Health Environ, 2024, 5(1): 237-245
DOI: 10.25082/HE.2024.01.001

RESEARCH ARTICLE

Study of thermal comfort in some standard school buildings: A case of Madagascar island

Sinta Rivel[1,2] **Modeste Kameni Nematchoua**[1,3,4,*] **Raminosoa Jean Chrysostome**[1] **Rafefimanana Sambilason Richard**[1]

[1] Higher Polytechnic School, University of Antsiranana, Antsiranana, Madagascar
[2] Department of Civil Engineering, Higher Institute of Technology Antsiranana, Antsiranana, Madagascar
[3] Laboratory of Energy and Environment, Faculty of Sciences, University of Yaounde 1, Yaounde, Cameroun
[4] School of Informatics, Computing and Cyber Systems, Northern Arizona University, United States

Correspondence to: Modeste Kameni Nematchoua, Higher Polytechnic School, University of Antsiranana, Antsiranana, Madagascar;
E-mail: kameni.modeste@yahoo.fr

Received: April 25, 2024;
Accepted: July 6, 2024;
Published: July 11, 2024.

Citation: Rivel S, Nematchoua MK, Chrysostome RJ, et al. Study of thermal comfort in some standard school buildings: A case of Madagascar island. *Health Environ*, 2024, **5**(1): 237-245.
https://doi.org/10.25082/HE.2024.01.001

Abstract: This study focuses on thermal comfort in some classroom school buildings of the Malagasy Ministry of National Education, located in the city of Diego-Suarez, characterized by a warm tropical climate throughout the year. This study was carried out in December 2023, then between January and February 2024. The analysis is based on the adaptive approach, using questionnaires and taking measurements of thermal parameters via weather sensor. During study hours from 7:30 a.m. to 11:30 a.m. in the morning and 2:30 p.m. to 5:30 p.m. in the afternoon, the questionnaires are completed at the same time as in-situ measurements are taken. In total, 223 questionnaires were completed by the occupants including (students and teachers), distributed in four classrooms of two different primary schools. The results reveal that the percentage of thermal acceptance inside the old school reaches 35%, compared to only 15% for the modern school. The majority of respondents believe that the air flow speed is more favorable in the old building, with a perception of comfort at 60%, compared to 40% for the modern building.

Keywords: school buildings, thermal comfort, tropical climate, natural ventilation, adaptive approach

1 Introduction

The learning environment plays a crucial role in academic success, where comfort in the classroom is a key factor directly impacting students' well-being and academic performance [1]. According to Hasina et al. [2], "Improving thermal comfort in buildings is of increasing importance, both from an environmental point of view and from the quality of life of occupants." To ensure student comfort, several factors must be taken into account [3]. Nematchoua et al. [3] emphasizes that by understanding the complex interactions between the building envelope, the heating and cooling systems, as well as the occupants' preferences, we will be able to identify the most suitable solutions to guarantee optimal thermal comfort. "Classrooms, where students spend a large part of their day, require conditions favorable to learning [4]. Physical comfort, influenced by factors such as temperature, ventilation, lighting and acoustics, can significantly affect students' ability to concentrate and absorb information [5]. Guermia and Fatiha [6] note that by considering parameters such as the size of the windows, the type of glazing and the associated solar protection, it becomes possible to create classrooms offering optimal thermal comfort. Temperature and relative humidity are two important parameters allowing to improve classroom comfort [7]. Extreme temperatures can reduce students'cognitive performance, while poor air quality can lead to drowsiness and reduced alertness [3]. Nematchoua et al. [8] highlight the need to assess energy consumption and carbon emissions in different building types to understand their impact on thermal comfort. In addition, Nematchoua et al. [9] analyzed experimental and subjective data in 67 traditional habitats and 25 schools in Madagascar, revealing that traditional buildings offer better comfort with a comfort temperature ranging from 24.6 to 28.4°C. Afren et al. [10] evaluated the thermal comfort of school buildings in an Algerian city, concluding dissatisfaction due to an architectural design unsuitable for local climatic conditions. Marzita et al. [11] explored the impact of urban development on the thermal comfort of classrooms in Malaysia, highlighting students' high awareness of thermal comfort. Johnson and Fitzgerald [12] highlighted the importance of a positive emotional climate for learning, demonstrating that supportive emotional environments boost student safety and motivation.The objective of this study is to evaluate thermal comfort in two configurations of school buildings of the Malagasy Ministry of National Education using the completion of questionnaires by students and teachers and in-situ measurements using weather sensor giving air temperature, ambient temperature, relative humidity and wind direction. Solutions will be proposed to achieve comfort conditions in a tropical country like Madagascar. To better dissect this article, we will adopt the following plan: Presentation of the case studies, working methodology, results and discussions and finally the conclusion.

2 Methods

2.1 The climatic characteristics of the city of Antsiranana

Antsiranana city is located at Cape Amber (Tendron'iBobaomby) in the northern part of Madagascar island . To the west there is the Mozambique Channel and to the East the Indian Ocean. Its area extends over 47 km2. The city has a tropical climate with two seasons: a rainy season between December and March, with the presence of monsoon, and a dry season which lasts eight months, from April to November, with the varatraza (strong wind speed up to 22 m/s from east to north west). Generally, it is hot all year round, although temperatures drop slightly from June to September. The coordinates of the Antsiranana city are latitude: 12°16'S; longitude: 49°17'E; altitude: 43.0m . Each year, Relative humidity ranges from 54% to 85.5%.

2.1.1 Wind

According to the building standard resistant to natural hazards in Madagascar Updated in April 2022 by the Prevention and Emergency Management Unit (CPGU) attached to the Prime Minister of Madagascar, the wind map is divided into 5 zones. The wind speed values are 32 km/h for normal winds and 170 km/h for cyclonic winds. In the town of Diego-Suarez the wind blows constantly from South-West to North-East.

2.1.2 Rainfall

Throughout the Malagasy territory, the rainfalls with particular abundance from November to March. Indeed, the yearly precipitation is between 339 and 394 mm according to the rainfall map. Figure 1 shows the record precipitation from 2018 to 2022.

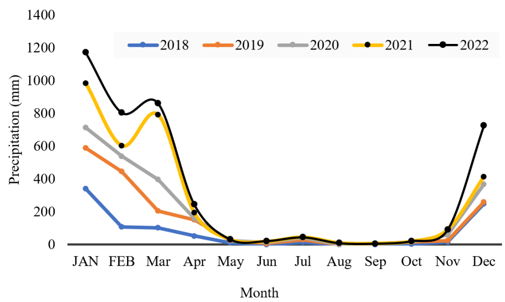


Figure 1 Variation of precipitation in Antsiranana city between 2018 and 2022

2.1.3 Temperature

In general, the air temperature is warm all year . The average temperature is 26°C for a maximum average temperature of 28°C with a maximum of 34°C in December and a minimum average temperature of 19°C in July. Figure 2 shows a variation of air temperature between 2018 and 2022.

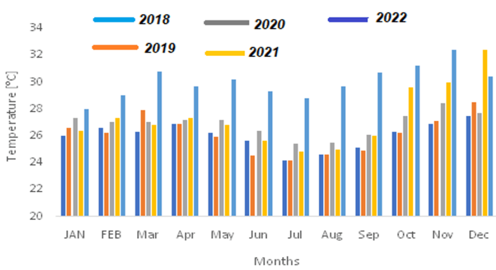


Figure 2 Air temperature from 2018 to 2022

2.1.4 Sunshine

The average sunshine varied between 6 and 10h/day, from January to December, as shown in Table 1.

Table 1 Average sunshine in Antsiranana in 2020

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Sunshine (h/j)	6.0	6.0	6.9	8.5	9.0	8.5	8.7	9.0	9.8	9.9	8.6	7.4

2.2 School plans

Nowadays, the Malagasy Ministry of National Education (MEN) has two standard plans for school buildings with two types of classrooms. (Table 2)

Table 2 Characteristics both plans (traditional and modern)

Plans	Traditional plan(PAEB)	Modern plan (ESM 02 class)
Directions	North, South,	North, South,
Distribution	02 classroom	02 Classroom with bathroom
Built surface	112.00 m^2	121.20 m^2
Dimension	$16.80\times7.40\times2.65$ m^3	$19.50\times7.48\times3.30$ m^3
Ceiling height	Sloped ceiling, minimum 2.65 m; maximum 5.00 m	3.30 m
Opening surface	18.18 m^2	16.12 m^2
Ventilation	5% of total surface area	5% of total surface area
opening type	Metal, french style	Aluminum/door french style; sliding windows
Colors	Base: dark gray; elevation: stone	Interior: white; exterior: white, purple, fuchsia
Student population	115	108
Roofing	Gabled sheet metal roof	Roof terrace inaccessible except maintenance
Wall	Concrete block 23 cm	Concrete block 23 cm
False ceiling	Pine batten ceiling	

(1) The old standard plan developed from 2014 to 2017 called PAEB standard plan or even standard plan for the Basic Education Support Project. (Figure 3)

Figure 3 Case of traditional plan PAEB, a) outside, b) inside.

(2) The new standard plan applied since 2019 known as ESM 02 Classroom or even Manarapenitra School 02 classroom. (Figure 4)

Figure 4 Case of modern plan (ESM 02 Classroom

2.3 Campaign and measurement

The study of thermal comfort in buildings, and in particular in educational establishments, is essential to guarantee an environment conducive to learning and the well-being of occupants. The methodology employed in such studies must be both rigorous and multidimensional to capture the various facets of thermal comfort. A well-designed methodology helps collect accurate data and provide evidence-based recommendations for improving the thermal conditions of school buildings.

The main objective of this methodology is to determine the current thermal conditions of classrooms and to identify the factors influencing the comfort of students and educational staff. This includes assessing temperatures, relative humidity, air quality, and occupants' subjective perception of their thermal environment and proposing solutions in the event of discomfort. To complete this study, we will develop the adaptive approach which is based on two main concepts: the completion of questionnaires by occupants and taking in-situ measurements through the use of weather sensors.

2.3.1 Campaign

The questionnaires aim to collect subjective data on thermal comfort as perceived directly from the occupants of school buildings, namely students and teaching staff. This data makes it possible to understandusers' perceptions and feelings regarding thermal comfort. A total of 223 questionnaires were completed by the occupants dispatched to the Public primary schools of study in the Antsiranana I . Data was collected from 7:30 a.m. to 11:30 a.m. in the morning, and, from 2:30 p.m. to 5:30 p.m. in the afternoon and spanned the hottest months of the year (January, February and December). The languages used for the questionnaires are French and Malagasy, everyone was free to choose their preference. In addition, anonymity is respected. The questionnaire includes: personal data (age and gender), thermal parameters (external and internal environment, air movement), activities related to metabolism, clothing, parameters related to construction (orientation, materials used, openings, ventilation) and above all their sensation in relation to comfort as well as the solutions proposed. Before proceeding with filling, the latter was carefully explained to the operators. The height of the occupants varies from 1.40 m to 1.85 m and their weight is around 35 kg to 90 kg.

2.3.2 Measurement

In-situ measurements are taken at the same time as users fill out the questionnaires. The approach aims to obtain objective data on the thermal conditions of classrooms using weather sensors. These measurements provide precise information on temperature, relative humidity, and wind speed direction which are essential for assessing thermal comfort. The sensor used in this study has the following characteristics: transmission range 80m, frequency 433.92 Mhz, Outdoor temperature range: -20°C to 60°C (±1°C), Indoor temperature range: 0 at 50°C (±1°C), Humidity range: 20 to 95% RH (±5%). Figure 5 shows the measurement device.

Figure 5 Wireless weather sensor

In both cases of buildings, the interior measurement points were in the middle of the classrooms at 1 m of height. The measurement campaigns took place during the hottest months of the year (January, February, and December). We start taking the shots in the morning from 7:30 a.m. to 11:30 a.m. and in the afternoon from 2:30 p.m. to 5:30 p.m. in accordance with the study hours allocated by the supervisory Ministry in the city of Antsiranana.

3 Results and discussion

3.1 Analysis of questionnaires

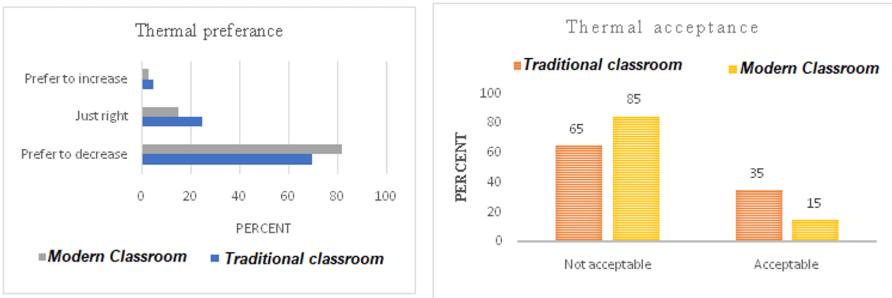
In total, 223 questionnaires were collected and analyzed. Before proposing an adaptive approach, it was crucial to understand voters' reactions to their environment. To this end, the following paragraph analyzes statistics relating to occupants and personal thermal variables.

In this study, the age of voters ranged from 6 to 13 years for primary school students and from 20 to 58 years for members of the teaching staff (Table 3). Given the youth of the students and to guarantee the reliability of the data, 20 civil engineering students were mobilized to facilitate the completion of the questionnaires.

Table 3 Characteristics of responders)

Plan Configuration	Age			Size (cm)			Student Population			Weight [kg]		
	Min	Med	Max	Min	Med	Max	Man	Woman	Total	Min	Med	Max
Standard Plan PAEB	6	10	58	100	110	170	63	52	115	20	25	70
Standard Plan ESM 02 Classroom	7	12	56	110	120	175	59	49	108	18	24	86

We note that the participants of the PAEB standard plan are generally younger, smaller in height and lighter in weight than those of the ESM 02 Salles plan. These participant demographic and physical data are important for analyzing the impact of individual characteristics on thermal comfort in this study. (Figure 6)



a) b)

Figure 6 Occupant vote, thermal preference (left) and thermal acceptance (right)

We see from the occupants' votes that 70% want to reduce the ambient temperature inside the classrooms (PAEB standard plan) compared to 82% for the ESM 02 room standard plan. Less than 25% of voters find that they do not need to increase or decrease temperatures. Since Madagascar is a tropical country and the hot climate dominates Diego throughout the year, only 5% feel the need to increase the temperature. Thus, a tiny portion of students and teaching staff find that the thermal conditions are acceptable (35% for the old standard plan compared to 15% for the new standard plan). (Figure 7)

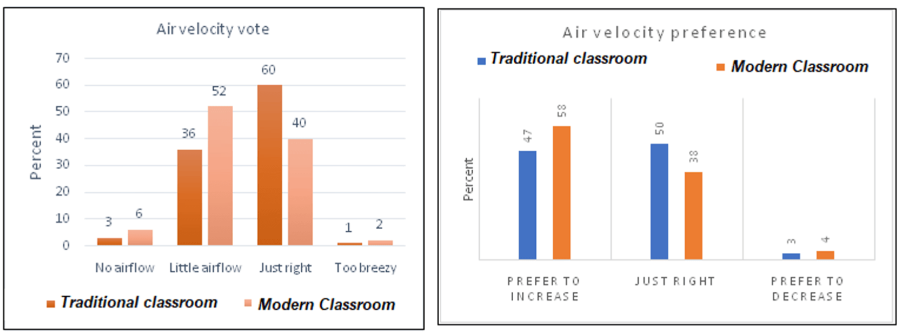


Figure 7 Velocity vote (left) et air velocity preference (right)

Taking into account the topography of the land, the masking effects, the direction of the prevailing wind for the city of Diego which is from East-West, the orientation of the two school buildings as well as the percentages of openings and ventilation, force It is noted that the majority of voters judge that the percentage of air flow speed is 60% for the PAEB type plan compared to 40% for the ESM 02 room plan. Less than 2% of occupants feel that there is too much air, given the year-round hot climates in the city of Antsiranana. More than 58% wanted to increase the air speed for the ESM type plan given the sliding windows used which halves the percentages of the structure during its opening.

3.2 Analysis results from weather sensors

To carry out the series of measurements, only natural cooling systems were used and the campaigns were staggered by 1 hour and in accordance with the study hours which extended from 7:30 a.m. to 11:30 a.m. in the morning and 2:30 p.m. to 5:30 p.m. the afternoon. (Figure 8)

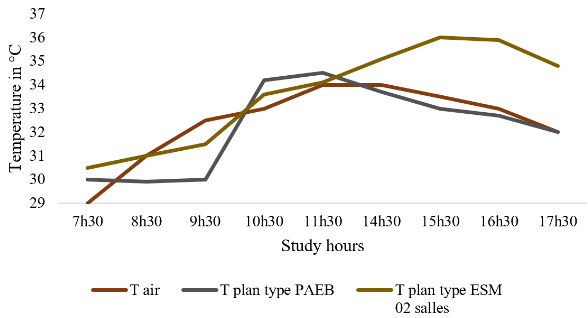


Figure 8 Comparison between outside and ambient temperature

As the climate of the city of Diego is hot all year round and to take into account the most unfavourable cases, we took the maximum hourly temperature values of the hottest months (December, January and February) for the last 23 years, from 2000 to 2023, in accordance with meteorological data . Thus, comparisons were made of outdoor air temperatures(T-air), and ambient temperatures inside(T) the two classroom configurations of the supervisory Ministry. We observe that :

(i)The results found by Roumaissa et al. [13], which stipulate that the interior temperature of the rooms is higher than the exterior temperature before the room is occupied because the door was closed throughout the night, which causes the heat accumulation inside the room was checked. Endeed, During the day, the classroom absorbs heat from the sun through the walls, roof, and windows. Even after the sun sets, these surfaces continue to radiate the absorbed heat. If the room is closed all night, heat cannot escape effectively, leading to heat buildup inside. This phenomenon is known as the internal greenhouse effect.

(ii)At the end of the morning, the interior ambient temperatures of the classrooms are higher than the exterior temperature, taking into account that at midday the daily temperature of Antsiranana city is maximum and above all the occupancy densities per room are quite high (0.96 people /m2 for the modern school compared to 1.02 people/m2 for the old school) added to metabolic activities and clothing pressure.

(iii)Throughout the afternoon, indoor temperatures are lower than outdoor temperatures, which is normal since the climate is becoming cooler; Except for the case of the modern plan whose interior atmosphere is quite warm, taking into account the choice of sliding window because when opening, it reduces the opening percentage by generating a loss of 7.50 m^2 i.e equivalent of loss of 31% of the opening surface, which explains the discomfort of users, especially during the afternoon.

Regarding relative humidity data, we have the minimum and maximum values in each day of year. So, to calculate the hourly humidity values in accordance with school opening hours (7:30 a.m. to 11:30 a.m. in the morning and 2:30 p.m. to 5:30 p.m. in the afternoon), we will use the PERRIN DE BRICHAMBAUT equation to find the missing values:

$$\mathrm{T_{ae}} = \frac{\mathrm{T_{max}} + \mathrm{T_{min}}}{2} + \frac{\mathrm{T_{max}} - \mathrm{T_{min}}}{2} \cos\frac{2\pi}{\mathrm{T_0}} (\mathrm{t} - \mathrm{t_{max}}) \tag{1}$$

$$\mathrm{H_{rae}} = \frac{\mathrm{H_{rmax}} + \mathrm{H_{rmin}}}{2} + \frac{\mathrm{H_{rmax}} - \mathrm{H_{rmin}}}{2} \cos\frac{2\pi}{\mathrm{T_0}} (\mathrm{t} - \varnothing) \tag{2}$$

Where, $\mathrm{T_{min}}, \mathrm{T_{max}}$: maximum and minimum ambient air temperatures in °C;
$\mathrm{H_{rmin}}, \mathrm{H_{rmax}}$: maximum and minimum relative humidity of ambient air in %;
t: time elapsed from mid night in hours;
$\mathrm{T_0}$ = 24 h: ambient period of ambient air temperature oscillations;
$\mathrm{T_{max}}$ = 14 h: for Madagascar;
$\varnothing = \frac{2\pi \mathrm{t_{max}}}{\mathrm{T_0}} + \pi$

After obtaining the hourly temperatures, we take the average of all the values corresponding to the hot months . Figure 9 shows the variation of indoor and outdoor relative humidity.

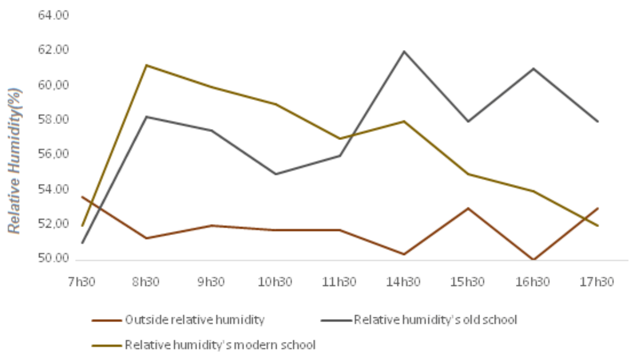


Figure 9 Comparison between outside and interior's relative humidity (in %)

The result shown in Figure 9 confirm the research results obtained by Roumaissa et al. [13] who explained that the exterior humidity values are reduced compared to the interior humidity values. Thus we have an average difference in relative humidity between exterior and interior of 6.44%.

3.3 Analysis of construction costs

Taking into account the parameters linked to inflation experienced by the Antsiranana city, Table 4 shows the construction estimate for the two standard study plan configurations.

Table 4 Estimate's old and modern primary school

Estimation	Amount (€)	
	Old school	Modern School
Preliminary Activity	1,219.38	1,219.38
Earthworks	120.81	184.91
Infrastructure Work	4621.53	4,410.95
Superstructure Work	8,099.62	3,566.11
Mansory and Facelift	6,193.32	7,675.30
Framework – Roofing – Celling - Waterprofing	5,225.53	16,057.56
Joinery	1,800.17	5,496.29
Sanitation	110.60	289.24
Paintings	3,004.19	2,858.78
Total Amount [Ttc]	32,826.76	45,099.20
Price Per M2	293.10	372.11

It is noticed that the old configuration is more comfortable and more affordable compared to the modern plan.

4 Conclusion

This study on thermal comfort in two-classroom school buildings, located in the Antsiranana city , highlights the challenges posed by the hot tropical climate prevailing all year round. Air temperatures range from 23 to 34°C, with an average of 28.5°C, and relative humidity ranges from 43% to 85.5%. December is the hottest month of the year, while July records the lowest temperatures.The occupants' votes show that in hot periods, 70% of users of PAEB type rooms want a reduction in the interior temperature, compared to 82% for those in modern buildings. This reflects significant dissatisfaction with the indoor thermal environment of both configurations. Measurements of thermal parameters taken inside the two types of rooms, using weather sensors, reveal that ambient temperatures during school opening hours are higher than those of the outside air. This phenomenon is attributed to the closing of rooms outside of class hours, which leads to a build-up of heat.

Overall, both building configurations are not comfortable during the hottest times of the year. However, the typical PAEB plan offers some comfort during the months of June, July and August, unlike the modern plan, which is not comfortable at any time of the year, not even during the coolest month, July.The study highlights the importance of rethinking the design of school buildings in regions with a tropical climate, by integrating techniques that make it possible to better manage thermal variations and improve occupant comfort. Adopting bioclimatic design strategies, such as improving natural ventilation, optimizing building orientation and using suitable building materials, could significantly improve thermal comfort in schools.

Abbreviations

PAEB:	Basic Education Support
ESM:	ManarapenitraSchool
MEN:	Ministry of National Education
DIANA:	Diego, Ambilobe, Nosybe et Ambanja
EPP:	Public PrimarySchool
CISCO:	School District
DREN:	Regional Direction of National Education
ASHRAE:	American Society of Heating, Refrigerating and Air Condition Engineers
PVC:	Polyvinil Chloride
CPGU:	Prevention and Emergency Management Unit

Acknowledgements

The authors are grateful to the voters who agreed to participate in this study during the investigation of different classrooms.

Conflicts of interest

The authors declare that they have no conflict of interest.

References

[1] Nematchoua MK, Ricciardi P, Buratti C. Statistical analysis of indoor parameters an subjective responses of building occupants in a hot region of Indian ocean, a case of Madagascar island. Applied Energy. 2017, 208: 1562-1575.
https://doi.org/10.1016/j.apenergy.2017.08.207

[2] Ratrimoarisonina HA, Ramaleoharinjato J, Randriamalala TR, et al. Contribution a la mise en place d'un systeme de gestion de base de donnees de lateritede la region analamanga madagascar, 2019.
https://hal.science/hal-02278369

[3] Nematchoua MK, Orosa JA, Buratti C, et al. Comparative analysis of bioclimatic zones, energy consumption, CO2 emission and life cycle cost of residential and commercial buildings located in a tropical region: A case study of the big island of Madagascar. Energy. 2020, 202: 117754.
https://doi.org/10.1016/j.energy.2020.117754

[4] Nematchoua MK, Orosa JA, Reiter S. Climate change: Variabilities, vulnerabilities and adaptation analysis-A case of seven cities located in seven countries of Central Africa. Urban Climate. 2019, 29: 100486.
https://doi.org/10.1016/j.uclim.2019.100486

[5] Kameni Nematchoua M, Tchinda R, Ricciardi P. Thermal comfort and air movement preference in some classrooms in Cameroun. Journal of Renewable Energies. 2023, 17(2).
https://doi.org/10.54966/jreen.v17i2.441

[6] Bouchahm G, Bourebia F. L'impact de l'orientation des parois transparentes sur le confort thermique dans une salle de classe à Constantine. Sciences & Technologie. D, Sciences de la terre. 2010, 71-80.

[7] Kameni Nematchoua M, Vanona JC, Orosa JA. Energy Efficiency and Thermal Performance of Office Buildings Integrated with Passive Strategies in Coastal Regions of Humid and Hot Tropical Climates in Madagascar. Applied Sciences. 2020, 10(7): 2438.
https://doi.org/10.3390/app10072438

[8] Nematchoua MK, Orosa JA, Ricciardi P, et al. Transition to Zero Energy and Low Carbon Emission in Residential Buildings Located in Tropical and Temperate Climates. Energies. 2021, 14(14): 4253.
https://doi.org/10.3390/en14144253

[9] Nematchoua MK, Ricciardi P, Buratti C. Adaptive approach of thermal comfort and correlation between experimental data and mathematical model in some schools and traditional buildings of Madagascar under natural ventilation. Sustainable Cities and Society. 2018, 41: 666-678.
https://doi.org/10.1016/j.scs.2017.11.029

[10] Afren R, Benabbas M, Zemmouri N, et al. Impact of the typology of school buildings on the internal thermal conditions, in a hot and dry climate. Energy Procedia. 2017, 122: 505-510.
https://doi.org/10.1016/j.egypro.2017.07.305

[11] Puteh M, Adnan M, Ibrahim MH, et al. An Analysis of Comfortable Teaching and Learning Environment: Community Response to Climate Change in School. Procedia - Social and Behavioral Sciences. 2014, 116: 285-290.
https://doi.org/10.1016/j.sbspro.2014.01.209

[12] Johnson KEVIN, Fitzgerald CARL. A study of the emotional climate in the classroom. The New Hampshire Journal of Education. 2013, 16.

[13] Afren R, Zemmouri N, Djaghrouri D, et al. Experimental study of the thermal behavior of school building in hot and arid regions. 2018, 1-12.