Thermal comfort and air quality in Chilean schools, perceptions of students and teachers

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ABSTRACT: we present findings of naturally ventilated classroom conditions in primary school buildings in the city of Concepción, Chile, where there is no adherence to indoor environmental quality standards. We focused on thermal comfort and environmental perceptions of students and teachers, during fall and winter seasons. The goal is to examine the perceptions of children and teachers by analyzing responses to conditions in their classrooms, related to their socioeconomic context driven by school type. Approximately 888 students, aged 10-14 years old, were surveyed from nine schools during fall season, and 333 students from four schools during winter. A total of 2,271 subject responses were collected in two campaigns. Physical measurements included: ambient air temperature, relative humidity, airspeed, radiant temperature, and CO_2. Simultaneous subjective responses were collected through electronic surveys on tablets which included questions on thermal sensation, thermal acceptability, and thermal preference. We examined thermal sensation trends, perceptions of comfort and air quality, across public, private-subsidized, private-nonsubsidized schools. Results show that about ~80% of teachers and students voted their thermal sensation primarily within the three central categories of the scale (-1, 0, +1). A small distinction can be seen in fall season in the private-subsidized school with a tendency towards a warm thermal sensation (+1), which corresponded to higher indoor temperatures. High indoor CO_2 concentration levels were measured in all of the classrooms, with a maximum of 4327 ppm in winter in public schools, and a minimum of 858 ppm in fall in private-subsidized schools.

KEYWORDS: School buildings, thermal comfort, school children, Field survey, developing country.

INTRODUCTION

School buildings are one of the most critical environments because of the significant amount of time that children spend indoors at school and home during the developmental years of life. Closer attention needs to be paid to the indoor climate of classrooms, to promote comfort and well-being that support academic performance and user satisfaction. Young children are more susceptible to environmental pollutants than adults (Mendell and Heath 2005). Higher temperature and poor ventilation have been identified as elements that create unfavorable effects on children's thermal comfort and performance, as shown in previous fieldwork studies (Cui et al. 2013; Haverinen-Shaughnessy et al. 2015; Bakó-Biró et al. 2012; Mendell et al. 2013). Thermal comfort of occupants in a given environment not only depends on physical parameters but also on the interaction of physiological and psychological factors. Children's physiological characteristics are different from those of adults (e.g. in office settings), which may influence their perception and thermal preference as shown in the literature (Montazami, Gaterell, Nicol, Lumley, & Thoua, 2017; Mors ter, Hensen, Loomans, & Boerstra, 2011; Zomorodian, Tahsildoost, & Hafezi, 2016, Mendell & Heath, 2005). Limited studies exist in which the perspectives of children and teachers regarding their perception of the indoor environment are combined in a single study.

In adaptive thermal comfort, "occupants are deemed as active agents in creating ideal indoor thermal conditions" (Kim and de Dear 2018; Brager and de Dear 1998) through adaptive strategies such as opening windows. In classrooms however, school children have no control over windows, unless directed by a teacher. Additional clothing adaptations are limited because of dress code policies requiring student uniforms.

This study presents fieldwork results of thermal comfort and environmental perceptions of students and teachers in naturally-ventilated primary schools in Southern Chile. This study looks deeper occupant perceptions of classroom environmental conditions, including thermal preferences as related to contextual factors such as a socio-economic status (type of school, home conditions, and health-related symptoms). The study is guided by several research questions: (1) What are the physical conditions of classrooms in schools in Concepción city?; (2) Do expectations of comfort differ between students and teachers?; and (3) Do subjective perceptions of classrooms differ between the types of schools?

1.0. METHODOLOGY

1.1. Field site selection

The fieldwork includes subjective surveys with simultaneous measurements of classroom environmental conditions of schools in the metropolitan area of Greater Concepción (hereafter MACG) in the cities of Concepción and San Pedro de la Paz, at 36ºS of latitude. The MACG is the biggest conurbation outside of Santiago (Chile's capital). Both cities were selected because of their proximity to the city center, similar climate conditions, the highest population of inhabitants, and the number of school buildings within the MACG (i.e., a total of 104 schools from the public, private-subsidized and, private-nonsubsidized sectors).

Climate conditions for Concepción and San Pedro de la Paz, based on the Köppen Classification System are warm-summer Mediterranean (Csb), with relatively cold winters and mild summers. From historical weather data from Climate Consultant 6.0–2018, the range of annual average temperature in Concepción is 13ºC (55.4ºF), an annual average minimum of 8ºC (46.4ºF), an annual average maximum of 18ºC (64.4ºF). The maximum temperature can reach up to 28ºC (83ºF) during the summer months (December through March) and the low temperature can reach -2ºC (28ºF) during winter (June through September). Relative humidity averages can range between 58% and 90%. Sky coverage for this location has an annual average mean of 49%, an average minimum of 18% and the average maximum of 75%. Predominant annual wind direction is from the southwest, and during winter months the predominant wind direction is from north to south with a wind speed of 20 m/s (67 ft/s).

1.2. School selection and classroom description

Three types of schools exist in Chile: public, private-subsidized, and private-nonsubsidized. The differences among the three types are related to ownership, administration, socioeconomic level of the families, the index of vulnerability (IVE-SINAE index); developed by the government which measures the social vulnerability of students. This index is based on a set of criteria that allows identifying different groups of the populations of students in primary and secondary education according to the level of vulnerability they present. "Vulnerable" is classified into three hierarchy priorities: 1) socioeconomic risk, 2) socio-educational risk related school performance, attendance or desertion of the educational system, and 3) same socioeconomic risk as the second priority but without the socio-educational risk related. The IVE-SINAE can also provide subsidies for free breakfast and lunches, as well as other scholarships and government programs. The selection of the participating schools was based on their IVE index range: 100%-70% (IVE) for public school, 69%-20% (IVE) for private-subsidized and 19%-0% (IVE) for private-nonsubsidized schools. Previous studies on thermal comfort and environmental conditions in classrooms (Soto-Muñoz et al., 2015; Trebilcock et al., 2016b and Almeida et al., 2010), were performed in public school settings only. This study provides new research for other school types.

Nine schools participated in this study: four public, two private-subsidized and three private-nonsubsidized across Concepción and San Pedro de la Paz. For more detailed information, see table 1. The selection criteria included: 1) middle school grade levels (6th to 8th grade); 2) naturally ventilated classrooms; 3) no HVAC system and limited heating; 4) similar heavyweight structure (reinforced concrete or brick with seismic design provisions); 5) similar spatial configuration of classrooms; and 6) classroom space per student ≥ 1.1 m^2 (11.8 ft^2) (classroom density range of 30 to 45 students per classroom). From the nine schools, a total of 28 classrooms were surveyed during fall season, and 11 during winter season. All selected school buildings are multi-story, and surveys were conducted on different floors, depending on classroom location. The average floor area of the classrooms was 50.49 m^2 (543.46 ft^2), much smaller compare to recommend ASHRAE 62.1 (ASHRAE, 2016) occupant density 35/100 m^2 (35/ft^2).

1.3. Subjects

All subjects were from the local area of Concepción and San Pedro de la Paz with a few exceptions of immigrants from Brazil, Haiti, and Venezuela. The selection of middle school students for this study was motivated by the limited number of thermal comfort studies performed on primary schools. Also, in Chilean schools from first to eighth-grade levels, students spend all day in the same classroom versus other schools where the students might move to different classrooms for different subjects. Only the teachers move from one classroom to another. Therefore, groups of students spend a significant amount of time inside the same room, and are familiar with their indoor environment for the entire year. Middle schoolers, sixth through eighth grade, 10-14 years old (e.g., there was one case of a 19-year-old), were chosen for their ability to understand questions and reasoning at that age.

Middle school teachers were also surveyed during the fieldwork at the same time of the students in order to compare their perceptions of the classroom conditions with student responses. Most classroom environments had one teacher, but in some cases, up to three teachers were present in each classroom (headteacher, student teacher, and/or a teacher specialized in learning disabilities).

A total sample size of 888 students and 58 teachers participated in the field survey campaign in the fall season (April and May): 426 males (~48%) and 462 females (~52%). In the winter season, 333 students and 23 teachers participated (July and August): 173 males (~52%) and 160 females (~48%).

2.0. DATA COLLECTION

2.1. Ethical and responsible conduct research

Approval was obtained by the Institutional Review Board (IRB) for research involving human subjects, from both the University of Oregon and the Universidad de Concepción, prior to the start of data collection.

2.2. Measurements of indoor and outdoor environmental parameters

Measurements of indoor and outdoor environmental parameters were obtained: classroom thermal and air quality measurements were taken during the same time as the surveys were administered. In accordance with standards: ISO 7726 “Ergonomics of the thermal environment Instruments for measuring physical quantities” (ISO 7726 2001) and ASHRAE 55-2017 “Thermal Environmental Conditions for Human Occupancy” (ASHRAE, 2017), a Testo 480 data logger, with indoor probes were used to collect ambient air temperature, relative humidity, airspeed, radiant temperature (globe thermometer with a diameter = 150mm), and CO_2 concentration levels. Dylos DC1700 sensors for particle counts at $PM_{2.5}$ and PM_{10} were used. Each parameter was measured at the height of 1.1m (3.6 ft.) above the floor level based on the recommendations of ISO 7726 (ISO 7726 2001) and ASHRAE 55 (ASHRAE, 2017). Outdoor environmental conditions, such as temperature, relative humidity, CO_2, and $PM_{2.5}$ and PM_{10} were also collected for the duration of the study from a local weather station at one of the school sites in Concepción.

For clothing insulation, the checklist from ISO 7730 (ISO 7730 2005) and ASHRAE 55 were used to match CLO levels of Chilean students uniforms and teachers' outfits. For metabolic rate, the students were mostly seated, doing writing or light work, and estimated as "nearly sedentary," equivalent to 1.2 met (70 W/m2 or 22 Btu/h*ft2), according to ISO 7730.

2.3. Survey questionnaire

Multiple versions of the survey questionnaire were checked with an external assistant teacher and university professors to ensure that it was suitable for the age group. The survey design included the use of emoji images and colors for the different scales, as other studies have done (Trebilcock et al. 2017; Teli, James, and Jentsch 2013; Haddad, Osmond, and King 2017). This survey allowed the students to take the survey on a touch-sensitive interface using tablet devices. Offline software (Qualtrics) was used to collect responses. Use of these devices greatly supported engaging the students in the activity, raising interest and participation. The survey was conducted in Spanish; therefore, the scales and questions were translated into that language by the researcher. Prior to carrying out the actual surveys, pilot studies were conducted in order to ensure the proper functioning of tablets, gather feedback on the clarity of the questions, and prepare for logical administration of the surveys.

The questionnaire consisted of five parts: 1) current status of thermal comfort, air movement, and air quality using thermal sensation vote (TSV), air quality sensation vote (AQV), preference and acceptability. This section also included clothing questions regarding items worn during the class visits; 2) personal satisfaction about home and classroom environmental conditions, health-related symptoms experienced in the past; 3) house conditions; 4) impacts of environmental factors on classwork; and 5) general demographic information. For this paper, results from section a portion of section 1 are presented, since data analyses for the other sections are currently in progress.

Survey questionnaires were administered 20 to 30 minutes after students/teachers had settled in their classroom environments. Specific classroom times were selected for visits, to avoid time periods when students had PE class on the day of the survey, to minimize higher activity levels. Measurements were collected during two classroom visits in the same day (morning 8:30–11:30 am and afternoon 1:00–4:30 pm respectively) during fall and winter season. The field study used a longitudinal survey approach, the same classrooms and students were surveyed in both seasons. Because of school academic schedules (ending first semester and winter break) in June and July months, the study was conducted in four schools only during the winter season, instead of all nine in the first campaign. It is important to note that these four schools had the same participating subjects from the first field study during fall, with minor changes due to newly registered students or withdrawn students from the classroom.

3.0. RESULTS

3.1. Assessments of physical environmental measurements

During the field study campaigns in fall, the average outdoor dry bulb temperature was 12.5ºC (54.5ºF) for April and 11.6ºC (53ºF) for May, with a minimum temperature of 8.5ºC and a maximum of 18ºC. The lowest temperature was registered early in the morning between 5, and 6 am, whereas the highest temperature was reached around 2 to 3 pm, just before school release. The mean indoor air temperature (Ta) of classrooms was 19.9 ºC, with a maximum of 23.8 ºC and a minimum of 16.5ºC during fall. The mean indoor relative humidity (RH) was 65.8% with a range of 42%–85%. In winter, the average outdoor temperature ranged between 9 and 10ºC during July and August, with a minimum temperature of 5.6ºC and a maximum of 15ºC, respectively. Classroom average indoor air temperature in winter was 18.8ºC, with a minimum of 15.0ºC and a maximum of 23.8ºC. Public schools registered the highest mean value of relative humidity of 75.3%, and a maximum of 85% during fall. However, in winter the maximum of 85% was measured in Private-subsidized. High levels of CO_2 was also recorded with a mean average of 1625 ppm and a maximum of 3330 ppm in Public schools during fall. However, CO_2 average levels of 2066 ppm and the maximum of 3580 ppm in Private-nonsubsidized during winter. The high mean indoor air temperature was registered in Private-subsidized schools with an average of 22ºC and maximum of 24ºC. Low mean indoor temperatures were measured in Public school of 16.5ºC during fall and of 15ºC in Public and Private-nonsubsidized schools. It is important to note that air velocity in all classrooms during visits was very low, almost imperceptible, with an average of 0.09 m/s in fall and winter and a maximum of 0.16 m/s. Due to low outdoor temperatures, windows were mostly closed. In all surveyed schools, they relay solemnly on operable windows for air renovation, since there is no mechanical system or use of fans in any of the classrooms. High concentration levels of CO2 were measured across all schools, with maximum concentrations of 4,326 ppm in winter in public schools and a minimum of 858 ppm in fall in private-subsidized schools. Average CO2 ranges between 1,600-1,900 ppm, more than 1,000 ppm above outdoor levels (average ~500 ppm).

The operative temperature (Top) for this study was calculated as the average of the air temperature (Ta) and the mean radiant temperature (MRT), as specified in ASHRAE 55 (ASHRAE, 2017). For prevailing mean outdoor air temperatures, an exponentially weighted running mean temperature was used based on the studies of Humphreys (Humphreys & Nicol 1998; Humphreys and Nicol 2002) and ASHRAE 55 (ASHRAE, 2017). An exponentially weighted mean temperature puts more weight on temperatures from days closer to the current one, as noted by Nicol and Humphrey (Humphreys & Nicol, 1998). People's responses depend heavily on their immediate thermal history. As seen in figure 1, indoor operative temperature plotted in ASHRAE 55-2017 adaptive chart, ranging from ~7.5 to ~11 ºC, falls outside the comfort zone. Only at the beginning of the study (April) temperatures were inside the comfort zone.

Table 1. Summary of classroom visits, building details, sample size, and number of surveys for different seasons

School type	No. of classroom surveyed	No. of floors surveyed	Average height of classroom (m)	Average floor area of classroom (m^2)	Classroom seating capacity (n of tables)	Classroom density area/n students (m^2)	Fall survey campaign				Winter survey campaign			
							Sample size (N)		Total number of surveys (ns)		Sample size (N)		Total number of surveys (ns)	
							Students	*Teachers*	*Students*	*Teachers*	*Students*	*Teachers*	*Students*	*Teachers*
Public	14	2, 3	3.25	47.81	30–35	1.36	386	32	762	36	72	5	141	7
Private-subsidized	6	2, 4	2.95	60.45	40–45	1.34	202	8	332	8	206	13	392	13
Private-nonsubsidized	8	2, 3	3.02	43.21	25–30	1.44	300	18	448	18	55	5	109	5
Average			3.07	50.49		1.38								
Total	28						888	58	1542	62	333	23	642	25

3.2. Thermal sensation votes and preferences

Results in Figure 2 show approximately 80% of the teachers and students voted their thermal sensation primarily within the three central categories of the scale (-1, 0, +1). The mean TSV for students is 0.92 (SD 1.15) in fall and -0.4 (SD 1.27) in winter; for teachers, mean TSV 0.03 (SD 1.0) in fall and -0.28 (SD 1.37) in winter were found.

Comparing thermal sensation students and teachers, across types of schools during fall (Figure 3A), similar distribution patterns occur with very slight shifts towards the warm side of the scale for students and the cool side of the scale for teachers (Figure 3B). For students, there are no significant differences between school types, except for private-subsidized which showed a slight shift toward a warm thermal sensation, corresponding to higher indoor temperature measured in those classrooms.

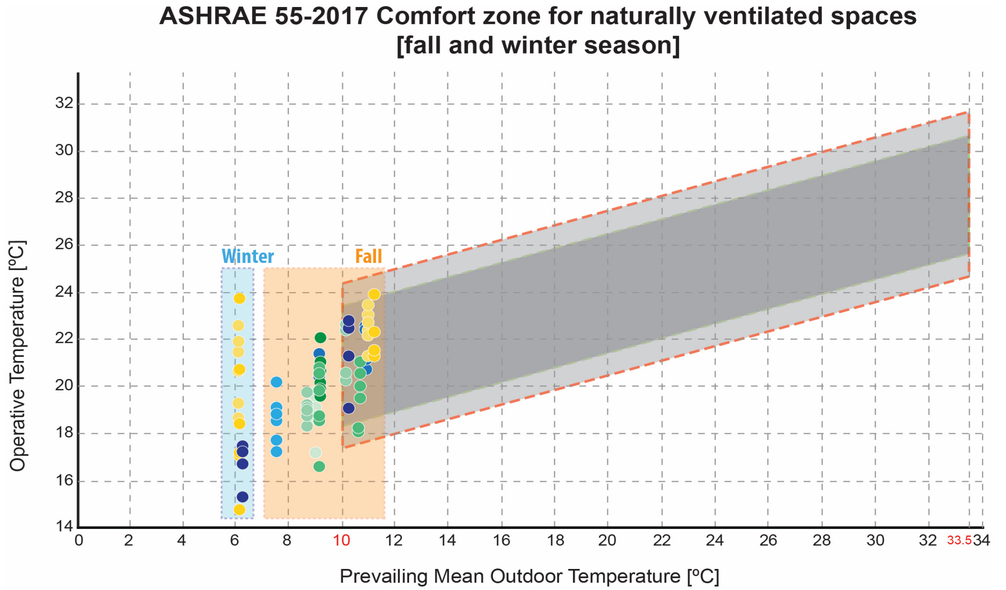

Figure 1. Indoor operative temperature plotted on ASHRAE 55-2017 adaptive charts for fall and winter seasons. Each point represents an individual classroom indoor operative temperature per survey test (am and pm).

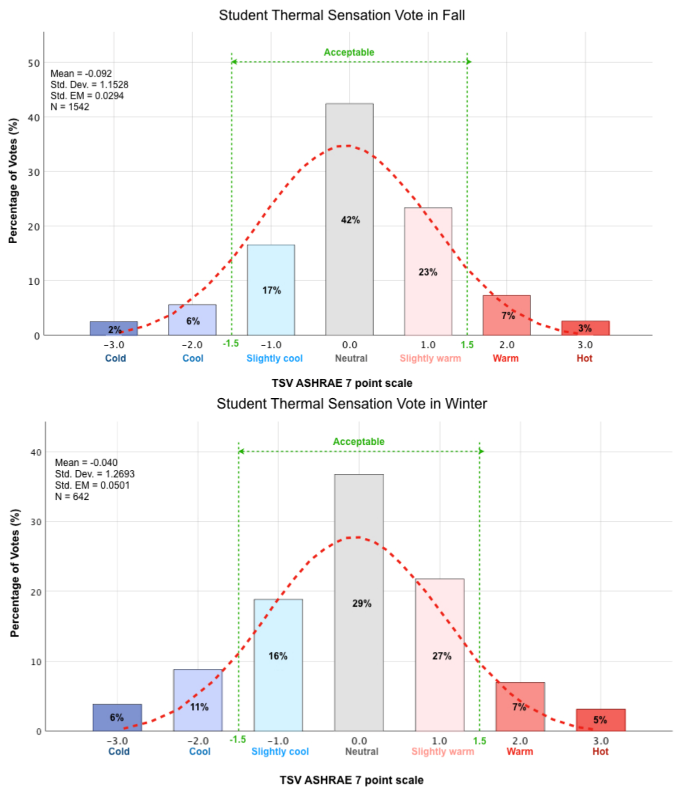

Figure 1A, 1B. Distribution of thermal sensation votes (TSVs) for student in all schools, based on ASHRAE 7-point scale, during winter and fall seasons.

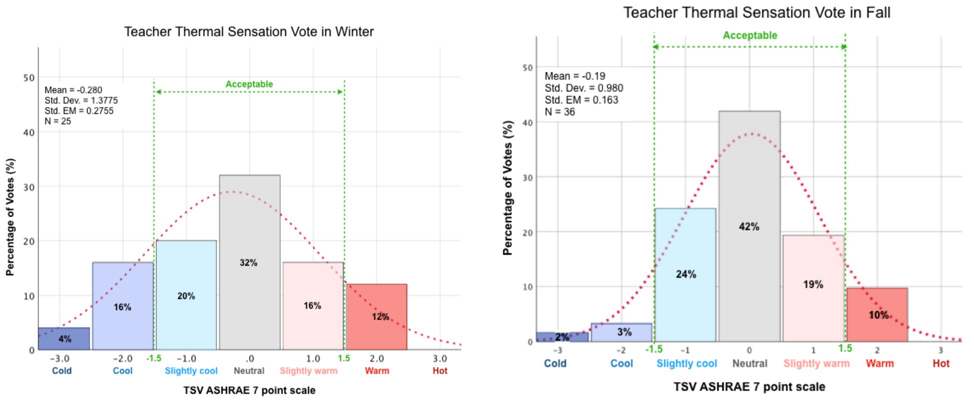

Figure 2A, 2B. Distribution of thermal sensation votes (TSVs) for teachers in all schools, based on ASHRAE 7-point scale, during winter and fall seasons**.**

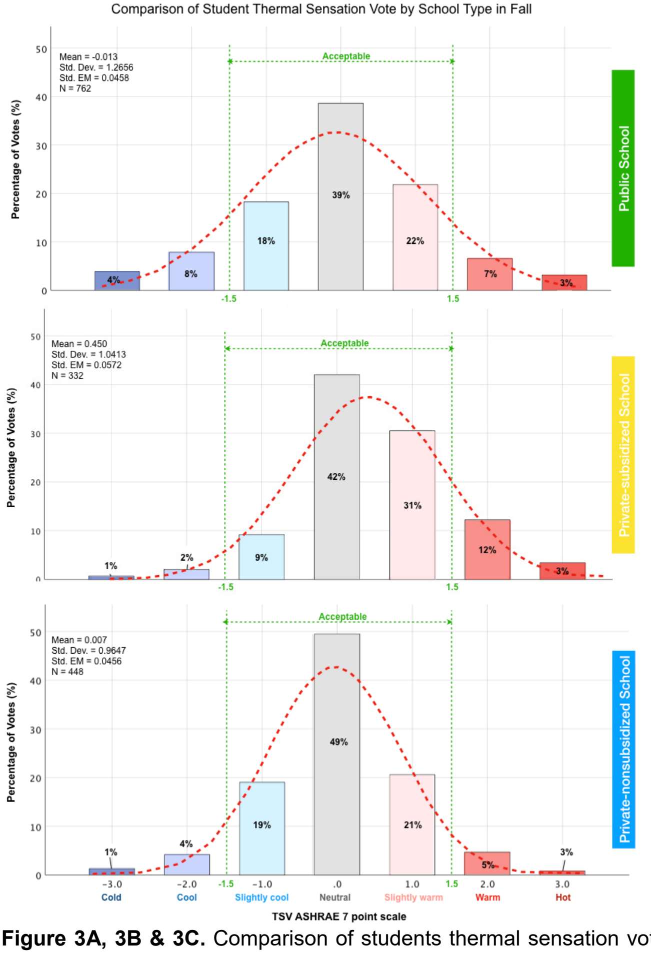

Figure 3A, 3B & 3C. Comparison of students thermal sensation votes (TSVs) distributions for different schools type during fall. Top: public schools; center: private-subsidized; bottom: private-nonsubsidized.

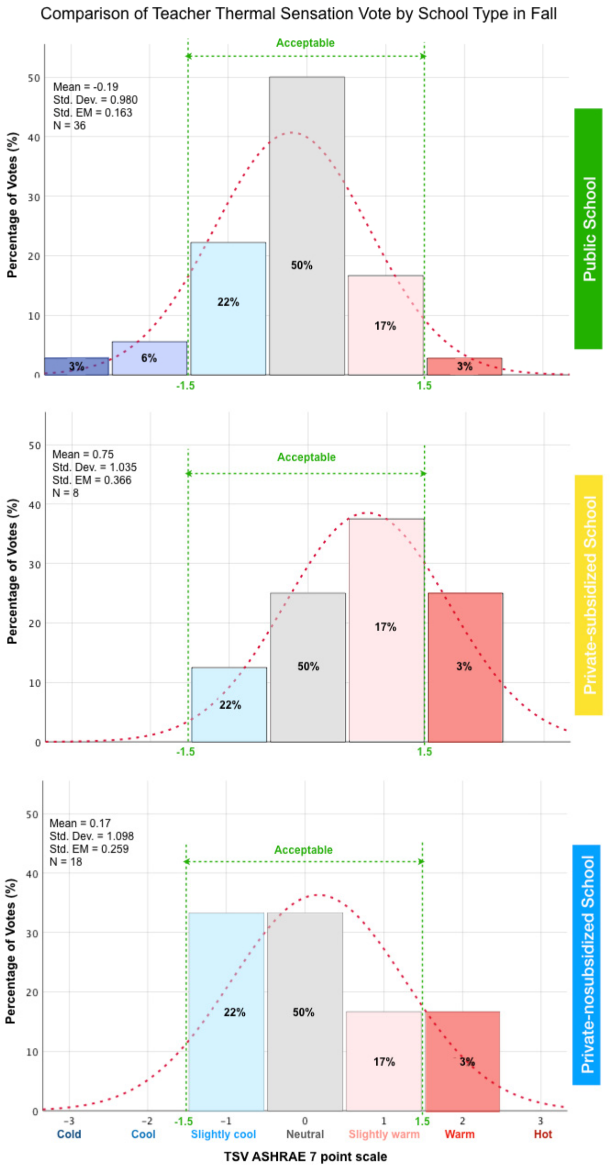

Figure 4A, 4B & 4C. Comparison of teachers thermal sensation votes (TSVs) distributions for different schools type during fall. Top: public schools; center: private-subsidized; bottom: private-nonsubsidized.

Regarding their thermal preference (TPV), corresponding to the question "how would you prefer the temperature of your classroom?", more than 50% of both teachers and students preferred "no change."

CONCLUSIONS

Primary school children, aged 10-14, were capable of understanding thermal sensation and preference rating scales, and their responses are similar to adult responses. The distribution of thermal sensation votes for student and teacher, more than 80%, fall within the three central categories of the scale (-1, 0, +1) of the ASHRAE thermal sensation scale during the fall season. However, in winter 68% (students) and 72% (teachers) votes are concentrated in three central categories, suggesting the consistent responses between students and teachers

across all schools. Teachers' thermal sensation had a slight tendency towards slightly cold scales, which can correspond to their lower metabolic rate compared to students whose tendency was towards slight warm scales.
The perceptions of the students across different school types do not show a significant difference. A small distinction can be seen during the fall season for private-subsidized schools with a small tendency towards a warm thermal sensation, which is corroborated by the measured indoor temperatures compared to other schools. The latter suggests that students can perceive the conditions of their classroom based on the physical measurements collected.

Air quality across all schools was poor, with very high concentrations of CO2 levels due to high-density classroom and little air movement (i.e., windows were mostly close), which limits the air ventilation. Thus, affecting the performance of students by feeling tired and difficulty concentrating at the end of each period. Also, high percentages of relative humidity across all school types, in some cases presence of mold, can have a more significant impact on health and well-being of students and teachers, thus suggesting new strategies need to be implemented through better architectural design, that can improve indoor classroom conditions.

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