INFLUENCE OF THE THERMAL AND LIGHTING PERFORMANCE IN CLASSROOMS ON THE COGNITIVE PRODUCTIVITY OF STUDENTS IN COLOMBIA

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ABSTRACT

This paper examines the influence of the thermal and lighting performance in classrooms on the cognitive productivity of students attending public schools in the principal three cities of Colombia: Bogota, Medellin and Cali. The methodology used involves the application of cognitive performance tests and thermal and visual perception surveys, along with measurements of climatic parameters in 34 classrooms of 14 schools in 2017 and 2018. The results were analyzed using transversal correlational regressions. Among the conclusions, this study found that the operative temperature turned out to be the most conclusive variable explaining cognitive performance relationships.

KEYWORDS

school classrooms, environmental comfort, thermal performance, lighting performance, cognitive performance and productivity.

1. INTRODUCTION

Quality Education and affordable clean energy are two valuable priorities of the United Nations in the effort to achieve sustainable development (ONU n.d.). Aside from education coverage, it requires the implementation of energy-efficient pedagogical environments that guarantee suitable working conditions in classrooms, while reducing the excessive dependency on electrical energy. In Colombia, the Colombian Technical Standard NTC 4595 (Ministerio de Educación Nacional. República de Colombia 2006), defines the planning and design of school facilities and environments. Nevertheless, studies demonstrate that the recommendations of the standard do not necessarily guarantee comfortable classrooms at the visual (Arango-Díaz et al. 2013), thermal and acoustic level (Montoya 2019; Montoya and San Juan 2018). Within the framework of designing and constructing schools according to the guidelines of standard NTC

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4595, the objective of this document is to consider the thermal and visual comfort aspects of classrooms in relation to the academic performance of students.

On the international scene, comfort conditions in classrooms are defined by the ASHRAE international standards on comfort (Standard 2017). From the thermal point of view, the standard establishes a thermal sensation scale: –3 cold, –2 cool, –1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot. In schools, several investigations have been made to define and to compare indoor temperature at which most occupants are comfortable, and this is known as the neutral temperature. Studies demonstrate that the occupants of naturally ventilated classrooms are satisfied to a greater extent, when compared to those of air-conditioned classrooms (Mishra and Ramgopal 2015a). The neutral temperatures identified in the literature reach 26.3°C (Hwang et al. 2006) and up to 26.8°C (Mishra and Ramgopal 2014b), thus exceeding the maximum permissible limit by the ASHRAE 55 standard, which is, for summer, 24°C (60% RH, 1.0 > Met < 1.3 Clo = 1) and 25°C with a thermal insulation of Clo = 0. Studies in classrooms demonstrated a close relationship between the mean of thermal sensation votes and an 80% acceptability (Jensen et al. 2009), but no correlation between acceptability and classrooms with and without air conditioning has been proved (Mishra and Ramgopal 2015a). Along that same line, comfort perception has also been related to a high productivity in specific tasks (Jiang et al. 2018), and a significant relationship between the discomfort votes and 34% and 48% of the variations on test scores has been shown, although these results are not strong (Hoque and Weil 2014).

The inconsistency in the results of the measurements of classrooms suggests that, although comfort requires an integral approach, it is not necessary to sacrifice the diagnosis of each specific topic, such as visual, thermal and acoustic (Ricciardi and Buratti 2018). Other studies relate several environmental aspects with academic performance, such as the work done by Torrecilla, Javier, and Martinez-Garrido (2012) in 9 countries of Ibero-America, which demonstrated that there are no statistically significant relationships between performance in mathematics and language and the classroom environment, since all of the spaces have acceptable conditions.

From the relationship between comfort conditions in the classroom and academic performance, thermal factors have been widely studied in recent decades (Holmberg and Wyon 1969; Hoque and Weil 2016; Schoer and Shaffran 1973) demonstrating that those who study in classrooms with inadequate ventilation and heating systems have a lower academic performance than those who study in classrooms with natural ventilation (Kalamees et al. 2015). Additionally, a lower room temperature increases the speed of the work, including some other aspects, like attention and deduction (Jiang et al. 2018). On the other hand, in naturally ventilated classrooms, located in warmer climates, performance is not affected by temperature variations (Munksgaard 2005), given the possibilities of adaptation such as slowing down tasks, opening windows and removing clothing wear.

From the perspective of visual comfort, one of the most important aspects is related to the necessity to satisfy the required lighting levels to perform visual tasks that can be achieved with natural, artificial or conjugated illumination. While conjugated illumination can attain significant savings in power consumption, several studies demonstrate the advantages of daylight over artificial illumination in academic environments (Barrett et al. 2017; Davis 2003a; Murillo and Martinez-Garrido 2012; Shishegar and Boubekri 2016; Wargocki and Wyon 2007; Zhu et al. 2019). In relation to daylight, several researchers have studied the relationship between naturally illuminated environments and academic performance (Cachán et al. 2012; Konis 2013; Plympton et al. 2000; Shishegar and Boubekri 2016; Trebilcock Kelly, Maureen; Soto Muñoz, Jaime; Figueroa San Martin, Rodrigo; Piderit-Moreno 2016). Other researchers have opted to focus on academic performance in relation to the source of color temperature and illuminance with artificial light systems, registering lesser omission errors, a greater reading understanding and a greater reading speed with lighting levels of 150lx, 300lx or 1060 lx (Barkmann et al. 2010; Liu et al. 2020). Meanwhile, Baron, Rea and Daniels (1992) state that, with low levels of illumination (150 lx), better labor results were registered than with an illumination of 1500 lx in the work plane.

Additionally, the Heschong Mahone Group (Heschong Mahone Group 1999a; b), in a study that included more than 2,000 classrooms in the United States, indicated that efficiency in the elaboration of mathematical tests and reading comprehension increased from 20–26% in a naturally illuminated classroom, when compared to a poorly illuminated classroom. Supported by this study, Davis (Davis 2003a; b) found that in more illuminated rooms, a 21% improvement in the learning rate is evident, when compared with poorly illuminated classrooms. The author concludes about the importance of guaranteeing lines of sight to the exterior and controlling the glare and manipulation of windows. In spite of this, other authors have found a weak relationship between the academic performance of students and lighting conditions, explained by the adaptative capacity of people (Murillo and Martinez-Garrido 2012; Trebilcock Kelly, Maureen; Soto Muñoz, Jaime; Figueroa San Martin, Rodrigo; Piderit-Moreno 2016)

Other studies have focused on specific aspects of each topic, for example, some studies have analyzed low ventilation rates and their effect on the learning process (Allen et al. 2016; Bakó-Biró et al. 2012; Haverinen-Shaughnessy et al. 2011; Pulimeno et al. 2020) and in relation to the visual aspects, some studies have analyzed the approach of color temperature and its effect in detail detection tasks (Monteoliva et al. 2016). To summarize, in spite of researchers' efforts to assess the implications of thermal factors and illumination on academic performance, the analysis of the results becomes difficult, since there are several variables involved in executing academic labor, like language and mathematics, which are complex processes that involve factors like the teacher–student relationship, individual development, particular cognitive skills and/or abilities, educational processes, etc. Therefore, the current study measures the impact on cognitive processes, like attention and executive function (specifically graphical fluidity), because they are basic for learning and important for adapting to the constant changes that the environment generates, especially in the educational context (Chun and Turk-Browne 2007; Lezak et al. 1995). Thus, any interference in the performance of these processes interferes with the academic achievements of students. In addition, while they are specific cognitive processes, the measurement of their performance can be conducted using specific, standardized and validated tests, according to the precise moment in the development of those students who are subject to assessment.

The studies on cognitive performance based on tests of attention, perception, comprehension and deduction, and their relationship with the environmental aspects of the classroom, have been mainly developed in countries with seasonal conditions in air-conditioned classrooms with a mild climate in China (Jiang et al. 2018). Similarly, in Denmark (Wargocki and Wyon 2007), in Costa Rica (Porras-Salazar et al. 2018) and in India (Mishra and Ramgopal 2014a; b, 2015a), these studies relate the environmental quality of classrooms with cognitive performance through specific evaluations or exercises relating to the regular topics of a course.

In research with experimental designs, researchers control the variables to determine their relationship with cognitive performance. In some of these, variables like carbon dioxide, illumination and acoustics remain constant, while the thermal aspects, like air temperature, relative humidity and air speed, are controlled, and their relationship with cognitive performance is analyzed (Jiang et al. 2018). Others control the environmental temperature and/or air renovation rate to compare the results with classrooms without the manipulation of environmental conditions (Wargocki and Wyon 2007). The duration of the measurements in the research varies, while some last for several consecutive weeks (Porras-Salazar et al. 2018; Wargocki and Wyon 2007); others last for three years (Mishra and Ramgopal 2014a, 2015a; b). However, all have in common that the different moments of measurement are integrated, while the differences are established by classroom or by building. Regarding the results, they can also vary according to the type of task and not only its nature (Baron et al. 1992; Munksgaard 2005), but also the duration and intensity of the stress factor (Heschong Mahone Group 1999b) which has the maximum impact on perception tasks, followed by psychomotor response and lastly cognitive tasks (Montoya 2019).

Finally, the relationship between temperature and performance was demonstrated in manual tasks and not in mental tasks (Munksgaard 2005), especially in activities with a high complexity or creative demand. Nevertheless, when subjects have a prolonged practice in different activities, moderate heat does not affect their development (Baron et al. 1992), which may be a result of adaptation.

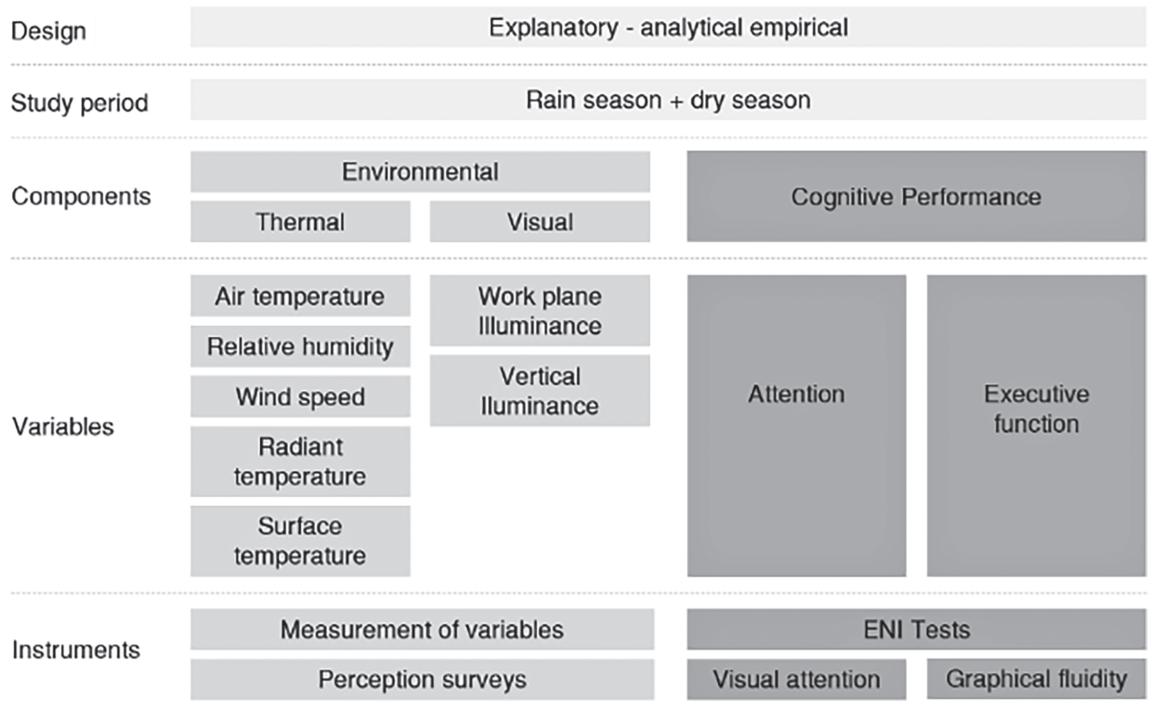
This study is developed within the framework of the research entitled "Identification of environmental performance factors (acoustic, thermal and visual) that determine the mental health of teachers and students in public schools of Bogota, Medellin and Cali: baseline for analyzing the impact of public policy, according to NTC 4595," of San Buenaventura University in Medellin and Cali, La Salle University in Bogota, Colombia, and the La Plata National University, with the support of Colciencias (Administrative Department of Science, Technology and Innovation in Colombia).

2. METHODOLOGY

In order to evaluate the relationship between the thermal and lighting conditions of educational environments and the cognitive performance of students, cognitive performance tests and thermal and visual perception surveys were applied. These measurements were conducted in line with similar studies (Lezak et al. 1995; Montoya 2019), and others that engage the community to build more responsible relationships between the built environment and resources (Wheeler 2017). The measurements were taken in 40 classrooms of 14 educative institutions in the Colombian territory during two periods between 2017 (measurement 1) and 2018 (measurement 2) with different subjects in each period. Thus, experts carried out a strict protocol to structure and organize the data collection that allows the influence of thermal and lighting conditions on the cognitive performance of students to be understood. Colombia, being a tropical country, does not have any significant climatic changes through the year. However, rainy and dry periods can be identified. Due to this difference, the measurements were made in both periods. The results were analyzed using transversal correlational regressions. Figure 1 shows a graphic summary of the study methodology employed.

It must be observed that, unlike other investigations in which environmental variables are controlled and different scenarios are simulated for the application of cognitive tests (Allen et al. 2016), in this research the environmental variables were measured and cognitive tests applied in environments known to the participants and that were framed within the local regulations. This way, although the number of scenarios generated from environmental variables is restricted and,

FIGURE 1. Graphical explanation of the methodological process.



therefore, the possibility of finding stronger relations or associations is reduced, the possibility of modifying environmental conditions is guaranteed, as is traditionally done in these types of spaces, through the operation of windows, doors, light switches, among others. In the tropical Colombian context, public schools do not have mechanical devices to regulate the thermal environment; in that sense it was not possible nor realistic to use controlled spaces.

2.1 Climate

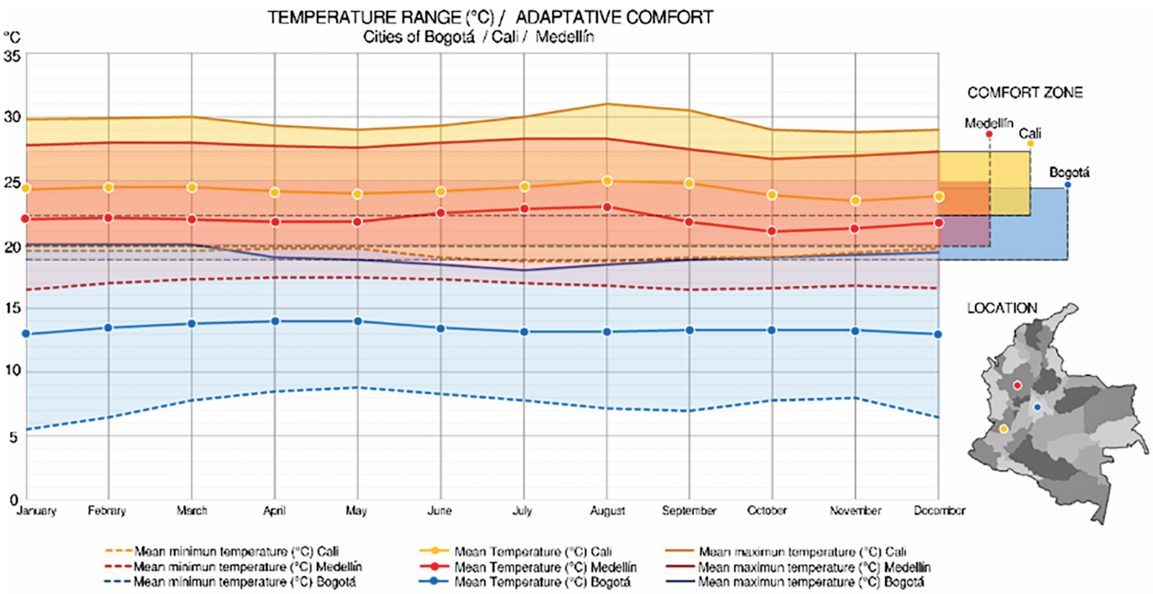
Three capital cities of Colombia with different climatic characteristics were chosen: Bogota (lat. 4.5 N, lon. 74.1 W, 2600 AMSL), Cali (lat. 3.4 N, lon. 76.5 W, 920 AMSL) and Medellin (lat. 6.3 N, lon. 75.5 W, 1500 AMSL). The climatic characteristics of the three cities were processed using official information from the Hydrology, Meteorology and Environmental Studies Institute, as shown in Figure 2.

Using Equation 1, proposed by the leading authors of the adaptive model (Nicol et al. 2012), the Comfort Temperature (T. comf) was calculated for each city. Using Equation 2 (Nicol et al. 2012), the acceptable temperature range to define the comfort zone, with a 90% acceptability, was calculated. The comfort zone for Bogotá was between 20.3°C and 25.3°C, for Cali, between 23°C and 28°C, and for Medellin, its results were between 22.2°C and 27.2°C.

$$T\text{comf} = 0.31 * T\text{pma(out)} + 17.8 \tag{1}$$

$$T\text{accept} = T\text{comf} \pm T\,\text{lim} \tag{2}$$

FIGURE 2. Temperature range and adaptative comfort.



Taccept = Limits of the acceptable comfort zones; Tpma(out) = mean outdoor temperature t pma(out): Bogotá = 16.2°C, Medellin = 22.2°C and Cali = 24.8°C); T lim = 2.5 K or the range of the acceptable temperatures for 90%.

2.2 Institutions and classrooms

In total, 14 educational institutions, located in the three cities, were chosen (5 in Bogota, 4 in Cali, 5 in Medellin). The selection of those three cities was made with the aim to have a sample with different Colombian weather conditions. There were two criteria for the selection of schools: (i) they were public institutions; and (ii) all the schools in each city were close to each other or at similar altitudes.

During the two years of the study, 40 classrooms were assessed (13 in Bogota, 11 in Cali, and 16 in Medellin). For a classroom to be analyzed, it had to meet the following criteria: (i) the building it was in was built before 2000 and was therefore designed according to the NTC 4595 guidelines (Colombian technical norm that establishes the design and environmental comfort guidelines for classrooms); (ii) the spaces were unilaterally day lighted and did not have an A/C system; and (iii) they were classrooms for the fifth or sixth grades. Table 1 shows the assessed classrooms for each city during both assessment periods.

TABLE 1. Classrooms evaluated in each measurement period by city.

	Measurement 1 (Rainy Period)	Measurement 2 (Dry Period)
Cali	6	6
Bogota	5	5
Medellin	5	7

FIGURE 3. Examples of the assessed classrooms: a) Bogota, b) Cali, c) Medellin

FIGURE 3. *(Continued)*

The selected rooms were typically built with materials like concrete or clay bricks; in some cases, they were parge-coated and painted with light colors on the inside, with clay tiles and a wood tablet ceiling on the top floors. The fenestration of all classrooms was made of clear glass; in some cases, they had metal gratings for ventilation. The classrooms' lighting systems were a series of T8 fluorescent lamps, which remained in the state that students or teachers considered suitable for that moment. The main differences between all classrooms were the size of the windows and types of shading elements, according to the NTC 4595 guidelines. Figure 3 shows examples of typical classrooms in the schools.

The evaluation of the relationship between the cognitive performance of students and the classrooms' thermal and lighting performance did not take into account the architectural specifications of each room, because the aim was not to assess them, but to understand the influence of environmental factors on the cognitive performance of the students.

2.2.1 NTC 4595 constructive criteria

Technical norm NTC 4595 classifies the guidelines for the design and construction of comfortable classrooms, with three different geographical and weather types. However, these are only basic architectural parameters that lack clear technical definitions, environmental objectives or methodologies to satisfy the comfort parameters (see Table 2).

2.3 Students

For the evaluation of the participants, 66 groups of fifth- and sixth-grade students were selected. The students' selection was made based on the fulfillment of several conditions: Students who

TABLE 2. NTC 4595´s guidelines by weather classification.

City	Weather type	Visual comfort	Thermal comfort
Bogota	Moderated, cold and/or temperate	Effective window of 1/3 of the space area	Openings of 1/15 of the space area, with minimum wind exposure to predominant flow. At least 2.7 m of room height.
Cali	Humid warm	Effective window of 1/5 of the space area	Openings placed at 45° from predominant winds or use of facade elements to channel the air flow. Opening size of 1/6 of the space area.
Medellin	Dry warm	Effective window of 1/4 of the space area	Openings placed between 30° and 90° from predominant winds, taking up 1/9 of the space area. At least 3.0 m of room height.

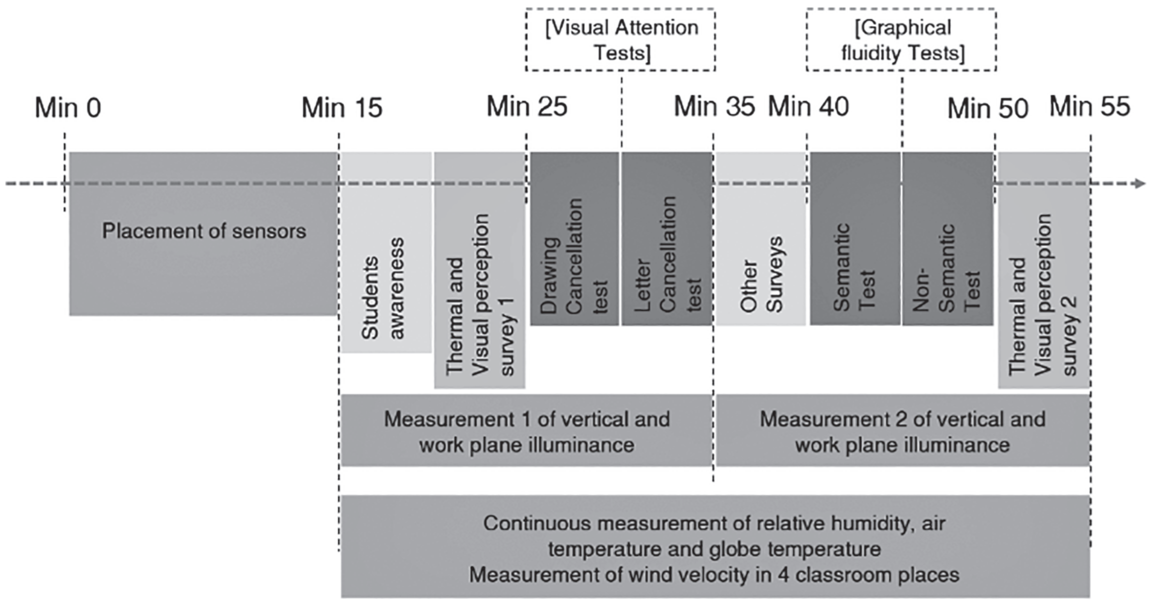
accepted to participate and had authorization from their parents. All parents gave their informed consent for inclusion before their children participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol for the research with code 125574455877 was approved by the Ethics Committee of San Buenaventura University, according to Article 11 of Resolution 008430 of the Health Ministry of Colombia of October 4th 1993, and on May 10th of 2016. Additionally, students who had not repeated school years, without physical and/or mental pathologies and without medication, were interviewed. The final size of the sample was 873 students. For the procedure of the data and descriptive analysis, SPSS program version 25 was used, and the frequency distributions were determined. The characteristics per evaluation year for the different cities are shown in Table 3.

The age range of the selected children was between 10 and 14 years. However, 92.7% of the sample was between 10 and 12 years old.

TABLE 3. Measurement instruments of the thermal and lighting variables.

	Measurement 1 (Rain period)	Measurement 2 (Dry period)
Number of participants	354	519
Average Age	11.3 years	10.7 years
Gender	51% boys 49% girls	49% boys 51% girls
Distribution by city	Cali: 47% Bogota: 26% Medellin: 27%	Cali: 23% Bogota: 34% Medellin: 43%

FIGURE 4. Implementation chronology of the experiments in the classrooms.



2.4 Data collection

For each group of students in each classroom, there was a data collection procedure, including the measurement of environmental variables, application of cognitive performance tests and thermal and visual perception surveys. Altogether, for each classroom, the application of the experiment took approximately 55 minutes. Figure 4 summarizes the sequence of the experiment in each classroom.

2.4.1 Environmental variable measurements

The procedures expressed in Table 4 were used to characterize the thermal and lighting performance.

Additionally, the operative temperature (To) was calculated using the registered data, according to equation 1, and the difference between the operative temperature and comfort temperature (To-Tcomf) was also calculated.

In order to maintain students' normal behavior and everyday activities undisturbed, the light conditions of each classroom were maintained in the same condition as that in which they were found. The measurements, that were made in each workstation, were made without switching on or off any lamps, nor opening or closing the windows. The placement of the sensors is shown on Figure 5.

The participants also answered a survey of 8 questions concerning their visual and thermal perception and preference, sensation of glare, natural ventilation and amount of clothing (See appendix A)

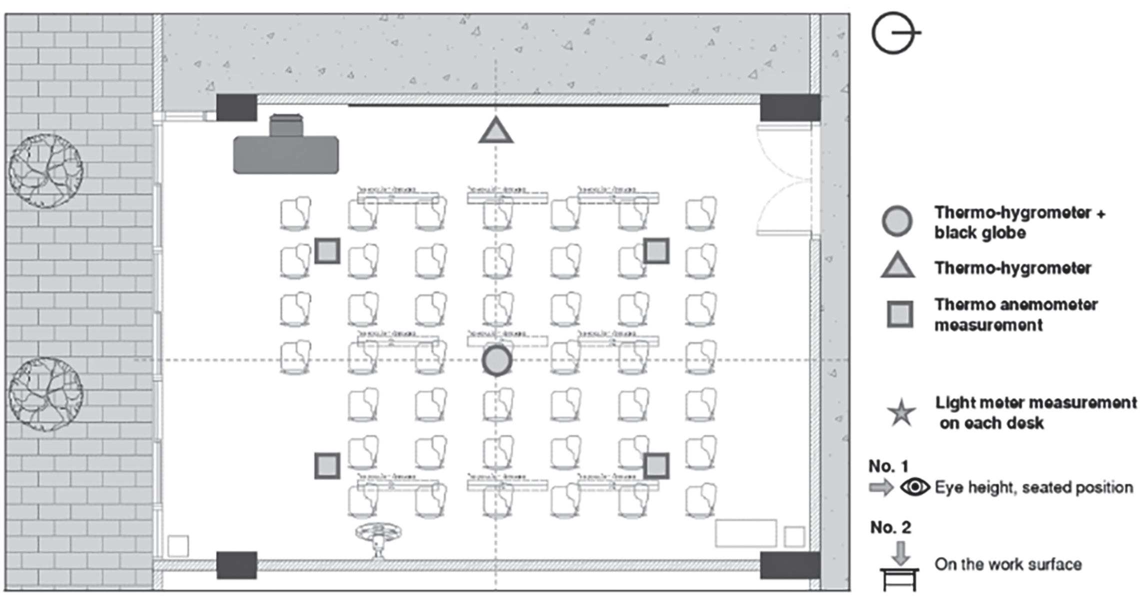
2.4.2 Cognitive performance evaluation instruments

For the evaluation of the cognitive performance of the students, the Infantile Neuropsychological Evaluation (ENI), elaborated by Matute, Rosselli, Ardila and Ostrosky-Solís (Matute et al. 2007), was utilized to analyze the Neuropsychological processes, called domains, of children

TABLE 4. Measurement instruments of the thermal and lighting variables.

Variable	Unit of measurement	Report Frequency	Equipment	Location
Wind Speed	m/s	15 seconds	Thermo anemometer	4 zones of the classroom
Work plane or Horizontal illuminance	lx	2 times in total. Horizontal illuminance 1 and horizontal illuminance 2	Light meter	Work plane of each subject
Vertical Illuminance at eye height	lx	2 times in total. Vertical illuminance 1 and vertical illuminance 2	Light meter	Eyes of each subject
Air Temperature	°C	1 minute	Thermo-hygrometer	Center of the classroom
Radiant Temperature	°C	1 minute	Thermo-hygrometer + black globe	Center of the classroom
Relative Humidity	%	1 minute	Thermo-hygrometer	Center of the classroom

FIGURE 5. Measurement equipment placement in the classrooms.



between five and sixteen years old. The test has been standardized with public and private school samples, and it is considered to be reliable and valid for test–retest and expert judgment applications, as well as for correlations with other cognitive assessment tests. It was selected for this study because it was developed in Spanish, is validated for Colombian children, and can be applied to groups. For this work, the visual attention and graphic fluidity domains were assessed, with two tests each domain (see Appendix B).

The visual attention tests measure the ability of students to select a relevant stimulation and stay focused on a task. The graphic fluidity test assesses the students' ability to have an effective, creative and socially accepted conduct (Tirapu-Ustárroz et al. 2005).

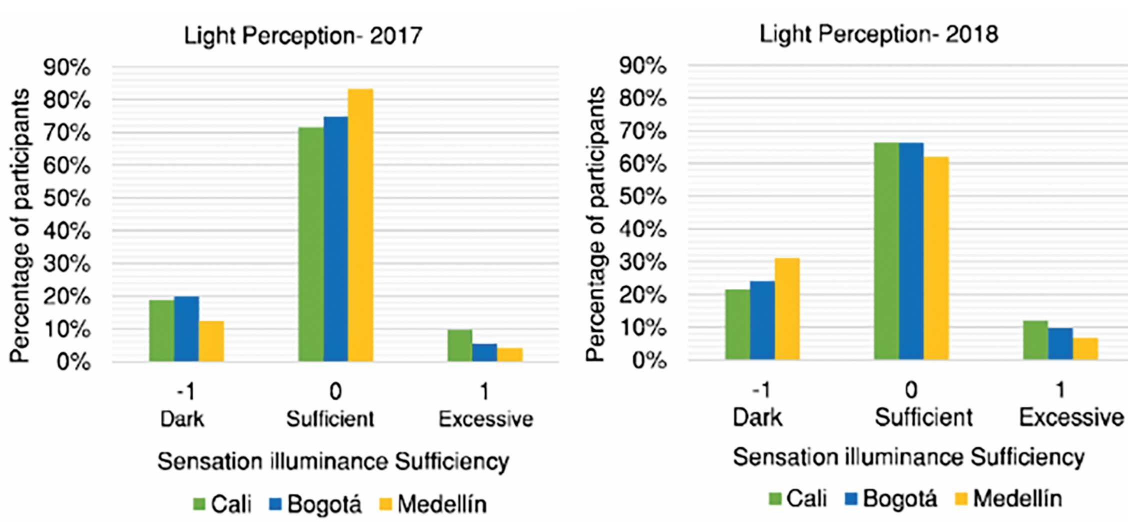
The tests were applied in the same order, following a structured protocol to administrate them and repeating the process in the same way every time, because it is necessary to apply psychological tools to ensure the reliability of the results in those conditions. Additionally, applying the attention tests first prevented the subjects from having fatigue due to the application time. In this way, the establishment of a detailed protocol minimizes the evaluator effect and the evaluation situation of the subjects, allowing for a homogeneity in the assessment of the different subjects, classrooms, and schools.

3. RESULTS

3.1 Lighting Assessment

The results of the surveys display a similar behavior in both years, with a greater percentage (between 60% to 70%) concentrated in the sufficient category, followed by the insufficient category (12% to 32%), and finally, the excessive category, with a percentage below 12% (see Figure 6). The analysis per year shows that in 2017, in the 3 cities, the percentage of students who perceived a sufficient lighting level was over 70%, whereas in 2018, it had a slight decrease, at over 60%. On the other hand, while in Bogota and Cali, the students' behavior was similar in both years, a difference appeared in Medellin between 2017 and 2018 among those who perceived the lighting environment as sufficient (20% higher in 2017) and those who perceived the spaces as dark (18% higher in 2018).

FIGURE 6. Proportion of participants versus perception of lighting level.



Regarding the horizontal illuminances recorded, there were differences between the 3 cities and both years assessed. In both years, the lowest horizontal illuminances were registered in Medellin, with values below 300 lux on the table for over 60% of the students in 2018. Meanwhile, Bogota and Cali displayed close records (60% and 55%, respectively) in the rank of +500 lx in 2018, with the most significant difference between the ranks of 100–300 lux and 300–500 lux. Figure 7 shows higher lighting levels recorded in Cali in 2017.

On the other hand, regarding the vertical illuminance, differences per year and city are shown. In 2017, Bogota had 48% of the participants in the low illuminance rank (100–300 lux), Medellin had 45% with illuminances within the proper rank (300–500 lux), and Cali had 48% in the high rank (+500 lux). By 2018, in the first cities, those percentages decreased, while in Cali, they reached 55% in the high rank (+500 lux) (Figure 8).

When comparing the horizontal (Figure 7) and vertical illuminance (Figure 8), it can be seen that, in Cali, the values of vertical illuminance were similar to the horizontal ones in both

FIGURE 7. Proportion of participants versus registered horizontal illuminance levels.

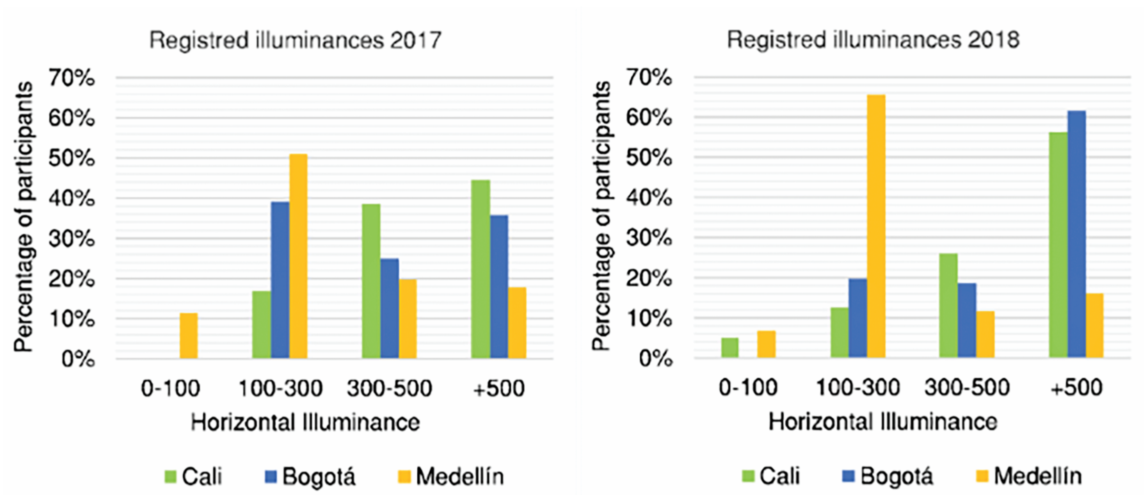
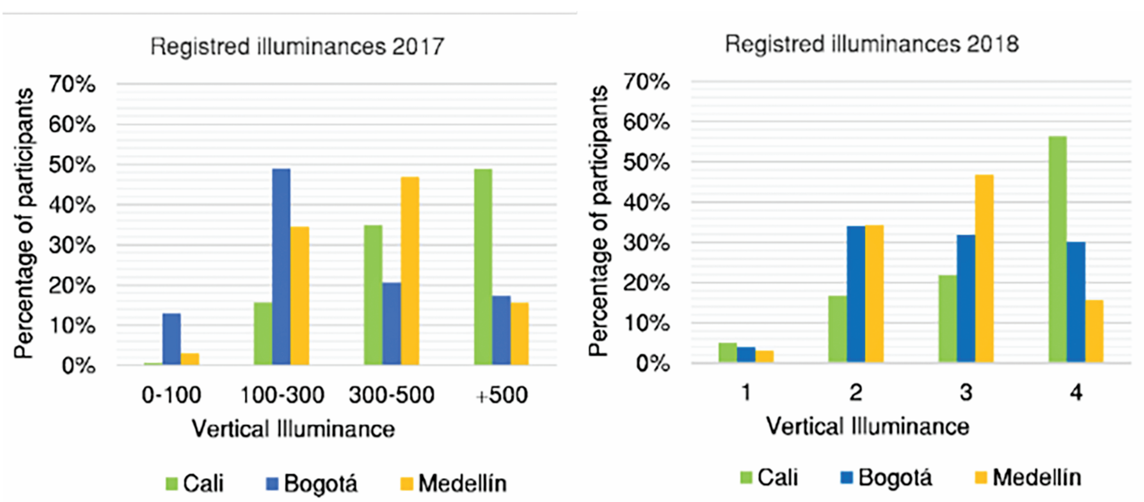


FIGURE 8. Proportion of participants versus vertical illuminance levels recorded in workstations.



years. Meanwhile, in Bogota, there is a trend toward vertical illuminance levels being lower than horizontal ones, which is contrary to what happens in Medellin, where the vertical illuminances are superior to the horizontal ones.

Since the data of illuminances did not display a homogenous distribution in the Kolmogorov Smirnov normality test carried out, an analysis of the difference of averages was conducted in more than two independent samples using the Kruskal Wallis Test in order to prevent extreme data from affecting the results. The results displayed in Table 5 express significant differences in the vertical and horizontal illuminances of the three cities assessed for the total sample and for the data obtained during the different periods of the year. Cali was the city that obtained the most quantity of values over the mean in the four illuminances levels. Medellin had the fewest values over the mean in the horizontal illuminance.

Then, a Spearman correlation of the illuminance levels was conducted using the results of attention levels and graphical fluidity tests, in each city. The variable age was included in order to determine if it had some interference in the cognitive processes assessed. Table 6 shows that in Cali, the horizontal illuminance 1 has an inverse relationship with the errors in letter cancellation and a direct relationship with the non-semantic fluidity, which means that when horizontal illuminance 1 increases, the errors in the attention test decrease, and the performance in non-graphical fluidity increases (to create figures from points in a period of 3 minutes). Horizontal

TABLE 5. Significant differences between the cities for the recorded illuminances.

		Total sample					Year 2017		Year 2018	
	City	N 873	Kruskal-Wallis H Test Sig.	Mean	> Mean	<= Mean	N 354	Kruskal-Wallis H Test Sig.	N 519	Kruskal-Wallis H Test Sig.
Horizontal Illuminance 1	Cal.	285	203,999 2 ,000	391	182	103	166	59,684 2 ,000	119	154,237 2 ,000
	Bog.	269			178	91	92		177	
	Med.	319			74	245	96		223	
Vertical Illuminance 1	Cal.	285	71,076 2 ,000	392	198	87	166	79,947 2 ,000	119	19,658 2 ,000
	Bog.	269			112	157	92		177	
	Med.	319			124	195	96		223	
Horizontal Illuminance 2	Cal.	285	191,008 2 ,000	380	184	101	166	31,870 2 ,000	119	169,196 2 ,000
	Bog.	269			176	93	92		177	
	Med.	319			76	243	96		223	
Vertical Illuminance 2	Cal.	285	50,569 2 ,000	383	194	91	166	57,029 2 ,000	119	19,275 2 ,000
	Bog.	269			117	152	92		177	
	Med.	319			124	195	96		223	

TABLE 6. Relationship between the thermal variables recorded and the results of the cognitive tests in Cali.

		Successes in Drawing Cancellation	Errors in Drawing Cancellation	Total (successes – errors) for Drawing Cancellation	Successes in Letter Cancellation	Errors in Letter Cancellation	Total (successes – errors) for Letter Cancellation	Semantic Fluidity	Non-semantic Fluidity
Horizontal Illuminance 1	Correlation Coeff.	–.029	–.052	–.006	.055	–.124*	.080	.097	.118*
	Sig. (bilateral)	.628	.383	.925	.359	.037	.176	.104	.047
	N	285	285	285	285	285	285	285	285
Vertical Illuminance 1	Correlation Coeff.	.037	–.009	.048	.050	–.087	.062	.121*	.062
	Sig. (bilateral)	.531	.878	.420	.404	.144	.300	.041	.297
	N	285	285	285	285	285	285	285	285
Horizontal Illuminance 2	Correlation Coeff.	.026	–.053	.038	.053	–.113	.079	.133*	.069
	Sig. (bilateral)	.658	.368	.520	.369	.056	.182	.025	.245
	N	285	285	285	285	285	285	285	285
Vertical Illuminance 2	Correlation Coeff.	.067	–.032	.073	.073	–.102	.086	.132*	.014
	Sig. (bilateral)	.260	.591	.216	.219	.086	.146	.026	.811
	N	285	285	285	285	285	285	285	285
Age	Correlation Coeff.	.140*	–.024	.132*	.071	–.026	.082	.167**	–.004
	Sig. (bilateral)	.018	.685	.026	.234	.657	.167	.005	.950
	N	285	285	285	285	285	285	285	285

**. The correlation is significant at a 0.01 level (bilateral).
*. The correlation is significant at a 0.05 level (bilateral).
City = Cali

illuminance 1 and vertical illuminances 1 and 2 showed a direct relation with semantic fluidity (greater number of drawings in three minutes). However, the semantic fluidity in this group also showed a significant direct relation with age.

The results of the successes and errors in the Letter Cancellation test of children in Bogota are shown in Table 7. The results demonstrate a better performance in the attention test, when the illuminance levels are lower. While for the verbal fluidity test, the children in Bogota had a similar performance to that of the children in Cali, as shown in the previous table, the superior illuminance levels favor a greater performance in the graphical fluidity test at the semantic level (to make a greater number of drawings under specific conditions in 3 minutes).

TABLE 7. Relationship between the thermal variables recorded and the results of the cognitive tests in Bogota.

		Success in Drawing Cancellation	Errors in Drawing Cancellation	Total (successes – errors) for Drawing Cancellation	Successes in Letter Cancellation	Errors in Letter Cancellation	Total (successes – errors)	Semantic Fluidity	Non-semantic Fluidity
Vertical Illuminance 1	Correlation Coef.	–.106	–.060	–.104	–.217**	.111	–.216**	.163**	.046
	Sig. (bilateral)	.084	.330	.089	.000	.070	.000	.007	.456
	N	269	269	269	269	269	269	269	269
Vertical Illuminance 1	Correlation Coef.	–.103	–.046	–.101	–.202**	.150*	–.208**	.143*	.084
	Sig. (bilateral)	.092	.448	.099	.001	.014	.001	.019	.168
	N	269	269	269	269	269	269	269	269
Horizontal Illuminance 2	Correlation Coef.	–.084	–.065	–.082	–.175**	.123*	–.173**	.166**	.073
	Sig. (bilateral)	.172	.285	.182	.004	.044	.005	.006	.233
	N	269	269	269	269	269	269	269	269
Vertical Illuminance 2	Correlation Coef.	–.089	–.064	–.086	–.179**	.139*	–.182**	.151*	.079
	Sig. (bilateral)	.145	.299	.160	.003	.023	.003	.013	.194
	N	269	269	269	269	269	269	269	269
Age	Correlation Coef.	.031	–.127*	.035	.058	–.052	.073	–.035	.082
	Sig. (bilateral)	.611	.037	.572	.346	.400	.236	.571	.181
	N	269	269	269	269	269	269	269	269

** The correlation is significant at a 0.01 level (bilateral).
* The correlation is significant at a 0.05 level (bilateral).
City = Bogota

The correlation analysis conducted in Medellin did not show significant relations between the illuminance levels and the performance of children in the cognitive tests of attention and graphical fluidity.

Overall, although the measurements were not made exclusively with natural light but with conjugated light, the results are consistent with the findings of the Heschong Mahone Group (Heschong Mahone Group 1999b; a), and Davis (Davis 2003a; b), because some relations between the lighting level of the classrooms and the cognitive tests are demonstrated. However, these relations are not definitive. This lack of strength in the relationship might be due to the adaptation capacity of the people (Murillo and Martinez-Garrido 2012; Trebilcock Kelly, Maureen; Soto Muñoz, Jaime; Figueroa San Martin, Rodrigo; Piderit-Moreno 2016) and to the differences in their visual requirement for the application of the tests.

3.2 Thermal Assessment

For the analysis of the thermal comfort, the scale of thermal sensation was used: cold (–3), cool (–2), slightly cool (–1), neutral (0), slightly warm (+1), warm (+2), hot (+3). Votes for the three central values of the scale (–1, 0, +1) are considered votes for comfort, and the rest are considered votes for discomfort due to heat (+2 and +3) and cold (–2 and –3), (ASRHAE 2005).

3.2.1 Survey and measurement results

During both moments of the study, most of the students perceived the thermal environment as comfortable, with over 76% of votes for the three central categories of –1, 0, +1, which are assumed to be votes for comfort (Nematchoua et al. 2014; Wong and Khoo 2003), which is higher than the percentage of votes for discomfort due to heat (+2, +3) and those for discomfort due to cold (–2, –3), (See Figure 9).

In 2017, the perception of comfort was superior in Medellin (83.3%) and Bogota (82.6%), with a Ta of 23.4°C and 67.3% RH and 21.5°C and 58.6% RH, respectively (Table 1). Finally, in Cali, the comfort percentage was 77.1%, with the highest Ta at 25.8°C, with 70.3% RH.

Regarding the discomfort votes, although lower, Bogota displayed most discomfort votes due to heat (16.3%), being the city with the lowest temperatures, followed by Medellin (11.4%) and Cali (10.2%), which indicates that those who are accustomed to high temperatures, as in the case of Cali and Medellin, tolerate those temperatures more easily, and they do not perceive those temperatures as uncomfortable. To further prove the previous statement, the greatest discomfort due to cold appeared in Cali (5.4%), followed by Medellin (5.2%) and, finally, Bogota (1.1%).

While in 2018, the Ta increased in Cali (26.3°C) and in Medellin (26°C), these remained within the expected rank, with most votes for comfort, at 76.5% and 71.7%, respectively. These results are consistent with studies of naturally ventilated classrooms in terms of comfort, with temperatures within the limit determined by the normative (Baruah et al. 2014; Hwang et al. 2006). On the contrary, in Bogota, the Ta remained close to that of the previous year (21.3°C), with 77.4% comfortable votes. Regarding discomfort, it increased due to heat in Cali (17.6%) and Medellin (22.9%), while in Bogota, it remained similar (17.5%).

The Kruskal Wallis Test was carried out using the air temperature (Ta), operative temperature (To) variables and the difference between the operative temperature and temperature

FIGURE 9. Proportion of participants versus thermal sensation.

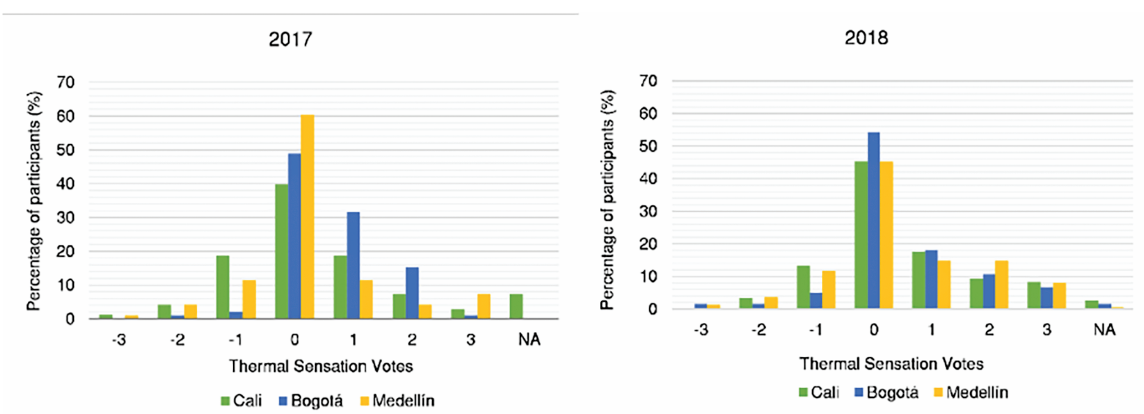


TABLE 8. Votes regarding thermal sensation in 2017 and 2018.

YEAR	CITY	RH (%)	Ta (°C)	CLO	PERCENTAGE OF THERMAL SENSATION VOTES								TOTAL (%)
					–3	–2	–1	0	1	2	3	NA	
2017	Cal	70.3	25.8	0.61	1.2	4.2	18.7	39.8	18.7	7.2	3.0	7.2	100
					5.4		77.1			10.2		7.2	
	Bog	58.6	21.5	0.79	0.0	1.1	2.2	48.9	31.5	15.2	1.1	0	100
					1.1		82.6			16.3		0	
	Med	67.3	23.4	0.62	1.0	4.2	11.5	60.4	11.5	4.2	7.3	0	100
					5.21		83.3			11.4		0	
2018	Cal	69.8	26.3	0.68	0.0	3.4	13.4	45.4	17.6	9.2	8.4	2.5	100
					3.4		76.5			17.6		2.5	
	Bog	50.2	21.3	0.87	1.7	1.7	5.1	54.2	18.1	10.7	6.8	1.7	100
					3.4		77.4			17.5		1.7	
	Med	54.6	26.0	0.67	1.3	3.6	11.7	45.3	14.8	14.8	8.1	0.4	100
					4.9		71.7			22.9		0.4	

of comfort (To-Tcomf), calculated through equation 1, in order to determine the existence of significant differences between the cities and the total sample, and between the cities. Table 9 displays significant differences in the temperatures of the three cities, with diverse measurements. From these results, it can be inferred that, from the thermal point of view, the cities assessed represent different climatic conditions. In the total sample, the air temperature had a

TABLE 9. Significant differences in the thermal variables by city.

	City	Total sample					Year 2017		Year 2018	
		N 873	Kruskal-Wallis H test Sig.	Mean	> Mean	<= Mean	N 354	Kruskal-Wallis H test Sig.	N 519	Kruskal-Wallis H TestSig.
Ta	Cal	285	492,486	23.60	185	100	166	229,804	119	306,132
	Bog	269	2		13	256	92	2	177	2
	Med	319	0,000		122	97	96	0,000	223	0,000
To	Cal	285	211.862	24.11	157	128	166	232,450	119	302,398
	Bog	269	2		50	219	92	2	177	2
	Med	319	0,000		212	107	96	0,000	223	0,000
To-Tcomf	Cal	285	89,572	–0.697	144	141	166	11,304	119	162,244
	Bog	269	2		70	199	92	2	177	2
	Med	319	0,000		212	107	96	0,004	223	0,000

higher number of records above the mean in Cali, whereas the operative and neutral temperature had a higher number of records above the mean in Medellin. Bogota had the highest number of records below or equal to the mean at the three temperatures. However, in spite of the differences found, the students did not perceive extreme conditions of discomfort, which is comparable to the findings of similar studies made in two periods of the year (Baruah et al. 2014).

The highest percentage of the operative temperature (To) values was in the rank of comfort on the adaptive model (see equation 2). According to this model, discomfort due to cold appeared mainly in Bogota, followed by Medellin, whereas discomfort due to heat mostly appeared in Medellin and Cali. The previous data show the variability of temperatures that appeared in Medellin in both years, which is completely different than that in Bogota and Cali, where the situation was constantly cold and hot, respectively. To verify if the difference in the operative temperature classification according to the adaptive model differs significantly between the cities, a chi-squared test was carried out for the difference of proportions. The results in Table 10 express the significant differences (sig. 0.00 Chi-squared 136.306, df 4 for 873 valid cases) between the cities for the stated variables.

In order to delve into the relationship between thermal conditions and cognitive performance, an association test was carried out (see Table 11) between the classification of the comfort zone according to the adaptive model and the levels of cognitive performance of the total sample. To analyze the data, in the table, under 25% was assumed to be a low performance result, and high performance results were assumed to be over 75%. There were significant associations (sig. 0.029 squared Chi 10.770, df 4 for 873 valid cases) with the performance level in the attention tests (drawings and letters), where the highest percentage (78%) of successes in the test was found in temperatures within the comfort rank.

Additionally, the table shows that the proportion of successes between medium and high was greater for those students located in the comfort zone (74.7%), compared with those students located in the discomfort due to cold zone (67.5%) and discomfort due to heat zone (67.4%). Other studies showed a significant relationship between the discomfort votes and percentages between 34% and 48% of the variations in the test scores (Hoque and Weil 2014).

The scores were standardized for the different tests of temperature and cognitive performance, and a Spearman correlation was carried out for the data with abnormal behavior. Age was included as a variable that was possibly involved. Regarding the operative temperature and the difference between the operative temperature and comfort temperature, Table 12 shows an inverse relationship with successes in the attention tests (drawing and letter cancellation) and a

TABLE 10. Relation of records of the operative temperature and comfort zone.

City	Classification of the operative temperature according to the adaptive model			Total
	Discomfort by cold (To < Taccept)	Comfort zone	Discomfort by heat (To > Taccept)	
Bogota	17	252	0	269
Cali	0	236	49	285
Medellin	14	193	112	319
Total	31	681	161	873

TABLE 11. Association between the comfort zone ZC of the adaptive model and performance in terms of successes in drawing.

	Proportion of successes						Total	
	Low		Medium		High			
	f	%	f	%	f	%	f	%
Discomfort due to cold (To < Taccept)	10 (32.5%)		14 (45%)		7 (22.5%)		31 (3.5%)	
Comfort zone (ZC)	171 (25.1%)		305 (44.7%)		205 (30%)		681 (78%)	
Discomfort due to heat (To > Taccept)	52 (32.3%)		80 (49.6%)		29 (18%)		161 (18.5%)	
Total	233		399		241		873 (100%)	

TABLE 12. Correlation between thermal variables and the results of the cognitive tests in Cali.

			Success in Drawing Cancellation	Errors in Drawing Cancellation	Total (successes – errors) for Drawing Cancellation	Successes in Letter Cancellation	Errors in Letter Cancellation	Total (successes – errors) for Letter Cancellation	Semantic Fluidity	Non-semantic Fluidity
To	Pearson Correlation	–.128**	0.046	–.135**	–.268**	.132**	–.183**	0.037	.130**	
	Sig. (bilateral)	0.000	0.172	0.000	0.000	0.000	0.000	0.269	0.000	
	N	873	873	873	873	873	873	873	873	
To-Tcomf	Pearson Correlation	–.154**	0.005	–.155**	–.185**	.147**	–.104**	0.016	.114**	
	Sig. (bilateral)	0.000	0.881	0.000	0.000	0.000	0.002	0.642	0.001	
	N	873	873	873	873	873	873	873	873	
Age	Pearson Correlation	.094**	0.043	.088**	–0.041	–0.012	–0.030	0.064	0.030	
	Sig. (bilateral)	0.005	0.203	0.009	0.224	0.731	0.369	0.057	0.376	
	N	873	873	873	873	873	873	873	873	

*The correlation is significant at a 0.05 level.

** The correlation is significant at a 0.01 level.

direct relationship with the errors in letter cancellation. This discovery is consistent with studies that found an inverse relation between temperature and work speed, attention and deduction (Jiang et al. 2018), as well as other studies made by Wargocki, Wyon, Matysiak and Irgens, which found a direct relation with a decrease in attention errors of 10% (Wargocki et al. 2005). In this respect, cognitive performance is higher when there is thermal comfort, as indicated on previous work (Hoque and Weil 2016), although the results are not absolutely conclusive.

Nevertheless, the findings of the current research contradict the hypothesis maintained by the adaptive model, which states that those students accustomed to a warm climate do not see an effect in their performance due to temperature variations, which is mainly due to factors like being accustomed to the temperature and adaptation capacity to those environments.

In addition, the table also shows a direct relation between operative temperature and non-semantic fluidity and between the difference between the operative temperature and comfort temperature and the non-semantic fluidity. This may be because, unlike the attention tests, the non-semantic fluidity test had a dose of pressure on the participants, because it required them to answer the test in one minute. With this in mind, as shown by Corgnati et al. (2007), the sensation of thermal comfort can significantly affect performance.

Special care must be taken when interpreting the relationships mentioned with the successes in drawing cancellation tests, since Table 14 shows the relationship with age, and there could be interference in age, as similar studies made by age ranks indicate (Corgnati et al. 2007).

On the other hand, the tests with the statistical chi squared do not express an association between the thermal sensation votes of the students (comfort, discomfort due to cold and discomfort due to heat) and the performance in the cognitive tests (high, medium and low). This reaffirms the discoveries of other studies, developed in iberoamerican classrooms with acceptable environmental conditions, which have not found statistically significant relations between performance tests and perception of comfort (Murillo and Martinez-Garrido 2012).

3.3 Multiple hierarchical regressions

The previous analysis shows significant buy weak relations between the studied variables. Therefore, aiming to understand how combined variables affect the cognitive performance, better than separated variables, there were conducted multiple hierarchical regressions, in which every variable was added as a step. To gain statistical power, all the participants (of the three cities and two periods) were evaluated together in one group, because the one-way ANOVA test shows more variations with each city data, instead of between all of them. To define how the variable age could explain the variance better that any other environmental variable, it was controlled by introducing it in the step one of the analysis models of Attention and Executive Function dependent variables. Table 13 shows the Pearson correlation of all participants sample, including Vertical and Horizontal Illuminance normalized by Lg10.

As shown in Table 13, neither of the variables shown a strong correlation with cognitive performance variables (attention and executive function), but the small correlations were significant. Therefore, there were carried out hierarchical lineal regressions between the variables that shown significant relations and the variables that indicated good cognitive performance (correct answers on drawing cancellations, correct answers on letter cancellations, semantic fluidity and non-semantic fluidity). In Table 14 is presented the model that got the greater contribution to a significant r2 value and big enough on the thermal and lighting variables. This, having into account that the cognitive performance is a psychological variable that can

TABLE 13. Correlation coefficients of model variables.

	1	2	3	4	5	6	7	8
1 Ta	1							
2 To	.990**	1						
3 Thermal sensation	.763**	.768**	1					
4 To – Tcomf	.909**	.927**	.825**	1				
5 Horizontal Illuminance 1 Lg10	–.117**	–.108**	–.145**	–.068*	1			
6 Vertical Illuminance 1 Lg10	.075*	.076*	–.029	.038	.722**	1		
7 Horizontal Illuminance 2 Lg10	–.124**	–.112**	–.096**	–.074*	.576**	.410**	1	
8 Vertical Illuminance 2 Lg10	.040	.039	–.032	.008	.606**	.741**	.605**	1
9 Right answers on drawing cancellation	–.110**	–.128**	–.081*	–.154**	.042	–.023	.054	–.004
10 Right answers on letter cancellation	–.249**	–.268**	–.077*	–.185**	.000	–.090**	.109**	–.041
11 Semantic fluidity	.049	.037	.055	.016	–.005	.053	.046	.084*
12 Non-semantic fluidity	.136**	.130**	.093**	.114**	–.030	.053	–.006	.048
13 Age	.040	.023	–.022	–.132**	.005	.092**	–.023	.073*

**. The correlation is significant at a 0.01 level (bilateral). *. The correlation is significant to a 0.05 level (bilateral).

be explained by multiple individual, contextual variables and/or other environmental variables as ventilation rate (Haverinen-Shaughnessy et al. 2011), which were not analyzed in this study. It was excluded from this model the air Temperature (Ta) because it showed collinearity. The other variables had scores above 3, which suggest no multicollinearity. Before the analysis it was verified that the theoretical assumptions underlying multiple regression including normality, linearity and homoscedasticity were met.

The regression analysis conducted on the complete data shows that the considered predictors (To, To-Tcomf, Thermal sensation, Vertical Illuminance 1 Lg10 and Horizontal Illuminance 2 Lg10) on the model, produce a significant contribution [$F(6,866) = 19,203$), $p < .001$] to the degree of explaining a 13% variance on the Cognitive Attention Performance (letter cancelation test). Excepting the variable age, all the variables significantly contributed to the prediction. The greater contribution was from To.

4. CONCLUSIONS

From the thermal point of view, the results demonstrate significant differences between the temperatures (To, Ta, To-Tconf) of the classrooms in the 3 cities; however, most of the students expressed a sensation of comfort. The previous statement can be a result of the students being

TABLE 14. Hierarchical Regression predicting Attention (correct answers on Letter cancellations).

Model	Predictors			β	R2
Step 1	Age		F(1,871) = 1,480), p .224	–.041	.002
Step 2	Control	Age		–.035	.073
	Predictor	To	F(2,870) = 31,942), p < .001	–.268***	
Step 3	Control	Age		.042	.103
		To		–.736***	
	Predictor	To – Tcomf	F(3,869) = 29,859), p < .001	.503***	
Step 4	Control	Age		.018	.120
		To		–.715***	
		To – Tcomf		.286**	
	Predictor	Thermal sensation	F(4,868) = 26,180), p < .001	.237***	
Step 5	Control	Age		.022	.122
		To		–.707***	
		To – Tcomf		.287**	
		Thermal sensation		.227***	
	Predictor	Vertical Illuminance 1 Lg10	F(5,867) = 21,245), p < .001	–.042	
Step 6	Control	Age		.023	.132
		To		–.658***	
		To – Tcomf		.251*	
		Thermal sensation		.230***	
		Vertical Illuminance 1 Lg10		–.091*	
	Predictor	Horizontal Illuminance 2 Lg10	F(6,866) = 19,203), p < .001	.114**	

***p = 0.000 **p < .01; *p < .05; p < .10†; β = Standardized beta; R2 = Coefficient of determination accustomed to the environment and the adaptation capacity of people in latitudes near the Equator line regarding environmental conditions that are either too cold or too hot, with slight variations throughout the year. However, a slight tendency is evident toward discomfort due to heat for the students of Medellin and Bogota, who are accustomed to lower temperatures, reflecting a greater sensitivity to increases in temperature during the study.

The results also demonstrate significant differences between the proportions of people by city who would be cold, hot or in a comfort zone according to the adaptive model. The results of the calculations using the adaptive model are consistent with the votes of the students in Cali and Medellin. However, for Bogota, the thermal sensation of the students does not necessarily agree with the results of the adaptive model. This may be explained by the low natural ventilation rate in the classrooms of Bogota.

In spite of this, the operative temperature turned out to be the most conclusive variable explaining cognitive performance relationships, and the adaptive model therefore had a greater utility for the analysis, while the thermal sensation votes did not have any relation with the cognitive performance:

- It is evident that there is a significant association between the successes in the drawing attention test and the comfort ranks according to the adaptive model.
- The results demonstrate that a higher operative temperature yields a lower number of successes and a higher number of errors in the attention tests. This relationship also exists when the difference between the operative temperature and comfort temperature is positive, that is to say, when the heat sensation tends to increase according to the adaptive model.
- The non-semantic fluidity test showed a direct relationship with the operative temperature and with the difference between the operative temperature and comfort temperature, that is to say, a higher heat sensation was related to a better performance. Other studies are needed to delve into the explanation of the relationship, which may be due to the longer duration of the execution time of the test (3 minutes), motivation to involve a creative process, etc.

From the point of view of lighting, the results demonstrate that, irrespective of the lighting level, most students expressed that the lighting level was sufficient to perform the typical activities that take place in the classroom. In addition, the results of the measurements demonstrated differences between the cities regarding the magnitude between the vertical illuminance and horizontal illuminance, which is probably due to the configuration of the facades of those classrooms.

The lighting level may influence the cognitive performance of students: The results of the relation between lighting levels and performance on the tests show, overall, a direct relationship between illuminances and semantic fluidity tests. Despite this, relations are weak, as shown by Liu et al. (2020). Meanwhile, there are differences between the cities in the relationship between the lighting level and attention tests. In order to delve into this, studies will be necessary to consider the differences between horizontal illuminance and vertical illuminance and adaptation to lighting conditions, according to the indoor and outdoor illuminance availability.

The hierarchical regression predicting attention (correct answers on letter cancellations) confirmed that the variations on the attention variable (letter cancellations) are significantly explained by the identified predictive effects. The results show that the thermal factors like operative temperature (To), the difference between the operative temperature and comfort temperature (To-Tcomf) and thermal sensation as well as the horizontal illuminance have a strong relation with the cognitive attention performance.

Regarding the methodology, the combined use of specific instruments from different disciplines generated complex and differentiated results. It is important to mention that the methodological design may be applied in other contexts and normative frameworks at a national level, as well as an international one, thanks to the mixed approach, because objective and subjective information was considered. This will allow new discoveries to be correlated and conclusions at other levels to be generated. In future research it is suggested to measure the operative temperature simultaneously in various points in the classroom so that better precision of this variable can be achieved, which proved to be so important.

This survey had a methodology focused on a real field study instead of a controlled laboratory environment and was based on public schools of the Colombian territory; therefore, the data collected was limited to typical environmental conditions of classrooms, in which the space could be modified by the users to meet certain desired conditions, as is usually made. This made the search of possible associations between the environmental and cognitive variables, more complex. Furthermore, this kind of transversal correlational regression study can only establish associations between the environmental and cognitive variables, without considering the other environmental and/or personal variables that by multicausality could have an influence on the relation. In future research it is suggested to enlarge the number of participants.

Thanks to the important background search that was conducted when facing the investigation problem, the methodological design was strengthened by means of putting together tools, methods and approaches from several areas of knowledge. This generated interesting results, to which there are currently no approaches at the national level, and enriching discussions on the topic, which are related to other studies.

It is fundamental that, in this type of study, where people from different sociocultural contexts take part, and it is conducted in several locations, all the procedures carried out are the product of rigorous planning, and their importance is validated through pilot tests. Thus, the occurrence of systematic errors can be avoided when applying the instruments.

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APPENDIX A

Thermal perception and preference survey

Name:		Date:
Grade:	Gender:	Age:

The aim of this survey is to find out how are you feeling right now, about which you will find some questions below. Try to answer the questions as quickly as possible. There are no correct or incorrect answers. Mark your answer with an X.

1. To read and write on this form, I think my desk has:

    ____ Little light

    ____ Enough light

    ____ Too much light

2. I would rather my desk had:

    ____ More light

    ____ Less light

    ____ The same amount of light

3. To read and write on this form:

    ____ I can see properly, and there are not annoying glares.

    ____ I can see properly, but there are annoying glares.

    ____ I cannot see properly, because there are annoying glares.

    ____ I can see properly for another reason, which is: ____________________

4. At this moment, I feel that the temperature is:

    ____ Too hot

    ____ Hot

    ____ A little hot

    ____ Normal (I'm not hot or cold)

    ____ A little cold

    ____ Cold

    ____ Too cold

5. In this moment I would like the temperature to be:

    ____ A lot hotter

    ____ A little hotter

    ____ Like it is now

    ____ A little colder

    ____ A lot colder

6. I would rather the classroom:

    ____ Have more wind

    ____ Stay the same

    ____ Have less wind

7. Mark with an X all the clothes you are wearing right now:

8. At this moment, I think about the wind that:

    ____ I like it, because it is hot, and it refreshes me.

    ____ I like it, because it is (cool) fresh.

    ____ I do not like it, because it is not enough, it is hot, and it does not refresh me.

    ____ I do not like it, because I am cold, and it is making me feel colder.

APPENDIX B

For the evaluation of the cognitive performance, the Infantile Neuropsychological Evaluation (ENI), elaborated by Matute, Rosselli, Ardila and Ostrosky-Solís (Matute et al. 2007), was utilized to analyze the Neuropsychological processes, called domains, of children between five and sixteen years old. The test has been standardized with public and private school samples, and it is considered to be reliable and valid for test–retest and expert judgment applications, as well as for correlations with other cognitive assessment tests. It was selected for this study, because it was developed in Spanish, is validated for Colombian children, and can be applied to groups. For this work, the visual attention and graphic fluidity domains were assessed, with two tests for each domain.

The visual attention tests measure the students' ability to select a relevant stimulation and stay focused on a task. The graphic fluidity test assesses the students' ability to have an effective, creative and socially accepted conduct (Tirapu-Ustárroz et al. 2005).

The tests were applied in the same order, following a structured protocol to administer them and repeating the process in the same way every time, because it is necessary to apply psychological tools to ensure the reliability of the results in those conditions. Additionally, applying the attention tests first prevented the subject from having fatigue due to the application time. In this way, the establishment of a detailed protocol minimizes the evaluator effect and the evaluation situation of the subjects, allowing for homogeneity in the assessment of the different subjects, classrooms, and schools.

Cognitive performance assessment tests, visual attention domain:

Drawing cancellations. This includes a page with 44 big and small rabbits. In one minute, the person must cross out, using a pencil, the biggest rabbits possible. The direct score for this test was taken as the result of the correct answers, minus the incorrect answers (small rabbits crossed out).

Letter cancellations. This includes a page with 82 letters distributed into several lines. In one minute, the person must cross out, using a pencil, the letter "X," only when an "A" is before it. The direct score for this test was taken as the result of the correct answers, minus the incorrect answers.

Cognitive performance evaluation tests, graphic fluidity domain:

Semantic fluidity. This consists of a page with 35 squares of 2.5 cm on each side. The person must draw the most meaningful figures possible in a 3-minute period. One point is given for each right (correct) drawing, and the direct score for this test is the amount of correct answers.

Non-Semantic fluidity. This consists of a page with 35 squares of 2.5 cm on each side. On each of the corners of the squares, there is a black point and a white point in the middle of the square. The person must draw the most geometric figures possible by linking the points with 4 straight lines that touch the white point at least once in a 3-minute period. One point is given for each right (correct) figure, and the direct score for this test is the amount of correct answers.

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