Standard for School Design in The Tropics: Compliance and Classroom Comfort

Olga Lucia Montoya[1*], Cesar Augusto Mejía[2]

[1*]Faculties of Architecture, San Buenaventura University, Cali, Colombia
[2]Art and Design; Human and Social Sciences, San Buenaventura University, Cali, Colombia

Corresponding author: olmontoy@usbcali.edu.co, camzulua@usbcali.edu.co*

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For the design of schools in Colombia, NTC 4595: Planning and Design of School Facilities and Environments, offers design recommendations to achieve comfortable spaces in terms of thermal, visual and auditory comfort. The aim of the contribution, derived from a PhD research, is to analyze the comfort in classrooms of public schools in Cali in terms of: a. climatic moments and b. level of compliance with the Technical Standard, in order to validate the relevance of the recommendations to the comfort perceived by students. The methodology used is the User Perception Environmental Audit, in four public schools, for which measurements of environmental parameters were made with specialized equipment and surveys of 535 students. Statistical processing was carried out using test for paired samples, and one-way ANOVA's. Among the main findings is the low use of external environmental conditions, derived from inflexible architectural envelopes; in addition to the low relationship between compliance with the standard and the comfort perceived by students. This demonstrates the need for further study of the normative ranges and recommendations for tropical contexts such as the one studied.

Keywords: Thermal, visual and auditory comfort, Colombian Technical Standard - NTC, compliance

1. INTRODUCTION

Integral comfort (hygro-thermal, visual and auditory) is one of the aspects that integrate the quality of a space, its study in classrooms, has been mainly given in countries with seasons, the closest to the present study are those developed in Chile during winter and summer (Trebilcock et al., 2012), in Argentina (San Juan et al., 1999), and few studies conducted in the equatorial tropic strip developed in Colombia (Iglesias García et al., 2016; Zapata Rueda et al., 2018; Montoya, 2019).

Several studies have shown the implications of envelope design on thermal comfort in classrooms. Subhashini & Thirumaran (2018) present an improvement in thermal performance, based on a higher degree of solar protection in the envelope. Teli et al. (2014) analyze the effect of the envelope (materiality, glazed surfaces and shading elements), the height of the space and climate control devices on students' perception of comfort. In terms of thermal sensation, Tablada et al. (2005) point out that studies conducted over the last three decades in naturally ventilated schools in hot climates show that the thermal sensation reported is warmer than that indicated in the standards (Liang et al., 2012).

In terms of visual comfort, analyses focused on demonstrating the relationship between visual comfort and energy consumption in subtropical classrooms (Ho et al., 2008) show that the correct selection of façade elements for light reflection improves lighting conditions inside classrooms, as well as energy savings in the case of the implementation of appropriate horizontal sunshades (Ho et al., 2008), which generate savings of 70% of the usual consumption. Monteoliva and Pattini (2013a) report savings between 50% and 80% through the use of natural lighting to achieve adequate illumination during the day, resulting in energy-efficient buildings (Filippín, 2005).

For the design of classrooms in the tropics, special considerations must be made regarding protection from solar radiation (James & Christian, 2012; Subhashini & Thirumaran, 2018), such as avoiding the uncontrolled entry of direct sunlight into the space, which has negative consequences such as unwanted brightness and high contrasts (Wu & Ng, 2003), as well as raising temperatures and producing visual discomfort (Villalba et al., 2011). In these cases, it is important to avoid annoying reflections and favor good color reproduction (Zapata Rueda et al., 2018) in order to perform visual tasks with the least effort, risk and damage to eyesight (Lamberts, Dutra, & Pereira, 2014). For this, ensuring adequate illuminance throughout the space is one of the fundamental aspects.

According to the Colombian Technical Standard NTC 4595 (Civil Engineering and Architecture. Planning and Design of School Facilities and Environments), is 300 lux for the 2000 version and the more demanding 500 lux indicated for the 2015 version, as in Argentina and the Netherlands, exceeding the threshold of countries with similar conditions such as Mexico (400 lux) and Brazil (200 lux) (Pattini, 2000). Illuminance levels below 300 lux reduce the perception of visual stimuli, affecting cognitive performance (Jago & Tanner, 1999).

As for auditory comfort, it manifests itself in the form of echoes and annoying noises, affecting the transmission of sound emitted by a specific source, in this case, the teacher or the students themselves (Pattini, 2000). To avoid these problems, a well-designed classroom takes into account acoustic parameters such as background noise and reverberation time (American National Standards Institute [ANSI]/ Acoustical Society of America [ASA], 2010), to facilitate listening for students (Kumar, 2009). Studies by Dockrell & Shield (2006) demonstrate the negative impacts of noise on school performance, especially on verbal tasks. Other tasks that were affected were those related to memory and reading in the presence of prolonged background noise (Ljung & Kjellberg, 2009). Aspects that influence the acoustic conditions in classrooms include the ability of materials to block sound; the degree of insulation and sealing; and reflections on opposing surfaces, which can generate resonances. The size of the space, the presence of furniture and the number of people should also be considered (Medina, 2009).

For designers of educational spaces, the Colombian Technical Standard 4595 determines design recommendations for comfortable classrooms in the following areas: thermal (13 recommendations), visual (25) and auditory (6), according to the type of climate. However, recent research (Arango-Díaz, Giraldo Vásquez, Cano Valencia, & Arenilla Cuervo, 2013; Gutierrez, 2009; Zapata Rueda et al., 2018), demonstrates the poor conditions that can occur in classrooms, despite following the recommendations of the standard. For this reason, studies such as the one presented here are relevant, in schools carried out under the NTC, through the Environmental Audit of User Perception (AAPU), to contribute to the knowledge of comfort and the applicability of the standard.

It is hypothesized that compliance with the Colombian Technical Standard-4595 in classrooms in Cali should promote adequate conditions of thermal, visual and auditory comfort, being a suitable instrument for designers of educational spaces.

The aim of this contribution is to analyze the comfort in classrooms of public schools in Cali in terms of: a. climatic moments and b. level of compliance with the Technical Standard, in order to validate the relevance of the recommendations in terms of the comfort perceived by students and from this knowledge, to provide recommendations.

2. METHODOLOGY

2.1. CASE STUDIES AND PARTICIPANTS

The study was carried out in Cali, the third capital city of Colombia, located at 3°25' north latitude, 76°30' west longitude, between 950 and 1100 m above sea level, in a tropical climate. As shown in Figure 1, the schools have the characteristic of being courtyard schools, with the classrooms in direct relation to the outside Figure 2.

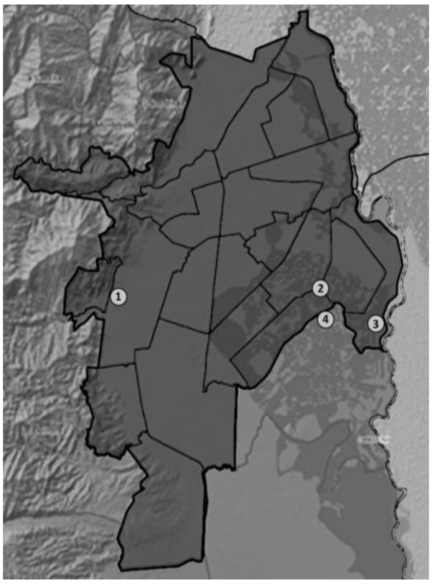

Figure 1: typology of schools and classrooms studied

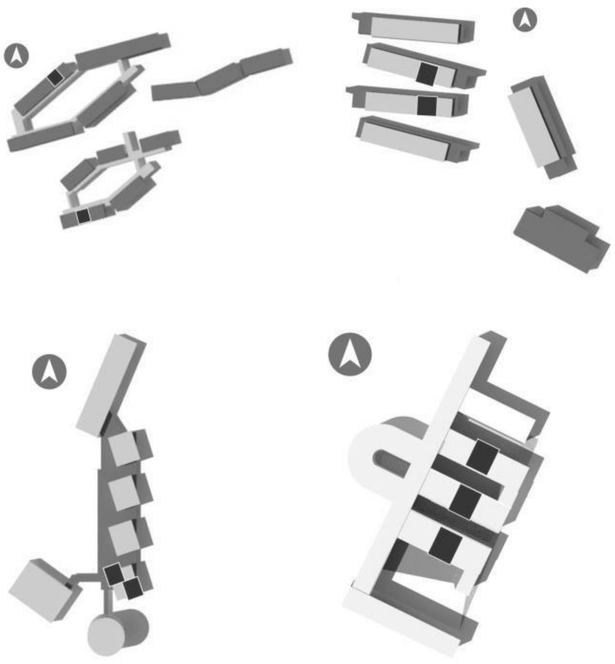

Figure 2: typology of schools and classrooms studied

The envelope of the schools has materials such as ceramic brick block (10 mm thick), concrete (20 mm thick), with façade elements for constant air flow such as louvers, fretwork and metal grilles as shown in Figure 3. In each school two classrooms were selected from grades 5-6 (to ensure similar ages), in typical condition (not at the extremes) with differentiated situation in terms of: i. North or South orientation; ii. i. north or south facing; ii. low floor or top floor with exposed roof, to test the impact of being with exposed roof to radiation.

Figure 3: Interior view of classrooms

The survey was applied to a sample of 535 students between 8 and 16 years of age (Med = 12.5, SD = 1.67), between the 5th and 7th grades of high school. In the rainy period (month 1) 276 students and in the dry period (month 2) 265 students. Of the participants, 51.4% were male and 48.6% were female. On the CLO (clothes) scale, the group scores showed values of 0.54 CLO in month 1 and 0.52 CLO in month 2, values that correspond to a similar level of sheltering for all public schools in the city.

2.2. INSTRUMENTS

2.2.1. Instruments for The Measurement of Physical-Environmental Variables

Table 1 presents in detail the equipment, specification and measurement characteristics.

Table 1: Instruments for measuring physical variables

	Environmental parameters	Type of measurement	Interval	Equipment	Technical specifications	Location
THERMAL	Outdoor temperature (°C) and relative humidity (%)	Type of measurement Interval	Every 10 minutes	HOBO U23 Pro V2	Accuracy ±0.21°C between 0° to 50°C, ±2.5% between 10% to 90% RH (typical).	Corridor outside the classroom
	Indoor temperature (°C) and relative humidity (%)	Continuous	Every 10 minutes	HOBO U12-012	Accuracy ±0.35°C between 0° to 50°C, ± 2.5% between 10% to 90% RH (typical).	Wall of the board
	Wind Speed	Continuous	Every 30 minutes	LM-8000 Lutron	Range 0.4 to 30.0 m/s with resolution 0.1 m/s.	Nine points in the classroom
	Surface temperature	Manual	Every 30 minutes	NUBBE	Range -50 to 380 °C, and accuracy ±2%.	At various points on each Surface
VISUAL	Illuminance (lux) outside	Manual	On time	Luxometer Lutron LX-1102	Range:40.00/400.0/4,000/40,000/400,000 Lux. Resolution: 0.01 Lux to 100 Lux	In unshaded outdoor courtyard
	Illuminance (lux) above working surface	Manual	Puntual	Luxmeter Lutron LX-1102 Sound level meter	Range :40.00/400.0/4,000/40,000/400,000 Lux. Resolution: 0.01 Lux to 100 Lux Class 1 sound level meter and spectrum analyzer for third octave and octave bands.	In unshaded outdoor courtyard An interior spot
SOUND	Background Noise	Manual	Every 30 minutes	Sound level meter	Class 1 sound level meter and spectrum analyzer by third octave and octave bands	An interior point
	Reverberation Time	Manual	Every 15 minutes			

2.2.2. Comfort Perception Survey

A survey was designed to assess the students' perception of comfort, consisting of a total of 14 questions. This survey was designed to cover the same three categories recorded at the environmental level: visual comfort, thermal comfort and auditory comfort. Most of the items asked users to rate, using a likert scale, their level of comfort in the classroom. The remaining items used dichotomous questions (Yes/No) to assess the presence/absence of discomfort under certain conditions.

2.2.3. User-Perception Environmental Audit-Aapu

This technique was designed to assess the conditions of the classrooms by incorporating environmental parameters (objective) and probing user comfort factors (subjective) (San Juan et al., 2014). In order to carry out the AAPU, the rectors of the last public schools built in the city after 2000, the year in which the NTC 4595 standard was introduced, were contacted through the Municipal Education Secretariat. At the same time, fieldwork sheets were designed to record the observed physical data measured by specialized measuring equipment.

The AAPU was carried out in two periods of 2017 with different thermo-hygrometric conditions. The first measurement was conducted in March (rainy month-1) and the second in August (dry month-2), similar to other studies conducted in tropical and subtropical climates (Nematchoua et al., 2014). For the objective component, (a) continuous measurements were taken inside the classrooms and outside (in a corridor towards the courtyard) with recordings every 10 minutes thanks to specialized data acquisition equipment, for 25 days in each period; and (b) spot or instantaneous measurements inside the classroom simultaneously with the application of the (c) Comfort survey, once for each period.

The subjective field of the audit is centered on the user opinion survey, supported by the participatory workshop strategy based on previous experiences (San Juan et al., 1999), which is based on a didactic space where the concepts and questions that make up the instrument are explained in a simple way (Figure 4). The approach to the subjective field of the audit was in line with the procedure defined by the Bioethics Committee of the San Buenaventura University of Cali, and with the approval of the children's guardians.

Figure 4: Application of the survey

2.2.4. Processing for Thermal, Visual and Auditory Compliance and Comfort

To determine the comfort situation in each of the themes, comfort ranges were defined in accordance with national and international standards, and obtained through the following procedures (on-site measurement or equation), as presented in Table 2, as follows:

Table 2: Procedure for finding comfort

Thermal	**Instrument**	**Variable**	**Description**	**Comfort range**
Thermal Comfort	Equation	Operating Temperature	To = A*T_a + (1-A) T_mr Where: To= Operating temperature Ta= Air temperature Tmr= Mean radiant temperature A (value as a function of air velocity) = 0.5 (<0.2m/s); = 0.6 (0.2 to 0.6 m/s); = 0.7 (0.6 to 1.0 m/s)	22,5 a 26° C
	Specialized Equipment	Relative Humidity (%)	Measurement outside and inside the classroom for 2 months	60%
Visual Comfort		Illuminance (Lux)	Measurement on each student's workstation	300 a 500 lux
	Equation	Light Dia-CLD Coefficient (%)	CLD (%) = (Indoor Illuminance/Outdoor Illuminance) *100	≥2%
		Uniformity Coefficient –U (%)	Uo (%) =Minimum Illuminance/Medium Illuminance	≥ 60%
Auditory Comfort	Specialized Equipment	Background Noise (dB)	Measured in classroom condition with students and furniture, and unoccupied (no students, no furniture).	40 a 45 dB
		Reverberation Time (Sec)	Measured in unoccupied classroom condition	09 a 1,0

In addition, for Tmr it was necessary to find the form factors, emissivities and temperatures of each surface (Forbes, 2017) and equation (1) presented in ASHRAE Chapter No. 8 (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], 2005).

$$T_{mr} = t_1 F_{-1} + t_2 F_{-2} + \cdots + t_N F_{-N}$$

(1)

- Where:
- t 1 = Surface temperature surface 1
- F-1 = Surface form factor surface 1
- t 2 = Surface temperature surface 2
- F-2 = Surface form factor surface 2
- = Surface temperature of each surface in space
- F-N = Shape factor of each surface of the space

2.2.5. Weighting of The Standard

The standard establishes different recommendations for each theme, for visual 25 recommendations, for thermal 13 recommendations and for auditory 6 recommendations. The alternatives in the thermal and visual themes are common (opening sizes, façade protection elements, materials, orientation and elements of the immediate context), while in the auditory theme, only variations apply in terms of opening sizes and materials, see Table 3.

Table 3: Alternative Design NTC4595 Standard

ALTERNATIVE DESIGN NTC4595 STANDARD			**Termal**	**Visual**	**Hearing**
	1	Openings	Relation to area 1/6m, 1/9m	Ratio to area 1/5. 60% ♦ if there is protection.	
	2	Radiation protection	Eaves and louvered shutters	orientation other than north-south	
	3	Materials	Alternatives from solar gain factor Materials with a mass of 0.15 m If the roof is thin plate + ceiling. Solid roof with reflective material	Alternatives from light reflection coefficients	Alternatives from acoustic absorption Absorbent materials on top of walls Sound-attenuating ceilings in top-floor classrooms
	4	Orientation	Surface 45" for winds. Surfaces facing north-south	Axis north – south	
	5	Context	Exterior ventilation	Separation between buildings Dimension of courtyards	Space grouping

For the analysis proposed in each classroom, each of the aspects that make up the design recommendations are discriminated, as well as the comfort ranges, and their compliance is weighted, with a score of 1 (if compliant) and 0 (if not compliant).

2.3. STATISTICAL PROCESSING

Two sets of analyses were carried out for hypothesis testing:(a) Comparison between the two periods (rainy season and dry season). Due to the characteristics of the measurements made (a single measurement for each classroom), t-tests for independent samples were performed. In this case, the comparison of the physical measurements was carried out, as well as the comfort survey.

b) Based on the levels of compliance with the standard assigned to each of the classrooms, three groups were formed, as follows: low group (percentile < 30); medium group (percentiles between 31 and 70); high group (percentiles > 71). Using this distribution of the groups, single-factor ANOVAs were performed, taking the level of compliance with the standard as a factor, and the perception of comfort as the dependent variable. Tukey's post-hoc tests were used.

3. RESULTS

The outdoor ambient temperature was slightly higher in the dry period (month 1), while relative humidity was higher in the rainy period (month 2), in accordance with the tropical climate with homogeneous temperatures throughout the year, and intermittent periods of drought and rainfall (Table 4).

Table 4: Outdoor Temperature and Relative Humidity in the study periods

Parameter	Measurements	Rainy Period (Month 1)	Dry Period (Month 2)
Outdoor Temperature (°C)	Maximum	31, 3	36,6
	Average	24,6	26,1
	Minimum	20,5	20,6
Outdoor Relative Humidity (%)	Maximum	90,8	88,2
	Average	73,2	64,1
	Minimum	42,6	28,9

3.1. COMPARISON BETWEEN MOMENTS

Regarding illuminance, when comparing the natural illuminance (lux) of the first month (M = 870.471; SD = 1077.465) very similar values were observed to the second month (M = 733.949; SD = 759.471). The difference between these two measures was not statistically significant [t (529) = 1.675; p = 0.095]. When comparing the artificial illuminance of the first month (M = 1114.442; SD = 1051.059) with the second month (M = 1043.034; SD = 874.814), no significant difference was seen either [t(530)= 0.848; p = 0.397]. For both natural and artificial lighting, the average values are within the range recommended by the standard.

Figure 5 shows the distribution of the values obtained for the physical lighting variables (Lux and CDL) grouped according to the expected levels. In the same figure, it can be seen that the largest proportion of the records are grouped in the values "insufficient" (35%) and "excessive" (25%). The "sufficient" category, which corresponds to the optimal lighting values, only contains 14.9% of the cases.

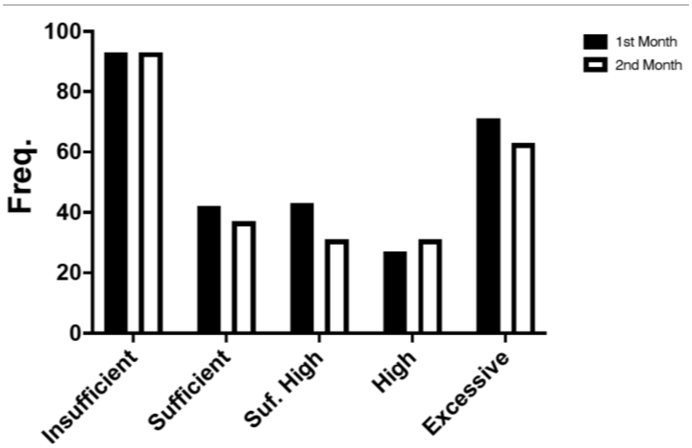

Figure 5: Illuminance comparison between month 1 and month 2.

Levels: Insufficient: 0-299 lux; Sufficient: 300 to 500 lux; High Sufficient: 501 - 750 lux; High: 751 to 1000 lux; Excessive: +1001lux.

When comparing the CDL of the first month under natural conditions (M = 2.249; SD = 2.781) with the second month (M = 1.656; SD = 1.957), significant differences were found [t (529) = 2.822; p = 0.005]. However, when comparing, under artificial conditions, the first month (M = 2.850; SD = 2.727) with the second month (M = 2.814; SD = 2.747) the differences are not significant [t (530) = 0.151; p = 0.880].

The distribution of the CDL values presented in Figure 6 indicates that the largest proportion of the records are concentrated in the "insufficient" category (69.5%). In this case, the "sufficient" category accounts for 18.5% of the cases, while the "excessive" category has the lowest proportion of cases (12.1%). The distribution of CDL values indicates that the highest proportion of records is concentrated in the "insufficient" category (69.5%). In this case, the "sufficient" category accounts for 18.5% of the cases, while the "excessive" category has the lowest proportion of cases (12.1%).

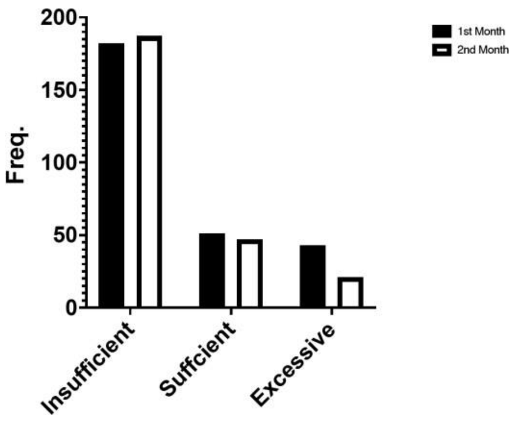

Figure 6: CDL comparison between month 1 and month 2.

Levels: Insufficient: 0- 1.9; Sufficient: 2% to 3% and Excessive: 4% and above.

On the other hand, when asked the question "How is the lighting at your desk?", the average responses were very similar between month 1 (Med. = 2.01; SD = 0.541) and month 2 (Med. = 1.93; SD = 0.532). In both cases, these values indicate that the majority of students (approx. 70%) consider the lighting at their desks to be appropriate. With regard to the question "Does the light coming in through the window cause discomfort to the eyes?", the students' answers do not vary much between month 1 (Med. = 1.29; SD = 0.453) and month 2 (Med. = 1.27; SD = 0.443). Overall, the majority of students (72 %) responded that the light coming through the window is annoying. The last question in this category was: "Is it necessary to turn on the lights during the day? Here again, similar responses were observed between month 1 (Med. = 1.86, SD = 0.479) and month 2 (Med. = 1.82, SD = 0.516). The highest proportion of responses is concentrated in the option "sometimes" (73%). The option "never" accounts for about 20% while the option "always" had the lowest number of responses (6%).

Regarding thermal comfort conditions, the measures of operating temperature between the first month (M = 26.473; SD = 2.226) and the second month (M = 26.458; SD = 1.066) show no significant differences [t(539)= 0.097; p = 0. 923], see Figure 7. In contrast, the indoor RH measurements do show significant differences [t(530)= 9.651; p < 0.001] when comparing the measurement in month 1 (M = 67.227; SD = 9.985) with the measurement in month 2 (M = 60.339; SD = 6.061).

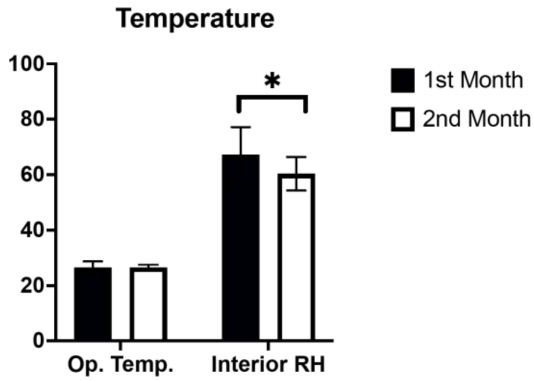

Figure 7: Comparisons of Operating Temperature and Indoor RH month 1 and 2

In the category of thermal comfort, a question with response options 1 to 7 was presented. In this case the scores indicating comfort would be between 3 and 5. Options 1 and 2 correspond to discomfort towards the cold end, while options 6 and 7 correspond to discomfort towards the hot end. Student responses to this question are concentrated between values 4 and 5 (approx. 40%). Interestingly, a high peak (25%) is observed for answer option 2 (cold discomfort). (Figure 8).

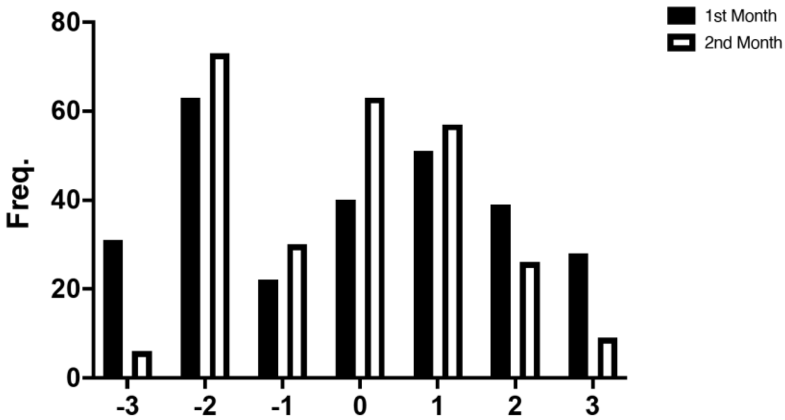

Figure 8: Temperature perception (1st month – 2nd month) Responses on the wind chill scale. Levels: -3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot

In the case of auditory comfort, measurements were taken on only one occasion, since the acoustic environment is a single one and no variations are expected between the two times of the study, except for a particular school activity or outside event. These measures were peak sound intensity levels (Med. = 73.2, SD = 4.46) and reverberation time with furniture (Med. = 1.39, SD = 0.359).

To address the perception of comfort, the question "Are there disturbing noises in or near your classroom?" was asked. In this case, the majority of students answered in the affirmative (80.6%). Additionally, the frequency of these noises was asked and the majority of the students responded that they are heard only occasionally (45%), 38% responded that they are heard repeatedly, and 17% responded that these noises are heard continuously.

As a final aspect of the contrast between the rainy and dry months, perceptions of comfort between the two months were compared in each of the categories (visual, auditory and thermal). The results show that there are no significant differences in visual comfort [t(538)= -1.506; p = 0.133] or auditory comfort [t(537)= 1.354; p = 0.117]. On the other hand, in the case of thermal comfort, significant differences were observed between month 1 (Med. = 2.88; SD = 1.175) and month 2 (Med. = 3.404; SD = 1.059) [t(539)= -5.361; p < 0.001], as presented in Figure 9.

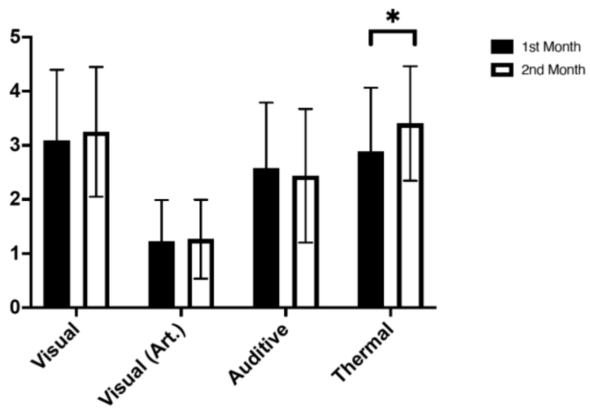

Figure 9: Comparison of visual, auditory and thermal comfort perception in each month

3.3. EFFECT OF DESIGN ON COMFORT PERCEPTION

The second hypothesis test of this study was aimed at verifying the effect of compliance with design standards on the comfort perceived by users. To carry out this procedure, the compliance scores were grouped into three levels (high, medium and low) which were used as a factor in the one-way analysis of variance (ANOVA) for each of the subjects as shown in Figure 10.

In the case of visual comfort, a group effect is observed (F = 6.306; p = 0.002). Post-hoc analyses reveal significant differences between the high group and the other groups. However, these differences appear in the opposite direction to that expected, i.e. the high compliance group has the lowest level of comfort. In terms of thermal comfort, a group effect was observed (F = 3.527; p = 0.030). When looking at the post-hoc tests, significant differences appear only between the low and medium compliance groups. In this case, the middle group has the highest average comfort perception. Although the high group has a lower score than the medium group, these differences are not significant. Finally, no group effects are observed for hearing comfort (F = 0.420; p = 0.657), indicating that there was no effect of compliance with the standard on users' perceived comfort.

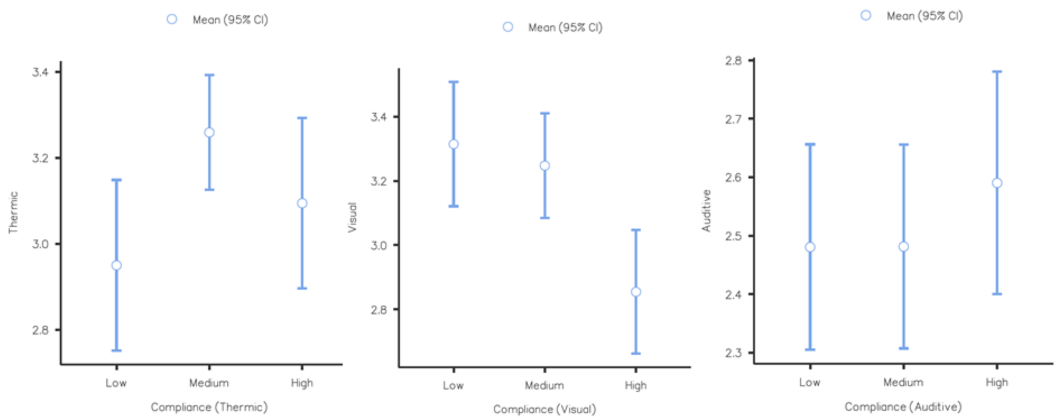

Figure 10: Effect of compliance with design standards on perceived comfort

4. DISCUSSION

Ht. 1-Comparison Between Rainy and Dry Months

The similarity of illuminance in the classrooms with insufficient and excessive extreme values in the two months, with slightly different CLD values showing a greater availability of the light resource in month 1, with a higher percentage of excessive levels, which shows that despite the different exterior lighting conditions, the enclosure homogenizes the interior conditions (possibly characteristics of the interior space such as the finishes, the color and the geometry of the classroom itself).

However, the students' responses showed a greater sensitivity and discomfort to the light coming in through the window (72%) over the two months, which may be of concern given the excessive and deficient conditions inside the classroom. This indicates the need to look further into aspects of the envelope in the tropics, taking care not only of aspects such as the distribution of openings (Arango-Díaz et al., 2013) but also the very conditions of filtering that the envelope may have in tropical contexts (Koenigsberger et al., 1973).

Other studies that evaluate comfort in classrooms in Colombian cities in the months of March (equinox) and November (close to the winter solstice), show similar behavior between the two months of this study in Cali (with percentages between 10% and 35%) (Zapata Rueda et al., 2018), without presenting the highest percentages in the extreme values (insufficient and excessive) as those found in this study. This may be due to the differences between measurement times, or to the dynamic nature of light inside the spaces, which makes it difficult to analyze and predict (Monteoliva & Pattini, 2013).

In addition to the homogenization of outdoor conditions by envelope, which makes little use of outdoor lighting, it should be borne in mind that illuminance levels below the 300 lux recommended by the standard in 2000 and then updated in its 2015 version to 500 lux, reduce the perception of visual stimuli, affecting cognitive performance (Jago & Tanner, 1999).

This may also be aggravated by the condition of habituation expressed by the majority of students (70%), who rated the lighting conditions on the desk as appropriate. It should be borne in mind that this positive assessment is due to the addition of artificial lighting which, according to 73% of the participants, should be present.

The use of the CLD metric has been widely questioned in recent years, given its limitations in assessing the visual performance of a space, both because it was designed for cloudy skies and because it bears little relation to the climatic conditions of specific locations (Bian & Ma, 2017). However, in this text it is used for the analysis, since the standard indicates it as a reference value for a comfortable classroom, indicating that the interior should ensure a CLD above 2%. However, the maximum permissible value is not specified, which may imply the risk of excessive light entering the classroom without the shading system filtering and controlling it. It should be noted that values between 4 and 6% are more appropriate for contexts with marked seasons and cloudy skies (Wu & Ng, 2003).

Regarding the thermal aspect, the similar to and the differentiated %RH in the two moments are coherent with the location close to the equator (without climatic seasons) and the chosen moments: dry and rainy. This situation differs from that recorded in other studies based on measurements in warm-temperate climates (Baruah et al., 2014).

The students' perception of the hygrothermal conditions was similar in the two months, with 48.9% of the responses concentrated in the three central categories indicating comfort, with a slight concentration towards slightly warmer conditions. It is striking that in a warm climate such as Cali, children perceive greater discomfort due to cold (25%), which could indicate the need to revise the thermal scale used by the standard, which is based on adult perception, as well as the need to include other variables such as the social and living conditions of the children.

On the other hand, the high indicative values of auditory comfort recorded in all the classrooms in the study highlight a problem already pointed out in other studies carried out after this one (Zapata Rueda et al., 2018) common to this day to classrooms in warm environments where a permeable architectural envelope is favored to achieve thermal comfort (Iglesias García et al., 2016), to the detriment of the acoustic quality of the space.

HT. 2- EFFECT OF DESIGN ON PERCEIVED COMFORT

For the design of classrooms in the tropics, special consideration should be given to aspects such as protection from solar radiation (James & Christian, 2012; Subhashini & Thirumaran, 2018), and avoiding uncontrolled direct sunlight entering the space. In the study rooms, group differences in compliance do not alter the perception of the lighting on the study table (Figure 11).

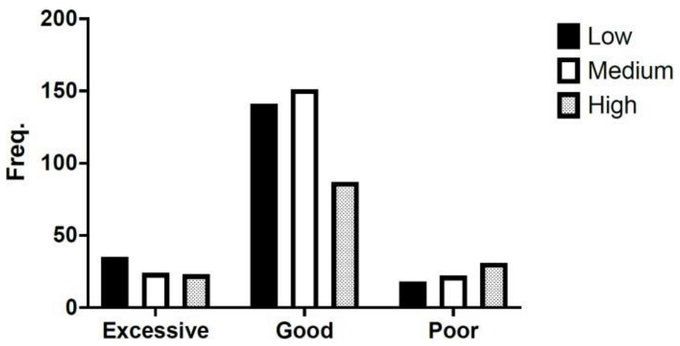

Figure 11: Comparison of visual comfort and visual perception compliance

Other lighting considerations such as the distribution and design of the openings in the façade, the geometry of the classroom itself and the type of window can favor uniformity in illuminance (Arango-Díaz et al., 2013) and avoid negative consequences such as unwanted glare and high contrasts (Wu & Ng, 2003), or raise temperatures and generate visual discomfort (Villalba et al., 2011), such as direct light entering through windows as in the cases studied, regardless of compliance with the standard.(Figure 12)

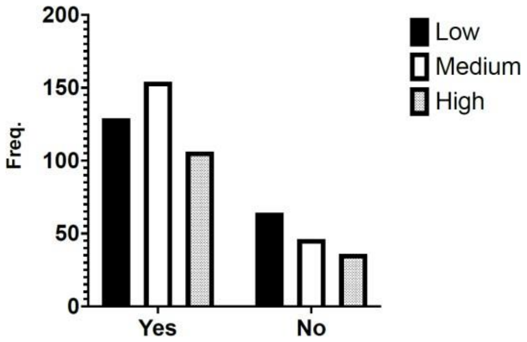

Figure 12: Discomfort with light entering through Windows

The objective of the NTC 4595 standard on the subject of visual comfort is to use natural lighting for a large part of the school day (Colombian Institute of Technical Standards and Certification [ICONTEC], 2000), however, according to the responses, lights are switched on for a large part of the school day, regardless of the level of compliance as shown in Figure 13, to improve the lighting environment, which implies an increase in energy consumption (Harputlugil & de Wilde, 2020) as well as the waste of natural resources as indicated in the standard.

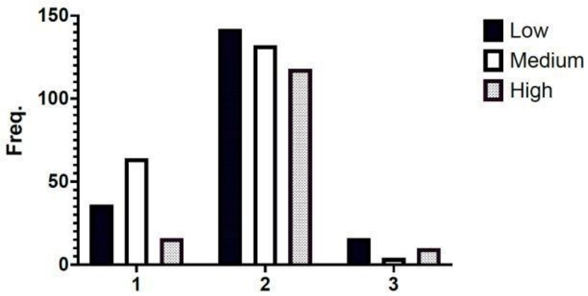

Figure 13: Need to switch on the light in the morning and compliance with the rule

According to NTC 4595, a classroom is thermally comfortable if the majority of people perceive the environment as comfortable (Colombian Institute of Technical Standards and Certification [[ICONTEC], 2015). The results of the present study showed higher comfort in the dry period (month 2) with the highest temperatures up to 5.6 °C compared to month 1, consistent with the statement of Tablada et al. (2005) who point out that studies developed in the last three decades in naturally ventilated schools in hot climates show that the thermal sensation reported is warmer than that stated in the standards (Liang et al., 2012).

In the present study, the classrooms with the highest compliance do not necessarily fall into the categories indicative of comfort, which shows that compliance with thermal recommendations is not directly related to the comfort perceived by students (see Figure 14).

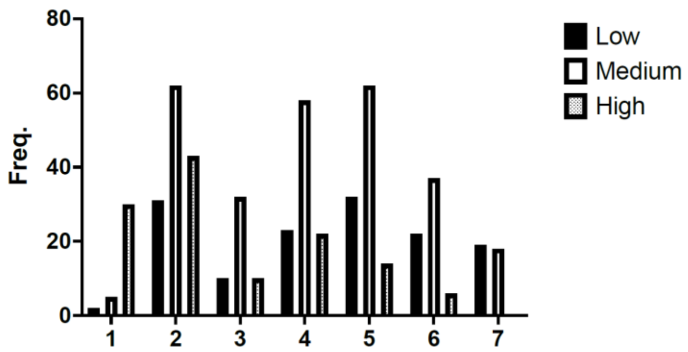

Figure 14: Thermal comfort and compliance with standards

In terms of acoustic quality, poor acoustic quality in classrooms manifests itself in the form of echoes and disturbing noises, which affect the transmission of sound emitted by a specific source, in this case, the teacher or the students themselves (Pattini, 2000).

In opposition to the findings found in this study with maximum sound intensity values of 73.2 dB, the World Health Organization WHO establishes 35 dB as the appropriate value for background noise, noting that values above 80 dB have an impact on aggressive behavior (Zapata Rueda et al., 2018). Furthermore, study such as the one conducted by Sato et al. (2007) on young and adult listeners (Sato et al., 2007), show that the appropriate speech level is 60 dB with reverberation time between 0 and 2 seconds. The same study identified that in background noise conditions between 40 and 50 dB (range close to that of classrooms), the lowest required speech level was 65 dB (Zapata Rueda et al., 2018).

Regarding reverberation time, the NTC 4595 standard establishes a permissible value between 0.9 and 1.0 second, a wider limit than that determined by ANSI / ASA S12.60 and Building Bulletin 93, which recommends between 0.6 and 0.7 seconds in reverberation time. The rooms in this study yielded mean values of 1.39 seconds with furniture and over 1.5 seconds without furniture. These values should be viewed in conjunction with the background noise, as the high permeability of the classroom may reflect a low reverberation time, to the detriment of the high background noise implied by a classroom in direct relation to the outside and with little control of the outside acoustic conditions (see Figure 15).

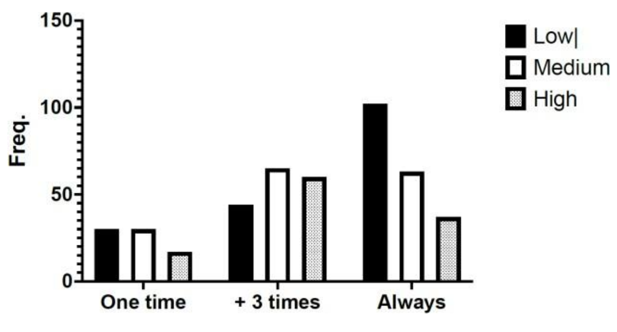

Figure 15: Presence of noise and compliance with the norm. Noise frequency (low-medium-high)

As shown in Figure 16, all groups by level of compliance report similar noise annoyance. In the same graph, there is a strong relationship between low compliance and perceived higher frequency of noise nuisance.

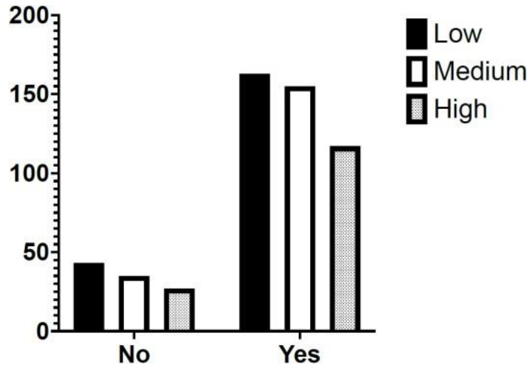

Figure 16: Frequency of disturbing noises during the working day. Noise presence (Low – Meidum – High)

Poor acoustic quality has negative implications for teachers, as it can lead to vocal fatigue, lack of motivation and drowsiness (Zapata Rueda et al., 2018) as well as hearing impairment, irritability and headaches (Medina, 2009).

5. CONCLUSIONS

The reference values of the standard for visual and acoustic issues are based on standards designed for other contexts, with little reflection of the situation inside classrooms. Thermal comfort is even more critical, as the standard does not commit to any range or model of comfort, leaving this important issue undefined. There is concern that young people may adapt to poor visual and thermal conditions in spaces where they traditionally spend long days, with the implications this may have on the pedagogical process.

As demonstrated throughout the text, the objective of the comfort chapter of the standard is not met in the cases studied, as compliance with the standard is not directly related to the comfort assessed. Conclusions such as these were possible thanks to the methodology of the Environmental User Audit and the interdisciplinary architectural and statistical analysis carried out, which can be replicated for the analysis of other standards in a variety of contexts.

It is urgent to deepen the characterization of teaching and learning environments, such as those presented in this contribution, in cities with similar climatic conditions, among others like the one in this study, which would lead to a broader Latin American perspective.

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