Indoor Environmental Quality In Preschool Buildings In an Andean City In Ecuador

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ABSTRACT

Indoor environmental quality has been associated with the health and wellbeing of building occupants; nevertheless, there is limited evidence in this regard for Latin American schools. This research aimed to characterize indoor environmental quality in public and private preschools in an Andean city in Ecuador. Data collection comprised onsite monitoring for the thermal-humidity microclimate of 90 classrooms in 30 preschools in Cuenca-Ecuador (March-August 2018). Infrared thermography and direct observation were applied to determine dampness. Classrooms seemed to be inadequate thermal-humidity microclimates; only a few maintained a comfortable temperature (6%) and relative humidity (11%) throughout the shift. When comparing public and private schools, in private schools, temperatures below the comfort range (61.3% in private schools vs 31.4% in public schools, $p<0.001$) and relative humidity measures above the comfort range were more frequent (74.3% in private schools vs. 58.6% in public schools, $p<0.001$). Hollow blocks were the primary construction material in private and public schools. Sixty-four per cent of private schools operated in adaptive, reused buildings, vs 19% in public schools ($p<0.05$). Infrared thermography confirmed dampness in 26% (n=23) of the classrooms in the covering structures indoors (15% in public vs 33% in private schools, $p<0.05$). This research reveals the urgent need to develop specific regulations and control mechanisms for building sustainable and healthy environments for preschools in Ecuador.

KEYWORDS

indoor environment, preschools, building pathologies, hygrothermal conditions, environmental illnesses

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INTRODUCTION

The health and wellbeing of children must be prioritised to achieve sustainable development goals (Bruckauf & Cook, 2017). Although child mortality has decreased globally, monitoring the factors threatening health is still imperative to ensure a fulfilling childhood (GBD 2017 Child and Adolescent Health Collaborators et al., 2019). Among the multiple determinants of children's health, the school indoor environment is critical; apart from their homes, children spend more time at school than in any other building (Fadeyi et al., 2014), with an average of 1.480 hours per year (Ackley et al., 2020). School buildings must enhance a fulfilling and pleasant teaching-learning process and guarantee that occupants are not exposed to hazardous agents (Kapoor et al., 2021; Salthammer et al., 2016). An inadequate indoor environment in classrooms has been associated with asthma, the most common chronic condition in children (Smedje & Norbäck, 2001b), allergies, sleep disorders, lack of attention, and irritative mood (Al horr et al., 2016; Kapoor et al., 2021; Salo et al., 2009).

A comprehensive estimate of the quality of buildings regarding the health and wellbeing of its occupants is the Indoor Environmental Quality (IEQ); it comprises aspects such as thermal, visual and acoustic comfort, and air quality (*CDC—Indoor Environmental Quality—NIOSH Workplace Safety and Health Topic*, 2019; Kapoor et al., 2021; Korsavi et al., 2020). Indoor air quality (IAQ) is defined by indoor respirable air composition and is among the essential features of IEQ (*ASHRAE Terminology*, 2023). The hygrothermal microclimate is a critical determinant of IAQ and depends on indoor air temperature, relative humidity, and ventilation (Kraus, 2017). Other attributes, such as the building's age, maintenance practices, construction materials, type of ventilation, and the portion of the building envelope in direct contact with the exterior (i.e., terraced or detached buildings), might also affect IEQ (Turunen et al., 2014). Building materials, such as concrete or brick, can contribute to dampness and mould storage (Salo et al., 2009; World Health Organization. Regional Office for Europe, 2009).

Building pathologies

Dampness is defined as "any visible, measurable or perceived outcome of excess moisture that causes problems in buildings, such as mould, leaks or material degradation, mould odour or directly measured excess moisture (in terms of relative humidity or moisture content) or microbial growth" (World Health Organization. Regional Office for Europe, 2009, p. 3). Dampness is the most common building pathology and results from moisture penetration into the materials (i.e., bricks, walls), causing deterioration and an unhealthy indoor environment (Agyekum et al., 2013). Depending on the level of moisture, climatic conditions, area, relative humidity, building materials, and maintenance, among other aspects, different symptoms may become visible in buildings. For example, high humidity or hygroscopic construction material properties can promote mould growth without direct contact with water (Agyekum et al., 2013; World Health Organization; Regional Office for Europe, 2009). Sudden fluctuations in relative humidity or weather conditions (common in the Andean region) can lead to efflorescence secondary to accelerated water evaporation in a building area with signs of dampness (Agyekum et al., 2013). Worryingly, dampness and mould indoors are associated with sick-building syndrome (Redlich et al., 1997), characterised by general health symptoms (headache, fatigue, nausea) (Turunen et al., 2014), mucosal symptoms (eye, nose, or throat irritation), upper respiratory tract symptoms (cough, increased infections), wheezing, asthma in sensitised people (World Health Organization; Regional Office for Europe, 2009) skin conditions (itch, rash or eczema)

(Takaoka et al., 2015), illness-related absenteeism (Turunen et al., 2014), and poor school performance (Barrett et al., 2015; Mendell & Heath, 2005; Zomorodian et al., 2016). On the other hand, high relative humidity and air temperature favour the growth of mites and fungi (Baldacci et al., 2015; Cyprowski et al., 2013; Salo et al., 2009), which are potential risk factors for respiratory symptoms and allergic exacerbations.

There are several methods to analyse signs of moisture and dampness in buildings. The most commonly used comprises applying surveys to users or direct inspections in search of visible signs of moisture, mould, or dampness. However, these methods may depend on the memory of the occupants, or in some cases, the signs are not visible to the naked eye or rely on the training or perception of the observers. A relatively affordable and non-invasive alternative is infrared imagery, which analyses heat loss in buildings, increases the sensitivity of detecting and understanding differences in surface temperature, and allows an objective assessment of moisture and dampness (Balaras & Argiriou, 2002; Seo et al., 2014; Usamentiaga et al., 2014).

BACKGROUND

Evidence on IEQ in schools

The available evidence regarding IEQ in schools originates mainly from developed regions (Kapoor et al., 2021; Sadrizadeh et al., 2022). Inadequate comfort and poor or natural ventilation have been reported in primary and secondary schools in high-income countries (Ackley et al., 2020; Kapoor et al., 2021; Oliveira et al., 2019; Turunen et al., 2014). Worryingly, research has demonstrated that air quality in school classrooms is worse when compared with other environments, such as houses and offices (Sadrizadeh et al., 2022). Natural ventilation is commonly used in schools and has been reported as the most essential factor associated with poor air quality. The regulations for school buildings' ventilation vary across countries but are inadequate to account for children's metabolic rates, physical activity, and common pollutants. Poor ventilation has been associated with respiratory conditions and lower school performance (Sadrizadeh et al., 2022). Evidence regarding IEQ in preschools is scarce worldwide; this is unfortunate, as young children have immature immune systems (Zhang et al., 2021).

Evidence on IEQ in Schools in Latin America

The research in the field is predominantly conducted in home environments (Valderrama-Ulloa et al., 2020). The available research targeting schools in Latin America has focused on hygrothermal conditions in elementary and secondary schools in countries with marked seasons, such as Brazil, Argentina, and Chile, and inadequate thermal comfort is often reported (Boutet et al., 2011; Soto-Muñoz & Trebilcock, n.d.; Trebilcock et al., 2016; Valderrama-Ulloa et al., 2020). We also identified some studies performed predominantly in Chile, testing different strategies to improve the thermal comfort of a few classrooms with mixed results (Boutet et al., 2013; Kelly et al., 2016; Trebilcock et al., 2016). Latin America is a region with vast economic inequalities. Nevertheless, insufficient evidence regarding IEQ in schools from deprived versus wealthy regions exists. Only one study in Chile reported that children from lower socioeconomic strata reported lower temperature comfort at school during the winter (Trebilcock et al., 2017).

Although a systematic review addressing IEQ in Latin America was published in 2020, the authors did not critically appraise the quality of the manuscripts retained (Valderrama-Ulloa et al., 2020). We noted that several studies were published in special issues of conference proceedings or corresponded to grey literature. This highlights the need for more research following rigorous peer review processes; recent evidence shows that publications on special issues tend to have lower standards (Hanson et al., 2023).

To the best of the authors' knowledge, evidence of IEQ in schools in Ecuador is absent. Most of the research regarding IEQ in Ecuador has been performed in houses in the Andean highlands, with the available evidence demonstrating inadequate thermal comfort (Miño-Rodríguez et al., 2016; Quesada et al., 2018). Comprehensive research on IEQ in the northern Andean region school settings requires special attention due to the unique geographic and climatic conditions characterised by a lack of marked seasons and high attitudes (Hidalgo & Lara, 2018).

The Ecuadorian school system

The Ecuadorian school system comprises three levels: preschools, elementary schools, and high schools. Preschool involves two levels; the first, dedicated to 0–3-year-olds, is not offered by the government, while preschool level II, targeting 3–5-year-old children, must be offered on a mandatory basis by the government but is not compulsory for accessing the elementary system (Instituto Nacional de Evaluación Educativa, 2018). From preschool level II, the schools can be privately or publicly operated. Public schools include tuition-free institutions funded by the Ministry of Education or the Ministry of Social and Economic Inclusion and partially subsidised schools with reduced monthly tuition paid by the parents. Parents pay the full monthly tuition fee in private schools. Activities in most private preschools are held in the morning (07H30–12H35), while public preschools have a double-shift-school system: morning (07H30–12H35) and afternoon (13H00-18H00) shifts with different children attending during each shift due to the high demand. According to data from the Ministry of Education, 72% of children enrolled in preschool attend public schools nationwide (Instituto Nacional de Evaluación Educativa, 2018).

Data from elementary and secondary schools show enormous heterogeneity between public and private schools. For example, children from higher socioeconomic backgrounds tend to attend private schools more frequently; therefore, the school type (i.e., public versus private) is an indirect marker of the socioeconomic level of the children. On the other hand, the infrastructure of private schools tends to differ between public and private schools (Javier Murillo et al., 2020). However, there is no evidence in this regard in preschools. By the time our study and in the case of public schools, several institutions operated for several decades, while others were renovated or built in large areas according to the plan of the so-called millennium schools, focused on improving the infrastructure of public schools (*Unidades Educativas del Milenio—Ministerio de Educación*, n.d.).

The Ministry of Education regulates the functioning of public and private schools. The guidelines for the approval of private school buildings regarding IEQ include aspects such as adequate classroom capacity (25 students per classroom, 2 to 2.5 sqm/student), availability of natural light and ventilation sources and adequate physical accessibility (Servicio de Contratación de Obras SERCOP, 2017). Therefore, adaptive reuse buildings such as single-family houses that meet the guidelines could serve as schools (Ministerio de Inclusión Económica y Social & Ministerio de Educación, 2016). Adaptive reuse buildings as schools are not new; the available evidence originates primarily from high-income countries (Buthke et al., 2020; Huang & Wey, 2019; Spector, 2003). Premises such as factories, shopping malls, mansions, and supermarkets have been adapted as schools as early as the 1960s (Spector, 2003). Although these practices have the potential to favour the circular economy and mitigate the environmental impact of urbanisation, they must be carefully planned to meet the minimum requirements to ensure the wellbeing and health of users (Spector, 2003; Tam & Hao, 2019). As far as we know, whether adaptive reused buildings are used as schools or if they are adequate environments is poorly understood in Latin America.

Research outline

Considering the particularities of the Ecuadorian school system and the absence of data in a region with particular living and climatic conditions, it is relevant to conduct a study concerning IEQ in schools. This information can be used to design future interventions.

This research aims to explore the classroom's status in preschools, emphasising microclimate (thermal-humidity microclimate) and building pathologies (i.e., mould, dampness) in a large sample of preschool classrooms in an Andean region in Ecuador. Furthermore, considering the great disparities between public and private school settings, this study offers a first overview regarding specific attributes in each setting that would potentially affect IEQ and, thus, children's health. In detail, besides comparing the thermal-humidity microclimate and building pathologies, we will summarise variables such as building age, construction materials, cleaning practices, and whether the schools operate in adaptive reuse buildings for public and private schools.

This report is part of a study designed to identify environmental factors associated with allergic diseases in preschool children in Ecuador (Ochoa-Avilés et al., 2020).

METHODOLOGY

Study design and setting

An observational study was conducted in Cuenca, located in the Andean highlands of Ecuador at 2550 meters above sea level (Delgado, 2013). Cuenca had 614,539 inhabitants in 2018, of whom 28,603 were aged 3 to 5 years (Instituto Nacional de Estadísticas y Censos INEC, 2010).

Cuenca, an Andean city in the equatorial zone, has no marked seasons throughout the year, with minimal fluctuations in hygrothermal conditions. Depending on the rainfall, a short dry season occurs from June to September, and a wet season from October to May. The fluctuations in humidity and temperature are minimal over the seasons. For example, in 2017, the average air temperature and relative humidity in the wet season were 13.83°C and 80.28%, respectively, versus 13.14°C and 75.08% in the dry season (Bustamante Campoverde, 2018). This study is part of a project that aims to measure the prevalence of asthma, rhinitis, and eczema among a representative sample of preschool children living in the high-altitude Andean city of Cuenca, Ecuador, and identify associated risk factors.

Sampling

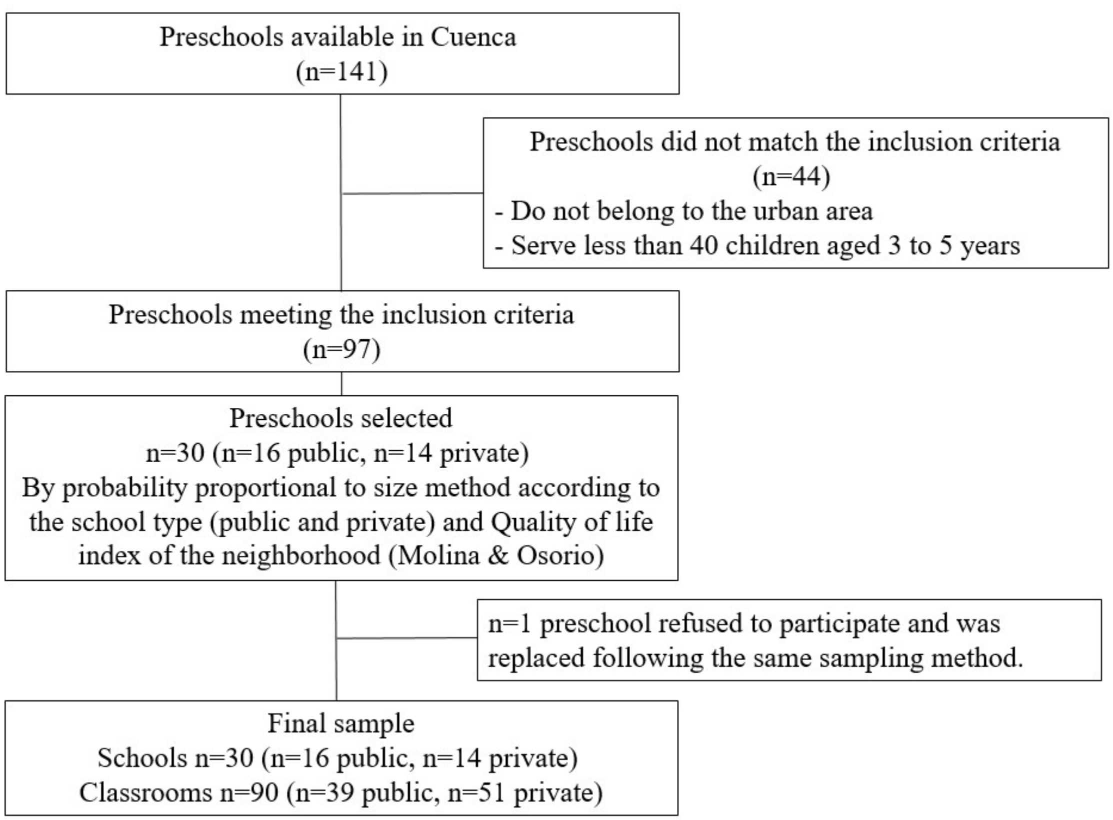
Thirty preschools (from 141) were randomly selected in line with the overall research objective: to identify environmental factors associated with allergic diseases in preschool children in Cuenca. The schools were selected following a probability proportional to size sampling according to their type (public or private) and neighbourhood Quality of Life Index (QoL) (high or low) proposed by Molina and Osorio (2014) (Molina & Osorio, 2014). This report is part of a study that comprehensively analyses the factors related to allergic diseases in preschool children in Andean Ecuador. The schools were selected to determine the prevalence of allergic diseases in a representative sample of children aged 3–5 years and provide an overview of certain aspects of IEQ. We reported a detailed description of school selection in a previous publication (Ochoa-Avilés et al., 2020). Figure 1 displays the school selection process. Following the project's objective, all the available school classrooms (n 1–8) were included.

Data collection

The selected schools were inspected between March and August 2018. Before data collection, a pilot test was performed to standardise the procedures and test the equipment. All the measurements were carried out by trained field architects using an adapted version of a validated form applied in official school inspections (Ochoa Pesántez, 2012). The Ministry of Education applies the form in consultancies for the public school's renovation program (2008–2017). It was chosen because it has been used locally and allows the inspection of variables such as building materials and pathologies indoors and outdoors.

After the pilot, we realised that in some cases, data such as the year of construction or renovation were unavailable from official records. In addition, we noticed that some schools were operating in adaptive reused houses, and the children were curious about the presence of equipment for measuring hygrothermal conditions. Therefore, we decided the data would be obtained from an in-person interview with the school principal if no official records existed. Besides, we added an item in the form to register whether the school was operating in an adaptive reused building, and we were careful to locate the thermal-humidity microclimate measuring sensor in

FIGURE 1. Flowchart of preschool selection.



areas inaccessible to children. Finally, we ensured that the data collected allowed us to describe the status of building features associated with symptoms and development of allergic diseases. For this purpose, we conducted an exhaustive literature review to ensure that the data collected enables us to categorise the study variables according to their correlation with allergic diseases. The following sections describe the variables, their categories, and their respective references supporting the associations with allergic diseases.

School building general data

Data collection involved two stages. In the first stage, in-person semi-structured interviews were performed with the school principal of each institution and school official records were searched (if available) to collect the following data: date of construction (before or after 2000), year of last renovation, perception of history of humidity, adaptive reuse building status (yes/no), frequency of superficial cleaning per day (sweep, vacuum, and dust cleaning), frequency of thorough cleaning per month (fumigation and disinfection) (Smedje & Norbäck, 2001a; Takeda et al., 2009; Tranter, 2005). In the second stage, observational analysis of the building's predominant construction material (hollow blocks, solid blocks, adobe, mixed materials, panels), the conservation status of the entire building, type of ventilation (natural, mechanical, or hybrid), the kind of building concerning the sharing of walls with other buildings (detached/terraced) and the existence of air conditioning and heating. Two evaluators conducted the observations after inspecting the entire building during regular class hours to reach a consensus in case of doubts; all forms were reviewed at the end of data collection to identify missing data or inconsistencies.

Classroom thermal-humidity microclimate

Air temperature and relative humidity were monitored during 24 hours with 30-minute intervals using a HOBO Temperature/Relative Humidity/Light/Ext Data Logger #U12-012 (Onset Computer Corporation, MA, USA). The device was placed inside the classroom on a flat surface (i.e., a wall) far from doors, windows, and heat sources that could alter the results (Holst et al., 2016) at a vertical distance of 1.65 to 1.80 meters from the floor to prevent potential contact with children (International Organization for Standardization, 2001). The readings during class hours were used for the current analysis. Temperature (Appendix 1) and relative humidity (Appendix 2) readings per classroom over the school day were displayed using line charts. To provide a deep analysis of the thermal-humidity microclimate data, all the readings (n=1001) were classified according to the comfort standards for temperature and humidity as defined by the ASHRAE Standard 55—Thermal Environmental Conditions for Human Occupancy (Ashrae, 2016) below the comfort range (<18.5 °C), within the comfort range (18.5–25.5 °C), and above the comfort range (>25.5 °C). A similar definition was made for humidity, below the comfort range (<30%), within the comfort range (30%–60%), and above the comfort range (>60%). Finally, based on the cut-offs proposed by Acevedo et al. (2019), we calculated the proportion of temperature and humidity readings ideal for mite growth (23.9 °C to 26.7 °C, 70% to 90%, respectively).

Building pathologies

Structured inspections were performed to register visual signs of building pathologies such as mould, detachments, and efflorescence in outdoor and indoor building surfaces (i.e., support, covering, and finishing). Infrared thermography technology was applied to determine dampness (Pleşu et al., 2012). We used a FLIR E30 InfraRed Camera (160 x 120 IR Resolution)

(FLIR Systems, Inc. OR, US). First, a general picture of each wall, floor, and ceiling surface was taken and analysed in situ; if a lower surface temperature compared with the total surface was observed, a detailed infrared photo was taken to confirm the presence of dampness (Information registered in Form A3 and A4).

Statistical analysis

Data were double-entered by two independent researchers using EpiData software (Christiansen et al. JM. (Ed.) EpiData—Comprehensive Data Management and Basic Statistical Analysis System. Odense Denmark, EpiData Association, 2010– . *http://www.epidata.dk*), and any discrepancies were corrected with the original forms. Data are presented as frequency distribution and bar charts. The Chi-square test or Fisher test (if appropriate) was applied to evaluate differences in building and classroom data between public and private schools. All analyses were done using Stata V.12.0 (Stata Statistical Software: Release 12. College Station, TX: StataCorp LLC). The graph charts were obtained using RStudio (Rstudio Team (2020): Integrated Development for R. RStudio, PBC, Boston, MA URL *http://www.rstudio.com/*) and edited (in format) using Adobe Illustrator version 16.0.3.691.

Ethical considerations

The study protocol was approved by the Ethics Committee of the San Francisco de Quito University (approval 2017-164E) and by the Ecuadorian Ministry of Education.

FINDINGS

School characteristics

The general characteristics of the 30 schools are shown in Table 1. Ninety classrooms from 30 schools were assessed; 43% belonged to the public and 57% to private schools. Most of the schools had a morning shift (70%, n=21); seven public schools had afternoon shifts (23.3%), and two public schools had both shifts (6.6%). Among the 16 public schools included, 15 were free of charge, and the government partially subsidised the fee for one school. Over half of the schools (53.3%) were in neighbourhoods with low QoL index (Molina & Osorio, 2014).

TABLE 1. Characteristics of the preschools (n=30)*.

Variable	Categories	n (%)
Preschool type	Private	14 (46.6)
	Public	16 (53.3)
Shift school system	Morning shift	21 (70.0)
	Afternoon shift	7 (23.3)
	Both shifts	2 (6.6)
Quality of Life Index (QoL)[a]	Low	16 (53.3)
	High	14 (46.6)

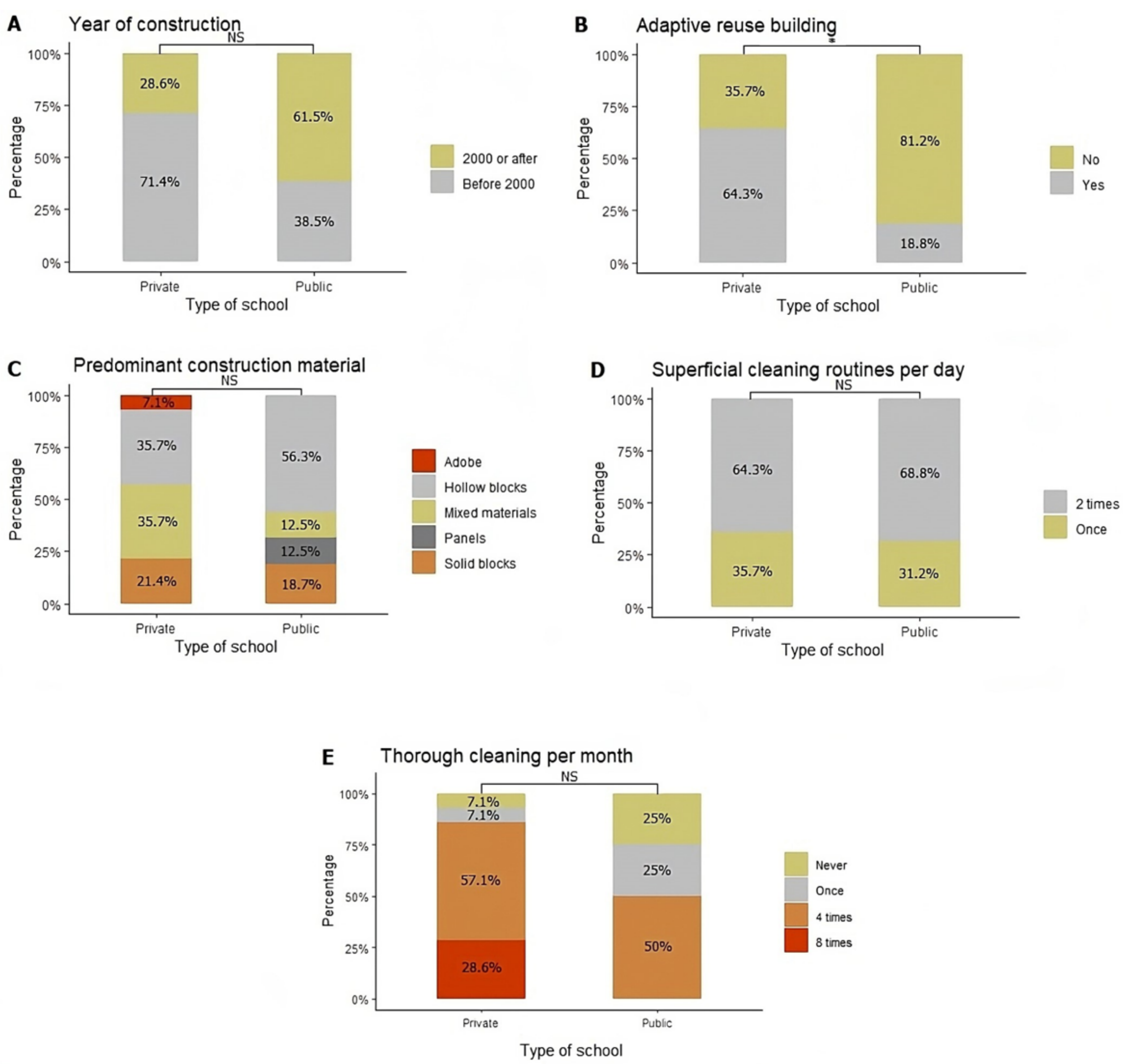
[a]QoL of the neighbourhood where the school is located.
*Data obtained from the Ministry of Education (*https://educacion.gob.ec/*)

School building general data

Figure 2 illustrates the school building characteristics of private and public schools. Records of the exact date of construction were only available for some of the schools. The school principals of 20 schools recalled the year of construction; according to them, 61.5% of the public schools were built in 2000 or after, compared with 28.6% of the private schools (p=0.350). Most schools were renovated during 2017 (70%, n=21). The percentage of adaptive reuse buildings in private schools was significantly higher than in public schools (64.3% vs. 18.8% $p = 0.024$). All the adapted buildings were old family houses/mansions. Most schools operated in detached buildings (80%, n=24), with no differences between public and private schools.

Although there were no significant differences in the predominant construction material by the school type, hollow blocks were the primary material (56.3% public; 35.7% private), and only in private preschools, few classrooms (7.1%, n=4) were built with adobe. No differences were found between school types concerning superficial cleaning routines per day. For

FIGURE 2. Characteristics of the school building.



Note: $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

thorough cleaning for public and private preschools, "four times" per month was the predominant response (53.3%, n=16), without statistical differences. All the classrooms had natural ventilation, and none of the school buildings had air conditioning or heating systems.

Classroom data

Thermal-humidity microclimate

Appendices 1 and 2 display the temperature and relative humidity readings per classroom of public and private schools during class hours; the international comfort standard ranges are shaded in grey. Temperature readings in public and private schools laid within the comfortable ranges around 10 am. Only five classrooms (6%) maintained temperatures within comfortable ranges during the shift. The graphs of the relative humidity levels show that some classrooms tend to reach the comfort range at the end of the school shift, and only 11 classrooms (12%) kept ideal relative humidity during the whole shift.

During class hours, 1001 temperature and relative humidity readings were analysed and compared with international comfort standards (Ashrae, 2016). Table 2 summarises the temperature and relative humidity readings below, above, or within the comfort range. Forty-nine per cent of the temperature readings were within the comfort range, but in the private preschools' temperature readings were predominantly below the comfort range (61.3%) in contrast to public schools, where only 31.4% of the readings were below the comfort range ($p<0.001$). Relative humidity readings were above the comfortable range in 67% of the cases (74.3% in private schools vs. 58.6% in public schools, $p<0.001$).

Only 4.9% of the air temperature readings were within the ideal range for mite growth, with a higher proportion of readings potentially favouring mite growth in public preschools than private preschools (10.2% vs 0.7%). On the other hand, ideal relative humidity ranges for

TABLE 2. Thermal-humidity microclimate compared with Ashrae (2016) comfort standards and readings within ideal temperature for mite growth* (n = 1001 readings).

		Total	Public schools	Private schools	
n (%)		**n (%)**	**n (%)**		***p*-value**
Temperature	Below the comfort range	482 (48.1)	138 (31.4)	344 (61.3)	<0.001
	Within the comfort range	490 (49.0)	274 (62.3)	216 (38.5)	<0.001
	Above the comfort range	29 (2.9)	28 (6.4)	1 (0.2)	<0.001
Relative humidity	Below the comfort range	3 (0.3)	3 (0.7)	0 (0.0)	<0.001
	Within the comfort range	323 (32.3)	179 (40.7)	144 (25.7)	<0.001
	Above the comfort range	675 (67.4)	258 (58.6)	417 (74.3)	<0.001
Ideal temperature for mite growth (Yes)*		49 (4.9)	45 (10.2)	4 (0.71)	<0.001
Ideal relative humidity for mite growth (Yes)*		192 (19.2)	63 (14.3)	129 (23.0)	0.001

* (Acevedo et al., 2019)

mite growth were more frequent (19%), with private schools presenting a higher proportion of readings potentially favouring mite growth (23% vs. 14.3%, p=0.001).

Building Pathologies

During the visual inspections of outdoor and indoor areas, mould, detachment, and efflorescence were uncommon (Table 3). Mould was identified mainly in the support structure outdoors (10%). Similarly, detachments mainly occurred in the covering structure outdoors (8%). Dampness measured by infrared imagery outdoors was identified in the support and covering

TABLE 3. Building pathologies (n=90 classrooms).

	Total	Public	Private	
	n (%)	**n (%)**	**n (%)**	***p*-value**
Outdoors				
Support structure				
Mould	9 (10.0)	5 (12.8)	4 (7.8)	0.332
Dampness*	12 (13.3)	2 (5.1)	10 (19.6)	0.042
Covering structure				
Mould	1 (1.1)	1 (2.6)	0 (0.0)	0.433
Detachment	7 (7.8)	3 (7.7)	4 (7.8)	0.648
Efflorescence	3 (3.3)	1 (2.6)	2 (3.9)	0.601
Dampness*	6 (6.7)	0 (0.0)	6 (11.7)	0.029
Finishing structure				
Mould	1 (1.1)	0 (0.0)	1 (2.0)	0.567
Detachment	5 (5.6)	3 (7.7)	2 (3.9)	0.374
Efflorescence	1 (1.1)	0 (0.0)	1 (2.0)	0.567
Indoors				
Support structure				
Mould	1 (1.1)	0 (0.0)	1 (2.0)	0.567
Detachment	1 (1.1)	1 (2.6)	0 (0.0)	0.433
Efflorescence	3 (3.3)	0 (0.0)	3 (5.9)	0.177
Dampness*	7 (7.8)	3 (7.7)	4 (7.8)	0.648
Covering structure				
Detachment	11 (12.2)	4 (10.3)	7 (13.7)	0.436
Efflorescence	3 (3.3)	1 (2.56)	2 (3.9)	0.601
Dampness*	23 (25.6)	6 (15.4)	17 (33.3)	0.044
Finishing structure				
Detachment	5 (5.6)	4 (10.3)	1 (2.0)	0.109

*Defined with infrared thermography

structures among tweleve (13%) and six (7%) classrooms, respectively. Indoors, dampness in the support structure was identified only in seven classrooms (8%). In contrast, indoor dampness in the covering structure was most common, identified among 23 classrooms (26%).

The building pathologies were similarly distributed between public and private schools, except for dampness in the outside support and the covering structures, which were more often identified in private preschools.

DISCUSSION

This study is the first evaluation of preschool infrastructure in Ecuador in terms of IEQ. The data show that classrooms have no adequate thermal-humidity microclimates; only a few maintained a temperature and relative humidity within the comfort ranges throughout the shift. Most of the temperature readings (48%) were below the limits considered comfortable, while relative humidity was above the comfortable limit in 70% of the readings. This unfavourable thermal-humidity microclimate in the classrooms may be because heating systems are not commonly used in the region; another possible explanation is that the buildings are not constructed to be efficient. In addition, all the schools used natural ventilation, a widely known source of poor air quality (Barrett et al., 2015; Zhang et al., 2021). Ecuador has an energy efficiency standard for construction issued by the Ministry of Housing and Urban Development, with general guidelines for residential buildings. Still, unfortunately, its application for the approval of architectural projects is not mandatory, and control mechanisms are not in force (Ministerio de Vivienda y Desarrollo Urbano, 2018)

Although we could not measure the children's perception of thermal comfort due to their young age, the air temperature measures are mostly above or below the comfort range. Evidence demonstrates that school thermal discomfort could compromise students' performance and wellbeing (Souza et al., 2020). Research performed in Latin America has reported that children in the region have an extraordinary capacity to adapt to adverse hygrothermal conditions (Kelly et al., 2016; Trebilcock et al., 2017), and the temperature threshold to achieve comfort in children is lower than the official standards (Kelly et al., 2016; Trebilcock et al., 2017). In line with these results, evidence from other regions shows that thermal comfort might be achieved at 2–3 °C lower than the standards for adults (Sadrizadeh et al., 2022).

There are no major differences in public and private school building features, except for the use of adaptive reuse buildings, which were predominant in private schools (64%) but significantly less frequent in public preschools (19%). To the best of our knowledge, there are no previous records of the use of adaptive reuse buildings in schools in the region. However, this study shows that private schools tend to be implemented in adaptive reused buildings with the permission of official entities (i.e., the Ministry of Education). The last could explain the differences in air temperature and relative humidity measurements between public and private schools, with private schools presenting lower temperatures and higher relative humidity measures, which might favour mite growth and the occurrence of allergic diseases such as asthma and rhinitis.

Another important finding related to buildings is that hollow blocks are the predominant construction materials for both types of preschools. Despite being widely used, this material is related to dampness, especially bricks or concrete (Salo et al., 2009), and thus could also explain the findings related to temperature and humidity comfort ranges.

Mould and other signs of moisture to the naked eye were rare indoors. However, indoors, dampness confirmed by infrared imaging was identified in 26% of the classrooms and was more frequent in private school classrooms (33% vs. 15%). Our estimate is lower compared to reports in Danish schools, where it exceeded 60% (Holst et al., 2016), possibly due to differences in climatic conditions. In Cuenca-Ecuador, there are no marked seasons, which favours the constant opening of windows and the effective use of natural ventilation sources, thus decreasing the risk of dampness. As explained in the background section, studies in preschools are scarce. This study offers an initial estimate and should be replicated in similar contexts. Although dampness is lower compared to other regions, the fact that 1 in 4 classrooms show signs of dampness is worrisome and should be analysed in-depth as it could affect children's health and school performance. The higher occurrence of dampness in private schools may be explained by a worse thermal-humidity microclimate, possibly secondary to the fact that schools operate mainly in adaptive reused houses that have not been properly modified to provide a healthy indoor environment.

Because of the children's ages, we could not include a comfort questionnaire on the perceptions of thermal comfort. Additionally, the cross-sectional design does not allow us to determine causality between allergic diseases and our results. Nevertheless, we performed objective measurements, and our data provide important findings for further research. While, ideally, multiple temperature and humidity measurements should be performed, our study considered only one measurement due to the large number of classrooms selected according to the general objectives of the research (Ochoa-Avilés et al., 2020). Our research does not allow us to conclude the hygrothermal conditions in a specific classroom. Instead, our data provide preliminary results of the current situation concerning IEQ in public and private preschools in an Andean city in Ecuador. The results highlight the need to perform more research.

CONCLUSIONS AND RECOMMENDATIONS

This study seeks an initial evaluation of preschool infrastructure and its relationship with children's health and allergic diseases. Few classrooms maintain comfortable temperature ranges during the school shift, although they tend to reach an adequate temperature at some point. Relative humidity at comfortable ranges is inadequate in most readings for both public and private preschools. More studies must assess aspects that can influence IEQ in school settings; this information could be the basis for identifying factors that might be implicated in developing allergic diseases and school performance. In addition, the results could guide further studies and promote updates in the local regulations for school functioning in Ecuador and Latin America.

Our research reveals a need to improve the design and construction of educational infrastructures, including a building approach that considers children's health and a standard focused on adaptive reuse buildings. To avoid uncomfortable and harmful exacerbations of allergies and respiratory diseases and improve the design and construction of educational infrastructure, requirements should consider certain aspects: 1) Specific climatic conditions in the city, 2) Evaluation of classroom distribution, 3) Strategies to maximise heat gains and reduce thermal losses, good ventilation, and natural lighting. Finally, but not less critical, decision-makers must revise their standards for school approval, inspection, and functioning to ensure that students have adequate IEQ.

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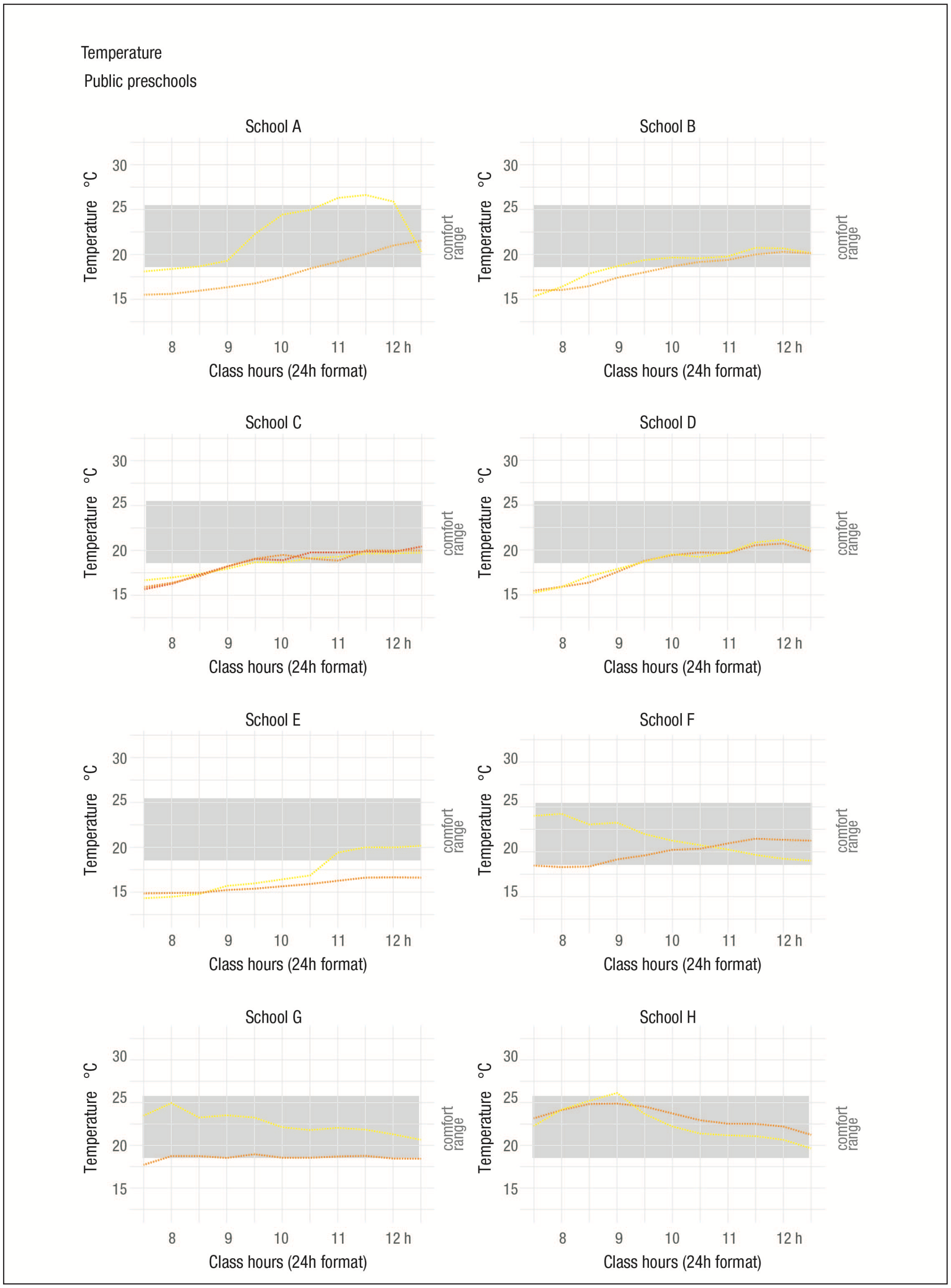
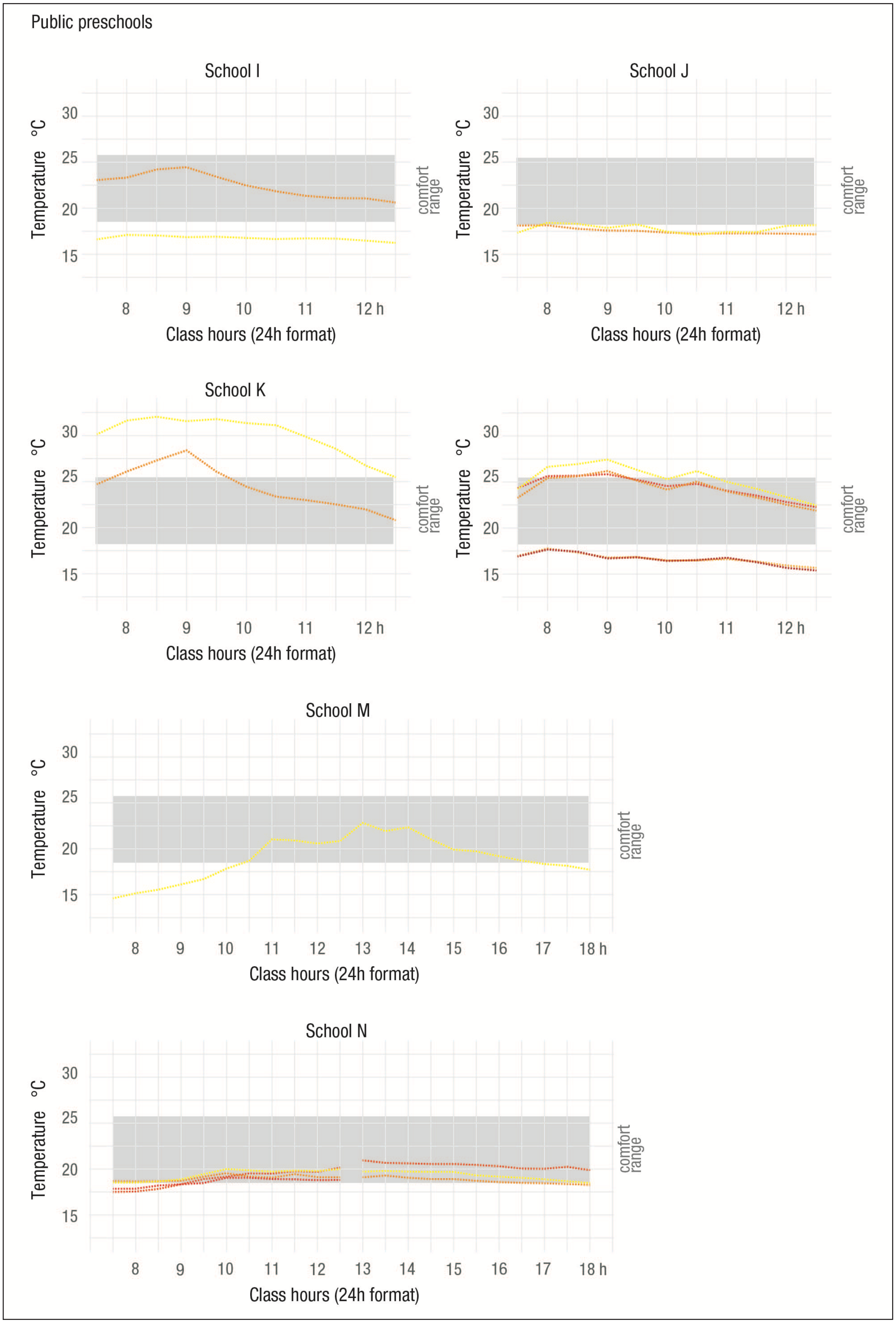
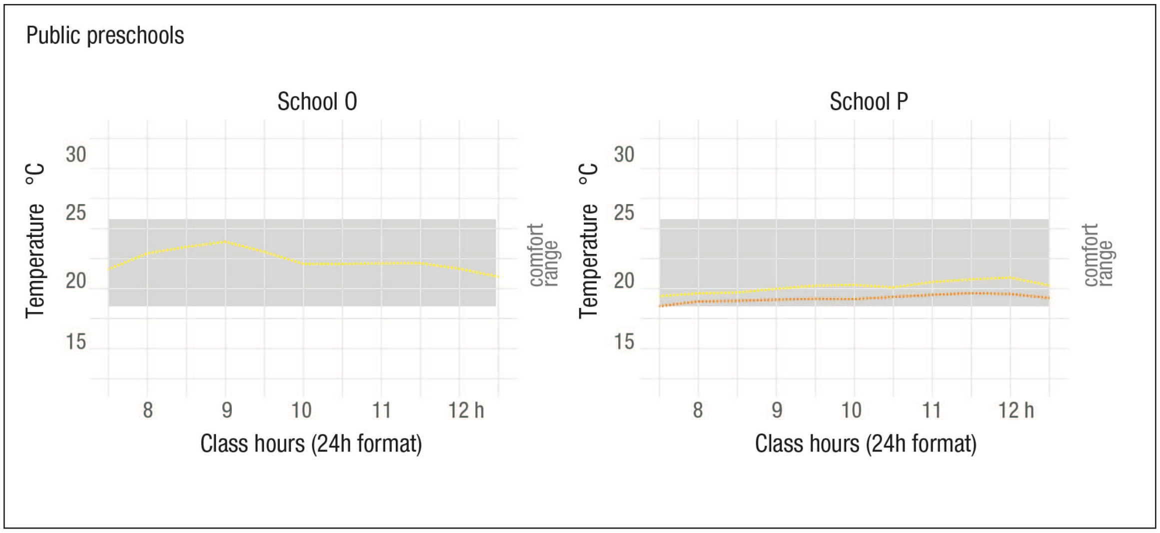
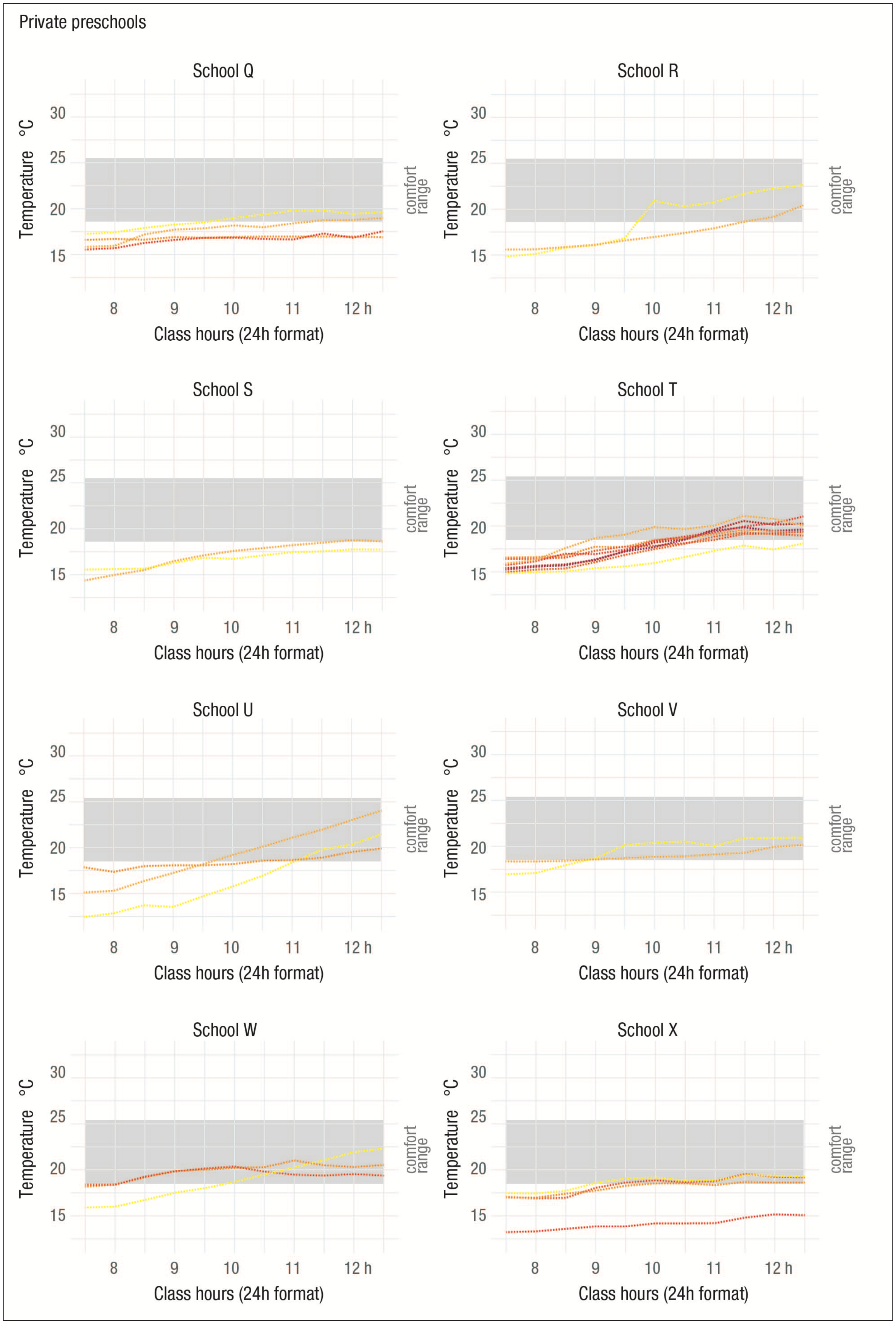
APPENDIX 1 AMBIENT TEMPERATURE READINGS

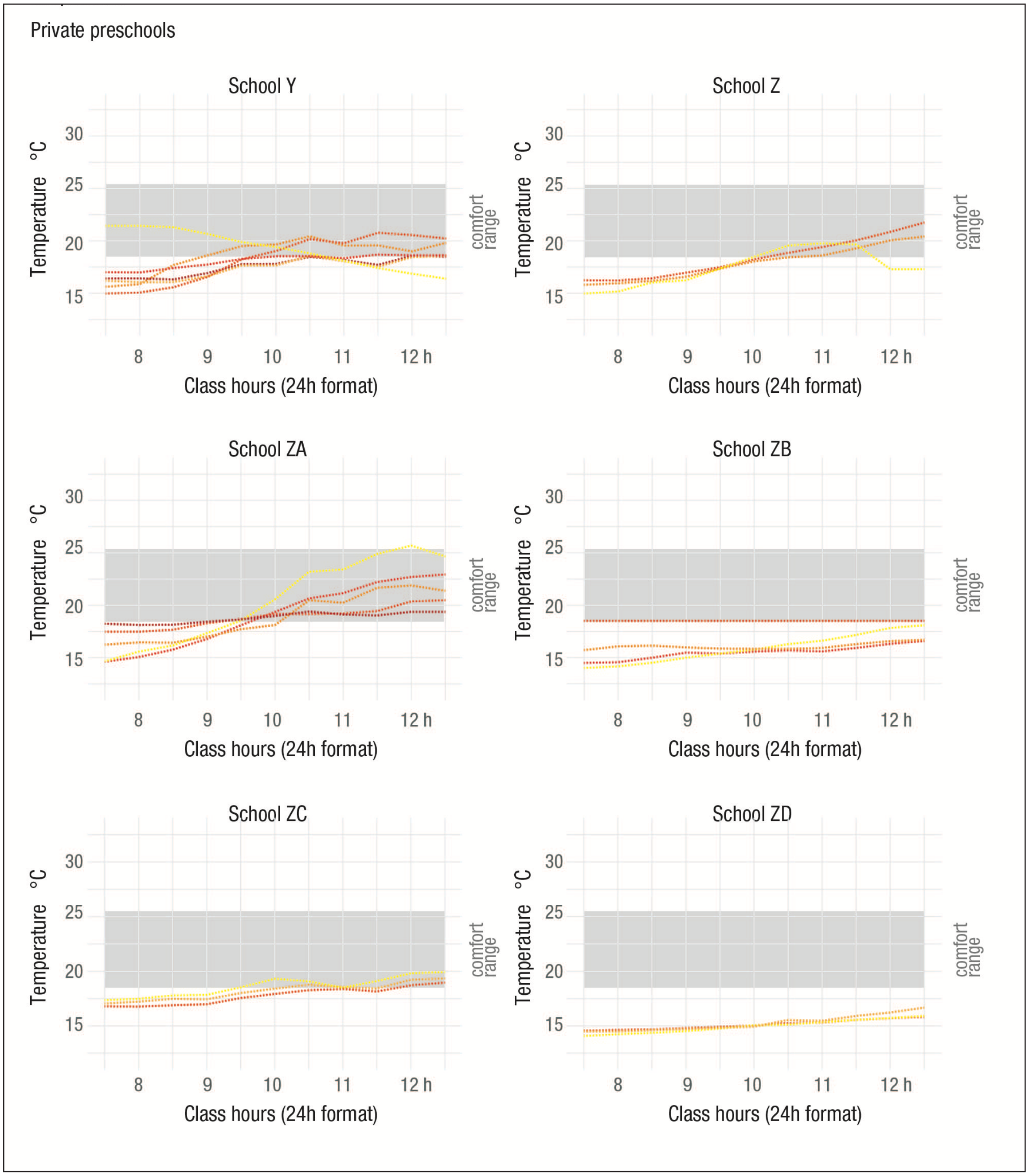
Appendix 1 Each figure represents a school, and each line is the ambient temperature readings (°C) for a specific classroom. The x-axis represents the day hour. The axis displays the ambient temperature in °C. The shaded area highlights the comfort standards for temperature (18.5 °C to 25.5 °C) as defined by the ASHRAE Standard 55—Thermal Environmental Conditions for Human Occupancy (Ashrae, 2016).




Public preschools
School I
School J
School K
School M
School N
Temperature °C
Class hours (24h format)
comfort range
30
25
20
15
8
9
10
11
12 h
13
14
15
16
17
18 h


Public preschools
School O
School P
Temperature °C
30
25
20
15
comfort range
8
9
10
11
12 h
Class hours (24h format)

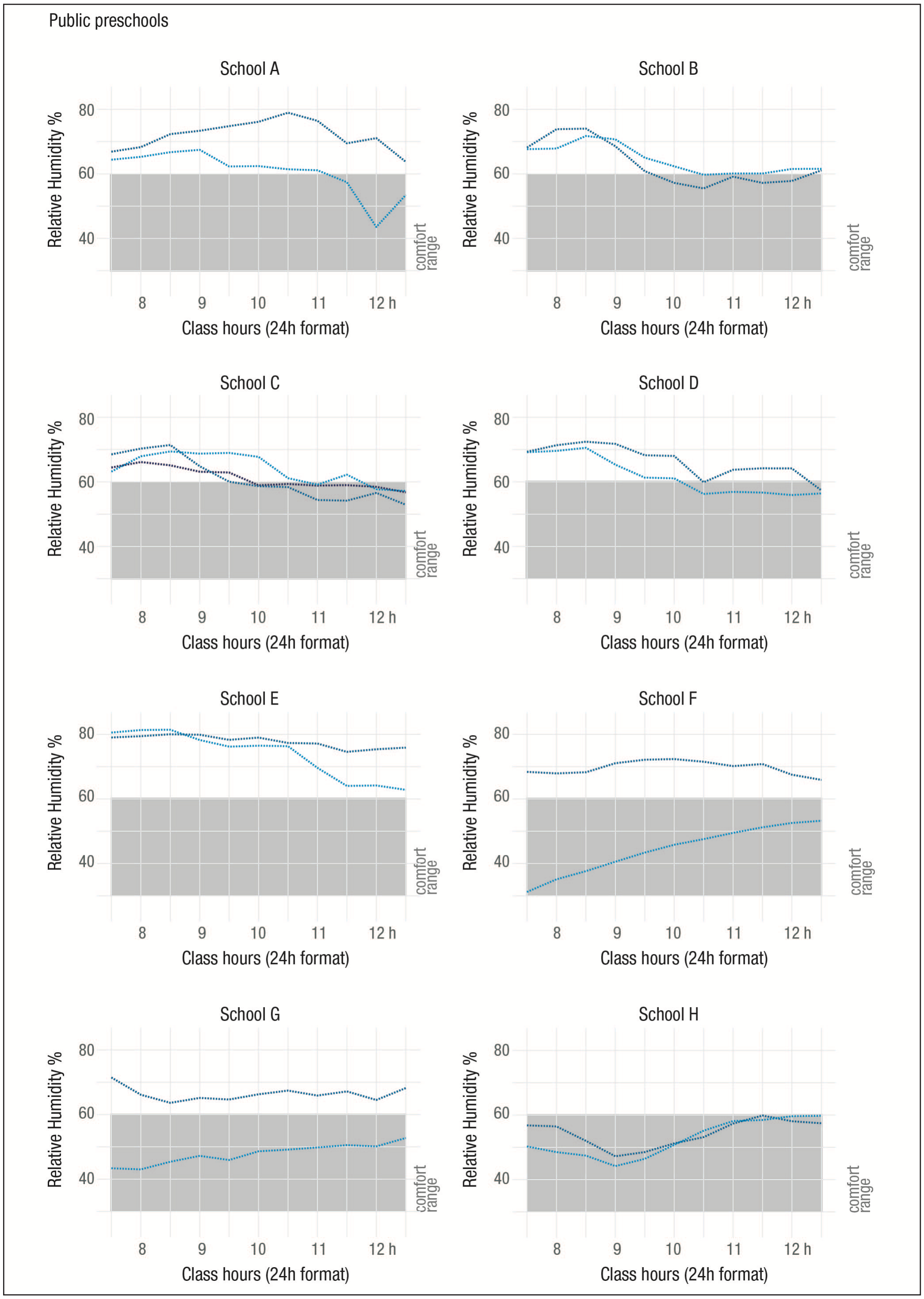

Private preschools
School Q
School R
School S
School T
School U
School V
School W
School X
Temperature °C
30
25
20
15
comfort range
8
9
10
11
12 h
Class hours (24h format)

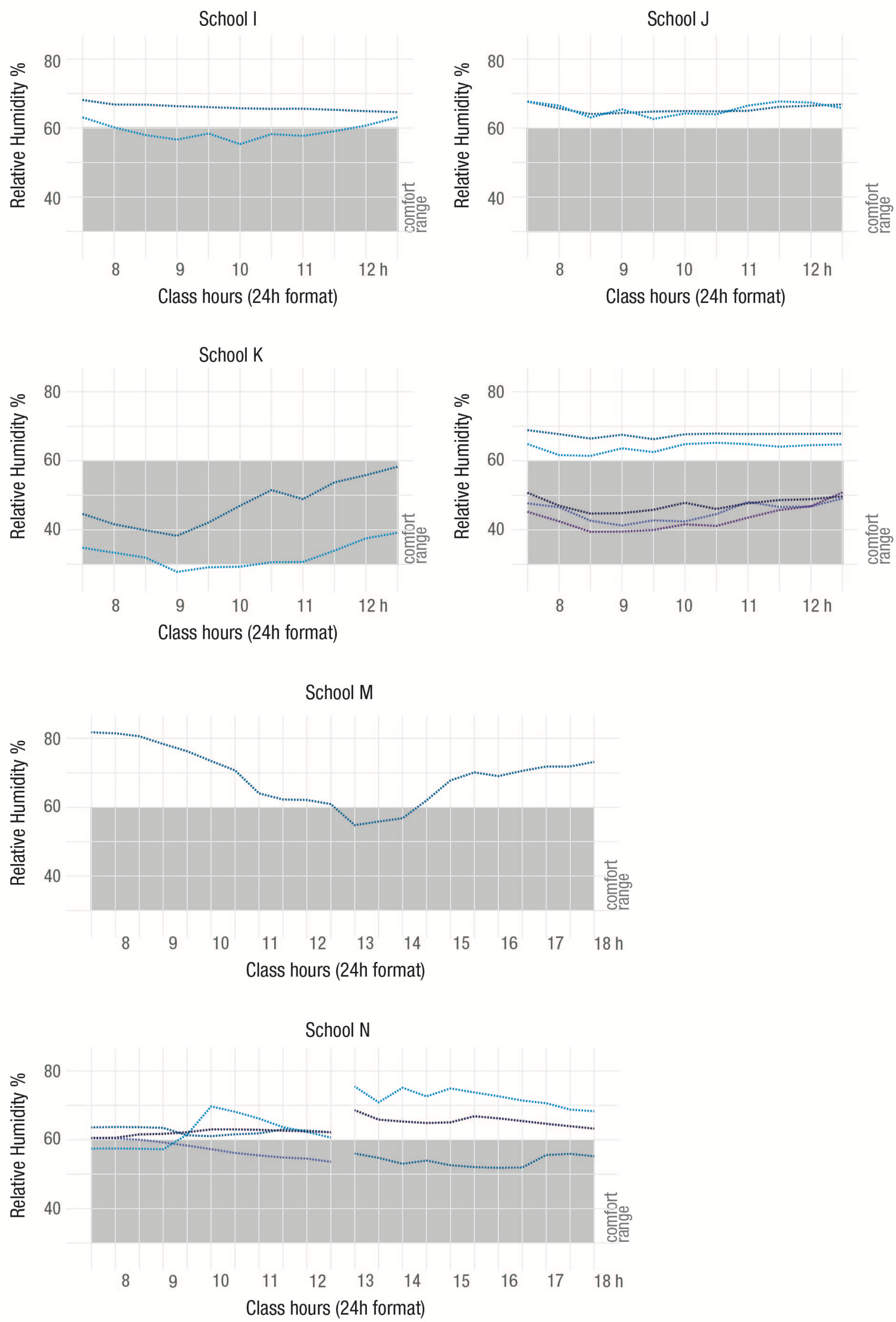


Private preschools
School Y
School Z
School ZA
School ZB
School ZC
School ZD
Temperature °C
comfort range
Class hours (24h format)
8
9
10
11
12 h
15
20
25
30

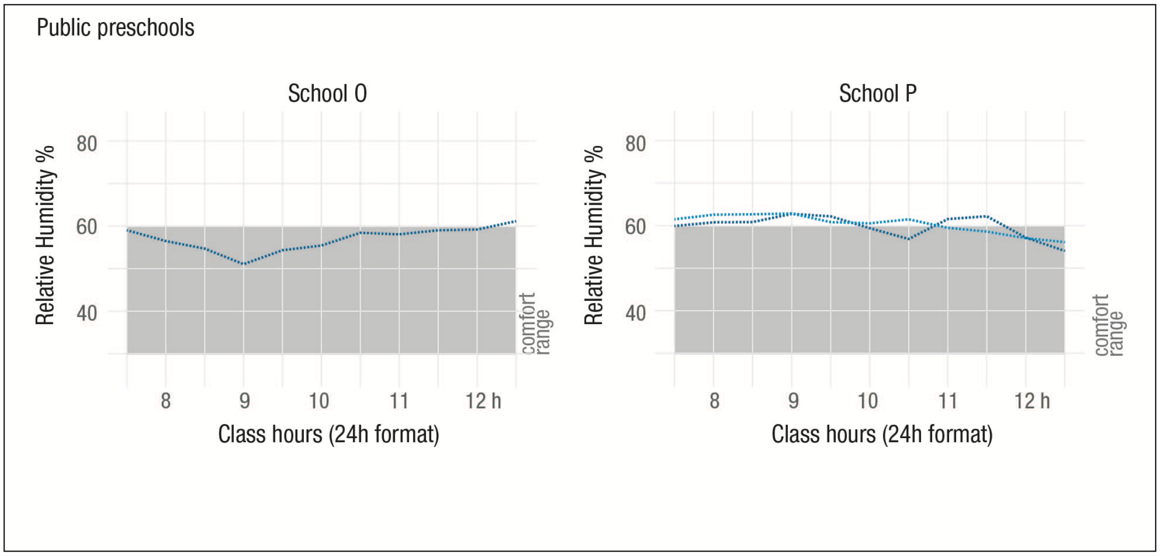
APPENDIX 2 RELATIVE HUMIDITY READINGS

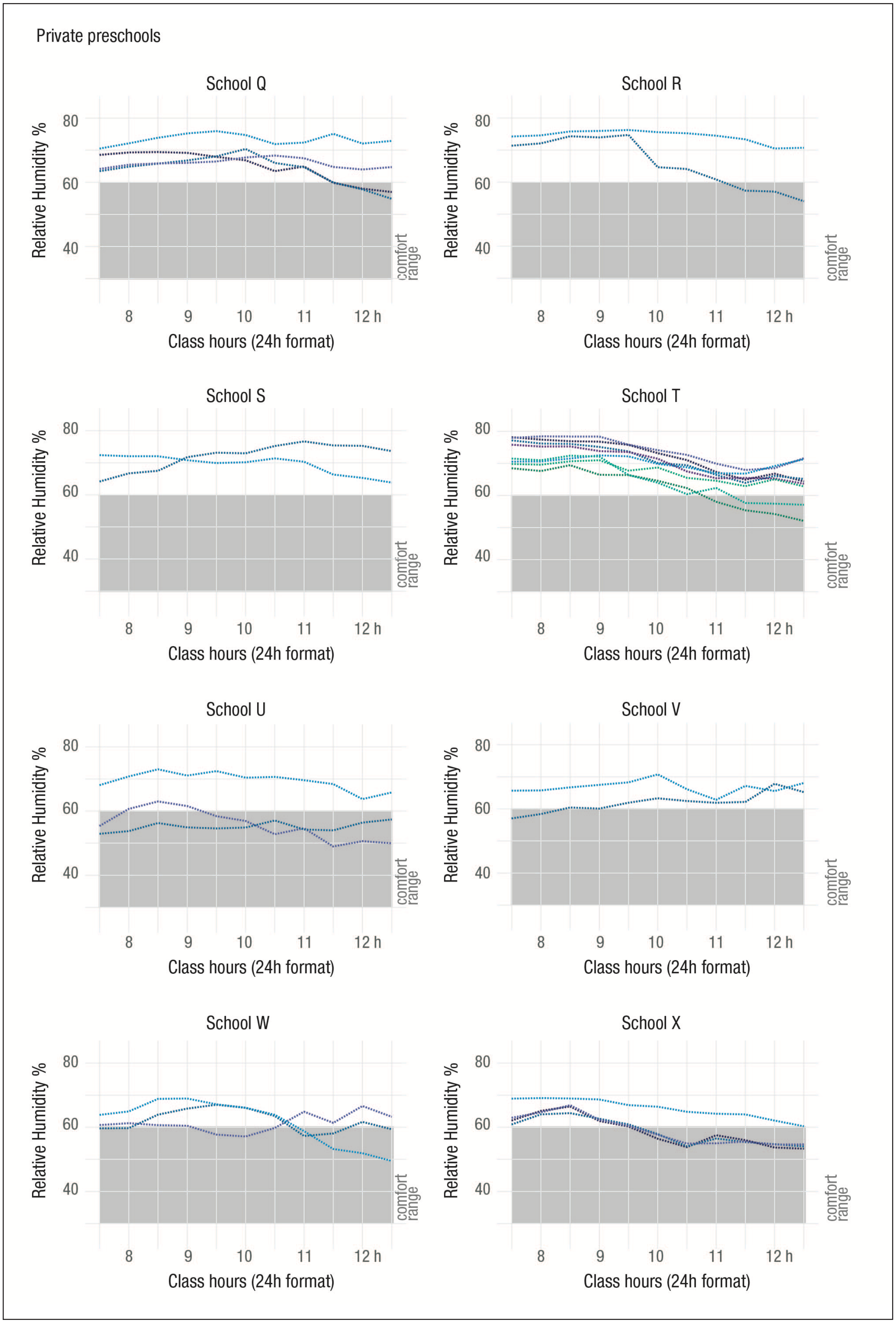
Each figure represents a school, and each line is the relative humidity readings (%) for a specific classroom. The x-axis represents the day hour. The Y-axis displays the relative humidity. The shaded area represents the comfort standards for relative humidity (30% to 60%) as defined by the ASHRAE Standard 55—Thermal Environmental Conditions for Human Occupancy (Ashrae, 2016).

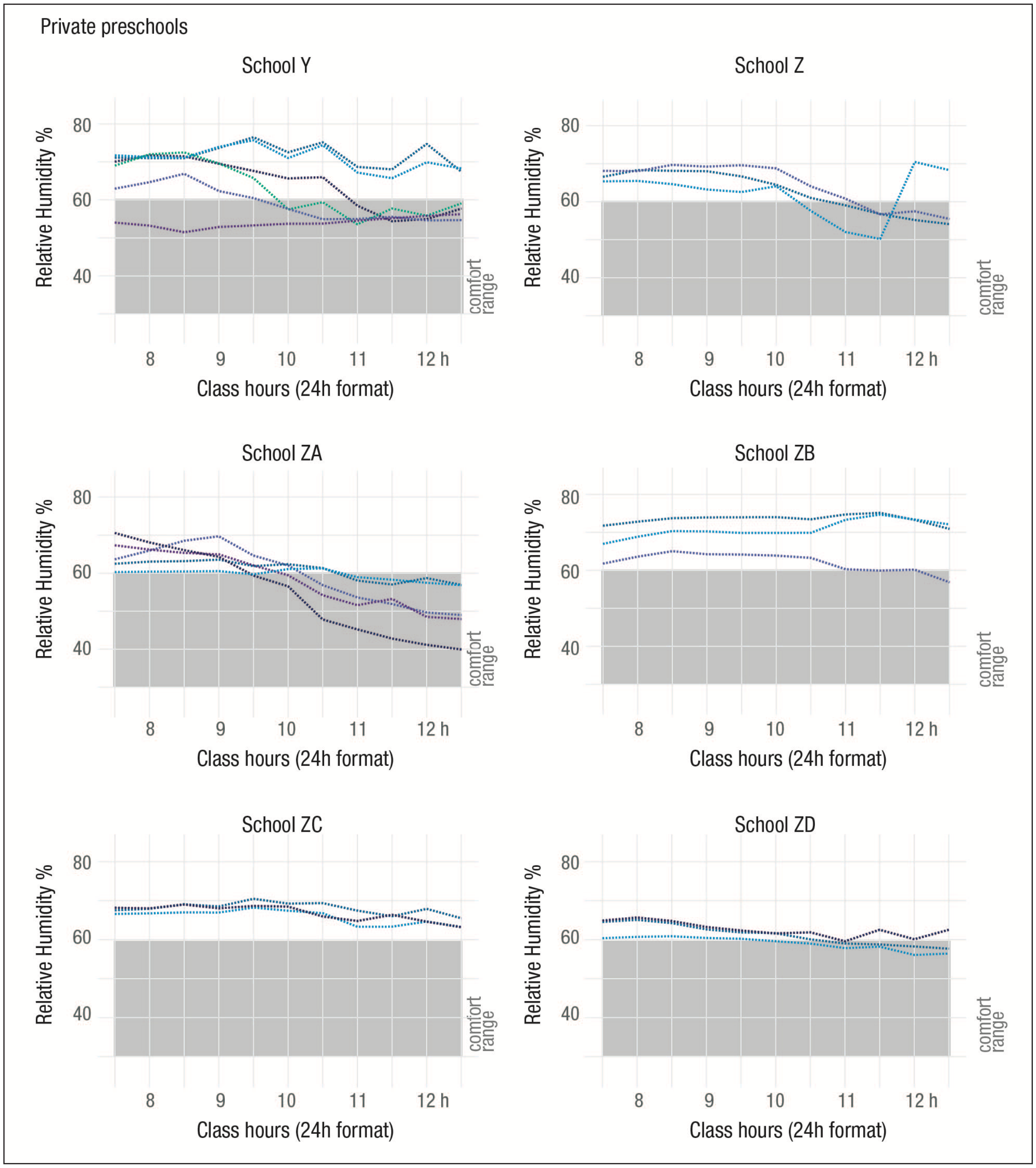




*Comfort range corresponds to ASHRAE 55 standard


Public preschools
School O
School P
Relative Humidity %
80
60
40
comfort range
8
9
10
11
12 h
Class hours (24h format)


Private preschools
School Q
School R
School S
School T
School U
School V
School W
School X
Relative Humidity %
80
60
40
comfort range
8
9
10
11
12 h
Class hours (24h format)



Private preschools
School Y
School Z
School ZA
School ZB
School ZC
School ZD
Relative Humidity %
80
60
40
comfort range
8
9
10
11
12 h
Class hours (24h format)