

Thermal Comfort and Educational Infrastructure Planning in Extreme-Heat Areas: Assessing Needs and Equipment Costs in Universities of Northern Cameroon

Raphaël Landry Abessolo Ondigui

Department of Educational Administration, The University of Garoua, North, Cameroon

Email: [rabessolo2\[at\]gmail.com](mailto:rabessolo2[at]gmail.com)

ORCID <https://orcid.org/0009-0004-1407-9490>

Abstract: *This study examined university users' perceptions of thermal comfort, determined the association between measured indoor temperature and perceived thermal discomfort, and estimated equipment needs and costs in universities of Northern Cameroon, where temperatures reach 45 °C in the shade. A quantitative approach with an analytical cross-sectional survey design was adopted, complemented by in situ temperature measurements, documentary analysis of equipment costs and interviews with administrators. Data were collected from 240 students and teachers in 12 rooms. The findings showed that 80.0 % of respondents perceived the thermal conditions as uncomfortable or very uncomfortable, with an overall mean of 3.15 (SD = 0.85). Indoor temperature was positively and moderately associated with perceived discomfort ($r = .31, p < .001$). Regression analysis further showed a significant positive association ($B = .070, p < .001$), although indoor temperature explained only 9.5 % of the variance in perceived discomfort ($R^2 = .095$). The study concludes that thermal discomfort is widespread and that indoor temperature is a significant but insufficient determinant of it. Integrating thermal comfort standards, prioritising low-cost passive measures and using cost per seat as a decision criterion are recommended for educational planning in extreme-heat areas.*

Keywords: thermal comfort, educational planning, extreme heat, equipment costs, university

1. Introduction

Educational planning has increasingly shifted from counting seats, teachers and budgets to examining the conditions under which teaching and learning actually take place. This shift has made the quality of the physical learning environment increasingly important because the provision of buildings alone does not guarantee that they can be used effectively. [1] [2] Among these conditions, thermal comfort has received little attention as a planning criterion, yet in areas where temperatures reach 45 °C in the shade, poorly ventilated and overcrowded lecture halls physically constrain teaching and learning [3] [4]. Rather than relying on occasional emergency measures such as adjusting timetables, such contexts require systematic diagnosis and investment planning.

Equipment such as fans, shading structures or air conditioning can improve conditions, but equipment does not automatically equal comfort. [2] show that student's comfort responses often differ from standard models, while the adaptive tradition highlights the role of expectations and context [5]. Orientation, occupancy density and energy supply determine real effectiveness. This is central because administrators influence classroom climate through budgets and equipment choices, and cost analysis [6] must be linked to user perceptions to avoid allocating scarce resources to poorly adapted options.

This issue is critical in sub-Saharan Africa, where enrolment growth puts pressure on infrastructure [7] [8] and where many institutions operate in hot climates with limited access to mechanical cooling is limited [9]. In Cameroon, higher-education infrastructure planning is governed by Law No. 005

April 2001 on the Orientation of Higher Education, which assigns the mission to organize and supervise higher education, and is operationalized by the National Development Strategy SND30 2020-2030 and the New University Governance Policy (2009) under the LMD/BMD reform [10]. The creation of the University of Garoua by Decree No. 2022/003 of 5 January 2022 is part of this university decentralization policy. In Northern Cameroon, temperatures reach 45 °C in the shade [11] [12], which makes thermal conditions in lecture rooms a concrete planning concern for universities such as the University of Garoua.

However, evidence from universities in extreme-heat areas of sub-Saharan Africa remains limited in the sources reviewed for this study. A systematic literature search conducted in June 2025 in Scopus, Web of Science, ERIC and Google Scholar using the keywords “thermal comfort” AND “higher education” AND “Africa” AND “heat” returned only 7 peer-reviewed studies on university lecture rooms in extreme-heat contexts, of which none focus on Northern Cameroon. Existing evidence provides important insights into the effects of heat on cognitive performance and into thermal comfort in educational buildings [3] [2], but considerably less is known about how university users in Northern Cameroon perceive thermal conditions, whether perceived discomfort is associated with measured indoor temperature, and what equipment would be needed at what cost. To address this gap, this study examines thermal comfort and equipment planning in universities of Northern Cameroon through three questions: (i) What are university users' perceptions of thermal comfort in lecture rooms? (ii) What is the association between measured indoor temperature and perceived thermal

discomfort? and (iii) What equipment is needed to improve thermal conditions, and at what cost per seat?

2. Literature Review

2.1 Thermal Conditions, Health and Learning

Research generally indicates that heat affects human performance and occupational health [13] and that classroom temperature is related to schoolwork performance [14] [15] reported that hotter school days reduce learning, with larger effects where cooling is less available. [3] found that young adults living in buildings without air conditioning performed worse on cognitive tests during a heat wave than those in air-conditioned buildings. Although these studies position thermal conditions as a significant condition for learning, they approach the issue differently: [4] use large administrative data on learning outcomes, whereas [3] examine cognitive function in a university-age population. Together, the evidence suggests that thermal conditions matter for educational outcomes, but the studies come from contexts whose climate, building stock and resources vary from those of Northern Cameroon.

2.2 Thermal Comfort in Educational Buildings

[2] reviewed thermal comfort research in educational buildings and highlighted that students' comfort responses often differ from those predicted by standard models, which supports adaptive approaches. Standards such as [16] provide reference ranges for occupied spaces, while the adaptive tradition emphasises that acceptable conditions depend on climate and opportunities for adaptation [5] [17]. This evidence implies that planners should not rely only on theoretical comfort ranges but should also consider users' own perceptions. However, most of the evidence reviewed concerns buildings in temperate or moderately hot climates, and it cannot establish how users perceive conditions when temperatures approach 45 °C.

2.3 Educational Planning, Equipment and Costs

Educational planning links needs diagnosis, standards and resource allocation [1]. In this tradition, cost analysis helps compare options by relating costs to the capacity or effects they provide [6]. Applying these principles to thermal infrastructure means comparing passive measures (shading, cross-ventilation, roof treatment), fans and mechanical cooling in terms of cost per seat covered and lifecycle costs, including energy and maintenance. Studies that integrate perceived comfort, measured conditions and equipment costs in a single planning analysis remain scarce in the databases searched (Scopus, Web of Science, ERIC and Google) as of June 2025, with only three studies combining all three dimensions in sub-Saharan higher education contexts [18] [19] [20]. Consequently, there is insufficient empirical evidence on whether university planners in extreme-heat areas can base equipment priorities on combined evidence of user perceptions, thermal measurements and costs. The present study addresses this gap by examining these three elements in universities of Northern Cameroon.

2.4 Conceptual Framework

Drawing on adaptive thermal comfort theory and the reviewed empirical literature, the study conceptualises the thermal environment and equipment level as conditions that shape perceived thermal comfort, which in turn is expected to be associated with educational outcomes such as attendance, concentration and teaching conditions. Planning decisions on equipment and investment feed back into the thermal environment. Measured indoor temperature, humidity and occupancy represent the physical conditions, while the perceived discomfort score represents users' experience.

2.5 Theoretical Framework

This study employed adaptive thermal comfort theory [5] [17], which posits that thermal comfort depends not only on the physical environment but also on occupants' expectations, behavioural adjustments (clothing, drinking, changing posture or schedules) and the context in which they operate. The theory assumes that people actively adapt to their thermal environment and that comfort preferences differ from those predicted by laboratory-based models [21].

The theory was selected because lecture rooms in the study area are mostly naturally ventilated or only partly equipped, and users routinely adapt to heat. Compared with Fanger's [22] heat-balance model, which predicts comfort from air temperature, radiant temperature, humidity, air speed, clothing and activity in controlled conditions, adaptive theory provides a more direct explanation of the mechanism examined in this study: perceived discomfort may be associated with measured temperature but is also shaped by context and adaptation opportunities. Nevertheless, the theory does not imply that adaptation removes the effects of heat; adaptive capacity has limits, and extreme conditions can exceed what behavioural adjustment can compensate [23]. The theory therefore provides an appropriate lens for examining both users' perceptions and the relationship between indoor temperature and perceived discomfort.

3. Methods/Approach

3.1 Research Design

The study employed an analytical cross-sectional survey design using a quantitative approach, complemented by in situ measurements, documentary analysis of costs and semi-structured interviews with administrators. The design was appropriate because data were collected from university users at a single point in time and allowed both a description of their perceptions of thermal comfort and an examination of the relationship between measured indoor temperature and perceived discomfort. The design was suitable for examining patterns and associations among variables without manipulating the study environment [24]. Because the data were cross-sectional, the observed relationships were interpreted as associations rather than causal effects.

3.2 Target Population

The target population comprised students and teachers of the University of Garoua (Faculty of Education and Faculty of

Arts, Letters, and Social Sciences) in Northern Cameroon (Garoua), in an area where temperatures reach 45 °C in the shade, together with university administrators responsible for infrastructure and budgeting. This population was appropriate because students and teachers are the direct users of lecture rooms, and administrators decide on equipment investments.

3.3 Sampling Technique and Sample Size

A stratified random sampling technique was used to select 12 rooms by room type (naturally ventilated and shaded, $n = 4$; partly equipped, $n = 4$; unequipped, $n = 4$) and 204 respondents (students $n = 204$; teachers $n = 36$). The sample size was determined to detect a small-to-medium correlation ($r = .20$, $\alpha = .05$, power = .80), which requires about 194 observations [25]; the achieved sample exceeded this requirement. Administrators ($n = 6$) were selected purposively for interviews. Generalisation is limited to the institutions represented in the sample.

3.4 Data Collection Method and Instrument

Data were collected through a structured questionnaire administered on paper during regular teaching periods. The questionnaire captured demographic characteristics, perceived thermal discomfort (items on a four-point scale: not uncomfortable to very uncomfortable), adaptation behaviours and equipment priorities. Air temperature and relative humidity were recorded in the same rooms and at the same hours (between 10:00 a.m. and 4:00 p.m.) with calibrated data loggers over 5 days, and occupancy was counted per session. Equipment costs were extracted from supplier quotations, invoices and maintenance records. Semi-structured interviews with administrators [26] [27] addressed budget constraints and equipment priorities and were analysed through thematic content analysis [28].

3.4 Measurement of the Main Variables

For the first objective, users' perceptions of thermal comfort were measured with the questionnaire item assessing the level of thermal discomfort experienced in the lecture room. For the second objective, thermal conditions were represented by the mean indoor air temperature (°C) recorded in each room during the survey period, and perceived discomfort by a composite score of 5 items. Higher scores represented stronger perceived discomfort. For the third objective, cost per seat covered was calculated as total equipment cost divided by the number of seats served, and lifecycle cost included acquisition, installation, energy and maintenance [6].

3.5 Validity and Reliability

The questionnaire was reviewed by three experts in educational planning, building physics and measurement to ensure that items aligned with thermal comfort dimensions, and it was pilot-tested with 20 respondents outside the sample. Before inferential analysis, the internal consistency of the perceived discomfort composite was assessed using Cronbach's alpha, with a coefficient of .70 or above considered acceptable [29]. Data loggers were calibrated against a reference thermometer before use.

3.6 Data Analysis

Quantitative data were analysed using IBM SPSS Statistics Version For the first objective, frequencies, percentages, means and standard deviations were used to describe perceptions. For the second objective, Pearson correlation analysis was used to establish the direction and strength of the relationship between indoor temperature and perceived discomfort, followed by simple linear regression to determine whether indoor temperature significantly predicted perceived discomfort; assumptions of normality, linearity and homoscedasticity were checked [30] [31]. For the third objective, descriptive cost indicators were computed and compared across equipment options. Statistical significance was determined at $p < .05$, while effect sizes and explained variance (R^2) were also reported to establish the practical importance of the relationships.

3.7 Ethical Considerations

Participation was voluntary, respondents were informed of the purpose of the study and gave informed consent, and personally identifiable information was excluded from the analytical dataset. Data were handled confidentially, stored securely and reported in aggregate form.

4. Results/ Discussion

4.1 Users' Perceptions of Thermal Comfort

The first objective examined users' perceptions of thermal comfort in lecture rooms. Responses were analysed using frequencies, percentages, means and standard deviations. The four response categories were ordered from the least to the strongest discomfort.

Table 1: Users' Perceptions of Thermal Comfort (N = 240)

Perceived thermal conditions	n	%
Not uncomfortable	12	5
Slightly uncomfortable	36	15
Uncomfortable	96	40
Very uncomfortable	96	40
Total	240	100
Mean (SD)	3.15 (0.85)	

The findings indicate strongly unfavourable perceptions of thermal conditions among university users. Overall, 80.0 % of respondents rated conditions as uncomfortable (40.0 %) or very uncomfortable (40.0 %) while only 5.0% rated them as not uncomfortable. The overall mean ($M = 3.15$, $SD = 0.85$) similarly shows a high level of perceived discomfort. This finding is consistent with Zomorodian [2], who noted that students' comfort responses in educational buildings often diverge from standard predictions, and with the concern raised by Park [4] and Cedeño [3] about the effects of heat where cooling is limited. Because the data are self-reported, the results indicate perceived conditions and should be read together with the measured indicators.

4.2 Thermal Conditions and Perceived Discomfort

The second objective was to examine the association between measured indoor temperature and perceived thermal discomfort. The analysis was conducted in three stages. First,

thermal indicators were examined descriptively (Table 2). Second, the internal consistency of the discomfort items was tested before constructing the composite score; the five items demonstrated acceptable reliability (Cronbach's $\alpha = .82$). Third, Pearson correlation and simple linear regression were conducted to determine the direction, strength and predictive relationship between indoor temperature and perceived discomfort.

Table 2: Measured Thermal Conditions and Perceived Discomfort

Indicator	N	Mean	SD
Indoor air temperature (°C)	240	36.4	2.8
Relative humidity (%)	240	28.6	7.4
Occupancy (persons per room)	240	118	41
Perceived discomfort (composite)	240	3.12	0.64

The results show high thermal loads in the surveyed rooms. Mean indoor temperature was 36.4°C (SD = 2.8), with 62.5% of observations above 35°C, the operational threshold adopted in this study. Mean relative humidity was 28.6% and mean occupancy 118 persons per room. The composite discomfort score (M = 3.12, SD = 0.64) places perceived discomfort at a high level. To establish whether indoor temperature was associated with perceived discomfort, the two variables were correlated, as shown in Table 3.

Table 3: Relationship between Indoor Temperature and Perceived Discomfort

Variables	N	r	p
Indoor temperature × Perceived discomfort	240	0.31	<.001

A statistically significant positive association was found between indoor temperature and perceived discomfort ($r = .31$, $p < .001$). This indicates that higher indoor temperatures were associated with greater perceived discomfort. The correlation was moderate by conventional benchmarks [25], indicating a meaningful but not dominant association. To determine the magnitude of this association further, a simple linear regression was conducted as presented in Table 4.

Table 4: Regression of Perceived Discomfort on Indoor Temperature

Predictor	B	SE	t	p
Constant	0.57	0.51	1.12	0.264
Indoor temperature	0.07	0.014	5	<.001

Model statistics: $R^2 = .095$; $F(1, 238) = 25.00$, $p < .001$.

The regression model was statistically significant and explained approximately 9.5 % of the variance in perceived discomfort ($R^2 = .095$). A one-degree increase in indoor temperature was associated with approximately a 0.07 -point increase in the discomfort score ($B = .070$, $p < .001$). Therefore, although indoor temperature was positively associated with perceived discomfort, its explanatory power was modest. The result suggests that temperature is one component of discomfort, while other conditions such as humidity, occupancy, air movement and individual adaptation may explain much of the remaining variation, which is consistent with adaptive thermal comfort theory [5]. The direction of the association is consistent with Wargocki [14] and Wargocki [15], who linked classroom temperature to children's school performance, and with the review by

Zomorodian [2], which highlights the role of context and adaptation in educational buildings.

4.3 Equipment Needs and Costs

The third objective estimated the cost of equipment options that could improve thermal conditions. Table 5 presents unit cost per room, seats covered per room, cost per seat and lifecycle cost over 10 years for each option, in Central African CFA francs (XAF).

Table 5: Equipment Options and Costs (XAF)

Option	Unit cost per room	Seats covered	Cost per seat	Lifecycle cost (10 years)
Shading structures	4,50,000	120	3,750	5,40,000
Natural ventilation / fans	3,60,000	120	3,000	7,20,000
Roof treatment	9,00,000	120	7,500	10,00,000
Air conditioning	24,00,000	120	20,000	68,00,000

The results show that natural ventilation with fans had the lowest cost per seat (3,000 XAF), followed by shading structures (3,750 XAF), while air conditioning had the highest cost per seat (20,000 XAF) and the highest lifecycle cost (6,800, 000 XAF per room) once energy and maintenance were included, about 9.4 times that of fans. Interviews with administrators revealed four recurring themes: (1) budget constraints limiting large-scale equipment purchase, (2) unreliable energy supply increasing operating costs for air conditioning, (3) limited maintenance capacity for mechanical systems, and (4) competing institutional priorities such as classroom expansion. These findings are consistent with the cost-based prioritisation advocated in educational planning [1] [6]: low-cost passive measures can be phased in first, while mechanical cooling would require a dedicated budget and secure energy supply. Overall, the findings indicate that thermal comfort in the surveyed university can be improved at limited cost per seat through passive measures and fans, and that air conditioning should be reserved for priority spaces.

5. Conclusion

The study concludes that university users in the study area largely perceive thermal conditions in lecture rooms as uncomfortable (80.0 %uncomfortable or very uncomfortable). Indoor temperature was significantly associated with perceived discomfort, but the relationship was moderate and explained 9.5% of the variation, which indicates that temperature is a significant factor among others in comfort. The cost analysis shows that natural ventilation with fans and shading offer the lowest cost per seat, while air conditioning has the highest cost per seat and lifecycle cost. This suggests that thermal comfort should be treated as a planning criterion for educational infrastructure and that investment decisions should combine user perceptions, measured conditions and cost per seat.

6. Future Perspectives

The study recommends that the Ministry of Higher Education, university management and other education authorities

should include thermal comfort criteria in building and room-allocation standards, prioritise low-cost passive measures (shading, cross-ventilation, roof treatment) and fans before costly mechanical cooling, and use cost per seat covered and lifecycle cost as procurement criteria. University planners should schedule classes in the best-conditioned rooms during the hottest hours, plan maintenance and energy supply together with equipment purchase, and set up a simple monitoring system with temperature thresholds. Given that indoor temperature explained only a small to moderate proportion of the variation in perceived discomfort, future studies should examine humidity, occupancy, air movement, adaptation behaviours and the effects of equipment on attendance and learning outcomes, ideally through longitudinal or quasi-experimental designs.

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Author Profile



Dr Raphaël Landry ABESSOLO ONDIGUI is an Assistant Lecturer in the Department of Educational Administration, Faculty of Education, The University of Garoua. He holds a Ph.D. in Educational Sciences, speciality: Educational Systems Planning, Master research in Educational Sciences, and Bachelor of Arts degree in Geography, option: Physical Geography, all obtained from the University of Yaounde I. Before joining the University of Garoua, Dr.

ABESSOLO ONDIGUI worked as a Part-time Lecturer in the Department of Educational Sciences at the Faculty of Arts, Letters and Social Sciences of the University of Bertoua. He has published 3 papers in peer-reviewed journals.