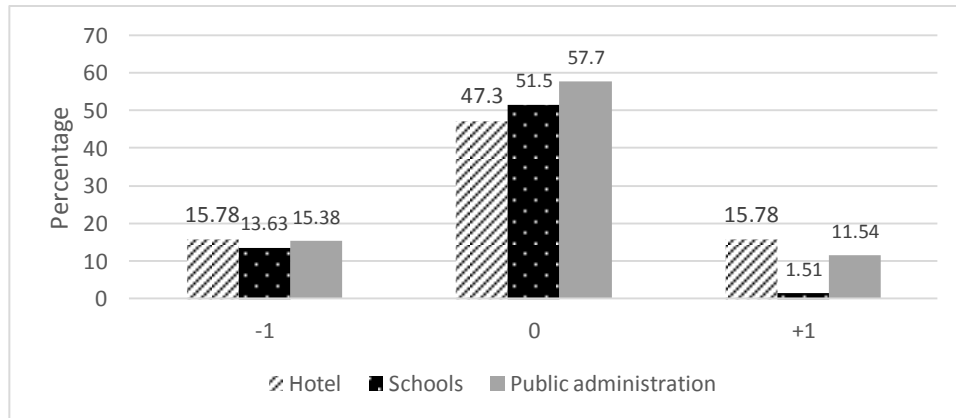


Figure 4-a : Thermal Preference - McIntyre Scale (Mountainous area)

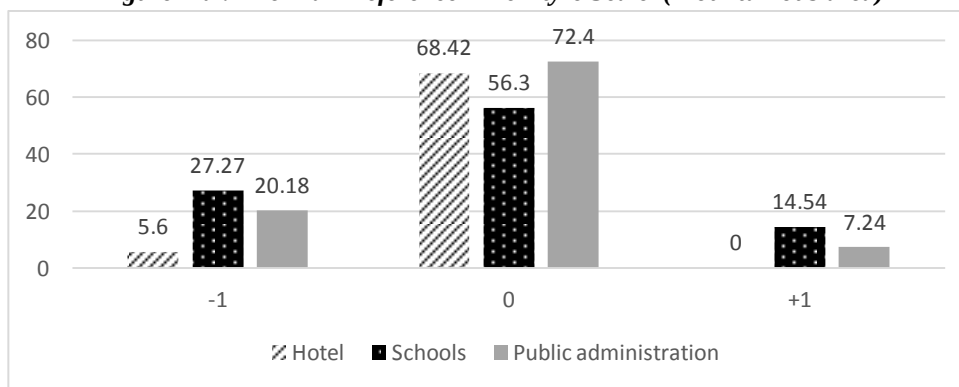


Figure 4-b : Thermal Preference - McIntyre Scale (Plain area)

4.6. PMV and thermal operative temperature

Figure 5 expresses the relationship between the PMV and the operative temperature. Fig 5-a (mountain area) and Fig 5-b (plain), give us the following linear regression:

♦ *Mountainous area*

$$PMV = 0.196T_{op} - 1.387 ; R^2 = 0.979 \quad (9)$$

$$\text{For a } PMV=0, \text{ we have : } T_{op \text{ neutral}} = 7.07 \text{ } ^\circ\text{C} \quad (10)$$

♦ *Plain area*

$$PMV = 0.33T_{op} - 5.028 ; R^2 = 0.74 \quad (11)$$

$$\text{For a } PMV=0, \text{ we have : } T_{op \text{ neutral}} = 14.83 \text{ } ^\circ\text{C} \quad (12)$$

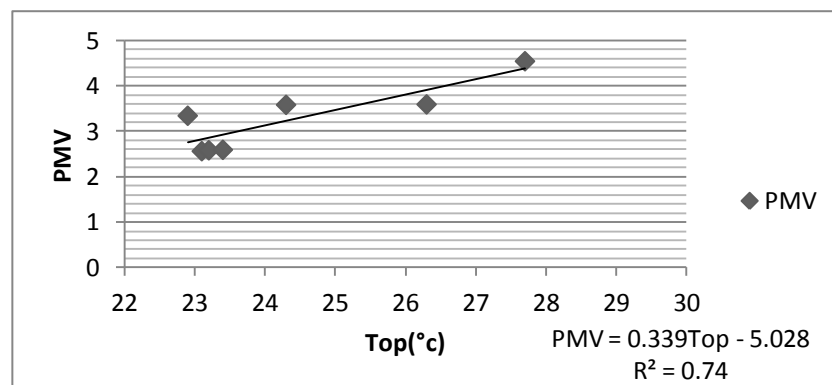


Figure 5-a : Neutral temperature (Mountainous area)

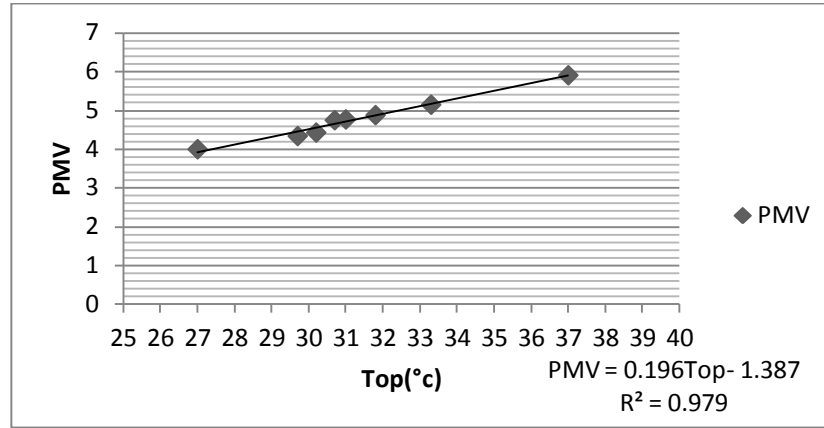


Figure 5-b : Neutral temperature (Plain area)

We can note that the PMV of Fanger does not give the correct ideal temperature, it underestimates the neutral temperature.

4.7. AMV and Neutral Operative Temperature

Figure 6 presents the relationship between the AMV and the operative temperature. Fig 6.a (mountain area) and Fig 6.b (plain) give us the following linear regression equations.

- Mountain area

$$AMV = -0.085Top + 1.708 ; R^2 = 0.458 \quad (13)$$

$$\text{For } AMV=0, \text{ we get : } Top_{neutral} = 20.09 \text{ } ^\circ\text{C} \quad (14)$$

- Plain area

$$AMV = -0.148Top + 3.097 ; R^2 = 0.811 \quad (15)$$

$$\text{For } AMV=0, \text{ we get : } Top_{neutral} = 20.92 \text{ } ^\circ\text{C} \quad (16)$$

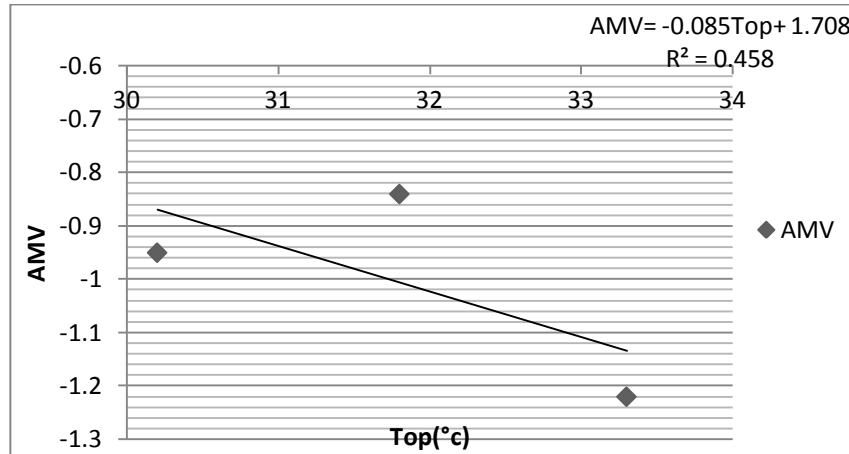


Figure 6-a : Neutral temperature (Mountainous area)

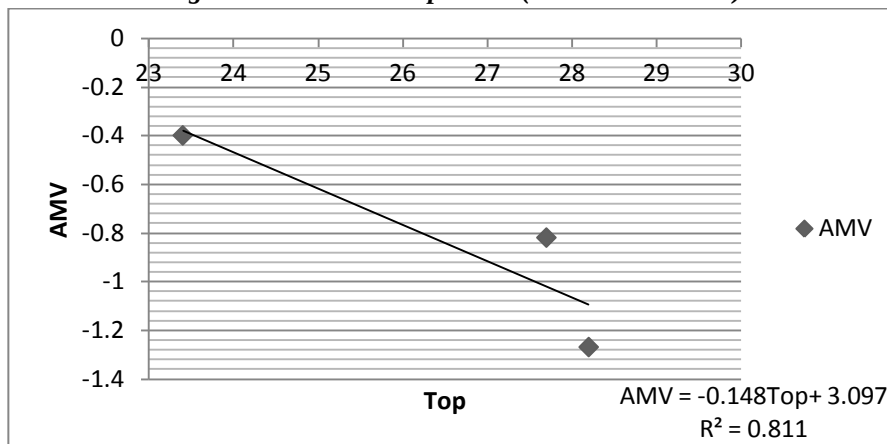


Figure 6-b : Neutral temperature (Plain area)

4.7.1 Comparison of neutral temperature to the predictions of international standards

✓ Standards ISO 7730

According to the ISO Standards 7730, for a class A comfort (high comfort class), the PPD in built environments should be less than 6 % and the ambient temperature must be between 21 °C and 23 °C in winter. From the above results, our various neutral temperatures obtained are not in line with this standard. This could be justified by the fact that even the climate is cold during the harmattan season it is better compared to the winter.

✓ Guidelines for internal climate conditions in winter (Christophe Zurcher-Thomas Franck)

According to the guidelines for internal climate conditions in winter, for offices, the temperature must be between 19 °C and 21 °C while for classrooms, the temperature must be between 19 °C and 21 °C. For hotel, the temperature must be between 19 °C and 21 °C. From the above results, one could see that our results meet these requirements.

4.8. PMV and relative humidity

Figure 7 presents the relationship between the PMV and the relative humidity. Fig 7-a (mountain area) and Fig 7-b (plain), give us the following linear regression equations:

♦ Mountainous area

$$PMV = -0.067 HR + 5.864 ; R^2 = 0.468 \quad (17)$$

$$\text{For } PMV=0, \text{ we get : } HR_{\text{neutral}} = 87.52\% \quad (18)$$

♦ Plain area

$$PMV = -0.119 HR + 7.371 ; R^2 = 0.489 \quad (19)$$

$$\text{For } PMV=0, \text{ we have : } HR_{\text{neutral}} = 61.94\% \quad (20)$$

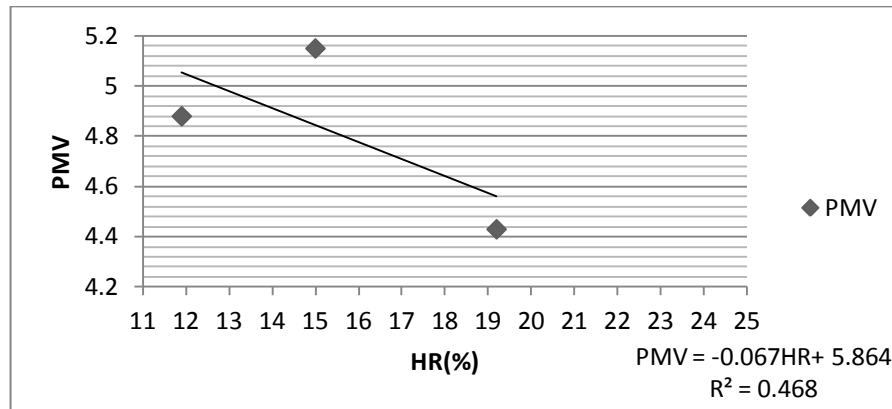


Figure 7-a : Neutral relative humidity(Mountainous area)

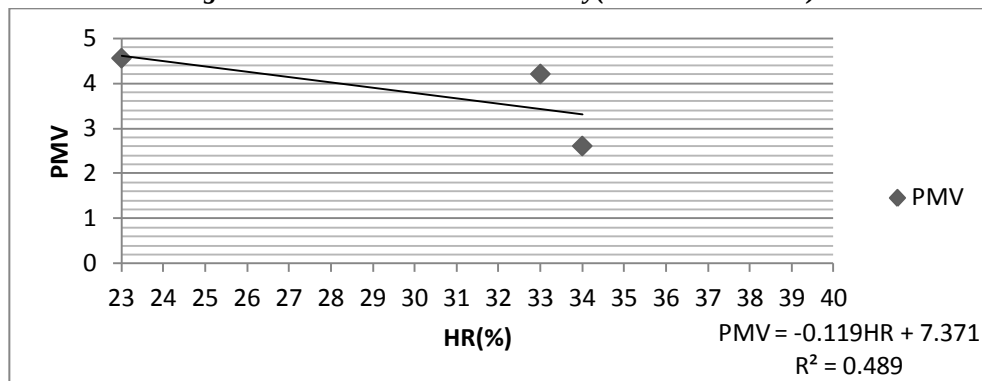


Figure 7-b : Neutral relative humidity(Plain area)

4.9. AMV and relative humidity

Figure 8 presents the relationship between the AMV and the relative humidity. Fig 8-a (mountain area) and Fig 8-b (plain), give us the following linear regression equations:

♦ Mountainous area

$$PMV = 0.108 HR - 3.278 ; R^2 = 0.92 \quad (21)$$

$$\text{For } AMV=0, \text{ we have : } HR_{\text{neutral}} = 30.35\% \quad (22)$$

♦ Plain area

$$PMV = 0.035 HR - 1.821 ; R^2 = 0.184 \quad (23)$$

$$\text{For } AMV=0, \text{ we have : } HR_{\text{neutral}} = 52.02\% \quad (24)$$

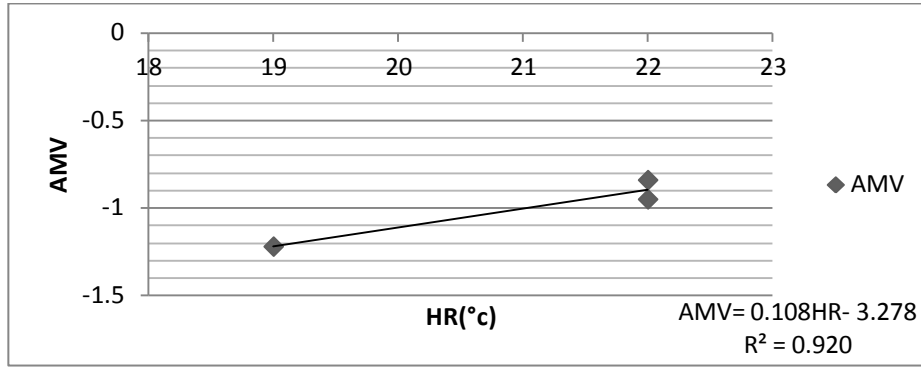


Figure 8-a :Neutral relative humidity(Mountainous area)

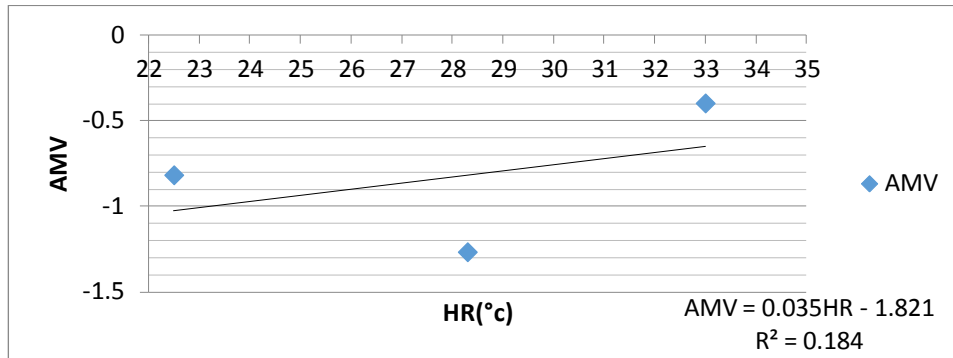


Figure 8-b :Neutral relative humidity(Plain area)

One could see that the neutral relative humidity of the mountain area with regard to public administrations, educational institutions and hotels, is not in adequacy with the directives for the internal climatic conditions (Christophe Zurcher-Thomas Franck) who recommend a relative humidity between 40 and 60% for offices and living rooms (Hotel), 45 and 55 % for Schools. While in the plain, it is in the above-mentioned intervals.

4.10. AMV and PMV

Figure 9 presents the relationship between de AMV and the PMV. Fig 9-a (mountain area) and Fig 10-b (plain), give us the following linear regression equations:

♦ Mountain area

$$PMV = -1.078AMV + 3.737 ; R^2 = 0.336 \quad (25)$$

$$\text{For } AMV=0, \text{ we have : } PMV=3.737 \quad (26)$$

♦ Plain area

$$PMV = -1.113AMV + 2.473 ; R^2 = 0.434 \quad (27)$$

$$\text{For } AMV=0, \text{ we have : } PMV=2.473 \quad (28)$$

In the mountains, we note that the PMV overestimates the thermal sensation in the case of our study, because for an AMV = 0 (neutral), the PMV = 3.737 (extremely hot). In the plain, we note that the PMV overestimates the thermal sensation in the case of our study, because for an AMV = 0 (neutral), the PMV = 2.473 (hot).

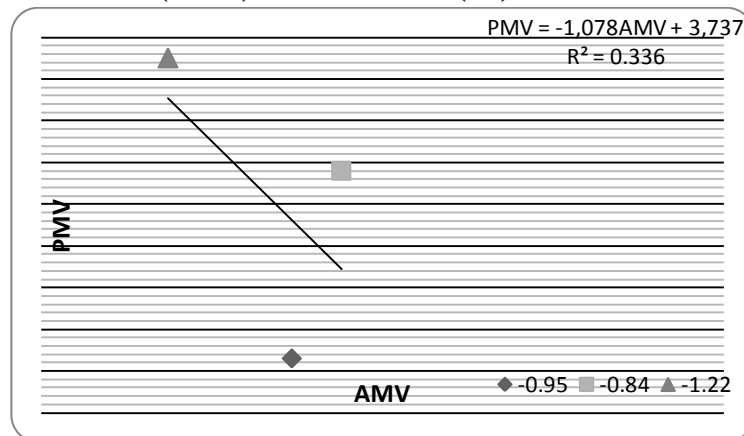


Fig 9-a: PMV-AMV (mountain area)

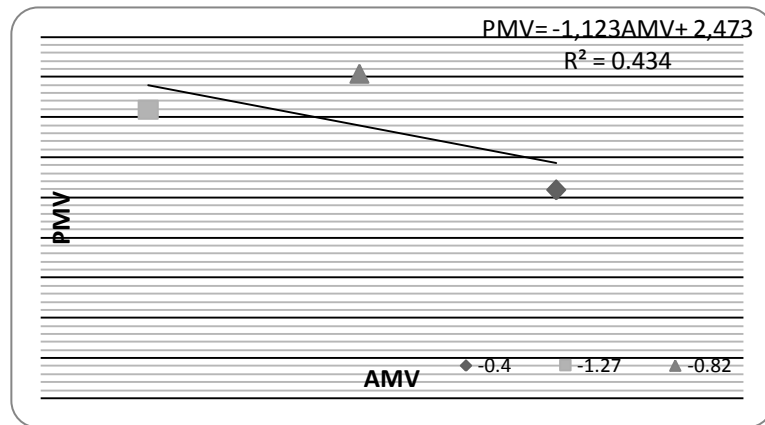


Fig 9-b: PMV-AMV (plain area)

4.11 Comfort zone

To obtain a thermal comfort situation, it is recommended that the PPD should be less than 5 %, which corresponds to a PMV between -0.5 and +0.5.

♦ Mountain area

$$AMV = -0.085Top + 1.708 ; R^2 = 0.458 \quad (29)$$

$$\text{For } AMV = -0.5, \text{ we have : } Top_1 = 22.45^\circ\text{C} \quad (30)$$

$$\text{For } AMV = 0.5, \text{ we have : } Top_2 = 14.20^\circ\text{C} \quad (31)$$

The operative temperatures of the comfort zone in the mountain zone are between 14.20 °C and 22.45 °C.

♦ Plain area

$$AMV = -0.148Top + 3.097 ; R^2 = 0.811 \quad (32)$$

$$\text{For } AMV = -0.5, \text{ we have : } Top_1 = 24.3^\circ\text{C} \quad (33)$$

$$\text{For } AMV = 0.5, \text{ we have : } Top_2 = 17.5^\circ\text{C}.$$

The operating temperatures of the comfort zone in the plain zone are between 17.5 °C and 24.3 °C.

5. Conclusion

The objective of this paper was to study thermal comfort in public buildings in the Sudano-Sahelian zone of Cameroon. In-situ data were taken during the harmattan season and the results based on the Actual Mean Vote showed that the neutral operative temperature varies between 20.09 °C and 20.92 °C while the neutral relative humidity was between 30.35 % and 61.94 % respectively for the mountain and plain areas. The operative temperatures of the comfort zone in the mountain area are between 14.20 °C and 22.45 °C while those of the plain area are between 17.5 °C and 24.3 °C. It was also observed that the thermal sensation is in the cold zone (slightly cold, cold and very cold) and that the PMV overestimates the thermal sensation. The occupants preferred the "neutral" thermal sensation (neither hot nor cold). The occupants have testified to "thermal unacceptable" especially for public administrations and schools. This is to say that the majority aspire for optimal thermal comfort.

6. Declaration of competing interest

The authors declare that there is no conflict of interest in regard with this work.

7. REFERENCES

- [1]- Benharkat S., Djamilia RS. Approche adaptative du confort thermique dans les espaces d'enseignement universitaire à Constantine (Algerie). Sciences fondamentales et Engineering N°14/Janvier 2016. Pages 19 à 28.
- [2]- Djongyang N., Tchinda R., Njomo D. Thermal comfort: a review paper. Renewable and Sustainable Energy Reviews 14 (2010a): 2626-2640.
- [3]- Roumaissa A., Noureddine Z, Djamilia D., Moussadek B. Etude expérimentale du comportement thermique des établissements scolaires dans les regions chaudes et arides. Courrier du Savoir-N°26, Mars 2018, pp259-268.
- [4]- Jannot Y., Djiako T. Economie d'énergie et confort thermique dans l'habitat en zone tropicale. Rev.Int.Froid 1994 Volume 17 Numéro 3.
- [5]- Bouthaina B. Evaluation du confort thermique et son impact sur l'habitat collectif. Mémoire de fin d'études, Université El Arabi Ben ,2016.
- [6]- Ioannou A., Itard L.. In-situ and real time measurements of thermal comfort and its determinants in thirty residential dwellings in the Netherlands. Energy and Buildings 139 (2017) 487-505.

- [7]- Castaño-Rosa R., Rodríguez-Jiménez CE., Rubio-Bellido C.R. Adaptive thermal Comfort Potential in Mediterranean Office Buildings: A case Study of Torre Sevilla. Sustainability 2018,10,3091.
- [8]- Rijal H.B. et al.: Adaptive model and the adaptive mechanisms for thermal comfort in Japanese dwellings. Energy and Buildings (2019).
- [9]- Kemajou A., Mba L.. Matériaux de construction et confort thermique en zone chaude ; Applications au cas des régions climatiques camerounaises. Revue Energies Renouvelables Vol.14 N°2 (2011) 239-248
- [10]- Djongyang N., René Tchinda. An investigation into thermal comfort and residential thermal environment in an intertropical sub-saharan Africa region : Field study report during the Harmattan season in Cameroon. Energy Conversion and Management 51(2010b)1391-1397.
- [11]- ASHRAE, American Society of Heating Refrigerating and Air-conditioning Engineers, éd 2009.
- [12]- Fergus J., Susan R. Rethinking thermal comfort. Building Research and Information, 45 :7,711-716.
- [13]- Berghout B., Forgues D., Monfet D. Simulation du confort thermique intérieur pour l'orientation d'un bâtiment collectif à Biskra, Algérie. Ecole de Technologie Supérieure, Montréal, Québec.
- [14]- Burrati C., Riccardi P. Adaptive analysis of thermal comfort in university classrooms :correlation between experimental data and mathematical models. Build environ 2009 ;44 :674-84.
- [15]- Corgnati SP, Ansaldi R, Filippi M. Thermal comfort in Italian classrooms under free running conditions during mid-seasons :assessment through objective and subjective approaches .Building and Environment 2009 ;44 :785-92.
- [16]- Heschong L. Architecture et volupté thermique. Parentheses. Marseille: p.93
- [17]- Hwang RL, Lin TP ,Cheng MJ, Chien JH. Patient thermal comfort requirement for hospital environments in Taiwan. Building and Environment 2001 ;36 :711-20.
- [18]- Izard. Architecture d'été construite pour le confort d'été. Aix-en-Provence : Edisud, 141 p .1034-1049.
- [19]- Martin O. L'analyse quantitative des données. 4^e édition. Erman Colin.
- [20]- Mokhtari AM, Brahimi K., Benziada R. Architecture et confort thermique dans les zones arides –Application au cas de la ville de Béchar. Revue Energies Renouvelables Vol.11 N°2 (2008) 307-315.
- [21]- Pigg S., Eilers M., Reed J . Behavioral aspects of lighting and occupancy sensors in private offices ;a case study of a university office building. ACEEE Summer Study on Energy Efficiency in Buildings.p 8161-8171.