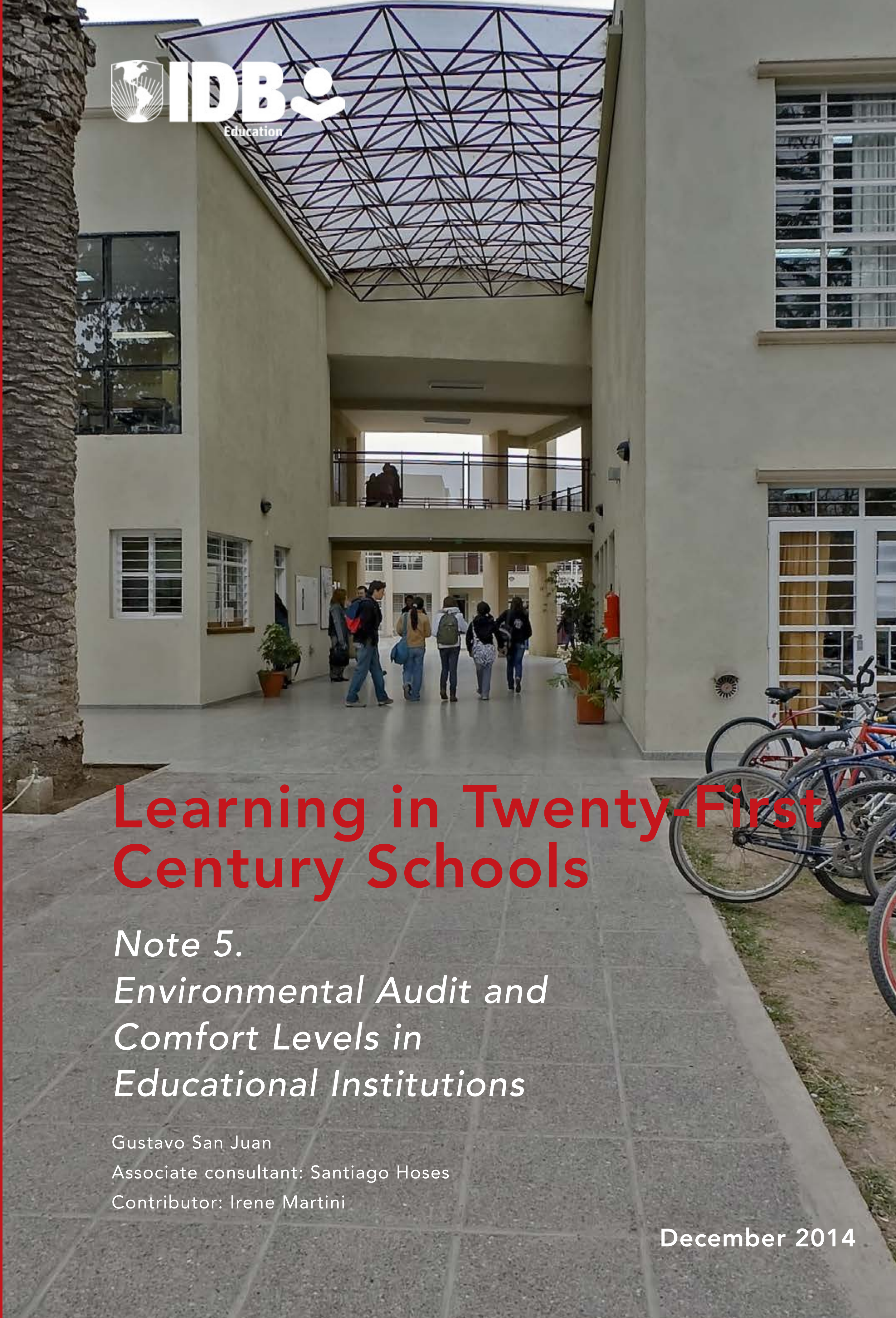


# Learning in Twenty-First Century Schools

*Note 5.*
*Environmental Audit and Comfort Levels in Educational Institutions*

Gustavo San Juan
Associate consultant: Santiago Hoses
Contributor: Irene Martini

December 2014

**Cataloging-in-Publication data provided by the**
**Inter-American Development Bank**
**Felipe Herrera Library**
San Juan, Gustavo.
Learning in Twenty-First Century Schools: note 5. Environmental Audit and Comfort Levels in Educational Institutions / Gustavo San Juan, Santiago Hoses, Irene Martini.
p. cm.
1. Education—Latin America. 2. Knowledge and learning—Latin America. 3. Energy auditing—Latin America.
I. Hoses, Santiago. II. Martini, Irene. III. Inter-American Development Bank. Education Division. IV. Title

*Cover photo:* School of Art no. 4-127, San Rafael, Mendoza, Argentina
*Source:* Ministry of Education of Argentina

# Environmental Audit and Comfort Levels in Educational Institutions

## Introduction

The study of comfort levels considers the factors that affect the balance between the body and its environment in buildings in order to ensure that these living spaces—in this case, classrooms—fall within what are referred to as "comfort zones," or in some cases, "life zones." There is a need to provide a suitable design that can provide the parameters and elements with which to generate concrete solutions.

Conducting environmental audits to identify the actual levels of the parameters in question and compare them to those set by national and international guidelines is important in reaching conclusions and formulating recommendations that will contribute to redesigning or retrofitting existing schools and designing new ones.

The comfort zone depends on each parameter analyzed and is the result of studies conducted by national and international institutions and specialized technical teams. These parameters are generally accepted as the permitted values for the various locations, climates, and activities in question. Defined as the psycho-physiological state in which the majority of the residents of a given space express a given degree of satisfaction with the environment around them, the comfort zone involves a balance between the outdoor and indoor environmental conditions of a given space, enabling a range of planned activities to be carried out in comfortable and satisfactory conditions.

When referring to environmental comfort, a number of conditions, or determining factors, must be considered. These can be categorized as follows:

- Environmental factors, such as hygrothermal comfort, lighting, and sound and air quality; and
- Architectural factors, such as the adaptability of the space and visual, auditory, and aesthetic contact.

It should be pointed out that the conditions associated with comfort may differ according to the perspective of each student in a given educational space at a given time and that balancing the factors that determine these conditions is essential to carrying out school activities in the most efficient way without impairing the students' health.

In this regard, the proper design of educational space should promote favorable conditions for teaching and learning so that both can take place without interruptions, inconvenience, or physiological damage and without altering the normal conditions required for comfort. The design of the building and its surroundings is an essential factor, in which the principles of bioclimatic balance (between climate and life) as well as energy and environmental efficiency are essential requirements for 21st-century schools.

With respect to the schools analyzed, attention to lighting conditions based on the proper design of the sections of the building envelope pertaining to the windows is an essential factor. Similarly, the appropriate treatment of the building's envelope should ensure that it serves as a mediator between interior and exterior climates, in both summer and winter. The acoustic quality of the spaces is another significant variable to consider.

In this respect, the demand for specific studies of the reality of schools in Latin America reveals the need for common methodologies and practices that will help reach conclusions and develop recommendations for defining strategies and policies for the sector.

## Methodology

Using environmental audits of user perceptions, including detailed audits of classrooms, with both qualitative and quantitative components, the aim was to identify significant environmental variables that can affect learning and to determine actual conditions and their relationship to the established standards.

The application of energy efficiency (EE) and environmental sustainability (ES) criteria in educational institutions within a best practices framework revealed a clear need to determine the baseline situation recorded in classrooms and, based on that, to take appropriate actions with respect to:

- The creation of new school spaces with suitably comfortable conditions;
- The promotion of education within a sustainable development (SD) framework, with the aim of improving user performance;
- The reduction of energy consumption, operating costs, and greenhouse gas emissions (GHG); and
- The transformation of schools into "educational models," which implies changes in the domain of the school community.

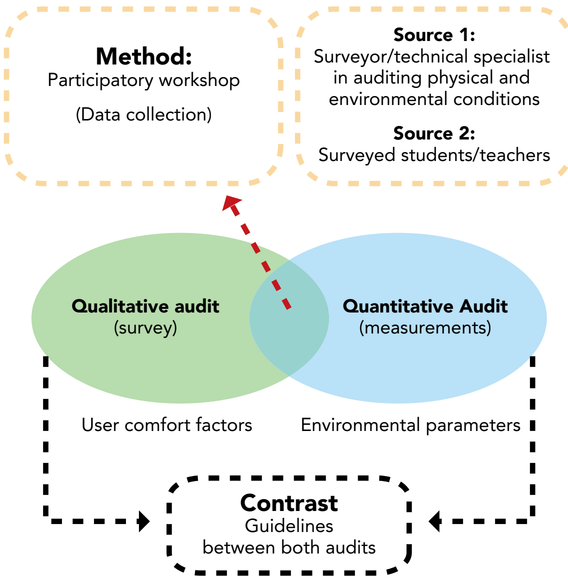
What is the purpose of a targeted audit related to user perceptions and the environmental conditions of the classroom space?

The environmental conditions of a building can be assessed through audits, including measurements or records of environmental parameters[1] and a survey of the users' comfort factors[2] based on individual perceptions (Figure 1). With respect to the former, records are used to define environmental quality based on instantaneous and continuous measurements, while subjective factors are gathered through user perception surveys. The inclusion of the users' opinions of the environmental conditions of the living space facilitates the setting of a baseline based on preexisting conditions (daily life) and at the same time clarifies types of sensations and reactions to discomfort. As the data used are qualitative, they may vary according to a variety of cultural, psychological, physiological, and social factors. From a methodological perspective, the data from both sources are compared in order to reach conclusions and formulate recommendations. The environmental comfort conditions recorded are then compared with the standard values and with user evaluations. These techniques make it possible not only to describe the actual situation but also to relate the results of both methodologies, thus creating and verifying new hypotheses.

1. Environmental parameters are "the objective characteristics of a particular space that can be evaluated in terms of energy and that summarize the actions of those who occupy this space. They can be analyzed independently of the users and constitute the explicit objective of environmental design in architecture." Serra, Rafael. 1999. *Arquitectura y Climas*. Barcelone: GG Básicos.

2. Comfort factors are "the characteristics that correspond to the users of a space. They are therefore conditions that are external to the space but that affect the users' appreciation of it. These personal conditions vary depending on the situation, but can include biological and physiological conditions (such as age, sex, genetics, etc.), sociological conditions (such as activity type, education, home environment, fashion, diet, and cultural acclimatization), and psychological conditions according to the individual characteristics of each user." Serra, Rafael. *Arquitectura y Climas*.

FIGURE 1.
Proposed methodology for the environmental audit of user perceptions




This type of audit is generally conducted in the classroom, with the understanding that: (i) it is where the processes of teaching and learning essentially take place within the school; (ii) it is the most important space within the school in terms of energy consumption; (iii) it is where the greatest precision is required in measuring the parameters for comfort (lighting, temperature, humidity, sound, and air quality); (iv) it is the most representative space within a school building; and (v) it is the most commonly used space in the building.[3]

A series of "action protocols" were developed to conduct this study. This was done firstly to ensure the correct application of knowledge by the technical teams from the countries involved, and secondly to ensure the standardized assessment of the data according to specific parameters. Once the Environmental Audits of User Perceptions and the Quantitative and Qualitative Audit Processing System were completed in each participating country, a specific methodology was developed to interpret the results.[4]

This assessment was based on the minimum number of environmental variables needed to characterize the classroom environment, reflected through a survey of user perceptions and the results of the quantitative measurements obtained using specific tools. Data processing involved: (i) presenting the results in a descriptive format; (ii) conducting a comparative analysis of experiences; (iii) connecting the results of the environmental measurements with those of user perceptions; and (iv) comparing the results with local and international standards.

A simplified version of the methodology used for the Environmental Audit of User Perceptions processed through the Quantitative and Qualitative Audit System according to the various processes, techniques, and teams involved is outlined below. Each phase is identified in Figure 2.

Phase 1: Data collection was based on the coordination of three elements:

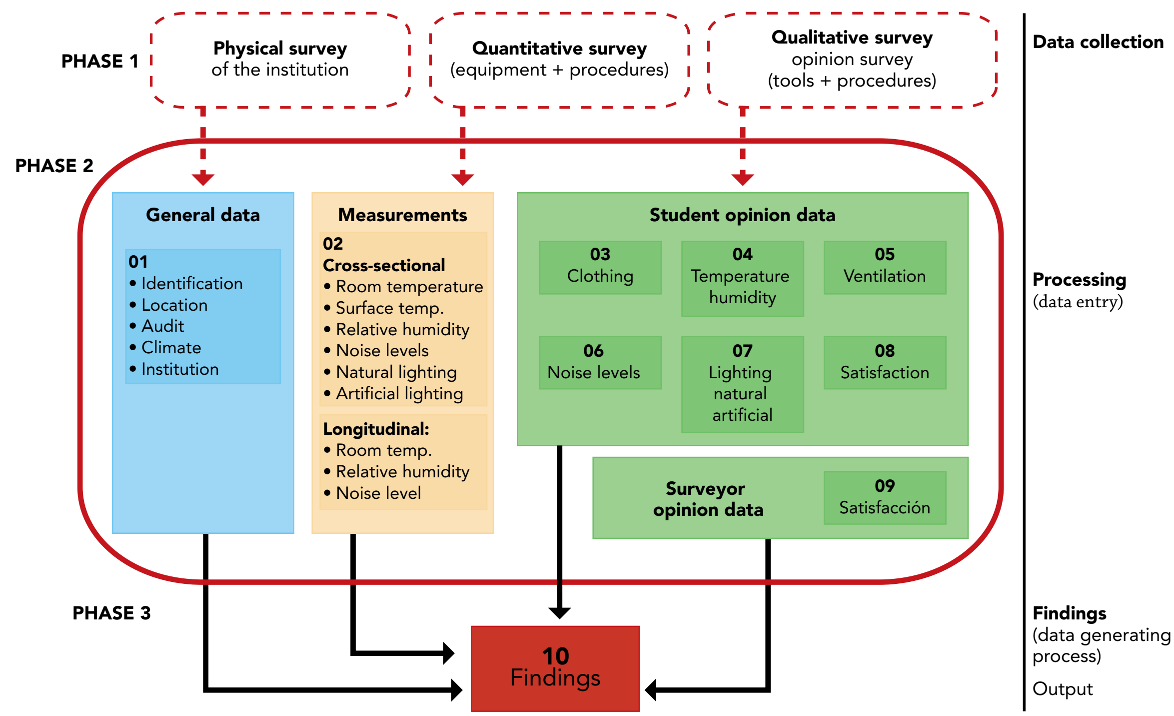
- A physical survey of the institution and the classroom;
- A quantitative survey of the environmental parameters of the classroom; and
- A qualitative survey, consisting of a simple *ad hoc* paper questionnaire aimed at primary school students. It was completed during class time as part of a participatory workshop.

Phase 2: Both the qualitative data thus obtained and the quantitative data drawn from the environmental audit were entered into the processing system,

3. San Juan Gustavo A. 2008. "Comportamiento Energético-Productivo y Ambiental de la Gestión de Redes Edilicias de Educación: Un Enfoque Sistémico en el Continuo de las Escalas del Hábitat." Doctoral Dissertation, Universidad Nacional de Salta, Argentina.

4. San Juan, Gustavo & Hoses, Santiago. 2013. "Análisis de la Auditoría Energética y de Condiciones de Confort en Establecimientos Educacionales (6 países)." Aprendizaje en las Escuelas del siglo XXI. BID RG-T2011 project.

FIGURE 2.
Methodological framework




which was designed using Excel spreadsheets, which offer the advantage of working in a numeric, graphical, open, flexible, and familiar environment. As the first step in analyzing the data, this tool aims to assimilate regional differences and systematize multiple measurements in a shared processing system.

Phase 3: Using the resulting data, the sample was analyzed according to statistical techniques, and assessments and conclusions were developed on three levels: (a) per classroom and educational institution; (b) per country; and (c) across countries. A variety of methodological considerations and international parameters were taken into account in order to compare the various climatic situations of each country and region. These included the following standard criteria and parameters:

- Local comfort ranges (LCR), established by each country's auditing team;
- General comfort range (GCR), based on the "comfort zone" concept developed by Givoni and the design guidelines shown in the "Bioclimatic Diagram," adjusted for different altitudes above mean sea level (AMSL);[5]
- A "comfort map," a model designed by Weilbacher,[6] provides the average temperatures for all 12 months of the year, 24 hours a day, based on average monthly temperatures. It displays hourly temperatures in different places using the local comfort ranges (LCR) of each country;

5. Givoni, Baruch. 1969. "Man, Climate, and Architecture". *Building Research Station, Israel Institute of Technology*. New York: Elsevier.

6. Weilbacher, Guillermo Gonzalo. Director of the Institute of Environmental Conditioning at the National University of Tucumán, Argentina.

- Noise levels, according to the World Health Organization (WHO), with levels above 65 db considered excessive;[7]
- The comfort range shared by all countries with respect to indoor classroom illuminance. Minimum = 300 lux, maximum = 750 lux, with an average recommended value of 500 lux;[8]
- A minimum uniformity coefficient of 0.3;[9]
- Clo Range: 0 to 0.5 = very light clothing; 1 = light clothing; 1 to 2 = warm clothing; greater than 2 = very warm clothing;[10] and
- The auditing technician's scoring: less than (-5) = unfavorable; from (-5) to (5) = normal; greater than (5) = favorable.

To conduct the regional analysis and set the guidelines for bioclimatic design, comfort maps were made for each location based on the relationship between the average annual temperature (°C) and relative humidity (%). Bioclimatic patterns for each location and for each audited classroom were also analyzed. Figure 3 provides an explanation of the analysis of the hygrothermal parameters and the selection of design guidelines for Tucumán, Argentina.

Figure 3.a presents an analysis of the climatic conditions based on the variation in recorded annual hygrothermal maximums, averages, and minimums for the warmest and coolest months, respectively.

Figure 3.b shows the positioning in the diagram of the hygrothermal parameters according to the measurements taken in each classroom during different seasons. This illustration provides the information necessary to setting the design guidelines that must be implemented so that these parameters fall within the comfort zone.

For example, in the case of Tucumán, Argentina, in the winter, warm air—which can be obtained through solar gain or traditional methods—is required, while in the summer, there is a need for cross-ventilation to eliminate excess heat and bring the temperature and humidity values down to within the comfort zone.

## Study sample

The sample used for this study, which follows a data consistency analysis,[11] consists of a total of 39 buildings in different locations in six different countries (in alphabetical order): Argentina (AR), Chile (CL), Colombia (CO), Costa Rica (CR), the Dominican Republic (DR), and Mexico (MX). The environmental audit was conducted during two seasons depending on the country (winter/summer, fall/spring, or rainy/dry). At each educational institution, two classrooms located on opposite sides of the building (N-S or E-W) were analyzed, which meant four audits per school, with the exception of the Dominican Republic and Colombia, where only two audits per school were conducted.

The number of classrooms analyzed consists of 117 cases, and the total number of students who responded to the survey and participated in the experiment is 2,677. The total base number of records consists of 1,296,960 field observations in addition to non-quantifiable data obtained during the field audits (Figure 4).

## Analysis across countries

Quantitative variables are those obtained through specific measurements requiring appropriate tools and the expert abilities of the auditing teams, while

7. In the classroom, at levels higher than 45 db, words become unintelligible and communication is affected. At over 75 db, hearing is impaired, while prolonged exposure to levels over 80/90 db can lead to hearing loss, and 100 db is considered toxic (WHO).

8. IRAM-AADL J 20-04, AADL J 20-04 and MCEN-1997 Guidelines for Argentina; TDRe DA-MOP 2012 for Chile; European UNE-EN 1264-2-2008 Guidelines; Building Bulletin 87 2003forn the UK; IESNA Lighting Handbook 2000 Guidelines for the USA.

9. Building Bulletin 87 2003 UK.

10. Clo is a unit of measurement used for the clothing index (clothing and other accessories). It is defined as the thermal insulation needed to maintain the skin at a stable and comfortable temperature for 8 hours when a person is stationary at a temperature of 20°C, with a relative humidity of 50% and without the impact of solar radiation. The unit equals a thermal insulation of 1 Clo = 0.155 $m^2$ × kW.

11. The study sample consists of cases that are sufficiently consistent to be included in the analysis, while those with incomplete or contradictory records were excluded.

FIGURE 3.A.

## Hygrothermal conditions by annual averages

Blue: minimum; Yellow: average; Red: maximum

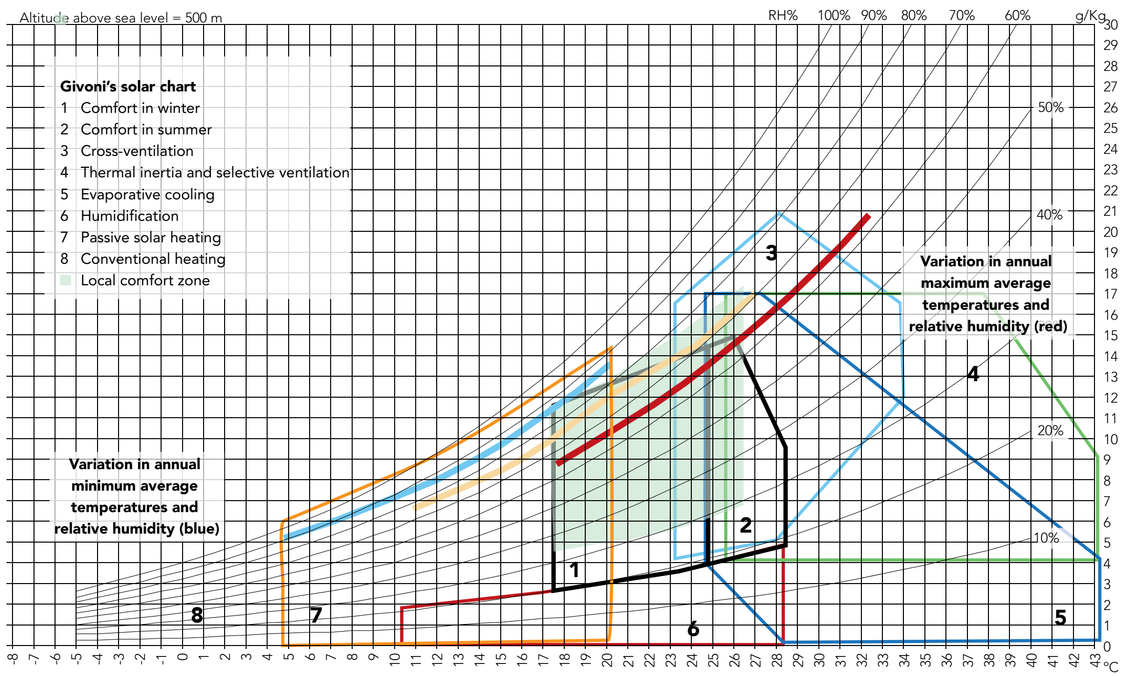



FIGURE 3.B.

## Hygrothermal conditions in each classroom with respect to the comfort zone (Green Area) and the annual average (yellow dot)

Blue dots: winter; red dots: summer

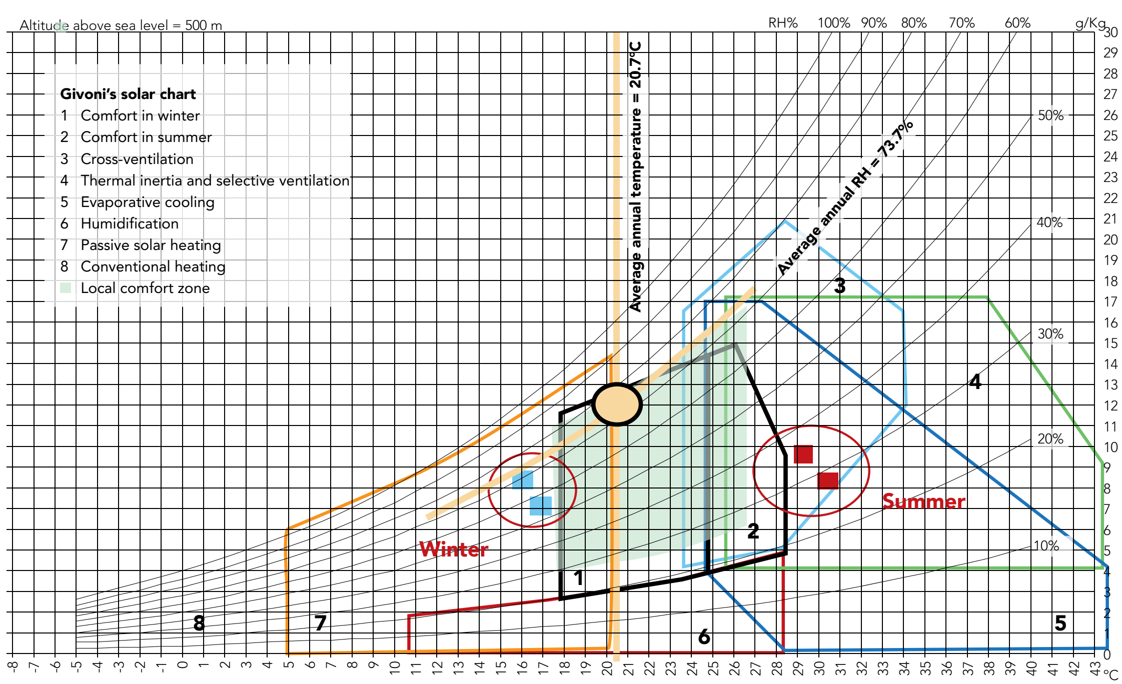


FIGURE 4.
Main data, by country

| | MX | CO | AR | RD | CR | CH | Total |
|---|---|---|---|---|---|---|---|
| Locations | 5 | 8 | 6 | 9 | 6 | 5 | 39 |
| Seasons | 2 | 1[a] | 2 | 2 | 2 | 2 | 2 |
| Number of classrooms audited | 20 | 16 | 22 | 18 | 24 | 17 | 117 |
| Number of students | 516 | 453 | 464 | 432 | 438 | 374 | 2677 |

a. One season, but as there are two classrooms per school, the total number of classrooms audited was 16.

qualitative variables are based on a survey of user opinions. This data collection technique is known as "post-occupational analysis" and is based on parameters compared to the local comfort ranges (LCR) of each country as well as to location and international guidelines, which together set the parameters for comfort.

In general terms, the creation of school infrastructure should aim for the following:

- To provide maximum efficiency in creating environmental conditions favorable to learning;
- To provide the environmental conditions necessary for spaces to ensure "a state of complete physical, mental and social well-being" (WHO);
- To minimize construction, operating, and maintenance costs;
- To incorporate energy efficiency (EE) criteria based on energy conservation guidelines and the incorporation of passive climate control systems;
- To introduce environmentally and user-friendly materials;
- To reduce the emission of pollutants into the atmosphere (SO2, CO, NOx, $CO_2$, HC, COV), especially in cases requiring conventional non-renewable energy sources;
- To respond to specific studies on the topic as well as to local and international guidelines that determine the most suitable standards; and
- To encourage ergonomic quality and flexibility with respect to changes.

The assessment confirmed that hygrothermal comfort is one of the main aspects to consider given that it can be improved through the use of air conditioning or, alternatively, building designs adapted to the environment and climate in question.

In general, there is a significant difference between the levels recorded and the established local comfort ranges. Approximately 30% of the sample fell within the comfort zone, while the remaining 70% was outside of it. The approximation or inclusion of the latter should be achieved firstly through the building itself and then through use of alternative climate control systems.

For example, in Argentina, there are locations in warm, temperate, and cold climates, at different altitudes above sea level, coastal and inland, and with differentiated seasons (winter and summer). During the winter, differences are observed between outdoor and indoor temperatures as a result of the use of heating devices (using natural gas), as in the case of the school in Bariloche. This difference involves energy consumption and the emission of pollutants into the atmosphere, which can be reduced through the use of passive solar systems. In these critical situations, indoor heating should be incorporated by: (i) using traditional systems; (ii) using bioclimatic criteria, by orienting surfaces that capture solar radiation northward; or (iii) incorporating passive thermal heating systems such as lightweight solar air collectors or heavy heat-accumulating walls, according to the utilization factor (kW) of the building (Figure 5).

During the summer, temperature levels exceeding the LCR were recorded in Tucumán and Resistencia. In these cases, the outdoor temperature is lower, which means that the body heat generated by occupants is contributing to the overheating of the building. In the remaining cases, the buildings functioned well, reducing the impact of outdoor conditions. There was no evidence of a relationship between recorded indoor temperatures and classroom orientation (Figure 6).

In the case of Resistencia, records show that temperatures are consistently above the comfort range (26°C). However, given that they are accustomed to this, only a third of the students reported they were hot (33%), although 43% were perspiring (Figures 7 and 8).

If we consider the case of Mexico, with respect to varying indoor temperatures in both winter and summer, situations were observed outside of the comfort range due to either a lack or an excess of heat. In the winter, between 40% and 60% of students reported being comfortable, with temperatures below the acceptable zone, revealing a degree of habituation to unfavorable conditions. In the summer, positive opinions fell below 35% in Campeche and Juárez, with indoor temperatures above the advisable levels. This implies that the majority of students (over 65%) reported experiencing unfavorable conditions (Figure 9). With regard to the concentration of relative humidity, all cases studied were within the comfort range, although the number of students reporting comfort varied from 20% to 60%.

Importance was given to the subjective opinions of students expressed through the survey as well as through the measurement of the amount of clothing they wore (Clo), understood as a response to the degree of discomfort faced with respect to the variable analyzed. The conclusion was that the outdoor climatic conditions that affect indoor conditions show a correlation with the amount of clothing worn, although this is undoubtedly influenced by external parameters, local customs, and a degree of habituation.

For example, in the case of Colombia, in the comparison of Clo vs. temperature during the rainy season, observations revealed that in thermal conditions above local comfort conditions, student responses in terms of clothing remained stable, with an average Clo of 0.5, or very light clothing, with maximums of 1.3, or warm clothing. During the rainy season, the mean average of students reporting that they were comfortable was 0.75, and they were using less clothing (Figure 10). It is worth noting the contradiction in the case of Yopal, where 72% of the students reported being comfortable although 64% of them were perspiring (Figure 11). An analysis of the dry season showed that within the comfort zone, the Clo remained stable, with an average mean of 0.65. However, in uncomfortable conditions due to high temperatures, the response was approximately 0.4 (Figure 12). In the case of Manaure, 46% of students reported feeling comfortable, and only 26% perspired (Figure 13).

Figure 14 shows the correlation between the recorded indoor temperatures and relative humidity, where only 20% of cases were conditions of hygrothermal comfort falling within the general comfort zone. It should be noted that for a more precise analysis, the LCR of each country should be taken into account. Additionally, the highest concentration of positive opinions of the surveyed students (red ellipse) corresponds to the Dominican Republic, Costa Rica, and Colombia, with opinions weighted slightly toward greater humidity and temperature. This situation was found in countries with both temperate and warm climates, suggesting a high degree of physical and cultural habituation.

This reading of the situation suggests two main conclusions:

- Outdoor climatic conditions directly affect indoor environmental conditions, exacerbated in many cases by heat dissipation and relative humidity

FIGURE 5.
Indoor temperature levels (°C) recorded in the classroom (winter)

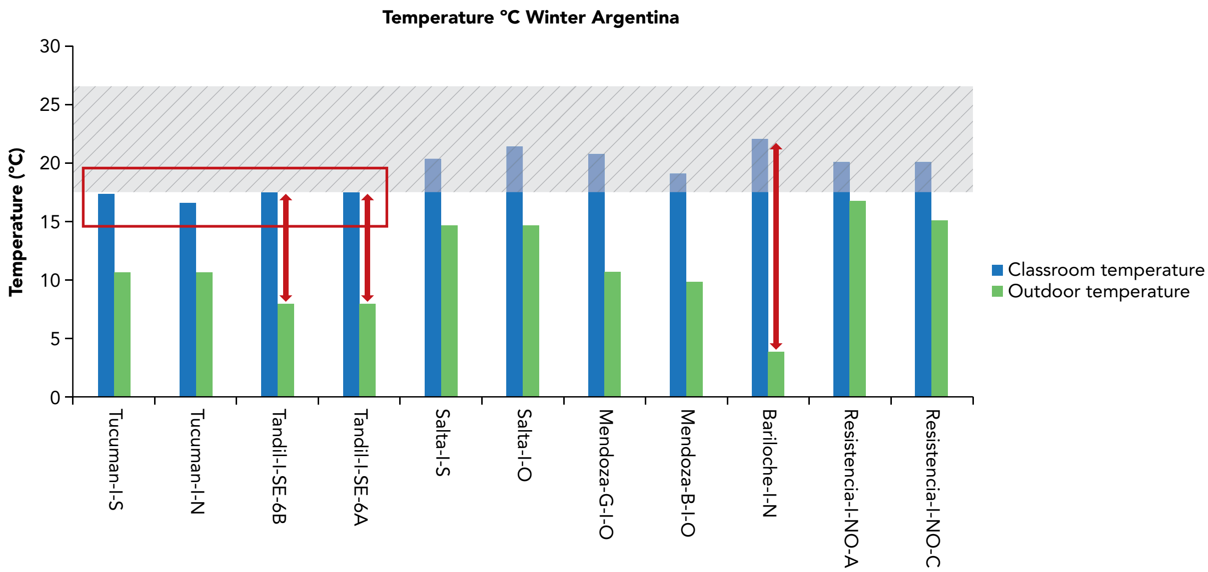
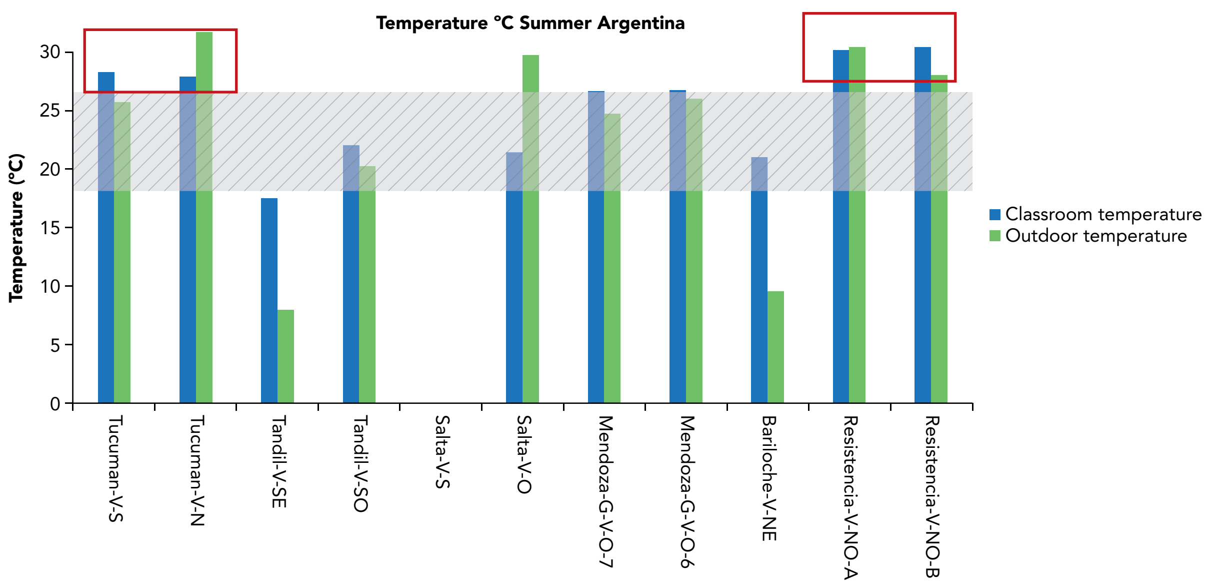



FIGURE 6.
Indoor temperature levels (°C) recorded in the classroom (summer)

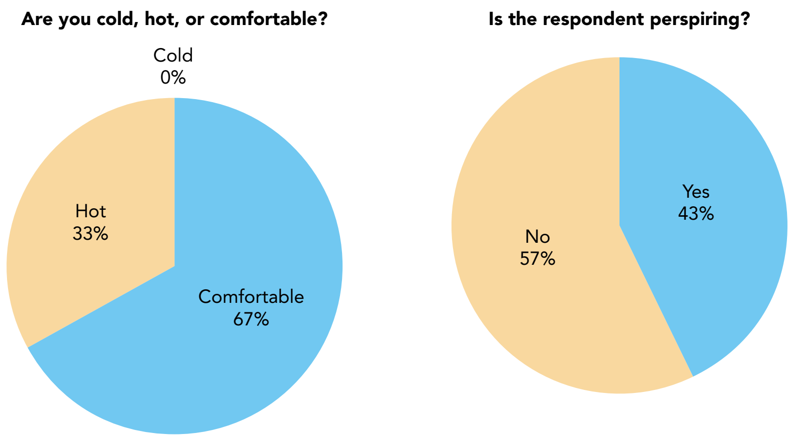



stemming from building use and activity (such as occupants and equipment);

- The audited buildings do not entirely resolve the situation, implying the need for improved design according to bioclimatic patterns that factor in regional and micro-regional climatic conditions, both in regard to the overall conception of the building as well as its respective parts (walls, floors, ceilings, windows, and doors). In the audited sample, 80% of the classrooms were outside of the comfort range used by the country.

With respect to student opinions of thermal comfort, 28% of all students surveyed reported being comfortable according to the LCR used, 20% were

FIGURES 7 AND 8.
Resistencia (summer)—Opinions of students surveyed




comfortable but with temperatures below acceptable levels (20°C), and the remaining 52% were comfortable with temperatures above 26°C. This clearly reveals a degree of habituation to critical conditions. Specific studies should be conducted in each country in order to verify or adapt the current standards.

While the solar orientation of the building is understood to be an important variable given the claim that solar radiation passing through windows can heat the air or raise the sun-air temperature of the outside parameters of the building, no correlation was observed. This suggests that in the designs studied,

FIGURE 9.
Thermal conditions with respect to the percentage of students reporting comfort

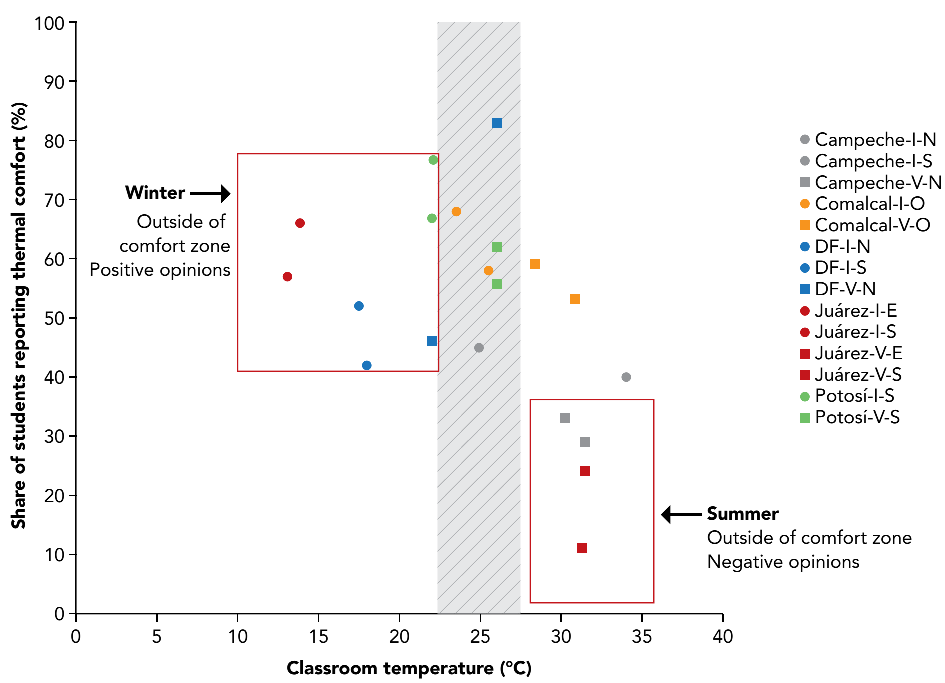


FIGURE 10.

Maximum, minimum, and average Clo, according to classroom temperature (rainy season)

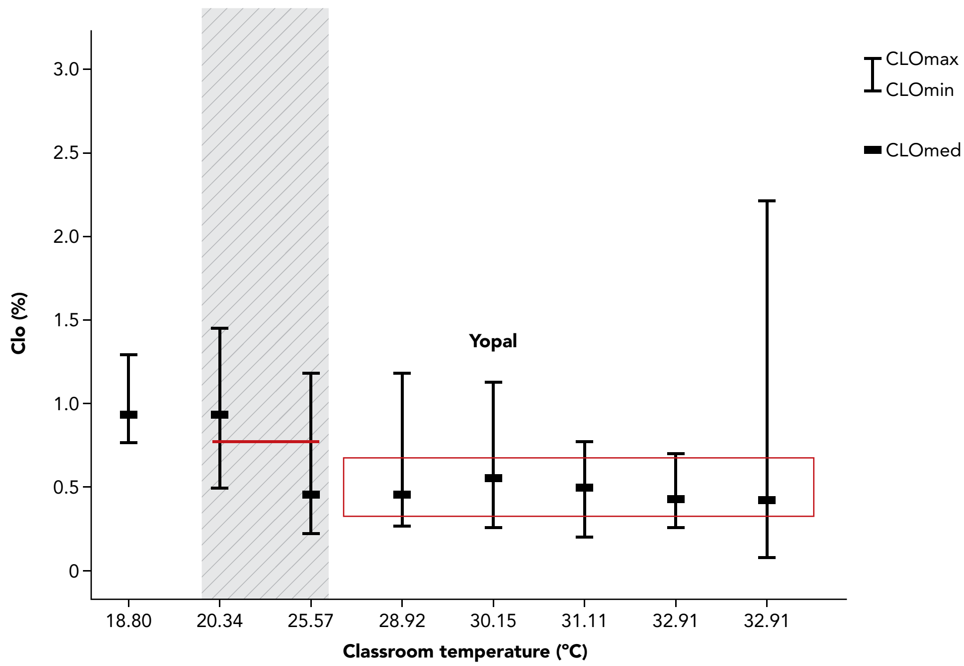



FIGURE 11.

Maximum, minimum, and average Clo, according to classroom temperature (dry season)

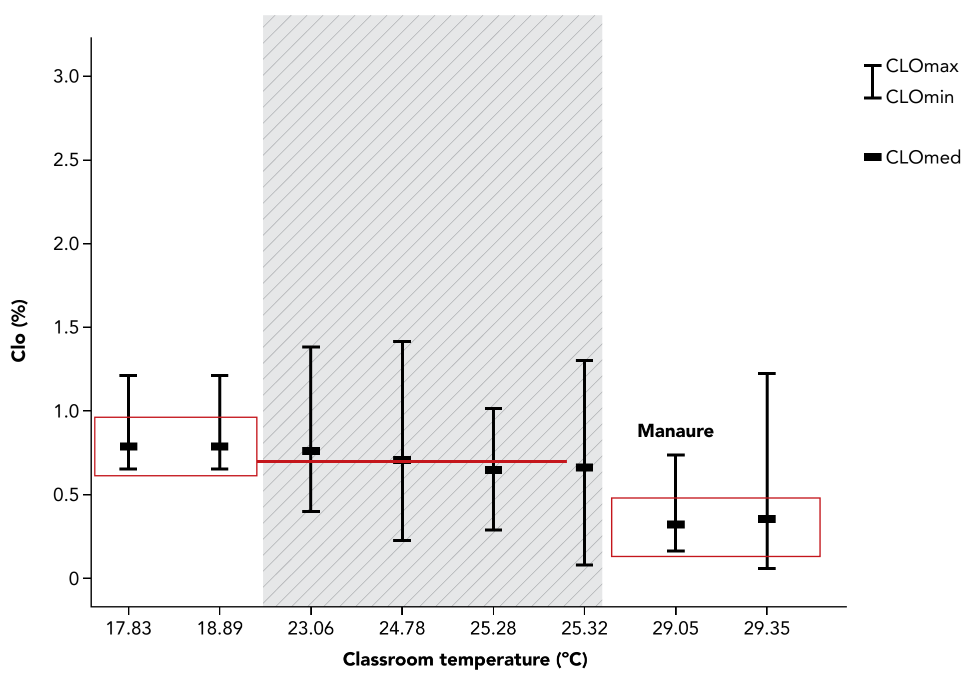


FIGURE 12.
Yopal (rainy season)

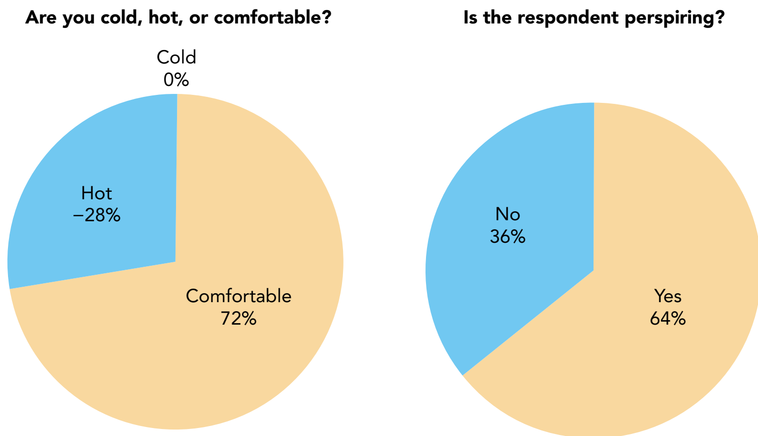
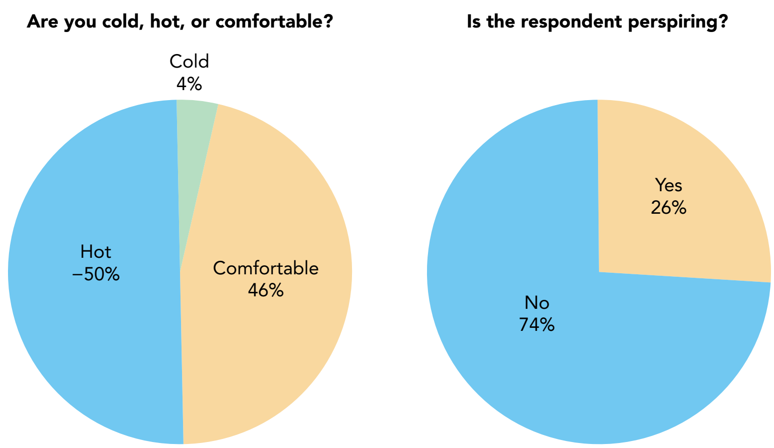



FIGURE 13.
Manaure (dry season)




indoor temperature was more closely related to outdoor temperature than to the orientation of windows or exposed surfaces.

During warm seasons, the surfaces of windows and exposed walls should be shaded. In temperate and warm climates, specific studies should be conducted to determine the type, dimensions, and quality of solar protection. There are different analogical and mathematical methods for simulating these types of developments, factoring in the sun's trajectory and sky types[12] in different geographical locations and seasons and at different times of day.[13]

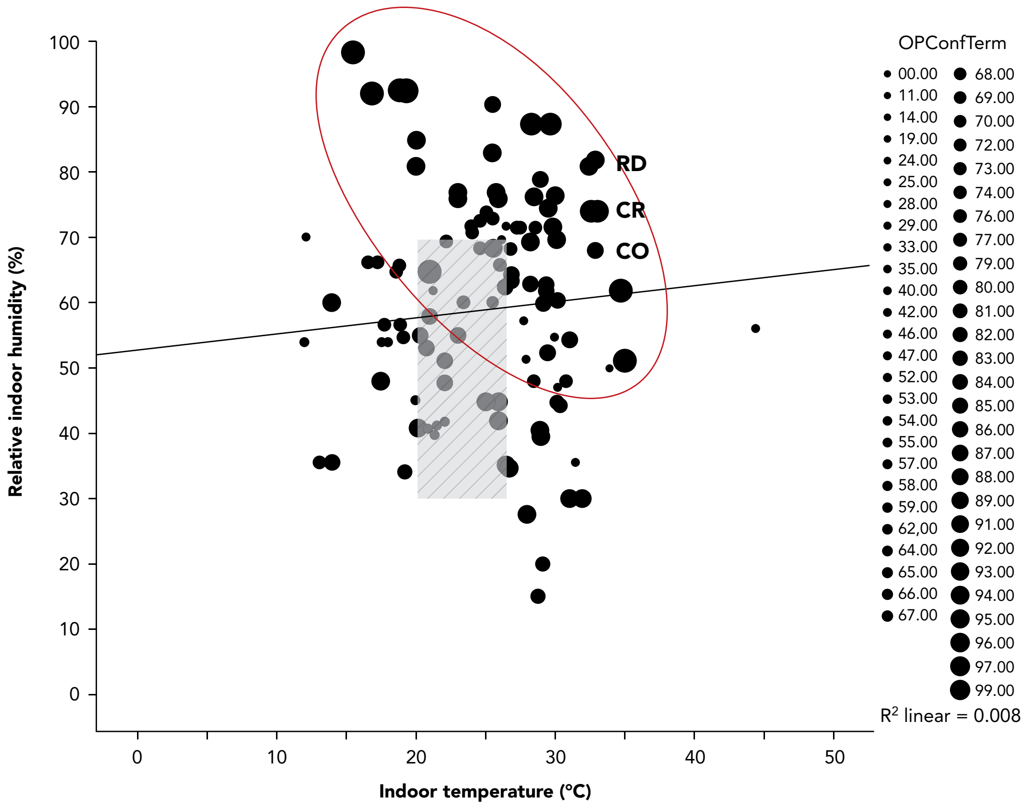
Given the diversity of regional situations, the sample was divided into two groups according to climate,

12. ICI (International Commission on Illumination); CIBSE (Chartered Institute of Building Services Engineers); IESNA (Illuminating Engineering Society of North America).

13. Hoses, Santiago, San Juan, Gustavo, Melchiori, Mariana, & Viegas, Graciela. 2001. "Estrategias de Control Solar en Aulas Escolares y Análisis de su Incidencia en la Iluminación Natural Interior mediante la Utilización de Modelos Analógicos a Escala." *Revista Avances en Energías Renovables y Medio Ambiente* 5: 25–30.

FIGURE 14.

Indoor temperature vs. relative indoor humidity, weighted by positive opinions of thermal comfort (117 classrooms)



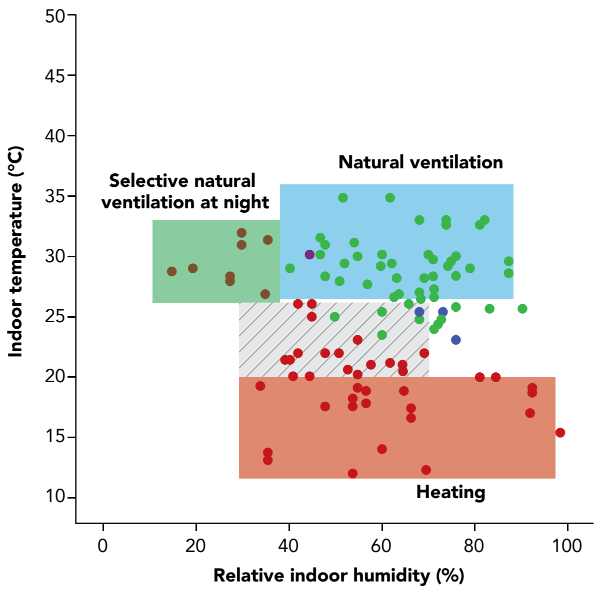

(Shaded area: Givoni comfort zone)

seasonal variation, and bioclimatic patterns (estimated based on annual average temperatures and relative humidity):

- Regions that required indoor heating (bioclimatic pattern 7: passive solar heat), such as Argentina (Salta, Tucumán, Mendoza, Tandil, Bariloche), Mexico (Mexico City, Juárez); Chile (Iquique, Tarapacá, Peñalolén, Peñaflor, Punta Arenas), and Colombia (Ipiales, Soacha). For this group, according to the season, some of the classrooms were below the hygrothermal LCR used while others were above, which highlights the importance of annual variations and the need for environmental conditioning;
- Regions that required air cooling (bioclimatic pattern 3: natural ventilation), such as Argentina (Salta, Tucumán, Mendoza, Resistencia), Mexico (Campeche, Juárez, Mexico City, Comalcalco, Potosí), Chile (Tarapacá, Iquique, Peñalolén, Peñaflor), Colombia (Yopal, Barranquilla, Manaure, Quibdo, Ipiales, Ibagué, Pereira). Dominican Republic (Altagracia, Bayaguana, Bonao, Los Alcarrizos, Monte Plata, Baní, Azua, Brisas del Este, La Caleta), and Costa Rica (Bebedero, Parrita, Luzon, El Carmen, Poasito, Panamá). Almost all of the locations in this group required natural ventilation or both natural ventilation and selective nightly ventilation (bioclimatic pattern 4) depending on thermal variation.

Figure 15 displays the hygrothermal position recorded in each classroom. The colored dots indicate the predominant annual bioclimatic pattern (blue = comfort; green = need for ventilation; red = need

FIGURE 15.
Indoor temperature vs. relative indoor humidity (117 classrooms)




for heating). The shaded area is the Givoni comfort zone. As can be seen, some of the locations require heating, especially during the winter (red shaded area), while others require cooling during the summer period (blue shaded area). In other situations (green shaded area), the records did not coincide with the annual bioclimatic pattern that mostly represents the location, requiring occasional selective ventilation during the night during the audited period.

This suggests the need for a responsible and strictly professional study of whether these hygrothermal imbalances can be resolved through the use of traditional conditioning systems, such as air conditioning or fans (energy-intensive systems), or whether they can be improved through bioclimatic criteria applied to the building itself and its surroundings.

Lighting comfort is understood to be one of the main factors to consider in a classroom situation, given that the resulting environment has a direct impact on the development of physiological and behavioral patterns, attention deficits, and vision, all of which affect students' comprehension. A solution can be found in the use of artificial lighting or, alternatively, through building designs adapted to the environment and the climate in question.

With regards to the illuminance levels (lux) recorded in the classrooms, the levels observed were generally below the admissible local comfort ranges (LCR) as well as international ones. The sample shows that in most cases, the minimum recorded illuminance value (below 300 lux) is critical, based on the lighting differences between areas close to windows and those further away. In other cases, the maximum values recorded were above the standard range.

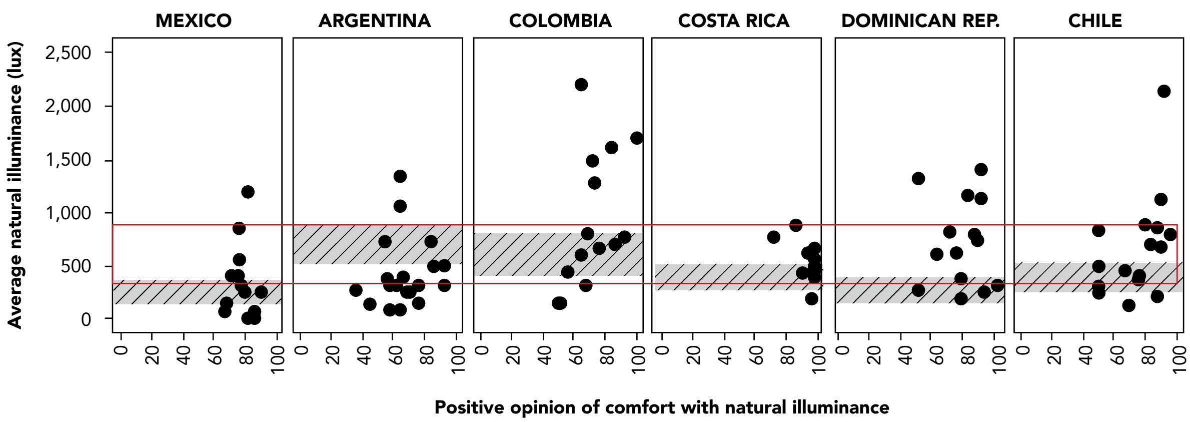
The disparity between outdoor and indoor illuminance levels reveals the arbitrary nature of the design of natural light sources in the classrooms studied, where the building in general does not appropriately alleviate or control these factors. In Mexico and Argentina, in most cases, the recorded values were below the minimum admissible value, while in Colombia, Costa Rica, and the Dominican Republic, the average values were within the comfort range, although there were several cases where maximum values exceeded the recommended values. Finally, in Chile, average values were low and within the LCR used.

As observed in Figure 16, the relationship between the positive opinions of students surveyed (abscissas from 0% to 100%) and the average natural illuminance (ordered) reveals a tendency toward positive opinions (comfort) when the records are within or close to the LCR used. This implies an acknowledgement by the students that when light is illuminating their desks, this improves their state of well-being.

This student response should persuade educational infrastructure designers to pay considerable attention to this variable.

For example, in Mexico, Colombia, and Costa Rica, the percentage of students in the comfort zone was between 60% and 100%. With greater dispersion, students in the Dominican Republic and Chile placed between 50% and 100%, while in Argentina, a positive value between 30% and 90% was reported, with

FIGURE 16.
Average natural illuminance vs. positive opinions of lighting comfort (117 classrooms)




Shaded area = LCR.
Red box = comfort range, according to international standards.
Yellow area = highest average of positive opinions.

lighting levels below the standard range (see the yellow areas in Figure 16).

In all of the countries studied, the minimum illuminance value used (below 300 lux) was critical, especially in the areas furthest from windows. For instance, in Mexico and Costa Rica, values below 100 lux were recorded, indicating the need to incorporate artificial lighting. On the other hand, in Colombia and Chile, values above 1,500 lux as well as the standard ranges were recorded.

In terms of the disparity in responses regarding lighting with respect to the design of natural lighting sources, Figure 17 shows that in the Dominican Republic (red dots), there is a significant disparity between the cases analyzed since with an average outdoor illuminance of 20,000 lux, recorded indoor levels were between 150 and 1,400 lux. In the case of Chile (green dots), while different outdoor illuminance levels between 20,000 and 110,000 lux were recorded, indoor levels were similar, in the order of 350 lux (Figure 17), while the positive opinions of the students fell within or close to the established comfort zone (Figure 18).

The recorded levels of indoor illuminance should be compared to the local comfort ranges (LCR) since they depend on the degree of habituation of the users to their region's sky type.

Acoustic comfort is another important factor to consider given its potential physiological impact and its effect on understanding audible communication, an essential factor in a space dedicated to teaching

FIGURE 17.
Average natural indoor illuminance vs. outdoor illuminance (117 Classrooms)

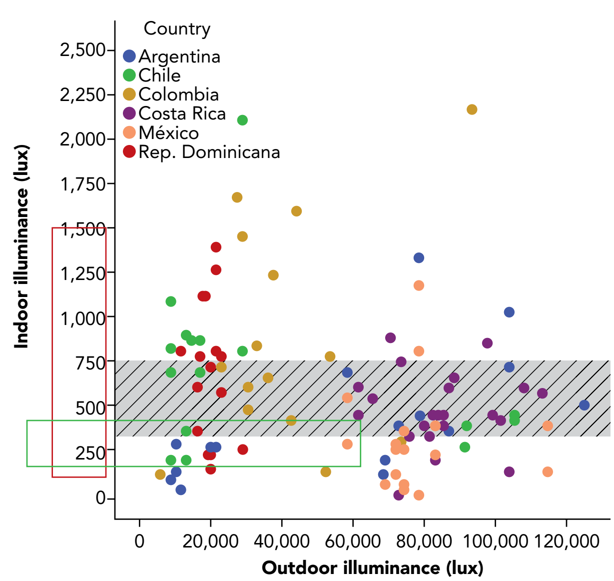
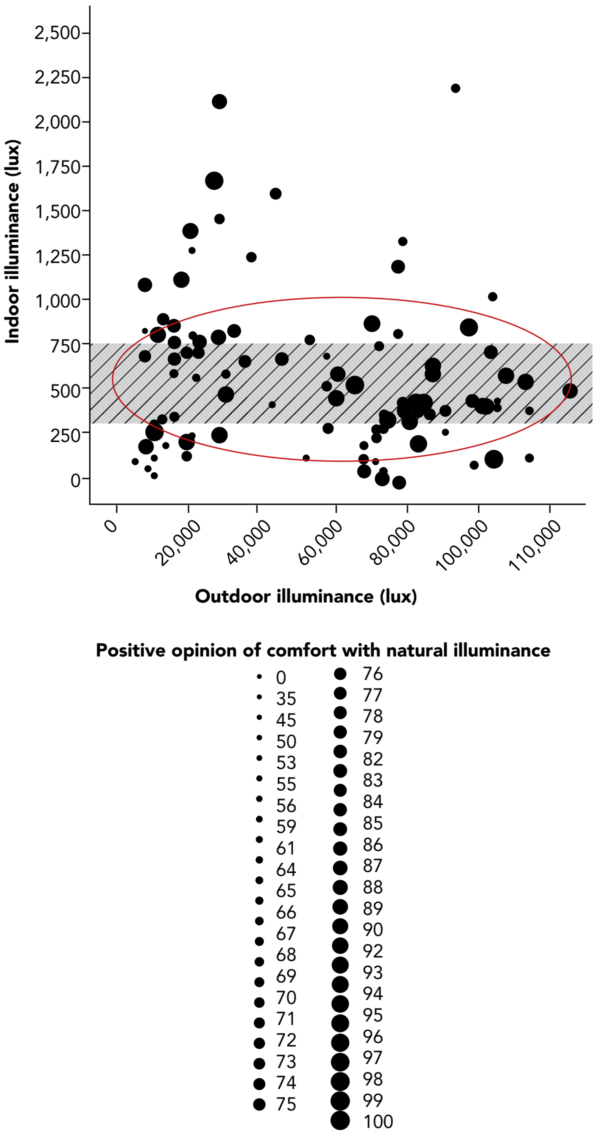


FIGURE 18.

Average natural indoor illuminance vs. outdoor illuminance, weighted for positive opinions regarding lighting comfort (117 classrooms)




and education. This can be optimized through designs aimed at reducing the sounds coming from outside as well as those generated within the educational space itself.

Figure 19 displays the instantaneous records from the audited classrooms. As shown, in most cases, sound intensity exceeds the maximum admissible levels within the LCR. This suggests the need to reduce airborne noise from outside by using acoustic barriers or incorporating appropriate solutions into the building's envelope, and in particular, the windows. There is also a clear need to address the indoor acoustic field.

Figure 20 shows that the highest proportion of students who reported being comfortable is in the quadrant between 62 and 85 db of indoor sound intensity and 50 to 85 db of outdoor sound intensity. Practically all of the cases described are outside of the comfort zone, suggesting a degree of habituation to the situation. Given that the acoustic level is considered a critical variable, further studies of the topic are recommended along with the implementation of appropriate technologies in new and existing buildings.

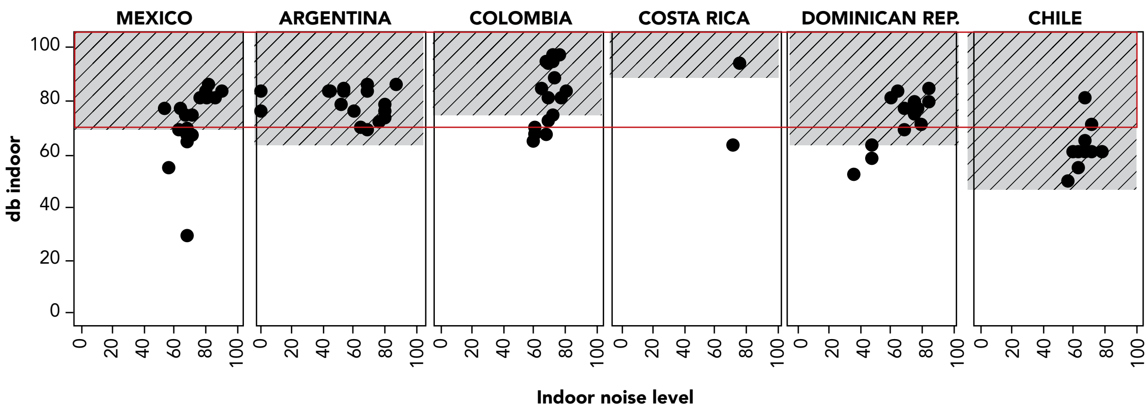
With respect to air quality, the concentration of carbon dioxide ($CO_2$) is an important factor to consider given its impact on health, whether coming from outside of the classroom or emitted by its occupants. High concentrations of $CO_2$ are toxic for humans. Beginning at 0.1% (1,000 ppm), $CO_2$ can become a factor in asthma and sick-building syndrome. This is the maximum permitted concentration for building design or air conditioning systems inside living spaces.

The study revealed that 20% of the sample exhibited levels of maximum concentration above the permitted limits, coinciding with institutions located in cold climates, where the windows are kept closed, decreasing air intake and the necessary renewal of air. In the remaining 80%, recorded levels were below the international standards used (American Society of Heating, Refrigerating, and Air Conditioning Engineers – ASHRAE), which set a maximum limit of 1,000 ppm (parts per million), although according to Spain's *Reglamento de Instalaciones Térmicas de los Edificios* (RITE) 2007, which is based on European Union (EU) regulations, levels should not exceed 500 ppm above the outdoor concentration (Figure 21).

The most affected countries are Argentina (Tandil, Tucumán, Bariloche), Chile (Iquique, Peñaflor, Peñalolén, Tarapacá, Punta Arenas) and to a lesser degree Colombia (Barranquilla, Soacha), with a total of 522 students affected (18% of the sample). The solution

FIGURE 19.

Intensity of indoor sounds (db) vs. intensity of outdoor sounds (db) (117 classrooms)



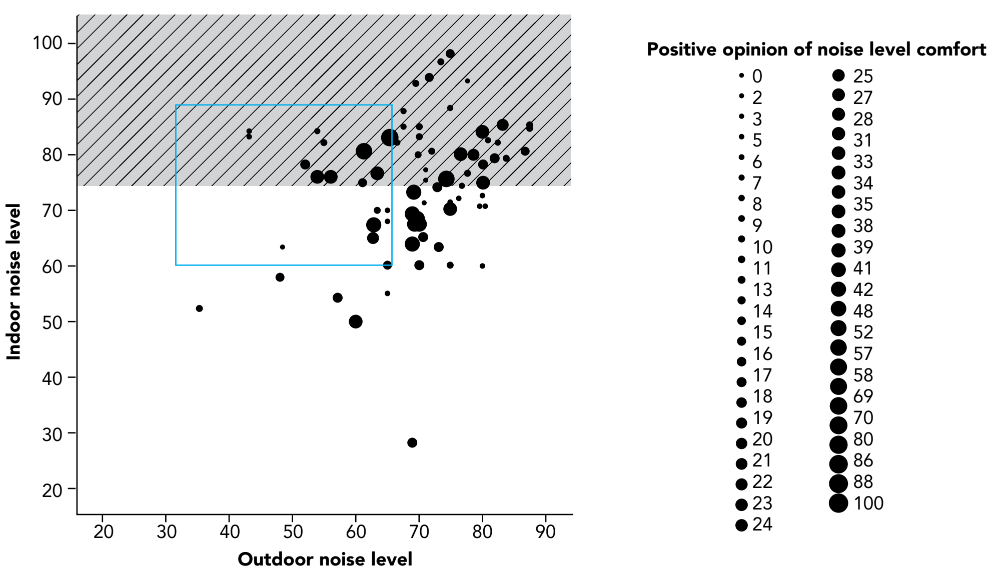

Shaded area = LCR; Red square = inadvisable levels according to international guidelines

for cases such as these is the incorporation of natural or automatic ventilation systems in order to remove stale air and air pollutants, as mentioned above. The other countries (Mexico, Costa Rica, and the Dominican Republic), were below the established limit.

The assessment of the auditing technician, or scoring, reflects an overall opinion of all the variables analyzed. As shown, 2% of the sample was rated favorably, 78% as normal, and the remainder (20%) unfavorably. This implies that the expert opinion estimated a positive score while the analysis confirmed anomalies with respect to the established LCRs. Perhaps, these data reveal a lack of awareness of the issue, or the technician's subjective scores may have obscured the

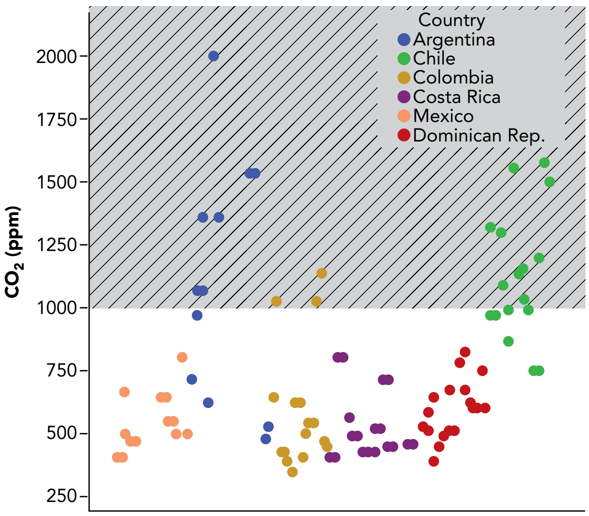
FIGURE 20.

Intensity of indoor sounds (db) vs. intensity of outdoor sounds (db) (117 classrooms), weighted for positive opinions



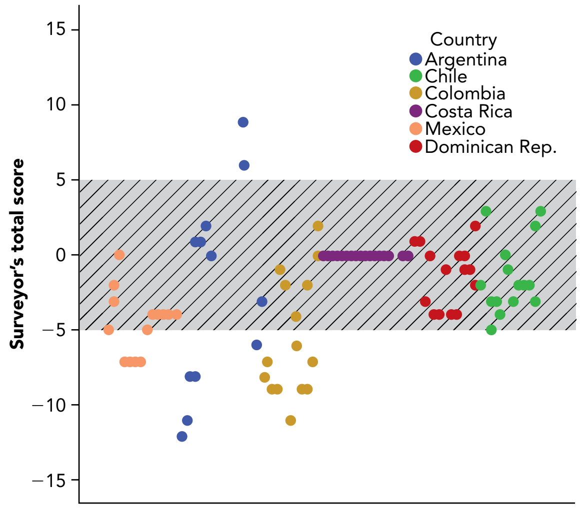

Shaded area = inadvisable levels according to guidelines; Blue square = concentration of positive opinions

FIGURE 21.
$CO_2$ levels recorded in the classrooms studied (100 classrooms)




Shaded area = inadvisable limit according to international guidelines

FIGURE 22.
General assessment of the auditing technician




Value between 5 and -5 = normal; above 5 = favorable; below -5 = unfavorable.

environmental situation audited, which, consciously or unconsciously, was revealed by the students themselves (Figure 22).

The sound variable is considered critical, that is, negative for the entire sample during the seasonal periods studied, coinciding with the measurements taken. In general, the topics associated with questions of aesthetic well-being were scored positively, which indicates that they do not represent a critical variable, at least not in the initial analysis carried out for the present study.

## Strategies to implement

The knowledge gathered through this study suggests the need for a series of shared steps to be taken in order to reach particular solutions with regard to both buildings and technologies, along with the revision of the current standards. School buildings should be transformed into efficient and effective buildings, not only given the kind of activities they are designed for, but also because they should serve as models for the rest of society. This requires changes in methodologies and design processes, as well as the incorporation of specific techniques that are briefly outlined below:

### Study the climate conditions of each site and define the bioclimatic patterns for each location.

One of the most important starting points is knowledge of the annual thermal conditions 24 hours a day. A "thermal comfort map" was therefore created for each location, with the following purpose: (a) to understand the conditions of the site and determine the comprehensive design response to be used; (b) to provide knowledge about the school buildings' period of use, within the category of what are called "intermittently occupied buildings" (daily, monthly, annually); (c) to recognize the thermal situation, according to the defined minimums and maximums of the local comfort range (LCR); and (d) to visualize the temperature distribution, 24 hours a day, for every month of the year.

As an example, Figure 23 presents the situation in Tucumán, Argentina, where, at the beginning of a cold day, temperatures are below 18°C (LCR) and heating is needed to achieve a comfortable state. This situation extends from May to September. During the summer months, when there are no classes, recorded temperatures were above 24°C, making cooling a necessity, while temperatures are comfortable during the equinoxes. Figure 24 displays the situation in Barranquilla, Colombia, which is quite different. During

FIGURE 23.
Thermal comfort map. Tucumán, Argentina.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 20.0 | 19.1 | 17.7 | 13.8 | 10.5 | 7.6 | 7.5 | 8.4 | 10.5 | 12.9 | 15.2 | 18.9 | 19.3 | 8.5 | 13.5 |
| 2 | 18.0 | 17.3 | 15.9 | 12.1 | 9.1 | 6.3 | 6.1 | 6.9 | 8.8 | 11.2 | 13.3 | 16.9 | 17.4 | 7.2 | 11.8 |
| 3 | 16.2 | 15.5 | 14.3 | 10.6 | 7.8 | 5.0 | 4.8 | 5.5 | 7.2 | 9.7 | 11.5 | 15.1 | 15.6 | 5.9 | 10.3 |
| 4 | 14.7 | 14.1 | 13.0 | 9.3 | 6.7 | 4.0 | 3.8 | 4.3 | 5.9 | 8.4 | 10.1 | 13.5 | 14.1 | 4.8 | 9.0 |
| 5 | 13.9 | 13.3 | 12.2 | 8.5 | 6.1 | 3.4 | 3.2 | 3.6 | 5.1 | 7.6 | 9.3 | 12.7 | 13.3 | 4.2 | 8.2 |
| 6 | 13.6 | 13.0 | 12.0 | 8.3 | 5.9 | 3.2 | 3.0 | 3.4 | 4.9 | 7.4 | 9.0 | 12.4 | 13.0 | 4.0 | 8.0 |
| 7 | 14.4 | 13.8 | 12.7 | 9.0 | 6.5 | 3.8 | 3.6 | 4.1 | 5.6 | 8.1 | 9.8 | 13.2 | 13.8 | 4.6 | 8.7 |
| 8 | 15.7 | 15.0 | 13.8 | 10.1 | 7.4 | 4.6 | 4.5 | 5.0 | 6.7 | 9.2 | 11.0 | 14.5 | 15.1 | 5.5 | 9.8 |
| 9 | 17.2 | 16.5 | 15.2 | 11.4 | 8.5 | 5.7 | 5.5 | 6.2 | 8.1 | 10.5 | 12.5 | 16.1 | 16.6 | 6.6 | 11.1 |
| 10 | 19.7 | 18.9 | 17.4 | 13.5 | 10.3 | 7.4 | 7.3 | 8.2 | 10.3 | 12.6 | 14.9 | 18.6 | 19.1 | 8.3 | 13.3 |
| 11 | 24.6 | 23.5 | 21.7 | 17.7 | 13.8 | 10.8 | 10.7 | 12.0 | 14.5 | 16.8 | 19.6 | 23.5 | 23.9 | 11.7 | 17.4 |
| 12 | 26.2 | 25.1 | 23.2 | 19.1 | 15.0 | 11.9 | 11.8 | 13.3 | 16.0 | 18.2 | 21.2 | 25.2 | 25.5 | 12.9 | 18.9 |
| 13 | 27.1 | 25.9 | 23.9 | 19.8 | 15.6 | 12.5 | 12.4 | 14.0 | 16.7 | 18.9 | 22.0 | 26.1 | 26.4 | 13.5 | 19.6 |
| 14 | 27.5 | 26.3 | 24.3 | 20.2 | 15.9 | 12.8 | 12.7 | 14.3 | 17.1 | 19.3 | 22.4 | 26.5 | 26.8 | 13.8 | 19.9 |
| 15 | 27.2 | 26.0 | 24.1 | 20.0 | 15.7 | 12.6 | 12.5 | 14.1 | 16.9 | 19.1 | 22.1 | 26.2 | 26.5 | 13.6 | 19.7 |
| 16 | 26.7 | 25.5 | 23.6 | 19.5 | 15.3 | 12.2 | 12.1 | 13.6 | 16.4 | 18.6 | 21.6 | 25.7 | 25.9 | 13.2 | 19.2 |
| 17 | 26.2 | 25.1 | 23.2 | 19.1 | 15.0 | 11.9 | 11.8 | 13.3 | 16.0 | 18.2 | 21.2 | 25.2 | 25.5 | 12.9 | 18.9 |
| 18 | 25.7 | 24.6 | 22.7 | 18.7 | 14.6 | 11.6 | 11.4 | 12.9 | 15.5 | 17.8 | 20.7 | 24.7 | 25.0 | 12.5 | 18.4 |
| 19 | 25.1 | 24.0 | 22.2 | 18.2 | 14.2 | 11.2 | 11.1 | 12.4 | 15.0 | 17.3 | 20.1 | 24.1 | 24.4 | 12.1 | 17.9 |
| 20 | 24.7 | 23.6 | 21.8 | 17.8 | 13.9 | 10.9 | 10.8 | 12.1 | 14.7 | 16.9 | 19.7 | 23.7 | 24.0 | 11.8 | 17.6 |
| 21 | 24.0 | 23.0 | 21.2 | 17.2 | 13.4 | 10.4 | 10.3 | 11.6 | 14.1 | 16.3 | 19.1 | 23.0 | 23.3 | 11.4 | 17.0 |
| 22 | 23.3 | 22.3 | 20.6 | 16.6 | 12.9 | 9.9 | 9.8 | 11.0 | 13.4 | 15.7 | 18.4 | 22.3 | 22.6 | 10.9 | 16.4 |
| 23 | 22.5 | 21.5 | 19.9 | 15.9 | 12.3 | 9.3 | 9.2 | 10.4 | 12.7 | 15.0 | 17.6 | 21.4 | 21.8 | 10.3 | 15.6 |
| 24 | 21.5 | 20.6 | 19.0 | 15.1 | 11.6 | 8.7 | 8.5 | 9.6 | 11.9 | 14.2 | 16.6 | 20.4 | 20.8 | 9.6 | 14.8 |

FRÍO · ZONA DE CONFORT · CALOR
18 ºC · 24 ºC

FIGURE 24.
Thermal comfort map. Barranquilla, Colombia.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 27.0 | 27.3 | 27.8 | 28.5 | 28.8 | 28.6 | 28.3 | 28.5 | 28.0 | 27.7 | 27.6 | 27.3 | 27.2 | 28.6 | 28.0 |
| 2 | 25.9 | 26.2 | 26.7 | 27.3 | 27.6 | 27.4 | 27.2 | 27.3 | 26.8 | 26.6 | 26.5 | 26.3 | 26.1 | 27.4 | 26.8 |
| 3 | 24.9 | 25.2 | 25.6 | 26.3 | 26.5 | 26.4 | 26.1 | 26.2 | 25.7 | 25.5 | 25.5 | 25.3 | 25.1 | 26.3 | 25.8 |
| 4 | 24.0 | 24.3 | 24.7 | 25.4 | 25.6 | 25.5 | 25.2 | 25.2 | 24.8 | 24.6 | 24.6 | 24.4 | 24.3 | 25.4 | 24.9 |
| 5 | 23.6 | 23.9 | 24.3 | 24.9 | 25.1 | 25.0 | 24.8 | 24.7 | 24.3 | 24.1 | 24.2 | 24.0 | 23.8 | 24.9 | 24.4 |
| 6 | 23.4 | 23.7 | 24.1 | 24.7 | 24.9 | 24.8 | 24.6 | 24.5 | 24.1 | 23.9 | 24.0 | 23.8 | 23.6 | 24.8 | 24.2 |
| 7 | 23.9 | 24.2 | 24.6 | 25.2 | 25.4 | 25.3 | 25.1 | 25.0 | 24.6 | 24.4 | 24.5 | 24.3 | 24.1 | 25.3 | 24.7 |
| 8 | 24.6 | 24.9 | 25.3 | 25.9 | 26.2 | 26.0 | 25.8 | 25.8 | 25.4 | 25.1 | 25.2 | 25.0 | 24.8 | 26.0 | 25.4 |
| 9 | 25.5 | 25.8 | 26.2 | 26.8 | 27.1 | 26.9 | 26.7 | 26.8 | 26.3 | 26.1 | 26.1 | 25.8 | 25.7 | 26.9 | 26.3 |
| 10 | 26.9 | 27.2 | 27.6 | 28.3 | 28.6 | 28.4 | 28.2 | 28.3 | 27.8 | 27.6 | 27.5 | 27.2 | 27.1 | 28.4 | 27.8 |
| 11 | 29.6 | 29.9 | 30.4 | 31.2 | 31.5 | 31.3 | 31.0 | 31.4 | 30.8 | 30.5 | 30.2 | 29.9 | 29.8 | 31.3 | 30.6 |
| 12 | 30.6 | 30.9 | 31.4 | 32.2 | 32.5 | 32.3 | 32.0 | 32.4 | 31.8 | 31.5 | 31.2 | 30.8 | 30.8 | 32.3 | 31.6 |
| 13 | 31.1 | 31.4 | 31.9 | 32.7 | 33.0 | 32.8 | 32.5 | 32.9 | 32.3 | 32.0 | 31.7 | 31.3 | 31.2 | 32.8 | 32.1 |
| 14 | 31.3 | 31.6 | 32.1 | 32.9 | 33.3 | 33.0 | 32.7 | 33.2 | 32.6 | 32.2 | 31.9 | 31.5 | 31.5 | 33.0 | 32.4 |
| 15 | 31.1 | 31.4 | 31.9 | 32.7 | 33.1 | 32.8 | 32.5 | 33.0 | 32.4 | 32.0 | 31.7 | 31.3 | 31.3 | 32.8 | 32.2 |
| 16 | 30.8 | 31.1 | 31.6 | 32.4 | 32.8 | 32.5 | 32.2 | 32.7 | 32.1 | 31.7 | 31.4 | 31.0 | 31.0 | 32.5 | 31.9 |
| 17 | 30.6 | 30.9 | 31.4 | 32.2 | 32.5 | 32.3 | 32.0 | 32.4 | 31.8 | 31.5 | 31.2 | 30.8 | 30.8 | 32.3 | 31.6 |
| 18 | 30.3 | 30.6 | 31.1 | 31.8 | 32.2 | 31.9 | 31.6 | 32.1 | 31.5 | 31.1 | 30.9 | 30.5 | 30.4 | 31.9 | 31.3 |
| 19 | 30.0 | 30.3 | 30.7 | 31.5 | 31.9 | 31.6 | 31.3 | 31.7 | 31.2 | 30.8 | 30.6 | 30.2 | 30.1 | 31.6 | 31.0 |
| 20 | 29.7 | 30.0 | 30.5 | 31.3 | 31.6 | 31.4 | 31.1 | 31.5 | 30.9 | 30.5 | 30.3 | 30.0 | 29.9 | 31.4 | 30.7 |
| 21 | 29.3 | 29.6 | 30.1 | 30.9 | 31.2 | 31.0 | 30.7 | 31.0 | 30.5 | 30.1 | 29.9 | 29.6 | 29.5 | 30.9 | 30.3 |
| 22 | 28.9 | 29.2 | 29.7 | 30.4 | 30.8 | 30.5 | 30.3 | 30.6 | 30.1 | 29.7 | 29.5 | 29.2 | 29.1 | 30.5 | 29.9 |
| 23 | 28.5 | 28.8 | 29.2 | 29.9 | 30.3 | 30.0 | 29.8 | 30.1 | 29.5 | 29.2 | 29.1 | 28.7 | 28.6 | 30.0 | 29.4 |
| 24 | 27.9 | 28.2 | 28.7 | 29.4 | 29.7 | 29.5 | 29.2 | 29.5 | 28.9 | 28.6 | 28.5 | 28.2 | 28.1 | 29.5 | 28.9 |

FRÍO · ZONA DE CONFORT · CALOR
23.5 ºC · 28.5 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

the morning, temperatures are within the established LCR (23.5 to 28.5°C). Starting at 11 a.m., conditions become more extreme and steps to lower temperatures are required.

Using the same examples, the chart below, based on Givoni's "bioclimatic chart," which includes temperature and relative humidity, shows average annuals for outdoors (yellow dots) and conditions inside the classrooms (blue dots for winter and red dots for summer). The bioclimatic patterns for each season can be determined using this information. In Tucumán, Argentina, the classroom requires heating in the winter to reach the comfort zone, either through traditional means or passive solar heating. During the summer, cool air from either natural ventilation or selective night ventilation is needed (Figure 25).

In Barranquilla, Colombia, the classroom situation was critical (33°C with 72% relative humidity), requiring natural ventilation in order to bring indoor conditions down to within the comfort zone (Figure 26).

## Identify specific strategies.

Strategies based on general design guidelines should be identified for both new and existing buildings, taking retrofitting techniques into account:

### Solar and wind orientation

Solar orientation should be considered in both cold and warm climates, whether it be for protection from direct radiation or to capture it for heat generation. This can be done by orienting the building toward the north or the south, with a ± 15° variation toward the east or west, according to the hemisphere. The perpendicularity of the areas of air ingress to the direction of the wind or breezes will encourage air movement and thermal discharge (Figures 27 to 29).

FIGURE 25.
Solar chart and bioclimatic patterns. Tucumán, Argentina.

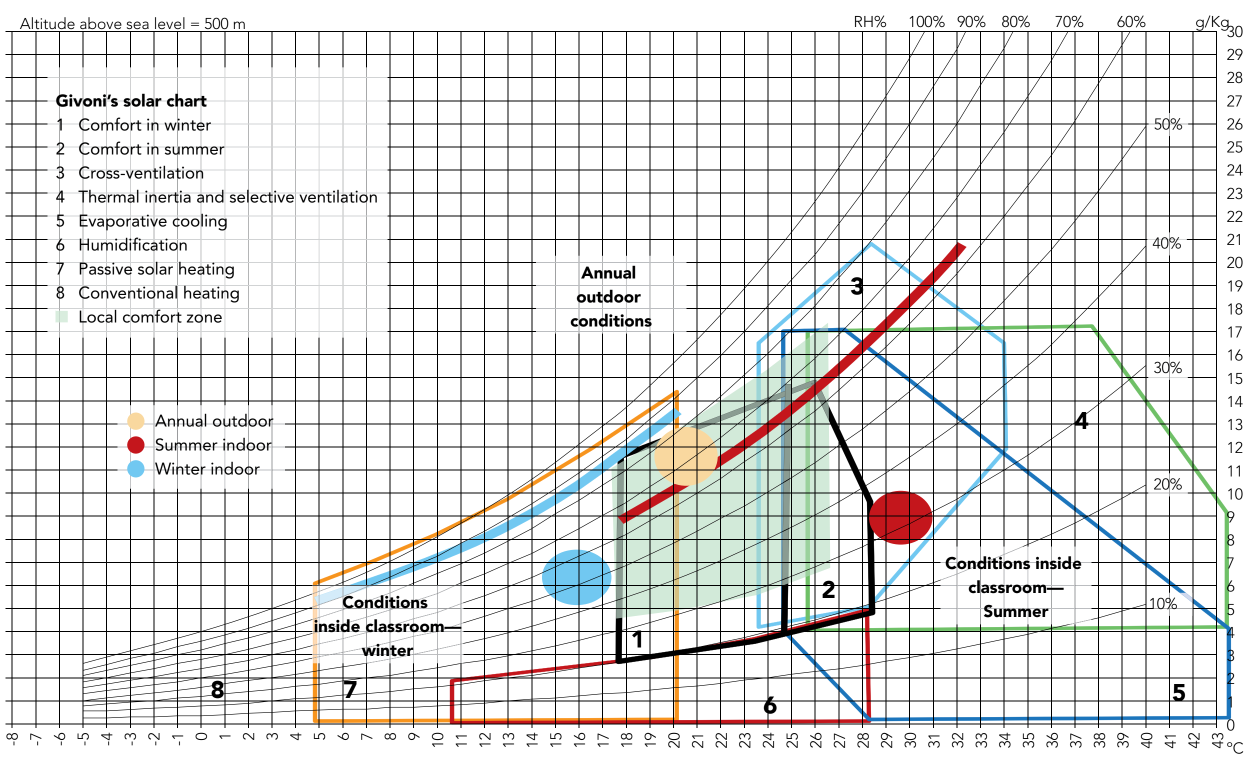


FIGURE 26.
Solar chart and bioclimatic patterns. Barranquilla, Colombia.

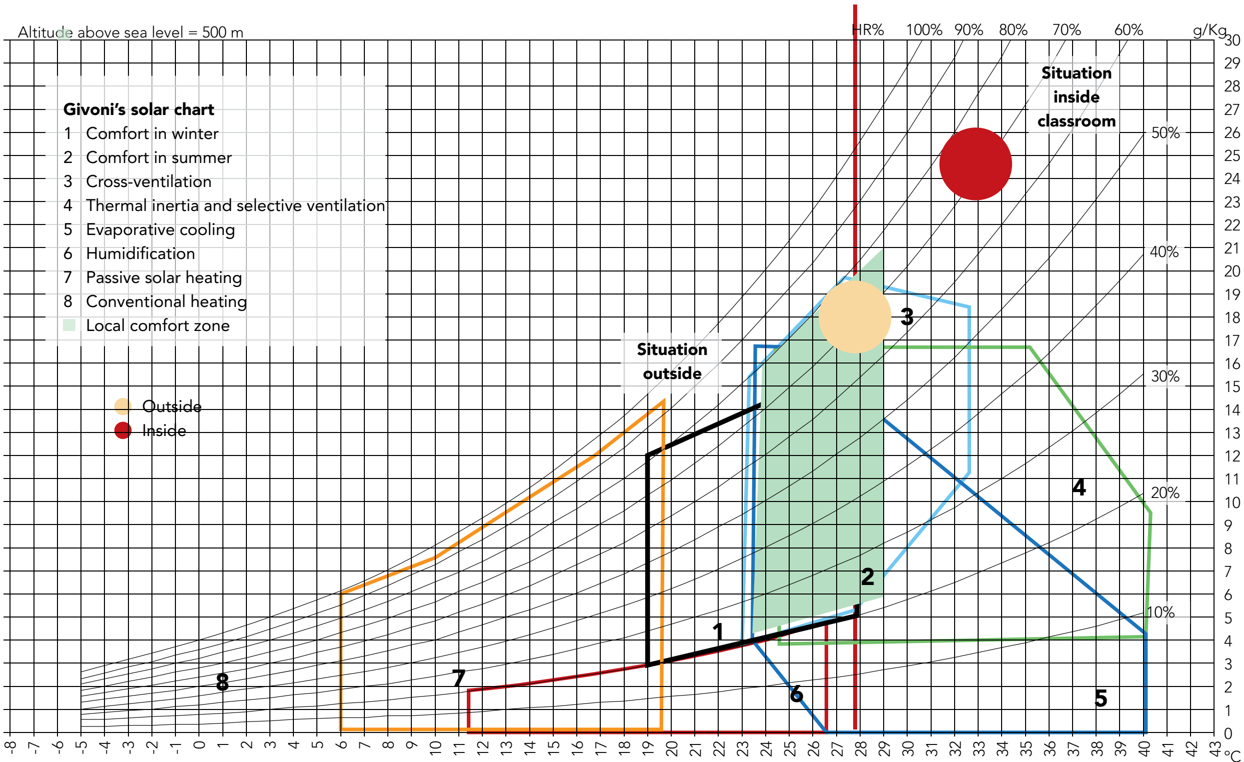



FIGURE 27.
Floor plan. Solar orientation.

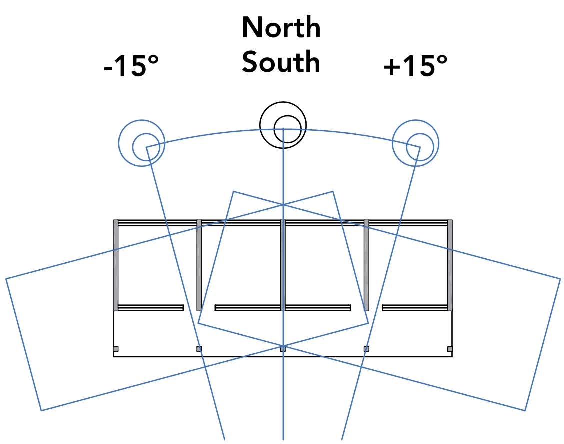



FIGURE 28.
Cutaway view. Solar orientation.

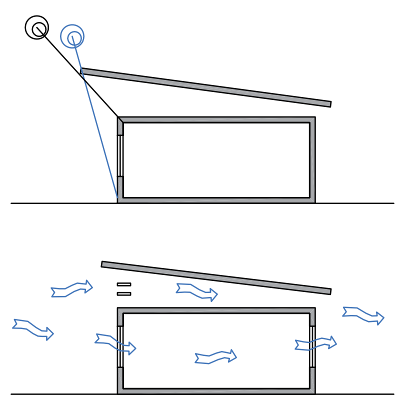
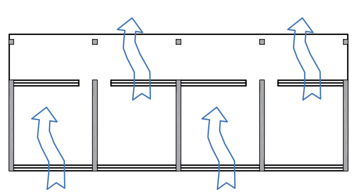


FIGURE 29.
Floor plan. Wind or breeze orientation



## Grouping

School buildings are constructed on one or more floors, with the upper floors more exposed to the outside environment. Horizontal grouping, or the use of a single floor, is dependent on climate conditions: (i) In cold environments, groupings preferably increase compactness (understood as the relationship between a closed volume and the sum of the surfaces of the building envelope, c=V/S) since that reduces the amount of exposed surfaces. Spaces with higher thermal loads, such as classrooms, should prioritize orientations that will allow them to take advantage of solar radiation for heat generation. (ii) In warm climates, open groupings are more suitable, with interstitial spaces between buildings to enable cross-ventilation (Figure 30). They should be oriented so that the longer sides are perpendicular to local winds or breezes. At these latitudes, given the sun's position, most solar radiation will affect the roof, justifying the use of shading systems, such as eaves or horizontal projections, to minimize the impact of radiation on external walls and prevent it from entering living spaces. With respect to solar orientation, priority should be given to locating walkways in the zones of greatest solar radiation, in order to reduce direct exposure of the windows. Figures 31 to 33 give examples of the buildings studied, with respect to horizontal compactness.

## Thermal insulation of the building envelope

In all cases, thermal insulation should be incorporated into the building envelope. In warm areas, it should be applied mainly to roofs and ceilings, since

FIGURE 30.
Grouping options

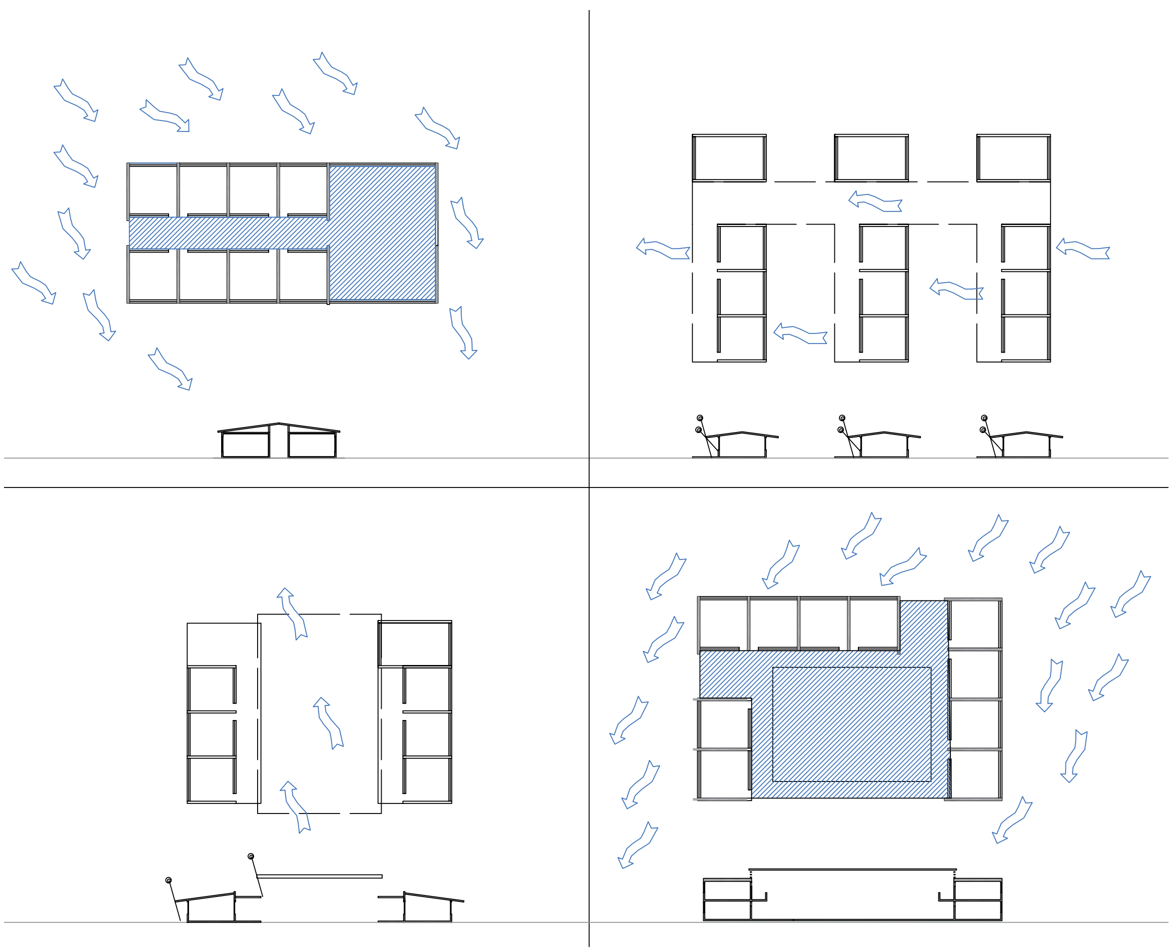


FIGURE 31.
Punta Arenas, Chile. Cold climate. (Compact grouping.)

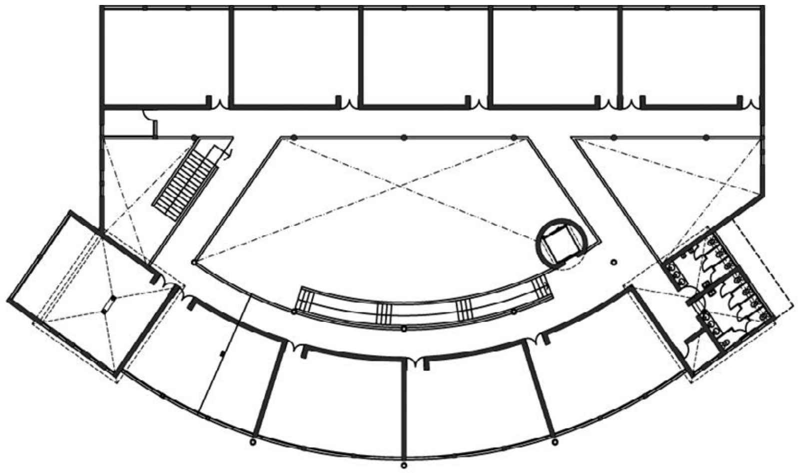


FIGURE 32.
Luzón, Costa Rica. Warm humid climate. (Open grouping.)

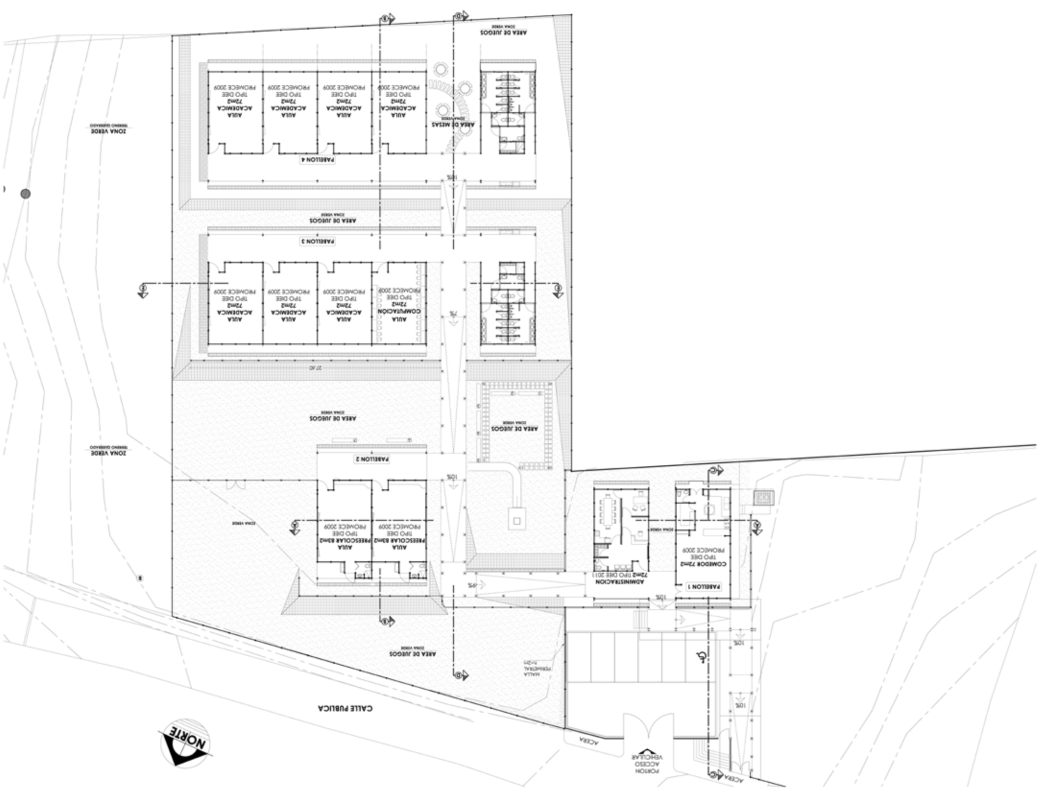
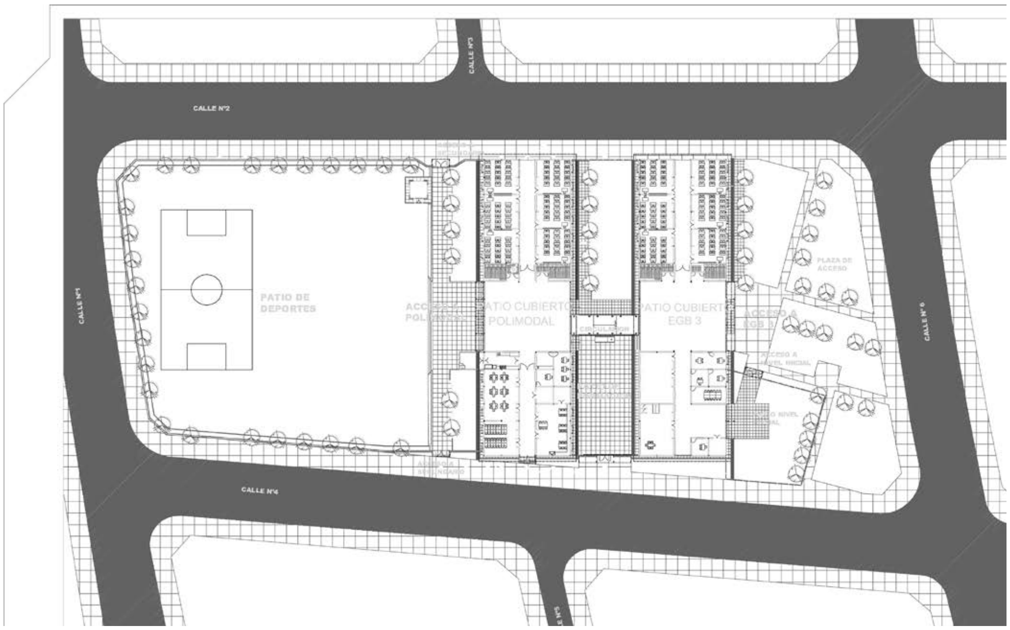


FIGURE 33.
Tucumán, Argentina. warm climate. (Open grouping.)




this is where the sun's impact is the greatest. In cold climates, it should be applied to the building envelope as a whole (roofs, walls, and floors). The use of woodwork with ensured thermal quality and double glazed windows (IGUs) is also recommended in order to minimize drafts and reduce thermal bridges. Insulation should be positioned in the building envelope (outside, intermediate, or inside) so that it functions as an extra layer, and the thickness and type of material used should be selected according to the climate in question. The criteria used below are those of "energy conservation" (Figures 34 to 36).[14]

## Thermal inertia

There are two aspects that should be taken into account, depending on the climate: (i) In warm or temperate dry climates, where the thermal difference between day and night is significant, "heavy" buildings are recommended. (ii) In humid climates, "lightweight" buildings with low thermal inertia are advised. A "heavy" building envelope with thermal mass is best when daily occupancy is extensive or continuous. Otherwise, when occupancy is discontinuous or limited to a portion of the day, a "light" building envelope should be used.

## Climate control

The need for heating and cooling can be resolved through conventional means, with the advantage that they are commonly used and easy to install and maintain. However, they are also energy intensive and consume non-renewable and contaminating sources (especially heating units). The displacement in the records is due to the incorporation of traditional thermal energy. Keeping "good practices" and the concept of sustainable and efficient design in mind, passive air conditioning systems, heat-accumulating walls, lightweight solar air collectors and windows that

14. A thermal bridge is a zone of the building envelope where heat is more easily transferred and where the greatest thermal losses and surface and interstitial condensation tend to occur. This can be caused by the use of materials with different conductivities or densities, or by geometrical issues.

FIGURE 34.
Hygrothermal insulation of the building envelope

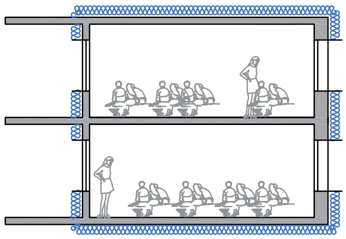


FIGURE 35.
Thermal insulation of a lightweight wall, without thermal inertia.

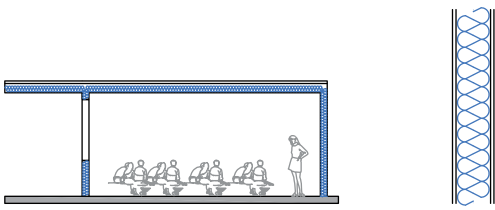
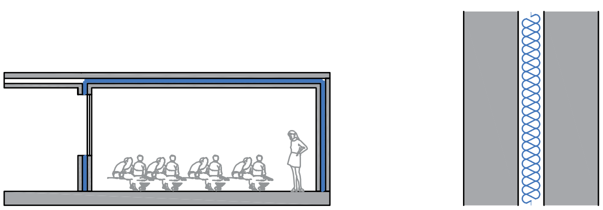


FIGURE 36.
Thermal insulation of a heavy wall, with thermal inertia.



facilitate heat gain, and greenhouses should also be considered (Figures 37 and 38).[15]

FIGURE 37.
Heat-accumulating wall

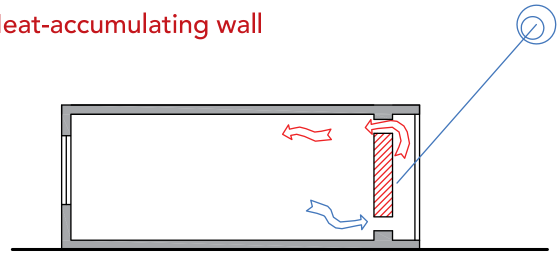
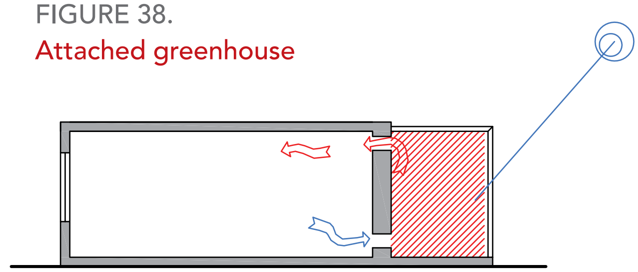



FIGURE 38.
Attached greenhouse




### Ventilation

In warm climates, architectural designs that facilitate natural ventilation should be used, although this should be accompanied by a design of outdoor spaces in order to reduce the temperature of the inbound air. This type of ventilation can be controlled, as needed, through openings at the height of the occupants' bodies or air extraction outlets located high in the building. On the other hand, heat can be removed from the building through the ceiling or shade roof. Selective night ventilation takes advantage of the air's enthalpic capacity, releasing heat accumulated by the building during the day. Air extraction can also be done using stack ventilation, exploiting thermal differences to aerate spaces (e.g., a solar chimney), or by using natural or forced wind or solar extraction. (Figures 39 to 44)[16]

### Solar control

This design guideline is indispensable in warm and temperate climates. Solar control aims to: (i) mitigate the effects of solar radiation on the building envelope, reducing overheating; (ii) minimize the direct impact of solar radiation inside the building through

15. A heat-accumulating wall is a wall directed towards the sun, north-facing in the southern hemisphere and south-facing in the northern hemisphere. It is built with materials that accumulate heat while under the effect of a thermal mass (such as water, stone, concrete and adobe) along with an air space, a transparent cover (greenhouse effect) and air vents. It was patented in 1881 by Edward Morse (US Patent 246626), but not disseminated until the 1960s by Félix Trombe and Jacques Michel.

16. The stack effect: a natural displacement of air from colder areas to warmer ones, taking advantage of the effect produced by the difference in air temperature and density.

FIGURE 39.
Ceiling ventilation

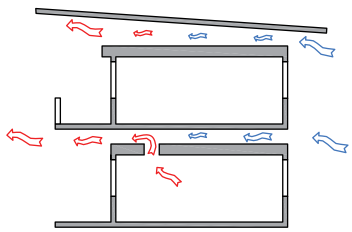


FIGURE 40.
Atrium ventilation

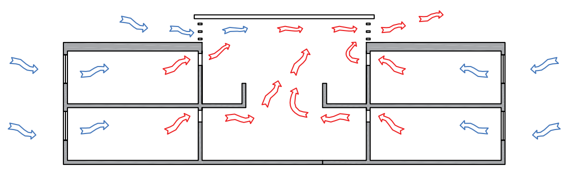


FIGURE 41.
Natural convective ventilation, associated solar chimney

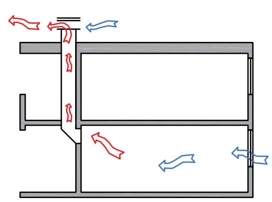


FIGURE 42.
Cross-ventilation with openings on opposite sides

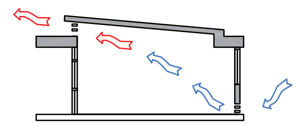


FIGURE 43.
Natural ventilation using thermal draft

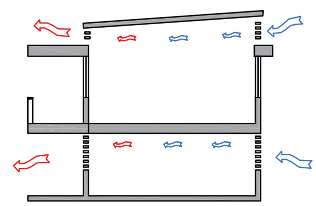
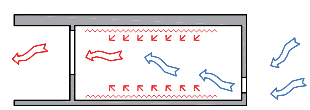


FIGURE 44.
Selective night ventilation



the windows; and (iii) avoid distracting reflections and glare.[17,18] Figure 45 illustrates several strategies for solar protection in school classrooms, shown to scale.

## Lighting

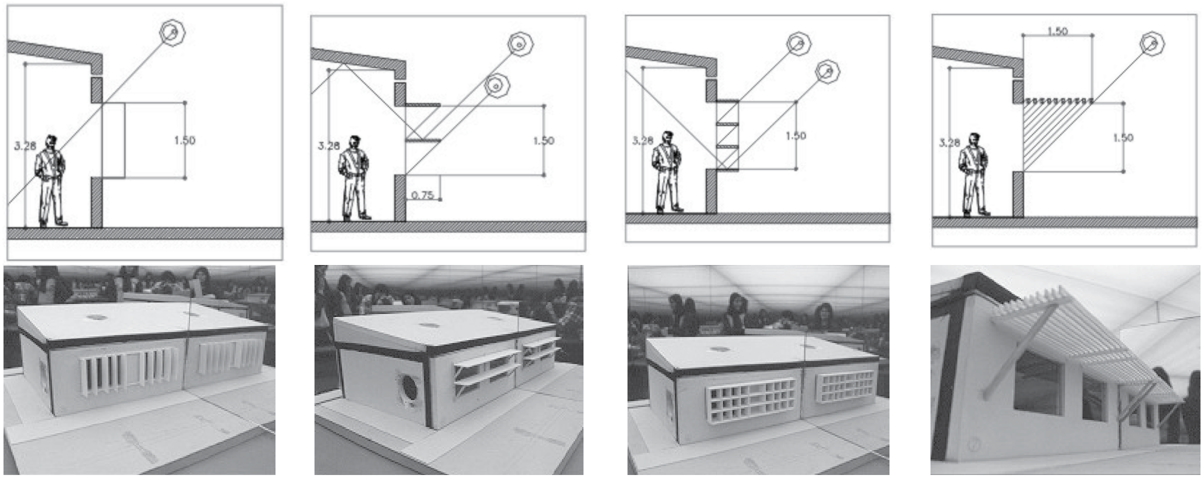
This is one of the most important guidelines to consider when designing a school, and especially classrooms, in order to ensure suitable lighting conditions and avoid physiological impairment. Project design decisions aim to: (i) maintain acceptable light levels according to national and international standards, which generally recommend daylight coefficients between 2% and 5%; (ii) generate an acceptable difference between minimum and maximum indoor illuminance levels (uniformity); (iii) avoid distracting reflections and glare; and (iv) reduce the use of artificial lighting, especially during the day.

With respect to natural lighting, the following design guidelines should be considered: (i) direction of the light source (from one side, two sides, or overhead), depending on the "sky type" and shape of the classroom (square or rectangular); (ii) source of

17. "Estrategias de control solar en aulas escolares y análisis de su incidencia en la iluminación natural interior mediante la utilización de modelos analógicos a escala". *Avances en Energías Renovables y Medio Ambiente Magazine*, ASADES. Vol. 5, 2001. Art. 149-05 pdf, pgs. 05.25-05.30. ISSN 0329-5184. S. Hoses, G. San Juan, M. Melchiori, G. Viegas.

18. "Diseño Bioclimático como aporte al proyecto arquitectónico". Publicación del Taller Vertical de Arquitectura N°2. San Juan, Santinelli, Varela. Facultad de Arquitectura y Urbanismo, Universidad Nacional de La Plata. 2013.

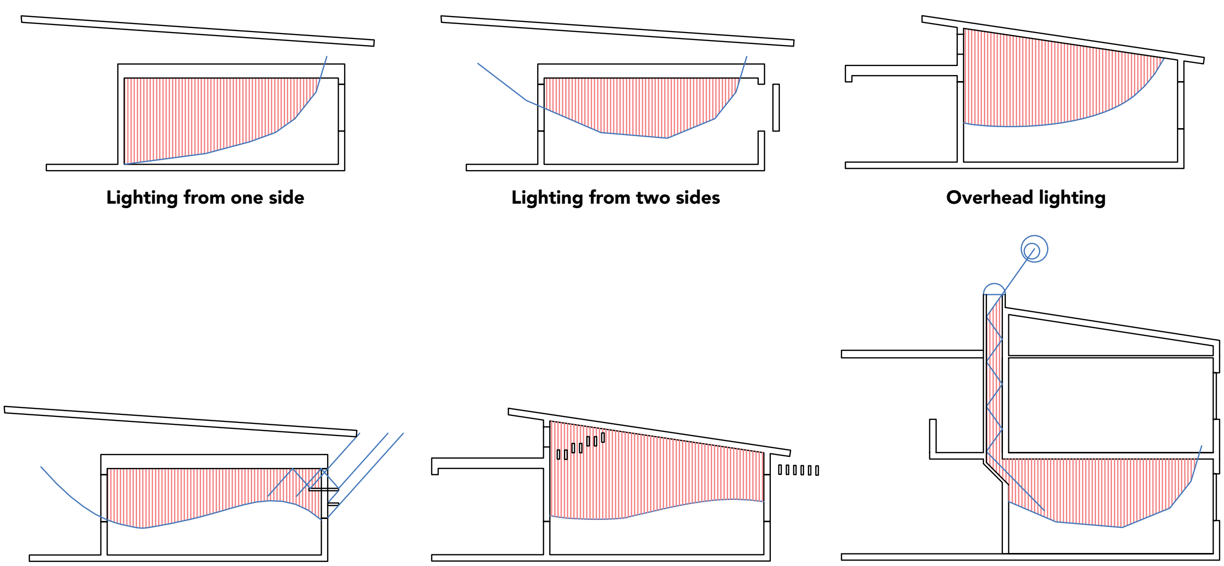
FIGURE 45.
Strategies for solar protection in classrooms




**Vertical slats** **Eaves and light shelves** **Brise-soleil** **Latticed overhang**

the lighting, whether it be direct, indirect, by reflection, or through intermediate spaces (attics, circulations); (iii) the reflection coefficients of indoor surfaces, using pale colors; (iv) direct solar radiation and direct exposure to the sky (especially clear skies with a high degree of luminance) must be countered by using architectural elements such as screens, diffusers, and solar control devices; (v) the design of the size and placement of apertures; and (vi) use of alternative components such as skylights, lightwells, and light shelves to distribute lighting throughout the whole classroom. With respect to artificial lighting, the following should be used: (i) long-lasting, energy-efficient fixtures that accurately reproduce the tones of light required in each space; (ii) automatic lighting systems; and (iii) circuits differentiated by zones according to their illuminance levels (Figure 46).

FIGURE 46.
Natural lighting systems



**Lighting from one side** **Lighting from two sides** **Overhead lighting**

**Light shelves** **Indoor diffusers** **Skylight or lightwell**

FIGURE 47.
Airborne sound insulation

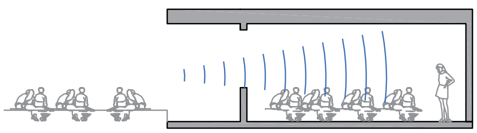


FIGURE 48.
Impact sound insulation

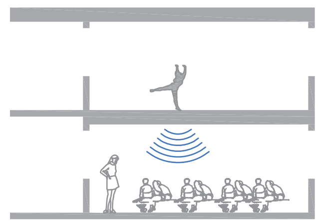
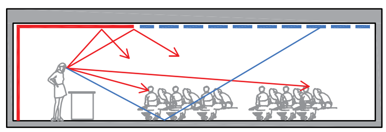


FIGURE 49.
Acoustic treatment of indoor surfaces




### Indoor air quality

This factor should be monitored, in order to ensure stable conditions and not exceed the recommended levels for hygrothermal quality, concentrations of pollutants (such as $CO_2$), and unpleasant odors. Selective, natural, or automatic ventilation should be considered, as well as air infiltration.

### Sound conditioning

This is considered one of the most critical variables of the present study, defined by the type and source of the noise: (i) outdoor noise, which can be minimized by distancing the most affected spaces from noise sources using outdoor barriers or through the building envelope itself; (ii) indoor noise, originating in the classroom itself, where an improvement in the acoustic field is needed in order to reduce reverberation, using absorbent materials or by altering the shape of the space itself; (iii) treatment of unpleasant sounds, such as bells or alarms, that can affect hearing and generate psychophysiological discomfort (Figures 47 to 49).

## Analysis of the audited institutions, according to regional location

A series of conclusions and general recommendations are presented below for each educational institution, based on the classrooms audits and different climate situations.

The different locations represent a range of climate conditions that can, for comparative analysis, be classified into three basic categories:

(1) Warm (tropical, humid or dry)
(2) Temperate (warm and cold)
(3) Cold (very cold)

Generic design guidelines are defined for these climate types, but must be adjusted in each case according to the altitude above sea level, maritime or continental influences, and microclimatic conditions. Based on the measurements recorded in each classroom, at different times of year and in different climate conditions, an analysis was conducted of what is needed in order to improve building conditions. These results have been classified according to their hygrothermal aspects into: (i) heating and use of thermal insulation and (ii) shading and natural ventilation.

The recognition and consideration of these results can serve as a basis for determining project strategies and technological implementation.

## ARGENTINA (AR)

The locations studied in winter and summer correspond to:

### Warm humid climate

- Martín Miguel de Güemes School, No. 698. Resistencia. Chaco Province.
- Lomas de Tafí School. Tucumán City. Tafí Viejo. Tucumán Province.

### Dry temperate climate

- Roque Chieli Primary School, No. 4731. Salta City. Salta Province.

### Cold temperate climate

- Escultor Roberto Rosas School, No. 1745. Mendoza City, Guaymallén. Mendoza Province.
- Elisa Solari de Levy Nicolás School, No. 14. Tandil. Buenos Aires Province.

### Very cold climate

- School No. 367. San Carlos de Bariloche. Río Negro Province.

### Warm humid climate requiring shading + ventilation + heating (Resistencia, Tucumán)

The conditions in Resistencia, at 52 m.a.s.l., correspond to a warm, humid climate, requiring air cooling. The average minimum temperature in winter is 11.7°C and the average maximum in summer is 31.2°C. Moderate winds come from the northeast and east. The harsh climate is a factor, determining a need for shade and cross-ventilation, as well as the treatment of plants in the area surrounding the building. The school consists of several isolated buildings with interstitial patios and partially covered south-facing walkways. Traditional building technology was used.

FIGURE 50.
Martín Miguel de Güemes School, No. 698. Resistencia.
Warm humid climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 26.3 | 25.2 | 24.1 | 21.0 | 18.0 | 15.7 | 14.4 | 16.7 | 18.8 | 21.3 | 22.8 | 25.3 | 25.6 | 16.0 | 20.8 |
| 2 | 24.5 | 23.7 | 22.6 | 19.5 | 16.5 | 14.3 | 12.7 | 14.9 | 17.0 | 19.7 | 21.0 | 23.6 | 23.9 | 14.5 | 19.2 |
| 3 | 22.9 | 22.3 | 21.2 | 18.1 | 15.1 | 12.9 | 11.2 | 13.2 | 15.4 | 18.2 | 19.4 | 22.1 | 22.4 | 13.1 | 17.7 |
| 4 | 21.5 | 21.1 | 20.0 | 17.0 | 13.9 | 11.7 | 9.9 | 11.7 | 13.9 | 16.9 | 18.1 | 20.8 | 21.1 | 11.8 | 16.4 |
| 5 | 20.8 | 20.4 | 19.4 | 16.3 | 13.3 | 11.1 | 9.1 | 11.0 | 13.2 | 16.2 | 17.3 | 20.0 | 20.4 | 11.2 | 15.7 |
| 6 | 20.5 | 20.2 | 19.2 | 16.1 | 13.1 | 10.9 | 8.9 | 10.7 | 12.9 | 16.0 | 17.1 | 19.8 | 20.2 | 11.0 | 15.5 |
| 7 | 21.3 | 20.8 | 19.8 | 16.7 | 13.7 | 11.5 | 9.6 | 11.5 | 13.7 | 16.7 | 17.8 | 20.5 | 20.9 | 11.6 | 16.1 |
| 8 | 22.4 | 21.8 | 20.8 | 17.7 | 14.7 | 12.5 | 10.7 | 12.7 | 14.8 | 17.7 | 18.9 | 21.6 | 21.9 | 12.6 | 17.2 |
| 9 | 23.8 | 23.0 | 22.0 | 18.9 | 15.9 | 13.6 | 12.0 | 14.1 | 16.3 | 19.0 | 20.3 | 22.9 | 23.2 | 13.8 | 18.5 |
| 10 | 26.0 | 25.0 | 23.9 | 20.8 | 17.8 | 15.5 | 14.2 | 16.5 | 18.6 | 21.1 | 22.5 | 25.1 | 25.3 | 15.8 | 20.6 |
| 11 | 30.4 | 28.7 | 27.6 | 24.6 | 21.5 | 19.2 | 18.4 | 21.0 | 23.1 | 25.2 | 26.8 | 29.3 | 29.5 | 19.7 | 24.6 |
| 12 | 31.9 | 30.0 | 28.8 | 25.8 | 22.7 | 20.5 | 19.8 | 22.6 | 24.6 | 26.6 | 28.3 | 30.7 | 30.9 | 21.0 | 26.0 |
| 13 | 32.6 | 30.7 | 29.5 | 26.5 | 23.4 | 21.1 | 20.5 | 23.4 | 25.4 | 27.3 | 29.0 | 31.4 | 31.6 | 21.7 | 26.7 |
| 14 | 33.0 | 31.0 | 29.8 | 26.8 | 23.7 | 21.4 | 20.9 | 23.8 | 25.8 | 27.6 | 29.4 | 31.8 | 31.9 | 22.0 | 27.1 |
| 15 | 32.8 | 30.8 | 29.6 | 26.6 | 23.5 | 21.2 | 20.7 | 23.5 | 25.5 | 27.4 | 29.2 | 31.6 | 31.7 | 21.8 | 26.9 |
| 16 | 32.3 | 30.4 | 29.2 | 26.2 | 23.1 | 20.8 | 20.2 | 23.0 | 25.0 | 26.9 | 28.7 | 31.1 | 31.2 | 21.3 | 26.4 |
| 17 | 31.9 | 30.0 | 28.8 | 25.8 | 22.7 | 20.5 | 19.8 | 22.6 | 24.6 | 26.6 | 28.3 | 30.7 | 30.9 | 21.0 | 26.0 |
| 18 | 31.4 | 29.6 | 28.4 | 25.4 | 22.3 | 20.0 | 19.3 | 22.1 | 24.1 | 26.1 | 27.8 | 30.2 | 30.4 | 20.6 | 25.6 |
| 19 | 30.9 | 29.2 | 28.0 | 25.0 | 21.9 | 19.6 | 18.9 | 21.6 | 23.6 | 25.6 | 27.3 | 29.8 | 29.9 | 20.1 | 25.1 |
| 20 | 30.5 | 28.8 | 27.7 | 24.7 | 21.6 | 19.3 | 18.5 | 21.2 | 23.2 | 25.3 | 26.9 | 29.4 | 29.6 | 19.8 | 24.8 |
| 21 | 29.9 | 28.3 | 27.2 | 24.1 | 21.1 | 18.8 | 17.9 | 20.5 | 22.6 | 24.7 | 26.3 | 28.8 | 29.0 | 19.2 | 24.2 |
| 22 | 29.3 | 27.8 | 26.6 | 23.6 | 20.5 | 18.3 | 17.3 | 19.9 | 21.9 | 24.1 | 25.7 | 28.2 | 28.4 | 18.7 | 23.6 |
| 23 | 28.5 | 27.1 | 26.0 | 22.9 | 19.9 | 17.6 | 16.6 | 19.1 | 21.2 | 23.4 | 25.0 | 27.5 | 27.7 | 18.0 | 22.9 |
| 24 | 27.6 | 26.4 | 25.2 | 22.2 | 19.1 | 16.9 | 15.7 | 18.2 | 20.3 | 22.6 | 24.1 | 26.6 | 26.9 | 17.3 | 22.1 |

FRÍO — ZONA DE CONFORT — CALOR
18 °C — 26 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 51.

Lomas de Tafí School. Tucumán City. Warm temperate climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 25.3 | 24.3 | 22.5 | 19.4 | 15.7 | 12.5 | 12.5 | 15.0 | 17.0 | 21.5 | 23.1 | 24.6 | 24.7 | 13.5 | 19.4 |
| 2 | 23.8 | 22.7 | 21.1 | 18.1 | 14.3 | 11.0 | 10.7 | 13.0 | 15.0 | 19.5 | 21.4 | 23.0 | 23.2 | 12.0 | 17.8 |
| 3 | 22.3 | 21.3 | 19.8 | 16.9 | 12.9 | 9.6 | 9.1 | 11.2 | 13.2 | 17.7 | 19.8 | 21.5 | 21.7 | 10.6 | 16.3 |
| 4 | 21.1 | 20.1 | 18.8 | 15.8 | 11.8 | 8.4 | 7.8 | 9.7 | 11.7 | 16.2 | 18.5 | 20.3 | 20.5 | 9.3 | 15.0 |
| 5 | 20.4 | 19.4 | 18.2 | 15.3 | 11.2 | 7.8 | 7.0 | 8.9 | 10.9 | 15.4 | 17.7 | 19.6 | 19.8 | 8.7 | 14.3 |
| 6 | 20.2 | 19.2 | 18.0 | 15.1 | 11.0 | 7.6 | 6.8 | 8.6 | 10.6 | 15.1 | 17.5 | 19.4 | 19.6 | 8.5 | 14.1 |
| 7 | 20.9 | 19.9 | 18.6 | 15.7 | 11.6 | 8.2 | 7.5 | 9.4 | 11.4 | 15.9 | 18.2 | 20.1 | 20.3 | 9.1 | 14.8 |
| 8 | 21.9 | 20.9 | 19.5 | 16.5 | 12.5 | 9.2 | 8.6 | 10.7 | 12.7 | 17.2 | 19.3 | 21.1 | 21.3 | 10.1 | 15.8 |
| 9 | 23.1 | 22.1 | 20.5 | 17.5 | 13.7 | 10.4 | 10.0 | 12.2 | 14.2 | 18.7 | 20.6 | 22.3 | 22.5 | 11.3 | 17.1 |
| 10 | 25.1 | 24.0 | 22.3 | 19.2 | 15.5 | 12.3 | 12.2 | 14.7 | 16.7 | 21.2 | 22.8 | 24.3 | 24.5 | 13.3 | 19.2 |
| 11 | 29.0 | 27.9 | 25.7 | 22.4 | 19.1 | 16.0 | 16.5 | 19.6 | 21.6 | 26.1 | 27.1 | 28.2 | 28.4 | 17.2 | 23.3 |
| 12 | 30.3 | 29.2 | 26.8 | 23.6 | 20.3 | 17.2 | 18.0 | 21.2 | 23.2 | 27.7 | 28.5 | 29.6 | 29.7 | 18.5 | 24.6 |
| 13 | 31.0 | 29.9 | 27.4 | 24.1 | 20.9 | 17.9 | 18.7 | 22.1 | 24.1 | 28.6 | 29.2 | 30.3 | 30.4 | 19.2 | 25.3 |
| 14 | 31.3 | 30.2 | 27.7 | 24.4 | 21.2 | 18.2 | 19.1 | 22.5 | 24.5 | 29.0 | 29.6 | 30.6 | 30.7 | 19.5 | 25.7 |
| 15 | 31.1 | 30.0 | 27.5 | 24.2 | 21.0 | 18.0 | 18.9 | 22.2 | 24.2 | 28.7 | 29.4 | 30.4 | 30.5 | 19.3 | 25.5 |
| 16 | 30.6 | 29.5 | 27.1 | 23.8 | 20.6 | 17.6 | 18.4 | 21.7 | 23.7 | 28.2 | 28.9 | 29.9 | 30.0 | 18.8 | 25.0 |
| 17 | 30.3 | 29.2 | 26.8 | 23.6 | 20.3 | 17.2 | 18.0 | 21.2 | 23.2 | 27.7 | 28.5 | 29.6 | 29.7 | 18.5 | 24.6 |
| 18 | 29.9 | 28.8 | 26.4 | 23.2 | 19.9 | 16.8 | 17.5 | 20.7 | 22.7 | 27.2 | 28.0 | 29.1 | 29.3 | 18.1 | 24.2 |
| 19 | 29.4 | 28.3 | 26.1 | 22.8 | 19.5 | 16.4 | 17.0 | 20.1 | 22.1 | 26.6 | 27.5 | 28.7 | 28.8 | 17.6 | 23.7 |
| 20 | 29.1 | 28.0 | 25.8 | 22.5 | 19.2 | 16.1 | 16.6 | 19.7 | 21.7 | 26.2 | 27.2 | 28.4 | 28.5 | 17.3 | 23.4 |
| 21 | 28.5 | 27.5 | 25.3 | 22.1 | 18.7 | 15.6 | 16.0 | 19.0 | 21.0 | 25.5 | 26.6 | 27.8 | 27.9 | 16.7 | 22.8 |
| 22 | 28.0 | 26.9 | 24.8 | 21.6 | 18.1 | 15.0 | 15.4 | 18.3 | 20.3 | 24.8 | 26.0 | 27.2 | 27.4 | 16.2 | 22.2 |
| 23 | 27.3 | 26.2 | 24.2 | 21.1 | 17.5 | 14.4 | 14.7 | 17.5 | 19.5 | 24.0 | 25.2 | 26.6 | 26.7 | 15.5 | 21.5 |
| 24 | 26.5 | 25.5 | 23.5 | 20.4 | 16.8 | 13.6 | 13.8 | 16.5 | 18.5 | 23.0 | 24.4 | 25.8 | 25.9 | 14.8 | 20.7 |

FRÍO — ZONA DE CONFORT — CALOR

18 °C — 26 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

## Resistencia

With respect to the hygrothermal situation of the audited classrooms, conditions recorded in the summer exceed the comfort zone. As a result, from 76% to 100% of students used light clothing and 68% to 87% reported being comfortable, while most felt that the air is stale (94% to 100%). This suggests a high degree of tolerance for extreme environmental conditions, especially during the summer. The grouping of buildings is suitable, enabling natural ventilation, although thermal insulation should be added to the walls and especially the roof, where the impact of solar radiation is the strongest. Nighttime thermal discharge is another potential way to give access to breezes. Outdoor spaces should be adapted to incorporate shade and vegetation into the surrounding area. In this case, heating is needed only during a few critical days.

## Tucumán

The hygrothermal conditions of the classrooms studied fell outside the thermal comfort zone in both winter and summer. Despite this, 56% to 68% of students reported being comfortable in the winter and 54% to

FIGURE 52.

Shading. Natural ventilation. Thermally insulated roof. Resistencia

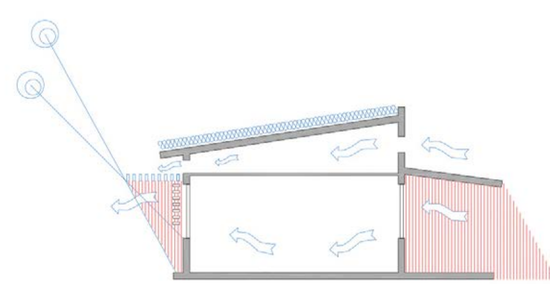
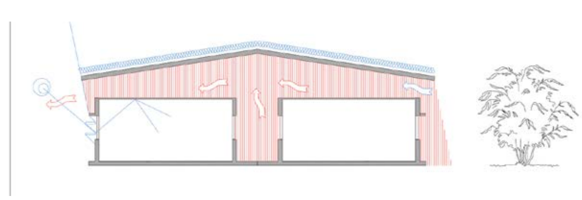


FIGURE 53.

Shading. Natural ventilation. Thermally insulated roof. Tucumán



81% in the summer. 57% to 75% were warmly dressed, while 56% reported perspiring in summer and 31% in winter. Ventilation is insufficient, since it does not eliminate the heat generated by a variety of sources, something that was reflected in the opinion of students that the air is stale (73% to 79%). With respect to the grouping of classrooms, while the layout of the building is suitable, enabling cross-ventilation, the thermal insulation of the "shade roof" should be improved. Strategies for cross and/or selective ventilation that take advantage of nighttime breezes are needed in order to eliminate the heat accumulated by the thermal mass during the day. Stack ventilation, which offers the potential for distancing outlet openings from the areas used by students, is another possibility to prevent noise from entering from the walkways and patios.

Overcast skies coupled with small windows seem to explain why lighting conditions in the classrooms barely meet the recommended design parameters, although student evaluation was positive (53% to 92%), which suggests a certain degree of habituation to these circumstances. The deficiencies observed were low illuminance levels in the areas furthest from the central windows, low uniformity coefficients, and the incidence of solar radiation on the working plane. A specific design for classroom facades is needed and should be completely north-facing. A device should be incorporated to prevent solar radiation from directly entering the classrooms, improve the distribution of indoor illuminance, and raise the light levels in the areas furthest from the windows (e.g., light shelves, *brise-soleil*, or overhead lighting).

In Tucumán, recorded levels of $CO_2$ were excessive, especially during the winter, when natural ventilation is obstructed in order to keep out the cold or noise from the patio. Opinion indicators revealed a high degree of discomfort with respect to the air quality, in both winter and summer (70% to 79%).

With regard to sound, higher than acceptable noise levels were recorded. Opinion indicators reveal a high degree of discomfort caused by irritating noises (79% to 100%), likely due to insufficient sound insulation between spaces and the reverberation generated in closed areas without any kind of acoustic treatment. End walls or ceilings with sound absorption should be used to reduce reverberation time, as well as ventilation systems that minimize the entry of airborne noise. This can be resolved by distancing ventilation openings or grates from noise sources (whether it be streets, corridors, or patios) or by establishing ventilation protocols for hours in which no students are present.

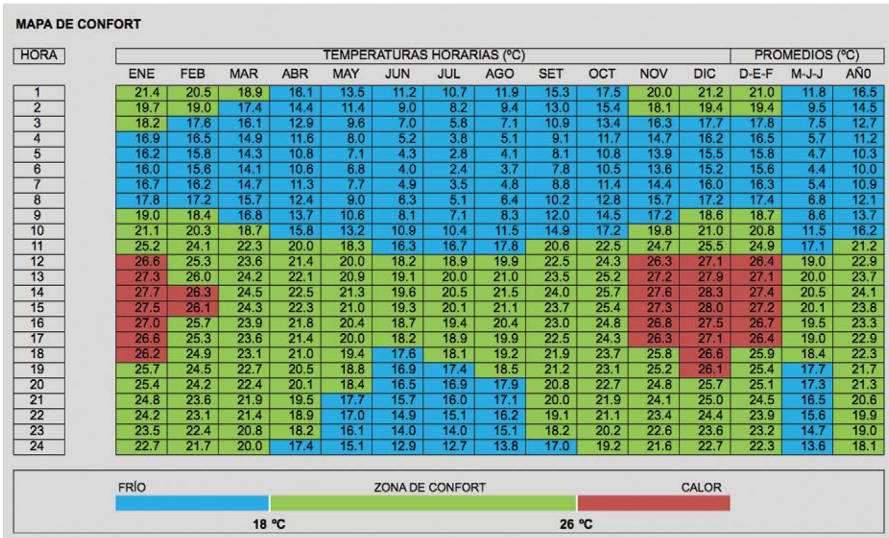
## Temperate Dry Climate Requiring Shading + Ventilation + Heating (Salta)

This is a suburban school in the capital city of Salta, at 1188 m.a.s.l., in an inland area. Salta has a temperate, dry climate, classified as bioclimatic zone IIIa (IRAM Regulation 11603) with a broad thermal variation between day and night (over 14°C), constant throughout the year, with relatively low maximum averages in summer (27.1°C) and an average minimum of 3.7°C in winter. The school is surrounded by low, scattered buildings. Winds in the summer are predominantly from the north and northeast, with a low average speed of 3 km/h. The building is on a single floor with classrooms around a square-shaped central patio and external hallways protected from solar radiation.

### Salta

Due to mid-range and low average temperatures with low relative humidity, insulation and thermal inertia in the building envelope are required in both winter and summer. Additionally, heating is needed in the winter. This can be resolved through the use of passive solar systems with north-facing collector facades (greenhouses, heat accumulating walls, or solar air collectors), cross-ventilation, and selective night ventilation. The hygrothermal conditions of the classrooms audited were within the comfort zone during the winter due to the use of heating systems. In summer, with hygrothermal levels above the comfort range, the school reaches 29°C and 35% relative humidity. This is due to warm air entering from the outside and inadequate thermal insulation in the building envelope, with

FIGURE 54.
Roque Chieli Primary School, No. 4731. Salta City.
Temperate dry climate.



MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 21.4 | 20.5 | 18.9 | 16.1 | 13.5 | 11.2 | 10.7 | 11.9 | 15.3 | 17.5 | 20.0 | 21.2 | 21.0 | 11.8 | 16.5 |
| 2 | 19.7 | 19.0 | 17.4 | 14.4 | 11.4 | 9.0 | 8.2 | 9.4 | 13.0 | 15.4 | 18.1 | 19.4 | 19.4 | 9.5 | 14.5 |
| 3 | 18.2 | 17.6 | 16.1 | 12.9 | 9.6 | 7.0 | 5.8 | 7.1 | 10.9 | 13.4 | 16.3 | 17.7 | 17.8 | 7.5 | 12.7 |
| 4 | 16.9 | 16.5 | 14.9 | 11.6 | 8.0 | 5.2 | 3.8 | 5.1 | 9.1 | 11.7 | 14.7 | 16.2 | 16.5 | 5.7 | 11.2 |
| 5 | 16.2 | 15.8 | 14.3 | 10.8 | 7.1 | 4.3 | 2.8 | 4.1 | 8.1 | 10.8 | 13.9 | 15.5 | 15.8 | 4.7 | 10.3 |
| 6 | 16.0 | 15.6 | 14.1 | 10.6 | 6.8 | 4.0 | 2.4 | 3.7 | 7.8 | 10.5 | 13.6 | 15.2 | 15.6 | 4.4 | 10.0 |
| 7 | 16.7 | 16.2 | 14.7 | 11.3 | 7.7 | 4.9 | 3.5 | 4.8 | 8.8 | 11.4 | 14.4 | 16.0 | 16.3 | 5.4 | 10.9 |
| 8 | 17.8 | 17.2 | 15.7 | 12.4 | 9.0 | 6.3 | 5.1 | 6.4 | 10.2 | 12.8 | 15.7 | 17.2 | 17.4 | 6.8 | 12.1 |
| 9 | 19.0 | 18.4 | 16.8 | 13.7 | 10.6 | 8.1 | 7.1 | 8.3 | 12.0 | 14.5 | 17.2 | 18.6 | 18.7 | 8.6 | 13.7 |
| 10 | 21.1 | 20.3 | 18.7 | 15.8 | 13.2 | 10.9 | 10.4 | 11.5 | 14.9 | 17.2 | 19.8 | 21.0 | 20.8 | 11.5 | 16.2 |
| 11 | 25.2 | 24.1 | 22.3 | 20.0 | 18.3 | 16.3 | 16.7 | 17.8 | 20.6 | 22.5 | 24.7 | 25.5 | 24.9 | 17.1 | 21.2 |
| 12 | 26.6 | 25.3 | 23.6 | 21.4 | 20.0 | 18.2 | 18.9 | 19.9 | 22.5 | 24.3 | 26.3 | 27.1 | 26.4 | 19.0 | 22.9 |
| 13 | 27.3 | 26.0 | 24.2 | 22.1 | 20.9 | 19.1 | 20.0 | 21.0 | 23.5 | 25.2 | 27.2 | 27.9 | 27.1 | 20.0 | 23.7 |
| 14 | 27.7 | 26.3 | 24.5 | 22.5 | 21.3 | 19.6 | 20.5 | 21.5 | 24.0 | 25.7 | 27.6 | 28.3 | 27.4 | 20.5 | 24.1 |
| 15 | 27.5 | 26.1 | 24.3 | 22.3 | 21.0 | 19.3 | 20.1 | 21.1 | 23.7 | 25.4 | 27.3 | 28.0 | 27.2 | 20.1 | 23.8 |
| 16 | 27.0 | 25.7 | 23.9 | 21.8 | 20.4 | 18.7 | 19.4 | 20.4 | 23.0 | 24.8 | 26.8 | 27.5 | 26.7 | 19.5 | 23.3 |
| 17 | 26.6 | 25.3 | 23.6 | 21.4 | 20.0 | 18.2 | 18.9 | 19.9 | 22.5 | 24.3 | 26.3 | 27.1 | 26.4 | 19.0 | 22.9 |
| 18 | 26.2 | 24.9 | 23.1 | 21.0 | 19.4 | 17.6 | 18.1 | 19.2 | 21.9 | 23.7 | 25.8 | 26.6 | 25.9 | 18.4 | 22.3 |
| 19 | 25.7 | 24.5 | 22.7 | 20.5 | 18.8 | 16.9 | 17.4 | 18.5 | 21.2 | 23.1 | 25.2 | 26.1 | 25.4 | 17.7 | 21.7 |
| 20 | 25.4 | 24.2 | 22.4 | 20.1 | 18.4 | 16.5 | 16.9 | 17.9 | 20.8 | 22.7 | 24.8 | 25.7 | 25.1 | 17.3 | 21.3 |
| 21 | 24.8 | 23.6 | 21.9 | 19.5 | 17.7 | 15.7 | 16.0 | 17.1 | 20.0 | 21.9 | 24.1 | 25.0 | 24.5 | 16.5 | 20.6 |
| 22 | 24.2 | 23.1 | 21.4 | 18.9 | 17.0 | 14.9 | 15.1 | 16.2 | 19.1 | 21.1 | 23.4 | 24.4 | 23.9 | 15.6 | 19.9 |
| 23 | 23.5 | 22.4 | 20.8 | 18.2 | 16.1 | 14.0 | 14.0 | 15.1 | 18.2 | 20.2 | 22.6 | 23.6 | 23.2 | 14.7 | 19.0 |
| 24 | 22.7 | 21.7 | 20.0 | 17.4 | 15.1 | 12.9 | 12.7 | 13.8 | 17.0 | 19.2 | 21.6 | 22.7 | 22.3 | 13.6 | 18.1 |

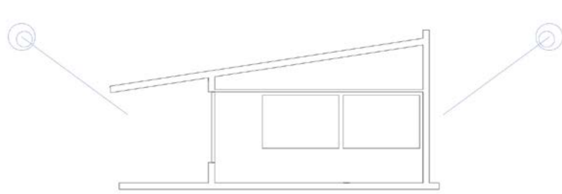


The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

a significant thermal load affecting the roof in particular. Despite the overheating recorded, 35% to 55% of students reported being comfortable, which reflects a degree of tolerance to extreme temperatures. In summer, many wear light clothing and reported perspiring (34% to 52%). In winter, the opinion of thermal conditions was still favorable (65% to 84%), though students adjusted their comfort level by wearing coats.

With respect to lighting conditions, recorded values fell within the LCR, although they did not meet the daylight coefficient, likely due to the size and location

FIGURE 55.
Shading. Natural ventilation. Thermally insulated building envelope. Salta.



of windows. Nevertheless, students evaluated this aspect favorably (65% to 85%). The distribution of natural light should be improved using windows that enable increased illuminance levels and distributing them more homogeneously throughout the building, avoiding the direct access of solar radiation and warm air from outside.

From an acoustic standpoint, most students reported discomfort (65% to 95%), with levels exceeding the comfort range. This is due to inadequate treatment of the indoor acoustic field. Absorbent surfaces should be added to the walls or ceilings. Winter was evaluated more negatively in terms of noise levels and air quality.

With respect to the latter, the vast majority of students perceived the air as stale (56% to 95%), with values generally within the admissible ranges for concentrations of $CO_2$. Therefore, this issue may be caused by heating equipment, the lack of humidity in the atmosphere, and odors generated by occupants.

### Temperate cold climate requiring shading + ventilation + heating (Mendoza, Tandil)

This is a suburban school located in the provincial capital in a temperate cold zone at 735 m.a.s.l. with oasis-like characteristics. Maximum average temperatures in summer are 31.7°C and minimum averages in winter are 1.7°C, with a low average annual relative humidity of 46.7% and 128 degree days (HDD18) of annual heating. Moderate winds come predominantly from the west-southeast quadrant in the winter and the south, northeast, southeast and southwest in the summer, with an annual rainfall of 200 mm. The school is organized as a single bay of classrooms on one floor, with a mono-pitched roof, and a partially covered arcade. Traditional-style construction was used.

Climate conditions in the city of Tandil, at 188 m.a.s.l., correspond to a temperate cold climate, requiring heating. The average minimum temperature in winter is 3.2°C and the average maximum in summer is 26.8°C, with winds from the southeast in winter and northwest, north and northeast in the summer. The building layout and envelope should be adapted for the harsh climate. It is a compact building on two floors around a central patio, with a large internal volume that is not conducive to climate control. Traditional technology was used, with medium-weight construction materials and a lightweight roof.

#### Mendoza

In the winter, the hygrothermal conditions of the classroom are below the LCR. In both winter and summer, most students (69% to 82%) reported being comfortable, although 50% to 82% were very warmly dressed during the winter. Heating is needed during the winter months. This can be resolved by incorporating passive solar systems or additional traditional heating sources. The thermal insulation in the entire building envelope should be improved, giving priority to the roofs, since this is where the greatest thermal losses

FIGURE 56.

Escultor Roberto Rosas School, No. 1745. Mendoza City.
Temperate cold climate (semi-arid).

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 24.7 | 23.6 | 20.6 | 16.5 | 11.8 | 8.5 | 8.1 | 10.7 | 12.8 | 18.0 | 21.4 | 22.6 | 23.6 | 9.5 | 16.6 |
| 2 | 22.8 | 21.8 | 18.8 | 14.7 | 10.0 | 6.7 | 6.3 | 8.8 | 10.9 | 16.1 | 19.4 | 20.2 | 21.6 | 7.7 | 14.7 |
| 3 | 21.0 | 20.0 | 17.2 | 13.0 | 8.2 | 5.1 | 4.7 | 7.0 | 9.1 | 14.3 | 17.5 | 18.0 | 19.7 | 6.0 | 12.9 |
| 4 | 19.5 | 18.6 | 15.9 | 11.6 | 6.8 | 3.6 | 3.4 | 5.5 | 7.5 | 12.7 | 16.0 | 16.2 | 18.1 | 4.6 | 11.4 |
| 5 | 18.7 | 17.8 | 15.1 | 10.9 | 6.0 | 2.9 | 2.6 | 4.7 | 6.7 | 11.9 | 15.1 | 15.1 | 17.2 | 3.8 | 10.6 |
| 6 | 18.4 | 17.5 | 14.9 | 10.6 | 5.7 | 2.6 | 2.4 | 4.4 | 6.4 | 11.6 | 14.8 | 14.8 | 16.9 | 3.6 | 10.3 |
| 7 | 19.2 | 18.3 | 15.6 | 11.4 | 6.5 | 3.4 | 3.1 | 5.2 | 7.2 | 12.4 | 15.7 | 15.8 | 17.8 | 4.3 | 11.2 |
| 8 | 20.4 | 19.5 | 16.7 | 12.5 | 7.7 | 4.5 | 4.2 | 6.4 | 8.5 | 13.7 | 17.0 | 17.3 | 19.1 | 5.5 | 12.4 |
| 9 | 21.9 | 21.0 | 18.1 | 13.9 | 9.2 | 6.0 | 5.6 | 7.9 | 10.0 | 15.2 | 18.5 | 19.2 | 20.7 | 6.9 | 13.9 |
| 10 | 24.4 | 23.4 | 20.3 | 16.2 | 11.6 | 8.3 | 7.8 | 10.4 | 12.6 | 17.8 | 21.1 | 22.2 | 23.3 | 9.2 | 16.3 |
| 11 | 29.1 | 28.0 | 24.6 | 20.7 | 16.2 | 12.8 | 12.1 | 15.1 | 17.5 | 22.7 | 26.2 | 28.2 | 28.4 | 13.7 | 21.1 |
| 12 | 30.8 | 29.6 | 26.1 | 22.2 | 17.8 | 14.3 | 13.6 | 16.8 | 19.1 | 24.3 | 27.9 | 30.2 | 30.2 | 15.2 | 22.7 |
| 13 | 31.6 | 30.4 | 26.8 | 23.0 | 18.6 | 15.1 | 14.3 | 17.6 | 20.0 | 25.2 | 28.8 | 31.2 | 31.1 | 16.0 | 23.5 |
| 14 | 32.0 | 30.8 | 27.2 | 23.4 | 19.0 | 15.5 | 14.7 | 18.0 | 20.4 | 25.6 | 29.2 | 31.7 | 31.5 | 16.4 | 24.0 |
| 15 | 31.7 | 30.5 | 27.0 | 23.1 | 18.7 | 15.2 | 14.5 | 17.7 | 20.1 | 25.3 | 28.9 | 31.4 | 31.2 | 16.1 | 23.7 |
| 16 | 31.2 | 30.0 | 26.5 | 22.6 | 18.2 | 14.7 | 14.0 | 17.2 | 19.6 | 24.8 | 28.3 | 30.7 | 30.6 | 15.6 | 23.1 |
| 17 | 30.8 | 29.6 | 26.1 | 22.2 | 17.8 | 14.3 | 13.6 | 16.8 | 19.1 | 24.3 | 27.9 | 30.2 | 30.2 | 15.2 | 22.7 |
| 18 | 30.2 | 29.1 | 25.6 | 21.7 | 17.3 | 13.8 | 13.1 | 16.2 | 18.6 | 23.8 | 27.3 | 29.5 | 29.6 | 14.7 | 22.2 |
| 19 | 29.7 | 28.5 | 25.1 | 21.2 | 16.7 | 13.3 | 12.6 | 15.7 | 18.0 | 23.2 | 26.8 | 28.8 | 29.0 | 14.2 | 21.6 |
| 20 | 29.3 | 28.1 | 24.7 | 20.8 | 16.3 | 12.9 | 12.2 | 15.3 | 17.6 | 22.8 | 26.3 | 28.3 | 28.6 | 13.8 | 21.2 |
| 21 | 28.6 | 27.5 | 24.1 | 20.2 | 15.7 | 12.3 | 11.6 | 14.6 | 16.9 | 22.1 | 25.6 | 27.5 | 27.9 | 13.2 | 20.6 |
| 22 | 27.9 | 26.8 | 23.5 | 19.6 | 15.0 | 11.6 | 11.0 | 13.9 | 16.2 | 21.4 | 24.9 | 26.6 | 27.1 | 12.6 | 19.9 |
| 23 | 27.1 | 26.0 | 22.8 | 18.8 | 14.2 | 10.9 | 10.3 | 13.1 | 15.4 | 20.6 | 24.0 | 25.6 | 26.2 | 11.8 | 19.1 |
| 24 | 26.2 | 25.1 | 21.9 | 17.9 | 13.3 | 10.0 | 9.4 | 12.2 | 14.4 | 19.6 | 23.0 | 24.4 | 25.2 | 10.9 | 18.1 |

FRÍO — ZONA DE CONFORT — CALOR

19.9 °C — 26.9 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 57.

Elisa Solari de Levy Nicolás School, No. 14. Tandil.
Temperate cold climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 20.0 | 19.1 | 17.7 | 13.8 | 10.5 | 7.6 | 7.5 | 8.4 | 10.5 | 12.9 | 15.2 | 18.9 | 19.3 | 8.5 | 13.5 |
| 2 | 18.0 | 17.3 | 15.9 | 12.1 | 9.1 | 6.3 | 6.1 | 6.9 | 8.8 | 11.2 | 13.3 | 16.9 | 17.4 | 7.2 | 11.8 |
| 3 | 16.2 | 15.5 | 14.3 | 10.6 | 7.8 | 5.0 | 4.8 | 5.5 | 7.2 | 9.7 | 11.5 | 15.1 | 15.6 | 5.9 | 10.3 |
| 4 | 14.7 | 14.1 | 13.0 | 9.3 | 6.7 | 4.0 | 3.8 | 4.3 | 5.9 | 8.4 | 10.1 | 13.5 | 14.1 | 4.8 | 9.0 |
| 5 | 13.9 | 13.3 | 12.2 | 8.5 | 6.1 | 3.4 | 3.2 | 3.6 | 5.1 | 7.6 | 9.3 | 12.7 | 13.3 | 4.2 | 8.2 |
| 6 | 13.6 | 13.0 | 12.0 | 8.3 | 5.9 | 3.2 | 3.0 | 3.4 | 4.9 | 7.4 | 9.0 | 12.4 | 13.0 | 4.0 | 8.0 |
| 7 | 14.4 | 13.8 | 12.7 | 9.0 | 6.5 | 3.8 | 3.6 | 4.1 | 5.6 | 8.1 | 9.8 | 13.2 | 13.8 | 4.6 | 8.7 |
| 8 | 15.7 | 15.0 | 13.8 | 10.1 | 7.4 | 4.6 | 4.5 | 5.0 | 6.7 | 9.2 | 11.0 | 14.5 | 15.1 | 5.5 | 9.8 |
| 9 | 17.2 | 16.5 | 15.2 | 11.4 | 8.5 | 5.7 | 5.5 | 6.2 | 8.1 | 10.5 | 12.5 | 16.1 | 16.6 | 6.6 | 11.1 |
| 10 | 19.7 | 18.9 | 17.4 | 13.5 | 10.3 | 7.4 | 7.3 | 8.2 | 10.3 | 12.6 | 14.9 | 18.6 | 19.1 | 8.3 | 13.3 |
| 11 | 24.6 | 23.5 | 21.7 | 17.7 | 13.8 | 10.8 | 10.7 | 12.0 | 14.5 | 16.8 | 19.6 | 23.5 | 23.9 | 11.7 | 17.4 |
| 12 | 26.2 | 25.1 | 23.2 | 19.1 | 15.0 | 11.9 | 11.8 | 13.3 | 16.0 | 18.2 | 21.2 | 25.2 | 25.5 | 12.9 | 18.9 |
| 13 | 27.1 | 25.9 | 23.9 | 19.8 | 15.6 | 12.5 | 12.4 | 14.0 | 16.7 | 18.9 | 22.0 | 26.1 | 26.4 | 13.5 | 19.6 |
| 14 | 27.5 | 26.3 | 24.3 | 20.2 | 15.9 | 12.8 | 12.7 | 14.3 | 17.1 | 19.3 | 22.4 | 26.5 | 26.8 | 13.8 | 19.9 |
| 15 | 27.2 | 26.0 | 24.1 | 20.0 | 15.7 | 12.6 | 12.5 | 14.1 | 16.9 | 19.1 | 22.1 | 26.2 | 26.5 | 13.6 | 19.7 |
| 16 | 26.7 | 25.5 | 23.6 | 19.5 | 15.3 | 12.2 | 12.1 | 13.6 | 16.4 | 18.6 | 21.6 | 25.7 | 25.9 | 13.2 | 19.2 |
| 17 | 26.2 | 25.1 | 23.2 | 19.1 | 15.0 | 11.9 | 11.8 | 13.3 | 16.0 | 18.2 | 21.2 | 25.2 | 25.5 | 12.9 | 18.9 |
| 18 | 25.7 | 24.6 | 22.7 | 18.7 | 14.6 | 11.6 | 11.4 | 12.9 | 15.5 | 17.8 | 20.7 | 24.7 | 25.0 | 12.5 | 18.4 |
| 19 | 25.1 | 24.0 | 22.2 | 18.2 | 14.2 | 11.2 | 11.1 | 12.4 | 15.0 | 17.3 | 20.1 | 24.1 | 24.4 | 12.1 | 17.9 |
| 20 | 24.7 | 23.6 | 21.8 | 17.8 | 13.9 | 10.9 | 10.8 | 12.1 | 14.7 | 16.9 | 19.7 | 23.7 | 24.0 | 11.8 | 17.6 |
| 21 | 24.0 | 23.0 | 21.2 | 17.2 | 13.4 | 10.4 | 10.3 | 11.6 | 14.1 | 16.3 | 19.1 | 23.0 | 23.3 | 11.4 | 17.0 |
| 22 | 23.3 | 22.3 | 20.6 | 16.6 | 12.9 | 9.9 | 9.8 | 11.0 | 13.4 | 15.7 | 18.4 | 22.3 | 22.6 | 10.9 | 16.4 |
| 23 | 22.5 | 21.5 | 19.9 | 15.9 | 12.3 | 9.3 | 9.2 | 10.4 | 12.7 | 15.0 | 17.6 | 21.4 | 21.8 | 10.3 | 15.6 |
| 24 | 21.5 | 20.6 | 19.0 | 15.1 | 11.6 | 8.7 | 8.5 | 9.6 | 11.9 | 14.2 | 16.6 | 20.4 | 20.8 | 9.6 | 14.8 |

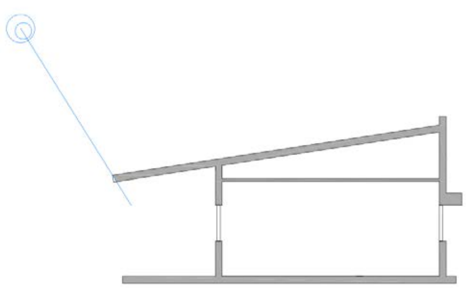
FRÍO — ZONA DE CONFORT — CALOR

18 ºC — 24 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 58.

Shading. Natural ventilation. Thermally insulated building envelope. Mendoza.



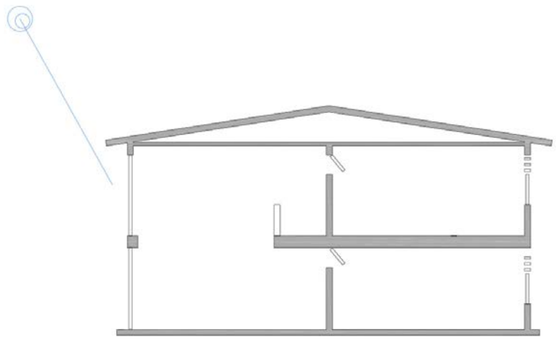
occur. In the summer, the hygrothermal conditions of the classroom are within the comfort range. In this case, window design should be improved in order facilitate cross-ventilation. The concentration of stale air is caused by a lack of ventilation and the use of heating in the winter, with 90% of students complaining of the air quality.

## Tandil

The hygrothermal conditions of the audited classrooms are outside the comfort zone during the winter, despite the presence of climate control technology. The majority of students reported being comfortable (81%), although 58% to 65% were warmly dressed. Heating can be resolved by using appropriate solar orientation and passive solar systems, such as solar air collector walls, either heavy or lightweight. The thermal insulation in the entire building envelope (walls, ceilings, floors, and glazed windows) should be improved to eliminate thermal bridges.

Most students had a positive opinion of the lighting (45% to 74%) in both locations, and averages in Tandil were within the acceptable range. Nevertheless, in Mendoza, the recorded illuminance levels in classrooms were low and irregular, and did not comply with the recommended standards. High illuminance levels were recorded close to the windows, while on the opposite side of classrooms, levels were low. This should be balanced out and suggests a need to

FIGURE 59.
Shading. Natural ventilation. Thermally insulated building envelope. Tandil.



reduce the maximum illuminance levels close to windows, especially north-facing ones, by designing window systems that produce more uniform illuminance levels throughout. Light shelves or shaded arcades could be used to prevent direct solar radiation from affecting the north-facing facade and reflect the light toward the opposite side of the classroom using pale colors for both the light shelves and the arcade floors, as needed. To increase illuminance levels in the darkest parts of the classrooms, reflective floors or lightwells in north-facing arcades can be used.

There was a general discomfort with noise levels (95% to 100%), regardless of the season, with recorded levels exceeding the standard values. The indoor acoustic field of classrooms and hallways should be treated.

In Tandil, the measured levels of $CO_2$ were above the acceptable standard (1356/2000 ppm) and student opinion clearly reflected this discomfort (79% in winter). Improvements in the naturally controlled ventilation system are needed or automatic systems should be incorporated.

## Very cold climate requiring heating (Bariloche)

School located on the outskirts of the city of Bariloche at 893 m.a.s.l. The average minimum temperature in winter is -1.1°C and the average maximum in summer is 20.4°C with 3681 degree days $HDD_{18}$ of

FIGURE 60.
School No. 367. San Carlos de Bariloche. Very cold climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 14.2 | 13.6 | 12.1 | 8.2 | 5.4 | 2.9 | 2.0 | 3.3 | 5.3 | 8.0 | 10.4 | 12.7 | 13.5 | 3.4 | 8.2 |
| 2 | 11.9 | 11.3 | 10.0 | 6.5 | 4.1 | 1.8 | 0.8 | 1.9 | 3.7 | 6.1 | 8.4 | 10.7 | 11.3 | 2.2 | 6.4 |
| 3 | 9.8 | 9.2 | 8.1 | 5.0 | 2.9 | 0.8 | -0.2 | 0.6 | 2.2 | 4.3 | 6.6 | 8.8 | 9.3 | 1.2 | 4.8 |
| 4 | 8.0 | 7.4 | 6.5 | 3.7 | 1.8 | 0.0 | -1.1 | -0.4 | 0.9 | 2.9 | 5.1 | 7.2 | 7.5 | 0.2 | 3.5 |
| 5 | 7.0 | 6.4 | 5.6 | 2.9 | 1.3 | -0.5 | -1.6 | -1.0 | 0.2 | 2.1 | 4.3 | 6.4 | 6.6 | -0.3 | 2.8 |
| 6 | 6.7 | 6.1 | 5.3 | 2.7 | 1.1 | -0.6 | -1.8 | -1.2 | 0.0 | 1.8 | 4.0 | 6.1 | 6.3 | -0.4 | 2.5 |
| 7 | 7.7 | 7.1 | 6.2 | 3.4 | 1.7 | -0.2 | -1.3 | -0.6 | 0.7 | 2.6 | 4.8 | 7.0 | 7.2 | 0.1 | 3.3 |
| 8 | 9.1 | 8.5 | 7.5 | 4.5 | 2.5 | 0.5 | -0.6 | 0.3 | 1.7 | 3.8 | 6.1 | 8.2 | 8.6 | 0.8 | 4.4 |
| 9 | 10.9 | 10.3 | 9.1 | 5.8 | 3.5 | 1.4 | 0.3 | 1.3 | 3.0 | 5.3 | 7.6 | 9.8 | 10.4 | 1.7 | 5.7 |
| 10 | 13.8 | 13.3 | 11.8 | 7.9 | 5.2 | 2.7 | 1.8 | 3.1 | 5.1 | 7.7 | 10.1 | 12.4 | 13.2 | 3.2 | 7.9 |
| 11 | 19.5 | 19.0 | 16.9 | 12.1 | 8.4 | 5.3 | 4.7 | 6.5 | 9.2 | 12.4 | 15.0 | 17.4 | 18.6 | 6.2 | 12.2 |
| 12 | 21.4 | 20.9 | 18.7 | 13.5 | 9.6 | 6.2 | 5.7 | 7.6 | 10.6 | 14.0 | 16.6 | 19.1 | 20.5 | 7.2 | 13.7 |
| 13 | 22.4 | 21.9 | 19.6 | 14.2 | 10.1 | 6.7 | 6.2 | 8.2 | 11.3 | 14.8 | 17.5 | 20.0 | 21.4 | 7.7 | 14.4 |
| 14 | 22.9 | 22.4 | 20.0 | 14.6 | 10.4 | 6.9 | 6.4 | 8.5 | 11.6 | 15.2 | 17.9 | 20.4 | 21.9 | 7.9 | 14.8 |
| 15 | 22.6 | 22.1 | 19.7 | 14.4 | 10.2 | 6.8 | 6.2 | 8.3 | 11.4 | 14.9 | 17.6 | 20.1 | 21.6 | 7.7 | 14.5 |
| 16 | 21.9 | 21.4 | 19.1 | 13.9 | 9.8 | 6.5 | 5.9 | 7.9 | 10.9 | 14.4 | 17.1 | 19.5 | 21.0 | 7.4 | 14.0 |
| 17 | 21.4 | 20.9 | 18.7 | 13.5 | 9.6 | 6.2 | 5.7 | 7.6 | 10.6 | 14.0 | 16.6 | 19.1 | 20.5 | 7.2 | 13.7 |
| 18 | 20.8 | 20.3 | 18.1 | 13.1 | 9.2 | 5.9 | 5.3 | 7.2 | 10.1 | 13.5 | 16.1 | 18.5 | 19.9 | 6.8 | 13.2 |
| 19 | 20.1 | 19.6 | 17.5 | 12.6 | 8.8 | 5.6 | 5.0 | 6.9 | 9.6 | 12.9 | 15.5 | 18.0 | 19.2 | 6.5 | 12.7 |
| 20 | 19.7 | 19.1 | 17.1 | 12.2 | 8.5 | 5.4 | 4.8 | 6.6 | 9.3 | 12.5 | 15.1 | 17.5 | 18.8 | 6.2 | 12.3 |
| 21 | 18.9 | 18.3 | 16.3 | 11.6 | 8.1 | 5.0 | 4.4 | 6.1 | 8.7 | 11.9 | 14.4 | 16.8 | 18.0 | 5.8 | 11.7 |
| 22 | 18.0 | 17.5 | 15.6 | 11.0 | 7.6 | 4.7 | 3.9 | 5.6 | 8.1 | 11.2 | 13.7 | 16.1 | 17.2 | 5.4 | 11.1 |
| 23 | 17.1 | 16.5 | 14.7 | 10.3 | 7.1 | 4.2 | 3.4 | 5.0 | 7.4 | 10.4 | 12.9 | 15.3 | 16.3 | 4.9 | 10.4 |
| 24 | 15.9 | 15.4 | 13.7 | 9.5 | 6.4 | 3.7 | 2.9 | 4.3 | 6.6 | 9.4 | 11.9 | 14.3 | 15.2 | 4.3 | 9.5 |

FRÍO — ZONA DE CONFORT — CALOR
18 °C — 24 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

heating. Average annual relative humidity is 65.8%, with intense snowfall during the winter. Due to the annual hygrothermal conditions, heating is required during practically the entire school term. The building is compact with a central hallway. Classrooms are organized in two bays, facing northeast and southwest. Traditional construction. Classrooms are square-shaped with lighting entering from one side.

### Bariloche

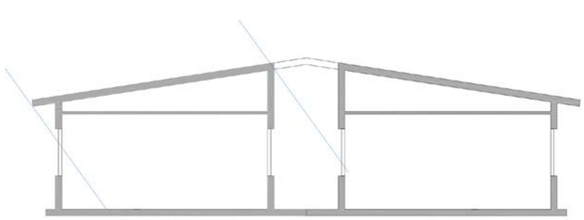
The hygrothermal conditions of the audited classrooms were within the comfort zone, due to the use of traditional climate control technology. The majority of students reported being comfortable (65% to 97%) and were warmly dressed (45% to 56%). Heating can be enhanced by using appropriate solar orientation and passive solar systems, such as lightweight solar air collector walls. The thermal insulation of the entire building envelope (walls, ceilings, floors, and glazed windows) should be improved to eliminate thermal bridges.

The majority of students had a positive opinion of the lighting (59% to 93%), coinciding with average acceptable values.

Discomfort with noise levels was generalized (94% to 100%) and levels were above the admissible values. The acoustic field of classrooms and internal hallways should be treated, and the air conditioning equipment should be relocated away from those areas.

The measured concentrations of $CO_2$ were far above the acceptable standards (1530 ppm) and student opinion clearly reflected this discomfort (71% in winter and 44% in summer). Ventilation should be optimized, using either naturally controlled or automatic systems.

FIGURE 61.
Thermally insulated building envelope.
Solar + traditional heating. Bariloche.



## COLOMBIA (CO)

The locations studied correspond to the dry or rainy seasons:

### Warm humid climate

- El Progreso School. Yopal.
- Carrasquilla Industrial School. Quibdó.

### Warm dry climate

- Germán Vargas Cantillo School. Barranquilla.
- Lachoon Mayapo Rural Ethno-educational School. Manaure.

### Temperate warm climate

- Bicentenario School. Ibagué.
- Samaria School. Pereira.

### Temperate cold climate

- Seminario School. Ipiales.
- Soacha Para Vivir Mejor School. Soacha.

## Warm humid climate requiring shading + ventilation (Yopal, Quibdó)

Yopal has a warm tropical climate, with average annual temperatures between 22°C and 30.4°C (and a significant warm period for six months of the year). The school consists of a block of classrooms with south-facing hallways, grouped on two levels. Classrooms have lighting on both sides, entering from opposite facades, and the building faces north. Woodwork is not used nor are classrooms treated with latticed vertical slats.

The school is located at 43 m.a.s.l., where the average temperature is 28°C. Due to its particular geographical location, it receives the highest average annual precipitation of all of South America, with levels above 8991 mm. The warm climate presents mild, stable conditions, with a high humidity content, requiring constant natural cross-ventilation

FIGURE 62.

## El Progreso Educational Institute. Yopal. Warm climate.

**MAPA DE CONFORT**

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 28.8 | 28.5 | 28.2 | 26.9 | 26.3 | 25.2 | 24.9 | 25.6 | 26.2 | 27.0 | 27.1 | 27.5 | 28.2 | 25.5 | 26.8 |
| 2 | 28.4 | 27.8 | 28.0 | 26.5 | 26.0 | 24.9 | 24.7 | 25.4 | 25.9 | 26.6 | 26.8 | 27.1 | 27.8 | 25.2 | 26.5 |
| 3 | 28.0 | 27.2 | 27.7 | 26.1 | 25.7 | 24.7 | 24.4 | 25.2 | 25.6 | 26.3 | 26.5 | 26.8 | 27.3 | 24.9 | 26.2 |
| 4 | 27.6 | 26.7 | 27.5 | 25.8 | 25.5 | 24.5 | 24.2 | 25.0 | 25.4 | 26.1 | 26.3 | 26.6 | 27.0 | 24.7 | 25.9 |
| 5 | 27.5 | 26.4 | 27.4 | 25.7 | 25.3 | 24.3 | 24.1 | 24.9 | 25.2 | 25.9 | 26.1 | 26.4 | 26.8 | 24.6 | 25.8 |
| 6 | 27.4 | 26.3 | 27.4 | 25.6 | 25.3 | 24.3 | 24.1 | 24.9 | 25.2 | 25.9 | 26.1 | 26.4 | 26.7 | 24.6 | 25.7 |
| 7 | 27.6 | 26.6 | 27.5 | 25.8 | 25.4 | 24.4 | 24.2 | 25.0 | 25.3 | 26.0 | 26.2 | 26.5 | 26.9 | 24.7 | 25.9 |
| 8 | 27.9 | 27.0 | 27.7 | 26.0 | 25.6 | 24.6 | 24.4 | 25.1 | 25.5 | 26.2 | 26.4 | 26.7 | 27.2 | 24.9 | 26.1 |
| 9 | 28.2 | 27.5 | 27.9 | 26.3 | 25.8 | 24.8 | 24.6 | 25.3 | 25.8 | 26.5 | 26.7 | 27.0 | 27.6 | 25.1 | 26.4 |
| 10 | 28.7 | 28.4 | 28.2 | 26.8 | 26.2 | 25.2 | 24.9 | 25.6 | 26.2 | 26.9 | 27.1 | 27.4 | 28.2 | 25.4 | 26.8 |
| 11 | 29.8 | 30.1 | 28.8 | 27.8 | 27.0 | 25.9 | 25.5 | 26.2 | 26.9 | 27.7 | 27.8 | 28.2 | 29.4 | 26.1 | 27.6 |
| 12 | 30.1 | 30.7 | 29.0 | 28.1 | 27.2 | 26.1 | 25.7 | 26.4 | 27.2 | 28.0 | 28.1 | 28.5 | 29.8 | 26.4 | 27.9 |
| 13 | 30.3 | 31.0 | 29.1 | 28.3 | 27.3 | 26.2 | 25.8 | 26.5 | 27.3 | 28.1 | 28.2 | 28.6 | 30.0 | 26.5 | 28.1 |
| 14 | 30.4 | 31.1 | 29.2 | 28.4 | 27.4 | 26.3 | 25.9 | 26.5 | 27.4 | 28.2 | 28.3 | 28.7 | 30.1 | 26.5 | 28.2 |
| 15 | 30.3 | 31.0 | 29.2 | 28.3 | 27.4 | 26.3 | 25.9 | 26.5 | 27.4 | 28.2 | 28.3 | 28.7 | 30.0 | 26.5 | 28.1 |
| 16 | 30.2 | 30.8 | 29.1 | 28.2 | 27.3 | 26.2 | 25.8 | 26.4 | 27.3 | 28.1 | 28.2 | 28.6 | 29.9 | 26.4 | 28.0 |
| 17 | 30.1 | 30.7 | 29.0 | 28.1 | 27.2 | 26.1 | 25.7 | 26.4 | 27.2 | 28.0 | 28.1 | 28.5 | 29.8 | 26.4 | 27.9 |
| 18 | 30.0 | 30.5 | 29.0 | 28.0 | 27.1 | 26.0 | 25.7 | 26.3 | 27.1 | 27.9 | 28.0 | 28.4 | 29.6 | 26.3 | 27.8 |
| 19 | 29.9 | 30.3 | 28.9 | 27.9 | 27.0 | 26.0 | 25.6 | 26.2 | 27.0 | 27.8 | 27.9 | 28.3 | 29.5 | 26.2 | 27.7 |
| 20 | 29.8 | 30.1 | 28.8 | 27.8 | 27.0 | 25.9 | 25.5 | 26.2 | 27.0 | 27.7 | 27.9 | 28.2 | 29.4 | 26.1 | 27.7 |
| 21 | 29.7 | 29.9 | 28.8 | 27.7 | 26.9 | 25.8 | 25.5 | 26.1 | 26.9 | 27.6 | 27.8 | 28.1 | 29.2 | 26.0 | 27.5 |
| 22 | 29.5 | 29.7 | 28.7 | 27.6 | 26.8 | 25.7 | 25.4 | 26.0 | 26.7 | 27.5 | 27.6 | 28.0 | 29.1 | 25.9 | 27.4 |
| 23 | 29.3 | 29.4 | 28.6 | 27.4 | 26.6 | 25.6 | 25.3 | 25.9 | 26.6 | 27.4 | 27.5 | 27.9 | 28.9 | 25.8 | 27.3 |
| 24 | 29.1 | 29.0 | 28.4 | 27.2 | 26.5 | 25.4 | 25.1 | 25.8 | 26.5 | 27.2 | 27.4 | 27.7 | 28.6 | 25.7 | 27.1 |

FRÍO — ZONA DE CONFORT — CALOR

23.1 ºC — 28.1 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 63.

## Carrasquilla Industrial Educational Institute. Quibdó. Warm humid climate.

**MAPA DE CONFORT**

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 27.1 | 27.3 | 27.7 | 28.0 | 28.7 | 29.7 | 29.7 | 29.4 | 28.9 | 28.2 | 28.0 | 27.5 | 27.3 | 29.4 | 28.3 |
| 2 | 26.0 | 26.2 | 26.7 | 26.9 | 27.6 | 28.6 | 28.5 | 28.2 | 27.8 | 27.1 | 26.9 | 26.4 | 26.2 | 28.2 | 27.2 |
| 3 | 25.0 | 25.2 | 25.7 | 26.0 | 26.6 | 27.5 | 27.3 | 27.1 | 26.8 | 26.1 | 25.9 | 25.4 | 25.2 | 27.1 | 26.2 |
| 4 | 24.1 | 24.3 | 24.8 | 25.2 | 25.7 | 26.6 | 26.3 | 26.1 | 25.9 | 25.3 | 25.1 | 24.5 | 24.3 | 26.2 | 25.3 |
| 5 | 23.7 | 23.9 | 24.4 | 24.7 | 25.3 | 26.1 | 25.8 | 25.6 | 25.5 | 24.9 | 24.7 | 24.1 | 23.9 | 25.7 | 24.9 |
| 6 | 23.5 | 23.7 | 24.2 | 24.6 | 25.1 | 25.9 | 25.6 | 25.4 | 25.3 | 24.7 | 24.5 | 23.9 | 23.7 | 25.5 | 24.7 |
| 7 | 24.0 | 24.2 | 24.7 | 25.0 | 25.6 | 26.4 | 26.1 | 25.9 | 25.8 | 25.2 | 25.0 | 24.4 | 24.2 | 26.0 | 25.2 |
| 8 | 24.7 | 24.9 | 25.4 | 25.7 | 26.3 | 27.1 | 27.0 | 26.7 | 26.5 | 25.8 | 25.6 | 25.1 | 24.9 | 26.8 | 25.9 |
| 9 | 25.6 | 25.7 | 26.2 | 26.5 | 27.1 | 28.1 | 27.9 | 27.7 | 27.3 | 26.7 | 26.5 | 25.9 | 25.7 | 27.7 | 26.8 |
| 10 | 27.0 | 27.1 | 27.6 | 27.8 | 28.5 | 29.6 | 29.6 | 29.2 | 28.7 | 28.0 | 27.8 | 27.3 | 27.1 | 29.2 | 28.2 |
| 11 | 29.7 | 29.9 | 30.3 | 30.4 | 31.3 | 32.5 | 32.7 | 32.3 | 31.5 | 30.6 | 30.4 | 30.1 | 29.9 | 32.1 | 31.0 |
| 12 | 30.7 | 30.8 | 31.2 | 31.2 | 32.2 | 33.5 | 33.8 | 33.3 | 32.4 | 31.5 | 31.3 | 31.0 | 30.8 | 33.1 | 31.9 |
| 13 | 31.2 | 31.3 | 31.7 | 31.7 | 32.7 | 34.0 | 34.3 | 33.8 | 32.9 | 32.0 | 31.8 | 31.5 | 31.3 | 33.6 | 32.4 |
| 14 | 31.4 | 31.5 | 31.9 | 31.9 | 32.9 | 34.2 | 34.6 | 34.1 | 33.1 | 32.2 | 32.0 | 31.7 | 31.5 | 33.9 | 32.6 |
| 15 | 31.2 | 31.3 | 31.7 | 31.8 | 32.7 | 34.0 | 34.4 | 33.9 | 32.9 | 32.1 | 31.9 | 31.5 | 31.4 | 33.7 | 32.5 |
| 16 | 30.9 | 31.0 | 31.4 | 31.5 | 32.4 | 33.7 | 34.1 | 33.6 | 32.6 | 31.8 | 31.6 | 31.2 | 31.1 | 33.4 | 32.1 |
| 17 | 30.7 | 30.8 | 31.2 | 31.2 | 32.2 | 33.5 | 33.8 | 33.3 | 32.4 | 31.5 | 31.3 | 31.0 | 30.8 | 33.1 | 31.9 |
| 18 | 30.4 | 30.5 | 30.9 | 31.0 | 31.9 | 33.1 | 33.4 | 33.0 | 32.1 | 31.2 | 31.0 | 30.7 | 30.5 | 32.8 | 31.6 |
| 19 | 30.1 | 30.2 | 30.6 | 30.7 | 31.6 | 32.8 | 33.1 | 32.6 | 31.8 | 30.9 | 30.7 | 30.4 | 30.2 | 32.5 | 31.3 |
| 20 | 29.8 | 29.9 | 30.4 | 30.4 | 31.3 | 32.5 | 32.8 | 32.4 | 31.5 | 30.7 | 30.5 | 30.1 | 30.0 | 32.2 | 31.0 |
| 21 | 29.4 | 29.6 | 30.0 | 30.1 | 31.0 | 32.1 | 32.4 | 31.9 | 31.2 | 30.3 | 30.1 | 29.8 | 29.6 | 31.8 | 30.6 |
| 22 | 29.0 | 29.2 | 29.6 | 29.7 | 30.6 | 31.7 | 31.9 | 31.5 | 30.8 | 30.0 | 29.8 | 29.4 | 29.2 | 31.4 | 30.2 |
| 23 | 28.6 | 28.7 | 29.1 | 29.3 | 30.1 | 31.2 | 31.4 | 31.0 | 30.3 | 29.5 | 29.3 | 28.9 | 28.7 | 30.9 | 29.8 |
| 24 | 28.0 | 28.1 | 28.6 | 28.8 | 29.5 | 30.6 | 30.7 | 30.4 | 29.7 | 29.0 | 28.8 | 28.3 | 28.2 | 30.3 | 29.2 |

FRÍO — ZONA DE CONFORT — CALOR

22.63 ºC — 29.63 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

and shading of outdoor spaces, walls, and windows. The school studied consists of a series of classrooms divided into two blocks, stacked symmetrically on two levels, with hallways alongside a longitudinal covered space, which functions as a patio. The classrooms are north- and south-facing and have constant cross-ventilation. The building has a light shade roof, medium-weight cement floors and dividing walls, and a completely permeable facade. The roofs have been designed to take advantage of the wind and thereby regulate the temperature inside the building. By using curved eaves, an attempt is made to bring air inside and improve the suction of hot air. Cross-ventilation is reinforced through the chimney effect and convection toward internal hallways. The building's main facades are north-south facing, while the east and west sides of the building are closed. The classrooms do not incorporate woodwork and are enclosed with metal screenings and galvanized mesh.

## Yopal

During the rainy season, conditions in the audited classroom exceed the LCR, with indoor temperatures of 31°C, higher than those recorded outdoors, due to the heating of the building mass and the thermal load of the occupants. Opinion indicators show that no more than 28% of students reported discomfort, although a high percentage (64% to 79%) were perspiring, which makes it clear that they are highly accustomed to extreme conditions. Cross-ventilation should be improved to further increase cooling, by: (a) using shading over outdoor areas so that air entering the building is cooler, and (b) preventing the outside of the building mass from heating up by using shading (walls, ceilings and cement floors) or (c) preventing the inside of the building mass from heating up by adding thermal insulation to the building envelope.

## Quibdó

The recorded hygrothermal conditions of the audited classrooms during the rainy period exceeded the LCR, with high temperatures and relative humidity (28.9°C and 89.7%). Opinion indicators show that all students during this season were wearing very light clothing.

FIGURE 68.
Shading. Natural ventilation. Yopal.

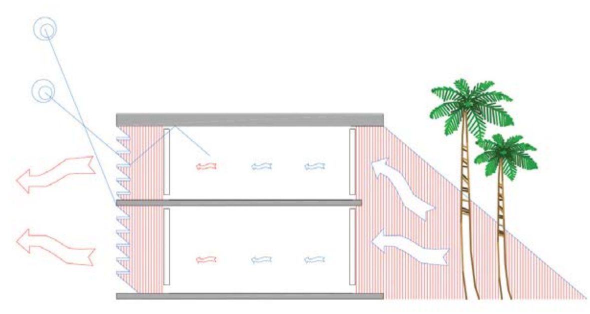
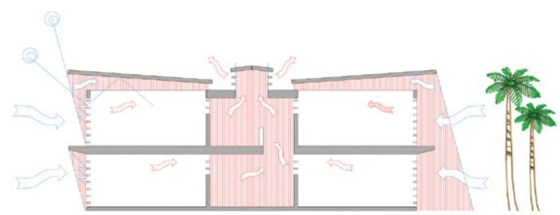


FIGURE 69.
Shading. Natural ventilation. Thermally insulated roof. Quibdó.



Over 60% were perspiring, although no more than 23% reported thermal discomfort. This implies that students accept perspiration as something natural, which suggests they are used to these extreme conditions. Some improvements can be made by shading outside areas and taking measures to prevent the outside and inside of the building mass and the facades from heating up and irradiating heat inside the building.

In Yopal, classroom lighting conditions were unfavorable, with indoor illuminance values below recommended levels. As observed, most of the time complementary artificial lighting is needed. (At the same time, there was no direct radiation hitting the desks, distracting reflections, or glare caused by this lighting.) Nevertheless, 68% of students considered the lighting suitable, indicating, once again, a high degree of habituation to deficient conditions. Quite a different situation was recorded in Quibdó, where in general terms lighting conditions were favorable, meeting the minimum illuminance levels recommended, albeit with a low uniformity coefficient. This did not seem to be an issue for students, given that almost all of them reported comfort (92% to 100%). It is likely that the direct views of the outdoors influenced this markedly positive evaluation. To improve these conditions, window design should be reconsidered, from an environmental quality standpoint rather than an aesthetic point of view. External solar protection should be added to increase shade density on the building's facades and avoid the direct impact of the sun.

In Yopal, most students (80% to 100%) reported irritating noise levels, given the lack of sound insulation (since the classrooms are open) and the reverberation produced by the absence of absorbent surfaces. In Quibdó, because the ventilation systems in the classrooms were constantly on, noise levels were beyond the comfort zone, with 70% of students reporting perceiving these noises. Classrooms also lack acoustic treatment. Common areas and building exteriors should be treated with acoustic shielding and sound barriers, in order to reduce levels of airborne noise. At the same time, treatment of the inside walls of the classrooms with thick, sound-absorbing materials is recommended in order to reduce reverberation times.

In all cases, concentrations of $CO_2$ were within the admissible range. Nevertheless, approximately 50% of students reported inadequate comfort with respect to the air quality. This suggests the presence of other issues that might affect the air, such as odors, humidity, and heat.

## Warm dry climate requiring shading + ventilation (Barranquilla, Manaure)

Barranquilla's climate is tropical and dry, with periods of greater humidity and high temperatures that remain constant throughout the year, with an average of 27.4°C. From November to early April, during the boreal winter, trade winds blow from the northeast, mitigating, in part, the intense heat, and toward the end of June, winds come from the southeast. In Barranquilla, there are two seasonal periods defined by precipitation; a dry period from December to April

FIGURE 70.
Germán Vargas Cantillo School. Barranquilla City. Warm dry climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 27.0 | 27.3 | 27.8 | 28.5 | 28.8 | 28.6 | 28.3 | 28.5 | 28.0 | 27.7 | 27.6 | 27.3 | 27.2 | 28.6 | 28.0 |
| 2 | 25.9 | 26.2 | 26.7 | 27.3 | 27.6 | 27.4 | 27.2 | 27.3 | 26.8 | 26.6 | 26.5 | 26.3 | 26.1 | 27.4 | 26.8 |
| 3 | 24.9 | 25.2 | 25.6 | 26.3 | 26.5 | 26.4 | 26.1 | 26.2 | 25.7 | 25.5 | 25.5 | 25.3 | 25.1 | 26.3 | 25.8 |
| 4 | 24.0 | 24.3 | 24.7 | 25.4 | 25.6 | 25.5 | 25.2 | 25.2 | 24.8 | 24.6 | 24.6 | 24.4 | 24.3 | 25.4 | 24.9 |
| 5 | 23.6 | 23.9 | 24.3 | 24.9 | 25.1 | 25.0 | 24.8 | 24.7 | 24.3 | 24.1 | 24.2 | 24.0 | 23.8 | 24.9 | 24.4 |
| 6 | 23.4 | 23.7 | 24.1 | 24.7 | 24.9 | 24.8 | 24.6 | 24.5 | 24.1 | 23.9 | 24.0 | 23.8 | 23.6 | 24.8 | 24.2 |
| 7 | 23.9 | 24.2 | 24.6 | 25.2 | 25.4 | 25.3 | 25.1 | 25.0 | 24.6 | 24.4 | 24.5 | 24.3 | 24.1 | 25.3 | 24.7 |
| 8 | 24.6 | 24.9 | 25.3 | 25.9 | 26.2 | 26.0 | 25.8 | 25.8 | 25.4 | 25.1 | 25.2 | 25.0 | 24.8 | 26.0 | 25.4 |
| 9 | 25.5 | 25.8 | 26.2 | 26.8 | 27.1 | 26.9 | 26.7 | 26.8 | 26.3 | 26.1 | 26.1 | 25.8 | 25.7 | 26.9 | 26.3 |
| 10 | 26.9 | 27.2 | 27.6 | 28.3 | 28.6 | 28.4 | 28.2 | 28.3 | 27.8 | 27.6 | 27.5 | 27.2 | 27.1 | 28.4 | 27.8 |
| 11 | 29.6 | 29.9 | 30.4 | 31.2 | 31.5 | 31.3 | 31.0 | 31.4 | 30.8 | 30.5 | 30.2 | 29.9 | 29.8 | 31.3 | 30.6 |
| 12 | 30.6 | 30.9 | 31.4 | 32.2 | 32.5 | 32.3 | 32.0 | 32.4 | 31.8 | 31.5 | 31.2 | 30.8 | 30.8 | 32.3 | 31.6 |
| 13 | 31.1 | 31.4 | 31.9 | 32.7 | 33.0 | 32.8 | 32.5 | 32.9 | 32.3 | 32.0 | 31.7 | 31.3 | 31.2 | 32.8 | 32.1 |
| 14 | 31.3 | 31.6 | 32.1 | 32.9 | 33.3 | 33.0 | 32.7 | 33.2 | 32.6 | 32.2 | 31.9 | 31.5 | 31.5 | 33.0 | 32.4 |
| 15 | 31.1 | 31.4 | 31.9 | 32.7 | 33.1 | 32.8 | 32.5 | 33.0 | 32.4 | 32.0 | 31.7 | 31.3 | 31.3 | 32.8 | 32.2 |
| 16 | 30.8 | 31.1 | 31.6 | 32.4 | 32.8 | 32.5 | 32.2 | 32.7 | 32.1 | 31.7 | 31.4 | 31.0 | 31.0 | 32.5 | 31.9 |
| 17 | 30.6 | 30.9 | 31.4 | 32.2 | 32.5 | 32.3 | 32.0 | 32.4 | 31.8 | 31.5 | 31.2 | 30.8 | 30.8 | 32.3 | 31.6 |
| 18 | 30.3 | 30.6 | 31.1 | 31.8 | 32.2 | 31.9 | 31.6 | 32.1 | 31.5 | 31.1 | 30.9 | 30.5 | 30.4 | 31.9 | 31.3 |
| 19 | 30.0 | 30.3 | 30.7 | 31.5 | 31.9 | 31.6 | 31.3 | 31.7 | 31.2 | 30.8 | 30.6 | 30.2 | 30.1 | 31.6 | 31.0 |
| 20 | 29.7 | 30.0 | 30.5 | 31.3 | 31.6 | 31.4 | 31.1 | 31.5 | 30.9 | 30.5 | 30.3 | 30.0 | 29.9 | 31.4 | 30.7 |
| 21 | 29.3 | 29.6 | 30.1 | 30.9 | 31.2 | 31.0 | 30.7 | 31.0 | 30.5 | 30.1 | 29.9 | 29.6 | 29.5 | 30.9 | 30.3 |
| 22 | 28.9 | 29.2 | 29.7 | 30.4 | 30.8 | 30.5 | 30.3 | 30.6 | 30.1 | 29.7 | 29.5 | 29.2 | 29.1 | 30.5 | 29.9 |
| 23 | 28.5 | 28.8 | 29.2 | 29.9 | 30.3 | 30.0 | 29.8 | 30.1 | 29.5 | 29.2 | 29.1 | 28.7 | 28.6 | 30.0 | 29.4 |
| 24 | 27.9 | 28.2 | 28.7 | 29.4 | 29.7 | 29.5 | 29.2 | 29.5 | 28.9 | 28.6 | 28.5 | 28.2 | 28.1 | 29.5 | 28.9 |

FRÍO — ZONA DE CONFORT — CALOR

23.5 °C — 28.5 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 71.

Lachoon Mayapo Rural Ethno-educational School. Manaure City.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 27.1 | 27.3 | 27.7 | 28.0 | 28.7 | 29.7 | 29.7 | 29.4 | 28.9 | 28.2 | 28.0 | 27.5 | 27.3 | 29.4 | 28.3 |
| 2 | 26.0 | 26.2 | 26.7 | 26.9 | 27.6 | 28.6 | 28.5 | 28.2 | 27.8 | 27.1 | 26.9 | 26.4 | 26.2 | 28.2 | 27.2 |
| 3 | 25.0 | 25.2 | 25.7 | 26.0 | 26.6 | 27.5 | 27.3 | 27.1 | 26.8 | 26.1 | 25.9 | 25.4 | 25.2 | 27.1 | 26.2 |
| 4 | 24.1 | 24.3 | 24.8 | 25.2 | 25.7 | 26.6 | 26.3 | 26.1 | 25.9 | 25.3 | 25.1 | 24.5 | 24.3 | 26.2 | 25.3 |
| 5 | 23.7 | 23.9 | 24.4 | 24.7 | 25.3 | 26.1 | 25.8 | 25.6 | 25.5 | 24.9 | 24.7 | 24.1 | 23.9 | 25.7 | 24.9 |
| 6 | 23.5 | 23.7 | 24.2 | 24.6 | 25.1 | 25.9 | 25.6 | 25.4 | 25.3 | 24.7 | 24.5 | 23.9 | 23.7 | 25.5 | 24.7 |
| 7 | 24.0 | 24.2 | 24.7 | 25.0 | 25.6 | 26.4 | 26.1 | 25.9 | 25.8 | 25.2 | 25.0 | 24.4 | 24.2 | 26.0 | 25.2 |
| 8 | 24.7 | 24.9 | 25.4 | 25.7 | 26.3 | 27.1 | 27.0 | 26.7 | 26.5 | 25.8 | 25.6 | 25.1 | 24.9 | 26.8 | 25.9 |
| 9 | 25.6 | 25.7 | 26.2 | 26.5 | 27.1 | 28.1 | 27.9 | 27.7 | 27.3 | 26.7 | 26.5 | 25.9 | 25.7 | 27.7 | 26.8 |
| 10 | 27.0 | 27.1 | 27.6 | 27.8 | 28.5 | 29.6 | 29.6 | 29.2 | 28.7 | 28.0 | 27.8 | 27.3 | 27.1 | 29.2 | 28.2 |
| 11 | 29.7 | 29.9 | 30.3 | 30.4 | 31.3 | 32.5 | 32.7 | 32.3 | 31.5 | 30.6 | 30.4 | 30.1 | 29.9 | 32.1 | 31.0 |
| 12 | 30.7 | 30.8 | 31.2 | 31.2 | 32.2 | 33.5 | 33.8 | 33.3 | 32.4 | 31.5 | 31.3 | 31.0 | 30.8 | 33.1 | 31.9 |
| 13 | 31.2 | 31.3 | 31.7 | 31.7 | 32.7 | 34.0 | 34.3 | 33.8 | 32.9 | 32.0 | 31.8 | 31.5 | 31.3 | 33.6 | 32.4 |
| 14 | 31.4 | 31.5 | 31.9 | 31.9 | 32.9 | 34.2 | 34.6 | 34.1 | 33.1 | 32.2 | 32.0 | 31.7 | 31.5 | 33.9 | 32.6 |
| 15 | 31.2 | 31.3 | 31.7 | 31.8 | 32.7 | 34.0 | 34.4 | 33.9 | 32.9 | 32.1 | 31.9 | 31.5 | 31.4 | 33.7 | 32.5 |
| 16 | 30.9 | 31.0 | 31.4 | 31.5 | 32.4 | 33.7 | 34.1 | 33.6 | 32.6 | 31.8 | 31.6 | 31.2 | 31.1 | 33.4 | 32.1 |
| 17 | 30.7 | 30.8 | 31.2 | 31.2 | 32.2 | 33.5 | 33.8 | 33.3 | 32.4 | 31.5 | 31.3 | 31.0 | 30.8 | 33.1 | 31.9 |
| 18 | 30.4 | 30.5 | 30.9 | 31.0 | 31.9 | 33.1 | 33.4 | 33.0 | 32.1 | 31.2 | 31.0 | 30.7 | 30.5 | 32.8 | 31.6 |
| 19 | 30.1 | 30.2 | 30.6 | 30.7 | 31.6 | 32.8 | 33.1 | 32.6 | 31.8 | 30.9 | 30.7 | 30.4 | 30.2 | 32.5 | 31.3 |
| 20 | 29.8 | 29.9 | 30.4 | 30.4 | 31.3 | 32.5 | 32.8 | 32.4 | 31.5 | 30.7 | 30.5 | 30.1 | 30.0 | 32.2 | 31.0 |
| 21 | 29.4 | 29.6 | 30.0 | 30.1 | 31.0 | 32.1 | 32.4 | 31.9 | 31.2 | 30.3 | 30.1 | 29.8 | 29.6 | 31.8 | 30.6 |
| 22 | 29.0 | 29.2 | 29.6 | 29.7 | 30.6 | 31.7 | 31.9 | 31.5 | 30.8 | 30.0 | 29.8 | 29.4 | 29.2 | 31.4 | 30.2 |
| 23 | 28.6 | 28.7 | 29.1 | 29.3 | 30.1 | 31.2 | 31.4 | 31.0 | 30.3 | 29.5 | 29.3 | 28.9 | 28.7 | 30.9 | 29.8 |
| 24 | 28.0 | 28.1 | 28.6 | 28.8 | 29.5 | 30.6 | 30.7 | 30.4 | 29.7 | 29.0 | 28.8 | 28.3 | 28.2 | 30.3 | 29.2 |

FRÍO — ZONA DE CONFORT — CALOR

22.63 °C — 29.63 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

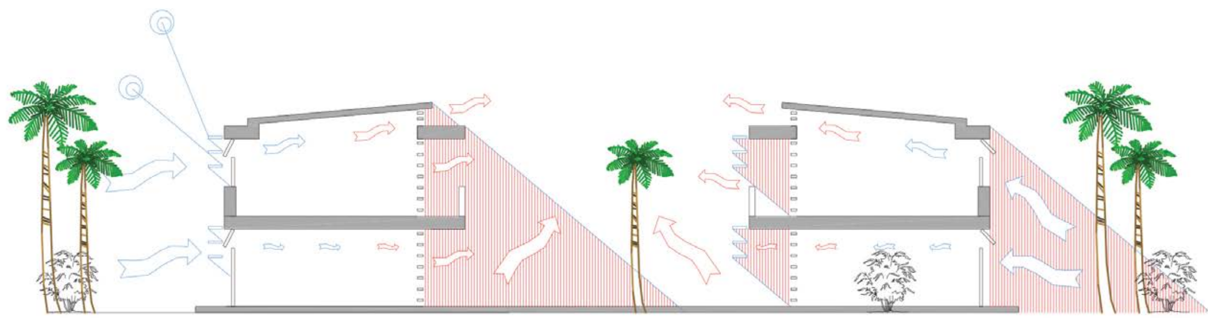
and a rainy period from April to early December. The building is organized around two central patios with hallways through an arcade. Groups of classrooms are stacked on two levels, with constant ventilation, facing north and south. The building is constructed with medium-weight technology and a light shade roof, to enable constant ventilation.

The climate conditions of Manaure are extreme, with a warm dry steppe climate throughout the year, cooled by sea breezes from the northeast. Annual temperatures vary between 28°C and 38°C. The high temperatures and intensity of the winds mean evaporation is very high. The winds from the northeast cause the driest period, with very scant precipitation. The building consists of isolated blocks of paired classrooms on a single floor. The school has a gable roof with projections over both facades, and medium-weight technology was used for the walls. It is located in a rural setting. Classrooms feature windows on two sides (north and south) and solar protection from fixed latticed tiles, which enable constant cross-ventilation.

## Barranquilla

Given the average annual temperatures and relative humidity, cross-ventilation should be incorporated, keeping in mind the need for incoming air to be cooler than the air outside (this implies the need for shading of outside areas and measures to prevent the overheating of the exterior and interior building mass). Additionally, selective night ventilation and thermal insulation (particularly in the roof) should be used in heavy-duty construction. These measures appear to have been taken into account in this project. Nevertheless, during the rainy period, recorded levels in the classroom were beyond the hygrothermal comfort ranges (32.9°C and 67.4% RH). Opinion indicators show that only 25% of students reported feeling hot, while the majority were perspiring, although they were wearing very light clothing and are highly accustomed to these extreme conditions. Improvements can be made to this project by using shade cover in outdoor areas to prevent the overheating of the outside and inside of the building mass and to avoid the impact of direct radiation on the south-facing windows.

FIGURE 68.
Shading. Natural ventilation. Barranquilla.



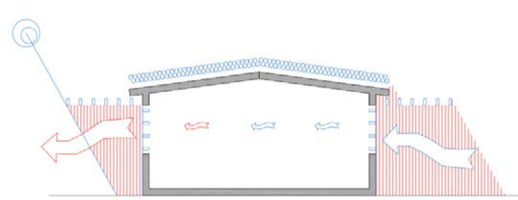
## Manaure

Temperature and humidity levels inside the classroom are very high (29.7°C and 78.6% RH), though they still fall within the comfort range; 54% of students reported discomfort and the same proportion said they were perspiring. The outdoor hygrothermal conditions are directly transferred to the inside of the classroom. As a consequence, the following steps should be taken: (i) to prevent the building mass from heating up outside and inside, thermal insulation of roofs should be improved, and to avoid the effects of thermal inertia, shading (of walls, roofs and windows) should be added; (ii) to improve cross-ventilation for an effective thermal discharge of the space, openings should be repositioned to take advantage of sea breezes, and shading should be increased in outdoor areas.

There are two different situations in terms of lighting. In Barranquilla, indoor illuminance levels are excessively high. The windows or the facades most exposed to the sun should be redesigned, incorporating outdoor protection to prevent solar radiation from directly entering the classroom and affecting the working plane, as well as to avoid the overheating of the building mass. Despite the unfavorable (or excessive) lighting conditions, only a relatively small proportion of students (less than 36%) showed they were aware of this situation, revealing a high degree of habituation. In Manaure, classroom lighting conditions were quite unfavorable, given that all records were below the established guidelines, while a high percentage of students reported discomfort (50%). Windows should be replaced and the other strategies mentioned above should also be applied.

The recorded sound levels exceeded the comfort zone and almost all the students surveyed (above 95%) reported irritating noises. This is likely mainly due to: (a) insufficient sound insulation in the classrooms with respect to the proximity of hallways and patios; (b) lack of treatment of the indoor acoustic field; and (c) the need for ventilation and the impossibility of closing off the classroom hermetically. The following measures are recommended: (a) treat the common and outdoor areas with noise shielding and sound barriers in order to reduce airborne noise levels; (b) improve sound insulation to prevent noise from entering; (c) prepare ceilings or internal classroom walls with thick, sound-absorbent materials to reduce reverberation times; (d) ventilate using systems that minimize

FIGURE 69.
Shading. Natural ventilation. Thermally insulated roof. Manaure.



the entrance of airborne noise, either by distancing openings or ventilation grates from noise sources (the street, hallways and patios, where applicable) or by establishing ventilation protocols for hours when no students are present.

In Manaure, no issues with $CO_2$ levels were recorded, while in Barranquilla, the concentration of $CO_2$ exceeded admissible levels in only some of the audited classrooms. In both cases, the percentage of users that reported discomfort remained constant, between 44% and 67%. The presence of other issues that might affect the air quality should be explored, such as odors generated by occupants, humidity, and air temperature.

## Temperate humid climate requiring shading + ventilation (Ibagué, Pereira)

Ibagué is located in the Andes mountain range, at an altitude of 1285 m.a.s.l., with an average temperature of 22°C. Given that it is near the equator, there is no seasonal cycle. Conditions are stable and mild, with a high relative humidity content, requiring cross-ventilation and shading of outdoor spaces, walls, and windows. The school is a large complex which alternates patios with blocks of paired classrooms on two floors and south-facing arcades. Classrooms are lit from both sides of the building and the school is principally north-facing with constant cross-ventilation. Medium-weight construction and a light shade roof were used.

FIGURE 70.
Bicentenario Education Institute. Ibagué. Temperate humid climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 20.3 | 20.7 | 20.8 | 20.5 | 20.7 | 20.6 | 20.7 | 21.0 | 20.9 | 20.4 | 20.3 | 20.1 | 20.4 | 20.7 | 20.6 |
| 2 | 18.9 | 19.3 | 19.5 | 19.3 | 19.4 | 19.2 | 19.2 | 19.5 | 19.4 | 19.1 | 19.0 | 18.8 | 19.0 | 19.3 | 19.2 |
| 3 | 17.6 | 18.0 | 18.3 | 18.1 | 18.2 | 18.0 | 17.8 | 18.1 | 18.1 | 17.9 | 17.8 | 17.5 | 17.7 | 18.0 | 17.9 |
| 4 | 16.5 | 16.9 | 17.3 | 17.1 | 17.2 | 16.9 | 16.6 | 16.9 | 16.9 | 16.8 | 16.8 | 16.5 | 16.6 | 16.9 | 16.9 |
| 5 | 15.9 | 16.3 | 16.7 | 16.6 | 16.7 | 16.3 | 15.9 | 16.2 | 16.3 | 16.3 | 16.3 | 15.9 | 16.0 | 16.3 | 16.3 |
| 6 | 15.7 | 16.1 | 16.5 | 16.4 | 16.5 | 16.1 | 15.7 | 16.0 | 16.1 | 16.1 | 16.1 | 15.7 | 15.8 | 16.1 | 16.1 |
| 7 | 16.3 | 16.7 | 17.1 | 16.9 | 17.0 | 16.7 | 16.3 | 16.7 | 16.7 | 16.7 | 16.6 | 16.3 | 16.4 | 16.7 | 16.7 |
| 8 | 17.2 | 17.6 | 17.9 | 17.8 | 17.9 | 17.6 | 17.3 | 17.6 | 17.7 | 17.5 | 17.5 | 17.1 | 17.3 | 17.6 | 17.5 |
| 9 | 18.3 | 18.7 | 18.9 | 18.7 | 18.9 | 18.6 | 18.5 | 18.8 | 18.8 | 18.5 | 18.5 | 18.2 | 18.4 | 18.7 | 18.6 |
| 10 | 20.1 | 20.5 | 20.6 | 20.4 | 20.5 | 20.4 | 20.5 | 20.8 | 20.7 | 20.2 | 20.1 | 19.9 | 20.2 | 20.5 | 20.4 |
| 11 | 23.6 | 23.9 | 23.9 | 23.5 | 23.7 | 23.8 | 24.2 | 24.6 | 24.3 | 23.4 | 23.3 | 23.3 | 23.6 | 23.9 | 23.8 |
| 12 | 24.8 | 25.1 | 25.1 | 24.6 | 24.8 | 25.0 | 25.5 | 25.9 | 25.6 | 24.6 | 24.4 | 24.4 | 24.8 | 25.1 | 25.0 |
| 13 | 25.4 | 25.7 | 25.6 | 25.1 | 25.3 | 25.6 | 26.2 | 26.6 | 26.2 | 25.1 | 24.9 | 25.0 | 25.4 | 25.7 | 25.6 |
| 14 | 25.7 | 26.0 | 25.9 | 25.4 | 25.6 | 25.9 | 26.5 | 26.9 | 26.5 | 25.4 | 25.2 | 25.3 | 25.7 | 26.0 | 25.9 |
| 15 | 25.5 | 25.8 | 25.7 | 25.2 | 25.4 | 25.7 | 26.3 | 26.7 | 26.3 | 25.2 | 25.0 | 25.1 | 25.5 | 25.8 | 25.7 |
| 16 | 25.1 | 25.4 | 25.3 | 24.9 | 25.1 | 25.3 | 25.9 | 26.2 | 25.9 | 24.8 | 24.7 | 24.7 | 25.1 | 25.4 | 25.3 |
| 17 | 24.8 | 25.1 | 25.1 | 24.6 | 24.8 | 25.0 | 25.5 | 25.9 | 25.6 | 24.6 | 24.4 | 24.4 | 24.8 | 25.1 | 25.0 |
| 18 | 24.4 | 24.7 | 24.7 | 24.2 | 24.4 | 24.6 | 25.1 | 25.5 | 25.1 | 24.2 | 24.0 | 24.1 | 24.4 | 24.7 | 24.6 |
| 19 | 24.0 | 24.3 | 24.3 | 23.9 | 24.1 | 24.2 | 24.7 | 25.0 | 24.7 | 23.8 | 23.7 | 23.7 | 24.0 | 24.3 | 24.2 |
| 20 | 23.7 | 24.0 | 24.0 | 23.6 | 23.8 | 23.9 | 24.3 | 24.7 | 24.4 | 23.5 | 23.4 | 23.4 | 23.7 | 24.0 | 23.9 |
| 21 | 23.2 | 23.5 | 23.6 | 23.2 | 23.3 | 23.5 | 23.8 | 24.2 | 23.9 | 23.1 | 22.9 | 22.9 | 23.2 | 23.5 | 23.4 |
| 22 | 22.7 | 23.0 | 23.1 | 22.7 | 22.9 | 23.0 | 23.3 | 23.6 | 23.4 | 22.6 | 22.5 | 22.4 | 22.7 | 23.0 | 22.9 |
| 23 | 22.1 | 22.4 | 22.5 | 22.2 | 22.3 | 22.4 | 22.6 | 23.0 | 22.8 | 22.1 | 21.9 | 21.8 | 22.1 | 22.4 | 22.3 |
| 24 | 21.4 | 21.7 | 21.9 | 21.5 | 21.7 | 21.7 | 21.9 | 22.2 | 22.0 | 21.4 | 21.3 | 21.2 | 21.4 | 21.7 | 21.7 |

FRÍO — ZONA DE CONFORT — CALOR

22.7 ºC — 27.7 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

Temperatures in Pereira, located at 1411 m.a.s.l., are stable and mild year-round and relative humidity is high, requiring cross-ventilation and shading of outdoor spaces, walls, and windows. This is a large-scale educational complex situated on the outskirts of the city in a densely populated area. Blocks of classrooms are stacked on two floors with south-facing arcades. Classrooms have lighting from both sides, entering from opposite facades, and the building faces north. Vertical sun shields on the facades provide solar protection.

## Ibagué

Conditions recorded inside the classroom during the dry season are within the local comfort range, although relative humidity levels are high (above 70%). Opinion indicators show that although only some of the students are warmly dressed (44%), the majority reported thermal comfort (69% to 88%). Thermal insulation of the building envelope is needed and the opaque, glassed-in area should be redesigned. Shading for outdoor areas should be improved to prevent

FIGURE 71.
Samaria Educational Institute. Pereira. Temperate humid climate.

MAPA DE CONFORT

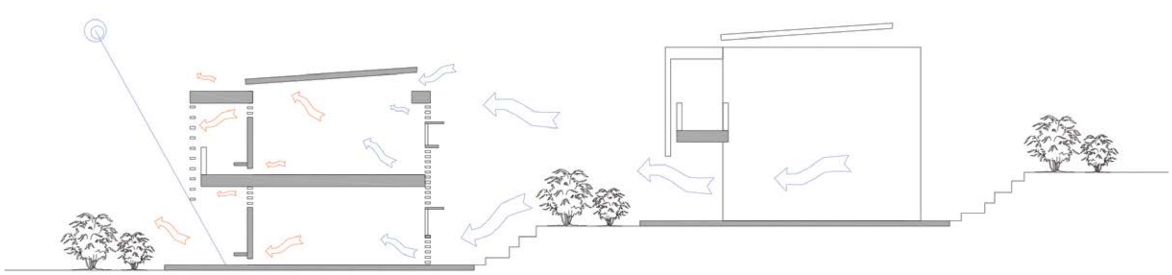
| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 21.5 | 21.6 | 21.7 | 21.4 | 21.1 | 21.1 | 21.3 | 21.4 | 21.1 | 20.9 | 20.9 | 21.2 | 21.4 | 21.2 | 21.3 |
| 2 | 20.1 | 20.2 | 20.3 | 20.1 | 19.9 | 19.9 | 19.9 | 20.0 | 19.7 | 19.6 | 19.6 | 19.9 | 20.1 | 19.9 | 19.9 |
| 3 | 18.8 | 18.9 | 19.0 | 18.9 | 18.8 | 18.7 | 18.6 | 18.6 | 18.4 | 18.4 | 18.5 | 18.7 | 18.8 | 18.7 | 18.7 |
| 4 | 17.7 | 17.8 | 18.0 | 17.9 | 17.8 | 17.7 | 17.5 | 17.5 | 17.4 | 17.4 | 17.5 | 17.6 | 17.7 | 17.7 | 17.7 |
| 5 | 17.1 | 17.2 | 17.4 | 17.4 | 17.3 | 17.2 | 16.9 | 16.9 | 16.8 | 16.9 | 17.0 | 17.1 | 17.1 | 17.1 | 17.1 |
| 6 | 16.9 | 17.0 | 17.2 | 17.2 | 17.1 | 17.0 | 16.7 | 16.7 | 16.6 | 16.7 | 16.8 | 16.9 | 16.9 | 16.9 | 16.9 |
| 7 | 17.5 | 17.6 | 17.8 | 17.7 | 17.6 | 17.5 | 17.3 | 17.3 | 17.2 | 17.2 | 17.3 | 17.5 | 17.5 | 17.5 | 17.5 |
| 8 | 18.4 | 18.5 | 18.7 | 18.6 | 18.4 | 18.4 | 18.2 | 18.2 | 18.1 | 18.1 | 18.1 | 18.3 | 18.4 | 18.3 | 18.3 |
| 9 | 19.5 | 19.6 | 19.7 | 19.6 | 19.4 | 19.3 | 19.3 | 19.4 | 19.1 | 19.1 | 19.1 | 19.3 | 19.5 | 19.3 | 19.4 |
| 10 | 21.3 | 21.4 | 21.5 | 21.2 | 21.0 | 21.0 | 21.1 | 21.2 | 20.9 | 20.7 | 20.7 | 21.0 | 21.2 | 21.0 | 21.1 |
| 11 | 24.8 | 24.9 | 24.9 | 24.4 | 24.1 | 24.1 | 24.6 | 24.8 | 24.3 | 23.9 | 23.8 | 24.2 | 24.6 | 24.3 | 24.4 |
| 12 | 26.0 | 26.1 | 26.0 | 25.5 | 25.1 | 25.2 | 25.8 | 26.0 | 25.4 | 25.0 | 24.9 | 25.4 | 25.8 | 25.4 | 25.5 |
| 13 | 26.6 | 26.7 | 26.6 | 26.0 | 25.6 | 25.7 | 26.4 | 26.6 | 26.0 | 25.5 | 25.4 | 25.9 | 26.4 | 25.9 | 26.1 |
| 14 | 26.9 | 27.0 | 26.9 | 26.3 | 25.9 | 26.0 | 26.7 | 26.9 | 26.3 | 25.8 | 25.7 | 26.2 | 26.7 | 26.2 | 26.4 |
| 15 | 26.7 | 26.8 | 26.7 | 26.1 | 25.7 | 25.8 | 26.5 | 26.7 | 26.1 | 25.6 | 25.5 | 26.0 | 26.5 | 26.0 | 26.2 |
| 16 | 26.3 | 26.4 | 26.3 | 25.8 | 25.4 | 25.5 | 26.1 | 26.3 | 25.7 | 25.3 | 25.2 | 25.6 | 26.1 | 25.6 | 25.8 |
| 17 | 26.0 | 26.1 | 26.0 | 25.5 | 25.1 | 25.2 | 25.8 | 26.0 | 25.4 | 25.0 | 24.9 | 25.4 | 25.8 | 25.4 | 25.5 |
| 18 | 25.6 | 25.7 | 25.6 | 25.1 | 24.8 | 24.8 | 25.4 | 25.6 | 25.0 | 24.6 | 24.5 | 25.0 | 25.4 | 25.0 | 25.2 |
| 19 | 25.2 | 25.3 | 25.3 | 24.8 | 24.4 | 24.5 | 25.0 | 25.2 | 24.7 | 24.3 | 24.2 | 24.6 | 25.0 | 24.6 | 24.8 |
| 20 | 24.9 | 25.0 | 25.0 | 24.5 | 24.1 | 24.2 | 24.7 | 24.9 | 24.4 | 24.0 | 23.9 | 24.3 | 24.7 | 24.3 | 24.5 |
| 21 | 24.4 | 24.5 | 24.5 | 24.0 | 23.7 | 23.8 | 24.2 | 24.4 | 23.9 | 23.5 | 23.5 | 23.9 | 24.3 | 23.9 | 24.0 |
| 22 | 23.9 | 24.0 | 24.0 | 23.6 | 23.3 | 23.3 | 23.7 | 23.8 | 23.4 | 23.1 | 23.0 | 23.4 | 23.8 | 23.4 | 23.5 |
| 23 | 23.3 | 23.4 | 23.4 | 23.0 | 22.7 | 22.8 | 23.1 | 23.2 | 22.8 | 22.5 | 22.5 | 22.9 | 23.2 | 22.9 | 23.0 |
| 24 | 22.6 | 22.7 | 22.7 | 22.4 | 22.1 | 22.1 | 22.4 | 22.5 | 22.1 | 21.9 | 21.9 | 22.2 | 22.5 | 22.2 | 22.3 |

FRÍO — ZONA DE CONFORT — CALOR

21.8 ºC — 26.8 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 72.
Shading. Natural ventilation. Thermally insulated building envelope. Ibagué
.



the building mass from heating on both the outside and inside.

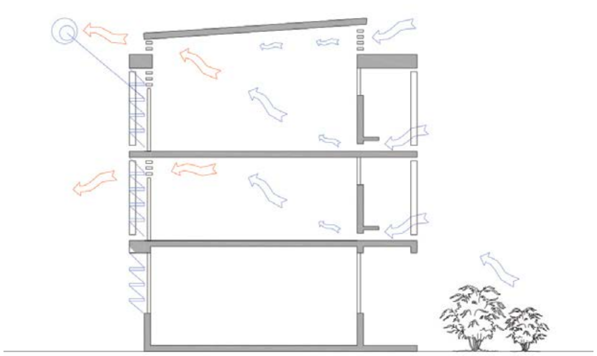
### Pereira

Values recorded in the audited classrooms during the dry season fall within the local comfort range. No more than 28% of students reported discomfort, coinciding with the percentage of students who were warmly dressed (25% to 30%). Due to climate characteristics, 40% of students reported that they normally perspire. Thermal insulation of the building envelope should be improved.

The lighting conditions in these classrooms were favorable, though uniformity was very low. In the areas furthest from the windows, illuminance levels were very low, while close to the windows, they were very high. Most of the students (66% to 76%) considered the lighting adequate. 50% of students reported distracting reflections. Artificial lighting is frequently needed. A specific design for windows is needed in order to incorporate more solar protection into the north-facing facade and improve the natural lighting on both sides.

Given the constant ventilation, sizeable population, and proximity of classrooms, most respondents (85% to 98%) reported irritating noise levels. The recorded sound levels exceeded the standard acceptable values. Sound insulation in the classroom should be improved by treating the ceilings with absorbent materials and using ventilation systems that minimize airborne noise.

FIGURE 73.
Shading. Natural ventilation. Thermally insulated building envelope. Pereira.



With respect to air quality, the recorded levels of $CO_2$ were within the permitted range in both schools. Nevertheless, in Pereira, 46% to 86% of students were quite adamant that the air is stale, perhaps due to high humidity levels or odors generated by occupants.

## Temperate cold climate requiring heating (Ipiales, Soacha)

The municipality of Ipiales, located at 2898 m.a.s.l., has a tropical mountain climate, stable temperatures with minimal fluctuation, and high relative humidity throughout the year. Due to its intertropical location, average monthly temperature variation is no more than 5°C. The average temperature is between 12°C and 17°C. The presence of valley and mountain breezes is notable. The school is a single building with classrooms grouped together on two levels and north-facing walkways. A lightweight roof and medium-weight building materials were used. Classrooms have symmetrical lighting from opposite facades, with a north-south orientation. Modules with grates for constant cross-ventilation are incorporated into the woodwork, located high in the space.

The conditions in Soacha, located at 2565 m.a.s.l., are stable with a temperate climate. The average annual temperature is 13.5°C, meaning that heating is required year-round. This is a large-scale "fortress-like" school complex, consisting of a semi-circular series of angled classrooms on two floors, with south-facing arcades and a lightweight roof. Classrooms receive asymmetrical lighting from both sides, since the main north-facing facade is unprotected, and complementary lighting comes from the east.

FIGURE 74.
## Seminario Educational Institute. Ipiales. Temperate humid climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 12.8 | 12.9 | 13.1 | 13.4 | 13.4 | 13.0 | 12.4 | 12.6 | 13.0 | 13.0 | 13.0 | 12.9 | 12.9 | 12.9 | 13.0 |
| 2 | 11.8 | 11.9 | 12.1 | 12.3 | 12.4 | 12.0 | 11.5 | 11.6 | 11.9 | 11.9 | 12.0 | 11.9 | 11.9 | 12.0 | 11.9 |
| 3 | 10.9 | 11.0 | 11.2 | 11.4 | 11.5 | 11.2 | 10.6 | 10.7 | 10.9 | 10.9 | 11.0 | 10.9 | 10.9 | 11.1 | 11.0 |
| 4 | 10.1 | 10.2 | 10.4 | 10.6 | 10.7 | 10.4 | 9.9 | 10.0 | 10.1 | 10.0 | 10.2 | 10.1 | 10.1 | 10.3 | 10.2 |
| 5 | 9.6 | 9.7 | 9.9 | 10.1 | 10.2 | 10.0 | 9.5 | 9.5 | 9.7 | 9.6 | 9.7 | 9.6 | 9.7 | 9.9 | 9.8 |
| 6 | 9.5 | 9.6 | 9.8 | 10.0 | 10.1 | 9.9 | 9.4 | 9.4 | 9.5 | 9.4 | 9.6 | 9.5 | 9.5 | 9.8 | 9.6 |
| 7 | 9.9 | 10.0 | 10.2 | 10.4 | 10.5 | 10.3 | 9.8 | 9.8 | 10.0 | 9.9 | 10.0 | 9.9 | 10.0 | 10.2 | 10.1 |
| 8 | 10.6 | 10.7 | 10.9 | 11.1 | 11.2 | 10.9 | 10.4 | 10.4 | 10.6 | 10.6 | 10.7 | 10.6 | 10.6 | 10.8 | 10.7 |
| 9 | 11.4 | 11.5 | 11.7 | 11.9 | 12.0 | 11.6 | 11.1 | 11.2 | 11.5 | 11.5 | 11.5 | 11.4 | 11.4 | 11.6 | 11.5 |
| 10 | 12.7 | 12.8 | 13.0 | 13.2 | 13.3 | 12.8 | 12.3 | 12.4 | 12.8 | 12.9 | 12.9 | 12.8 | 12.7 | 12.8 | 12.8 |
| 11 | 15.2 | 15.3 | 15.5 | 15.8 | 15.8 | 15.2 | 14.5 | 14.9 | 15.4 | 15.6 | 15.4 | 15.3 | 15.3 | 15.2 | 15.3 |
| 12 | 16.1 | 16.2 | 16.4 | 16.6 | 16.7 | 16.0 | 15.3 | 15.7 | 16.3 | 16.6 | 16.3 | 16.2 | 16.1 | 16.0 | 16.2 |
| 13 | 16.5 | 16.6 | 16.8 | 17.1 | 17.1 | 16.4 | 15.7 | 16.1 | 16.8 | 17.1 | 16.8 | 16.7 | 16.6 | 16.4 | 16.6 |
| 14 | 16.7 | 16.8 | 17.0 | 17.3 | 17.3 | 16.6 | 15.9 | 16.3 | 17.0 | 17.3 | 17.0 | 16.9 | 16.8 | 16.6 | 16.8 |
| 15 | 16.6 | 16.7 | 16.9 | 17.2 | 17.2 | 16.5 | 15.8 | 16.2 | 16.9 | 17.1 | 16.9 | 16.8 | 16.7 | 16.5 | 16.7 |
| 16 | 16.3 | 16.4 | 16.6 | 16.9 | 16.9 | 16.2 | 15.5 | 15.9 | 16.6 | 16.8 | 16.6 | 16.5 | 16.4 | 16.2 | 16.4 |
| 17 | 16.1 | 16.2 | 16.4 | 16.6 | 16.7 | 16.0 | 15.3 | 15.7 | 16.3 | 16.6 | 16.3 | 16.2 | 16.1 | 16.0 | 16.2 |
| 18 | 15.8 | 15.9 | 16.1 | 16.4 | 16.4 | 15.7 | 15.1 | 15.4 | 16.0 | 16.3 | 16.0 | 15.9 | 15.9 | 15.7 | 15.9 |
| 19 | 15.5 | 15.6 | 15.8 | 16.1 | 16.1 | 15.5 | 14.8 | 15.1 | 15.7 | 16.0 | 15.7 | 15.6 | 15.6 | 15.4 | 15.6 |
| 20 | 15.3 | 15.4 | 15.6 | 15.8 | 15.9 | 15.3 | 14.6 | 14.9 | 15.5 | 15.7 | 15.5 | 15.4 | 15.3 | 15.2 | 15.4 |
| 21 | 14.9 | 15.0 | 15.2 | 15.5 | 15.5 | 14.9 | 14.3 | 14.6 | 15.1 | 15.3 | 15.2 | 15.1 | 15.0 | 14.9 | 15.0 |
| 22 | 14.5 | 14.6 | 14.8 | 15.1 | 15.1 | 14.6 | 14.0 | 14.2 | 14.8 | 14.9 | 14.8 | 14.7 | 14.6 | 14.6 | 14.7 |
| 23 | 14.1 | 14.2 | 14.4 | 14.7 | 14.7 | 14.2 | 13.6 | 13.8 | 14.3 | 14.5 | 14.3 | 14.2 | 14.2 | 14.2 | 14.2 |
| 24 | 13.6 | 13.7 | 13.9 | 14.2 | 14.2 | 13.7 | 13.1 | 13.3 | 13.8 | 13.9 | 13.8 | 13.7 | 13.7 | 13.7 | 13.7 |

FRÍO | ZONA DE CONFORT | CALOR

17.94 °C | 24.94 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 75.
## Soacha Para Vivir Mejor School. Soacha. Temperate climate.

MAPA DE CONFORT

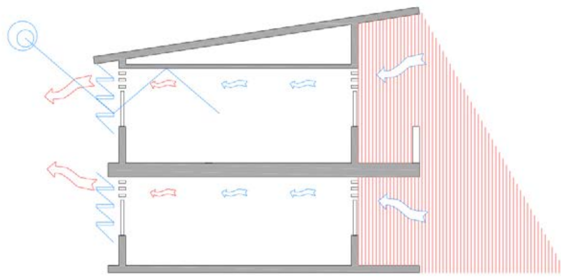
| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 10.9 | 11.4 | 11.5 | 11.5 | 11.4 | 11.1 | 10.6 | 10.9 | 10.9 | 11.1 | 11.2 | 11.0 | 11.1 | 11.1 | 11.1 |
| 2 | 9.5 | 10.0 | 10.2 | 10.3 | 10.2 | 9.9 | 9.5 | 9.7 | 9.7 | 9.8 | 10.0 | 9.7 | 9.7 | 9.9 | 9.9 |
| 3 | 8.2 | 8.7 | 9.0 | 9.2 | 9.1 | 8.8 | 8.5 | 8.6 | 8.5 | 8.7 | 8.9 | 8.5 | 8.5 | 8.8 | 8.7 |
| 4 | 7.1 | 7.7 | 8.0 | 8.3 | 8.1 | 7.9 | 7.6 | 7.7 | 7.5 | 7.7 | 7.9 | 7.5 | 7.4 | 7.9 | 7.7 |
| 5 | 6.5 | 7.1 | 7.4 | 7.8 | 7.6 | 7.4 | 7.2 | 7.2 | 7.0 | 7.2 | 7.4 | 6.9 | 6.8 | 7.4 | 7.2 |
| 6 | 6.3 | 6.9 | 7.2 | 7.6 | 7.4 | 7.2 | 7.0 | 7.0 | 6.8 | 7.0 | 7.2 | 6.7 | 6.6 | 7.2 | 7.0 |
| 7 | 6.9 | 7.5 | 7.8 | 8.1 | 7.9 | 7.7 | 7.5 | 7.5 | 7.3 | 7.5 | 7.7 | 7.3 | 7.2 | 7.7 | 7.6 |
| 8 | 7.8 | 8.4 | 8.6 | 8.9 | 8.7 | 8.5 | 8.2 | 8.3 | 8.2 | 8.3 | 8.5 | 8.1 | 8.1 | 8.5 | 8.4 |
| 9 | 8.9 | 9.4 | 9.6 | 9.8 | 9.7 | 9.4 | 9.1 | 9.2 | 9.1 | 9.3 | 9.5 | 9.1 | 9.2 | 9.4 | 9.3 |
| 10 | 10.7 | 11.2 | 11.3 | 11.3 | 11.3 | 10.9 | 10.5 | 10.7 | 10.8 | 10.9 | 11.1 | 10.8 | 10.9 | 10.9 | 11.0 |
| 11 | 14.3 | 14.6 | 14.6 | 14.2 | 14.4 | 13.9 | 13.2 | 13.6 | 13.9 | 14.0 | 14.2 | 14.1 | 14.3 | 13.8 | 14.1 |
| 12 | 15.5 | 15.7 | 15.8 | 15.2 | 15.4 | 14.9 | 14.2 | 14.6 | 15.0 | 15.1 | 15.2 | 15.3 | 15.5 | 14.8 | 15.2 |
| 13 | 16.1 | 16.3 | 16.3 | 15.7 | 15.9 | 15.4 | 14.7 | 15.1 | 15.5 | 15.6 | 15.7 | 15.8 | 16.1 | 15.3 | 15.7 |
| 14 | 16.4 | 16.6 | 16.6 | 16.0 | 16.2 | 15.7 | 14.9 | 15.4 | 15.8 | 15.9 | 16.0 | 16.1 | 16.4 | 15.6 | 16.0 |
| 15 | 16.2 | 16.4 | 16.4 | 15.8 | 16.0 | 15.5 | 14.7 | 15.2 | 15.6 | 15.7 | 15.8 | 15.9 | 16.2 | 15.4 | 15.8 |
| 16 | 15.8 | 16.0 | 16.0 | 15.5 | 15.7 | 15.2 | 14.4 | 14.9 | 15.3 | 15.4 | 15.5 | 15.5 | 15.8 | 15.1 | 15.4 |
| 17 | 15.5 | 15.7 | 15.8 | 15.2 | 15.4 | 14.9 | 14.2 | 14.6 | 15.0 | 15.1 | 15.2 | 15.3 | 15.5 | 14.8 | 15.2 |
| 18 | 15.1 | 15.3 | 15.4 | 14.9 | 15.1 | 14.6 | 13.9 | 14.3 | 14.6 | 14.7 | 14.9 | 14.9 | 15.1 | 14.5 | 14.8 |
| 19 | 14.7 | 15.0 | 15.0 | 14.6 | 14.7 | 14.3 | 13.6 | 14.0 | 14.3 | 14.4 | 14.5 | 14.5 | 14.7 | 14.2 | 14.4 |
| 20 | 14.4 | 14.7 | 14.7 | 14.3 | 14.4 | 14.0 | 13.3 | 13.7 | 14.0 | 14.1 | 14.2 | 14.2 | 14.4 | 13.9 | 14.2 |
| 21 | 13.9 | 14.2 | 14.3 | 13.9 | 14.0 | 13.6 | 12.9 | 13.3 | 13.6 | 13.7 | 13.8 | 13.8 | 13.9 | 13.5 | 13.7 |
| 22 | 13.4 | 13.7 | 13.8 | 13.5 | 13.6 | 13.2 | 12.5 | 12.9 | 13.1 | 13.2 | 13.4 | 13.3 | 13.4 | 13.1 | 13.3 |
| 23 | 12.8 | 13.1 | 13.2 | 13.0 | 13.0 | 12.6 | 12.1 | 12.4 | 12.6 | 12.7 | 12.8 | 12.7 | 12.9 | 12.6 | 12.7 |
| 24 | 12.1 | 12.4 | 12.6 | 12.4 | 12.4 | 12.0 | 11.5 | 11.8 | 11.9 | 12.1 | 12.2 | 12.1 | 12.2 | 12.0 | 12.1 |

FRÍO | ZONA DE CONFORT | CALOR

18.52 °C | 24.52 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 76.
Shading. Natural Ventilation. Thermally insulated building envelope. Ipiales



## Ipiales

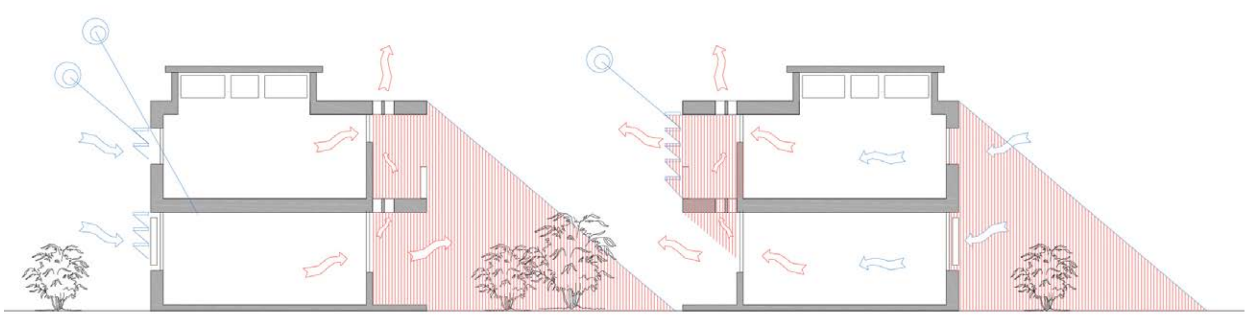
At the time that measurements were taken, the classrooms did not have the necessary conditions for thermal comfort, given that recorded values were below 18°C. Opinion indicators show that between 28% and 42% of students reported thermal discomfort. Nevertheless, only 3% were warmly dressed and a significant percentage (35% to 62%) reported perspiring, revealing a high degree of habituation to these unfavorable conditions. The following measures are required: (a) the incorporation of heating, which can be done through passive solar systems (greenhouses, heat accumulating walls, collector facades) and (b) thermal insulation of the building envelope, in which case the lack of a system to regulate the ventilation grates would have to be explored. In this case, ventilation strategies should also be implemented at different points of the year.

## Soacha

Given the average annual temperatures and relative humidity, heating should be incorporated. This can be done through the use of solar energy (heat accumulating walls, greenhouses, etc.) and thermal insulation of the building envelope. During the rainy season, recorded temperatures (above 18°C) and humidity levels were within the comfort zone. Nevertheless a quarter of students reported discomfort, between 16% and 29% were warmly dressed, and between 42% and 54% perspired. In this case, there was a notable difference between temperatures recorded in the north-facing and west-facing classrooms (1.5°C), and an almost 10% difference in recorded humidity levels.

Recorded light levels are acceptable. Nevertheless, the maximums were excessive, suggesting the need to control the impact of direct solar radiation on the working plane. More than 75% of students reported that lighting conditions were comfortable, revealing a high degree of habituation to these conditions. The design of the south-facing facades should be improved in order to: (a) capture solar radiation for heating; (b) prevent the direct impact of solar radiation on the working plane; and (c) distribute external

FIGURE 77.
Heating using passive systems. Soacha.



lighting throughout the classroom, in order to eliminate or reduce the use of artificial lighting.

With respect to the acoustic conditions, the recorded noise levels exceeded permitted values and a high percentage of students (89% to 94%) reported discomfort in this respect. The main reasons are likely: (a) insufficient sound insulation in the classrooms with respect to the proximity of the hallways and the roofed-in patio, along with the overpopulation typical of this type of educational complex, and (b) the lack of treatment of the indoor acoustic field. Treatment of the inside walls of the classrooms is necessary in order to reduce reverberation times and improve sound insulation, blocking out airborne noise.

The recorded levels of $CO_2$ in Ipiales were within the permitted range. Nevertheless, 36% of students reported poor air quality, likely due to humidity, cold temperatures, and odors generated by occupants. In Soacha, problems were found in recorded concentrations of $CO_2$ and many students were aware of the need to ventilate classrooms in order to improve conditions (62% to 65%).

## COSTA RICA (CR)

The locations studied in the dry and rainy seasons are as follows:

### Warm humid climate

- Life Zone: Premontane moist forest (basal belt transition). Bebedero School. Cañas Canton. Guanacaste Province.
- Life Zone: Tropical moist forest (prehumid transition). Parrita School No. 3755. Parrita Canton. Punta Arenas Province.
- Life Zone: Premontane wet forest (basal belt transition). Luzon School No. 3376. Matina Canton. Limón Province.
- Life Zone: Tropical wet forest (premontane transition). Líder El Carmen School No. 2605. Tilarán Canton. Guanacaste Province.

### Temperate humid climate

- Life Zone: Wet forest. Poasito School No. 1137. Alajuela Canton. Alajuela Province.
- Life Zone: Premontane moist forest. República de Panamá School. Desamparados Canton. San José Province.

### Warm humid climate requiring shading + natural ventilation (Bebedero, Parrita, Luzón, El Carmen)

Located on a flood plain, one meter above the natural terrain at an altitude of 15 m.a.s.l., the school building consists of two pavilions arranged in a single bay with covered hallways and north-facing classrooms. The climate has two distinct seasons. From December to April, the average rainfall is 25mm and, in October, 350mm. The minimum temperature is 22.5°C recorded in October and November and the maximum is 34.4°C in April, with an average annual temperature of 28.5°C. Average annual humidity is 70.5%. (Life Zone: moist forest). The building was constructed with light prefabricated materials and sloped roofs, which could be covered with shade cloth to improve natural ventilation and prevent overheating of the space.

Located at 10 m.a.s.l., it is characterized by two very pronounced seasons: dry, from January to March and very rainy, from May to November. May and December are transition months. The average annual precipitation is 500mm. The maximum temperature was recorded in March at 32.5°C and the minimum in January at 21.7°C, with an annual average of 27.1°C. The annual average relative humidity is 85%, which implies that the air is saturated at dawn. (Life zone: tropical moist forest). The building is divided into three different parts—an area for sports, an administrative area, and a lobby—with classrooms on two floors around a central patio. Classroom construction was done with poured concrete and blocks, while the rest is from prefabricated materials.

FIGURE 78.

Bebedero School. Warm humid climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 27.2 | 27.5 | 28.0 | 28.4 | 28.1 | 27.1 | 27.0 | 27.0 | 26.9 | 26.8 | 26.8 | 26.9 | 27.2 | 27.4 | 27.3 |
| 2 | 25.8 | 26.1 | 26.4 | 26.8 | 26.5 | 25.8 | 25.6 | 25.6 | 25.6 | 25.5 | 25.5 | 25.5 | 25.8 | 26.0 | 25.9 |
| 3 | 24.5 | 24.7 | 24.9 | 25.3 | 25.1 | 24.5 | 24.4 | 24.4 | 24.4 | 24.3 | 24.3 | 24.3 | 24.5 | 24.7 | 24.6 |
| 4 | 23.4 | 23.5 | 23.7 | 24.1 | 23.9 | 23.5 | 23.4 | 23.4 | 23.4 | 23.3 | 23.3 | 23.3 | 23.4 | 23.6 | 23.5 |
| 5 | 22.8 | 22.9 | 23.0 | 23.4 | 23.2 | 22.9 | 22.8 | 22.8 | 22.8 | 22.7 | 22.7 | 22.7 | 22.8 | 23.0 | 22.9 |
| 6 | 22.6 | 22.7 | 22.8 | 23.2 | 23.0 | 22.7 | 22.7 | 22.6 | 22.6 | 22.5 | 22.5 | 22.5 | 22.6 | 22.8 | 22.7 |
| 7 | 23.2 | 23.3 | 23.5 | 23.9 | 23.7 | 23.3 | 23.2 | 23.2 | 23.2 | 23.1 | 23.1 | 23.1 | 23.2 | 23.4 | 23.3 |
| 8 | 24.1 | 24.3 | 24.5 | 24.9 | 24.7 | 24.1 | 24.1 | 24.0 | 24.0 | 23.9 | 23.9 | 23.9 | 24.1 | 24.3 | 24.2 |
| 9 | 25.2 | 25.4 | 25.7 | 26.1 | 25.9 | 25.2 | 25.1 | 25.1 | 25.0 | 24.9 | 24.9 | 25.0 | 25.2 | 25.4 | 25.3 |
| 10 | 27.0 | 27.3 | 27.7 | 28.1 | 27.8 | 26.9 | 26.8 | 26.8 | 26.7 | 26.6 | 26.6 | 26.7 | 27.0 | 27.2 | 27.1 |
| 11 | 30.4 | 31.0 | 31.6 | 32.0 | 31.7 | 30.3 | 30.0 | 30.1 | 30.0 | 29.9 | 29.9 | 30.0 | 30.5 | 30.7 | 30.6 |
| 12 | 31.6 | 32.3 | 33.0 | 33.4 | 33.0 | 31.4 | 31.2 | 31.2 | 31.2 | 31.1 | 31.1 | 31.1 | 31.7 | 31.9 | 31.8 |
| 13 | 32.2 | 32.9 | 33.7 | 34.1 | 33.7 | 32.0 | 31.7 | 31.8 | 31.7 | 31.6 | 31.6 | 31.7 | 32.3 | 32.5 | 32.4 |
| 14 | 32.5 | 33.2 | 34.0 | 34.4 | 34.0 | 32.3 | 32.0 | 32.1 | 32.0 | 31.9 | 31.9 | 32.0 | 32.6 | 32.8 | 32.7 |
| 15 | 32.3 | 33.0 | 33.8 | 34.2 | 33.8 | 32.1 | 31.8 | 31.9 | 31.8 | 31.7 | 31.7 | 31.8 | 32.4 | 32.6 | 32.5 |
| 16 | 31.9 | 32.6 | 33.3 | 33.7 | 33.3 | 31.7 | 31.4 | 31.5 | 31.4 | 31.3 | 31.3 | 31.4 | 32.0 | 32.2 | 32.1 |
| 17 | 31.6 | 32.3 | 33.0 | 33.4 | 33.0 | 31.4 | 31.2 | 31.2 | 31.2 | 31.1 | 31.1 | 31.1 | 31.7 | 31.9 | 31.8 |
| 18 | 31.2 | 31.8 | 32.5 | 32.9 | 32.6 | 31.1 | 30.8 | 30.9 | 30.8 | 30.7 | 30.7 | 30.8 | 31.3 | 31.5 | 31.4 |
| 19 | 30.8 | 31.4 | 32.1 | 32.5 | 32.1 | 30.7 | 30.4 | 30.5 | 30.4 | 30.3 | 30.3 | 30.4 | 30.9 | 31.1 | 31.0 |
| 20 | 30.5 | 31.1 | 31.8 | 32.2 | 31.8 | 30.4 | 30.1 | 30.2 | 30.1 | 30.0 | 30.0 | 30.1 | 30.6 | 30.8 | 30.7 |
| 21 | 30.0 | 30.6 | 31.2 | 31.6 | 31.3 | 29.9 | 29.7 | 29.7 | 29.7 | 29.6 | 29.6 | 29.6 | 30.1 | 30.3 | 30.2 |
| 22 | 29.5 | 30.1 | 30.6 | 31.0 | 30.7 | 29.4 | 29.2 | 29.3 | 29.2 | 29.1 | 29.1 | 29.2 | 29.6 | 29.8 | 29.7 |
| 23 | 28.9 | 29.4 | 30.0 | 30.4 | 30.0 | 28.8 | 28.6 | 28.7 | 28.6 | 28.5 | 28.5 | 28.6 | 29.0 | 29.2 | 29.1 |
| 24 | 28.2 | 28.7 | 29.2 | 29.6 | 29.3 | 28.2 | 28.0 | 28.0 | 28.0 | 27.9 | 27.9 | 27.9 | 28.3 | 28.5 | 28.4 |

FRÍO — ZONA DE CONFORT — CALOR

22 ºC — 32 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 79.

Parrita School. Warm humid climate.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 26.5 | 27.2 | 27.5 | 27.5 | 27.1 | 26.7 | 26.8 | 26.6 | 26.7 | 26.0 | 26.1 | 26.1 | 26.6 | 26.9 | 26.7 |
| 2 | 26.3 | 27.2 | 27.3 | 27.4 | 27.1 | 26.7 | 26.8 | 26.4 | 26.5 | 26.0 | 26.1 | 26.1 | 26.5 | 26.9 | 26.7 |
| 3 | 26.2 | 27.1 | 27.2 | 27.3 | 27.0 | 26.6 | 26.8 | 26.3 | 26.3 | 26.0 | 26.0 | 26.1 | 26.4 | 26.8 | 26.6 |
| 4 | 26.1 | 27.0 | 27.1 | 27.2 | 27.0 | 26.5 | 26.8 | 26.2 | 26.2 | 26.0 | 26.0 | 26.0 | 26.4 | 26.8 | 26.5 |
| 5 | 26.0 | 27.0 | 27.0 | 27.1 | 27.0 | 26.5 | 26.8 | 26.1 | 26.1 | 26.0 | 26.0 | 26.0 | 26.3 | 26.8 | 26.5 |
| 6 | 26.0 | 27.0 | 27.0 | 27.1 | 27.0 | 26.5 | 26.8 | 26.1 | 26.1 | 26.0 | 26.0 | 26.0 | 26.3 | 26.8 | 26.5 |
| 7 | 26.1 | 27.0 | 27.1 | 27.2 | 27.0 | 26.5 | 26.8 | 26.2 | 26.2 | 26.0 | 26.0 | 26.0 | 26.4 | 26.8 | 26.5 |
| 8 | 26.2 | 27.1 | 27.2 | 27.2 | 27.0 | 26.6 | 26.8 | 26.3 | 26.3 | 26.0 | 26.0 | 26.0 | 26.4 | 26.8 | 26.6 |
| 9 | 26.3 | 27.1 | 27.3 | 27.3 | 27.1 | 26.6 | 26.8 | 26.4 | 26.4 | 26.0 | 26.1 | 26.1 | 26.5 | 26.8 | 26.6 |
| 10 | 26.4 | 27.2 | 27.4 | 27.5 | 27.1 | 26.7 | 26.8 | 26.5 | 26.6 | 26.0 | 26.1 | 26.1 | 26.6 | 26.9 | 26.7 |
| 11 | 26.8 | 27.4 | 27.8 | 27.8 | 27.2 | 26.9 | 26.9 | 26.9 | 27.0 | 26.1 | 26.2 | 26.2 | 26.8 | 27.0 | 26.9 |
| 12 | 26.9 | 27.5 | 27.9 | 27.9 | 27.2 | 27.0 | 26.9 | 27.0 | 27.2 | 26.1 | 26.2 | 26.3 | 26.9 | 27.0 | 27.0 |
| 13 | 27.0 | 27.5 | 28.0 | 28.0 | 27.2 | 27.0 | 26.9 | 27.1 | 27.3 | 26.1 | 26.2 | 26.3 | 26.9 | 27.0 | 27.0 |
| 14 | 27.0 | 27.5 | 28.0 | 28.0 | 27.2 | 27.0 | 26.9 | 27.1 | 27.3 | 26.1 | 26.2 | 26.3 | 26.9 | 27.0 | 27.1 |
| 15 | 27.0 | 27.5 | 28.0 | 28.0 | 27.2 | 27.0 | 26.9 | 27.1 | 27.3 | 26.1 | 26.2 | 26.3 | 26.9 | 27.0 | 27.0 |
| 16 | 26.9 | 27.5 | 27.9 | 27.9 | 27.2 | 27.0 | 26.9 | 27.0 | 27.2 | 26.1 | 26.2 | 26.3 | 26.9 | 27.0 | 27.0 |
| 17 | 26.9 | 27.5 | 27.9 | 27.9 | 27.2 | 27.0 | 26.9 | 27.0 | 27.2 | 26.1 | 26.2 | 26.3 | 26.9 | 27.0 | 27.0 |
| 18 | 26.9 | 27.4 | 27.9 | 27.9 | 27.2 | 26.9 | 26.9 | 27.0 | 27.1 | 26.1 | 26.2 | 26.3 | 26.9 | 27.0 | 27.0 |
| 19 | 26.8 | 27.4 | 27.8 | 27.8 | 27.2 | 26.9 | 26.9 | 26.9 | 27.1 | 26.1 | 26.2 | 26.2 | 26.8 | 27.0 | 27.0 |
| 20 | 26.8 | 27.4 | 27.8 | 27.8 | 27.2 | 26.9 | 26.9 | 26.9 | 27.1 | 26.1 | 26.2 | 26.2 | 26.8 | 27.0 | 26.9 |
| 21 | 26.8 | 27.4 | 27.8 | 27.8 | 27.2 | 26.9 | 26.9 | 26.9 | 27.0 | 26.1 | 26.2 | 26.2 | 26.8 | 27.0 | 26.9 |
| 22 | 26.7 | 27.4 | 27.7 | 27.7 | 27.1 | 26.9 | 26.9 | 26.8 | 26.9 | 26.1 | 26.1 | 26.2 | 26.8 | 27.0 | 26.9 |
| 23 | 26.6 | 27.3 | 27.6 | 27.7 | 27.1 | 26.8 | 26.9 | 26.7 | 26.9 | 26.1 | 26.1 | 26.2 | 26.7 | 26.9 | 26.8 |
| 24 | 26.6 | 27.3 | 27.6 | 27.6 | 27.1 | 26.8 | 26.9 | 26.7 | 26.8 | 26.1 | 26.1 | 26.2 | 26.7 | 26.9 | 26.8 |

FRÍO — ZONA DE CONFORT — CALOR

21.7 ºC — 32.5 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 85.

## Luzón School. Warm humid climate.

**MAPA DE CONFORT**

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 24.1 | 24.3 | 24.5 | 25.2 | 25.8 | 25.8 | 24.8 | 25.1 | 25.6 | 25.3 | 24.7 | 24.3 | 24.2 | 25.4 | 25.0 |
| 2 | 23.0 | 23.3 | 23.5 | 24.2 | 24.8 | 24.8 | 23.9 | 24.1 | 24.4 | 24.1 | 23.6 | 23.3 | 23.2 | 24.5 | 23.9 |
| 3 | 22.1 | 22.3 | 22.5 | 23.3 | 23.9 | 23.9 | 23.1 | 23.2 | 23.2 | 23.0 | 22.5 | 22.3 | 22.2 | 23.6 | 22.9 |
| 4 | 21.3 | 21.5 | 21.6 | 22.6 | 23.1 | 23.2 | 22.5 | 22.4 | 22.2 | 22.0 | 21.6 | 21.4 | 21.4 | 22.9 | 22.1 |
| 5 | 20.8 | 21.0 | 21.2 | 22.1 | 22.6 | 22.7 | 22.1 | 21.9 | 21.7 | 21.5 | 21.2 | 21.0 | 20.9 | 22.5 | 21.7 |
| 6 | 20.7 | 20.9 | 21.0 | 22.0 | 22.5 | 22.6 | 22.0 | 21.8 | 21.5 | 21.3 | 21.0 | 20.8 | 20.8 | 22.4 | 21.5 |
| 7 | 21.1 | 21.3 | 21.5 | 22.4 | 22.9 | 23.0 | 22.4 | 22.2 | 22.0 | 21.8 | 21.5 | 21.3 | 21.2 | 22.8 | 22.0 |
| 8 | 21.8 | 22.0 | 22.2 | 23.1 | 23.6 | 23.6 | 22.9 | 22.9 | 22.9 | 22.6 | 22.2 | 22.0 | 21.9 | 23.4 | 22.6 |
| 9 | 22.6 | 22.8 | 23.0 | 23.8 | 24.4 | 24.4 | 23.6 | 23.7 | 23.8 | 23.6 | 23.1 | 22.8 | 22.7 | 24.1 | 23.5 |
| 10 | 23.9 | 24.2 | 24.4 | 25.1 | 25.7 | 25.6 | 24.6 | 25.0 | 25.5 | 25.1 | 24.5 | 24.2 | 24.1 | 25.3 | 24.8 |
| 11 | 26.5 | 26.7 | 27.1 | 27.5 | 28.2 | 28.1 | 26.7 | 27.5 | 28.6 | 28.2 | 27.3 | 26.9 | 26.7 | 27.7 | 27.4 |
| 12 | 27.3 | 27.6 | 28.0 | 28.4 | 29.1 | 28.9 | 27.5 | 28.4 | 29.7 | 29.2 | 28.3 | 27.8 | 27.6 | 28.5 | 28.3 |
| 13 | 27.8 | 28.1 | 28.5 | 28.8 | 29.5 | 29.3 | 27.8 | 28.8 | 30.2 | 29.7 | 28.8 | 28.3 | 28.0 | 28.9 | 28.8 |
| 14 | 28.0 | 28.3 | 28.7 | 29.0 | 29.7 | 29.5 | 28.0 | 29.0 | 30.5 | 30.0 | 29.0 | 28.5 | 28.3 | 29.1 | 29.0 |
| 15 | 27.9 | 28.2 | 28.5 | 28.9 | 29.6 | 29.4 | 27.9 | 28.9 | 30.3 | 29.8 | 28.8 | 28.3 | 28.1 | 28.9 | 28.9 |
| 16 | 27.6 | 27.9 | 28.2 | 28.6 | 29.3 | 29.1 | 27.6 | 28.6 | 30.0 | 29.5 | 28.5 | 28.0 | 27.8 | 28.7 | 28.6 |
| 17 | 27.3 | 27.6 | 28.0 | 28.4 | 29.1 | 28.9 | 27.5 | 28.4 | 29.7 | 29.2 | 28.3 | 27.8 | 27.6 | 28.5 | 28.3 |
| 18 | 27.1 | 27.3 | 27.7 | 28.1 | 28.8 | 28.6 | 27.2 | 28.1 | 29.3 | 28.9 | 28.0 | 27.5 | 27.3 | 28.2 | 28.0 |
| 19 | 26.8 | 27.0 | 27.4 | 27.8 | 28.5 | 28.3 | 27.0 | 27.8 | 29.0 | 28.5 | 27.6 | 27.2 | 27.0 | 27.9 | 27.7 |
| 20 | 26.5 | 26.8 | 27.2 | 27.6 | 28.3 | 28.1 | 26.8 | 27.6 | 28.7 | 28.3 | 27.4 | 27.0 | 26.8 | 27.7 | 27.5 |
| 21 | 26.2 | 26.5 | 26.8 | 27.3 | 27.9 | 27.8 | 26.5 | 27.2 | 28.3 | 27.8 | 27.0 | 26.6 | 26.4 | 27.4 | 27.1 |
| 22 | 25.8 | 26.1 | 26.4 | 26.9 | 27.5 | 27.4 | 26.2 | 26.8 | 27.8 | 27.4 | 26.6 | 26.2 | 26.0 | 27.1 | 26.8 |
| 23 | 25.4 | 25.6 | 25.9 | 26.5 | 27.1 | 27.0 | 25.8 | 26.4 | 27.3 | 26.9 | 26.1 | 25.7 | 25.6 | 26.7 | 26.3 |
| 24 | 24.9 | 25.1 | 25.4 | 26.0 | 26.6 | 26.5 | 25.4 | 25.9 | 26.6 | 26.3 | 25.6 | 25.2 | 25.1 | 26.2 | 25.8 |

FRÍO — ZONA DE CONFORT — CALOR

20.7 ºC — 30 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 86.

## El Carmen School. Warm humid climate.

**MAPA DE CONFORT**

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 20.9 | 21.5 | 21.8 | 23.0 | 22.1 | 21.7 | 21.5 | 21.5 | 22.2 | 21.6 | 21.0 | 20.4 | 20.9 | 21.8 | 21.6 |
| 2 | 20.1 | 20.6 | 20.8 | 21.8 | 21.0 | 20.7 | 20.6 | 20.5 | 21.2 | 20.7 | 20.1 | 19.6 | 20.1 | 20.8 | 20.6 |
| 3 | 19.4 | 19.7 | 19.9 | 20.7 | 20.0 | 19.8 | 19.7 | 19.6 | 20.3 | 19.9 | 19.2 | 18.8 | 19.3 | 19.8 | 19.8 |
| 4 | 18.8 | 19.0 | 19.1 | 19.7 | 19.1 | 19.1 | 19.0 | 18.9 | 19.6 | 19.2 | 18.5 | 18.1 | 18.6 | 19.1 | 19.0 |
| 5 | 18.4 | 18.6 | 18.6 | 19.2 | 18.7 | 18.6 | 18.6 | 18.4 | 19.1 | 18.8 | 18.1 | 17.7 | 18.3 | 18.6 | 18.6 |
| 6 | 18.3 | 18.5 | 18.5 | 19.0 | 18.5 | 18.5 | 18.5 | 18.3 | 19.0 | 18.7 | 18.0 | 17.6 | 18.1 | 18.5 | 18.5 |
| 7 | 18.6 | 18.9 | 18.9 | 19.5 | 19.0 | 18.9 | 18.9 | 18.7 | 19.4 | 19.1 | 18.4 | 18.0 | 18.5 | 18.9 | 18.9 |
| 8 | 19.2 | 19.5 | 19.6 | 20.3 | 19.7 | 19.6 | 19.5 | 19.3 | 20.1 | 19.6 | 19.0 | 18.5 | 19.0 | 19.6 | 19.5 |
| 9 | 19.8 | 20.2 | 20.4 | 21.3 | 20.5 | 20.3 | 20.2 | 20.1 | 20.8 | 20.3 | 19.7 | 19.2 | 19.7 | 20.3 | 20.2 |
| 10 | 20.8 | 21.4 | 21.7 | 22.9 | 21.9 | 21.6 | 21.4 | 21.3 | 22.1 | 21.5 | 20.9 | 20.3 | 20.8 | 21.6 | 21.5 |
| 11 | 22.8 | 23.6 | 24.2 | 26.0 | 24.7 | 24.0 | 23.6 | 23.8 | 24.5 | 23.7 | 23.1 | 22.4 | 23.0 | 24.1 | 23.9 |
| 12 | 23.5 | 24.4 | 25.1 | 27.0 | 25.6 | 24.9 | 24.4 | 24.6 | 25.4 | 24.4 | 23.9 | 23.2 | 23.7 | 25.0 | 24.7 |
| 13 | 23.8 | 24.8 | 25.5 | 27.5 | 26.1 | 25.3 | 24.8 | 25.0 | 25.8 | 24.8 | 24.3 | 23.5 | 24.1 | 25.4 | 25.1 |
| 14 | 24.0 | 25.0 | 25.7 | 27.8 | 26.3 | 25.5 | 25.0 | 25.2 | 26.0 | 25.0 | 24.5 | 23.7 | 24.2 | 25.6 | 25.3 |
| 15 | 23.9 | 24.9 | 25.6 | 27.6 | 26.1 | 25.4 | 24.9 | 25.1 | 25.9 | 24.9 | 24.4 | 23.6 | 24.1 | 25.5 | 25.2 |
| 16 | 23.7 | 24.6 | 25.3 | 27.3 | 25.8 | 25.1 | 24.6 | 24.8 | 25.6 | 24.6 | 24.1 | 23.3 | 23.9 | 25.2 | 24.9 |
| 17 | 23.5 | 24.4 | 25.1 | 27.0 | 25.6 | 24.9 | 24.4 | 24.6 | 25.4 | 24.4 | 23.9 | 23.2 | 23.7 | 25.0 | 24.7 |
| 18 | 23.3 | 24.2 | 24.8 | 26.7 | 25.3 | 24.6 | 24.2 | 24.3 | 25.1 | 24.2 | 23.7 | 22.9 | 23.4 | 24.7 | 24.4 |
| 19 | 23.0 | 23.9 | 24.5 | 26.3 | 25.0 | 24.3 | 23.9 | 24.0 | 24.8 | 23.9 | 23.4 | 22.7 | 23.2 | 24.4 | 24.1 |
| 20 | 22.9 | 23.7 | 24.3 | 26.0 | 24.7 | 24.1 | 23.7 | 23.8 | 24.6 | 23.7 | 23.2 | 22.5 | 23.0 | 24.2 | 23.9 |
| 21 | 22.6 | 23.4 | 23.9 | 25.6 | 24.4 | 23.8 | 23.4 | 23.5 | 24.3 | 23.4 | 22.9 | 22.2 | 22.7 | 23.8 | 23.6 |
| 22 | 22.3 | 23.1 | 23.5 | 25.2 | 24.0 | 23.4 | 23.1 | 23.1 | 23.9 | 23.1 | 22.6 | 21.9 | 22.4 | 23.5 | 23.3 |
| 23 | 21.9 | 22.7 | 23.1 | 24.6 | 23.5 | 23.0 | 22.7 | 22.7 | 23.5 | 22.7 | 22.2 | 21.5 | 22.0 | 23.0 | 22.8 |
| 24 | 21.5 | 22.2 | 22.6 | 24.0 | 22.9 | 22.5 | 22.2 | 22.2 | 23.0 | 22.3 | 21.7 | 21.1 | 21.6 | 22.5 | 22.4 |

FRÍO — ZONA DE CONFORT — CALOR

20 ºC — 27 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

The most intense rainfalls take place during July and December with 450mm. The average annual precipitation is 300mm, with no dry season. Temperatures range between 20.7°C and 30.4°C, with an annual average of 25.5°C and an average relative humidity of 87.5%, which makes Luzón's climate somewhat uncomfortable, given that the body's thermoregulatory system is limited by the high relative humidity levels. (Life zone: wet forest.) The school building is located in a rural area at 15 m.a.s.l. It is organized into two parallel wings, each consisting of a single bay, and divided by a patio. It has open passageways and north-facing classrooms. It was built with prefabricated tiles and a gable roof.

The school building is located in a rural area at 530 m.a.s.l. A single bay of classrooms on one floor, along with an administrative area and preschool space are organized around a central patio. It was built using blocks of concrete, a metal gable roof, and open passageways through an arcade. The rainy period is between May and December with maximums of 300mm, generally in the form of constant drizzle and strong winds. Temperatures vary between 18.3°C and 27.8°C with an annual average of 24.5°C. The mornings are cool with temperatures below the LCR. The average annual relative humidity is 83%. (Life zone: moist tropical forest.)

### Temperate humid climate requiring shading + natural ventilation (Poasito, Panamá)

The climate has two seasons, with little precipitation between January and April and more between May and November (500mm), with an annual average of 250mm. The temperatures fluctuate between 12.1°C and 22.5°C, with an annual variation of 10°C and an annual average of 17.4°C. The annual average relative humidity is 85%. (Life zone: wet forest). The school is located at 1990 m.a.s.l. and consists of a complex arranged in pavilions that accompany the natural slope of the terrain. They are connected by partially covered passageways. Ramps and stairs bridge the various levels. The roofs have two slopes to encourage rainwater

FIGURE 82.
Poasito School. Temperate humid climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 15.9 | 16.0 | 16.7 | 17.4 | 17.3 | 17.6 | 17.8 | 17.9 | 17.9 | 17.8 | 17.7 | 17.4 | 16.4 | 17.6 | 17.3 |
| 2 | 14.8 | 14.9 | 15.3 | 16.0 | 16.0 | 16.5 | 16.9 | 16.9 | 16.9 | 16.9 | 16.8 | 16.6 | 15.4 | 16.5 | 16.2 |
| 3 | 13.8 | 13.8 | 14.1 | 14.8 | 14.9 | 15.5 | 16.0 | 15.9 | 16.0 | 16.0 | 16.0 | 15.8 | 14.4 | 15.5 | 15.2 |
| 4 | 12.9 | 12.9 | 13.0 | 13.8 | 13.9 | 14.6 | 15.2 | 15.1 | 15.2 | 15.2 | 15.3 | 15.1 | 13.6 | 14.6 | 14.4 |
| 5 | 12.5 | 12.4 | 12.4 | 13.2 | 13.4 | 14.2 | 14.8 | 14.6 | 14.7 | 14.8 | 14.9 | 14.7 | 13.2 | 14.1 | 13.9 |
| 6 | 12.3 | 12.2 | 12.2 | 13.0 | 13.2 | 14.0 | 14.7 | 14.5 | 14.6 | 14.7 | 14.8 | 14.6 | 13.0 | 14.0 | 13.7 |
| 7 | 12.8 | 12.7 | 12.8 | 13.6 | 13.7 | 14.5 | 15.1 | 14.9 | 15.0 | 15.1 | 15.2 | 15.0 | 13.5 | 14.4 | 14.2 |
| 8 | 13.5 | 13.4 | 13.7 | 14.4 | 14.5 | 15.2 | 15.7 | 15.6 | 15.7 | 15.7 | 15.7 | 15.5 | 14.1 | 15.1 | 14.9 |
| 9 | 14.3 | 14.4 | 14.7 | 15.5 | 15.5 | 16.1 | 16.5 | 16.4 | 16.5 | 16.5 | 16.4 | 16.2 | 15.0 | 16.0 | 15.7 |
| 10 | 15.7 | 15.9 | 16.5 | 17.2 | 17.1 | 17.5 | 17.7 | 17.8 | 17.8 | 17.7 | 17.5 | 17.3 | 16.3 | 17.4 | 17.1 |
| 11 | 18.5 | 18.8 | 19.9 | 20.5 | 20.2 | 20.2 | 20.1 | 20.3 | 20.3 | 20.1 | 19.7 | 19.4 | 18.9 | 20.2 | 19.8 |
| 12 | 19.4 | 19.8 | 21.1 | 21.6 | 21.3 | 21.2 | 20.9 | 21.2 | 21.2 | 20.9 | 20.4 | 20.2 | 19.8 | 21.1 | 20.8 |
| 13 | 19.9 | 20.3 | 21.7 | 22.2 | 21.8 | 21.7 | 21.3 | 21.7 | 21.6 | 21.3 | 20.8 | 20.5 | 20.2 | 21.6 | 21.2 |
| 14 | 20.1 | 20.5 | 22.0 | 22.5 | 22.1 | 21.9 | 21.5 | 21.9 | 21.8 | 21.5 | 21.0 | 20.7 | 20.4 | 21.8 | 21.5 |
| 15 | 19.9 | 20.3 | 21.8 | 22.3 | 21.9 | 21.7 | 21.4 | 21.8 | 21.7 | 21.4 | 20.9 | 20.6 | 20.3 | 21.7 | 21.3 |
| 16 | 19.6 | 20.0 | 21.4 | 21.9 | 21.6 | 21.4 | 21.1 | 21.5 | 21.4 | 21.1 | 20.6 | 20.3 | 20.0 | 21.4 | 21.0 |
| 17 | 19.4 | 19.8 | 21.1 | 21.6 | 21.3 | 21.2 | 20.9 | 21.2 | 21.2 | 20.9 | 20.4 | 20.2 | 19.8 | 21.1 | 20.8 |
| 18 | 19.1 | 19.4 | 20.7 | 21.3 | 20.9 | 20.9 | 20.6 | 20.9 | 20.9 | 20.6 | 20.2 | 19.9 | 19.5 | 20.8 | 20.5 |
| 19 | 18.8 | 19.1 | 20.3 | 20.9 | 20.6 | 20.6 | 20.3 | 20.6 | 20.6 | 20.3 | 19.9 | 19.7 | 19.2 | 20.5 | 20.1 |
| 20 | 18.5 | 18.8 | 20.0 | 20.6 | 20.3 | 20.3 | 20.1 | 20.4 | 20.4 | 20.1 | 19.8 | 19.5 | 19.0 | 20.3 | 19.9 |
| 21 | 18.2 | 18.4 | 19.6 | 20.1 | 19.9 | 19.9 | 19.8 | 20.1 | 20.0 | 19.8 | 19.5 | 19.2 | 18.6 | 19.9 | 19.5 |
| 22 | 17.8 | 18.0 | 19.1 | 19.7 | 19.4 | 19.5 | 19.5 | 19.7 | 19.6 | 19.5 | 19.1 | 18.9 | 18.2 | 19.5 | 19.1 |
| 23 | 17.3 | 17.5 | 18.5 | 19.1 | 18.9 | 19.1 | 19.1 | 19.2 | 19.2 | 19.1 | 18.8 | 18.5 | 17.8 | 19.0 | 18.7 |
| 24 | 16.7 | 16.9 | 17.8 | 18.4 | 18.3 | 18.5 | 18.6 | 18.7 | 18.7 | 18.6 | 18.3 | 18.1 | 17.3 | 18.5 | 18.1 |

FRÍO — ZONA DE CONFORT — CALOR
18 °C — 27 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 83.

Panamá School. Temperate humid climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 18.1 | 18.2 | 18.7 | 20.3 | 20.5 | 20.7 | 19.5 | 19.7 | 19.7 | 19.4 | 18.7 | 18.1 | 18.1 | 20.2 | 19.3 |
| 2 | 17.0 | 17.1 | 17.6 | 19.0 | 19.3 | 19.6 | 18.6 | 18.6 | 18.5 | 18.2 | 17.6 | 17.1 | 17.1 | 19.2 | 18.2 |
| 3 | 16.1 | 16.1 | 16.5 | 17.8 | 18.2 | 18.5 | 17.7 | 17.5 | 17.4 | 17.1 | 16.5 | 16.2 | 16.1 | 18.1 | 17.1 |
| 4 | 15.3 | 15.3 | 15.6 | 16.8 | 17.2 | 17.6 | 17.0 | 16.6 | 16.5 | 16.2 | 15.6 | 15.4 | 15.3 | 17.3 | 16.3 |
| 5 | 14.8 | 14.9 | 15.2 | 16.2 | 16.7 | 17.2 | 16.6 | 16.2 | 16.0 | 15.7 | 15.2 | 14.9 | 14.9 | 16.8 | 15.8 |
| 6 | 14.7 | 14.7 | 15.0 | 16.0 | 16.5 | 17.0 | 16.5 | 16.0 | 15.8 | 15.5 | 15.0 | 14.8 | 14.7 | 16.7 | 15.6 |
| 7 | 15.1 | 15.2 | 15.5 | 16.6 | 17.0 | 17.5 | 16.9 | 16.5 | 16.3 | 16.0 | 15.5 | 15.2 | 15.2 | 17.1 | 16.1 |
| 8 | 15.8 | 15.8 | 16.2 | 17.4 | 17.8 | 18.2 | 17.5 | 17.2 | 17.1 | 16.8 | 16.2 | 15.9 | 15.8 | 17.8 | 16.8 |
| 9 | 16.6 | 16.7 | 17.1 | 18.4 | 18.8 | 19.1 | 18.2 | 18.1 | 18.0 | 17.7 | 17.1 | 16.7 | 16.6 | 18.7 | 17.7 |
| 10 | 17.9 | 18.0 | 18.5 | 20.1 | 20.4 | 20.5 | 19.4 | 19.5 | 19.5 | 19.2 | 18.5 | 18.0 | 18.0 | 20.1 | 19.1 |
| 11 | 20.5 | 20.7 | 21.3 | 23.4 | 23.5 | 23.3 | 21.6 | 22.3 | 22.5 | 22.2 | 21.3 | 20.5 | 20.6 | 22.8 | 21.9 |
| 12 | 21.3 | 21.6 | 22.3 | 24.6 | 24.5 | 24.3 | 22.4 | 23.3 | 23.5 | 23.2 | 22.3 | 21.4 | 21.4 | 23.7 | 22.9 |
| 13 | 21.8 | 22.1 | 22.8 | 25.1 | 25.0 | 24.8 | 22.8 | 23.8 | 24.0 | 23.7 | 22.8 | 21.8 | 21.9 | 24.2 | 23.4 |
| 14 | 22.0 | 22.3 | 23.0 | 25.4 | 25.3 | 25.0 | 23.0 | 24.0 | 24.3 | 24.0 | 23.0 | 22.0 | 22.1 | 24.4 | 23.6 |
| 15 | 21.9 | 22.1 | 22.8 | 25.2 | 25.1 | 24.8 | 22.9 | 23.8 | 24.1 | 23.8 | 22.8 | 21.9 | 22.0 | 24.3 | 23.4 |
| 16 | 21.6 | 21.8 | 22.5 | 24.8 | 24.8 | 24.5 | 22.6 | 23.5 | 23.8 | 23.5 | 22.5 | 21.6 | 21.7 | 24.0 | 23.1 |
| 17 | 21.3 | 21.6 | 22.3 | 24.6 | 24.5 | 24.3 | 22.4 | 23.3 | 23.5 | 23.2 | 22.3 | 21.4 | 21.4 | 23.7 | 22.9 |
| 18 | 21.1 | 21.3 | 22.0 | 24.2 | 24.2 | 24.0 | 22.2 | 23.0 | 23.2 | 22.9 | 22.0 | 21.1 | 21.1 | 23.4 | 22.6 |
| 19 | 20.8 | 21.0 | 21.6 | 23.8 | 23.8 | 23.6 | 21.9 | 22.6 | 22.9 | 22.6 | 21.6 | 20.8 | 20.8 | 23.1 | 22.3 |
| 20 | 20.5 | 20.8 | 21.4 | 23.5 | 23.5 | 23.4 | 21.7 | 22.4 | 22.6 | 22.3 | 21.4 | 20.6 | 20.6 | 22.9 | 22.0 |
| 21 | 20.2 | 20.4 | 21.0 | 23.1 | 23.1 | 23.0 | 21.4 | 22.0 | 22.2 | 21.9 | 21.0 | 20.2 | 20.3 | 22.5 | 21.6 |
| 22 | 19.8 | 20.0 | 20.6 | 22.6 | 22.7 | 22.6 | 21.1 | 21.6 | 21.8 | 21.5 | 20.6 | 19.8 | 19.9 | 22.1 | 21.2 |
| 23 | 19.4 | 19.6 | 20.1 | 22.0 | 22.1 | 22.1 | 20.7 | 21.1 | 21.2 | 20.9 | 20.1 | 19.4 | 19.4 | 21.6 | 20.7 |
| 24 | 18.9 | 19.0 | 19.6 | 21.4 | 21.5 | 21.6 | 20.2 | 20.6 | 20.6 | 20.3 | 19.6 | 18.9 | 18.9 | 21.1 | 20.2 |

FRÍO — ZONA DE CONFORT — CALOR

18 °C — 25.4 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

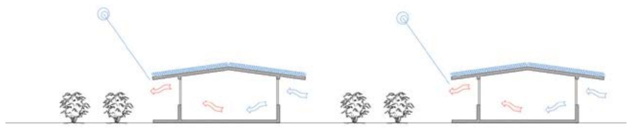
removal, but this component requires the use of thermal insulation to avoid gains during the warm period and losses during the cold one.

This building complex is located in an urban setting at 1166 m.a.s.l. It alternates rows of classrooms with interstitial patios organized around a bigger central patio. Classrooms are generally north-facing. The school was built out of concrete blocks, covered in sheet metal and prefabricated tiles. With respect to the climate, the temperature varies between 15°C and 25°C, with an annual average of 20°C. Maximum temperatures are recorded in April and minimums at dawn in January and February. Relative humidity is 80%. (Life zone: moist forest.) With respect to rainfall, the dry season is from December to April and the rainy season from May to October, with maximum levels of 300mm per month.

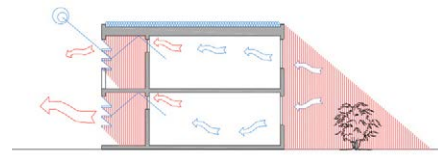
Costa Rica's climate is characterized by high temperatures and levels of relative humidity and divided into a dry season and a prolonged rainy season, which indicates a harsh climate from a hygrothermal perspective. The conditions in the audited classrooms were within the thermal comfort zone according to the LCR which, at this latitude, reflects the body's habituation to these extreme environmental conditions. In all of the classrooms studied, the records of inside temperatures exceeded those outdoors, due to the building's thermal load and internal gains from solar radiation and building occupancy. The recorded indoor temperatures were beyond the comfort range in the warm, humid climates of Bebedero (35°C) and Parrita (33°C), while in Poasito's temperate climate, temperatures around 18°C were recorded with a high humidity content (82% to 95%), both outside the LCR. In this particular case, the microclimatic conditions should be utilized to raise the temperature inside the classroom during the morning hours.

Practically all of the students were dressed with light or very light clothing and the majority reported being comfortable (67% to 99%), while a similar percentage reported perspiring in the classroom (50% to 100%), which suggests that the students are aware

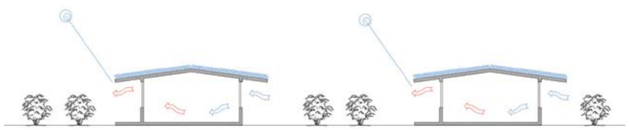
FIGURE 84.
Panamá design guidelines



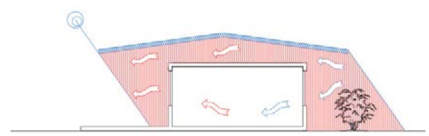
Shading. Natural ventilation.
Thermally insulated roof
**Bebedero**



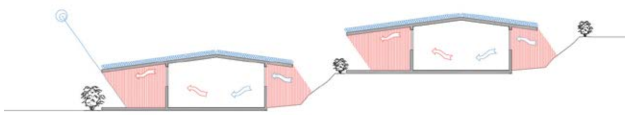
Shading natural ventilation.
Thermally insulated roof
**Parrita**



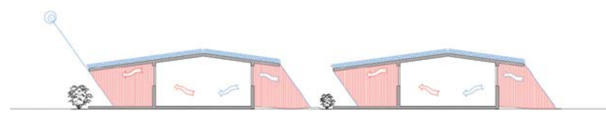
Shading natural ventilation.
Thermally insulated roof
**Luzón**



Shading. Natural ventilation.
Thermally insulated roof
**El Carmen**



Shading. Natural ventilation.
Thermally insulated roof
Poasito



Shading natural ventilation.
Thermally insulated roof
**Panamá**

of the unfavorable conditions. In all cases, shading should be used on outdoor surfaces and in the building envelope to prevent solar radiation from reaching the inside of the building through the windows. The roof is a key component in situations like this, given that it provides not only hydraulic protection, but offers thermal protection as well. "Shade roofs" are very useful in improving natural ventilation, accelerating wind currents, and assisting with the extraction of inside air (saturated in temperature and humidity). In warm, temperate climates like these, lightweight building materials are recommended since they offer little thermal inertia. The use of thermal insulation on all surfaces exposed to solar radiation is also important.

Significant disparities in the average illuminance levels were observed in the classrooms and locations surveyed. With respect to natural illuminance levels, the maximum averages were recorded in temperate climates (Panamá and Poasito), with levels that were unsuitably high for the activities in question. Minimum averages were recorded in warm climates (El Carmen and Luzón). In both situations, values fell outside the comfort zone. In the remaining cases, the light levels were acceptable. Regardless, the variable in question is clearly crucial in a classroom setting given the dynamic behavior of the luminous flux which depends on: (a) sky conditions; (b) the characteristics of windows; and (c) the qualities of the surfaces inside the classroom. Window designs should be used that filter and/or diffuse solar radiation, avoid direct impact on the working plane, and encourage natural (cross-) ventilation. Low uniformity conditions were recorded, given that the classrooms are rectangular and perpendicular to the light source. The distribution of natural light should be improved by designing windows which encourage increased illuminance levels and distributing them more homogeneously throughout the building, optimizing their size and location and, when possible, ensuring classrooms are lit from two sides, to balance maximums and minimums. The vast majority of students reported being comfortable with the lighting (92% to 100%).

From an acoustic standpoint, most students reported discomfort (72% to 100%) and this was reflected by the measurements taken. This variable should be taken into account. This situation is likely due to the lack of sound insulation and treatment of indoor surfaces.

Opinion indicators confirm that a high percentage of students feel the air is stale (74% to 100%), which can be explained more by the thermodynamic properties of the air outside than by the confinement of inside air. In terms of air quality in relation to $CO_2$ concentrations, all recorded values were below the acceptable levels (490 ppm to 795 ppm) thanks to constant ventilation.

## CHILE (CH)

The locations studied in winter and summer are as follows:

### Warm dry climate

- Northern desert zone. Border-Area Primary School. San Lorenzo de Tarapacá.

### Warm humid climate

- Northern coastal zone. Primary School and Artistic Development. Violeta Parra. Iquique.

### Temperate dry climate

- Central inland zone. Malloco School 664. Municipality of Peñaflor, Santiago de Chile.
- Central inland zone. Likankura School. Municipality of Peñalolén Santiago de Chile.

### Very cold climate

- Extreme southern zone. Patagonia School. Punta Arenas City.

### Warm dry climate requiring shading + ventilation + heating (Tarapacá)

This is a border-area school located in a small city in the middle of the desert at 1350 m.a.s.l., between the mountain range and the sea. Tarapacá has a warm, dry climate, with significant year-round thermal variation between day and night (over 20°C). Maximum averages are relatively low in summer and high in winter. The school is surrounded by low, scattered buildings. Winds in the summer are predominantly from the west and very intense. The building consists of a single floor with classrooms grouped around a quadrangular patio and outdoor hallways protected from the sun by a wooden pergola. Medium-weight construction materials and a flat roof were used.

### Tarapacá

Due to low and mid-range average temperatures and the low relative humidity, thermal insulation of the building envelope is needed in both winter and summer. In this case, supporting walls, polished concrete floors, and wooden enclosures were used, providing insulation and a certain degree of thermal inertia. Additional heating is needed. At this latitude, this can be achieved by using passive solar systems with north-facing collector facades (greenhouses, heat accumulating walls or solar air collectors). The hygrothermal conditions of the classrooms audited were above the comfort zone during almost the entire year, reaching 32°C and 42% relative humidity in the summer months. This may be due to the overheating produced

FIGURE 85.

Panamá Border-area Primary School. San Lorenzo de Tarapacá. Warm dry climate.

MAPA DE CONFORT

| HORA | COEF | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 0.46 | 13.8 | 14.1 | 13.2 | 11.8 | 10.5 | 9.2 | 9.1 | 9.4 | 10.6 | 11.8 | 13.1 | 13.2 | 13.7 | 9.6 | 11.7 |
| 2 | 0.32 | 11.2 | 11.5 | 10.5 | 8.9 | 7.5 | 6.3 | 6.1 | 6.3 | 7.5 | 8.7 | 10.0 | 10.3 | 11.0 | 6.6 | 8.7 |
| 3 | 0.19 | 8.7 | 9.0 | 8.0 | 6.2 | 4.8 | 3.5 | 3.2 | 3.4 | 4.6 | 5.9 | 7.1 | 7.6 | 8.4 | 3.8 | 6.0 |
| 4 | 0.08 | 6.6 | 7.0 | 5.9 | 3.9 | 2.4 | 1.2 | 0.8 | 0.9 | 2.2 | 3.5 | 4.6 | 5.3 | 6.3 | 1.5 | 3.7 |
| 5 | 0.02 | 5.5 | 5.9 | 4.8 | 2.6 | 1.1 | -0.1 | -0.5 | -0.5 | 0.8 | 2.1 | 3.2 | 4.0 | 5.1 | 0.2 | 2.4 |
| 6 | 0.00 | 5.1 | 5.5 | 4.4 | 2.2 | 0.7 | -0.5 | -0.9 | -0.9 | 0.4 | 1.7 | 2.8 | 3.6 | 4.7 | -0.2 | 2.0 |
| 7 | 0.06 | 6.2 | 6.6 | 5.6 | 3.4 | 2.0 | 0.8 | 0.4 | 0.4 | 1.7 | 3.0 | 4.1 | 4.8 | 5.9 | 1.1 | 3.3 |
| 8 | 0.15 | 8.0 | 8.3 | 7.3 | 5.3 | 3.9 | 2.7 | 2.4 | 2.5 | 3.7 | 5.0 | 6.2 | 6.7 | 7.7 | 3.0 | 5.2 |
| 9 | 0.26 | 10.0 | 10.3 | 9.4 | 7.6 | 6.3 | 5.0 | 4.8 | 4.9 | 6.2 | 7.4 | 8.6 | 9.0 | 9.8 | 5.3 | 7.5 |
| 10 | 0.44 | 13.5 | 13.7 | 12.8 | 11.4 | 10.1 | 8.8 | 8.7 | 9.0 | 10.2 | 11.4 | 12.7 | 12.8 | 13.3 | 9.2 | 11.2 |
| 11 | 0.79 | 20.1 | 20.2 | 19.6 | 18.6 | 17.6 | 16.2 | 16.3 | 16.8 | 17.9 | 19.1 | 20.5 | 20.0 | 20.1 | 16.7 | 18.6 |
| 12 | 0.91 | 22.4 | 22.4 | 21.9 | 21.1 | 20.2 | 18.7 | 18.9 | 19.5 | 20.6 | 21.7 | 23.2 | 22.5 | 22.4 | 19.3 | 21.1 |
| 13 | 0.97 | 23.5 | 23.5 | 23.0 | 22.4 | 21.5 | 20.0 | 20.2 | 20.8 | 21.9 | 23.0 | 24.5 | 23.8 | 23.6 | 20.6 | 22.4 |
| 14 | 1.00 | 24.1 | 24.1 | 23.6 | 23.0 | 22.1 | 20.6 | 20.9 | 21.5 | 22.6 | 23.7 | 25.2 | 24.4 | 24.2 | 21.2 | 23.0 |
| 15 | 0.98 | 23.7 | 23.7 | 23.2 | 22.6 | 21.7 | 20.2 | 20.5 | 21.1 | 22.2 | 23.3 | 24.8 | 24.0 | 23.8 | 20.8 | 22.6 |
| 16 | 0.94 | 23.0 | 23.0 | 22.4 | 21.8 | 20.8 | 19.3 | 19.6 | 20.2 | 21.3 | 22.4 | 23.9 | 23.2 | 23.0 | 19.9 | 21.7 |
| 17 | 0.91 | 22.4 | 22.4 | 21.9 | 21.1 | 20.2 | 18.7 | 18.9 | 19.5 | 20.6 | 21.7 | 23.2 | 22.5 | 22.4 | 19.3 | 21.1 |
| 18 | 0.87 | 21.6 | 21.7 | 21.1 | 20.3 | 19.3 | 17.9 | 18.1 | 18.6 | 19.7 | 20.8 | 22.3 | 21.7 | 21.7 | 18.4 | 20.3 |
| 19 | 0.83 | 20.9 | 20.9 | 20.3 | 19.5 | 18.5 | 17.0 | 17.2 | 17.7 | 18.8 | 20.0 | 21.4 | 20.9 | 20.9 | 17.6 | 19.4 |
| 20 | 0.80 | 20.3 | 20.4 | 19.8 | 18.8 | 17.8 | 16.4 | 16.5 | 17.0 | 18.2 | 19.3 | 20.7 | 20.2 | 20.3 | 16.9 | 18.8 |
| 21 | 0.75 | 19.4 | 19.5 | 18.8 | 17.8 | 16.8 | 15.3 | 15.5 | 15.9 | 17.1 | 18.2 | 19.6 | 19.2 | 19.3 | 15.8 | 17.7 |
| 22 | 0.70 | 18.4 | 18.5 | 17.8 | 16.8 | 15.7 | 14.3 | 14.4 | 14.8 | 15.9 | 17.1 | 18.5 | 18.2 | 18.4 | 14.8 | 16.7 |
| 23 | 0.64 | 17.3 | 17.4 | 16.7 | 15.5 | 14.4 | 13.0 | 13.1 | 13.4 | 14.6 | 15.8 | 17.1 | 16.9 | 17.2 | 13.5 | 15.4 |
| 24 | 0.57 | 15.9 | 16.1 | 15.3 | 14.1 | 12.9 | 11.5 | 11.5 | 11.9 | 13.1 | 14.2 | 15.6 | 15.5 | 15.8 | 12.0 | 14.0 |

CONFORT 20 a 24 ºC

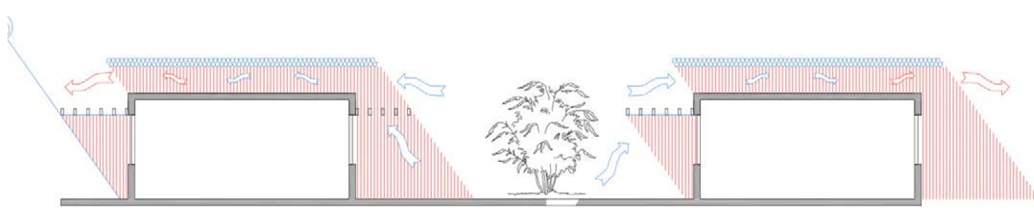
FRÍO menos de 20 ºC

CALOR más de 24 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 86.

Panamá shading. Natural nentilation. Thermally insulated building envelope. Thermal inertia. Tarapacá.



by warm air entering from the outside or through the roof, which is the only part of the building envelope not protected by shading. Given the high level of solar radiation, protection is recommended, through use of either improved thermal insulation or by incorporating ventilated "shade roofs." Despite the recorded overheating, 73% to 87% of students reported being comfortable, which reflects a certain degree of habituation or tolerance to extreme temperatures. During the winter, student opinion of thermal conditions was still favorable, although the majority (83% to 95%) were warmly dressed and admitted they were perspiring (86%).

Despite the presence of clear skies, the lighting conditions of the classrooms were generally unfavorable, given the presence of a single window of limited size located in the middle of the wall. The proportion of windows does not meet recommendations regarding the classroom area. Classroom illuminance levels were low and irregular and they do not meet the accepted comfort levels. Nevertheless, a significant proportion of students did not perceive this negatively (50% to 78%). The distribution of natural light should be improved by designing windows which encourage increased illuminance levels and distributing them more homogeneously throughout the building, optimizing the size and location of openings in order to avoid the direct access of solar radiation and warm air from outdoors.

From an acoustic standpoint, most students reported discomfort (67% to 75%), especially during the winter. Given the surroundings, this is likely due to inadequate treatment of the indoor acoustic field. Absorbent surfaces should therefore be added to the walls or ceilings. Winter received the most negative evaluation in terms of noise levels and air quality.

With respect to air quality, the majority of students perceived the air as stale (71% to 83%), with values generally within the admissible ranges for concentrations of $CO_2$. Therefore, this issue may be caused by heating equipment, the lack of humidity in the atmosphere, and odors generated by occupants.

## Warm humid climate requiring shading + ventilation + heating (Iquique)

This is an urban school, located in a coastal desert zone with a warm, humid climate where average temperatures are very high in summer and temperate in winter (generally quite homogeneous) and the relative humidity is high and constant throughout the year. This location is characterized by high levels of solar radiation and moderate winds, predominantly from the south, and breezes from both sea and land. Classrooms are organized on three floors surrounding patios with covered outdoor corridors, and have windows on two opposite sides. Medium-weight materials were used.

FIGURE 87.
Panamá Primary School and Artistic Development, Violeta Parra. Iquique. Warm humid climate.

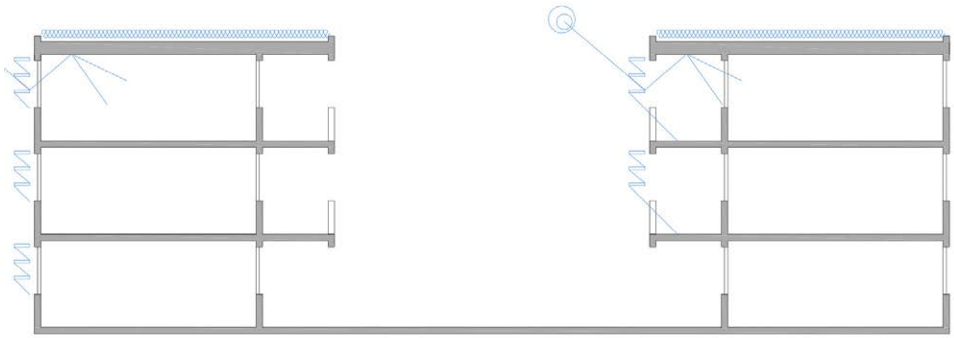
MAPA DE CONFORT

| HORA | COEF | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 0.46 | 21.0 | 21.1 | 20.2 | 18.4 | 17.0 | 16.0 | 15.3 | 15.5 | 16.1 | 17.0 | 18.3 | 19.8 | 20.6 | 16.1 | 18.0 |
| 2 | 0.32 | 19.9 | 20.1 | 19.2 | 17.4 | 16.1 | 15.2 | 14.7 | 14.8 | 15.4 | 16.2 | 17.4 | 18.8 | 19.6 | 15.3 | 17.1 |
| 3 | 0.19 | 19.0 | 19.1 | 18.2 | 16.5 | 15.3 | 14.5 | 14.0 | 14.2 | 14.7 | 15.5 | 16.5 | 17.8 | 18.6 | 14.6 | 16.3 |
| 4 | 0.08 | 18.2 | 18.2 | 17.4 | 15.7 | 14.6 | 13.9 | 13.5 | 13.7 | 14.2 | 14.9 | 15.8 | 17.1 | 17.8 | 14.0 | 15.6 |
| 5 | 0.02 | 17.7 | 17.8 | 17.0 | 15.3 | 14.2 | 13.6 | 13.2 | 13.4 | 13.9 | 14.6 | 15.4 | 16.6 | 17.4 | 13.7 | 15.2 |
| 6 | 0.00 | 17.6 | 17.6 | 16.8 | 15.1 | 14.1 | 13.5 | 13.1 | 13.3 | 13.8 | 14.5 | 15.3 | 16.5 | 17.2 | 13.6 | 15.1 |
| 7 | 0.06 | 18.0 | 18.1 | 17.3 | 15.6 | 14.5 | 13.8 | 13.4 | 13.6 | 14.1 | 14.8 | 15.7 | 16.9 | 17.7 | 13.9 | 15.5 |
| 8 | 0.15 | 18.7 | 18.8 | 17.9 | 16.2 | 15.0 | 14.3 | 13.9 | 14.0 | 14.5 | 15.3 | 16.3 | 17.6 | 18.3 | 14.4 | 16.0 |
| 9 | 0.26 | 19.5 | 19.6 | 18.7 | 17.0 | 15.7 | 14.9 | 14.4 | 14.5 | 15.1 | 15.9 | 17.0 | 18.3 | 19.1 | 15.0 | 16.7 |
| 10 | 0.44 | 20.8 | 21.0 | 20.0 | 18.3 | 16.8 | 15.9 | 15.3 | 15.4 | 16.0 | 16.9 | 18.1 | 19.6 | 20.5 | 16.0 | 17.8 |
| 11 | 0.79 | 23.4 | 23.6 | 22.6 | 20.8 | 19.0 | 17.8 | 16.9 | 17.1 | 17.7 | 18.8 | 20.4 | 22.1 | 23.0 | 17.9 | 20.0 |
| 12 | 0.91 | 24.3 | 24.5 | 23.5 | 21.6 | 19.8 | 18.5 | 17.5 | 17.7 | 18.3 | 19.5 | 21.2 | 22.9 | 23.9 | 18.6 | 20.8 |
| 13 | 0.97 | 24.7 | 24.9 | 23.9 | 22.0 | 20.1 | 18.8 | 17.8 | 18.0 | 18.6 | 19.8 | 21.5 | 23.4 | 24.3 | 18.9 | 21.1 |
| 14 | 1.00 | 24.9 | 25.2 | 24.1 | 22.3 | 20.3 | 19.0 | 18.0 | 18.1 | 18.8 | 20.0 | 21.7 | 23.6 | 24.6 | 19.1 | 21.3 |
| 15 | 0.98 | 24.8 | 25.0 | 24.0 | 22.1 | 20.2 | 18.9 | 17.9 | 18.0 | 18.7 | 19.9 | 21.6 | 23.4 | 24.4 | 19.0 | 21.2 |
| 16 | 0.94 | 24.5 | 24.7 | 23.7 | 21.8 | 20.0 | 18.7 | 17.7 | 17.8 | 18.5 | 19.7 | 21.4 | 23.2 | 24.1 | 18.8 | 21.0 |
| 17 | 0.91 | 24.3 | 24.5 | 23.5 | 21.6 | 19.8 | 18.5 | 17.5 | 17.7 | 18.3 | 19.5 | 21.2 | 22.9 | 23.9 | 18.6 | 20.8 |
| 18 | 0.87 | 24.0 | 24.2 | 23.2 | 21.3 | 19.5 | 18.3 | 17.3 | 17.5 | 18.1 | 19.3 | 20.9 | 22.7 | 23.6 | 18.4 | 20.5 |
| 19 | 0.83 | 23.7 | 23.9 | 22.9 | 21.0 | 19.3 | 18.1 | 17.1 | 17.3 | 17.9 | 19.0 | 20.6 | 22.4 | 23.3 | 18.2 | 20.3 |
| 20 | 0.80 | 23.5 | 23.7 | 22.7 | 20.8 | 19.1 | 17.9 | 17.0 | 17.1 | 17.8 | 18.9 | 20.5 | 22.2 | 23.1 | 18.0 | 20.1 |
| 21 | 0.75 | 23.1 | 23.3 | 22.3 | 20.5 | 18.8 | 17.6 | 16.7 | 16.9 | 17.5 | 18.6 | 20.1 | 21.8 | 22.7 | 17.7 | 19.8 |
| 22 | 0.70 | 22.7 | 22.9 | 21.9 | 20.1 | 18.5 | 17.3 | 16.5 | 16.7 | 17.3 | 18.3 | 19.8 | 21.5 | 22.4 | 17.4 | 19.5 |
| 23 | 0.64 | 22.3 | 22.5 | 21.5 | 19.7 | 18.1 | 17.0 | 16.2 | 16.4 | 17.0 | 18.0 | 19.4 | 21.0 | 21.9 | 17.1 | 19.1 |
| 24 | 0.57 | 21.8 | 21.9 | 21.0 | 19.2 | 17.6 | 16.6 | 15.9 | 16.0 | 16.6 | 17.6 | 19.0 | 20.5 | 21.4 | 16.7 | 18.7 |

| | | | | |
|---|---|---|---|---|
| CONFORT | 20 | a | 24 | ºC |
| FRÍO | | menos de | 20 | ºC |
| CALOR | | más de | 24 | ºC |

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 88.
Panamá shading. Natural ventilation. Thermally insulated building envelope. Solar heating. Iquique.



## Iquique

The hygrothermal conditions of the classroom are within the thermal comfort zone but with high levels of relative humidity. Nevertheless, more than 50% of students reported discomfort. Additionally, in the north-facing classroom more than 70% of students were perspiring. Ventilation is insufficient since it does not manage to eliminate the heat generated by direct gain. In the classrooms with a northern exposure, light shelves or diffusers should be used to prevent direct radiation from entering the building. When classrooms are grouped on more than one level, care should be taken with those located on the upper floors by using shading, ventilation, or thermal insulation to limit thermal gains. Cross-ventilation and/or selective night ventilation should be used in order to take advantage of breezes and eliminate the heat accumulated by the building mass during the day. Stack ventilation is another option which has the added benefit of being able to distance the air outlets from the areas used by students, thereby reducing the noise in arcades and patios. If heating is required during the winter, passive solar systems should be used.

The presence of cloudy skies seems to explain the lighting conditions of the classrooms which in very few cases fulfilled the recommended design parameters. Nevertheless, discomfort was only recorded in south-facing classrooms (50%), where the windows are just shaded with light curtains on the inside. Minimum illuminance levels were very low in the areas furthest from the main windows, with low uniformity coefficients, and solar radiation was directly affecting the working plane. The facades of the north-facing classrooms should be redesigned, incorporating devices such as light shelves or *brise-soleil* to prevent solar radiation from directly entering the classrooms, improve the distribution of indoor illuminance, and raise the light levels in the areas furthest from the windows.

Opinion indicators reveal a high degree of discomfort caused by noise levels (90% to 100%), likely due to the lack of sound treatment of indoor surfaces and the need for ventilation, which prevents the classroom from being properly sealed off from sound. In order to improve the acoustic quality of the classroom, end walls or ceilings with sound absorption should be used. Additionally, ventilation systems that minimize airborne noise, distancing the ventilation grates from noise sources, are preferable.

Although $CO_2$ concentration levels were within the admissible range (with the exception of one south-facing classroom in the winter), opinion indicators reveal a high degree of discomfort with respect to the air quality (60% to 87%). This may be due to the high humidity levels.

## Temperate dry climate requiring shading + ventilation + heating (Peñaflor, Peñalolén)

The climate in Peñaflor is temperate and dry, with a broad thermal range. In the summer, the temperature variation between day and night is over 17°C. This decreases during the winter. Relative humidity is low in summer, with a tendency to increase during the winter. Solar radiation is high during the summer and decreased in the winter, with moderate winds from the southwest and relative calm during the summer. Due to these conditions, heating is required in the winter, while cross-ventilation and solar control should be used in the summer. The building consists of a string of classrooms with a covered outdoor corridor that opens onto a patio. The school has two floors, uses traditional medium-weight construction materials and is located in an urban setting. The classrooms studied have two rows of windows on opposite sides.

The climate in Peñalolén is temperate and dry with a broad thermal range. The temperature fluctuation between day and night is significant during the summer (over 17°C) and decreases during winter (approximately 11°C). Solar radiation is high during thesummer and low during the winter. Relative humidity is low in summer with a tendency to increase during the winter months. Moderate winds come predominantly from the southwest with relative calm during the summer. Due to these conditions, heating is required in the winter, while cross-ventilation and solar control should be used in the summer. Classrooms are organized in a string on three floors with covered outdoor corridors leading toward a patio. Medium-weight construction materials were used and classroom windows are on two adjacent walls.

### Peñaflor

During the winter, the hygrothermal conditions of the classroom are much lower than the levels

FIGURE 89.
Panamá Malloco School 664. Municipality of Peñaflor.
Temperate dry climate.

**MAPA DE CONFORT**

| HORA | COEF | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 0.46 | 20.5 | 19.9 | 18.1 | 14.8 | 11.8 | 9.1 | 8.8 | 10.1 | 11.9 | 14.6 | 17.0 | 19.4 | 19.9 | 9.9 | 14.7 |
| 2 | 0.32 | 18.2 | 17.6 | 15.9 | 12.8 | 10.1 | 7.6 | 7.3 | 8.4 | 10.1 | 12.6 | 14.8 | 17.1 | 17.7 | 8.3 | 12.7 |
| 3 | 0.19 | 16.1 | 15.5 | 13.8 | 10.9 | 8.5 | 6.2 | 5.9 | 6.9 | 8.5 | 10.8 | 12.9 | 15.0 | 15.5 | 6.9 | 10.9 |
| 4 | 0.08 | 14.3 | 13.7 | 12.1 | 9.3 | 7.2 | 5.0 | 4.7 | 5.6 | 7.1 | 9.3 | 11.2 | 13.3 | 13.8 | 5.6 | 9.4 |
| 5 | 0.02 | 13.3 | 12.8 | 11.1 | 8.4 | 6.5 | 4.4 | 4.0 | 4.9 | 6.3 | 8.4 | 10.3 | 12.3 | 12.8 | 5.0 | 8.6 |
| 6 | 0.00 | 12.9 | 12.4 | 10.8 | 8.1 | 6.2 | 4.2 | 3.8 | 4.7 | 6.1 | 8.1 | 10.0 | 12.0 | 12.5 | 4.7 | 8.3 |
| 7 | 0.06 | 13.9 | 13.4 | 11.8 | 9.0 | 7.0 | 4.8 | 4.4 | 5.4 | 6.8 | 9.0 | 10.9 | 13.0 | 13.4 | 5.4 | 9.1 |
| 8 | 0.15 | 15.4 | 14.9 | 13.2 | 10.3 | 8.1 | 5.8 | 5.4 | 6.4 | 8.0 | 10.2 | 12.3 | 14.4 | 14.9 | 6.4 | 10.4 |
| 9 | 0.26 | 17.2 | 16.7 | 15.0 | 11.9 | 9.4 | 7.0 | 6.6 | 7.7 | 9.4 | 11.8 | 13.9 | 16.2 | 16.7 | 7.7 | 11.9 |
| 10 | 0.44 | 20.2 | 19.6 | 17.8 | 14.5 | 11.6 | 8.9 | 8.6 | 9.8 | 11.7 | 14.3 | 16.7 | 19.1 | 19.6 | 9.7 | 14.4 |
| 11 | 0.79 | 25.9 | 25.3 | 23.4 | 19.6 | 15.8 | 12.7 | 12.4 | 13.9 | 16.1 | 19.2 | 21.9 | 24.7 | 25.3 | 13.7 | 19.2 |
| 12 | 0.91 | 27.9 | 27.2 | 25.3 | 21.3 | 17.3 | 14.0 | 13.8 | 15.3 | 17.6 | 20.8 | 23.7 | 26.6 | 27.3 | 15.0 | 20.9 |
| 13 | 0.97 | 28.9 | 28.2 | 26.3 | 22.2 | 18.0 | 14.7 | 14.4 | 16.0 | 18.4 | 21.7 | 24.6 | 27.6 | 28.2 | 15.7 | 21.7 |
| 14 | 1.00 | 29.4 | 28.7 | 26.7 | 22.6 | 18.4 | 15.0 | 14.8 | 16.4 | 18.8 | 22.1 | 25.1 | 28.1 | 28.7 | 16.0 | 22.2 |
| 15 | 0.98 | 29.0 | 28.4 | 26.4 | 22.3 | 18.1 | 14.8 | 14.5 | 16.1 | 18.5 | 21.8 | 24.8 | 27.8 | 28.4 | 15.8 | 21.9 |
| 16 | 0.94 | 28.4 | 27.7 | 25.8 | 21.8 | 17.6 | 14.3 | 14.1 | 15.7 | 18.0 | 21.2 | 24.2 | 27.1 | 27.7 | 15.4 | 21.3 |
| 17 | 0.91 | 27.9 | 27.2 | 25.3 | 21.3 | 17.3 | 14.0 | 13.8 | 15.3 | 17.6 | 20.8 | 23.7 | 26.6 | 27.3 | 15.0 | 20.9 |
| 18 | 0.87 | 27.2 | 26.6 | 24.7 | 20.8 | 16.8 | 13.6 | 13.3 | 14.8 | 17.1 | 20.3 | 23.1 | 26.0 | 26.6 | 14.6 | 20.4 |
| 19 | 0.83 | 26.6 | 25.9 | 24.0 | 20.2 | 16.3 | 13.2 | 12.9 | 14.4 | 16.6 | 19.7 | 22.5 | 25.4 | 26.0 | 14.1 | 19.8 |
| 20 | 0.80 | 26.1 | 25.4 | 23.6 | 19.7 | 15.9 | 12.8 | 12.6 | 14.0 | 16.2 | 19.3 | 22.1 | 24.9 | 25.5 | 13.8 | 19.4 |
| 21 | 0.75 | 25.3 | 24.6 | 22.8 | 19.0 | 15.3 | 12.3 | 12.0 | 13.4 | 15.6 | 18.6 | 21.3 | 24.1 | 24.7 | 13.2 | 18.7 |
| 22 | 0.70 | 24.4 | 23.8 | 22.0 | 18.3 | 14.7 | 11.7 | 11.5 | 12.9 | 15.0 | 17.9 | 20.6 | 23.3 | 23.8 | 12.6 | 18.0 |
| 23 | 0.64 | 23.5 | 22.8 | 21.0 | 17.4 | 14.0 | 11.1 | 10.8 | 12.2 | 14.2 | 17.1 | 19.7 | 22.3 | 22.9 | 12.0 | 17.2 |
| 24 | 0.57 | 22.3 | 21.7 | 19.9 | 16.4 | 13.1 | 10.3 | 10.0 | 11.3 | 13.3 | 16.1 | 18.6 | 21.2 | 21.7 | 11.2 | 16.2 |

| | | | | |
|---|---|---|---|---|
| CONFORT | 20 | a | 24 | ºC |
| FRÍO | | menos de | 20 | ºC |
| CALOR | | más de | 24 | ºC |

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 90.

Likankura School. Municipality of Peñalolén. Santiago de Chile. Temperate dry climate.

**MAPA DE CONFORT**

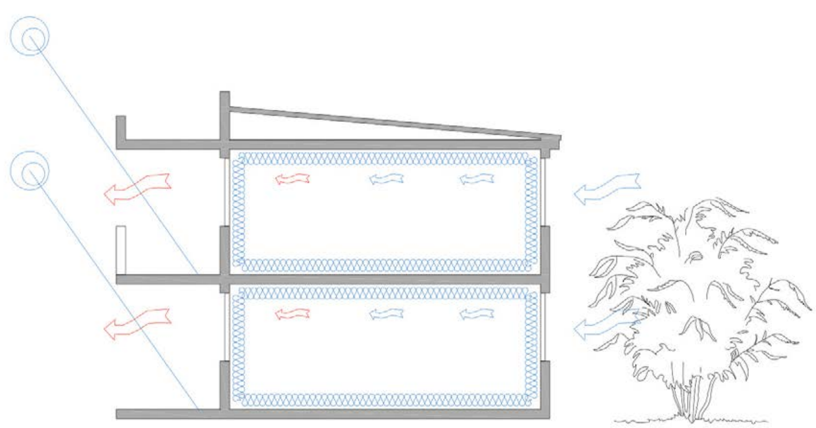
| HORA | COEF | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 0.46 | 20.7 | 20.1 | 18.2 | 15.0 | 12.0 | 9.3 | 9.0 | 10.3 | 12.0 | 14.7 | 17.1 | 19.5 | 20.1 | 10.1 | 14.8 |
| 2 | 0.32 | 18.3 | 17.7 | 15.9 | 12.9 | 10.3 | 7.8 | 7.4 | 8.6 | 10.2 | 12.7 | 15.0 | 17.2 | 17.8 | 8.5 | 12.8 |
| 3 | 0.19 | 16.2 | 15.6 | 13.8 | 10.9 | 8.7 | 6.4 | 6.0 | 7.1 | 8.6 | 10.9 | 13.0 | 15.1 | 15.6 | 7.0 | 11.0 |
| 4 | 0.08 | 14.3 | 13.7 | 12.0 | 9.2 | 7.3 | 5.2 | 4.8 | 5.8 | 7.1 | 9.3 | 11.3 | 13.3 | 13.8 | 5.7 | 9.4 |
| 5 | 0.02 | 13.3 | 12.7 | 11.0 | 8.3 | 6.5 | 4.5 | 4.1 | 5.0 | 6.4 | 8.5 | 10.4 | 12.3 | 12.8 | 5.1 | 8.6 |
| 6 | 0.00 | 13.0 | 12.4 | 10.7 | 8.0 | 6.3 | 4.3 | 3.9 | 4.8 | 6.1 | 8.2 | 10.1 | 12.0 | 12.5 | 4.8 | 8.3 |
| 7 | 0.06 | 14.0 | 13.4 | 11.7 | 8.9 | 7.0 | 5.0 | 4.6 | 5.5 | 6.9 | 9.0 | 11.0 | 13.0 | 13.5 | 5.5 | 9.2 |
| 8 | 0.15 | 15.5 | 14.9 | 13.1 | 10.3 | 8.2 | 5.9 | 5.6 | 6.6 | 8.0 | 10.3 | 12.4 | 14.5 | 15.0 | 6.5 | 10.4 |
| 9 | 0.26 | 17.3 | 16.7 | 14.9 | 12.0 | 9.5 | 7.1 | 6.8 | 7.9 | 9.5 | 11.9 | 14.1 | 16.3 | 16.8 | 7.8 | 12.0 |
| 10 | 0.44 | 20.3 | 19.7 | 17.8 | 14.7 | 11.8 | 9.1 | 8.7 | 10.0 | 11.8 | 14.4 | 16.8 | 19.2 | 19.8 | 9.9 | 14.5 |
| 11 | 0.79 | 26.2 | 25.6 | 23.5 | 20.1 | 16.1 | 12.9 | 12.6 | 14.2 | 16.3 | 19.3 | 22.2 | 25.0 | 25.6 | 13.9 | 19.5 |
| 12 | 0.91 | 28.2 | 27.6 | 25.4 | 21.9 | 17.6 | 14.2 | 13.9 | 15.6 | 17.8 | 21.0 | 24.0 | 26.9 | 27.6 | 15.2 | 21.2 |
| 13 | 0.97 | 29.2 | 28.6 | 26.4 | 22.8 | 18.3 | 14.9 | 14.6 | 16.3 | 18.6 | 21.9 | 24.9 | 27.9 | 28.6 | 15.9 | 22.0 |
| 14 | 1.00 | 29.7 | 29.1 | 26.9 | 23.3 | 18.7 | 15.2 | 14.9 | 16.7 | 19.0 | 22.3 | 25.4 | 28.4 | 29.1 | 16.3 | 22.5 |
| 15 | 0.98 | 29.4 | 28.8 | 26.6 | 23.0 | 18.5 | 15.0 | 14.7 | 16.5 | 18.7 | 22.0 | 25.1 | 28.1 | 28.7 | 16.0 | 22.2 |
| 16 | 0.94 | 28.7 | 28.1 | 25.9 | 22.4 | 18.0 | 14.5 | 14.2 | 16.0 | 18.2 | 21.5 | 24.5 | 27.4 | 28.1 | 15.6 | 21.6 |
| 17 | 0.91 | 28.2 | 27.6 | 25.4 | 21.9 | 17.6 | 14.2 | 13.9 | 15.6 | 17.8 | 21.0 | 24.0 | 26.9 | 27.6 | 15.2 | 21.2 |
| 18 | 0.87 | 27.5 | 26.9 | 24.8 | 21.3 | 17.1 | 13.8 | 13.5 | 15.2 | 17.3 | 20.5 | 23.4 | 26.3 | 26.9 | 14.8 | 20.6 |
| 19 | 0.83 | 26.9 | 26.3 | 24.1 | 20.7 | 16.6 | 13.3 | 13.0 | 14.7 | 16.8 | 19.9 | 22.8 | 25.6 | 26.2 | 14.3 | 20.1 |
| 20 | 0.80 | 26.4 | 25.8 | 23.7 | 20.2 | 16.2 | 13.0 | 12.7 | 14.3 | 16.4 | 19.5 | 22.3 | 25.1 | 25.7 | 14.0 | 19.6 |
| 21 | 0.75 | 25.5 | 24.9 | 22.9 | 19.5 | 15.6 | 12.5 | 12.2 | 13.7 | 15.8 | 18.8 | 21.6 | 24.3 | 24.9 | 13.4 | 18.9 |
| 22 | 0.70 | 24.7 | 24.1 | 22.0 | 18.7 | 15.0 | 11.9 | 11.6 | 13.1 | 15.1 | 18.1 | 20.8 | 23.5 | 24.1 | 12.8 | 18.2 |
| 23 | 0.64 | 23.7 | 23.1 | 21.1 | 17.8 | 14.2 | 11.3 | 10.9 | 12.4 | 14.4 | 17.2 | 19.9 | 22.5 | 23.1 | 12.2 | 17.4 |
| 24 | 0.57 | 22.5 | 21.9 | 19.9 | 16.7 | 13.4 | 10.5 | 10.2 | 11.6 | 13.5 | 16.2 | 18.8 | 21.3 | 21.9 | 11.4 | 16.4 |

| | | | |
|---|---|---|---|
| CONFORT | 20 a | 24 | ºC |
| FRÍO | menos de | 20 | ºC |
| CALOR | más de | 24 | ºC |

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

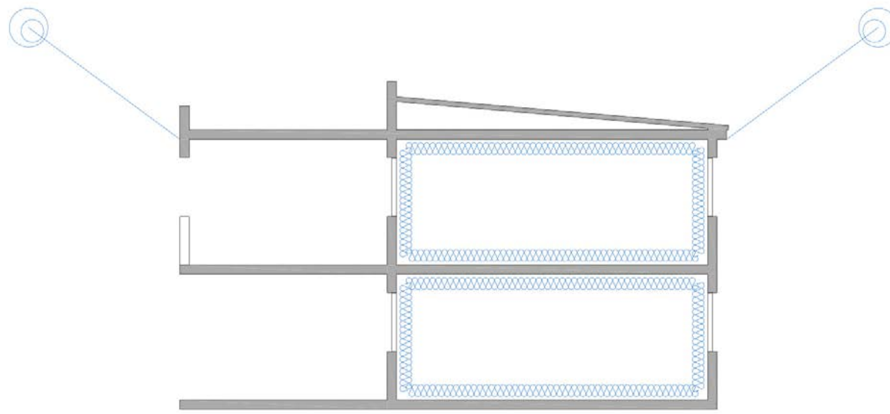
FIGURE 91.

Shading. Natural ventilation. Thermally insulated building envelope. Peñaflor.



recommended for comfort, with low temperatures and high relative humidity (12°C, 90%, respectively). The sensation of thermal discomfort is clear, and ranges from 50% of students in the south-facing classroom to 85% in the north. The high percentages of relative humidity mean that between 40% and 50% of students were perspiring, which may contribute to their opinion of discomfort. Heating is needed during the winter months. This can be resolved by using passive solar systems, such as north-facing collector

FIGURE 92.
Shading. Natural ventilation. Thermally insulated building envelope. Peñalolén.



facades, greenhouses, heat accumulating walls, or solar air collectors, or by adding traditional heating sources. The thermal insulation of the entire building envelope should also be improved to eliminate thermal bridges. Priority should be given to optimizing the insulation in the roof of the upper floors, since this is where the greatest thermal losses occur. During the summer, the hygrothermal situation falls within the LCR, despite the fact that more than 50% of students were perspiring and reported discomfort. In this case, window design should be improved, in order facilitate cross-ventilation, and solar gain should be reduced by incorporating "shade roofs" on the upper floors.

## Peñalolén

During the winter, the hygrothermal conditions of the classroom were much lower than the levels recommended for comfort, with low temperatures and high relative humidity (14°C and 80%, respectively). 50% of students were warmly dressed in the winter and a significant percentage reported thermal comfort, which reveals habituation to extreme conditions. During the summer, recorded levels were outside of the comfort range and overheating was observed. 50% of students were warmly dressed and more than a quarter perspired. Nevertheless, no more than 20% of students reported discomfort. Heating can be improved by using traditional sources (currently none are being used) along with passive solar systems on the north-facing collector facades, such as a greenhouse, heat accumulating walls, or lightweight solar air collectors. The thermal insulation of the entire building envelope (walls, ceilings, floors, and glazed windows) should be improved to eliminate thermal bridges.

In all cases, the recorded illuminance levels in classrooms were high and irregular, and did not comply with the recommended standards. Very high illuminance levels were recorded close to windows while on the opposite side of classrooms, levels were low. This situation should be balanced out. Most students reported being comfortable with the lighting conditions (80%). This suggests a need to reduce the illuminance levels close to windows, especially north-facing ones, by redesigning the window systems so that they produce more uniform illuminance levels throughout the classroom. Light shelves over the windows or shading on north-facing arcades may be used in order to prevent the direct impact of solar radiation and reflect light toward the opposite side of the classroom, with pale colors used on both the light shelves and arcade floors. Larger windows could also be used in the arcades as well as skylights with diffusers in the upper floors, as needed.

Approximately 95% of students reported a generalized sense of acoustic discomfort. This was reflected in all the audits, regardless of the season. This may be due to the need to keep the windows open for ventilation, although they open out onto the patio and arcades, as well as to the lack of indoor acoustic treatment. In Peñalolén, this is worsened by the large number of students in classrooms surrounding the patio on all three floors of the building. Sound insulation in classrooms should be improved, especially in common areas, to avoid airborne noise from entering. At the same time, the inside walls of classrooms should be treated in order to reduce reverberation. Additionally, ventilation systems can be improved by avoiding openings placed close to noisy areas so that the sound insulation of the building envelope is effective.

Due to a lack of ventilation combined with the use of heating systems in the winter, $CO_2$ levels exceeded the permitted values in all of the audited classrooms (with the highest values recorded during the winter in the south-facing classrooms). As a result, a high percentage of students reported stale air (35% to 71%).

## Very cold climate requiring heating (Punta Arenas)

Punta Arenas has a very cold climate, with low temperatures in the summer and very low ones in the winter. Heating is needed throughout the year and the heat generated through the thermal insulation of the building envelope should also be conserved by using IGUs with Low-E coating and eliminating thermal bridges. Given the harsh climate, hallways should be protected and heated (whether they be in a single or double bay or around covered patios) favoring more compact layouts that result in fewer losses through the building envelope. A string of classrooms arranged on two floors are organized around a central covered patio. The school is surrounded by scattered buildings.

FIGURE 93.
Patagonia School. Punta Arenas City. Very cold climate.

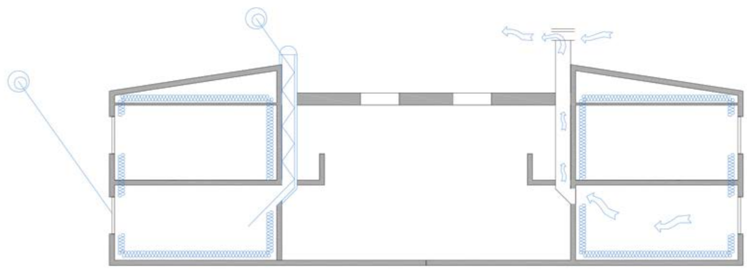
**MAPA DE CONFORT**

| HORA | COEF | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 0.46 | 10.3 | 10.0 | 8.6 | 6.2 | 3.5 | 1.6 | 1.1 | 2.4 | 4.2 | 6.3 | 6.3 | 9.6 | 9.9 | 2.0 | 5.8 |
| 2 | 0.32 | 9.1 | 8.8 | 7.5 | 5.3 | 2.7 | 0.9 | 0.4 | 1.6 | 3.2 | 5.2 | 4.7 | 8.4 | 8.8 | 1.3 | 4.8 |
| 3 | 0.19 | 8.1 | 7.8 | 6.5 | 4.5 | 2.0 | 0.2 | -0.2 | 0.9 | 2.3 | 4.1 | 3.3 | 7.3 | 7.7 | 0.7 | 3.9 |
| 4 | 0.08 | 7.2 | 6.9 | 5.6 | 3.7 | 1.4 | -0.3 | -0.7 | 0.3 | 1.6 | 3.2 | 2.0 | 6.4 | 6.8 | 0.1 | 3.1 |
| 5 | 0.02 | 6.7 | 6.4 | 5.2 | 3.3 | 1.1 | -0.6 | -1.0 | 0.0 | 1.1 | 2.8 | 1.3 | 5.9 | 6.3 | -0.2 | 2.7 |
| 6 | 0.00 | 6.5 | 6.2 | 5.0 | 3.2 | 1.0 | -0.7 | -1.1 | -0.1 | 1.0 | 2.6 | 1.1 | 5.7 | 6.1 | -0.3 | 2.5 |
| 7 | 0.06 | 7.0 | 6.7 | 5.5 | 3.6 | 1.3 | -0.4 | -0.8 | 0.2 | 1.4 | 3.1 | 1.8 | 6.2 | 6.6 | 0.0 | 3.0 |
| 8 | 0.15 | 7.7 | 7.4 | 6.2 | 4.2 | 1.8 | 0.0 | -0.4 | 0.7 | 2.0 | 3.8 | 2.8 | 7.0 | 7.4 | 0.5 | 3.6 |
| 9 | 0.26 | 8.6 | 8.3 | 7.0 | 4.9 | 2.4 | 0.6 | 0.1 | 1.3 | 2.8 | 4.7 | 4.1 | 7.9 | 8.3 | 1.0 | 4.4 |
| 10 | 0.44 | 10.1 | 9.8 | 8.4 | 6.1 | 3.4 | 1.5 | 1.0 | 2.3 | 4.0 | 6.1 | 6.1 | 9.4 | 9.8 | 1.9 | 5.7 |
| 11 | 0.79 | 13.0 | 12.7 | 11.2 | 8.4 | 5.3 | 3.2 | 2.7 | 4.2 | 6.5 | 8.9 | 10.1 | 12.3 | 12.7 | 3.7 | 8.2 |
| 12 | 0.91 | 14.0 | 13.7 | 12.1 | 9.2 | 5.9 | 3.8 | 3.3 | 4.8 | 7.3 | 9.9 | 11.5 | 13.3 | 13.7 | 4.3 | 9.1 |
| 13 | 0.97 | 14.5 | 14.2 | 12.6 | 9.6 | 6.2 | 4.1 | 3.6 | 5.1 | 7.7 | 10.4 | 12.2 | 13.8 | 14.2 | 4.6 | 9.5 |
| 14 | 1.00 | 14.7 | 14.4 | 12.8 | 9.8 | 6.4 | 4.2 | 3.7 | 5.3 | 7.9 | 10.6 | 12.5 | 14.1 | 14.4 | 4.8 | 9.7 |
| 15 | 0.98 | 14.5 | 14.2 | 12.6 | 9.7 | 6.3 | 4.1 | 3.6 | 5.2 | 7.8 | 10.4 | 12.3 | 13.9 | 14.2 | 4.7 | 9.6 |
| 16 | 0.94 | 14.2 | 13.9 | 12.3 | 9.4 | 6.1 | 3.9 | 3.4 | 5.0 | 7.5 | 10.1 | 11.8 | 13.6 | 13.9 | 4.5 | 9.3 |
| 17 | 0.91 | 14.0 | 13.7 | 12.1 | 9.2 | 5.9 | 3.8 | 3.3 | 4.8 | 7.3 | 9.9 | 11.5 | 13.3 | 13.7 | 4.3 | 9.1 |
| 18 | 0.87 | 13.6 | 13.3 | 11.8 | 8.9 | 5.7 | 3.6 | 3.1 | 4.6 | 7.0 | 9.6 | 11.0 | 13.0 | 13.3 | 4.1 | 8.8 |
| 19 | 0.83 | 13.3 | 13.0 | 11.5 | 8.7 | 5.5 | 3.4 | 2.9 | 4.4 | 6.7 | 9.2 | 10.6 | 12.7 | 13.0 | 3.9 | 8.5 |
| 20 | 0.80 | 13.1 | 12.8 | 11.2 | 8.5 | 5.3 | 3.2 | 2.7 | 4.2 | 6.5 | 9.0 | 10.2 | 12.4 | 12.7 | 3.8 | 8.3 |
| 21 | 0.75 | 12.7 | 12.4 | 10.9 | 8.2 | 5.1 | 3.0 | 2.5 | 4.0 | 6.2 | 8.6 | 9.7 | 12.0 | 12.3 | 3.5 | 7.9 |
| 22 | 0.70 | 12.2 | 11.9 | 10.5 | 7.8 | 4.8 | 2.7 | 2.3 | 3.7 | 5.8 | 8.2 | 9.1 | 11.6 | 11.9 | 3.3 | 7.6 |
| 23 | 0.64 | 11.7 | 11.4 | 10.0 | 7.4 | 4.5 | 2.4 | 2.0 | 3.4 | 5.4 | 7.7 | 8.4 | 11.1 | 11.4 | 3.0 | 7.1 |
| 24 | 0.57 | 11.2 | 10.9 | 9.4 | 7.0 | 4.1 | 2.1 | 1.6 | 3.0 | 4.9 | 7.2 | 7.6 | 10.5 | 10.8 | 2.6 | 6.6 |

| | | |
|---|---|---|
| CONFORT | 20 a 24 | °C |
| FRÍO | menos de 20 | °C |
| CALOR | más de 24 | °C |

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 94.
Thermally insulated building envelope. Passive solar systems. Punta Arenas.



### Punta arenas

The hygrothermal conditions of the audited classrooms fell within the comfort zone, due to the use of traditional heating. Most students reported being comfortable, although many of them were perspiring. The classrooms located on the upper floor had higher thermal losses through the building envelope. There is therefore a greater need for heating on this floor and special attention should be paid to the thermal insulation of the roof. Classroom organization should also aim to protect outside spaces from the intense winds that come from the western quadrant year-round. Solar radiation is moderate during the summer and very low during the winter. Heating can be improved, in part, through the use of passive solar systems, such as north-facing greenhouses or solar air collectors.

Nevertheless, the natural lighting of the audited classrooms did not fulfill the recommended parameters, although most students reported that they were adequate. The illuminance levels were very irregular, with very high levels recorded close to windows while at the back of the classrooms, levels were low. This is due to the fact that lighting enters the classrooms through a single wall of windows on the exposed side of the building. North-facing windows should be redesigned in order to increase illuminance levels throughout the classroom and avoid direct solar radiation on the inside.

With regard to sound, higher than acceptable noise levels were recorded and a high number of students reported discomfort (85% to 90%). One of the most basic issues to resolve is the insufficient sound insulation between classrooms, given the proximity of the closed patio and other classrooms, and the reverberation resulting from closed spaces lacking acoustic treatment.

$CO_2$ levels exceeded the recommended values. This is likely due to the need to reduce ventilation and minimize air infiltration to conserve the heat generated by traditional heating systems. Most students (60% to 85%) reported perceiving the air as stale.

## MEXICO (MX)

The locations studied during two seasons, winter and summer, dry and humid, are as follows:

### Warm humid climate

- Campeche City. School: Presidente Ávila Camacho. No. 04DPR0360E. Campeche State.
- Comalcalco City. School: Marcelino Margalli. No. 27DPR0148W. Tabasco State.

### Warm dry climate

- Ciudad Juárez. School: Jaime Torres Bodet. No. 08DPR2424B. Chihuahua State.
  Temperate dry climate
- Mexico City. School: Obras del Valle de México. No. 09DPR1535F.
- San Luis de Potosí. School: Prof. Carmen Serdán. No. 24DPR3268F. Potosí State.

### Warm humid climate requiring shading + cross-ventilation (Campeche, Comalcalco)

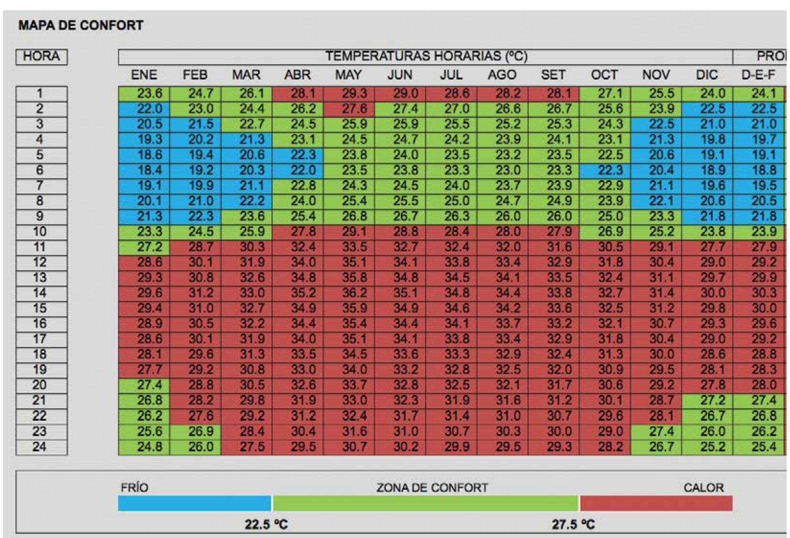
The school is located at 10 m.a.s.l. and the climate is warm and humid, with high relative humidity. Given these conditions, shading, solar control, and cross-ventilation should be used, especially on the upper level of the building. The school is situated in an urban setting and consists of a series of classrooms arranged in two symmetrical blocks, two stories high, around a central patio, accessed through covered outdoor corridors. Traditional medium-weight construction materials were used and the classrooms are lit on two sides, with north- and south-facing windows.

This is a tropical zone, with very little elevation above sea level (10m). Its proximity to the Gulf of Mexico generates a warm climate with maritime influence throughout practically the whole year. Temperatures vary between 15°C in cooler months (January and December) and 44°C during the warmest months. The annual average temperature is 26.4°C, with significant variation between day and night. There is a constant need for natural cross-ventilation. The school consists of a string of classrooms with a covered outdoor corridor. The two lower levels open out onto a covered patio, while the upper level is exposed on both sides, since it extends beyond the patio roof. The building consists of three levels, traditional medium-weight construction materials were used, and it is located in an urban setting. The classrooms studied have windows on two opposite sides.

#### Campeche

During the winter, the temperatures recorded inside the audited classroom fell outside of the comfort range (between 25°C and 34°C). Opinion indicators show that approximately a third of the students were warmly dressed and 60% perspired and reported thermal discomfort. During the summer period, indoor

FIGURE 95.
Presidente Ávila Camacho School. No. 04DPR0360E. Campeche. Warm humid climate.


MAPA DE CONFORT

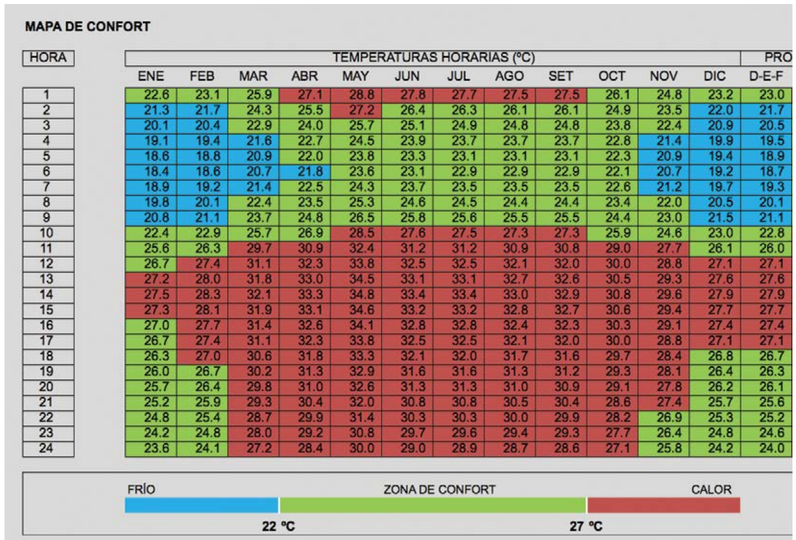
| HORA | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | PRO[M] D-E-F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | |
| 1 | 23.6 | 24.7 | 26.1 | 28.1 | 29.3 | 29.0 | 28.6 | 28.2 | 28.1 | 27.1 | 25.5 | 24.0 | 24.1 |
| 2 | 22.0 | 23.0 | 24.4 | 26.2 | 27.6 | 27.4 | 27.0 | 26.6 | 26.7 | 25.6 | 23.9 | 22.5 | 22.5 |
| 3 | 20.5 | 21.5 | 22.7 | 24.5 | 25.9 | 25.9 | 25.5 | 25.2 | 25.3 | 24.3 | 22.5 | 21.0 | 21.0 |
| 4 | 19.3 | 20.2 | 21.3 | 23.1 | 24.5 | 24.7 | 24.2 | 23.9 | 24.1 | 23.1 | 21.3 | 19.8 | 19.7 |
| 5 | 18.6 | 19.4 | 20.6 | 22.3 | 23.8 | 24.0 | 23.5 | 23.2 | 23.5 | 22.5 | 20.6 | 19.1 | 19.1 |
| 6 | 18.4 | 19.2 | 20.3 | 22.0 | 23.5 | 23.8 | 23.3 | 23.0 | 23.3 | 22.3 | 20.4 | 18.9 | 18.8 |
| 7 | 19.1 | 19.9 | 21.1 | 22.8 | 24.3 | 24.5 | 24.0 | 23.7 | 23.9 | 22.9 | 21.1 | 19.6 | 19.5 |
| 8 | 20.1 | 21.0 | 22.2 | 24.0 | 25.4 | 25.5 | 25.0 | 24.7 | 24.9 | 23.9 | 22.1 | 20.6 | 20.5 |
| 9 | 21.3 | 22.3 | 23.6 | 25.4 | 26.8 | 26.7 | 26.3 | 26.0 | 26.0 | 25.0 | 23.3 | 21.8 | 21.8 |
| 10 | 23.3 | 24.5 | 25.9 | 27.8 | 29.1 | 28.8 | 28.4 | 28.0 | 27.9 | 26.9 | 25.2 | 23.8 | 23.9 |
| 11 | 27.2 | 28.7 | 30.3 | 32.4 | 33.5 | 32.7 | 32.4 | 32.0 | 31.6 | 30.5 | 29.1 | 27.7 | 27.9 |
| 12 | 28.6 | 30.1 | 31.9 | 34.0 | 35.1 | 34.1 | 33.8 | 33.4 | 32.9 | 31.8 | 30.4 | 29.0 | 29.2 |
| 13 | 29.3 | 30.8 | 32.6 | 34.8 | 35.8 | 34.8 | 34.5 | 34.1 | 33.5 | 32.4 | 31.1 | 29.7 | 29.9 |
| 14 | 29.6 | 31.2 | 33.0 | 35.2 | 36.2 | 35.1 | 34.8 | 34.4 | 33.8 | 32.7 | 31.4 | 30.0 | 30.3 |
| 15 | 29.4 | 31.0 | 32.7 | 34.9 | 35.9 | 34.9 | 34.6 | 34.2 | 33.6 | 32.5 | 31.2 | 29.8 | 30.0 |
| 16 | 28.9 | 30.5 | 32.2 | 34.4 | 35.4 | 34.4 | 34.1 | 33.7 | 33.2 | 32.1 | 30.7 | 29.3 | 29.6 |
| 17 | 28.6 | 30.1 | 31.9 | 34.0 | 35.1 | 34.1 | 33.8 | 33.4 | 32.9 | 31.8 | 30.4 | 29.0 | 29.2 |
| 18 | 28.1 | 29.6 | 31.3 | 33.5 | 34.5 | 33.6 | 33.3 | 32.9 | 32.4 | 31.3 | 30.0 | 28.6 | 28.8 |
| 19 | 27.7 | 29.2 | 30.8 | 33.0 | 34.0 | 33.2 | 32.8 | 32.5 | 32.0 | 30.9 | 29.5 | 28.1 | 28.3 |
| 20 | 27.4 | 28.8 | 30.5 | 32.6 | 33.7 | 32.8 | 32.5 | 32.1 | 31.7 | 30.6 | 29.2 | 27.8 | 28.0 |
| 21 | 26.8 | 28.2 | 29.8 | 31.9 | 33.0 | 32.3 | 31.9 | 31.6 | 31.2 | 30.1 | 28.7 | 27.2 | 27.4 |
| 22 | 26.2 | 27.6 | 29.2 | 31.2 | 32.4 | 31.7 | 31.4 | 31.0 | 30.7 | 29.6 | 28.1 | 26.7 | 26.8 |
| 23 | 25.6 | 26.9 | 28.4 | 30.4 | 31.6 | 31.0 | 30.7 | 30.3 | 30.0 | 29.0 | 27.4 | 26.0 | 26.2 |
| 24 | 24.8 | 26.0 | 27.5 | 29.5 | 30.7 | 30.2 | 29.9 | 29.5 | 29.3 | 28.2 | 26.7 | 25.2 | 25.4 |



The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 96.

Marcelino Margalli School. No. 27DPR0148W. Comalcalco. Warm humid climate.



MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PRO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F |
| 1 | 22.6 | 23.1 | 25.9 | 27.1 | 28.8 | 27.8 | 27.7 | 27.5 | 27.5 | 26.1 | 24.8 | 23.2 | 23.0 |
| 2 | 21.3 | 21.7 | 24.3 | 25.5 | 27.2 | 26.4 | 26.3 | 26.1 | 26.1 | 24.9 | 23.5 | 22.0 | 21.7 |
| 3 | 20.1 | 20.4 | 22.9 | 24.0 | 25.7 | 25.1 | 24.9 | 24.8 | 24.8 | 23.8 | 22.4 | 20.9 | 20.5 |
| 4 | 19.1 | 19.4 | 21.6 | 22.7 | 24.5 | 23.9 | 23.7 | 23.7 | 23.7 | 22.8 | 21.4 | 19.9 | 19.5 |
| 5 | 18.6 | 18.8 | 20.9 | 22.0 | 23.8 | 23.3 | 23.1 | 23.1 | 23.1 | 22.3 | 20.9 | 19.4 | 18.9 |
| 6 | 18.4 | 18.6 | 20.7 | 21.8 | 23.6 | 23.1 | 22.9 | 22.9 | 22.9 | 22.1 | 20.7 | 19.2 | 18.7 |
| 7 | 18.9 | 19.2 | 21.4 | 22.5 | 24.3 | 23.7 | 23.5 | 23.5 | 23.5 | 22.6 | 21.2 | 19.7 | 19.3 |
| 8 | 19.8 | 20.1 | 22.4 | 23.5 | 25.3 | 24.6 | 24.5 | 24.4 | 24.4 | 23.4 | 22.0 | 20.5 | 20.1 |
| 9 | 20.8 | 21.1 | 23.7 | 24.8 | 26.5 | 25.8 | 25.6 | 25.5 | 25.5 | 24.4 | 23.0 | 21.5 | 21.1 |
| 10 | 22.4 | 22.9 | 25.7 | 26.9 | 28.5 | 27.6 | 27.5 | 27.3 | 27.3 | 25.9 | 24.6 | 23.0 | 22.8 |
| 11 | 25.6 | 26.3 | 29.7 | 30.9 | 32.4 | 31.2 | 31.2 | 30.9 | 30.8 | 29.0 | 27.7 | 26.1 | 26.0 |
| 12 | 26.7 | 27.4 | 31.1 | 32.3 | 33.8 | 32.5 | 32.5 | 32.1 | 32.0 | 30.0 | 28.8 | 27.1 | 27.1 |
| 13 | 27.2 | 28.0 | 31.8 | 33.0 | 34.5 | 33.1 | 33.1 | 32.7 | 32.6 | 30.5 | 29.3 | 27.6 | 27.6 |
| 14 | 27.5 | 28.3 | 32.1 | 33.3 | 34.8 | 33.4 | 33.4 | 33.0 | 32.9 | 30.8 | 29.6 | 27.9 | 27.9 |
| 15 | 27.3 | 28.1 | 31.9 | 33.1 | 34.6 | 33.2 | 33.2 | 32.8 | 32.7 | 30.6 | 29.4 | 27.7 | 27.7 |
| 16 | 27.0 | 27.7 | 31.4 | 32.6 | 34.1 | 32.8 | 32.8 | 32.4 | 32.3 | 30.3 | 29.1 | 27.4 | 27.4 |
| 17 | 26.7 | 27.4 | 31.1 | 32.3 | 33.8 | 32.5 | 32.5 | 32.1 | 32.0 | 30.0 | 28.8 | 27.1 | 27.1 |
| 18 | 26.3 | 27.0 | 30.6 | 31.8 | 33.3 | 32.1 | 32.0 | 31.7 | 31.6 | 29.7 | 28.4 | 26.8 | 26.7 |
| 19 | 26.0 | 26.7 | 30.2 | 31.3 | 32.9 | 31.6 | 31.6 | 31.3 | 31.2 | 29.3 | 28.1 | 26.4 | 26.3 |
| 20 | 25.7 | 26.4 | 29.8 | 31.0 | 32.6 | 31.3 | 31.3 | 31.0 | 30.9 | 29.1 | 27.8 | 26.2 | 26.1 |
| 21 | 25.2 | 25.9 | 29.3 | 30.4 | 32.0 | 30.8 | 30.8 | 30.5 | 30.4 | 28.6 | 27.4 | 25.7 | 25.6 |
| 22 | 24.8 | 25.4 | 28.7 | 29.9 | 31.4 | 30.3 | 30.3 | 30.0 | 29.9 | 28.2 | 26.9 | 25.3 | 25.2 |
| 23 | 24.2 | 24.8 | 28.0 | 29.2 | 30.8 | 29.7 | 29.6 | 29.4 | 29.3 | 27.7 | 26.4 | 24.8 | 24.6 |
| 24 | 23.6 | 24.1 | 27.2 | 28.4 | 30.0 | 29.0 | 28.9 | 28.7 | 28.6 | 27.1 | 25.8 | 24.2 | 24.0 |

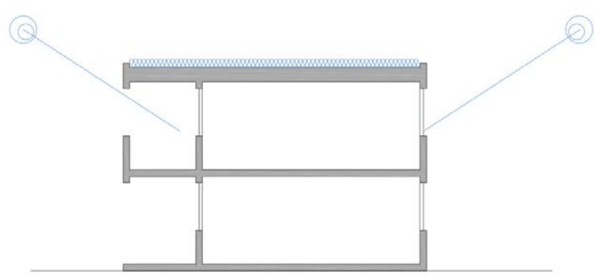
FRÍO — ZONA DE CONFORT — CALOR

22 °C — 27 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 97.

Shading. Natural ventilation. Thermally insulated roof. Campeche.

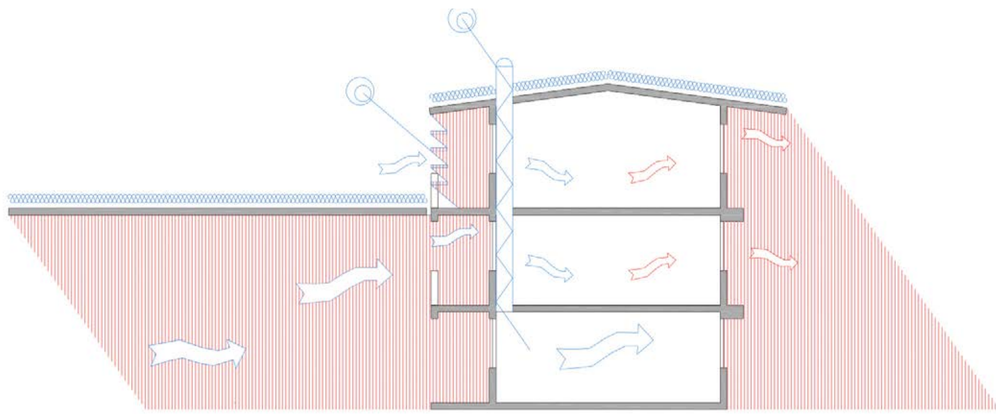


temperatures above 30°C were recorded, exceeding temperatures outside. This means that the building envelope is inadequate and radiation is entering through the windows. 70% of students reported thermal discomfort and were also perspiring. Cross-ventilation is needed and the air entering the building should be cooler than the air outside. Outside areas should be shaded and measures should be taken to prevent the building envelope from overheating. Options for doing so include solar chimneys, shade roofs, and improved shading on the south-facing facade.

## Comalcalco

The audited classroom meets the conditions for hygrothermal comfort in the winter. However, during the summer, the situation is critical, with high temperatures and relative humidity reaching 35°C and 83.6% inside. However, student opinion regarding discomfort was between 32% and 47% and did not reflect this variation. Between 38% and 57% of students reported perspiring. Their tolerance to adverse conditions was greater in the summer and they reported comfort in conditions of significant overheating. In this case, in order to reach acceptable levels, energy-intensive air conditioning units must be used, although this could be avoided if the building envelope were adapted to include thermal insulation, passive solar heating, shading (especially of classrooms on the upper levels), solar control, and cross-ventilation.

FIGURE 98.
Shading. Natural ventilation. Thermally insulated roof. Comalcalco.



As a general rule, in the winter, illuminance levels are very low, with little uniformity and glare, while in the summer, illuminance is high near the windows and low near the arcade. This situation should be balanced out. In some cases, due to the need to shutter windows in order to avoid direct solar radiation, the light levels were below the desired range throughout the year, even when complementary artificial lighting was used. Despite the conditions described, only a small percentage of the students reported discomfort (15% to 32%), which suggests a high degree of habituation to unfavorable lighting conditions. Solar protection and improved window design should be prioritized in order to balance the illuminance levels and avoid distracting reflections and glare. Potential solutions include the introduction of light shelves, reflective floors in the north-facing arcades, skylights with diffusers on upper floors, and lightwells for the lower floors.

The recorded noise levels are excessive almost all the time, given the noise entering from the covered patio or the street (general activity and heavy traffic) as well as the reverberation in classrooms without acoustic treatment. With respect to perception of noise levels, between 75% and 100% of the students reported unfavorable conditions. The sound insulation of the classrooms should be improved, especially those bordering on common or public areas, in order to avoid the ingress of airborne noise. At the same time, the inside walls of the classrooms should be treated to reduce reverberation.

In all the classrooms audited, the recorded $CO_2$ levels were within the acceptable range. However, during the summer, the air quality received a negative evaluation by a high percentage of students (between 65% and 75%) due to the heat, humidity, and odors generated by occupants.

## Warm dry climate requiring shading + cross-ventilation + heating (Ciudad Juárez)

The climate in Ciudad Juárez, located at 1246 m.a.s.l. is extreme desert. The annual average temperature of the city is 16.7°C, with a thermal variation of 22°C between the coldest and warmest months. (The average in January is 5.3°C and in July, 35.6°C.) Additionally, the temperature variation between day and night is significant. During the summer, the temperatures are warm during the day, temperate at night, and cool at dawn (fluctuating between 35°C and 18°C). In the winter, temperatures are cool during the day and very cold at night (fluctuating between 14°C and -1°C). Temperatures vary greatly from one season to the next, suggesting a need for passive solar heating,

FIGURE 99.

Jaime Torres Bodet School. No. 08DPR2424B. Juárez. Warm dry climate.

**MAPA DE CONFORT**

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 7.2 | 9.8 | 13.5 | 17.1 | 21.9 | 27.3 | 28.1 | 26.7 | 23.5 | 17.9 | 11.3 | 7.5 | 8.2 | 25.7 | 17.7 |
| 2 | 5.2 | 7.5 | 11.2 | 14.8 | 19.6 | 25.0 | 26.1 | 24.8 | 21.6 | 15.8 | 9.2 | 5.4 | 6.0 | 23.6 | 15.5 |
| 3 | 3.3 | 5.4 | 9.1 | 12.7 | 17.5 | 22.8 | 24.3 | 23.0 | 19.8 | 13.9 | 7.2 | 3.5 | 4.1 | 21.6 | 13.5 |
| 4 | 1.7 | 3.7 | 7.3 | 10.8 | 15.7 | 21.0 | 22.8 | 21.5 | 18.2 | 12.2 | 5.5 | 1.8 | 2.4 | 19.8 | 11.9 |
| 5 | 0.9 | 2.7 | 6.3 | 9.8 | 14.7 | 20.0 | 22.0 | 20.7 | 17.4 | 11.3 | 4.6 | 0.9 | 1.5 | 18.9 | 10.9 |
| 6 | 0.6 | 2.4 | 6.0 | 9.5 | 14.4 | 19.7 | 21.7 | 20.4 | 17.1 | 11.0 | 4.3 | 0.6 | 1.2 | 18.6 | 10.6 |
| 7 | 1.5 | 3.4 | 7.0 | 10.5 | 15.4 | 20.7 | 22.5 | 21.2 | 17.9 | 11.9 | 5.2 | 1.5 | 2.1 | 19.5 | 11.6 |
| 8 | 2.7 | 4.8 | 8.5 | 12.0 | 16.8 | 22.2 | 23.8 | 22.5 | 19.2 | 13.3 | 6.6 | 2.9 | 3.5 | 20.9 | 12.9 |
| 9 | 4.3 | 6.6 | 10.3 | 13.8 | 18.6 | 24.0 | 25.3 | 24.0 | 20.7 | 14.9 | 8.3 | 4.5 | 5.1 | 22.6 | 14.6 |
| 10 | 6.9 | 9.4 | 13.2 | 16.8 | 21.5 | 27.0 | 27.8 | 26.4 | 23.3 | 17.6 | 11.0 | 7.2 | 7.9 | 25.4 | 17.4 |
| 11 | 11.9 | 15.0 | 19.0 | 22.6 | 27.2 | 32.7 | 32.7 | 31.2 | 28.2 | 22.9 | 16.4 | 12.5 | 13.2 | 30.9 | 22.7 |
| 12 | 13.6 | 17.0 | 20.9 | 24.6 | 29.1 | 34.7 | 34.3 | 32.9 | 29.8 | 24.7 | 18.2 | 14.3 | 15.0 | 32.7 | 24.5 |
| 13 | 14.5 | 17.9 | 21.9 | 25.6 | 30.1 | 35.7 | 35.2 | 33.7 | 30.7 | 25.6 | 19.1 | 15.2 | 15.9 | 33.7 | 25.4 |
| 14 | 14.9 | 18.4 | 22.4 | 26.1 | 30.6 | 36.2 | 35.6 | 34.1 | 31.1 | 26.1 | 19.6 | 15.7 | 16.3 | 34.1 | 25.9 |
| 15 | 14.6 | 18.1 | 22.1 | 25.8 | 30.3 | 35.9 | 35.3 | 33.8 | 30.8 | 25.8 | 19.3 | 15.4 | 16.0 | 33.8 | 25.6 |
| 16 | 14.0 | 17.4 | 21.4 | 25.1 | 29.6 | 35.2 | 34.8 | 33.3 | 30.3 | 25.2 | 18.7 | 14.8 | 15.4 | 33.2 | 25.0 |
| 17 | 13.6 | 17.0 | 20.9 | 24.6 | 29.1 | 34.7 | 34.3 | 32.9 | 29.8 | 24.7 | 18.2 | 14.3 | 15.0 | 32.7 | 24.5 |
| 18 | 13.0 | 16.3 | 20.3 | 23.9 | 28.5 | 34.1 | 33.8 | 32.3 | 29.3 | 24.1 | 17.6 | 13.7 | 14.4 | 32.1 | 23.9 |
| 19 | 12.5 | 15.7 | 19.6 | 23.3 | 27.8 | 33.4 | 33.2 | 31.8 | 28.7 | 23.5 | 17.0 | 13.1 | 13.8 | 31.5 | 23.3 |
| 20 | 12.0 | 15.2 | 19.1 | 22.8 | 27.4 | 32.9 | 32.8 | 31.4 | 28.3 | 23.1 | 16.5 | 12.7 | 13.3 | 31.0 | 22.8 |
| 21 | 11.3 | 14.4 | 18.3 | 22.0 | 26.6 | 32.1 | 32.1 | 30.7 | 27.6 | 22.3 | 15.8 | 11.9 | 12.6 | 30.3 | 22.1 |
| 22 | 10.6 | 13.6 | 17.5 | 21.1 | 25.7 | 31.3 | 31.4 | 30.0 | 26.9 | 21.6 | 15.0 | 11.2 | 11.8 | 29.5 | 21.3 |
| 23 | 9.8 | 12.6 | 16.5 | 20.1 | 24.8 | 30.3 | 30.6 | 29.2 | 26.1 | 20.7 | 14.1 | 10.3 | 10.9 | 28.5 | 20.4 |
| 24 | 8.8 | 11.5 | 15.3 | 19.0 | 23.6 | 29.1 | 29.6 | 28.2 | 25.1 | 19.6 | 13.0 | 9.2 | 9.8 | 27.5 | 19.3 |

FRÍO — ZONA DE CONFORT — CALOR

19 ºC — 25 ºC

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

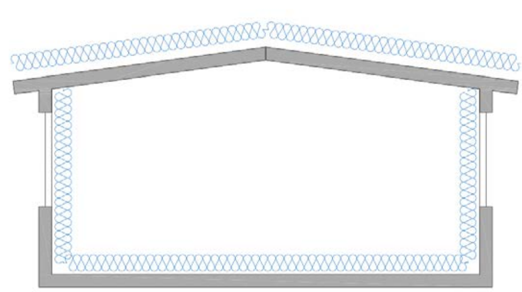
selective night ventilation, shading, and solar control. The school is located in a low-density urban setting and consists of a series of classrooms in separate, single-floor buildings. Light construction materials were used with a gable roof which projects out over both facades where the windows are located.

## Ciudad Juárez

The annual hygrothermal situation is critical during both seasons of the year. Given the average temperature and relative humidity conditions, heating is required during the winter months. This can be achieved, in part, by using solar energy. When measurements were taken, the classrooms did not have the conditions necessary for thermal comfort, since recorded values (13°C and 45% relative humidity) were below the LCR. Nevertheless, only a portion of the students reported feeling cold (34% to 43%), a quarter were warmly dressed, and almost 50% reported perspiring. During the summer, temperatures above 30°C, exceeding the comfort range, were recorded indoors due to insufficiencies in the building envelope and the impact of solar radiation entering through the windows. Cross-ventilation and, most importantly, selective night ventilation are needed. Opinion indicators reveal that students reported a high degree of thermal discomfort (76% to 89%), while 38% to 50% were perspiring. This suggests a high degree of habituation to unfavorable conditions. In general, the classrooms are cold during the winter and the energy consumption

FIGURE 100.

Shading. Natural ventilation.
Thermally insulated building envelope.
Passive solar systems. Ciudad Juárez.



used to heat them is significant, although the comfort levels are still not reached. Passive ventilation systems, using underground tubes to cool the air as it enters the building, or heat discharge systems, such as solar chimneys, could be used during the summer months, while in the winter, heating could be improved by using greenhouses or heat accumulating walls.

Illuminance and uniformity levels were insufficient in the classrooms. However, no more than 35% of students reported discomfort in all cases.

With respect to noise levels, during the winter, they exceed the acceptable range. However, only a small percentage of students reported discomfort (30% to 48%). During the summer, recorded values were acceptable. Nevertheless, opinion indicators reveal a high degree of discomfort caused by irritating noises (75%). There are four factors that contribute to this situation: (a) insufficient sound insulation in the classrooms; (b) the proximity of classrooms to covered hallways; (c) the lack of treatment of the indoor acoustic field; and (d) the need for ventilation, especially during the summer months, which means that classrooms are not adequately closed off. In order to improve the acoustic quality of the classroom, end walls or ceilings with sound absorption should be used, along with ventilation systems that minimize the ingress of airborne noise.

With respect to air quality, the vast majority of students perceived the air as stale (30% to 76%), with values generally within the admissible ranges for concentrations of $CO_2$. Therefore, this issue may be caused by heating equipment, the lack of humidity in the atmosphere, and odors generated by occupants.

## Temperate dry climate requiring shading + cross-ventilation + heating (Mexico City, San Luis de Potosí)

Mexico City has a unique climate at an altitude of 2240 m.a.s.l. in a valley surrounded by volcanoes and mountains. There are two seasons, dry and rainy. The first is characterized by sunny days and significant temperature decreases toward the evening, while the summer is characterized by a warm climate, frequent rain, and temperatures that can reach 35°C. Given the annual average temperatures and relative humidity, heating, shading, and cross-ventilation should all be used. The school is situated in an urban setting and consists of a series of classrooms arranged in two symmetrical blocks, three stories high, around a central patio with outdoor covered arcades. Traditional medium-weight construction materials were used and the classrooms are lit from two sides, with north- and south-facing windows.

The city is located at 1870 m.a.s.l. with a temperate, semi-arid climate. The hygrothermal situation is stable throughout the year, with annual averages of 18°C and 54% relative humidity. The relative humidity is low due to scant rainfall (393mm), with a different situation during the winter, requiring heating which can be achieved by using solar energy. During the summer, temperatures rise and cross-ventilation should be used. The school is located in a medium-density urban setting and consists of a series of classrooms in separate, single-floor buildings with eaves on the facades. A gable roof and medium-weight construction materials were used. The classrooms studied were lit by two sets of windows on opposite sides of the room.

### Mexico City

During the winter months, the fluctuation of outdoor temperatures from day to night is less than 16°C and temperatures inside the classroom reflect the effects of thermal inertia (with a buffer zone of 7°C and, at most, a 6-hour delay). The hygrothermal values recorded indoors are slightly below the comfort zone. 58% of the students reported feeling cold, 43% were warmly dressed, and 70% said they were perspiring. The heating should be improved, and this can be achieved by using passive solar systems. During the summer, the audited classrooms meet the criteria for thermal comfort, while more than 50% of students reported feeling warm and perspiring, although their clothing was seasonally appropriate. The hygrothermal conditions were within the comfort zone most of the time.

FIGURE 101.

## Obras del Valle de México School. No. 09DPR1535F. Mexico City. Temperate dry climate.

MAPA DE CONFORT

| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 12.5 | 14.2 | 16.6 | 18.1 | 19.1 | 18.8 | 17.9 | 18.0 | 17.8 | 16.6 | 14.7 | 13.0 | 13.2 | 18.6 | 16.4 |
| 2 | 9.7 | 11.4 | 13.6 | 15.3 | 16.6 | 16.8 | 16.0 | 16.3 | 15.9 | 14.4 | 12.2 | 10.4 | 10.5 | 16.5 | 14.1 |
| 3 | 7.1 | 8.8 | 10.9 | 12.8 | 14.3 | 14.9 | 14.2 | 14.6 | 14.2 | 12.4 | 9.9 | 8.0 | 8.0 | 14.5 | 11.8 |
| 4 | 4.9 | 6.5 | 8.6 | 10.7 | 12.4 | 13.4 | 12.7 | 13.2 | 12.7 | 10.7 | 7.9 | 6.0 | 5.8 | 12.8 | 10.0 |
| 5 | 3.7 | 5.3 | 7.3 | 9.5 | 11.4 | 12.5 | 11.9 | 12.5 | 11.9 | 9.8 | 6.9 | 4.9 | 4.6 | 11.9 | 8.9 |
| 6 | 3.3 | 4.9 | 6.9 | 9.1 | 11.0 | 12.2 | 11.6 | 12.2 | 11.6 | 9.5 | 6.5 | 4.5 | 4.2 | 11.6 | 8.6 |
| 7 | 4.5 | 6.1 | 8.2 | 10.3 | 12.1 | 13.1 | 12.4 | 13.0 | 12.4 | 10.4 | 7.6 | 5.6 | 5.4 | 12.5 | 9.6 |
| 8 | 6.3 | 7.9 | 10.1 | 12.0 | 13.6 | 14.4 | 13.7 | 14.1 | 13.6 | 11.8 | 9.2 | 7.3 | 7.2 | 13.9 | 11.2 |
| 9 | 8.5 | 10.2 | 12.4 | 14.2 | 15.6 | 15.9 | 15.2 | 15.5 | 15.1 | 13.5 | 11.1 | 9.3 | 9.3 | 15.6 | 13.0 |
| 10 | 12.1 | 13.8 | 16.1 | 17.7 | 18.7 | 18.5 | 17.6 | 17.8 | 17.5 | 16.3 | 14.3 | 12.6 | 12.9 | 18.3 | 16.1 |
| 11 | 19.2 | 20.9 | 23.5 | 24.5 | 24.9 | 23.6 | 22.4 | 22.2 | 22.3 | 21.7 | 20.6 | 19.0 | 19.7 | 23.6 | 22.1 |
| 12 | 21.6 | 23.4 | 26.0 | 26.8 | 27.0 | 25.3 | 24.1 | 23.8 | 23.9 | 23.5 | 22.7 | 21.2 | 22.1 | 25.5 | 24.1 |
| 13 | 22.8 | 24.6 | 27.3 | 28.0 | 28.1 | 26.2 | 24.9 | 24.5 | 24.7 | 24.4 | 23.8 | 22.3 | 23.2 | 26.4 | 25.1 |
| 14 | 23.4 | 25.2 | 27.9 | 28.6 | 28.6 | 26.6 | 25.3 | 24.9 | 25.1 | 24.9 | 24.3 | 22.9 | 23.8 | 26.8 | 25.6 |
| 15 | 23.0 | 24.8 | 27.5 | 28.2 | 28.2 | 26.3 | 25.0 | 24.6 | 24.8 | 24.6 | 23.9 | 22.5 | 23.4 | 26.5 | 25.3 |
| 16 | 22.2 | 24.0 | 26.6 | 27.4 | 27.5 | 25.7 | 24.5 | 24.1 | 24.3 | 24.0 | 23.2 | 21.8 | 22.7 | 25.9 | 24.6 |
| 17 | 21.6 | 23.4 | 26.0 | 26.8 | 27.0 | 25.3 | 24.1 | 23.8 | 23.9 | 23.5 | 22.7 | 21.2 | 22.1 | 25.5 | 24.1 |
| 18 | 20.8 | 22.6 | 25.2 | 26.1 | 26.3 | 24.7 | 23.5 | 23.2 | 23.3 | 22.9 | 22.0 | 20.5 | 21.3 | 24.9 | 23.4 |
| 19 | 20.0 | 21.7 | 24.3 | 25.3 | 25.6 | 24.2 | 23.0 | 22.7 | 22.8 | 22.3 | 21.3 | 19.8 | 20.5 | 24.2 | 22.7 |
| 20 | 19.4 | 21.1 | 23.7 | 24.7 | 25.1 | 23.7 | 22.6 | 22.4 | 22.4 | 21.8 | 20.7 | 19.2 | 19.9 | 23.8 | 22.2 |
| 21 | 18.4 | 20.1 | 22.7 | 23.7 | 24.2 | 23.0 | 21.9 | 21.7 | 21.7 | 21.1 | 19.9 | 18.3 | 18.9 | 23.0 | 21.4 |
| 22 | 17.4 | 19.1 | 21.6 | 22.8 | 23.3 | 22.3 | 21.2 | 21.1 | 21.1 | 20.3 | 19.0 | 17.4 | 18.0 | 22.3 | 20.5 |
| 23 | 16.2 | 17.9 | 20.3 | 21.6 | 22.3 | 21.4 | 20.4 | 20.3 | 20.2 | 19.4 | 17.9 | 16.3 | 16.8 | 21.3 | 19.5 |
| 24 | 14.8 | 16.5 | 18.9 | 20.2 | 21.0 | 20.4 | 19.4 | 19.4 | 19.3 | 18.3 | 16.6 | 15.0 | 15.4 | 20.3 | 18.3 |

FRÍO ZONA DE CONFORT CALOR

19 °C 26 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 102.

## Prof. Carmen Serdán School. No. 24DPR3268F. San Luis de Potosí. Temperate dry climate.

MAPA DE CONFORT

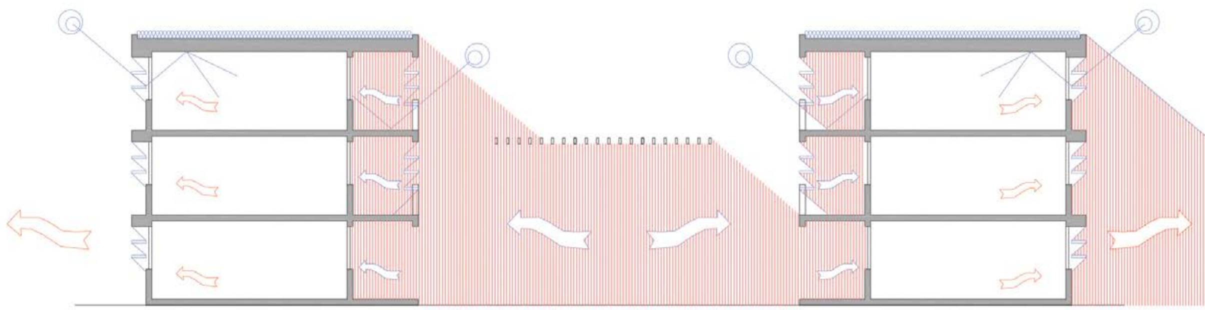
| HORA | TEMPERATURAS HORARIAS (°C) | | | | | | | | | | | | PROMEDIOS (°C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | A |
| 1 | 12.9 | 14.7 | 17.2 | 19.7 | 21.0 | 20.6 | 19.3 | 19.3 | 18.3 | 17.2 | 15.5 | 13.7 | 13.8 | 20.3 | |
| 2 | 11.0 | 12.7 | 15.1 | 17.6 | 19.1 | 18.9 | 17.8 | 17.8 | 16.9 | 15.6 | 13.7 | 11.8 | 11.8 | 18.6 | |
| 3 | 9.2 | 10.8 | 13.2 | 15.7 | 17.3 | 17.4 | 16.4 | 16.4 | 15.6 | 14.1 | 12.0 | 10.1 | 10.0 | 17.1 | |
| 4 | 7.7 | 9.2 | 11.5 | 14.0 | 15.8 | 16.1 | 15.2 | 15.2 | 14.5 | 12.8 | 10.5 | 8.6 | 8.5 | 15.7 | |
| 5 | 6.9 | 8.3 | 10.6 | 13.1 | 15.0 | 15.4 | 14.6 | 14.5 | 13.9 | 12.1 | 9.8 | 7.8 | 7.6 | 15.0 | |
| 6 | 6.6 | 8.0 | 10.3 | 12.8 | 14.7 | 15.2 | 14.4 | 14.3 | 13.7 | 11.9 | 9.5 | 7.5 | 7.4 | 14.8 | |
| 7 | 7.4 | 8.9 | 11.2 | 13.7 | 15.5 | 15.9 | 15.0 | 14.9 | 14.3 | 12.6 | 10.3 | 8.3 | 8.2 | 15.5 | |
| 8 | 8.6 | 10.2 | 12.6 | 15.1 | 16.8 | 17.0 | 16.0 | 15.9 | 15.2 | 13.6 | 11.5 | 9.5 | 9.5 | 16.6 | |
| 9 | 10.1 | 11.8 | 14.2 | 16.7 | 18.3 | 18.2 | 17.2 | 17.1 | 16.3 | 14.9 | 12.9 | 11.0 | 11.0 | 17.9 | |
| 10 | 12.6 | 14.4 | 16.9 | 19.4 | 20.8 | 20.3 | 19.1 | 19.1 | 18.1 | 17.0 | 15.3 | 13.4 | 13.5 | 20.1 | |
| 11 | 17.3 | 19.5 | 22.2 | 24.7 | 25.6 | 24.4 | 22.8 | 22.8 | 21.7 | 21.1 | 19.8 | 18.2 | 18.3 | 24.3 | |
| 12 | 19.0 | 21.3 | 24.0 | 26.5 | 27.3 | 25.8 | 24.0 | 24.1 | 22.9 | 22.5 | 21.4 | 19.8 | 20.0 | 25.7 | |
| 13 | 19.8 | 22.2 | 24.9 | 27.4 | 28.1 | 26.5 | 24.7 | 24.8 | 23.5 | 23.2 | 22.2 | 20.6 | 20.8 | 26.4 | |
| 14 | 20.2 | 22.6 | 25.4 | 27.9 | 28.5 | 26.9 | 25.0 | 25.1 | 23.8 | 23.5 | 22.6 | 21.0 | 21.3 | 26.8 | |
| 15 | 19.9 | 22.3 | 25.1 | 27.6 | 28.2 | 26.7 | 24.8 | 24.9 | 23.6 | 23.3 | 22.3 | 20.7 | 21.0 | 26.6 | |
| 16 | 19.4 | 21.7 | 24.5 | 27.0 | 27.7 | 26.2 | 24.4 | 24.5 | 23.2 | 22.8 | 21.8 | 20.2 | 20.4 | 26.1 | |
| 17 | 19.0 | 21.3 | 24.0 | 26.5 | 27.3 | 25.8 | 24.0 | 24.1 | 22.9 | 22.5 | 21.4 | 19.8 | 20.0 | 25.7 | |
| 18 | 18.4 | 20.7 | 23.4 | 25.9 | 26.7 | 25.4 | 23.6 | 23.7 | 22.5 | 22.0 | 20.9 | 19.2 | 19.5 | 25.2 | |
| 19 | 17.9 | 20.1 | 22.8 | 25.3 | 26.2 | 24.9 | 23.2 | 23.3 | 22.1 | 21.5 | 20.4 | 18.7 | 18.9 | 24.8 | |
| 20 | 17.5 | 19.7 | 22.4 | 24.9 | 25.7 | 24.6 | 22.9 | 22.9 | 21.8 | 21.2 | 20.0 | 18.3 | 18.5 | 24.4 | |
| 21 | 16.8 | 19.0 | 21.6 | 24.1 | 25.1 | 24.0 | 22.4 | 22.4 | 21.3 | 20.6 | 19.3 | 17.6 | 17.8 | 23.8 | |
| 22 | 16.1 | 18.2 | 20.9 | 23.4 | 24.4 | 23.4 | 21.8 | 21.9 | 20.8 | 20.0 | 18.7 | 17.0 | 17.1 | 23.2 | |
| 23 | 15.3 | 17.3 | 20.0 | 22.5 | 23.5 | 22.7 | 21.2 | 21.2 | 20.2 | 19.3 | 17.9 | 16.1 | 16.3 | 22.5 | |
| 24 | 14.4 | 16.3 | 18.9 | 21.4 | 22.6 | 21.9 | 20.4 | 20.5 | 19.5 | 18.5 | 17.0 | 15.2 | 15.3 | 21.6 | |

FRÍO ZONA DE CONFORT CALOR

20 °C 26 °C

The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 103.
Shading. Natural ventilation. Thermally insulated roof. Passive solar systems. Mexico City.



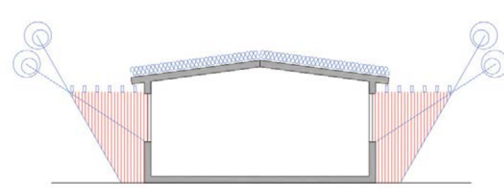
## San Luis de Potosí

During the winter, the recorded temperatures and humidity levels meet the criteria for comfort and, accordingly, the percentage of students reporting discomfort was relatively low (23% to 38%). The relative humidity levels inside were generally within the acceptable range. However, the cold is dry and that occasionally led to lower than recommended humidity levels, which can cause problems of dryness in mucous membranes and tear ducts. In summer, conditions within the school were generally comfortable, with overheating recorded in specific situations. This can be resolved by using cross-ventilation. During the summer, between 33% and 44% of students reported thermal discomfort, while a greater proportion perspired (66% to 96%). Heating should be incorporated through the use of passive systems (collector facades or heat-accumulating walls) on the southern facade of the building; shading should be used to prevent overheating; the thermal insulation of the building envelope can be improved; and cross-ventilation is recommended. The addition of vegetation around the building would increase the humidity levels in the air and reduce the temperature of the air entering the classrooms.

In Mexico City, high minimum and maximum illuminance levels were recorded in the north-facing classrooms (up to 3900 lux). In San Luis de Potosí, recorded levels were generally acceptable in both summer and winter, although illuminance levels could be increased. The recommended uniformity levels are not reached in either case, and glare was also an issue. Nevertheless, only a quarter of the students reported discomfort. The design of the south-facing classroom facades could be improved either by incorporating devices used to avoid the direct impact of solar radiation on the working plane (for example, light shelves or *brise-soleil* on the facades) or by introducing indirect lighting on the roof in order to raise the illuminance levels in the areas furthest from the windows, thereby improving the indoor light distribution and completely eliminating the need for artificial lighting.

With respect to the noise levels recorded, both inside and outside the classroom, values were above the comfort range. Approximately 86% of students

FIGURE 104.
Shading. Natural ventilation. Thermally insulated roof. Passive solar systems. San Luis de Potosí.



reported a general sensation of acoustic discomfort. This was reflected in all the audits, regardless of the season. The schools in question are overpopulated which means that recreation times must be doubled, resulting in occasional disturbance for those who are still in class. There is also a need to open the windows for ventilation and a lack of acoustic treatment in the classrooms. Ventilation systems should be improved, avoiding openings close to the noisiest areas (streets, patios, or arcades, depending on the situation) so that the sound insulation of the building envelope can be effective. Sound insulation should also be added inside classrooms to reduce reverberation.

No issues with $CO_2$ levels were found. Although most students indicated the need for ventilation inside the classrooms, only 30% to 42% reported discomfort with respect to this factor.

## DOMINICAN REPUBLIC (DR)

### Warm humid inland climate

- Villa Alta Gracia. San Cristobal Province. Nuestra Señora de Fátima School, No. 21058310.
- Bayaguana. Monte Plata Province. Moraima Veloz de Báez School, No. 29006211.
- Bonao. Monseñor Nouel Province. Jaqueline Lima School, No. 28085818.
- Los Alcarrizos. Santo Domingo Province. Mi Bandera School, No. 1230419.
- Monte Plata. Monte Plata Province. Rafael María Díaz Gavilán School, No. 29041915.

### Warm humid climate with coastal influence

- Baní. Peravia Province. Santa Rosa School, No. 17030216.
- Azua. Azua Province. San Martín de Porres School, No. 2051219.
- Brisas del Este. Santo Domingo Province. Prof. Juan Bosch School, No. 32005111.
- La Caleta. Santo Domingo Province. Santa Lucía School, No. 32003517.

### Warm humid climate requiring shading + natural ventilation

The climate of the Dominican Republic is warm, humid, and predominantly tropical, with annual average temperatures between 25°C and 35°C. Rainfall is abundant, given its proximity to the Atlantic Ocean and the Caribbean Sea and its altitude above sea level. The rainy season is between April and November, with hurricanes two or three times a year, and maximums reached in July. The locations studied presented different climate conditions according to their altitude above sea level (ranging from 12m to 196m), average annual rainfall (between 78mm and 227mm), and their proximity to the sea. Given these characteristics, lightweight buildings are appropriate (without indoor thermal mass), with the longer sides of the buildings preferably facing north-south. In cases where heavy or medium-weight materials were used, the buildings should be thermally insulated from the inside.For all of the classrooms audited, during both seasons, humidity levels inside the building were recorded between 55% and 80%, with temperatures between 27°C and 30°C, which exceed the local comfort level. Most students were logically dressed with light and very light clothing (73% to 100%). A direct correlation between student opinion regarding the indoor temperature and the recorded conditions was not found. In any case, of the eighteen classrooms audited (during both seasons), in twelve of them, a high percentage of students reported comfort (76% to 91%), which reveals a degree of habituation to unfavorable hygrothermal conditions. In only eight situations the majority reported perspiring (55% to 87%) and in six, that the air was stale.

Recommended strategies for improved design include shading, lower thermal mass, and natural ventilation. Shading is recommended on south-facing vertical surfaces as well as maximum protection for the roof, which can be done by using "shade roofs" that optimize cross-ventilation. Taking into account the direction of the wind and breezes, cross-ventilation can

FIGURE 105.

## Thermal comfort map. According to average annuals. Baní.

**MAPA DE CONFORT**

| HORA | TEMPERATURAS HORARIAS (ºC) | | | | | | | | | | | | PROMEDIOS (ºC) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENE | FEB | MAR | ABR | MAY | JUN | JUL | AGO | SET | OCT | NOV | DIC | D-E-F | M-J-J | AÑ0 |
| 1 | 25.5 | 25.8 | 26.4 | 27.0 | 27.4 | 27.7 | 28.3 | 28.2 | 27.8 | 27.3 | 26.7 | 25.6 | 25.6 | 27.8 | 27.0 |
| 2 | 24.0 | 24.3 | 25.0 | 25.5 | 26.0 | 26.4 | 26.9 | 26.8 | 26.4 | 25.9 | 25.2 | 24.1 | 24.1 | 26.4 | 25.5 |
| 3 | 22.6 | 22.9 | 23.6 | 24.2 | 24.7 | 25.1 | 25.7 | 25.5 | 25.1 | 24.6 | 23.8 | 22.7 | 22.7 | 25.2 | 24.2 |
| 4 | 21.5 | 21.7 | 22.4 | 23.0 | 23.6 | 24.1 | 24.6 | 24.4 | 23.9 | 23.4 | 22.6 | 21.6 | 21.6 | 24.1 | 23.1 |
| 5 | 20.8 | 21.0 | 21.8 | 22.4 | 23.0 | 23.5 | 24.0 | 23.8 | 23.3 | 22.8 | 22.0 | 20.9 | 20.9 | 23.5 | 22.4 |
| 6 | 20.6 | 20.8 | 21.6 | 22.2 | 22.8 | 23.3 | 23.8 | 23.6 | 23.1 | 22.6 | 21.8 | 20.7 | 20.7 | 23.3 | 22.2 |
| 7 | 21.2 | 21.4 | 22.2 | 22.8 | 23.4 | 23.9 | 24.4 | 24.2 | 23.7 | 23.2 | 22.4 | 21.3 | 21.3 | 23.9 | 22.9 |
| 8 | 22.2 | 22.4 | 23.2 | 23.8 | 24.3 | 24.7 | 25.3 | 25.1 | 24.6 | 24.1 | 23.4 | 22.3 | 22.3 | 24.8 | 23.8 |
| 9 | 23.4 | 23.6 | 24.3 | 24.9 | 25.4 | 25.8 | 26.3 | 26.2 | 25.8 | 25.3 | 24.6 | 23.5 | 23.5 | 25.8 | 24.9 |
| 10 | 25.3 | 25.6 | 26.2 | 26.8 | 27.2 | 27.5 | 28.1 | 28.0 | 27.6 | 27.1 | 26.5 | 25.4 | 25.4 | 27.6 | 26.8 |
| 11 | 29.1 | 29.3 | 29.9 | 30.4 | 30.6 | 30.9 | 31.5 | 31.5 | 31.2 | 30.7 | 30.2 | 29.2 | 29.2 | 31.0 | 30.4 |
| 12 | 30.3 | 30.6 | 31.2 | 31.7 | 31.8 | 32.0 | 32.7 | 32.7 | 32.5 | 32.0 | 31.4 | 30.4 | 30.5 | 32.2 | 31.6 |
| 13 | 31.0 | 31.3 | 31.8 | 32.3 | 32.4 | 32.6 | 33.3 | 33.3 | 33.1 | 32.6 | 32.1 | 31.1 | 31.1 | 32.8 | 32.2 |
| 14 | 31.3 | 31.6 | 32.1 | 32.6 | 32.7 | 32.9 | 33.6 | 33.6 | 33.4 | 32.9 | 32.4 | 31.4 | 31.4 | 33.1 | 32.5 |
| 15 | 31.1 | 31.4 | 31.9 | 32.4 | 32.5 | 32.7 | 33.4 | 33.4 | 33.2 | 32.7 | 32.2 | 31.2 | 31.2 | 32.9 | 32.3 |
| 16 | 30.7 | 31.0 | 31.5 | 32.0 | 32.1 | 32.3 | 33.0 | 33.0 | 32.8 | 32.3 | 31.8 | 30.8 | 30.8 | 32.5 | 31.9 |
| 17 | 30.3 | 30.6 | 31.2 | 31.7 | 31.8 | 32.0 | 32.7 | 32.7 | 32.5 | 32.0 | 31.4 | 30.4 | 30.5 | 32.2 | 31.6 |
| 18 | 29.9 | 30.2 | 30.7 | 31.2 | 31.4 | 31.7 | 32.3 | 32.3 | 32.1 | 31.6 | 31.0 | 30.0 | 30.0 | 31.8 | 31.2 |
| 19 | 29.5 | 29.8 | 30.3 | 30.8 | 31.0 | 31.3 | 31.9 | 31.9 | 31.6 | 31.1 | 30.6 | 29.6 | 29.6 | 31.4 | 30.8 |
| 20 | 29.2 | 29.4 | 30.0 | 30.5 | 30.7 | 31.0 | 31.6 | 31.6 | 31.3 | 30.8 | 30.3 | 29.3 | 29.3 | 31.1 | 30.5 |
| 21 | 28.6 | 28.9 | 29.5 | 30.0 | 30.2 | 30.5 | 31.2 | 31.1 | 30.8 | 30.3 | 29.8 | 28.7 | 28.8 | 30.6 | 30.0 |
| 22 | 28.1 | 28.4 | 29.0 | 29.5 | 29.7 | 30.0 | 30.7 | 30.6 | 30.3 | 29.8 | 29.2 | 28.2 | 28.2 | 30.1 | 29.5 |
| 23 | 27.4 | 27.7 | 28.3 | 28.9 | 29.1 | 29.4 | 30.1 | 30.0 | 29.7 | 29.2 | 28.6 | 27.5 | 27.6 | 29.6 | 28.8 |
| 24 | 26.7 | 27.0 | 27.6 | 28.1 | 28.4 | 28.8 | 29.4 | 29.3 | 29.0 | 28.5 | 27.8 | 26.8 | 26.8 | 28.9 | 28.1 |

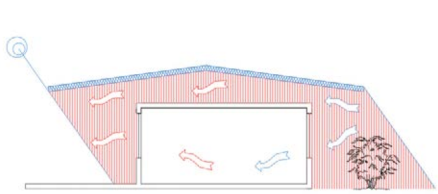
FRÍO — ZONA DE CONFORT — CALOR

21 ºC — 27 ºC

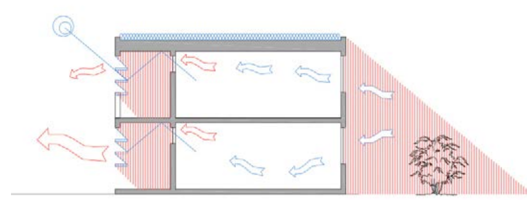
The temperature graph shows the average temperature in °C for each hour of the day (vertical axis) during each month of the year (horizontal axis). The green shading represents comfortable temperatures at the site; the red, uncomfortably hot temperatures; the blue, uncomfortably cold temperatures.

FIGURE 106.

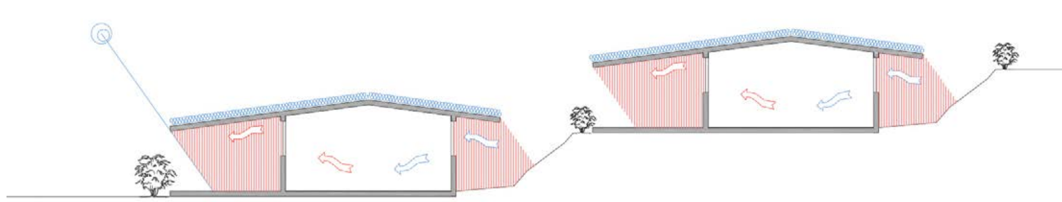
## Design guidelines



Cross-ventilation



Shading



Thermally insulated roof
Solar and wind orientation

be achieved between the ceiling and the roof, and in buildings with several floors, between the ceiling and floor tiles. Another possibility for avoiding the impact of direct solar radiation is the use of ventilated roofs and facades that enable the convective extraction of hot air. The incorporation and treatment of intermediate spaces such as open and ventilated sunshades or arcades that encourage cross-ventilation should be considered (Figure 106). On the other hand, the south-facing windows should be redesigned in order to minimize the direct view of the sky and to regulate and distribute lighting throughout the classroom, while at the same time enabling cross-ventilation. Another of the important aspects to consider is the treatment of outdoor spaces with native vegetation.

Between 60% and 95% of students reported that lighting conditions were comfortable, while excessive average levels (above 750 lux) were recorded in many of the classrooms.

With respect to noise perception, the majority of students surveyed reported discomfort, with recorded levels between 62 db and 84 db, which exceed the comfort range used, suggesting the need to treat the acoustic field inside the classroom.

## Conclusions

This study presents a series of methodological and empirical aspects of the analysis of the environmental conditions of schools, based on the audits conducted to determine the comfort levels in educational institutions in six Latin American countries. The results were also compared with the geographical situation of each location, regional climates, and national and international standards. Both subjective and objective data were gathered; the former were obtained through opinion surveys, while the latter were based on standardized measurements carried out by the various regional teams.

This chapter summarizes the results obtained through this process on three different levels: (a) by audited educational institution and season; (b) by country; and (c) among countries. Recommendations were formulated for each country and educational institution, given the climate characteristics of the school's location.

Familiarity with the actual classroom situation facilitated the assessment of good practices currently employed and helped identify critical situations where improvements can be made in the buildings to optimize environmental conditions and better support the processes involved in teaching and learning.

Based on data gathered, it is clear that the hygrothermal conditions do not generally correspond to the recommended standards. Natural lighting is considered a critical condition in a classroom, due to the needs of scholastic activities and a concern for the psychophysical health of occupants. The results of the study showed that, in some cases, illuminance and uniformity levels do not correspond to physiological needs. In this case, student opinion revealed a certain degree of habituation to unfavorable conditions. Some of the noise levels recorded in the sample exceeded the comfort range, which makes this another critical factor. With respect to air quality, in some cases the $CO_2$ levels recorded in the winter were higher than the acceptable standards. In these cases, the need to regulate ventilation and air infiltration sometimes generated other thermal, hygrometric, or odor issues that affected student opinion of this parameter. Further studies are need.

The surveyed students provided their opinion of the environmental variables analyzed. In some cases, they reflected the comfortable or uncomfortable situations recorded, while in others habituation was a factor, due to cultural issues and physical tolerance. In other words, it should be noted that temperature and natural lighting are critical parameters from an objective standpoint. However, this was not always reflected in student opinion. Due in part, as mentioned above, to habituation and also to the potential to handle the negative impact of these factors in the classroom by adjusting the amount of clothes worn, opening or closing windows, the use of curtains, independent regulation of heaters and fans and the use of complementary artificial lighting. On the other hand, students clearly indicated that noise levels and air quality produce the most discomfort for them. Solutions for these issues are more difficult to find since they depend on finding alternative possibilities for ventilation or the potential to close classrooms hermetically.

From an environmental standpoint, in the schools where situations were unfavorable, retrofitting techniques should be used to achieve reasonably comfortable conditions that support teaching and learning. In the case of newly designed buildings, bioclimatic criteria should be considered in order to improve the aspects that were identified as critical by this study. The criteria described above should be used by national organizations in charge of school management to determine a course of action for future school buildings.

In conclusion, the cases studied generally complied with the necessary conditions for their role as educational institutions, however they should seek to improve the levels of livability and comfort and move toward environmental sustainability.

In this sense, the importance of conducting specific studies on the situation in Latin America reveals the need for common methodologies and practices that will help reach conclusions and develop recommendations to define strategies and intervention policies for the education sector.

The implementation of actions such as those proposed here will help bring the level of development up to an acceptable state, appropriate for school buildings that contribute to improvements in "Learning in Twenty-First-Century Schools."

Education

www.iadb.org/education
http://blogs.iadb.org/education/
education@iadb.org