Improving Thermal Comfort Conditions in K-12 Educational Buildings in Hot and Humid Climate

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Abstract

Improving thermal comfort conditions in K-12 educational buildings in hot and humid climate

Diana Carolina Guerrero Yañez

The school buildings in Colombia are designed and built based on geographical locations, available materials, and regional construction systems. However, external weather conditions and building design can have a significant impact on the indoor thermal conditions of classrooms and the thermal comfort of students, which affects the academic performance and productivity of students. This thesis investigates the thermal comfort performance of an educational building located in a hot and humid city in Colombia as a case study to evaluate the current design guidelines by the Ministry of Education and provide recommendations on improving the thermal conditions in educational buildings.

The selected school is a representative building of Colombian educational facilities, built under the architectural and structural guidelines established by the national government. This school is a concrete structure without mechanical cooling. It has features such as vertical louvers and light shelves to provide solar shading and cross ventilation. However, field observation discovered that 82% of the time, students experienced thermal and visual discomfort in elementary classrooms.

To investigate the potential causes and provide mitigation strategies, a whole building energy simulation is conducted. Design Builder is used to model the indoor thermal conditions of the school building based on existing building configuration under climatic conditions data collected. ASHRAE 55 adaptative model is used for the evaluation of thermal comfort. It is found that in these classrooms, 62% of the time, the thermal conditions are outside the acceptable range during the year. The effect of mitigation measures, i.e. occupancy, roof insulation, shading, and natural ventilation rates on indoor thermal conditions are investigated through simulations.

It is found that occupancy levels of 1.65m^2/student and 2.85m^2/student and natural ventilation from 4.0 to 6.0 ACH rate have a significant impact on the indoor temperature and relative humidity, and thus the thermal comfort. Passive design strategies are provided as general recommendations for optimizing the school building design to meet ASHRAE-55 requirements.

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Nomenclature

°C	Celsius degrees
met	Metabolic rate, rate of energy production of the body
clo	Unit for resistance to heat transfer
t_o	operative temperature
t_a	air temperature
$\bar{t}_r$	mean radiant temperature
t_g	globe temperature
V	air velocity in m/s
t_{sk}	skin temperature °C
f_{cl}	Clothing area factor
Q	airflow rate, cfm
rh	relative humidity %

Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

Improving the thermal condition in educational buildings impacts academic performance regarding attention, concentration, and learning processes. In addition, recent studies identify the relation between the occupants' performance and thermal comfort, considering the lack of comfort causes "Environmental stress." (Yang, Wenjie, Lin, Yingxin, 2017). This psychological perception responds to an external stimulus affecting people of any age, and the reaction is different between one person and another. Recently studies identified that environmental stress conditions could have long-term consequences on students. For example, in Colombia during 2009 and 2010, ocular and visual disorders were diagnosed in 25.4% of students in public schools. In addition, diseases caused by classroom orientation and refractive conditions in 20.9% and eyelid disorder in 4.4% with a decreased visual acuity in 3.1% (Vanessa, Calonge, Alberto,2018), and affecting 22.7% of the total population of the country who is in school-age.

Furthermore, a favorable learning environment correlates significantly with student participation, teacher support, and optimizing the school functions. Studies have shown that features such as classroom design, ergonomics, thermal comfort, ventilation, and lighting play a role in creating favorable conditions for effective learning process, minimizing some physical environmental stressors as temperature (heat or cold), noise, and glare (Buonocore, De Vecchi, Scalco, Lamberts, 2018) (Lopez-Pérez, Florez-Prieto, Ríos-Rojas, 2019)

The importance of climate analysis is indispensable in the building design process to achieve environmental control in classrooms. For instance, Colombia is located in the northwestern region of South America; according to the Köppen Climate Classification, there are a variety of climates, from tropical to cold mountains, passing through dry and temperate (Ahrens, 2013). With this complex variety, there exists an opportunity to design alternatives for each type of location.

Moreover, general guidelines have been developed by the ministry of education as recommendations for the construction of educational buildings based on international regulations. The suitability of these guidelines is evaluated in this thesis by analyzing the thermal conditions of a school building located in Cucuta, Colombia, as a case study. A northeast city with an annual average of 34ºC, 72% average relative humidity, and prevailing winds from north and southeast. Cucuta has a high-temperature variance during the day, and an absence of seasons during the year. Therefore, this building is the setting for the thermal comfort analysis in hot and humid climates in Colombia and understanding the effect of thermal variables.

The school was selected as a case study for being designed under current national guidelines focusing on earth-quake resistant calculations, sanitary and hydraulic systems but lacked environmental analysis requirements, besides the high number of students, which requires acceptable thermal comfort beyond the regular academic day. The building has been built with local construction materials like reinforced concrete structure, concrete blocks on the walls without insulation layers, and concrete vertical louvers and exterior light shelves as shading elements. The envelope has additional openings and a non-insulated roof with a metal structure.

According to ASHRAE 55-10, thermal comfort is a subjective condition that expresses satisfaction with the thermal environment. In contrast, for the World Health Organization, thermal comfort is a state of complete physical, mental, and social well-being. The thermal comfort is analyzed through indoor environmental conditions to achieve acceptable thermal comfort for occupants. ASHRAE 55-10 is commonly used in North America to study the effect of thermal discomfort, and Colombian NTC 4595, 5316, and 6199 are the standard codes to identify the thermal, visual, and audio comfort in buildings. The regulations establish general parameters and determine two types of climates in Colombia: moderate cold and warm, and hot dry and warm humid climates. Mine while, ASHRAE 55 standard defines for Colombia a comfort range for summer of 22.5 ° C <Operating Temperature (To) <26 ° C, 60% RH, and metabolic rate unit (met) ≤ 1.2, where a maximum of 10% is accepted percentage of the unsatisfied population. The regulation establishes operative temperatures and comfort equations based on natural ventilation buildings' adaptive thermal comfort model.

Despite the considerable impact of the educational building configuration on thermal comfort, just a few studies have been developed for the principal cities in Colombia regardless of the variety of climates (Montoya, O. L. Villegas, G. 2009.). This thesis aims to collect data in a city with a hot and humid climate, identify the parameters that impact the thermal variation, evaluate educational building performance through ASHRAE 55 2010 standard, and propose passive strategies without using active ventilation systems to improve thermal comfort.

1.2 RESEARCH OBJECTIVES AND APPROACHES

Based on analysis of thermal conditions of the case study building, this research intends to:

-Evaluate the thermal comfort performance in a representative educational building in hot and humid climate of Colombia according to ASHRAE 55-10 standard through simulations using Design Builder software.

-Identify the leading causes of thermal stress and discomfort in the educational buildings built in compliance with the national construction guidelines and under current weather and occupancy conditions.

-Investigate the impact of design and operation parameters on the indoor thermal conditions through a parametric study.

-Provide recommendations on passive design strategies to mitigate the thermal discomfort meeting ASHRAE 55-10 requirements and the national regulation for educational buildings in a hot and humid climate.

1.3 OUTLINE OF THE THESIS

This thesis includes seven chapters as follows:

Chapter 1 describes the importance of thermal comfort in educational buildings and gives a brief explanation of the research objectives.

Chapter 2 contains greater details of previous literature regarding thermal comfort in educational buildings, the impacts on the student's performance, current building standards and codes in Colombia, and the thermal comfort modeling method.

Chapter 3 explains the methodology applied in the case of study and the procedures developed in the on-site visit. Besides, it describes the site measurements collected in Cucuta, Colombia, including environmental factors, general occupants' profile, and building construction materials. Finally, summarize the simulations set-up, procedure, and all the variables analyzed on Design-Builder software.

Chapter 4 Compile the current conditions results through different parameters selected and discussed the results from occupancy levels, natural ventilation and roof configuration simulations.

Chapter 5 contains the conclusion of the study with contributions and future work suggesting passive design strategies for the case study.

Chapter 2. LITERATURE REVIEW

2.1 INTRODUCTION

A literature review was conducted to identify existing studies and analyses indicating the importance of thermal comfort for educational buildings in hot and humid climates. Determine the analysis method used for this specific climate and recognize recommendations referred in the national codes. In addition, this chapter includes a detailed explanation of the adaptative comfort method used, the parameters, and the variables applied in the simulations. The thermal comfort concept, according to the World Health Organization (WHO, 1964), is defines as "a state of complete physical, mental and social well-being." This complex sensation depends on temperature, humidity, and ventilation rate factors where the human body feels comfortable and in balance with its environment. (Szokolay, 1985). Therefore, thermal comfort is essential for architects and engineers in the design process to prevent future conditions as sick building syndrome (SBS) symptoms affecting the occupant's productivity.

In the late 1960s, P.O.Fanger created a static heat-balance model intending to define a referenced set of indoor environmental variables to provide acceptable thermal conditions to the occupants. Fanger's model was only designed for the application in artificially controlled spaces (McIntyre, 1973). In the 1970s, Nicol and Humphreys approached the adaptive model of thermal comfort in naturally ventilated environments and incorporated in 2004 into the ASHRAE Standard 55 according to the research of Brager and de Dear, developing an adaptive model of thermal comfort.

Despite having current regulations, it is a priority to consider that an adequate design requires a balance of the thermal performance and an acceptable indoor quality condition (Allard, F., & Santamouris, M.1998). Educational buildings have different thermal requirements due to specific daily and weekly occupancy periods, differences in occupants' activity, clothing, and adaptation levels (i.e., change of position, dress) In addition, these buildings require to development of specific studies of thermal comfort.

2.2 IMPORTANCE OF STUDYING THERMAL COMFORT IN STUDENTS' PERFORMANCE

In modern societies, people spend over 90% of their time indoors. Students are not an exception spending more time at school than any other building except at home, highlighting the importance of providing comfortable indoor thermal conditions in these buildings. In 1968, one of the first researches investigated the effects of the thermal environment on students' performances. The research was conducted on 36 women and 36 men in climatic chambers with light clothing and temperatures 29 – 41°C, indicating a relationship between the time to complete a task and indoor temperature, the best performance corresponding to 26.7 C. At this temperature, the students involved completed the assigned work in the shortest time (Enander, A. E., & Hygge, S. 1990).

From the late 90s, different studies started to identify the importance of thermal comfort and the direct relation with student productivity, considering that the best environmental conditions result in a better teaching-learning relation, reducing physiological problems, and increasing school performance (Nicolas and Bailey, 1997). Furthermore, in educational buildings, it has been shown that children aged between 8-9 years old increase their concentration with adequate temperature levels (Kuller, 1992). Productivity, defined as the capacity for processing and discerning graphical information, measuring the alertness, processing speed of digit arithmetic, and concentration in short-term memory tasks, could be predicted based on air temperature, thermal sensation, or thermal satisfaction. The optimal productivity was obtained when people felt "neutral" or "slightly cool," and the increase of thermal satisfaction positively affected productivity. Productivity loss emerged along with thermal discomfort caused by the too high or too low air temperature (Yang Geng, Wenjie, Borong, Yingxi 2017).

Also, there is a direct relationship between learning performance improvement and decreased percentage of students dissatisfied with the indoor environment (Mumovicet al., 2009). It is essential to maintain adequate indoor air quality in schools as a contributing factor to the learning performance of students (Fisk,2000; Synnefa et al., 2003). Some tests explored the relation between increasing ventilation rate and the positive benefits for health, comfort, and productivity (Allen, Macnaughton, Satish, Santana, Vallarino, Spengler 2015). Furthermore, a study identified the impact of air movement on thermal comfort and the efficient performance according to effects on the comfort, health, and productivity in tropical climates (E. Koehn, 1985).

Some studies suggest a controlled environment affects occupants' thermal perceptions, making them more tolerant to uncomfortable conditions (Humphreys, Nicol, Raja 2007). Classroom thermal conditions have to be considered carefully because of the high occupant density and the negative influences that an unsatisfactory thermal environment has on learning and performance (Coley, Greeves, & Saxby, 2007; Fisk,2000). A lack of comfort causes "environmental stress," thereby producing a negative trend among the students (Ossama, Gamal, Amal, 2006).

However, the comfort temperature preferences and perceptions of children are different compared with an adult. In the last decade, studies have recommended lower temperatures for elementary schools than those recommended for high schools, based on the young people have a more significant metabolism per unit body surface than adults (University of Toronto Press; 1972). Studies suggest that children are more sensitive to higher temperatures than adults leading to dangerous situations for the health, and concluding that there is a difference of *up to 2°C* lower than the adaptive comfort model predictions between the thermal perceptions of children and adults, particularly for those aged between 7 and 11 years old (Teli, Jentsch, James 2012).

Possible explanations for lower comfort temperature may be the higher metabolic rate per kg body weight, the limited available adaptive opportunities in classrooms, and the fact that children do not constantly adapt their clothing to their thermal sensation. The school schedule includes outdoor playing, unlike offices where occupants stay inside in sedentary activities for most of the day; this variation of activity levels and the strong relationship with the outdoor climate may also influence *children's thermal perception* (Teli, Jentsch, James 2012).

2.3 THERMAL COMFORT PARAMETERS

According to ASHRAE 55-2010, four environmental factors and two personal factors should be addressed to analyze thermal comfort: temperature, mean radiant temperature, humidity, airspeed, activity, and clothing.

2.3.1 Temperature

According to ASHRAE 55-10, **Air temperature** is the average temperature of the air surrounding an occupant concerning location and time. The **Operative temperature** is "the uniform temperature of an imaginary black enclosure and the air within it" (Hoff, 1993). "An occupant would exchange the same amount of heat by radiation plus convection as in the actual no uniform environment, no uniform environment" (Robert, 2021). The t_o is the average of the air temperature and the mean radiant temperature weighted, respectively, by the convective heat transfer coefficient and the occupant's linearized radiant heat transfer coefficient. For occupants in near sedentary activity (with metabolic rates between 1.0 and 1.3 met), not in direct sunlight, it is acceptable to approximate the relationship with acceptable accuracy by:

$$t_o = (t_a + \bar{t}_r)/2 \qquad \text{Equation (1)}$$

Where:

- t_o = operative temperature
- t_a = air temperature
- $\bar{t}_r$ = mean radiant temperature.

According to NTC 2316, the operative temperature for the activity depends on the time-weighted average and clothing insulation. Where:

$$t_o \text{ active} = t_o \text{ sedentary} - 3(1 + clo)\,(\text{met} - 1.2)\,(°\text{C}) \qquad \text{Equation (2)}$$

This equation is used for 1.2 to 3 met and the min. The operative temperature allowed for these activities is 15°C.

2.3.2 Mean Radiant Temperature

A key variable in the thermal calculation for the human body is the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual nonuniform enclosure. Measurements of the global temperature, air temperature, and air velocity can be combined to estimate the mean radiant temperature. Mean radiant temperature is measured using a globe thermometer. The mean radiant temperature can be calculated:

$$\bar{t}_r = t_g + 2.42 \text{ x } V(t_g - t_a) \qquad \text{Equation (3)}$$

Where:

- t_g = globe temperature
- V= air velocity in m/s
- t_a = air temperature

2.3.3 Humidity

According to ASHRAE 55-10 is a general reference to the moisture content of the air. It is expressed in terms: ***Vapor pressure*** is the pressure exerted by a vapor in thermodynamic equilibrium solid or liquid at a given temperature. ***The dew-point temperature*** is when water vapor starts to condense out of the air; the moisture holds in the air above the temperature. If the dew-point temperature is nearby to the dry air temperature, the relative humidity is high; if the dew point is below the dry air temperature, the relative humidity is low. As air temperature changes, the dew point remains constant unless the water is added or removed from the air.

Wet-bulb temperature is the adiabatic saturation temperature measured by a thermometer with the bulb wrapped in wet muslin. The adiabatic evaporation and the cooling effect are indicated by a "wet-bulb temperature" inferior to the dry-bulb temperature. There is an equilibrium between heat gained for the wet bulb due to the wet bulb is cooler than the air and heat lost due to evaporation. The wet-bulb temperature is the temperature of an object that can be achieved through evaporative cooling, assuming good airflow and the ambient air temperature remains the same. ***Humidity ratio*** is s the ratio of weight of moisture to the weight of dry air in the air–vapor mixture, which is expressed with the mass of water vapor in the humid air to the partial pressure of the dry air.

Furthermore, ***Relative humidity*** refers to the moisture content (i.e., water vapor) of the atmosphere as a percentage of the amount of moisture kept by the atmosphere at a given temperature and pressure without condensation. Variables, to describe a specific air condition, the humidity variables must be used in conjunction with dry-bulb temperature. High humidity not only reduces the evaporative cooling rate but also encourages the formation of skin moisture (sweat), which the body senses as uncomfortable. Moreover, mildew growth is frequently a severe problem when the humidity is high.

In Fundamentals of the ASHRAE manual, behaviors in particular environments refer to hot and humid climates. The tolerance limits in high temperatures vary with the ability to sense temperature, lose heat by regulatory sweating, and move heat from the body core by blood flow to the skin surface. Lower humidity limits are not established for thermal comfort, so the standard does not define a minimum humidity level. Nonthermal comfort factors (skying drying, dryness of eyes) can occur at lower humidity levels.

2.3.4 Air Speed

According to ASHRAE 55-10 is the rate of air movement at a point. Without regard to direction, the average airspeed surrounds a representative occupant concerning location and time. Air velocities influence the heat transfer rate between that air and surfaces. The higher the velocity of the air, the heat transfer will be higher. Higher velocities can be beneficial where heat transfer is necessary and depends on the surface characteristics. Indoor air velocities also influence thermal comfort. The greater the air velocity, the higher the heat exchange between people and the air around them. Generally, air velocities inside buildings are lower than the outside and can identify areas where air velocities could be close to 0 m/s. In naturally ventilated spaces, when the inside and outside air temperatures have a considerable difference, an internal air velocity of 0.1 m/s may be assumed in some simple heat transfer calculations.

2.3.5 Activity

The activity refers to the routine carried out in a given time. The metabolic power increases in proportion to work intensity; the metabolic range varies according to the activity, the person, and the environmental conditions. According to ASHRAE 55-10 1 met= 58.2 W/m^2. Some specific activities are referred to in the following table indicating the metabolic rate:

Table 2.1 Metabolic rate for scholar activities (Source: ASHRAE 55-10)

Activity	Metabolic Rate		
	met units	W/m2	Btu/h ft2
Reading /Seated	1.0	55	18
Writting	1.0	60	18
Typing	1.1	65	20
Filling, seated	1.2	70	22
Filing, standing	1.4	80	26
Walking about	1.7	100	31
Standing, relaxed	1.2	70	22

When metabolic rate must be determined more accurately, an empirical equation developed by Nishi (1981) could be applied:

$$M = \frac{567\,(0.23RQ + 0.77)\,Q_{O2}}{A_D} \qquad \text{Equation (4)}$$

Where:

- M= Metabolic rate, Btu/h·ft^2
- RQ= respiratory quotient
- Q_{O2}=Volumetric rate of oxygen consumption at conditions 32°F, 14.7 psi, ft^3/h

2.3.6 Clothing Insulation

In ASHRAE Fundamentals handbook to determine the clothing insulation is estimated based on tables and equations, the clothing thermal efficiency is calculated by:

$$f_{cl} = \frac{t_{cl} - t_o}{t_{sk} - t_o} \qquad \text{Equation (5)}$$

While the intrinsic clothing insulation es calculated with:

$$R_{cl} = \frac{t_{sk} - t_o}{q} - \frac{1}{hf_{cl}} \qquad \text{Equation (6)}$$

Where:

- t_{sk} = skin temperature °C
- t_o = Operative temperature

- f_{cl} = Clothing area factor
- q= heat loss from mannikin in Btu/h ft2

According to ASHRAE 55-10, the clo is the unit that expresses the thermal insulation provided by a single piece of clothing and clothing ensembles where 1 clo= 0,155 m^2 °C/W. Because clothing insulation can not be measured for most routine engineering applications, tables of measured values can be used for various clothing ensembles as shown in the Table 2.2:

Table 2.2 Typical insulation and permeability values for clothing ensembles (Source: ASHRAE 55-10)

Ensemble Description	*Icl (clo)*	*fcl*	*i cl*
Trousers business shirt shoes	0.61	1.20	0.41
Medium length skirt blouse shoes	0.74	1.19	0.41
Sweat pants sweatshirt sneakers	0.89	1.27	0.35
Business suit or casual with sweater	0.96	1.23	
Medium skirt blouse slip jacket	1.10	1.46	

2.4 BUILDING STANDARDS AND CODES

Colombian regulations are based on international standards for the design and construction of buildings. The existing codes are developed to solve concerns about the design of structural systems to satisfy the seismic conditions in the country. The Colombian seismic-resistant construction regulation (SNR-10), based on ASHRAE Handbook fundamentals, establishes the requirements for residential and non-residential construction systems. Additionally, the Colombian technical standard defines the acceptable thermal environmental conditions (NTC 5316-2004) based on the international ANSI/ASHRAE Standard 55.

NTC 4595 and NTC 6199, planning and design of school facilities, and Colombian technical standards, organize the parameters to improve the thermal comfort in school buildings. Besides, School 10 guideline is the regulation developed in the national 2014-2018 governmental plan, which defined the strategies for expanding educational coverage around the country, improving the educational system.

2.4.1 ASHRAE Handbook: Fundamentals

A publication of the nonprofit technical organization, ASHRAE is considered a repository of information about heating, ventilation, air-conditioning, and refrigeration. In chapter nine, this international standard describes thermal comfort, defining the basic concepts, measurements, and conditions to establish adequate thermal comfort. While in chapter sixteen, named ventilation and infiltration, provides the basic concepts, terminology, and calculations for indoor ventilation.

In the thermal comfort chapter, natural ventilation is defined as the airflow caused by wind and could pass through intentional openings in a building shell. Under some circumstances, it can control the temperature and contaminants percentage when mechanical air conditioning is unavailable. The standard also determines the design and calculation of indoor parameters.

The average speed, prevailing direction, and obstructions can affect the ventilation rate, the dimension and design of openings determine the airflow rates, if the flow is caused by wind only, the rate of air force through ventilation inlet openings by wind is calculated by:

$$Q = 88.0 C_v A U \quad \text{Equation (7)}$$

Where:

- Q = airflow rate, cfm
- C_v = effectiveness of openings (Cv is assumed to be 0.5 to 0.6 for perpendicular winds and 0.25 to 0.35 for diagonal winds)
- A = free area of inlet openings, ft^2
- U = wind speed, mph
- 88.0 = unit conversion factor

In the ninth chapter, thermal comfort in section 11 named special environments, introduced recommendations for designing buildings with natural ventilation; In hot and humid climates, the priority is to increase the air velocity in the occupied rooms. Topography, landscaping, and surrounding buildings should redirect airflow and give maximum exposure to breezes. Vegetation can funnel breezes and avoid wind dams, which reduce the driving pressure differential around the building. A smaller opening inlet than the outlet creates higher inlet velocities. Meanwhile, an outlet smaller than the inlet makes lower but more uniform airspeeds through the room. The openings should be accessible to occupants.

Additionally, long façades, doors and openings should be oriented to be exposed to breezes. Architectural elements (wing walls, parapets, and overhangs) should promote airflow into the building. Finally, the benefits of the wind depend on the airstream; openings with bigger areas than calculated are desirable when the occupancy level increase or in sweltering weather.

2.4.2 ANSI/ASHRAE Standard 55-2010. Thermal Environmental Conditions for Human Occupancy

In 1970, the ‘steady state’ thermal comfort theory became the base of international thermal comfort standards such as ASHRAE 55. Thermal comfort has been developed from different research and conceptual approaches. ASHRAE 55 standard specifies the acceptable indoor thermal environmental conditions and personal factors for designing, commissioning and testing indoor spaces acceptable to a majority of the occupants within a room. ASHRAE standard 55 was published in 1966, updated in versions 2004, 2010, and 2017.

2.4.2.1 Modelling Adaptative Method

Adaptive comfort concepts have been included in the ASHRAE standard since 2004, incorporating natural ventilation designs for more sustainable, energy-efficient, and occupant-friendly designs. Computer modeling and the adaptive method based on indoor temperature ranges and meteorological parameters support natural ventilation design. Since then, different researches and related adaptive comfort standards have been released worldwide, including Colombia through NTC 4595.

The comfort of the indoor environment is complex and responds to the interaction of environmental factors as air temperature, radiant temperature, humidity, and airspeed. Additionally, personal factors as clothing insulation, metabolic are addressed in this standard. ASHRAE 55-2010 specifies thermal environmental conditions acceptable for healthy adults, excluding non-thermal environmental factors like air quality, acoustics, and lighting. This standard only addresses thermal comfort in a steady state in a specific location, for occupants as staying more than 15 minutes, understanding that the effect of prior exposure or activity may affect comfort perceptions for approximately one hour.

It would be helpful to remember that this standard defines operative setpoints for buildings based on the metabolic rate of occupants, as shown in table 2.3 and the variations in occupant clothing levels. In contrast, the available data contains limited information regarding the comfort requirements of children. The conditions required for thermal comfort in naturally ventilated spaces are not the same as mechanical ventilated spaces. Field experiments have shown that the subjective notion of thermal comfort in naturally ventilated rooms differs due to different thermal experiences, control availability, and occupant expectations.

Table 2.3 Metabolic rates for typical scholar tasks (Source ASHRAE 2010)

Metabolic Rates for Typical Tasks

Activity	Metabolic Rate		
	met units	W/m2	Btu/h ft2
Reading /Seated	1.0	55	18
Writting	1.0	60	18
Typing	1.1	65	20
Filling, seated	1.2	70	22
Filing, standing	1.4	80	26
Walking about	1.7	100	31
Standing, relaxed	1.2	70	22

In buildings where the occupants are near-sedentary physical activities, metabolic rates are between above 1.3 met; there is no airspeed limit. Nevertheless, if the occupants do not control airspeed and the operative temperature is lower than 23°C, the upper limit should be 0.20 m/s. For cases where the operative temperature is between the ranges 23°C and 25.5°C without occupant control, the standard recommends calculating the airspeed using:

$$V_a = 50.49 - 4.4047(t_o) + 0.096425(t_o)^2 \qquad \text{Equation (8)}$$

Where:

- V_a = Average Air Speed
- t_o = Operative Temperature

In this method, the occupants have metabolic rates from 1.0 to 1.3 met and are free to adapt their clothing to the indoor thermal conditions within a range between 0.5 to 1.0 *clo*.

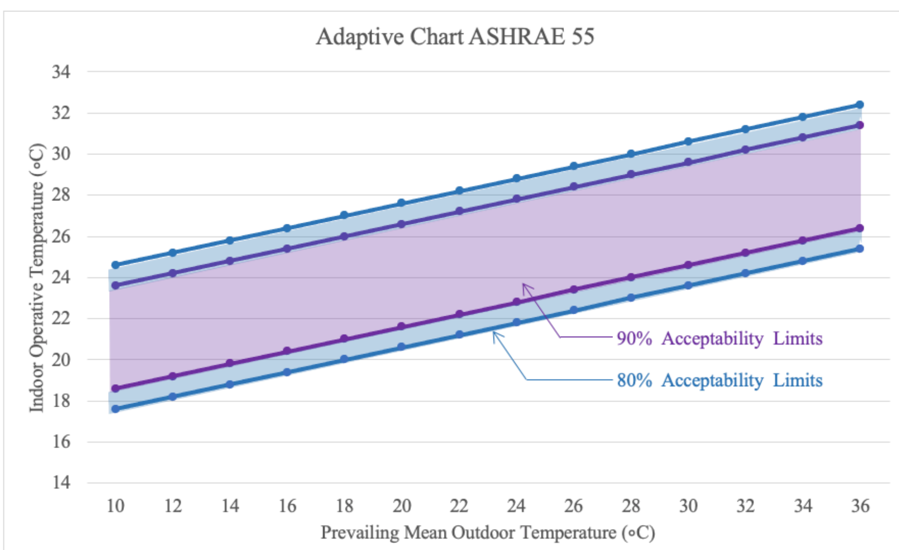


Figure 2.1. Adaptive Chart (Source: ASHRAE 55-10)

Figure 2.1 shows the adaptative chart used for thermal discomfort in buildings based in the comparison between the indoor operative temperature and prevailing mean outdoor temperature, and do not identify discomfort caused by an air temperature difference between the feet and the head, an asymmetric radiant field, local convective cooling (draft), or contact with a hot or cold floor. The adaptative method assume for people's clothing adaptation in naturally conditioned spaces by relating the acceptable range of indoor temperatures to the outdoor climate, the clothing level according to the school building occupants are:

Table 2.4 Clothing insulation values for typical scholar configuration (ASHRAE 55-2010)

Clothing Description	*Icl (clo)*
Trousers casual shirt shoes	0.6
Medium length skirt blouse shoes	0.7
Sweat pants sweatshirt sneakers	0.8
Suit or casual with sweater	0.9
Medium skirt blouse slip jacket	1.1

The thermal environment is evaluated through calculations and computer modeling for validating the thermal comfort from environmental measurements. Also, the adaptive model is applied for determining the comfort zone boundaries. It is essential to define the criteria, including the indoor air temperature, mean radiant temperature, humidity, airspeed, clothing, and activity rate.

The adaptive approach for occupant's thermal comfort relies on analyzing the data collected during thermal comfort occupant surveys. The seven-point thermal sensation scale area is used to rate from "hot" to "cold," and the satisfaction method provides the occupant's satisfaction responses from "very satisfied" to "very dissatisfied."

The researchers use a statistical method to analyze the recorded data from field surveys. The comfort criteria in existing buildings are directly determined from occupants' responses using acceptability ranges, and the sample size should be relevant with a high response rate. The evaluation should predict the occupant's satisfaction from seven points score, dividing the number of votes falling between -1 and +3 where 0 is neutral and +3 very acceptable inclusive. The probability of comfort acceptability is obtained divided by total votes during the survey period. The standard defines the essential concepts of thermal comfort. However, it is necessary to have thermal comfort definitions for hot and humid climates in South America.

2.4.3 ANSI/ASHRAE 62.1 2019 Ventilation for Acceptable Air Quality

This standard was published in 1973, and it has been considered to improve indoor air quality in buildings. Ventilation rates and other measures are described to improve indoor air quality into an acceptable rate to occupants and minimize adverse health effects. Three procedures for ventilation design are described: the IAQ procedure, the ventilation rate procedure, and the natural ventilation procedure.

Natural ventilation is defined as the ventilation provided by wind through doors, windows, or other intentional openings in the building. It is indispensable identify local contaminants from the surroundings, develop a local survey describing the building, compiling observation of odors information, visible contaminants, and potential contaminants sources to improve the air quality in a building.

The natural ventilation is the procedure to provide air through openings to the outdoor, and is used in conjunction with mechanical ventilation systems. It is determined by the hourly environmental conditions, including outdoor dry bulb temperature, dew point temperature, wind speed, air direction, and internal heat gains during expected hours of natural ventilation operation. And providing acceptable quantities of air according to the main activity defined in the building

Where louvers or screens obstruct openings, the area shall be based on the net-free area of the opening. Interior zones without openings should be ventilated through adjoining zones. The openings between zones shall be permanently unobstructed and have a free area not less than twice the percentage of the occupied floor area or 25 ft^2 (2.3 m^2), whichever is greater.

Ventilation rate has two driving forces in natural ventilation, buoyancy and wind. They can work cooperatively or competitively based on the wind speed, wind direction, indoor-outdoor air/surface temperature, and the intentional airflow path. The natural ventilation procedure presents the strategies for airflow. The regulation demands that all the natural ventilation zones include a mechanical ventilation system, except for those where the openings cannot be closed during periods of expected occupancy and are permanently open.

2.4.4 Colombian Seismic Resistant Construction Regulation NSR-10

Colombia is regulated for Earthquake Resistant Construction through the NSR-10, which determines the structural conditions that a building must-have to an earthquake (Figure 2.2). This standard identifies the design and construction parameters, calculations, and requirements according to the building materials and local conditions. Four construction materials are defined as accepted for buildings with two or more floors:

structural concrete, clay blocks, metal structure, and wood. The regulation is organized into 11 chapters from title A to K; chapter C defines reinforced and prestressed concrete structures design parameters. At the same time, chapter A describes the structural earthquake-resistant design of reinforced concrete structures, strength, and performance requirements.

In the same way, Chapter D defines the design parameters of reinforced masonry structures and the materials in a masonry structure. For buildings from one to three stories, the structural systems used are: reinforced concrete frames, structural steel frames, steel frames with eccentric diagonals, reinforced and partially reinforced masonry walls. The masonry walls must be distributed laterally of the structure; the façades must be built with materials that meet NSR-10 requirements, are available in the region, and meet durability, easy maintenance, and optimal environmental conditions.

The standard is analyzed and applied by national standard form; an official document required for all building projects at the design stage. Each municipality can review and approve this form, which includes identifying the sustainable construction strategies, classified in passive, active, or passive/active design, as shown in Table 2.5. However, this information is not defined as mandatory, and it does not imply adding support documentation for the license processing.

Table 2.5 Information required in national building license form (Source: NSR -10)

18. Sustainable Building Strategies					
Passive Strategies	☐	Active Strategies	☐	Passive/Active Strategies	☐

Passive strategies must be incorporated in the building design to maximize indoor thermal control, improve ventilation, and reduce energy consumption to create comfortable conditions for occupants. These do not involve mechanical or electrical systems. The strategies should consider the climate, landscape location, orientation, shape, solar protection, material selection, thermal mass, insulation, interior design, and openings for solar access, daylight, and ventilation.

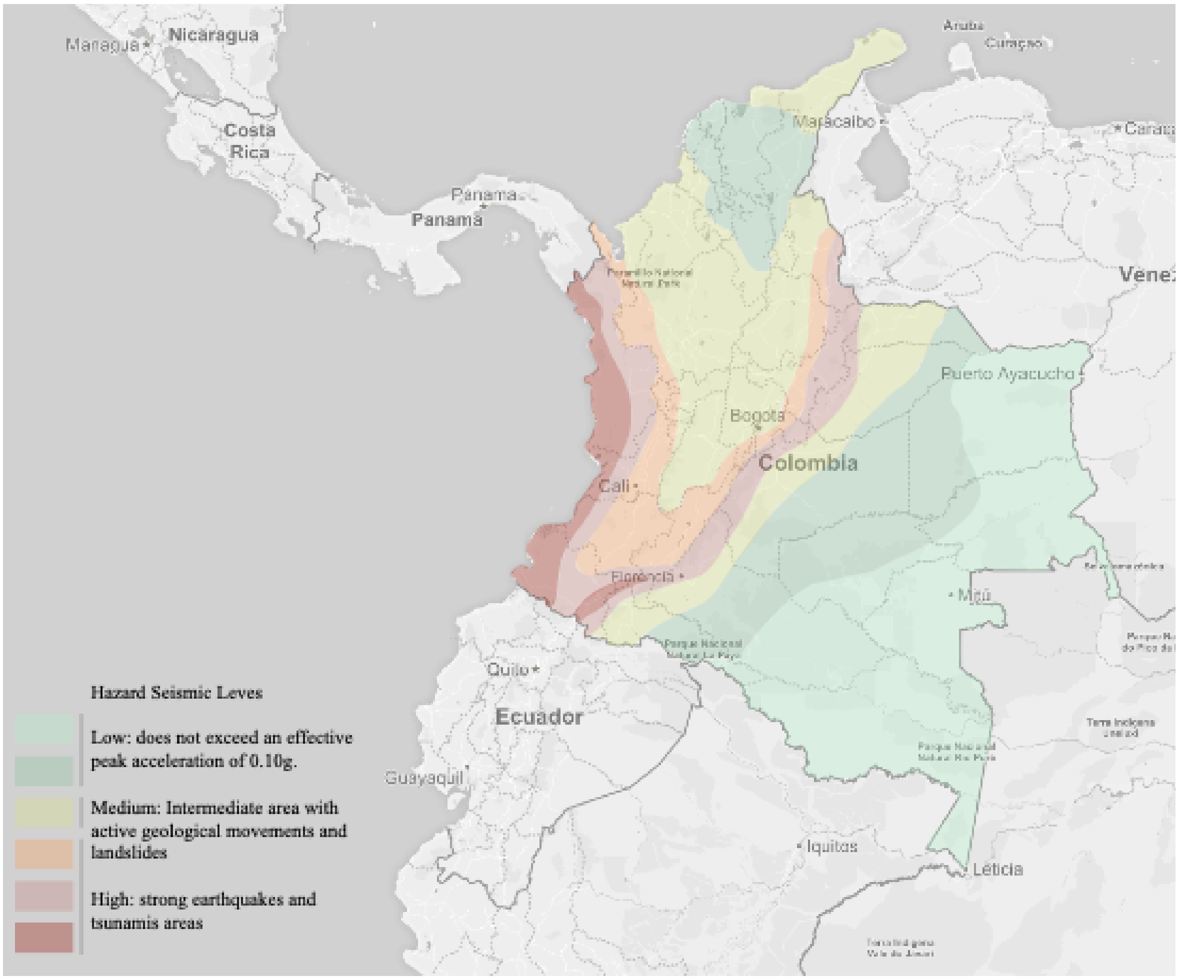


Figure 2.2. Seismic hazard zones in Colombia (Source: NSR-10)

On the other hand, if the designer applies active strategies in the building design, mechanical and electrical systems improve thermal comfort like boilers, air conditioning, mechanical ventilation, and lighting. In this case, the builder must present the savings percentages and their implementation. No documentation is required for monitoring and control.

2.4.5 Thermal environmental conditions for human occupancy NTC 5316

This standard regulates the thermal environmental conditions in buildings in Colombia, this regulation is a direct translation from English to Spanish of the ANSI-ASHRAE 55 standard by the Colombian Institute of certification (ICONTEC). According to the document, the thermal environment acceptance and thermal comfort perception are related to the metabolic rate, environment, physiological adjustments, and body temperatures. The standard defines a thermal comfort area if 80% of the occupants accept it. The comfort range for summer is established at 22.5 ° C <Operating Temperature (To) <26 ° C, with 60% relative humidity (rh), and metabolic rate unit (met) ≤ 1.2, and a maximum of 10% of the population is accepted unsatisfied. In this case, ASHRAE 55-10 standard takes the thermal sensation scale and establishes two methods to determine the thermal comfort of buildings.

Table 2.6 shows the outdoor conditions influence clothing values. Clothes configuration for students in hot and humid climates consist of light blue trousers, light pants, and short-sleeved shirts with clothing insulation values from 0.35 to 0.6 clo. In addition, the operating temperature range to obtain comfort in hot climates is higher than in cold climates, with a t_o = 22.5°C to 26°C at 60% rh and t_o = 23.5°C to 27°C the effective temperature lines are between 23°C and 26°C as shown in the Figure 2.3.

Table 2.6 Clothing insulation (*clo*) values (Source: NTC 5316)

Clothing Insulation Values

Outfit	clo
Long-sleeved cotton blouse, knee-length skirt, half pants	0.5
Shorts cotton shirt long pants strap socks hard soled shoes	0.6

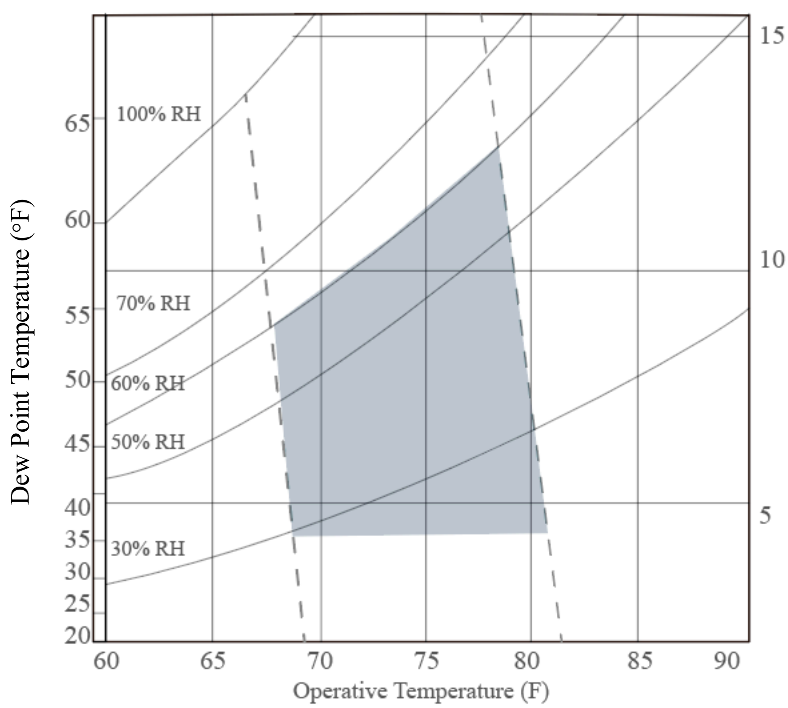


Figure 2.3. Acceptable operating temperature ranges in hot climates (Source: NTC 5316)

The minimum airspeed ranges to obtain thermal comfort is not defined as a fixed number in the standard (*Figure 2.4*). The operating temperature increases if the airspeed also increases; for sedentary conditions, the strategy should not decrease more than 3°C the indoor temperature and the airspeed should be greater than 1 m/s.

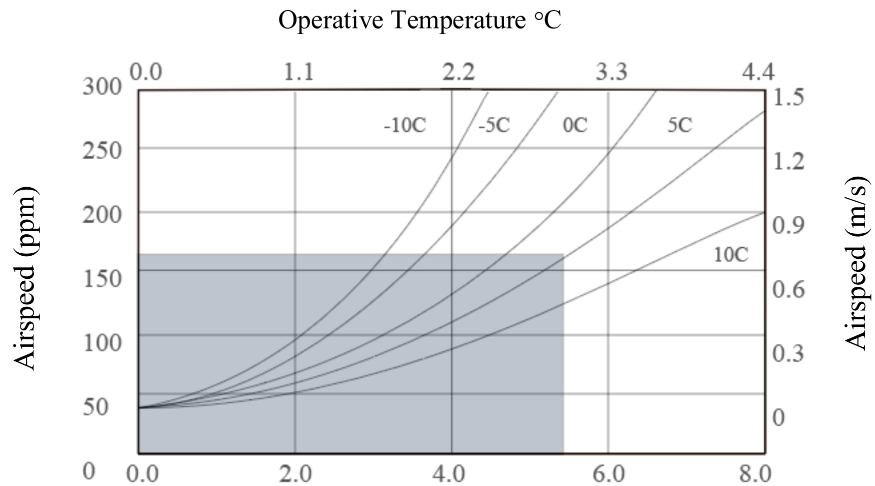


Figure 2.4. Airspeed and operative temperature for sedentary activities (Source: NTC 5316)

Airspeed required to compensate for the increase in temperature the starting point is 0.2 m/s with a temperature of 26°C. When there are temperature fluctuations, four factors must be considered: basal temperature, degrees per hour at which the temperature increases, degrees per hour at which the temperature decreases, and the fluctuation peak amplitude. If the operative temperature exceeds 1.1°C, the rate of temperature change should not exceed 2.2 ACH. The airspeed can cause unwanted cooling of the body, defined as air current, the turbulence intensity that can vary between 30% and 60%. Finally, the standard defines that the operative temperature (t_o) can be estimated from ambient temperature (t_a) and radiant temperature (t_r) by the relation:

$$t_o = \alpha\, t_a + (1-\alpha)\, t_r \qquad \text{Equation (9)}$$

Where:

- α depends or airspeed (v) related in the following table:

Table 2.7. Air speed *(v)* (Source: NTC 5316)

Air Speed v (m/s)	(fpm)	a
0 - 0.2	0 - 40	0.5
0 - 0.2	0 - 40	0.6
0.6 - 1.0	120 - 200	0.7

2.4.6 Planning and design of school environments and facilities NTC 4595

The construction planning and design of educational buildings are regulated by the Colombian technical standards institute and the national certification ICONTEC through the NTC 4595 from 2015. This standard is also used to evaluate and modify existing school facilities, prioritizing earthquake-resistant materials. The code is based on the number of students per classroom, electrical, sanitary, and hydraulic networks, and basic concepts to implement for thermal, visual comfort, and air quality.

The educational buildings should be located in urban areas with a range no more than 1000 mt; the construction land must have less than 15% slope and shall have a relation width/length ratio of 1:1 to 1:4. The following table arranges the building occupancy index:

Table 2.8 Construction areas for educational buildings (Source: NTC 4595)

Number Students	Floors	Occupancy Index	Construction Index	m2/student
480	2	0.52	1.03	5.74
690	2	0.50	1,0	5.33
1440	2	0.53	1.06	4.81

Kindergarten classrooms must be located on the first floor, elementary on the second floor, and high school up to a fourth floor. The classrooms typologies are classified as follows:

Table 2.9 Ooccupancy level for educational buildings (Source: NTC 4595)

Area	Students/Teachers	M2/Students
Kinder Garden	20	2.0
Elementary School	40	1.65
High School	40	1.65

The accessibility section is focused on doors, corridors, ramps, and stairs design and construction parameters. The doors must have a width not less than 0.80 mt and a free height of 2.05 m, while the corridors must be more than 1.80 m wide in classrooms and 1.20 m in the office area with a minimum height of 2.20 m. The ramps must have a slope between 5% and 9%, with a minimum width of 1.80 m. Finally, the stairs must have a minimum width of 1.20 m with treads between 0.28 m and 0.35 m and risers between 0.14 m and 0.18 m. The lighting section defined the classrooms and corridors must meet the following levels of average illuminance and maximum glare (UGR) as shown in Table 2.10:

Table 2.10 Lighting parameters in educational buildings (Source: NTC 4595)

Area	Lx	UGR
Classroom	500	19
Hall	100	25
Library	500	19
Laboratory	500	19

The chapter about comfort defines thermal comfort recommendations to improve the conditions in educational buildings; this section includes visual comfort, thermal comfort, acoustic comfort, and air quality. In the visual comfort section, the use of daylight is prioritized, specifying the openings in humid and hot climates should be 1/5 of the total floor area. In addition, transition spaces such as eaves should be no more than 2/3 of the total height and should be located perpendicular or with a variation up to 45 degrees to the north-south axis. In the thermal comfort section, external conditions should not disturb the academic activities development and classifying the country in the climatic zones as shown in table 2.11:

Table 2.11 Climate area classification in Colombia (Source: NTC 4595)

Area		Temperature	Relative Humidity	Rain	Wind Speed
Cold	>1800 mts	12-17	60%-80%	1000-3000 mm	1-3 m/s
Warm	800-1800	18-24	70-85	2000-3000	1-3 m/s
Dry Hot	0-800	>24	<75%	0-1500	2-3 m/s
Humid Hot**	0-801	>25	>75%	1500-7000	1-3 m/s

** winds north-east alisios

In humid and hot climates, the minimum height is 3.0 m for elementary and high school classrooms and 2.2 m for kindergarten. Further, the building must avoid direct radiation and use vegetation as temperature modulators. In terms of construction materials, only 7.5% of the solar heat gain factor must be transmitted to the interior of the classrooms, and the rest of the facades are only 5%. In the roof configuration is recommended a variety of plastic, zinc, and galvanized tiles and metal structures with a ceiling, generating an interior air chamber of not less than 0.20 m of high. Further, the roof configuration must be ventilated that guarantee air passage in hot, dry, and humid climates. The tiles must be selected in materials with a high reflective percentage.

Finally, this chapter establishes the comfort zone within the temperature range of 18°C to 24°C and relative humidity between 20% and 80%. However, these ranges may vary, depending on the climatic zone and include the acceptable temperature ranges according to the adaptive chart ASHRAE 55-10.

2.4.7 Planning and design of school environments, Colombian technical standard NTC 6199

The national regulation defines the planning and design of educational buildings. From 2016, it is also used to evaluate and adapt educational complexes. This standard establishes the occupancy levels according to the number of students per classroom; the maximum capacity is 320 students per building or 3.61m2/person for two-story buildings and 2.42 m2/person for three-story buildings. Further, Chapter 5 defines the maximum occupancy per classroom according to age. In this case, children between 3 to 5 years old should be in a leading group of 20 children per classroom and 25 children per classroom for students between 5 and 6 years old. Architectural elements such as doors must not be less than 0.80 meters wide, and corridors must have slopes less than 6% and a minimum width of 1.20 meters. Moreover, the regulation also defines kitchen, bathrooms, electrical hydraulic and sanitary design, and technical specifications for electrical lighting.

Regarding thermal comfort, this standard also focuses on the building morphology, excluding the use of specialized mechanical equipment, contemplating natural ventilation, and controlling solar radiation. It also defines four climatic zones in the country: cold, warm, dry-warm, and humid-warm. The humid-warm zone is between 0 to 800 MSL, with temperatures above 24°C, 75% relative humidity, 1.500 mm to 7.000 mm annual rainfall, and airspeed from 1 m/s to 3 m/s. Also, the optimal thermal comfort conditions refer to temperature ranges between 18°C and 24°C and relative humidity between 20% to 80% following the parameters of ASNI / ASHRAE 55 2004. It recommends openings at 45 degrees to increase the airspeed and use elements on the facade, such as eaves. The effective area of the ventilation openings shall be 1/6 of the total classroom area, and the minimum height must be 2.50 meters.

Respecting solar radiation control, the buildings must be oriented perpendicular to the north-south axis. Eaves, lattices, pergolas, sunshades, and other construction elements can control the sunlight. Construction materials must guarantee a solar gain factor of more than 7.50%, and the walls must have a thermal transmission coefficient of more than 3 W /m2°C. Similarly, the roof configuration must include a false ceiling and an interior air chamber greater than 0.20m high. It is possible to use thermal insulation materials such as fiberglass. The openings should be 1/5 of the floor area to allow access to daylight and increase the natural ventilation.

2.4.8 School 10 Guideline for the architectural design of schools' buildings

This regulation was developed by the Ministry of Education and is a reference for building design. This document includes design, implementation, and construction parameters for building educational infrastructure. The regulation is based on the B. Givoni diagram to analyze the thermal comfort strategies from ASHRAE 62.1 2007, as shown in Table 2.12. In Figure 2.5, the document proposes four types of building design, which the typology named as 24 or more classrooms for grades 0 to 11 was used in the reference building.

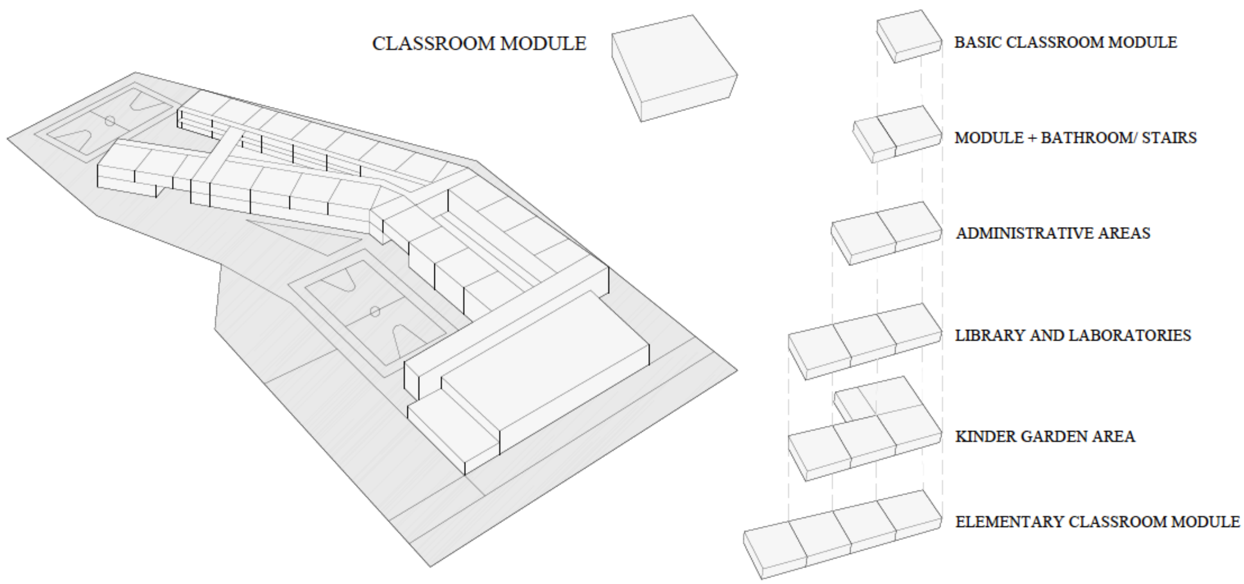


Figure 2.5. Architectural configuration for building prototype *(Source: School 10)*

Table 2.12 Occupancy levels (Source: School 10)

24 classroom 0-11 grade			
Area	Students	Area m2	m2/student
Kindergarden	80	40	2.0
Elementary	80	66	1.65
High School	80	66	1.65

In this typology, floors in vinyl or ceramic tile finishes are suggested, wooden and rubber are also recommended for external floors. Besides, use native vegetation in open areas, vehicular design parking without crossing pedestrian paths, and availability of bike parking. The library and auditorium should be located close to main entrance.

As a complement to the architectural recommendations, thermal strategies were developed for this location. Complex weather conditions characterize Colombia. About 913,000 km2 are between zero and one thousand meters above sea level with an average temperature above 25°C, corresponding to 80% of the national territory as shown in Figure 2.7. It receives most solar radiation, generating air movements between equatorial and polar latitudes from the northeast and Southeast. Trade winds or easterlies are the permanent east-west prevailing winds the flow near the equatorial zone called the intertropical confluence zone, causing the warm air to rise, causing cooling of air by expansion, generating condensation and clouds. Therefore, rainfall becomes stronger and more frequent. For hot and humid climates, it is defined as a heat stress area with indoor temperatures greater than 36°C, and thermal discomfort with temperatures greater than 28°C. In Figure 2.6, the upper limit is located at 28°C for naturally ventilated spaces to reach thermal comfort in the occupants.

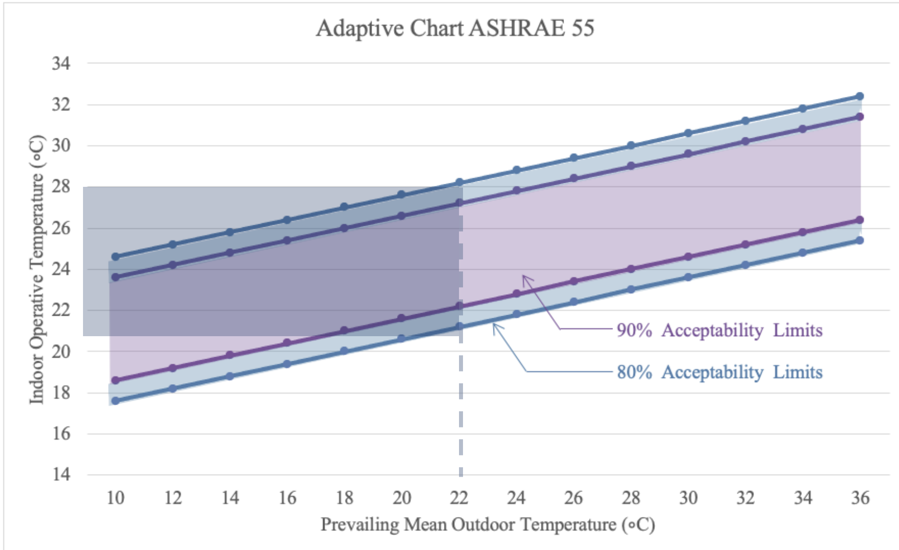


Figure 2.6. Optimal bioclimatic design for hot and humid climates. (Source: School 10)

Some recommendations are suggested for hot and humid climates to improve the natural ventilation: identify the wind direction, any natural or artificial barriers that could affect wind direction, analyze potential sources of dust or other contaminant agents that affect air quality, and develop an architectural design to improve the crossed ventilation.

Passive strategies as sloped roofs with low thermal transmission materials and reflective finish treatment, avoiding direct solar radiation in longer facades with protective eaves and light-colored finishes. Construction strategies such as concrete slab roof with an air camera, thermal insulation, and light-colored finish are recommended. Similarly, the light strategies can effectively reflect daylight off the ceiling and redirect it while reducing glare or excessive light levels near openings. Daylight deflectors are recommended with finishes in reflective colors.

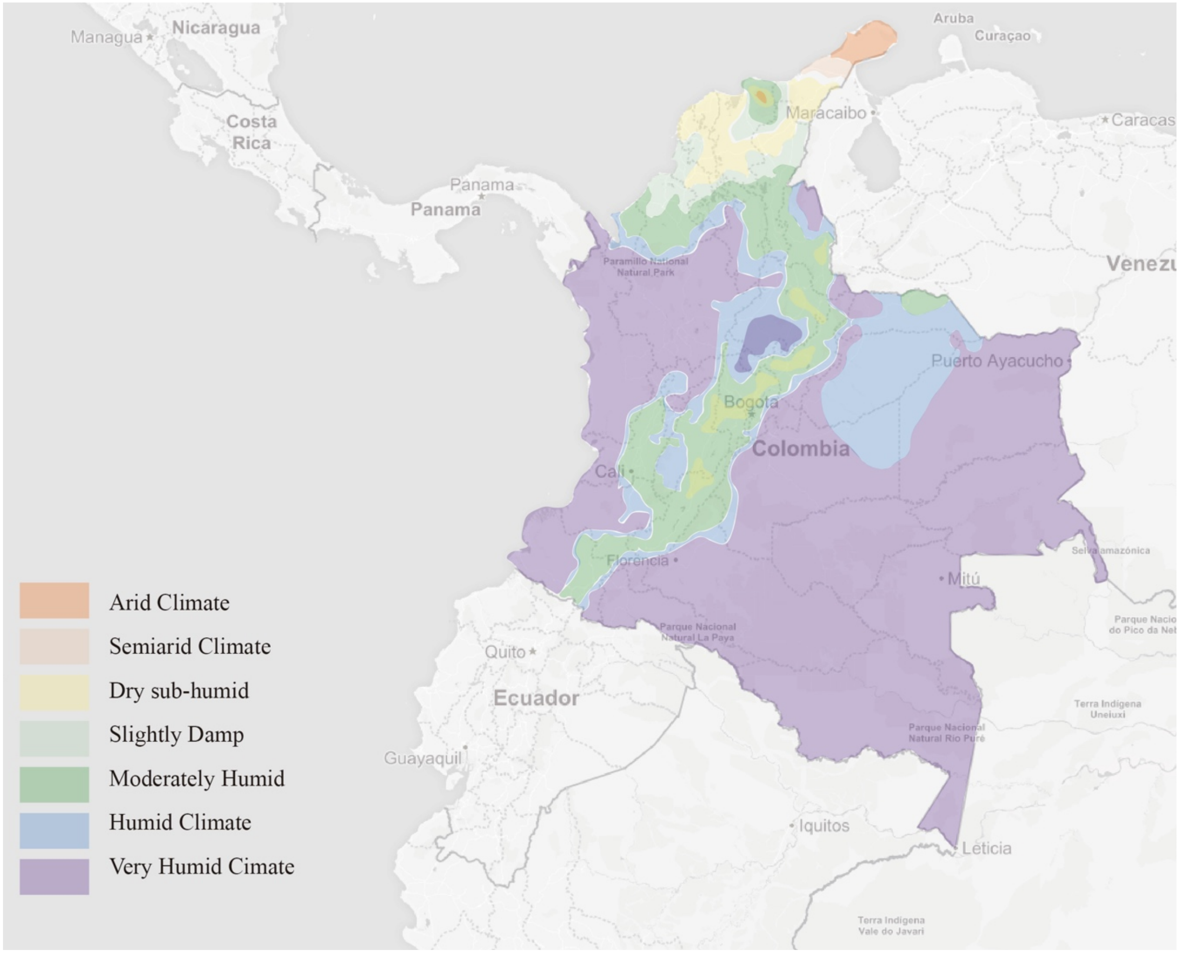


Figure 2.7. Climate characterization Colombia, (Source: IDEAM)

Finally, the guideline proposes a methodology for thermal comfort design: First, determine the design for the most representative climate periods where external weather conditions indicate maximum and minimum temperatures.

Then, develop the thermal load calculations to define the total air volume necessary for renewal and dissipation of heat, sizing the required openings that guarantee natural ventilation. In particular, natural ventilation calculations are required in systems based on dynamic effects (cross ventilation), thermal effects (chimney effect), or a combination of the above. Second, analyze the solar radiation, determining the impact during the scholarly activities. Determine the azimuth and angle of incidence on the building. Finally, dynamic simulation (CFD) software, mathematical models, or validation tools such as Abacus wind tunnels could validate the bioclimatic design.

2.5. THERMAL COMFORT MODELING METHODS

The adaptive comfort model is applied in naturally ventilated buildings and determines indoor conditions' acceptability given the mean outdoor air temperature and the indoor operative temperature. This model is used as an indicator for occupant adaptation to outdoor conditions and determines the acceptability of indoor conditions. The model also considers people's clothing adaptation in naturally conditioned spaces by relating the acceptable range of indoor temperatures to the outdoor climate, so it is unnecessary to estimate the clothing values. No humidity or air-speed limits are required when this option is used, as shown in Figure 2.8.

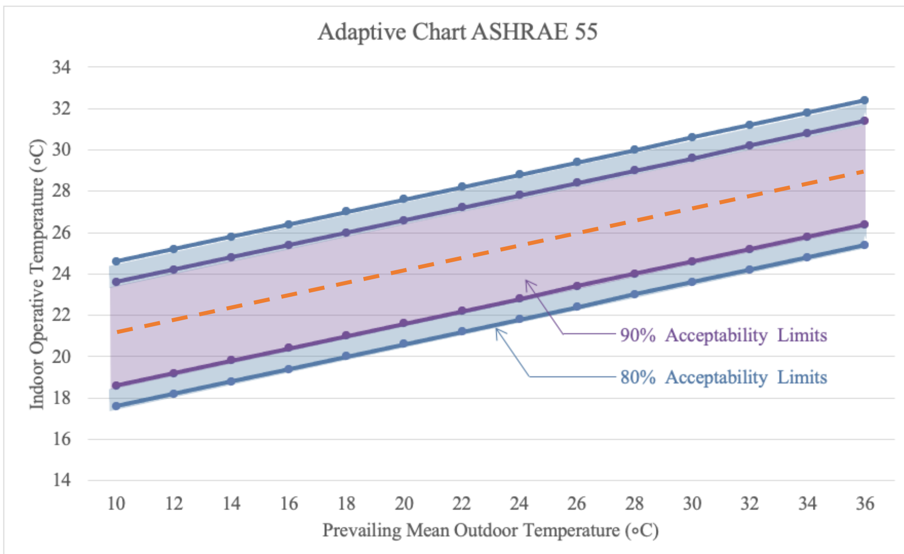


Figure 2.8. Acceptable operative temperature ranges for naturally conditioned spaces (ASHRAE 55 2010)

In ASHRAE Standard 55, the monthly mean outdoor air temperature used in the adaptive comfort model, is defined as the simple running average of the previous thirty daily average outdoor air temperatures. The model defines two comfort regions: 80% Acceptability limits and 90% Acceptability limits. The central line of the model (orange), or operative comfort temperature, is defined as:

$$t_{oc}=0.31 \cdot t_{out}+17.8 \quad \text{Equation (10)}$$

Where:

- t_{oc} – operative comfort temperature (°C), calculated as the average of the indoor air dry-bulb temperature and the mean radiant temperature of zone inside surfaces
- t_{out} – monthly mean outdoor air dry-bulb temperature (°C).

The monthly prevailing mean outdoor temperature is a simple running average of the previous thirty daily average temperatures, calculated directly from the weather file (.epw).

ASHRAE 55-2010 define the acceptable ranges of operating temperature including two sets of limits: for 80% and 90%, acceptability limits are symmetrical about the central line and determined by the equation:

90% acceptability limit t in °C= 0.31 * outdoor air temperature + 17.8± 2.5 Equation (11)

80% acceptability limit t in °C= 0.31 * outdoor air temperature + 17.8± 3.5 Equation (12)

2.6 SUMMARY

The current national building standards include ASHRAE 55-10 and ASHRAE 62.1. The thermal comfort is identified according to the indoor and outdoor conditions. in Colombia, the outdoor weather conditions are the principal variable due to the variety of climates. Also, it is determined thermal comfort parameters such as temperature, humidity, airspeed, activity, and clothing.

The adaptative modeling method defined natural ventilation as the primary ventilation method, based on the ability of occupants to adapt to the thermal environment changes until thermal comfort is achieved. Therefore, this model does not consider specific extent parameters such as age, origin, gender, and occupant's adaptation processes. Moreover, few studies have been developed for hot and humid naturally ventilated classrooms.

The methodology used is frequently applied in naturally ventilated studies. Measurements and surveys on adaptive thermal comfort research consider the non-standard conditions identified and reaffirm the differences found between tropical and cold climates, hindering the establishment of accurate conclusions.

A comparative table of the parameters from current thermal comfort standards is shown in Table 2.13. Divergences between the regulations were identified, varying from 24°C to 28°C the comfort temperatures, the occupancy levels at 2.85m2/student are reducing to 1.65 m2/student by national standards, and discrepancy in natural ventilation ranges between 0.8 m/s and 1.0 m/s increasing to up to 3.0 m/s in national regulations. These differences were defined as the variables to analyze for the simulations identifying their influence in hot and humid climates.

Table 2. 13 Table of comparative parameters in currently standards

Standard	**Thermal Comfort**				**Occupancy**	**Natural Ventilation**
	Indoor Temperature (°C)	*Heigh Floor-Ceiling (mt)*	*Metabolic Rate (met)*	*Relative Humidity (%)*	*m2/person*	*Indoor Airspeed (m/s)*
ASHRAE Handbook Fundamentals	24.7 °C *Children* 26.7 °C *Adults*	3.05	1.0	60%-80%	2.85	1.0 m/s
ASHRAE 55-2010	23°C *Not Airspeed Control* 25.5°C *Airspeed Control*	3.05	1.0 - 1.3	60%-80%	2.85	0.30 - 1.0 m/s
ASHRAE 62.1-2019	26.7 °C	3.05	1.0	60%-80%	2.85	0.80 m/s
NTC 5316	23°C -27°C	3.00	1.2	60%	1.65	1.0 m/s
NTC 4595	18°C -24°C	3.00	1.2	60%-80%	1.65	1.0 - 3.0 m/s
NTC 6199	18°C -24°C	2.50	1.2	75%	3.61 *(Two floors)* 2.42 *(Three floors)*	1.0 - 3.0 m/s
School 10	28°C	3.00	1.2	60%-80%	2.0 *Kindergarden* 1.65 *Elementary*	1.0 - 3.0 m/s

Additionally, the current construction practices in Colombia do not include insulation layers in the roof configuration to control temperature or humidity. The construction systems are defined by the materials found in the region and not by their thermal capacities. It is necessary then, analyze the thermal conditions of hot and humid climates, define the performance of the current regulation's parameters and achieve indoor thermal comfort through construction passive strategies.

Chapter 3. METHODOLOGY

3.1 INTRODUCTION

ASHRAE 55 2010 is selected to evaluate acceptable thermal environments in different configurations. The climate conditions data were obtained through three sources: The Institute of Environmental Studies of Colombia (IDEAM), Camilo Daza local airport, and ASHRAE climatic design conditions station located at 8 kilometers away from the school, collecting general climate conditions data for the year 2018. Three on-site visits identified the classroom configuration, students' perception of the indoor conditions, the types of activities carried out on indoor areas, the type of vegetation within the educational institution, and the current structural conditions after eight years of use.

The school was selected as a representative public educational building typology for children from kindergarten to high school level. It was built under the guidelines of current regulations. In addition, qualitative and quantitative information has been collected on-site visits through empirical observation; thus, it is possible to compare the simulation results when the boundary conditions were similar to those acquired during the measurements.

3.2 GEOGRAPHICAL CONDITIONS IN CUCUTA, COLOMBIA

The geographical conditions in Cucuta directly affect the city's climate, which is located 320 meters above sea level with a total area of 1.176 km2. This city is located on the eastern mountain range of the Colombian Andes, in the northeast region of Colombia and closer to the border with Venezuela, as shown in Figure 3.1. With an approximate population of 1.046.106 in 2020, this city is considered the most important economic, commercial and urban city between the two countries.

The topography is both flat on the north and hilly on the south. Its high point is at 1666 meters above sea level, and the lowest point is at 80 meters above sea level. The most representative mountain, Mount Tasajero, is 987 meters above sea level with a tropical dry forest typical in sub-humid subtropical climates located on the equatorial line.

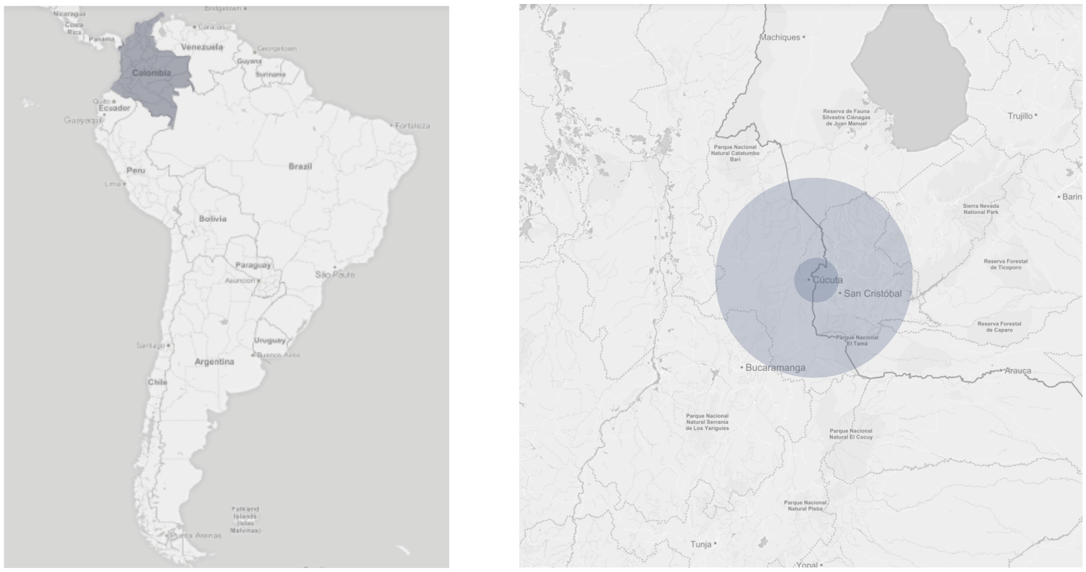


Figure 3.1. Geographical location 07°55 ' North latitude, 72°30' West longitude (Source: IDEAM)

3.2.1 Weather classification

The countries located on the equatorial line have climate and constant temperature; Colombia manages climates with minimal variations throughout the year, without significant magnitude weather phenomena such as hurricanes or tornadoes. According to the Köppen climate classification, four different climates with sub-classifications ranging from polar climate to humid tropical climate can be identified in the country, with humid tropical climate prevailing by 65% and Mediterranean oceanic climate by 22% of the total area of the country. 87% of the country's cities are located in humid tropical climates, tundra, and monsoon.

In the case of Cúcuta, it has a tropical savanna climate, bordering on a hot semi-arid climate according to the Köppen climate classification, where summers are short, very hot, and cloudy, and winters are hot and mostly cloudy throughout the year. During the year, the temperature generally ranges from 22°C to 33°C and rarely drops below 20°C or rises above 35°C. The driest months are January, February, June, and July; in contrast with April, May, September, October, and November. Finally, the annual precipitation is around 900 millimeters or 35 inches.

The information collected for the energy simulation program was obtained through the ASHRAE climatic design conditions station in collaboration with white box technologies in .epw format. The Figure 3.2 shows the selected station is located in San Antonio Táchira, Venezuela, Located at 7°48′52″ N 72°26′35″W. The information provided includes: Annual and monthly heating, humidification, cooling, dehumidification, enthalpy design conditions, dry-bulb wet-bulb temperatures, and monthly mean daily temperature ranges.

Figure 3.2. Weather station at 8 kms in San Antonio, Venezuela. (Source: ASHRAE climatic design conditions station)

3.2.2 Temperature

The minimum annual average temperature for the humid tropical region is 24°C, and 34°C, the maximum average temperature, and Colombia has the least seasonal variation due to the location. In Cucuta, the daily average temperature is 27.6°C and the maximum temperatures in the afternoon are around 32°C. The hot season lasts two months, from October to November, being November the hottest month with an average maximum temperature of 33°C and a minimum of 25°C. The cold season lasts three months, from December to February, with a daily average maximum temperature of less than 30°C. The coldest month is January, with an average minimum of 22°C and a maximum of 30°C, as shown in Table 3.1.

Table 3.1. Average monthly outdoor temperature for 1990-2018 (Source: Airport station. Cúcuta)

Year	*Anual average*	*Average Monthly Temperature*											
		Ene	*Feb*	*Mar*	*Abr*	*May*	*Jun*	*Jul*	*Ago*	*Sep*	*Oct*	*Nov*	*Dic*
1990	26.8	25.3	24.4	25.6	26.6	27	28.4	28.3	28.5	28.7	26.8	26.7	24.9
1991	27.4	25.4	26.6	26.6	27.3	28.1	28.7	28.4	28.6	28.8	27.9	26.8	25.7
1992	27.8	27.2	27.4	28.5	28.7	28.7	28.7	27.8	28.5	28.1	28.2	26.9	25.4
1993	27.6	26	26.5	27.7	28.1	27.8	28.6	28.2	28.8	28.3	28.4	26.6	26.2
1994	27.1	25.2	26.3	26.3	26.2	28.2	28.5	27.9	28.3	29.1	26.7	26.5	26.4
1995	27.5	27	27.9	27.1	27.3	28	28.4	28.2	27.8	28.9	27.2	26.9	26.2
1996	27.2	26.1	26.7	26.8	27.6	27.5	28	27.8	28.5	28.8	27.3	26.3	25.2
1997	27.7	24.7	25.5	26.1	27	28.7	28.4	28.7	29.6	29.6	28.2	28	29
1998	28.4	28.9	28.6	28.8	28.7	28.9	28.7	28.8	29.2	29.2	28.4	26.9	25.8
1999	26.6	24.8	24.2	25.8	27.1	28.3	28	28	28	27.1	26.9	26.2	24.8
2000	26.7	23.8	24.5	25	26.3	27.7	27.8	28.1	28.6	28	27.9	26	26.7
2001	27.7	26.4	26.7	27.9	27.1	28.4	28.1	28.7	29.7	28.6	28.3	26.4	26.6
2002	27.4	26	26.3	26.6	25.8	27.5	27.4	28.3	29	29.3	28.4	27.6	27.5
2003	27.9	27.9	28.3	28.5	27.7	28.7	27.5	28.2	29.3	28.9	28	26.7	26
2004	26.9	24.8	26.3	26.6	26.7	27.3	27.9	28	29	28.1	27.4	26.2	25.1
2005	27.2	24.9	24.6	27.5	27.9	27.3	28.5	28.5	29	29.6	27.5	26.1	25.2
2006	27.1	24.7	25.7	25.3	26	27.8	27.9	28.2	29.2	29.4	28.1	27.1	26.2
2007	27.2	26.1	27.4	27.4	27.3	28.5	28.4	28.3	27.8	28.3	26.9	26.2	24.8
2008	26.5	25	25.3	25.8	26.6	27	27.9	27.6	27.4	28.2	26.9	26.3	24.4
2009	27.0	24.9	24.6	24.3	26	27.2	28.3	28.1	28.7	29.9	28	27.4	27.1
2010	27.5	27.8	29.3	28.8	27.9	28.3	28.4	27.5	28.6	26.8	26.9	25.5	25
2011	26.4	25.2	25.2	24.2	25.7	26.9	27.6	27.8	28.9	28.5	26.4	25.9	25.2
2012	27.2	24.6	25.4	25.9	26.5	27.8	29	28.3	28.6	29.7	27.7	26.8	26.3
2013	27.5	26.4	25.9	27.4	27.9	27.2	28.3	28.9	28.6	29.4	28.5	26.4	25.7
2014	27.8	26.3	27.4	27.6	28.8	27.4	28.2	28.9	29.4	29.1	28	26.8	26.6
2015	27.7	26.6	26.8	26	27.1	28.7	28.6	28.6	29.5	(-)	(-)	(-)	(-)
2016	27.7	26.5	28	27.6	28.1	27.9	28.6	28.2	28.8	28.7	27.2	27	26.9
2017	26.9	26.5	26.4	26.8	27.6	29	28.1	28	27.5	27.1	26.7	25.7	24
2018	26.4	24.2	24.3	24.6	26.3	27.3	27.4	27.5	28.7	27.8	27.1	26.7	25.3

3.2.3 Relative Humidity

The dew point measures the amount of water vapor in the air; it feels drier at the lower dew point, and at the higher dew point, it feels more humid. The information obtained by the Institute of Hydrology, Meteorology, and Environmental Studies shows that for 20 years in Cucuta, the perceived humidity varies slightly. The annual period with the highest humidity percentage lasts ten months from August to June, with an uncomfortable level at least 84% of the time. November has the highest percentages, while July has the lowest rates, as shown in Table 3.2. The dew point tends to change slowly; although the temperature drops at night, the night is usually humid on a humid day.

*Table 3.2. Monthly a*verage relative humidity (%) for 2018 (Source: Camilo Daza airport station Cúcuta)

Day	*Monthly Relative Humidity 2018 (%)*											
	Jan	*Feb*	*Mar*	*Abr*	*May*	*Jun*	*Jul*	*Ago*	*Sep*	*Oct*	*Nov*	*Dic*
1	69	66	69	78	72	65	64	60	62	69	74	79
2	79	72	70	71	75	64	67	61	69	72	83	87
3	82	72	81	80	77	64	62	63	68	74	87	85
4	81	79	81	84	77	68	58	63	66	79	82	75
5	71	68	74	72	72	62	65	65	71	81	81	78
6	77	80	77	78	68	64	62	70	73	77	83	91
7	88	82	85	80	72	69	65	66	72	75	80	84
8	82	85	81	80	72	60	65	65	67	80	77	84
9	79	74	76	75	74	65	61	60	62	64	74	77
10	68	68	66	68	66	60	61	60	64	64	74	81
11	76	73	67	69	71	59	63	58	63	63	76	73
12	76	71	74	77	66	57	61	58	59	75	76	75
13	66	61	73	75	69	65	63	69	63	74	74	77
14	72	74	72	69	70	62	61	59	58	70	76	80
15	81	76	73	74	61	62	56	53	58	68	68	59
16	62	67	67	73	66	58	58	58	63	66	73	80
17	80	83	77	68	63	64	59	61	71	74	79	83
18	83	81	80	75	68	63	61	58	65	66	78	68
19	67	63	67	74	66	61	59	55	64	68	79	79
20	74	74	77	82	73	67	61	57	61	66	71	71
21	67	68	65	72	63	70	63	59	61	70	79	78
22	81	74	77	79	73	60	62	58	68	74	79	83
23	83	84	74	73	75	62	58	56	59	74	80	82
24	83	79	83	82	70	64	61	59	60	71	77	77
25	75	66	69	76	69	68	59	67	66	75	78	83
26	78	78	79	74	73	65	63	70	64	74	80	84
27	82	83	84	79	73	61	64	62	56	67	74	72
28	62	67	70	75	71	67	68	64	76	76	82	84
29	80		84	81	76	69	63	58	63	77	82	83
30	83		77	78	66	54	58	60	53	71	79	74
31	72		74		75		54	63		64		78

3.2.4 Wind

Cucuta is one of the cities in Colombia with higher rates of wind, reaching up to 67 kilometers per hour between July, August, and September. Solar radiation and geographical conditions determine the wind direction and speed. Cucuta is located where the trade winds converge. The breeze between the valley and the mountains generates a local airflow circulation system; when the slopes heat up due to the sun, raising the surface temperature and generating air currents that rise through the mountains, the ground cools, and the air descends.

Table 3.3. Wind direction monthly average. (Source: Institute of Hydrology, Meteorology and Environmental Studies IDEAM).

Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
NE	NE	NE	E	SE	SE	SE	SE	SE	E	E	EE

As shown in Table 3.4, there is a prevailing southeastern orientation from May to September without finding a predominant wind direction during the year. Between January and March, winds orientation prevailing northeast.

Table 3.4. Average wind speed (m/s) Source: Camilo Daza airport station Cucuta 1990-2018

Year	*Annual Average*	*Wind Speed*											
		Ene.	*Feb.*	*Mar.*	*Abr.*	*May.*	*Jun.*	*Jul.*	*Ago.*	*Sep.*	*Oct.*	*Nov.*	*Dic.*
1991	(-)	0.8	(-)	(-)	(-)	1.9	(-)	(-)	(-)	(-)	4.3	2.7	2.4
1992	3.0	2.1	2.1	2.3	1.8	2.6	5.8	5.4	5.4	2.6	2.7	1.4	1.2
1993	2.9	1.7	1.5	2.5	2.2	1.9	7.7	4.7	5.3	2.4	2.3	1.1	1.4
1994	2.6	0.9	1.2	1.2	1.8	2.7	5.2	4.8	4.7	3.7	1.6	1.3	1.5
1995	(-)	2.2	1.6	(-)	(-)	(-)	(-)	(-)	2.7	(-)	(-)	(-)	(-)
1996	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	4.1	3.9	2.3	1.9	1.9
1997	2,5	1.8	2.7	2,0	2.1	4.2	4.1	5.9	5.9	4.3	2.9	3,0	3.9
1998	3,0	2.8	2.7	2.5	3,0	3.9	4.8	4.9	3.7	3.1	3.2	2.5	1.4
1999	4,0	1.3	1.1	1.4	3.9	3.5	3.5	4.4	4,0	2.3	2.3	1.8	1.8
2000	3,0	1.9	1.8	2,0	2.3	2.8	3.3	4,0	(-)	(-)	(-)	(-)	(-)
2002	3,5	(-)	(-)	2.2	2.1	4,0	5.2	5.1	5.7	4.3	3.4	3.2	3,0
2003	3.3	2.9	2.8	2.4	2.8	4.3	3.6	4.6	4.9	3.9	2.7	2.1	2.3
2004	2.9	1.8	2.2	2.4	2.3	3.3	5.6	(-)	(-)	(-)	(-)	(-)	(-)
2005	3.2	(-)	(-)	(-)	(-)	2.3	3.7	4.8	4.3	4.2	2.4	2,0	1.8
2006	3.0	1.8	2.2	2,0	2.2	3.4	4.1	4.9	4.4	3.7	2.7	2.1	2.2
2007	2.9	2.2	2.7	2.4	2.3	3.1	4.7	4.5	3.2	3.4	2.4	2.1	1.7
2008	2.5	2,0	2.1	2.2	2.4	2.9	3.7	3.8	2.7	3.3	2,0	1.8	1.6
2009	2.7	1.8	1.8	1.7	1.9	2.6	3.9	4,0	3.8	4,0	2.8	2.2	2.2
2010	2.3	2.5	2.4	2.4	2.3	2.4	2.9	2.7	2.9	1.9	1.9	1.5	1.5
2011	2.2	1.6	1.6	1.5	1.7	2.2	2.9	3.5	3.5	2.8	1.7	1.6	1.6
2012	2.8	1.5	1.7	2.2	1.9	3.5	4.6	4.4	3.9	4.2	2.3	1.8	2.1
2013	2.8	2,0	1.9	2.1	2.3	2.3	4,0	4.7	4.1	3.7	2.6	1.9	2,0
2014	3.3	(-)	1.9	2.2	3.2	2.5	4.6	5.8	4.4	4.0	2.8	2.0	(-)
2016	4,2	3.3	3.4	3.2	4.3	4,0	7.9	6.2	6.1	3.9	2.1	2.6	3,0
2017	3.1	2.7	2.3	2.9	2.5	4.1	(-)	5.3	3.1	(-)	2.2	(-)	(-)
2018	2.6	(-)	2,0	1.4	2,0	0.4	4.8	6.3	2.5	(-)	1.8	2.4	(-)

3.3 OCCUPANTS

3.3.1 Socioeconomic conditions

According to the census of 2018, the population in Colombia was 44.200.000 (Table 3.5), where 10.449.500 are children of school-age, 80.2% of the children study in public school compared with 19.8% who study in private schools. The regions with the highest children population are Choco with 16.8%, La Guajira with 16.8%, and Norte de Santander with 15.2%, respectively. Cucuta is one of the cities with the higher percentage of the population in school-age due to the constant increment of temporary population migrating from Venezuela the last five years.

The educational programs are offered according to the economic conditions of the families classified by levels from 0 to 5. Firstly, levels 0, 1, and 2 are those families that depend economically on governmental financial support, having access to complete free-cost education in public institutions as the case study analyzed in this document. Secondly, levels 4 and 5 where children have access to private institutions in the principal cities. School is selected according to their home location, parents must pay a minimum fee to be accepted at the beginning of the year, and scholar supplies are not required. Breakfast and lunch, besides clothing, are also included in the academic period.

Table 3.5. Population increments per census in Colombia (Source: DANE,2018)

Total Population	44.200.000,00	2.018	
	41.468.384,00	2.005	(+)7%
	33.109.839,00	1.993	(+)25%
	20.666.920,00	1.985	

3.3.2 Educational System

The Colombian public educational system is classified into fundamental education and validation education. The education process begins at three years old with pre-kindergarten and kindergarten. Then, basic education or elementary school consisting of 5 years with students from 6 to 11 years old, and six years in high school with students from 12 to 17 years old. The period called fundamental education is mandatory for all children. The validation education system is also offered for people older than 18 who want to study basic education in a shorter time: elementary school provided in two years and high school in one year. This method allows for a more outstanding educational offer adaptable to adult population requirements.

According to the Ministry of National Education in Colombia, school buildings are classified according to the level of education. Those schools built by the government for children between 7- and 15-years old count with kindergarten, elementary and high school classrooms, besides the library, laboratories, and auditoriums. These buildings occupy around 20% of the non-residential area where indoor comfort and air quality are essential for the learning process. 80.2% of these institutions implement wind as the ventilation strategy to improve thermal comfort.

Table 3.6. Total number of students in Norte de Santander. (Source: DANE)

		Total Students	*Total Schools*
Kinder Garden	Rural Area	56.520	1394
	Urban Area	238.370	470
	Total	294.890	1864
Elementary School	Rural Area	71.400	1724
	Urban Area	1.003.040	449
	Total	1.074.440	2173

This document analyzes an educational building developed according to the national guidelines for children between 7 and 15 years old in fundamental education and adult validation programs. With an occupancy of 1.441 students daily, the total area per student shows an over-occupancy of 150% according to the country's regulations.

Finally, the teacher defines the configuration of the classrooms. The students of different grades learn the same topic in a classroom simultaneously. For example, in a group of 30 students, there may be ten fifth grade, ten from fourth grade, and ten from third grade receiving classes of the same topic. Therefore, the teacher confirms that each student receives the appropriate knowledge, works in the allotted time, and meets the weekly objectives as shown Figures 3.6.

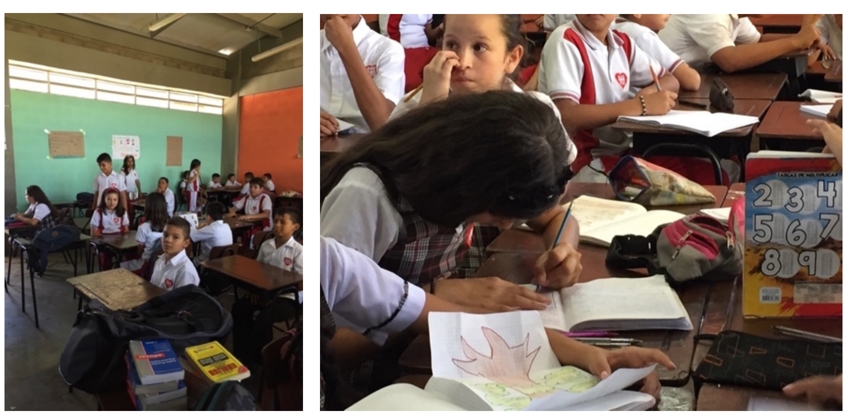


Figure 3.3. Students from different grades receiving class simultaneously

3.4 INDOOR THERMAL COMFORT VARIABLES

Three variables were analyzed based on the analysis of the current regulations in Colombia and the results of simulation of the current conditions. The occupancy level varied according to the regulation applied in the building construction program but not the architectural design, having the max number of students per classroom in kindergarten and a consistent number of students in elementary and high school classrooms. Natural ventilation was selected as the second variable due to the architectural analysis of the façade elements in the façade identified on-site visits and how the buildings prioritize the use of natural ventilation. And finally, the roof configuration was chosen as the last variable due to the possibility to improve the thermal conditions by adding insulation to the roof configuration.

3.4.1 Occupancy Level

This variable refers to the maximum number of students per classroom with the optimal thermal comfort according to the current standards, this variable is calculated in m2/ person. ASHRAE 55-2010, NTC 4595, the current conditions rates, and an empty classroom were compared, identifying the direct relation with the indoor thermal conditions in classrooms.

3.4.2 Natural Ventilation

This variable analyzes the air change rate ACH caused by wind and thermal pressures passing through intentional openings in the façade. In this study, a constant ACH is assumed to represent an equivalent average airflow rate provided by natural ventilation. Three types of openings were identified in this building, and concrete vertical louvers in the north and south façade, Six ACH rates were assumed from 1.0 to 6.0 ACH, in the model 1.0 ACH is identified as the rate of the current condition and 5.0 and 6 ACH as the rate recommended by ASHRAE 55-10.

3.4.3 Roof Configuration

This variable analyzes the current roof configuration. Five types of insulations materials were proposed to improve the indoor thermal conditions in the model, representing the metal structure, and tile material as constants in the roof configurations. Differences in thicknesses and R values were selected in this variable.

3.5 CASE STUDY: EDUCATIONAL BUILDING IN CUCUTA, COLOMBIA

The school building was selected as a representative public-school typology of for children between 7 to 16 years old due to the representative number of students registered in 2018. This school also offered basic education for adults and was built under the guidelines of current regulations. The school is located on the east side of the city, where the population belong to economic levels 0, 1, and 2. This school was built in 2010 by the national government and is currently managed by the catholic religion, offering different activities as shown in Figure 3.4.

Building Uses Requirements

- Day Activities
  - Languages
  - Sciences
  - Computer Sciences
- Night Activities
  - Governmental and President Elections
  - High school education for adults
  - national knwoledge test
  - Local cultural events

Figure 3.4. Activities developed in the educational building.

Figure 3.5. I. E. Monseñor Jaime Prieto Amaya School location (Source: Google Maps, 2018)

The educational institution has 10,000 m^2 organized into two areas without connection between them, as shown in Table 3.7, one for kindergarten and the other for primary and secondary. The second area is designed of three buildings. Two of them are located parallel in an east-west direction with classrooms on the first and second floors and 1700 m^2 per floor connected by ramps, and stairs at the end of the volume. The third one is for activities such as theater, dance, sports activities, and physics and chemistry laboratories.

Table 3.7 Total Area Jaime Prieto Amaya School

	Elementary		*Kindergarden*	
	m2	*Sq Ft*	*m2*	*Sq Ft*
Total Area	6.460,80	69.518,21	4.179,11	44.967,22
Total Area First Floor	1.702,70	18.321,05	899,78	9.681,63
Total Area Second Floor	1.510,28	16.250,61	213,37	2.295,86
Total Roof Area	1.702,70	18.321,05	899,78	9.681,63
Area per Classroom	28,12	302,57	54,11	582,22
Total Area			10.639,91	114.485,43

In the first stage, the buildings have elementary and kindergarten classrooms. At the same time, high school classrooms are located on the second floor. Additional services areas, restaurant, and library are still under construction, and no native vegetation is observed on the north, east, or west sides.

The facades follow a defined design pattern for the external sides. A series of vertical concrete louvers transfer the air through square openings towards the interior, users cannot operate it. While the interior facades are defined by the corridors that connect each classroom, the interior facades were designed with consecutive walls to control daylight access and thus, increase the temperature inside. It is essential to highlight that any building has a mechanical ventilation system.

These projects are built progressively, and their construction can last from 10 to 15 years. The second-floor roof is plastic tile with a metal structure without any insulation layer included in the roof configuration.

Figure 3.6. North façade elementary building and playground area.

The building facades were painted in white, as shown in Figure 3.6, following the recommendations of the national standard for hot and humid climates. In Figure 3.7, no additional elements are identified on the facade, such as pergolas, fixed roofs, or eaves for the principal access of the building.

Figure 3.7. Kindergarten and elementary areas.

3.5.1 Data collection and procedures

Site visit Methodology:

1. Once the institution to be analyzed was selected, several visits were defined at specific times to understand the occupation dynamics of the building. The first visit was carried out to understand the student's density, the dimensions of the circulations, and the indoor quality conditions in each of the classrooms.

   That same day a photographic record of Elementary and High School is made. Interviews are conducted with professors and cleaning services workers about their perception of comfort within the building.

2. The second visit was made between 11 am and 3 pm when the highest temperature is reached in the city and significant wind speed. A photographic record is taken of the elementary and high school areas and the institution's permit during this visit. Surveys are carried out on students to quantify their thermal comfort perception in the building.

   A data collection is also carried out about external environmental conditions obtained by the region's airport. Environmental and individual conditions measured students' comfort in the classrooms.

3. The last visit is made at 17:00 hours, taking a photographic record of the entire institution and using the thermal camera tool to determine materials performances.

The thermal comfort evaluation method was developed based on ASHRAE Standard 55-2010, defining the study as class III. The indoor measurements were taken at the height of 0.6 m above the floor, representing the average height of the occupant in the seated position. The indoor air temperature (t_a), relative humidity (rh) was measured using the EXTECH 42280 thermometer datalogger.

The climatic conditions data were obtained through three sources: The Institute of Environmental Studies of Colombia, Camilo Daza local airport, and San Antonio del Táchira ASHRAE climatic design conditions station. It is worth mentioning that the weather database contains data for the year 2018. In addition, qualitative and quantitative information has been collected through on-site visits; thus, it is possible to compare the simulation results when the outdoor conditions were similar to those acquired by measurements.

3.5.1.1 On-site visit

The building was measured in a site visit and confirmed through architectural plans. The educational complex has eighty classrooms located in 4 two-story buildings as shown in Figure 3.8 with 50 m^2 in average area, bridges, and stairs connecting all floors. Each volume is structured by a linear corridor connected with the classrooms. In terms of materiality, the buildings have a concrete heavyweight structure with high thermal mass, and a light sloping roof in plastic tiles and metal structure, without additional ceiling or thermal insulation. The façade counts with sequential openings and vertical louvers in concrete connecting the classrooms with the exterior and a series of discontinuous concrete walls in the corridor defining an outdoor playground area.

In this design, the east and west facades are shorter than the north and south, receiving less daylight and reducing thermal gain. While the south façade, where there is a mass of vegetation, receives wind most of the year. Finally, the north façade, since it does not have any thermal barrier, can present the most significant fluctuation of temperature and will then be selected to be simulated in the energy software.

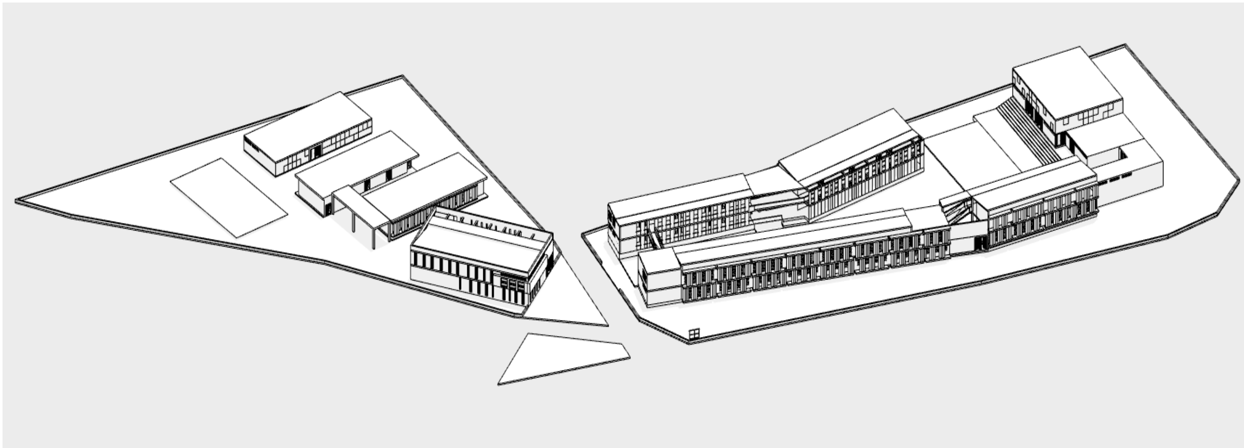
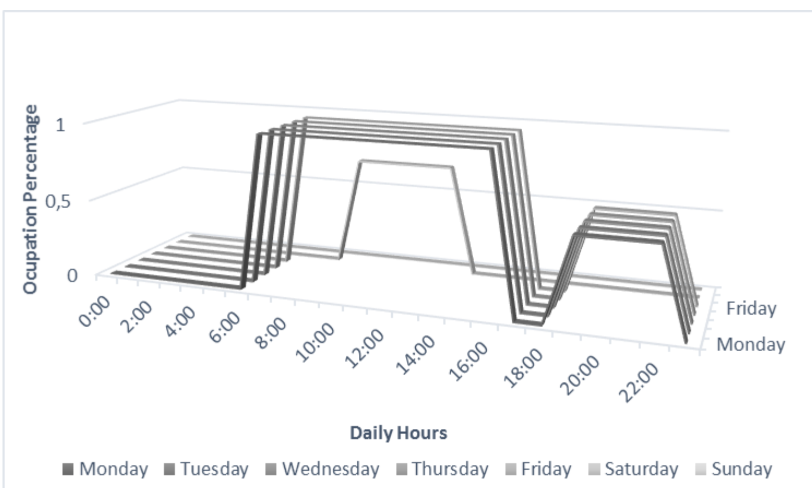


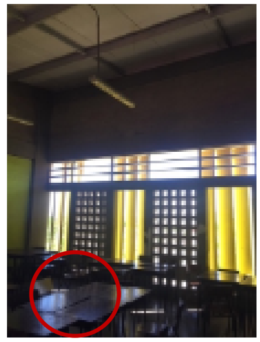
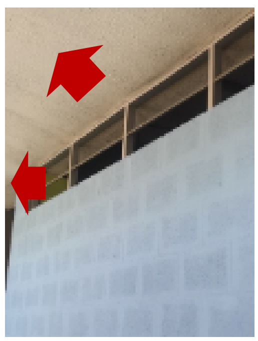
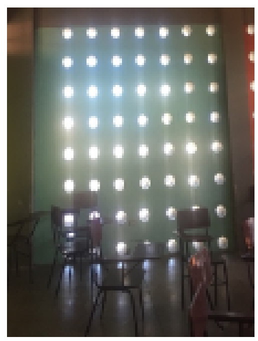
Figure 3.8. Educational buildings in axonometric view.

The buildings have a full occupancy during the day hours; the daily academic journey begins at 6:15 am during ten hours with breaks of 1 hour at 9:30 am and 12:30 pm from Monday to Friday. On weekdays, adults' validation education is organized from 6:00 pm to 9 pm, and Saturdays from 8:00 am to 2:00 pm as shown in Table 3.9, with a 55% occupancy building, especially the classrooms located on the first floor. That is, the priority is to achieve comfort range during the day hours. Activities such as presidential elections or local cultural events are not identified in this analysis.

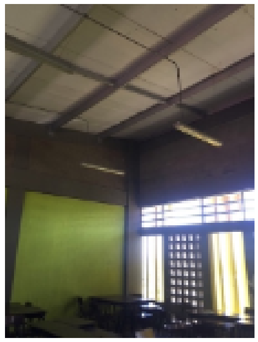
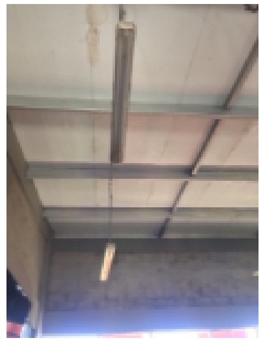
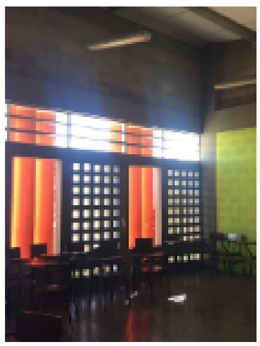
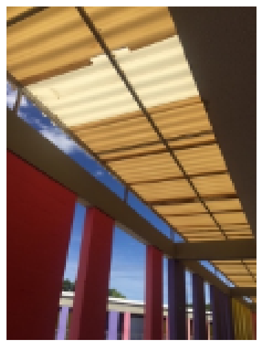
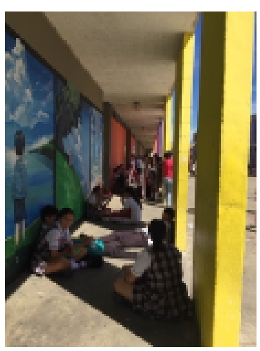
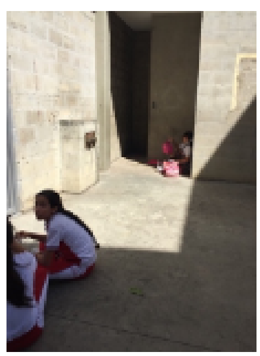
Table 3.8 Occupancy weekly schedule for educational building.



On-site visit educational building

Location	*Reference Image*	*Description*
Second Floor	  Façade patron design in external sides	The design pattern for the north and south external facades are identical. The upper part has a lateral opening of 0.60 meters and a series of smaller square openings of 0.15 x 0.15 meters as a filter for natural ventilation flow. In addition, a sequence of concrete louvers redirects the wind through the larger openings.
	  Ventilation openings	Between the classrooms and the corridors, the upper openings are designed as an evacuating system for hot air, reducing the temperature through this passive ventilation strategy.
Second Floor	  Current problems in façade	Some damage caused by water infiltration is evidenced in walls and ceilings due to waterproofing failures on the installation mistakes in the calculation of the slopes. and rainwater channeling

On-site visit educational building

Location	*Reference Image*	*Description*
Second Floor	  Roof structure in second floor classrooms	The roof configuration for classrooms on the second floor is a metal structure covered with plastic tile. It has no additional ceiling or air cavities.
	 Daylight conditions indoor classrooms  Plastic tile in corridors	The electrical lighting is distributed based on the metal structure, and the ceilings exceed three meters in height on the second floor. Thus, the perception of comfort changes compared to the first floor.
Playground	  Students' conditions in break time	The construction material used in facades and floors is concrete. The facade design remains the same patron. Dark areas are identified inside classrooms and glare areas in corridors and playtime areas.

On-site visit educational building

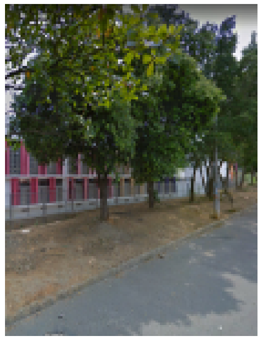
Location	*Reference Image*	*Description*
Playground	 Vegetation south side  External conditions	Vegetation areas are located on the south sidewalk of the building with heights up to 12 meters. The school does not have any vegetation plan.

Table 3.9. On-site visit educational building report

The dimension of the building was measured on a site visit and confirmed through architectural plans. During the three visits, indoor temperature and relative humidity were measured over a period of 24 hours, resulting in an average temperature of 30.87 ºC and relative humidity of 76.6%, which are higher than those stipulated by national regulations.

An as-built representation was created in the BIM software Autodesk Revit. The relevant floor plans and building sections were exported and used to accurately represent the buildings' geometry in the simulation Design Builder software. The resulting model is shown in Fig. 3.9. The model has inputted material properties, occupancy profiles, lighting, and electronic equipment specifications based on a building survey. The building contains four blocks with six zones, including classrooms, stairs, and halls.

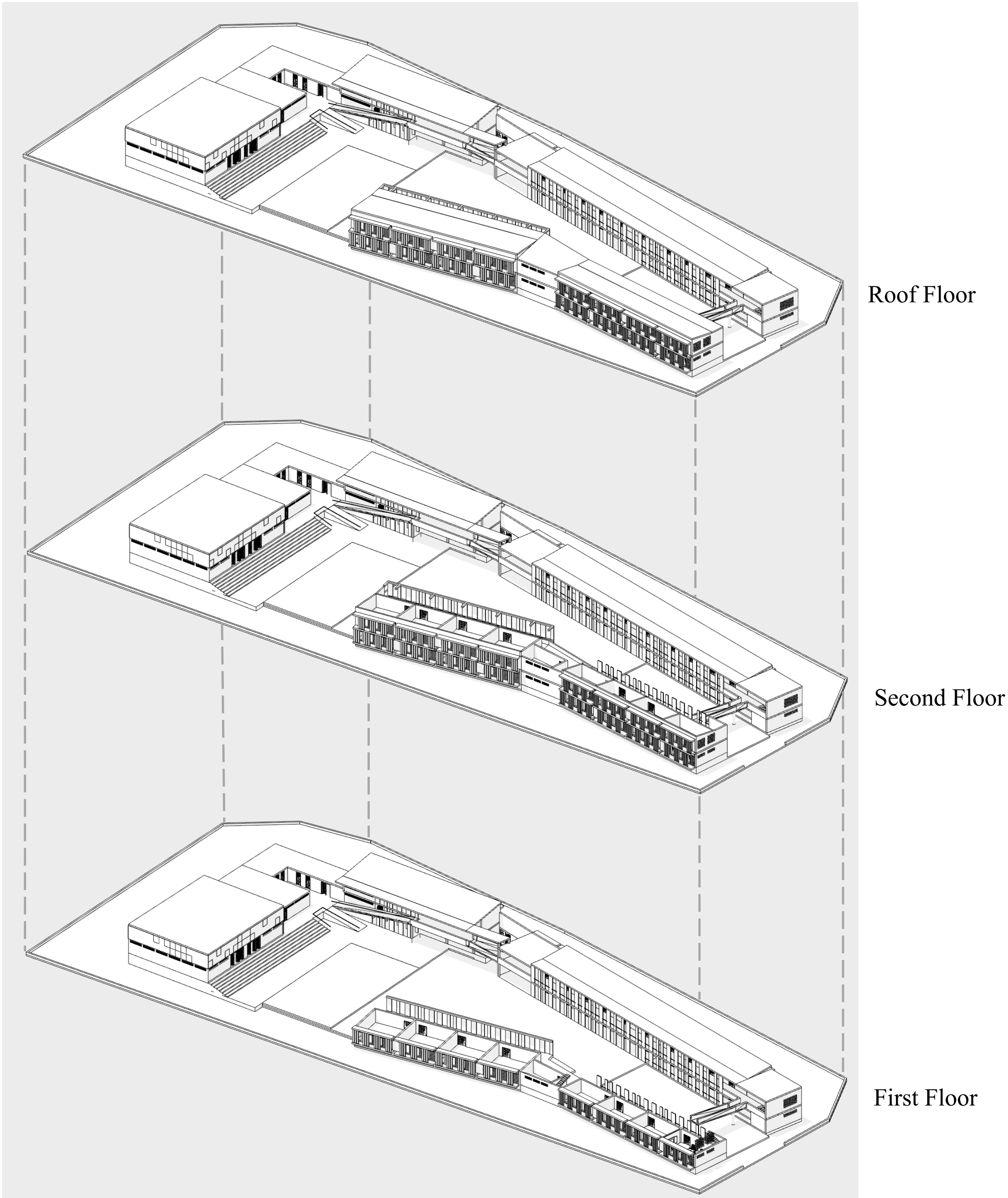


Figure 3.9. 3D view educational building by floors.

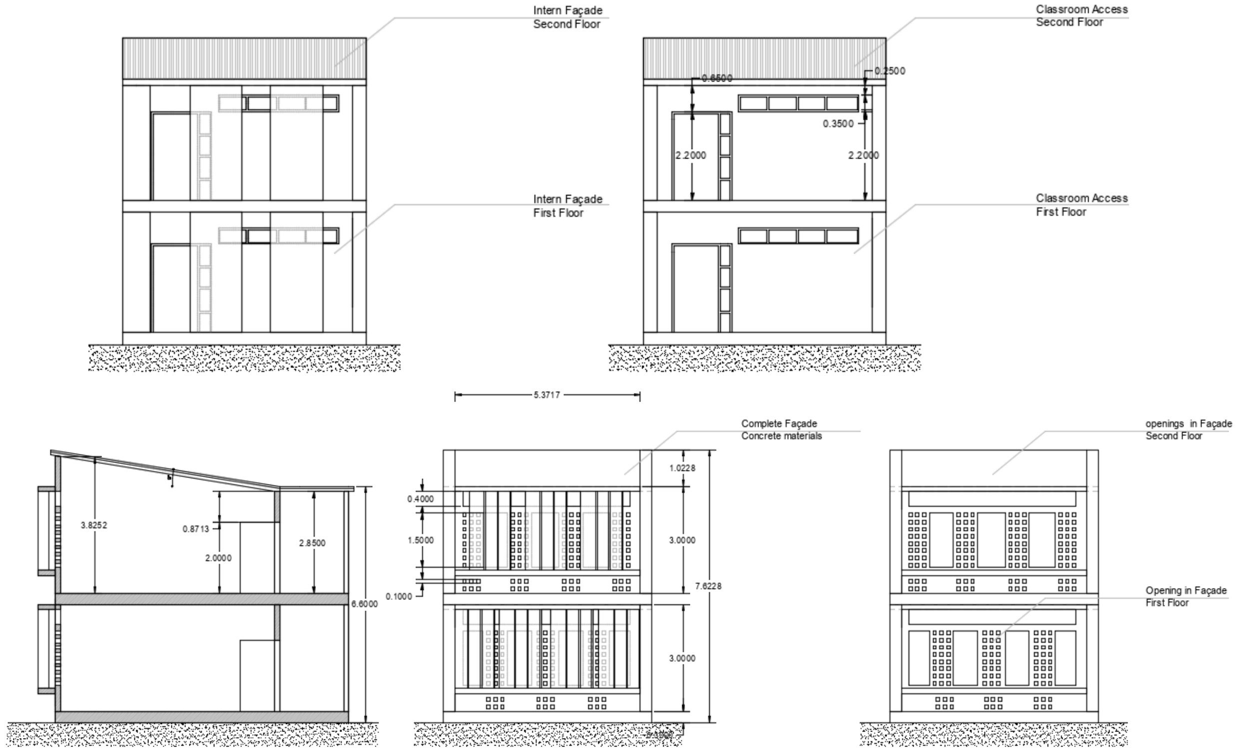


Figure 3.10. Façade configuration north and south sides.

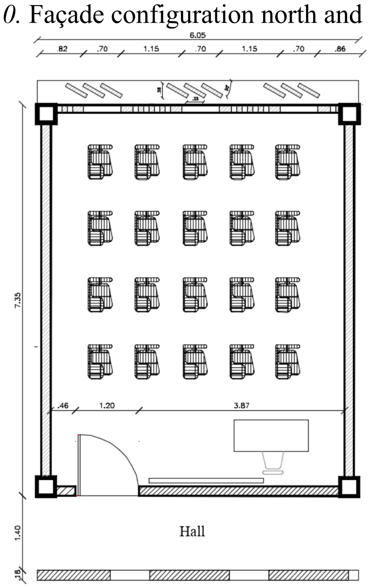


Figure 3.11. Classroom configuration in first and second floor.

3.5.1.2 Survey

Besides a subjective survey with an asynchronous questionnaire to validate the occupant's thermal comfort perspective, the questionnaire addressed the relationship between comfort sensation and thermal preference. The questionnaire is composed of four sections. The first section considers the demographic information; the second section includes thermal sensation preferences; the third and fourth have daylight comfort and air perception questions. The thermal sensation was evaluated with a 5- point scale ending with the choices "Cold" and "Hot," "slightly cool" and "slightly warmer," and a 5- point scale for satisfaction. The survey was conducted when participants had been seated for at least 30 min. and translated from Spanish to English.

With a total population of 1,441 students, the surveys identified that about four-fifths (82%) of students have a perception of thermal discomfort inside the classrooms, about half (46.7%) identify an unpleasant noise perception, and just over three-quarters (78%) request a decrease indoor temperature. Visual discomfort, including dark areas in the classrooms, was the most recurrent complaint among students. The survey also showed that children between 7 and 12 years old are much more sensitive to high temperatures than adults, expressing their perception with clear concepts about their thermal environment. (See Appendix B)

Table 3.10. Survey Configuration

	Age	Weight (Kg)	Height (m)	Metabolic rate (met)	Clothing Insulation
Min	6-7	19.6-22	1.12-1.18	1.4	0.71
Max	11-12	37.4-39.3	1.24-1.50	1.4	0.71
Median	8-10	28.2-27.4	1.28-1.33	1.4	0.71
Total					180

Note: *Metabolic rate of 1.4 met refers to seated with light activity and clothing insulation in 0.71 clo to medium-length skirt blouse and shoes according to ASHRAE 55-2010*

3.6 BUILDING THERMAL SIMULATION

3.6.1 Introduction

The indoor thermal conditions of the educational building are analyzed using the dynamic simulation software tool Design Builder, the first comprehensive user interface for the Energy Plus dynamic thermal simulation engine. Hourly weather data of Cucuta based on daily records from ten years are used for different simulations to evaluate the levels of comfort in the building performance.

The building is volumetrically modeled in the ArchiCAD program to define its geometry more efficiently, and it is imported through the gbXML format. The model and data are organized from a sequence of levels: site, building, four blocks, six surface areas including classrooms, stairs, corridors, and openings in façades. Finally, a standard component block is determined, establishing an adjacency of the enclosures to spaces in similar thermal conditions, that is, in adiabatic conditions.

ArchiCAD 21 (DXF, DWG, IFC XMLIFC, IFCXML)
↓
SketchUp Pro2020 (XMLIFC / IFCXML)
↓
REVIT (XML, FCI)
↓
Design Builder (3D/gbXML/XML)

Data were introduced progressively in the following order: The climate data follow the building configuration, then the activity, occupancy, and simulation scenarios. In the building configuration, the materials and elements in the model are defined and components responsible for the thermal exchange. Then, the occupancy data and user's activity were introduced. Afterward, climate data were submitted and were calibrated according to two factors climate data (t, rh) provided by a nearby weather station.

Different simulation scenarios need to be defined to establish thermal comfort. The current conditions are the departure point, and the first scenario is carried out as a baseline to identify the building performance requirements. The second scenario is the occupancy level which considers the thermal comfort performance according to the number of people per square meter; the values selected are established according to the current national regulations. The third scenario assumes natural ventilation through openings six sub-scenarios for the ventilation flow rate. The fourth and last scenario is the roof configuration proposing five sub-scenarios with different isolation layers. Finally, the results are imported to Microsoft Excel software to develop a comparative analysis and corroborate if thermal comfort levels are reached without an active ventilation system.

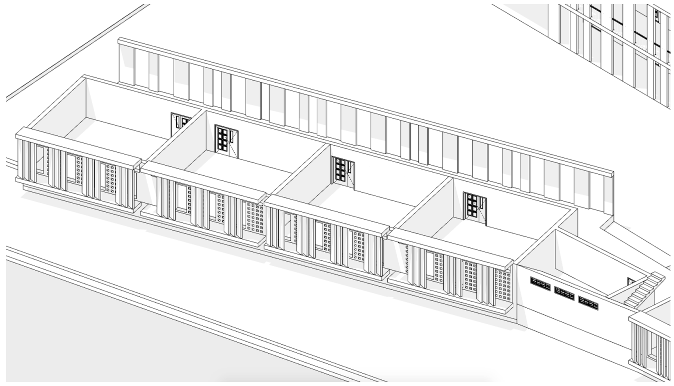


Figure 3.12. Module 4 classrooms

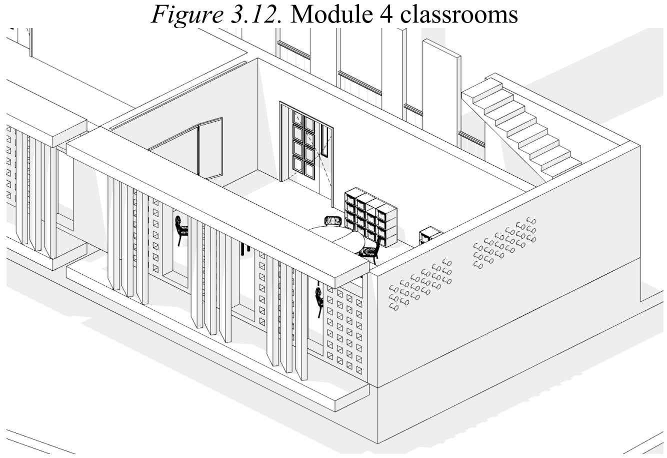


Figure 3.13. Indoor classrooms characteristics

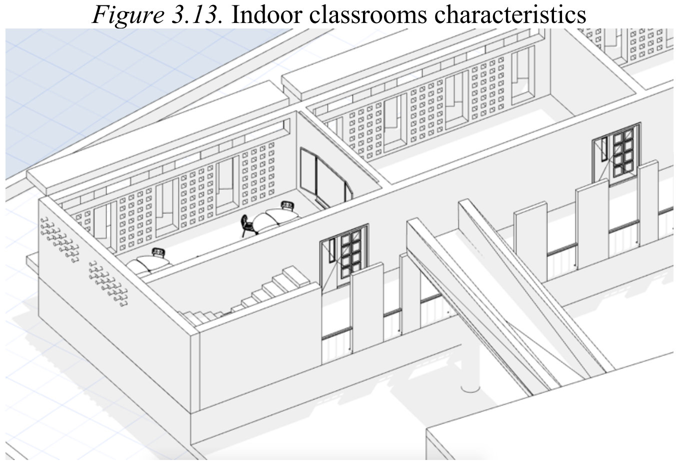


Figure 3.14. Internal façade view

3.6.2 Simulation set up and procedure

Once the model was imported in .xml format or the geometry has been created from the same software through blocks and surfaces, it is essential to adjust the project location and region template located at the site level. Each geographical location has a separate weather file describing the outdoor temperature, solar radiation, and different atmospheric conditions for every hour per year. In this case, the closest climatic design station to the building is San Antonio del Táchira, Venezuela, located at latitude 7.85 and longitude -72.45, with a climate zone according to ASHRAE 1A, and 378 meters height above mean sea level.

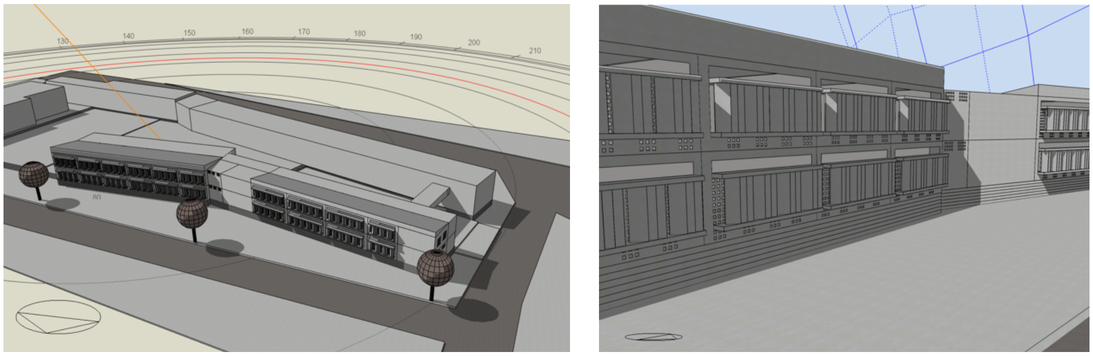


Figure 3.15. Model and openings details modelled in ArchiCAD.

Within the location tab, it is also essential to define that the wind exposure is 3-exposed to improve or reduce the U-values of the building materials due to the effects of air turbulence in the boundary layer between the exterior facade and ambient air. Subsequently, the characteristics of the building, information on the activity, the type of construction, the openings, and the lighting must be configured, as shown in Figure 3.15. Once these steps are complete, it is possible to start the calculations and simulations to analyze the local outside dry bulb temperature, outside dewpoint temperature, local wind speed, atmospheric pressure, and direct and diffuse horizontal solar radiation with the results obtained.

3.6.2.1. Layout

The building was split into four different blocks with different areas for accessible locations. The blocks referenced as Building 0201, Building 0203, Building Hall 0201, and Building Hall 0203 are located on the first floor, as shown in Figure 3.18. While Building 0202, Building 0204, Building Hall 0202, and Building Hall 0204 are located on the second floor, as shown in Figure 3.17. Connector 01, Connector 02, Connector Hall 01, and Connector Hall 02 refer to the building where stairs, corridors, and storage areas are located.

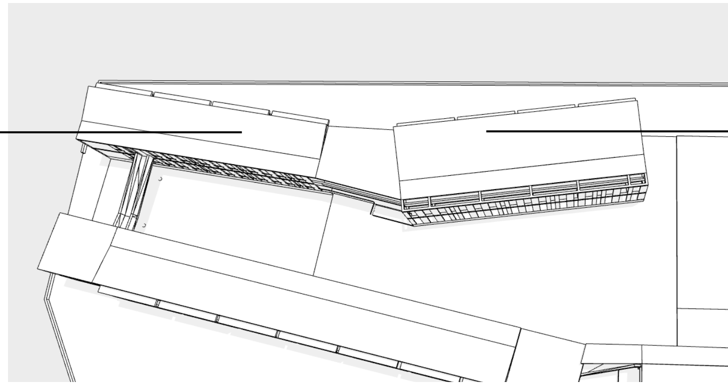


Figure 3.16. North Building configuration, Roof Floor.

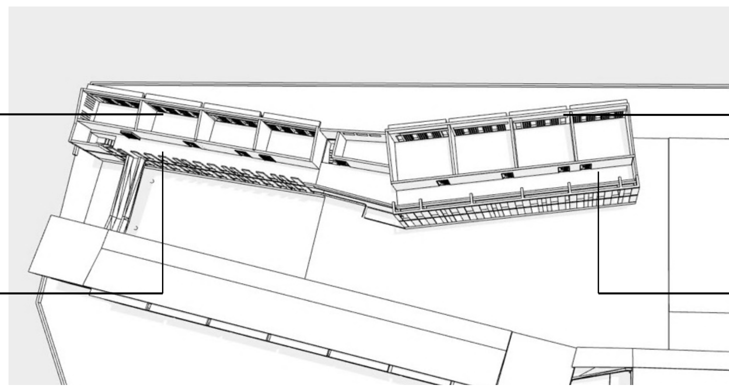


Figure 3.17. North Building configuration, Second Floor.

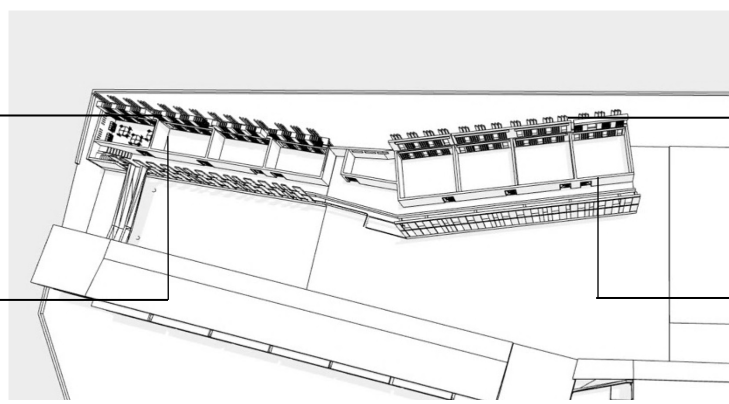


Figure 3.18. North Building configuration, First Floor.

Each model block also includes classrooms, corridors, and internal walls in two zones. Figure 3.16 shows flat and sloped roofs are placed in another block to define their parameters more easily in the roof configuration simulations.

- School Model
  - School Model Building
    - Building 0201
      - Classroom 0201
      - Classroom 0202
      - Classroom 0203
    - Building Hall 0201
    - Connector 01
      - Stairs
      - Storage
    - Connector Hall 01
    - Building 0203
      - Classroom 0205
      - Classroom 0206
      - Classroom 0207
      - Classroom 0208
      - Classroom 0209
      - Classroom 0210
    - Building Hall 0203
    - Building 0202
      - Classroom 0201
      - Classroom 0202
      - Classroom 0203
    - Building Hall 0202
    - Connector 02
      - Stairs
      - Storage
    - Connector Hall 02
    - Building 0204
      - Classroom 0205
      - Classroom 0206
      - Classroom 0207
      - Classroom 0208
      - Classroom 0209
      - Classroom 0210
    - Building Hall 0204
    - Building Roof 0202
    - Building Roof 0204

Figure 3.19. Model Configuration in Design Builder.

3.6.2.2. Activity

The activity tab includes each of the building blocks and areas. The main activity is selected at the building level as educational facilities classroom (+9) and in the non-residential building category. Design Building has a broad category of uses assigned characteristics according to ASHRAE 90.1 for this type of building. In addition, it is possible to select at the zones level: the classrooms in type 1 or standard, which refers to occupied or intermittently occupied zones, and in type 2 semi exterior unconditioned corridors and stairways. Other parameters can be assigned in this tab; it is the case of the activity category, selected as classroom/reading/training with a metabolic rate greater than 1.0 met according to ASHRAE and selecting 1.4 met for children. It also specifies the total occupied floor area and the floor area per person that varies according to each simulation reflected in the following table:

Table 3.11 Occupancy parameter according each simulation.

Building Area		m2/person									
		Building Conditions	*Natural Ventilation*	*Occupancy Rate*			*Roof Configuration*				
				ASHRAE	*NTC*	*full*	*1*	*2*	*3*	*4*	*5*
First Floor	Building 02 Hall 1	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Building 02 Hall 3	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Building 02 01	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Building 02 03	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Conector 1	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Conector Hall 1	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
Second Floor	Building 02 Hall 2	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Building 02 Hall 4	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Building 02 02	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Building 02 04	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Conector 2	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
	Conector Hall 2	1.35	1.35	2.85	1.65	1	1.35	1.35	1.35	1.35	1.35
Roof	Roof 0202	-	-	-	-	-	-	-	-	-	-
	Roof 0204	-	-	-	-	-	-	-	-	-	-

Additionally, the zones are classified as unconditioned in ceilings and ventilated in the classroom in the activity tab. Design Building offers an inheritance method, which means that the data loaded on the top level of the building level is automatically inherited in the blocks and zones below.

At the activity level, it is also possible to find the occupancy tab where the activities' schedule is set up within the building in days during one or more years with their occupancy percentage as shown in Table 3.12. It is also available on the building level to point out which days the building is not open during the year and holidays. In this case, the following class schedule is established during the weekdays for children and evenings and Saturdays for the adults' educational sessions. In addition, holidays and vacation periods are added during the year.

Table 3.12 Weekly schedule set up for the educational building.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Jan	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Feb	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Mar	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Apr	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
May	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Jun	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Jul	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Aug	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Sep	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Oct	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Nov	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off
Dec	7:00 - 16:00 & 19:00 - 22:00					9:30 - 13:00	Off

This schedule is also defined for classrooms, offices, and service areas such as libraries and laboratories. The metabolic activity is adjusted as standing/walking throughout the building with a factor of 0.75 for children, sports and plays activities are carried out on the courts and playgrounds. At the same time, clothing is defined as 2- schedule base, without summer or winter seasons during the year. Electronic equipment or computer boxes are not included in any classroom.

In the environmental control tab, the minimum fresh air for closed spaces is defined, setting the airflow related to the zones where the mechanical ventilation to the zone is enabled. The airflow rate is used to model the effects of natural ventilation. The values are based on occupancy or/and floor area l/s person, as shown in Table 3.13. In this case, it was determined in 4,719 l/s according to ASHRAE. Additionally, according to the regulation, the occupancy rate was 1.35m^2/person.

Table 3.13 cfm/person and l/s in classrooms (Source: ASHRAE 55-10)

Area	*cfm/person*	*l/s person*
Classroom (5-8)	10	5
Classroom (+9)	10	5

3.6.2.3. Construction

The construction tab specifies the elements in building configuration as external walls, internal partitions, ground, external and internal floors, and flat and pitched roofs, as shown in Table 3.14. Figure 3.20 shows despite Design-Builder having a complete list of construction materials and roof and wall configurations, for the educational building, each material was established with its thermal characteristics and specific configuration.

Table 3.14 Current building configuration.

Layer	**Material**	**Thickness (m)**
External Walls	Bricks in Concrete	0.203
Internal Partitions	Bricks in Concrete and plaster lightweight	0.160
Pitched Roof	Plastic Tiles	0.0006
Flat Roof	Cast Concrete Dense	0.250
Internal Floor	Cast Concrete Dense	0.300
External Floor	Cast Concrete	0.350

Each construction material is configured according to the material properties, number of layers, thickness (m), a reference image from the outer to the inner surface, and U-values achieved with or without thermal bridging is also defined. In this case, these attribute values will change in the roof configuration simulation for different thermal insulation. Also, the airtightness can be adjusted in this tab, considering that it is an unintentional and uncontrolled flow of outside air into the building due to gaps in the building façade and the porosity of building materials. It is always switched on by default and has a significant impact on calculations.

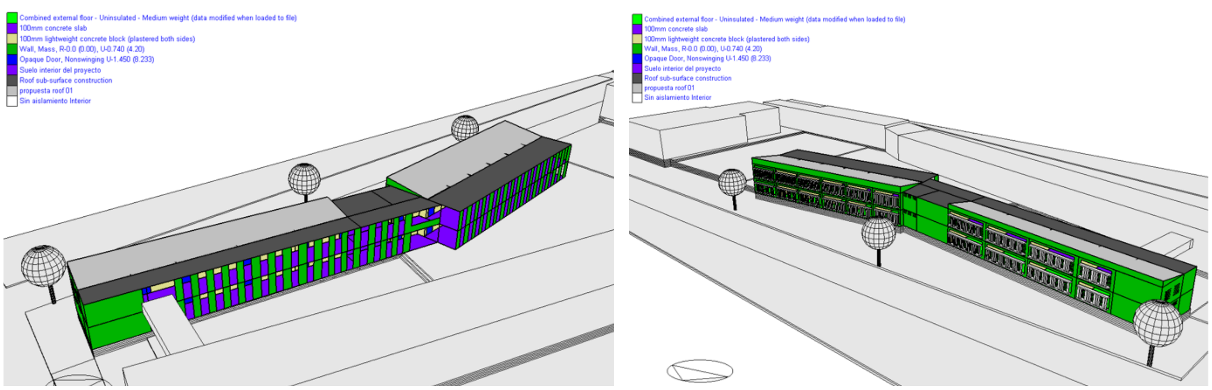


Figure 3.20. Building configuration in Design Builder according to construction materials.

3.6.2.4 Openings

This tab specifies all the openings in external or internal walls of the building and their suitable parameters. Also, the shading data parameters can be adjusted to avoid summer overheating by selecting diffusing blinds, shades, external fixed louvers overhang as shading devices. On the roof also is possible to choose skylights.

In this case, the building design includes concrete louvers added as elements in the facade design, as shown in Figure 3.21. The indoor openings are not user-operable. Elements like trees could be modeled through adjacent segments to the model, changing the transmittance of the shading component block.

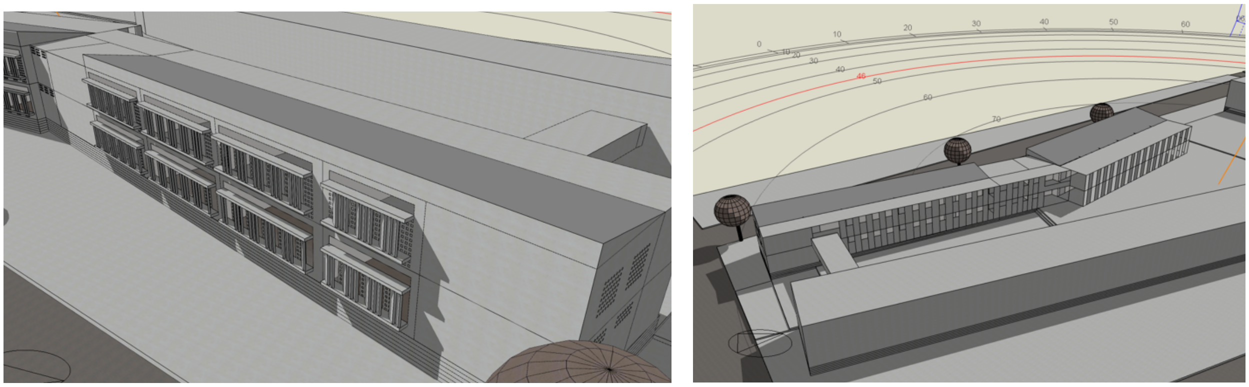


Figure 3.21. Opening configuration in external and internal façades

In the HVAC tab, configure all the heating, ventilation, and air conditioning system details, as shown in Table 3.15. Natural ventilation is active when the air temperature in the zone is higher than the natural ventilation setpoint temperature, which is defined as the deliberate ventilation through openings, vents, and doors. It is possible to specify the ventilation rate by zone o minimum fresh air per person criteria ACH to include assessment of the impact of natural ventilation scheme. The air change rate measures the air volume (either uniform or perfectly mixed) added to or removed in one hour from a room.

Table 3.15 ACH Rates for classrooms (Source: ASHRAE,2010)

Area	*ACH Rate*	
Computer room	10	14
Classroom	3	4
Laboratories	6	12

Natural ventilation systems introduce fresh air through the openings, vents, and doors, controlled in the simulations according to temperature sets and operating schedules. The ventilation rate is set by the maximum air change rate modified by the operation schedules in the activity tab. Selecting the model airflow through holes, virtual partitions, and internal openings is also essential. These options use the concept of mixing, where equal amounts of air are transferred between zones, and the flow rate is directly proportional to the opening area using the airflow rate per opening area.

Table 3.16 ACH for different configuration in simulations.

Building Area		ACH Air Changes per Hour																		
		Building Conditions	*Natural Ventilation*										*Occpancy Rate*			*Roof Configuration*				
			0.5	*1*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*	*4.5*	*3*	*ASHRAE*	*NTC*	*full*	*1*	*2*	*3*	*4*	*5*
First Floor	Building 02 Hall	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Building 02 Hall	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Building 02 01	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Building 02 03	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Conector 1	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Conector Hall 1	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Second Floor	Building 02 Hall	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Building 02 Hall	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Building 02 02	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Building 02 04	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Conector 2	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Conector Hall 2	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Roof	Roof 0202	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Roof 0204	0.8	0.5	1	1.5	2	2.5	3	3.5	4	4.5	3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

3.6.2.5 Lighting

The lighting tab allows selecting a template for schools such as standard space classroom reading/training. The type of lamp selected is surface mounted, and the power density of 13.0 w/m^2 in classrooms, 7.1 w/m^2 in corridors, and 9.0 w/m^2 in storage are selected according the current conditions registered on-site visit. The schedule of usage is the same as the activity school's schedule. This study includes the parameter due to the evidence in the site visit use electrical lighting during daylight hours, which could affect the student's thermal comfort in classrooms.

Figure 3.22. 3D modelling

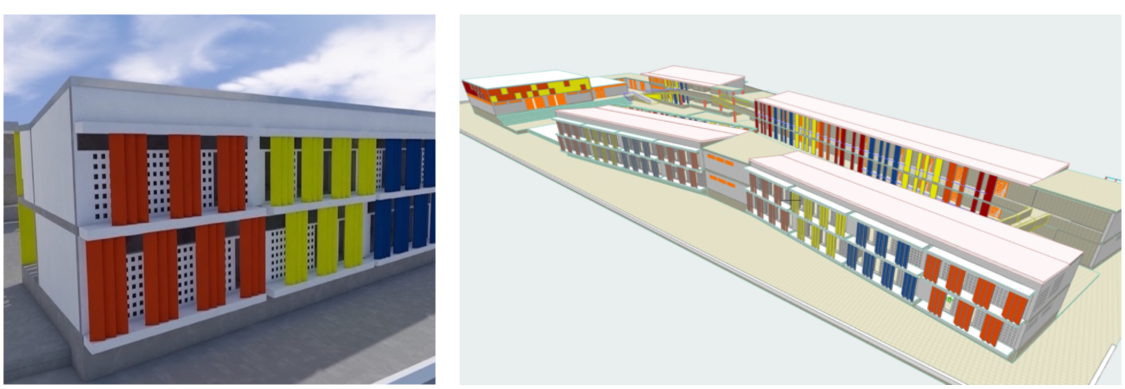


Figure 3.23. External façades modelling

Chapter 4. SIMULATION RESULTS

4.1. CURRENT CONDITIONS

Comparative studies evaluated diverse configurations performances between different parameters accepted by ASHRAE 55-2010 to understand current building conditions. Variations in 2018 were analyzed in monthly and daily periods. November and 13th were established as the month and day with the most significant fluctuation and highest temperature values.

A set of observations on the values taken by quantitative variables over time and the analysis of time series improved the understanding of the results, allowing to determine the variations within the comfort zone. Finally, these results are accepted as a base for analyzing the variables of occupancy, natural ventilation, and roof configuration, focusing on classroom 0202 on the second floor due to its geometry, constructive characteristics, and occupancy level.

These simulation results are used to identify the thermal condition in the current configuration of the building. The simulation was configured with the current occupancy conditions of 1.35 m^2/person and an average of 30-35 students per classroom. Dry-bulb temperature identified heat stress and discomfort periods, while humidity ratio parameters described moisture content. In addition, wind speed and direction were collected to identify impact patterns in indoor temperatures and how the moisture is transported from the indoor to the outdoor.

4.1.1. Temperature

Through the dry-bulb temperature, it is possible to identify the periods of overheating because it is not affected by the humidity of the air. According to School 10 guideline, acceptability limits are located at 28°C for thermal discomfort and 36°C for heat stress, resulting 62.0% of the time during one year shown in Figure 4.1 the classroom is considered in discomfort temperature with temperatures above 28°C, while 12% is above 36°C, resulting in heat stress. Figure 4.2 shows November with the same trend prevailing in 68.2% in discomfort temperatures and 18.3% in heat stress in the monthly period. During the daily analysis a shown in Figure 4.3, the dry bulb temperature is 27.2°C at 7:00 hours, and 42.5°C at 17:00 hours, defining the thermal discomfort and thermal stress hours are between 14:00 and 22:00 hours. During this time, most activities are carried out inside the classroom, and even during the night hours, the classroom is found in thermal discomfort temperatures.

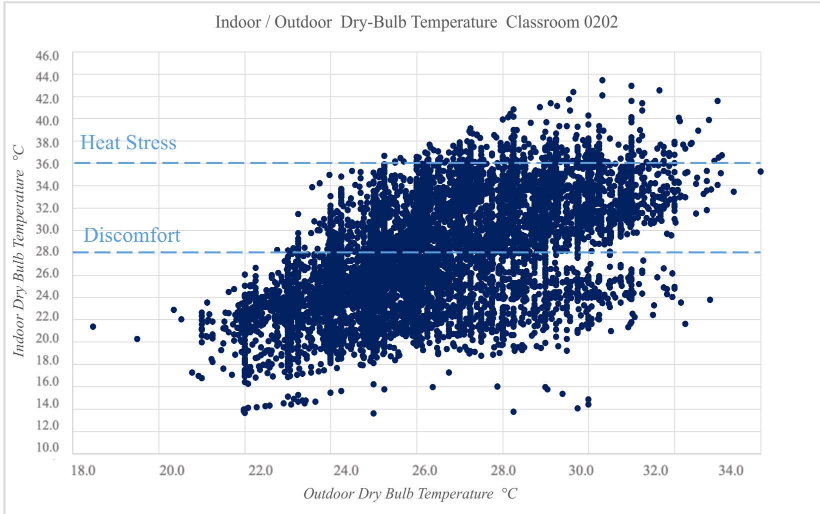


Figure 4.1. Correlation between indoor and outdoor dry bulb temperature for 2018

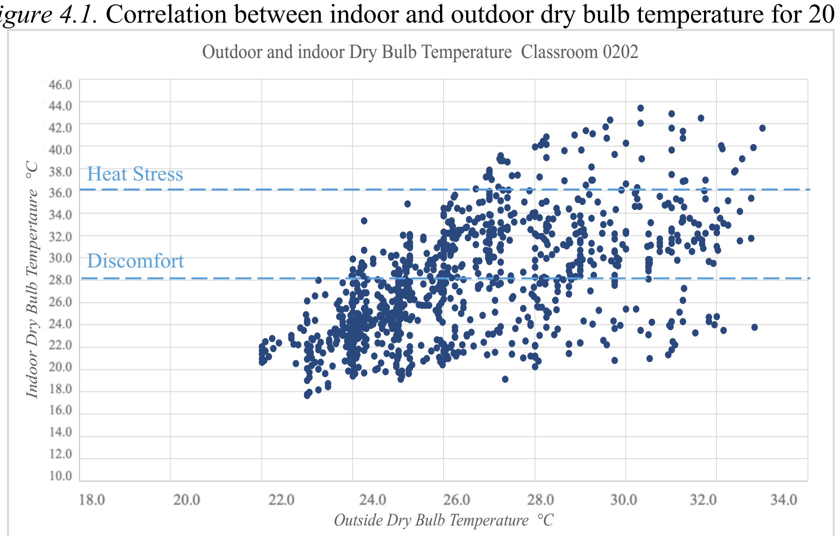


Figure 4.2. Correlation between indoor and outdoor dry bulb temperature on November

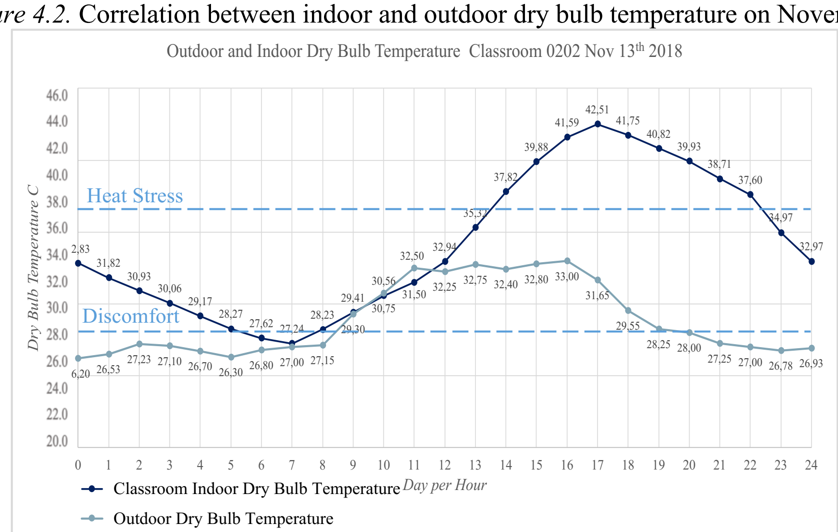


Figure 4.3. Correlation between indoor and outdoor dry bulb temperature on November 13th

4.1.2. Humidity

In annual results, Figure 4.4 shows 71.64% of the year the outdoor Relative Humidity is more significant than 80%, and 90%, the Indoor Relative humidity is greater than 80% in the same period, not admitting more water vapor, due to it is saturated. In November, a significant reduction of up to 55% in relative humidity is identified during weekends as shown in Figure 4.5, while on November 13th reflect a relative humidity of 100% from 0:00 to 9:00 a.m. and 8:00 p.m.to 00:00, the lowest relative humidity is identified at 17:00 hours in Figure 4.6, reflecting the same dynamics of the external condition. Relative humidity is a significant factor that influences thermal comfort. Indoor RH in the range of above 80% would be very uncomfortable to these school children who prefers even lower temperatures.

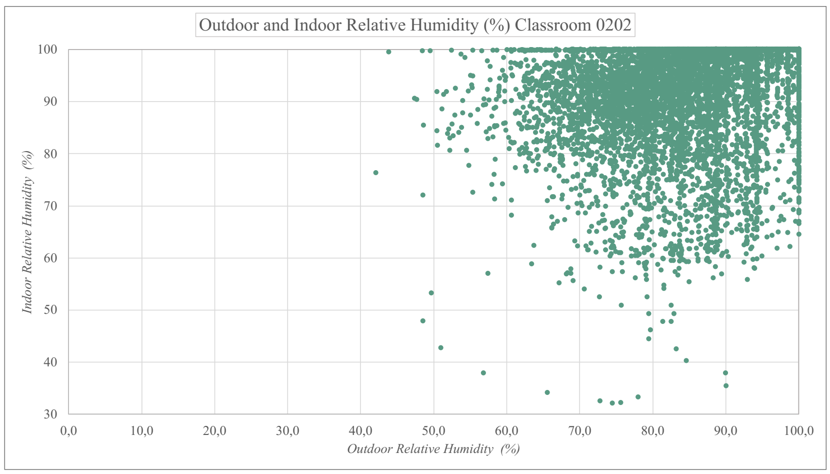


Figure 4.4. Correlation between indoor and outdoor relative humidity in 2018

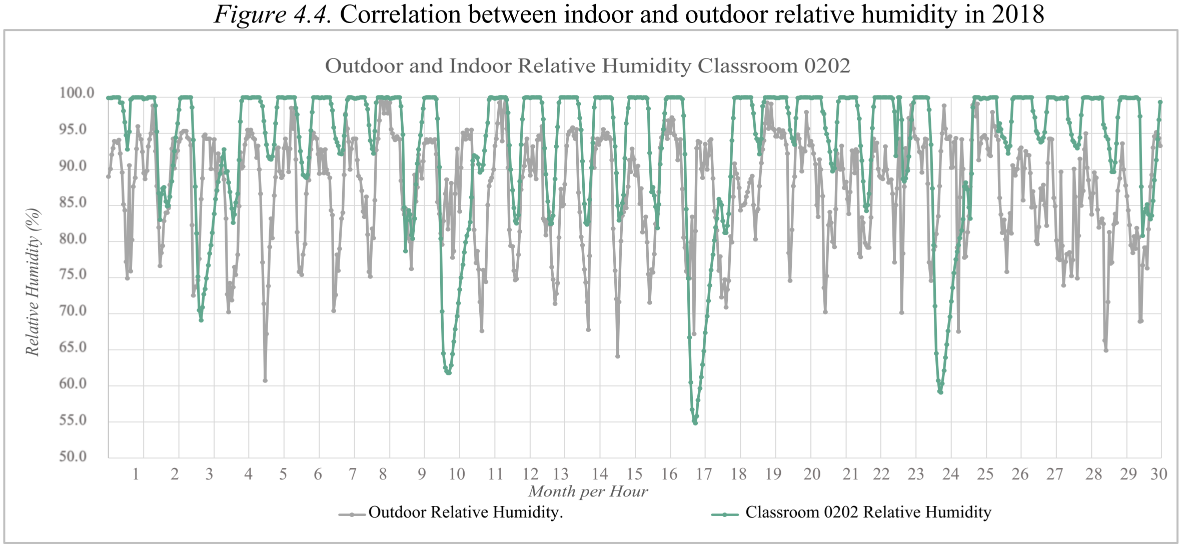


Figure 4.5. Correlation between indoor and outdoor relative humidity in November

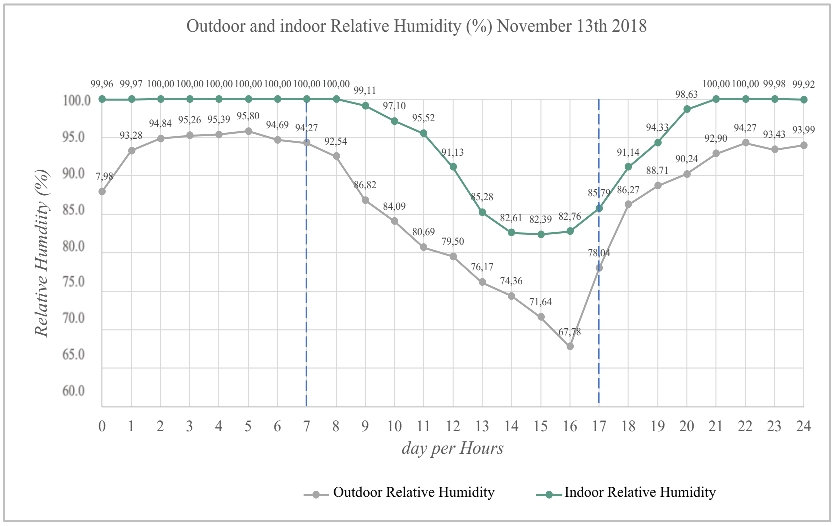


Figure 4.6. Correlation between indoor and outdoor Relative humidity on November 13th

The humidity ratio is used to evaluate the weight of water vapor per unit weight of dry air, which is used, with the temperature data, to estimate the capacity of the air to hold the quantity of water vapor. Figure 4.8 shows the annual results, hot air can contain more humidity than cold air, a maximum of 23.34 g/kg of indoor humidity ratio, also identifying at noon, relative humidity lowered due to higher temperature. Furthermore, this simulation showed the relationship between the outdoor and indoor conditions regarding moisture which that indoor humidity ratio is greater than outdoor due to the occupancy. On November 13th, the daily average outdoor humidity ratio showed 20.14 g/kg while indoor 18.52 g / kg, revealing a 9 g/kg difference as shown in Figure 4.9 due to the occupancy as a moisture source which means that natural ventilation will help remove moisture from indoor to outdoor.

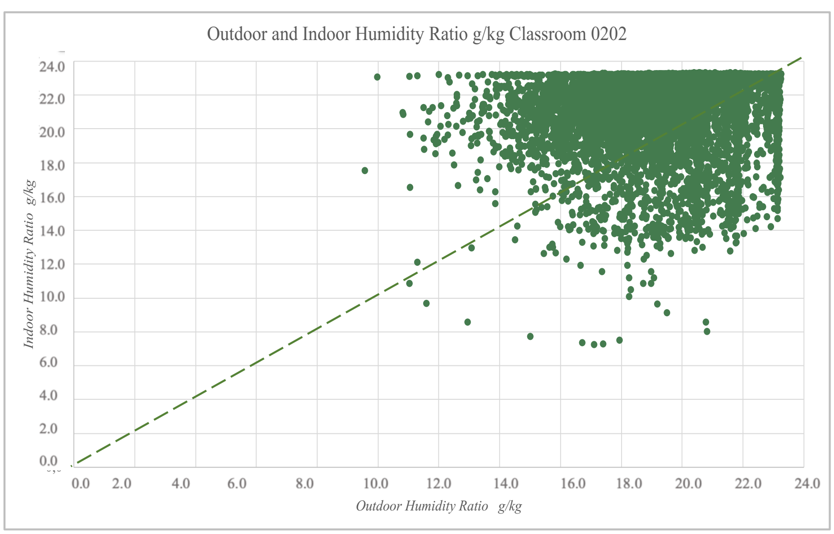


Figure 4.7. Correlation between indoor and outdoor humidity ratio in 2018.

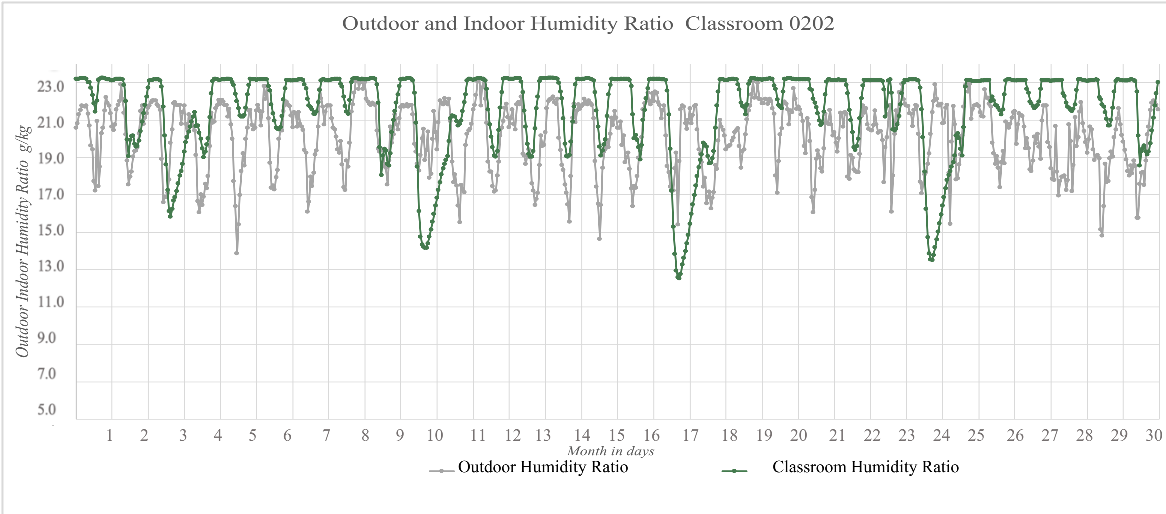


Figure 4.8. Correlation between indoor and outdoor humidity ratio in November

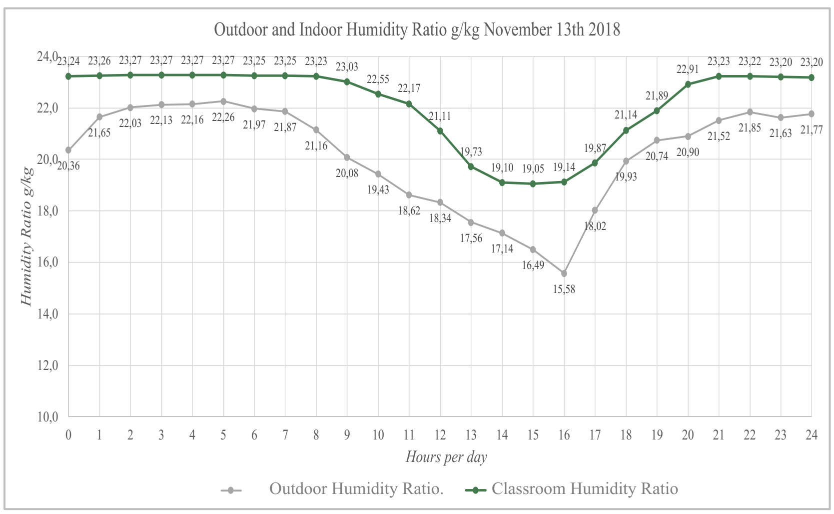


Figure 4.9. Correlation between indoor and outdoor air drier during November 13^{th}

4.1.3. Adaptative Thermal Comfort.

Figure 4.10 shows that 21.2% over the one-year period, the indoor operative temperature is within the acceptable operative ranges for naturally conditioned space as presented in ASHRAE 55-2010, where temperature above the 80% acceptability limit is considered overheating. The monthly analysis shows that November is the period with the highest number of overheating hours. 11.2% of the time, the indoor operative temperature is below 32.2°C, under a half of the time (49.5%), operative temperatures are below 34.0°C which is the threshold used to identify a discomfort period, and 8.5% of the time the temperature is below 28.0°C which establishes a thermal stress period as shown in Figure 4.11. Some causes are solar radiation, occupation percentage, and building orientation. According to indoor operative temperature results, in Figure 4.12, November 13th is the day with the highest overheating hours 100% of the time the classroom is in thermal discomfort.

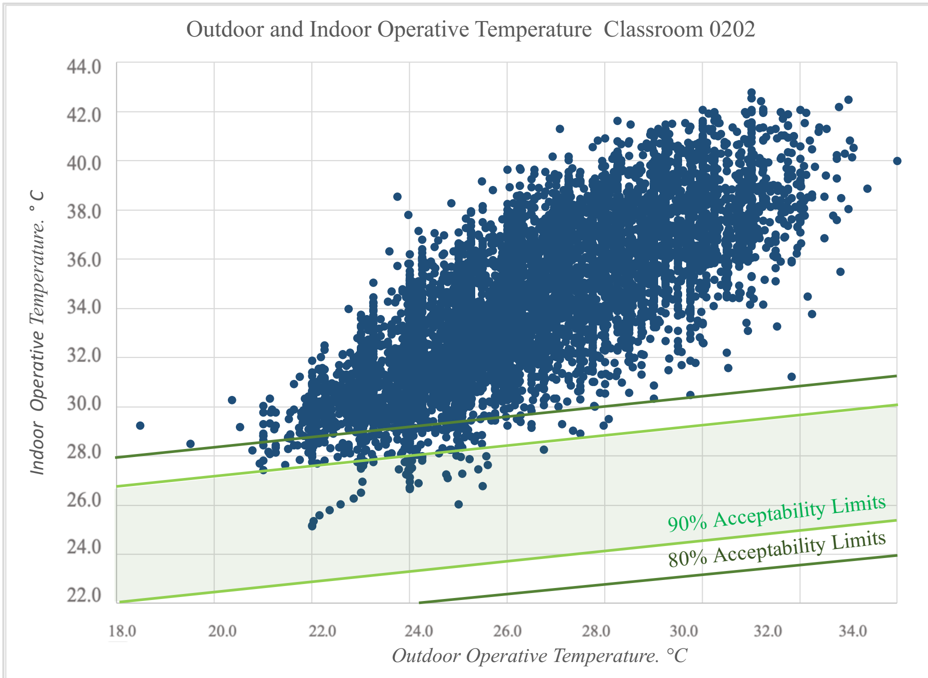


Figure 4.10. Correlation between indoor operative temp.and outdoor temp.in 2018.

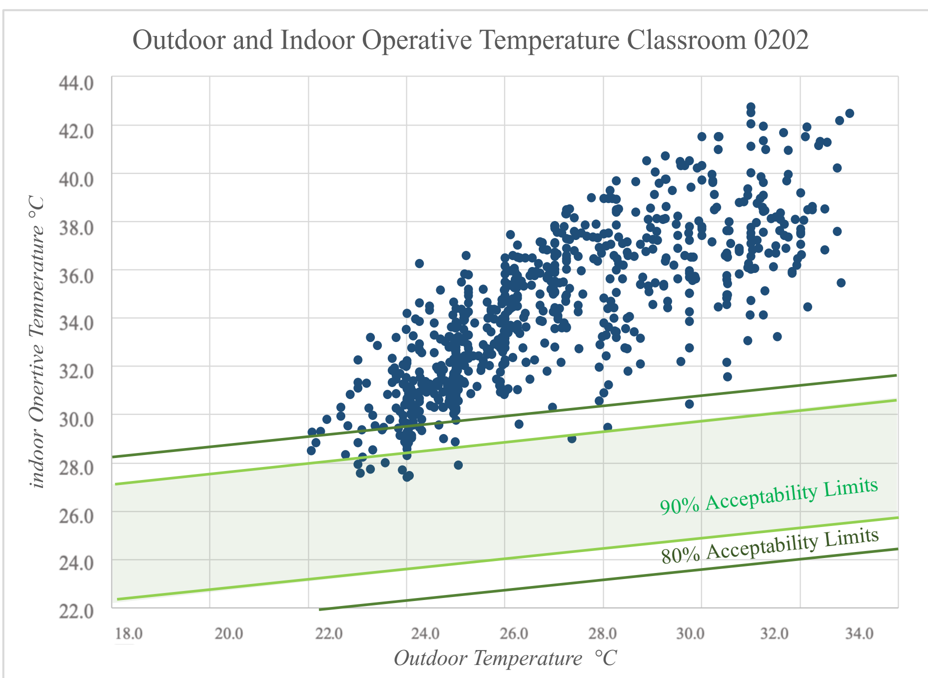


Figure 4.11. Correlation between indoor operative temp. and outdoor temp.in November 2018

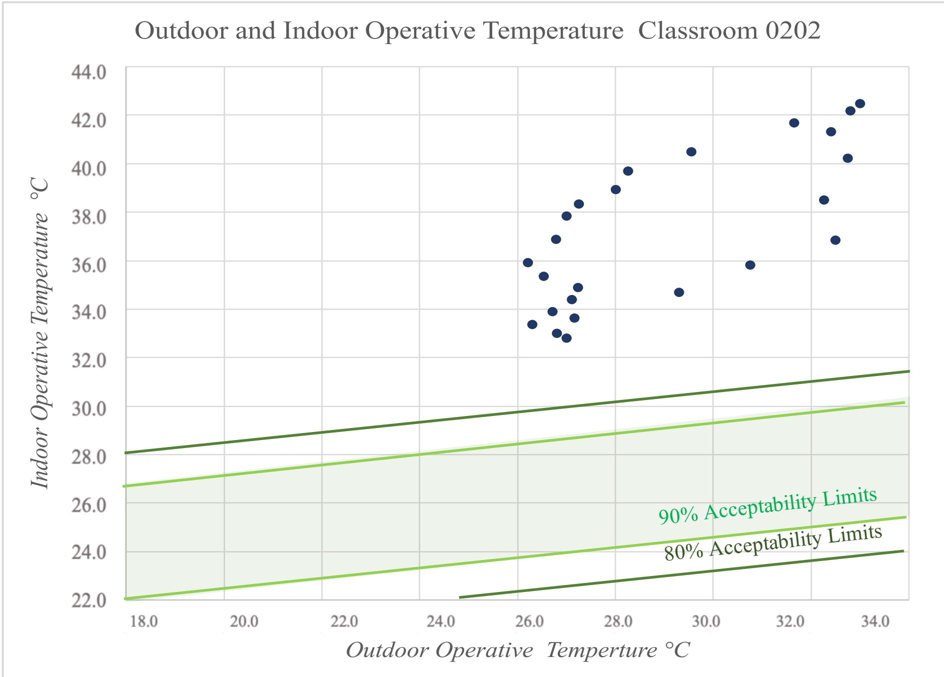


Figure 4.12. Correlation between indoor operative and outdoor temperature in November 13th 2018.

4.1.4 Wind and Air Flow

Wind speed is an essential factor influencing human thermal comfort; it enhances the heat transfer of the human body and the surrounding environment. As shown in Figure 4.13, the annual results vary from 0 to 9,8 m/s with a north and southeast direction. While Figure 4.14 shows in November, speed varies from 0 to 4.3 m/s, with a max value at 15:00 hours and min from 21:00 to midnight. On November 13th, the maximum ranges are between 2.3 to 3.8 m/s and the lowest values between 0 and 1.4 m/s, as shown in Figure 4.15.

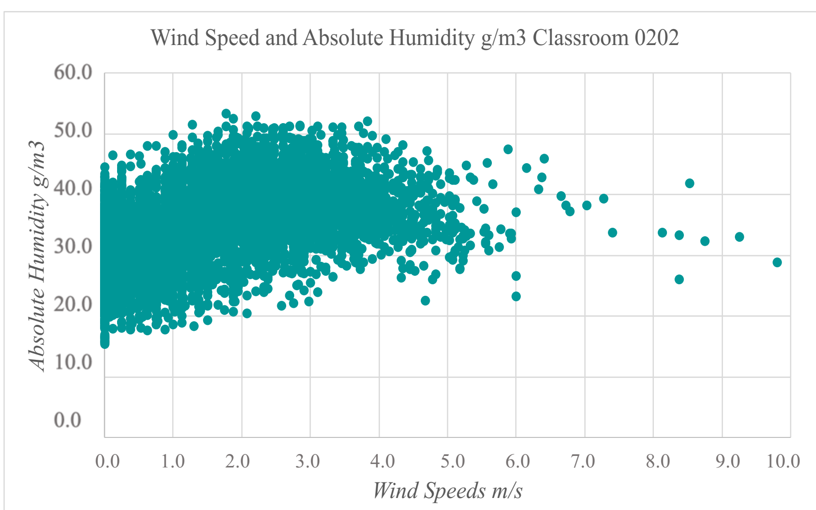


Figure 4.13. Correlation between humidity ratio and wind speed in 2018.

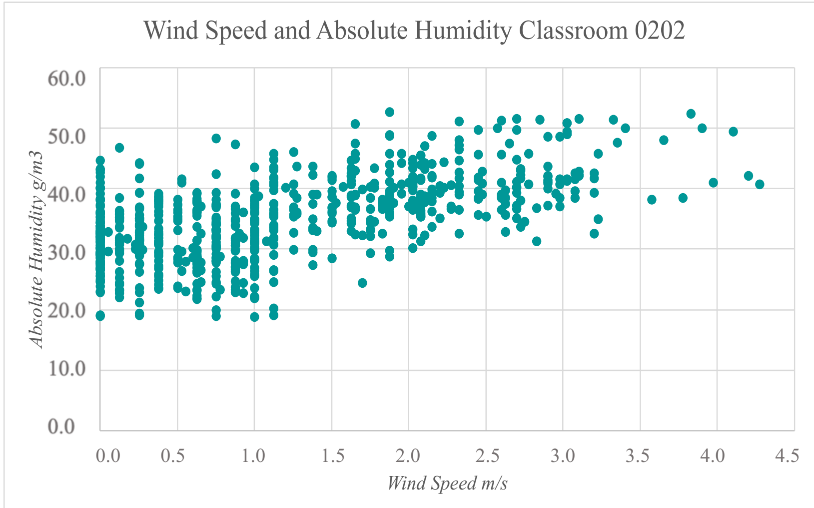


Figure 4.14. Correlation between Humidity ratio and wind speed on November 2018.

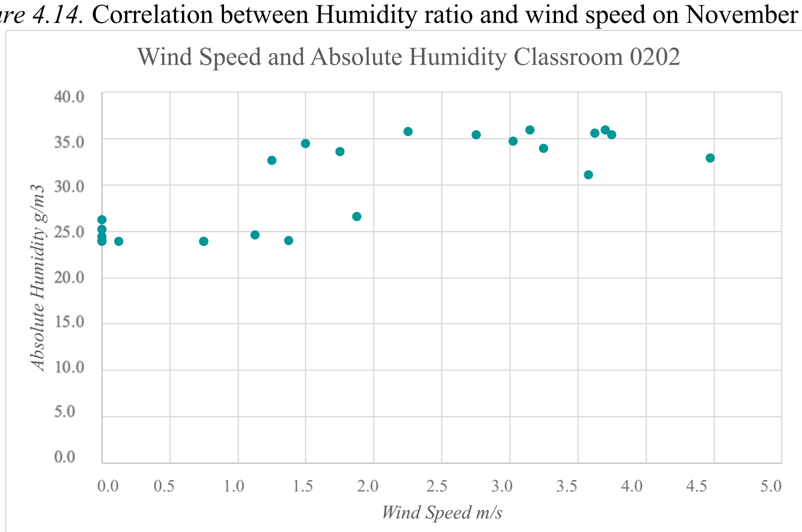


Figure 4.15. Correlation between relative humidity and wind speed in November 13th 2018.

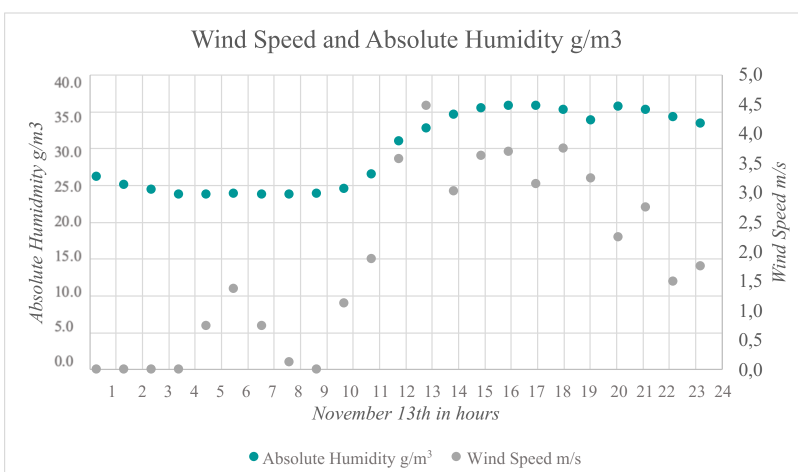


Figure 4.16. Correlation between wind speed and Absolute Humidity in November 13th 2018.

Simulations confirm that natural ventilation influences the removal of humidity excess. In November, 76% of the wind was between 0 -2m/s, with an absolute humidity interval between 20-45 g/m^3. On November 13th, as shown in Figure 4.15, the maximum wind speed was 4.5 m/s at 11:00 a.m., while the minimum rates were between 23:00 hours and 5:00 hours. Also, it is identified that during empty classroom hours, the speed of the wind increases, and the absolute humidity decreases. On the contrary, during school hours, the humidity increase, reaching a maximum of 35.7 g/m^3. Thus, identifying that natural ventilation is correlated in the design of this school.

4.2. OCCUPANCY LEVELS

The effect of occupancy on indoor thermal conditions and thermal comfort in the educational building is developed. four simulations are carried out according to the current regulations: the first one chose the national standard NTC 4595 with 1.65 m^2/person and an average of 31 students per classroom, the second one according to ASHRAE 55-2010 with 2.85 m^2/person with 18 students per classroom, the third one shows the conditions in an empty classroom applied to 24 hours per day, and finally the fourth one with 1.0 m^2/person with 50 students per classroom, shows the conditions with full occupancy in the classroom.

It has been assumed that an occupancy is scheduled as the educational building occupancy patterns that fluctuate during the day. The classroom zones have been considered occupied in 95% from 06:30 until 16:30 on weekdays and Saturdays for 8:00 to 14:00 hours. In addition, 18,8% of the time includes sports activities and recreational activities, are carried out outside the classroom as shown in Figure 4.18; Therefore, short periods of adaptation to internal climatic conditions are considered periods of thermal discomfort.

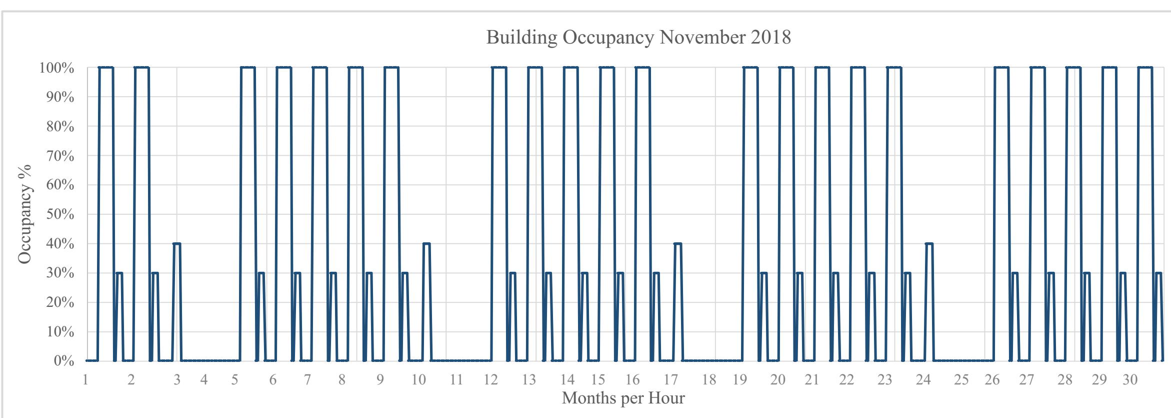


Figure 4.17. Building Occupancy in November 2018.

Time	*Hours/day*	*Activity*	*Location*	*%*
0:00 6:30	6.5	Empty	Classroom	27.10
6:30 10:00	3.5	Classes	Classroom	14.60
10:00 10:30	0.5	Lunch	Playground	2.10
10:30 12:30	2.0	Classes	Classroom	8.30
12:30 13:00	0.5	Break	Playground	2.10
13:00 16:30	3.5	Sport Activ	Playground	14.60
16:30. 18:00	1.5	Empty	Classroom	6.30
18:00 21:00	3.0	Classes	Classroom	12.50
21:00 0:00	3.0	Empty	Classroom	12.50

Figure 4.18. Daily Schedule activities.

4.2.1 Temperature

The dry-bulb temperature makes it possible to identify the overheating and thermal discomfort periods in the different occupation rates. Thus, a relationship between the occupancy and dry bulb temperature is evidenced by increasing the classroom occupancy level, increasing dry-bulb temperature. On November 13th, ASHRAE and NTC range presented a similar behavior with a reduction of 35.19% of the current conditions, a minimum temperature of 22.2°C, and a maximum of 27.55°C, while for NTC results, the min temperature is 24.59°C and a maximum 31.26°C at 16:00 hours, this variation occurs in a range of 9 hours, it means 37.5% of the time for a day as shown in Figure 4.20. ASHRAE is the only one with results below the line of thermal discomfort. Full occupancy classroom causes the highest values fluctuating between 27.8°C to 52.0°C, which comprise thermal discomfort and heat stress.

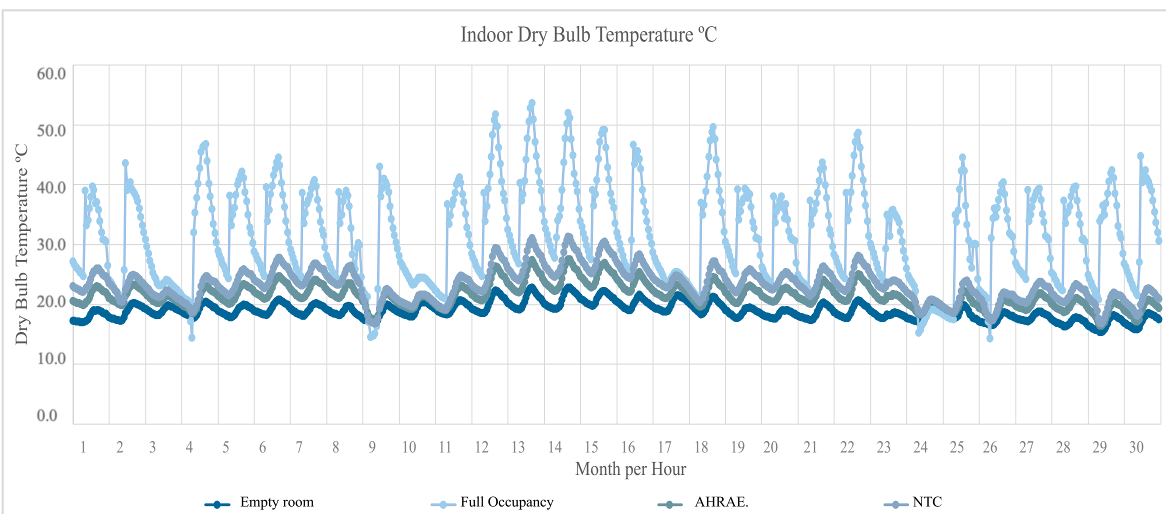


Figure 4.,19. Dry Bulb temperature for occupancy cases on November

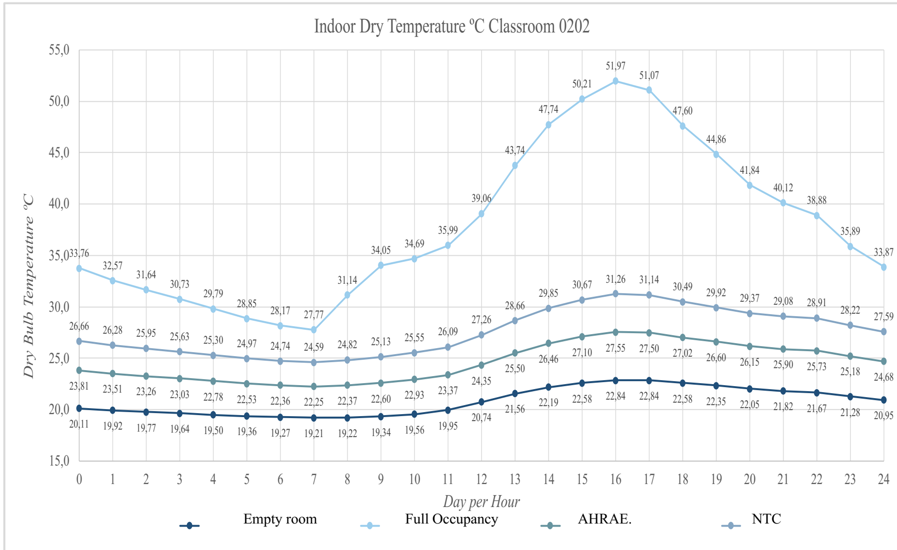


Figure 4.20. Dry Bulb temperature for occupancy cases on November 13th

4.2.2. Humidity

In the cases of fully occupied and empty classrooms, the behavior is similar except during the scholar activities hours. When the occupation increases, the relative humidity increases. ASHRAE and NTC variables fluctuate similarly, showing the national standard the lowest values in relative humidity to 52.6% as shown in Figure 4.22. The difference in relative humidity in a day reaches 27.3% between 7:00 and 16:00 hours.

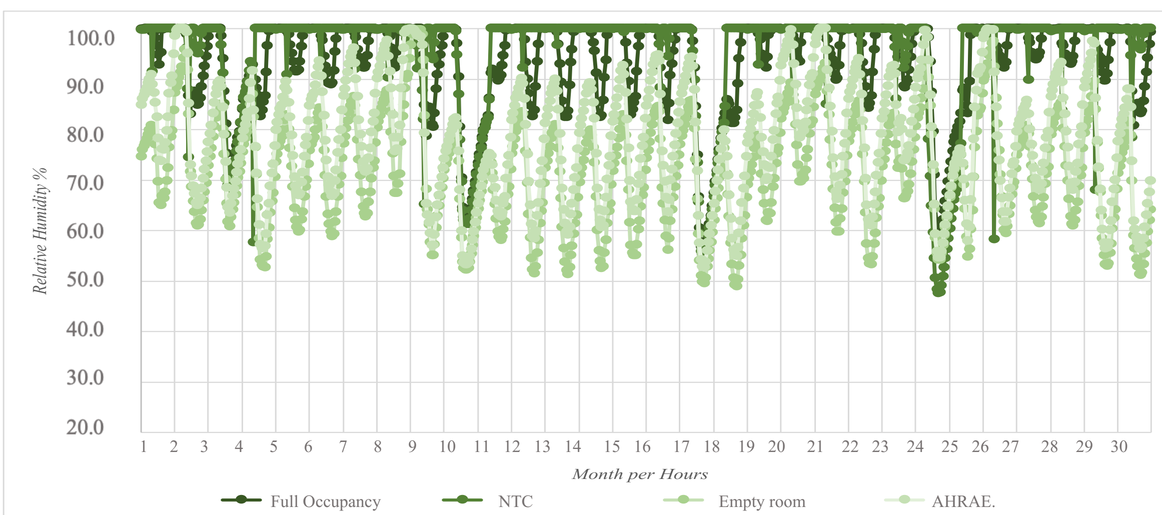


Figure 4.21. Indoor Relative Humidity for four cases on November 2018.

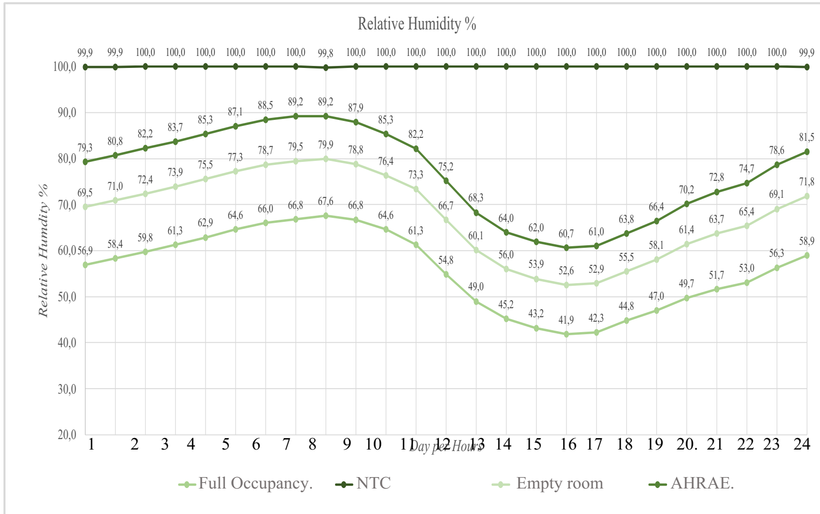


Figure 4.22. Indoor Relative Humidity for occupancy cases in November 13th 2018.

Comparing the current two regulations, ASHRAE proposes 1,5m^2 more per person than the national regulations, resulting in the reduction of 1.49 g/kg of humidity ratio and only 0.06°C of temperature operating and decreasing by 36% the level of occupancy per classroom. In figure 4.23, The increase of occupancy also increases the indoor humidity ratio. On November 13th, the value decreases from 22.09 g/kg for full room, 21.61 g/kg for current conditions, and 13.04 g/kg for an empty classroom, revealing a 9.05 g/kg difference as shown in Figure 4.24.

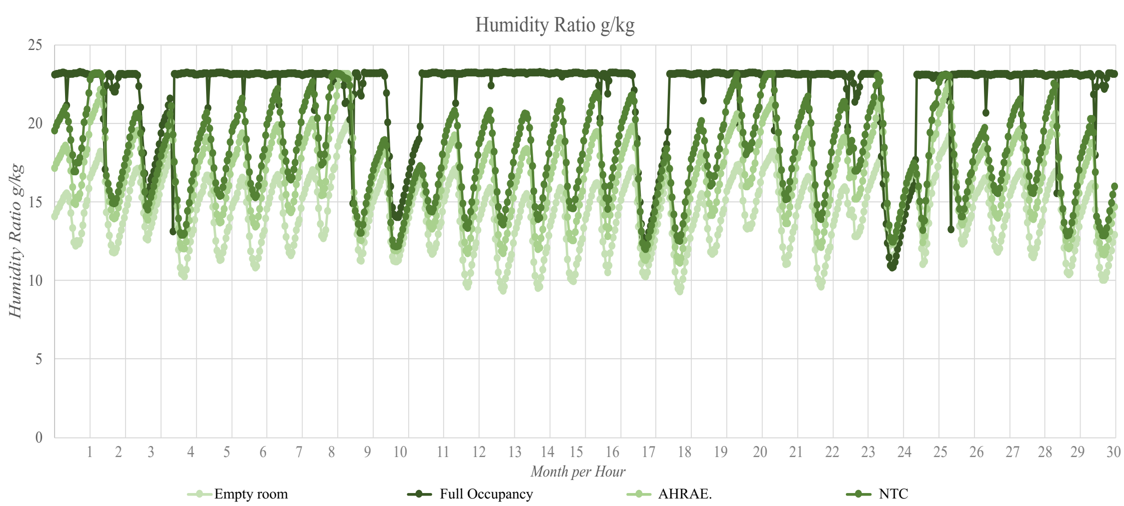


Figure 4.23. Indoor Humidity Ratio for four cases in November 2018.

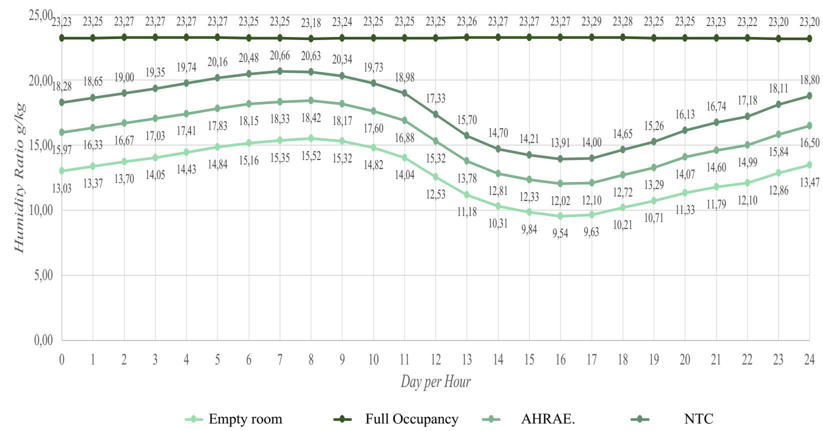


Figure 4.24. Indoor Humidity ratio for four cases in November 13th 2018.

4.2.3 Adaptative thermal comfort

ASHRAE and NTC occupancy levels reduced the indoor conditions to 2.5°C, 37.4% of the time in a year. These two regulations are within the limits of acceptability. For November, ASHRAE and NTC levels are within 80% acceptability limits 16% of the time. However, In Figure 4.27 for November 13th, any variable meets the limit of acceptability criteria, the indoor operative temperature at 11:00 is 38.2°C for 100% occupancy, 36.2°C for current conditions, 35.8°C for NTC and 34.8°C for ASHRAE The simulation also shows in Figure 4.28 that as the occupancy increases, the operative temperature increases; Increasing occupancy also increases the indoor humidity ratio. Also, the fluctuation reflects the occupation behavior with minimum temperatures at 7:00 hours and maximum at 16:00 hours.

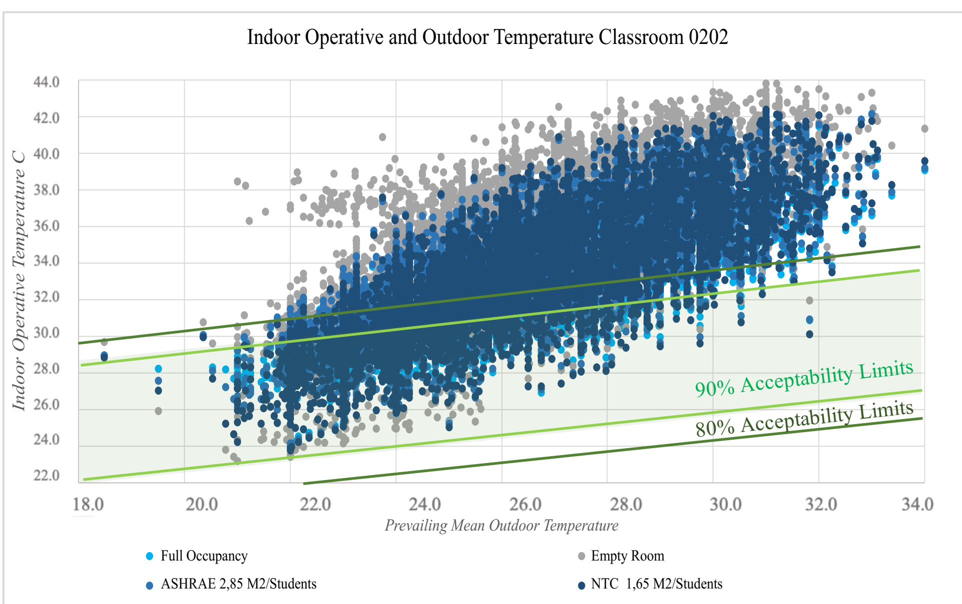


Figure 4.25. Correlation between indoor operative temperature and outdoor temperature in 2018.

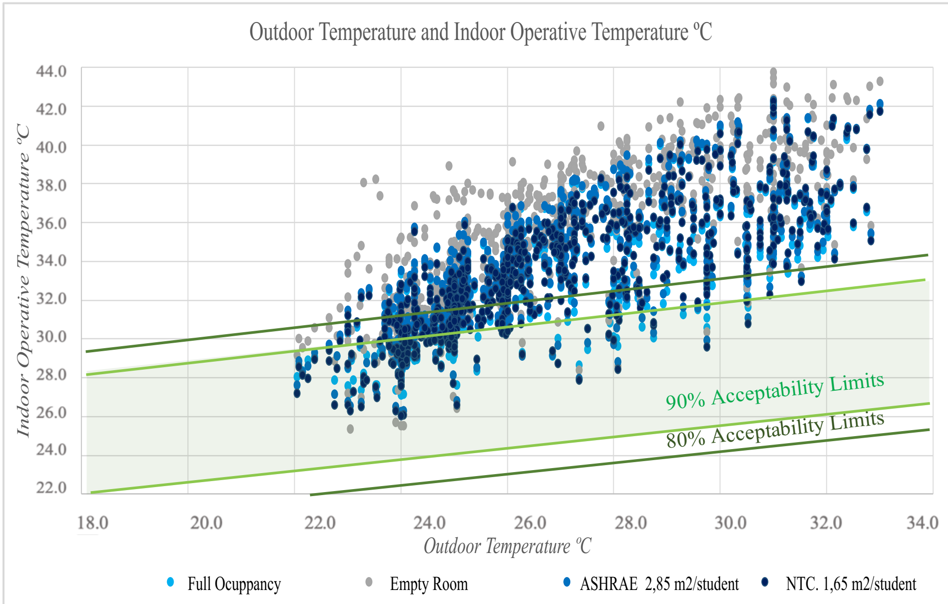


Figure 4.26. Correlation between indoor operative and outdoor temperature in November 2018.

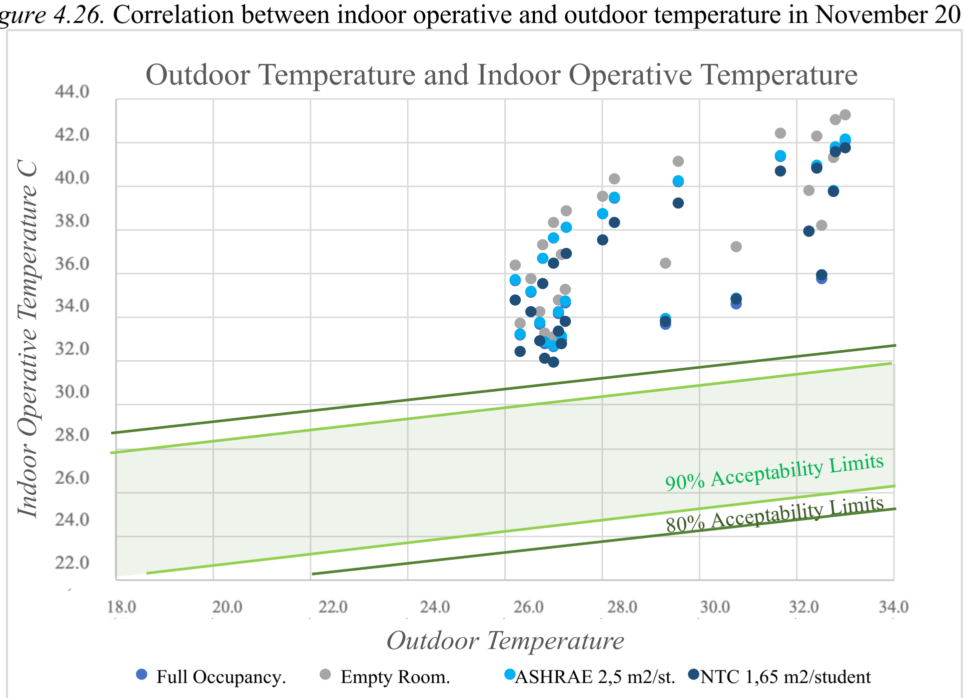


Figure 4.27. Correlation between indoor operative and outdoor temperature in November 13th 2018.

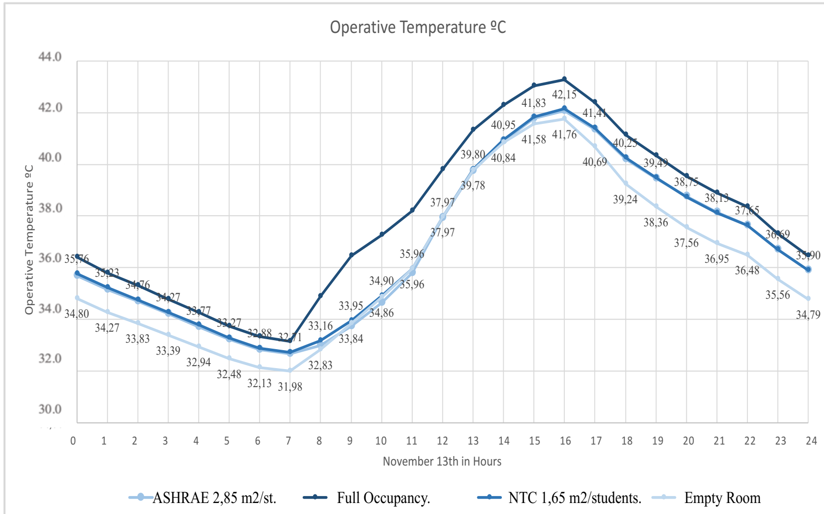


Figure 4.28. Effect of occupancy on hourly indoor operative temperature on November 13th 2018

4.3. NATURAL VENTILATION.

This school building uses natural ventilation through vertical louvers and light shelves without a mechanical system for cooling. The natural ventilation model in Design Builder was set up with a programmed maximum air change rate (ACH). The relationship between natural ventilation and indoor thermal comfort was evidenced by the simulation varying the rate from 1.0 to 6.0 ACH where 1.0 ACH was identified in the current conditions and 5.0 and 6.0 ACH as recommendation rates to improve comfort in educational buildings through natural ventilation according to the national regulations.

4.3.1. Temperature

The dry bulb temperature results identified that 5.0 and 6.0 ACH rates allow temperatures below the thermal discomfort line throughout the day with a min of 18.6°C and a maximum of 26.7°C in a range of 10 hours. In figure 4.29, For 4.0 ACH and 3.0 ACH cases, the temperature increased from noon and decreased from 17:00 hours. The minimum temperatures were identified, improving the ventilation to 6.0 ACH in 14°C and 26°C as the highest dry bulb temperature in the same case scenario. Finally, for November 13th 5.0 ACH case, the temperature reached 19.9°C as the lowest and 27.9°C as the maximum temperature recorded, while 4 ACH show a min temperature of 20°C and a maximum of 28.9°C.

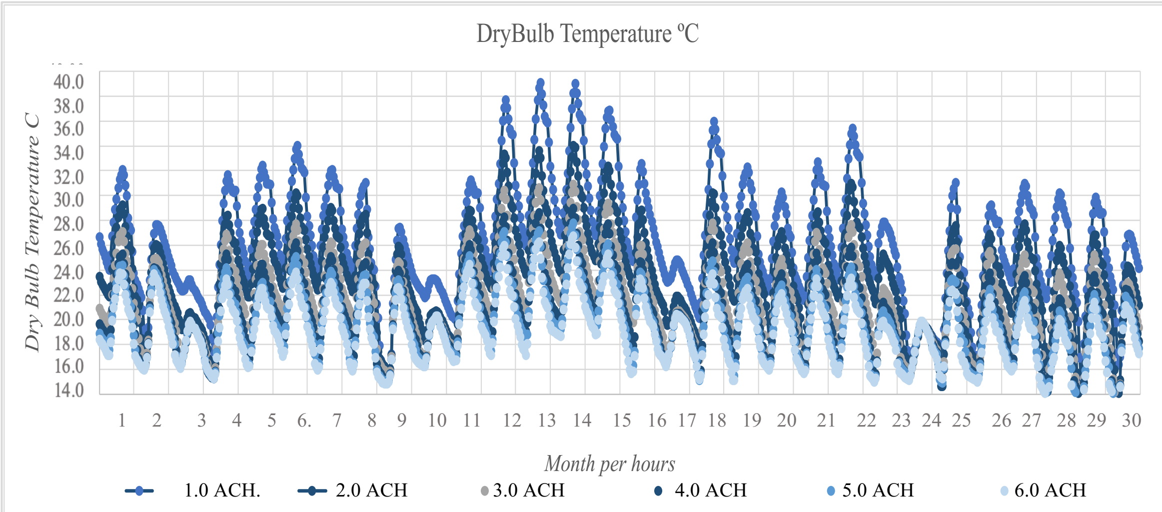


Figure 4.29. Dry Bulb temperature for four occupancy cases in November

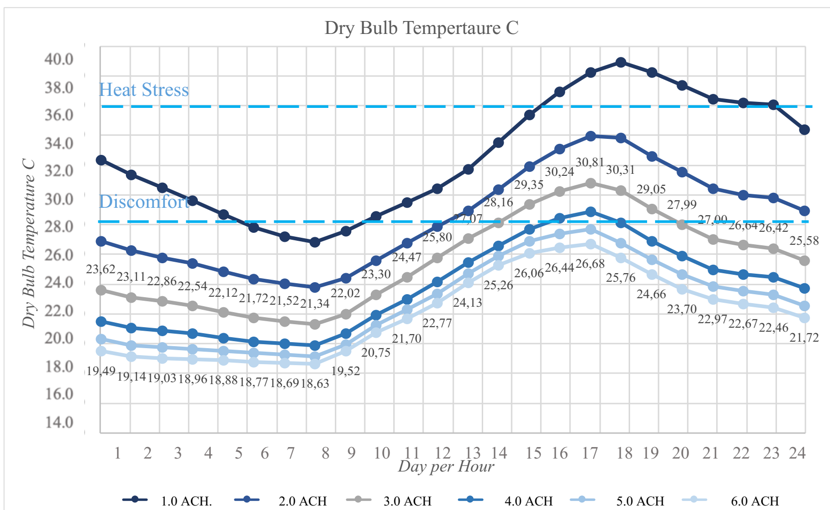


Figure 4.30. Dry Bulb temperature for four occupancy cases in November 13th

4.3.2. Humidity

The relative humidity and the humidity ratio also reflect the impact of the increase in natural ventilation, the cases 5.0 and 6.0 ACH reduced to a minimum of 67.5% and a maximum of 81% when in the current conditions the relative humidity reached 100%, in addition to presenting a minor difference, the student will positively perceive the temperature change. Furthermore, as shown in Figure 4.32, it is evident that the cases 1.0 ACH and 2.0 ACH do not significantly reduce the values of the current case. Therefore, the temperature does not decrease either. At the same time, 4.0 ACH shows 68.1% as a minimum and 86.4% as maximum relative humidity, for 5 ACH shows 68.5% as a min and 89.5% as max relative humidity at 17:00 and 7:00 hours, respectively.

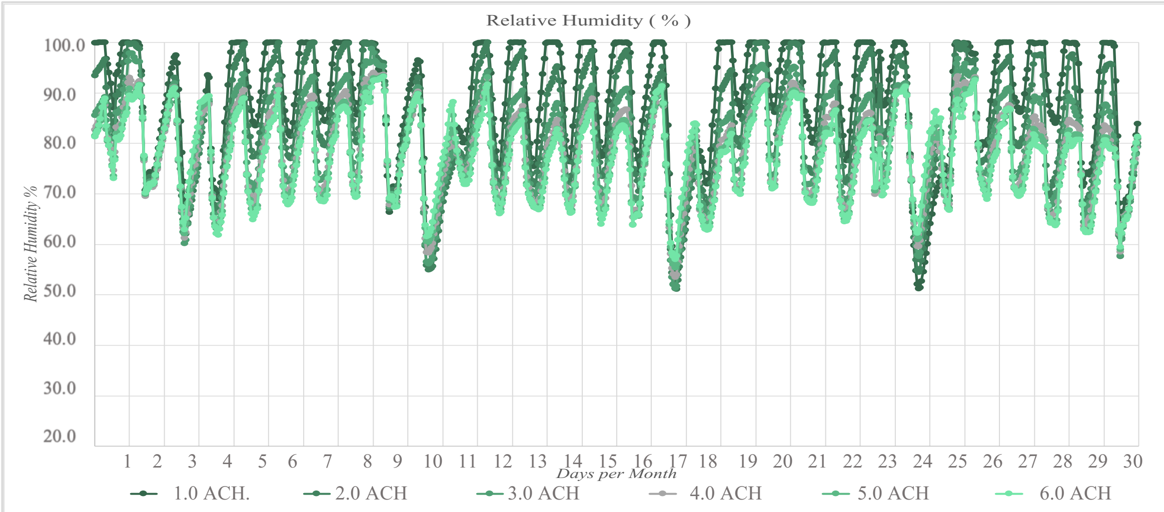


Figure 4.31. Indoor Relative Humidity for six cases in November 2018.

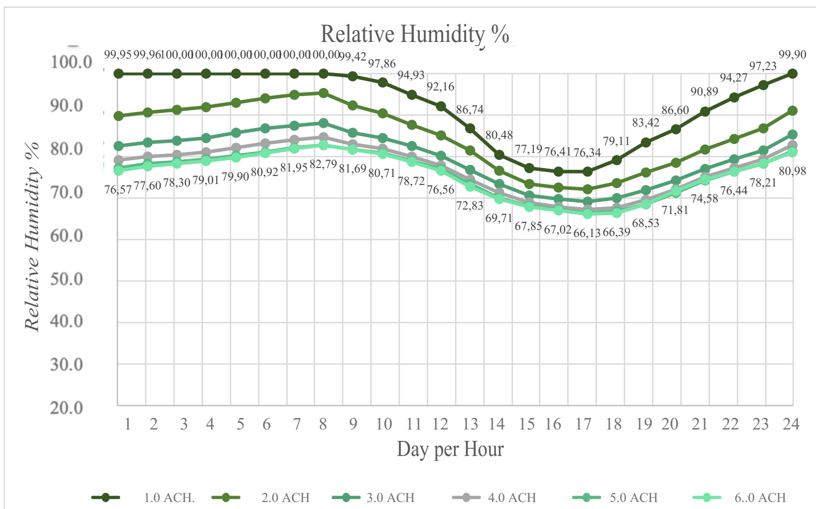


Figure 4.32. Indoor Relative Humidity for six cases in November 13th 2018.

In the Absolute Humidity results, Figure 4.33 shows the cases with the lowest results are 5.0 ACH and 6.0 ACH, with a minimum value of 18 g/m3 and a maximum of 47.8 g/m3. On November 13th, a difference between the cases 1.0 ACH and 6.0 ACH of 10 g/m3 and 1.0 g/m3 of absolute humidity between the cases 5.0 ACH to 6.0 ACH as shown in Figure 4.34 is also identified and confirmed the effectiveness of ventilation. Higher natural ventilation lowers the absolute humidity.

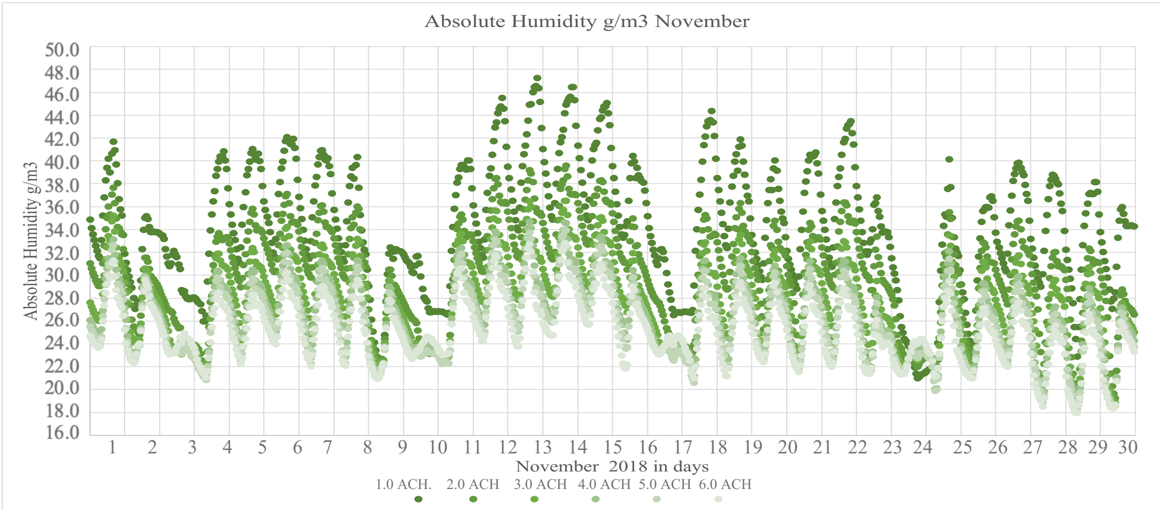


Figure 4.33. Indoor Humidity Ratio for four cases in November 2018.

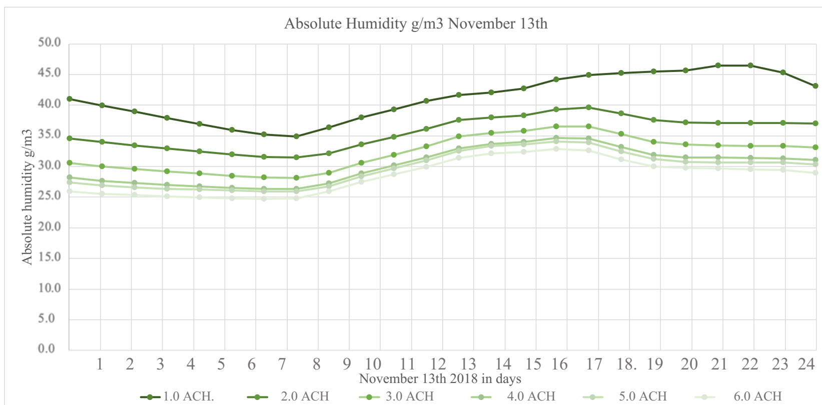


Figure 4.34. Indoor Humidity Ratio for four cases in November 13th 2018

4.3.3. Adaptative thermal comfort

According to the six natural ventilation cases, As shown in Figures 4.35, the results in operative temperature indicate that the operative temperature decreases when the airflow increases. Also, It shows that the ranges established by ASHRAE 55 for school buildings (5.0 ACH to 6.0 ACH) can reduce the operative temperature to 2,6°C and achieve the accepted comfort temperature range for hot and humid areas of 90% at 28.96°C and 26.48°C for 80% acceptability for one year.

For example, Figure 4.35 shows that in November, for 1.0 ACH, the operating temperature is 34.0°C on average, while 31.6°C and 31.3°C for 5.0 ACH and 6.0 ACH on average respectively. Besides 46.5% of the time 4.0 ACH is within acceptability limits, 54.2% for 5.0 ACH and 64.7% for 6.0 ACH, Thus, it shows that the 5.0 ACH to 6.0 ACH ranges established by ASHRAE 55-2010 for school buildings can reduce the operating temperature by 2.6°C.

Furthermore, the operative temperature decreases significantly concerning the airflow for November 13th, decreasing from 37.0°C for 1.0 ACH to 35.0°C for 5.0 ACH and 34.4°C 6.0 ACH as shown in Figure 4.36. Also, 14.8% of the time 4.0 ACH is within the acceptability limits, 22.4% of the time for 5 ACH and 30% for 6.0 ACH. It is identified that natural ventilation significantly impacts indoor thermal conditions and is the most effective passive strategy to reduce overheating in free-running buildings without mechanical cooling.

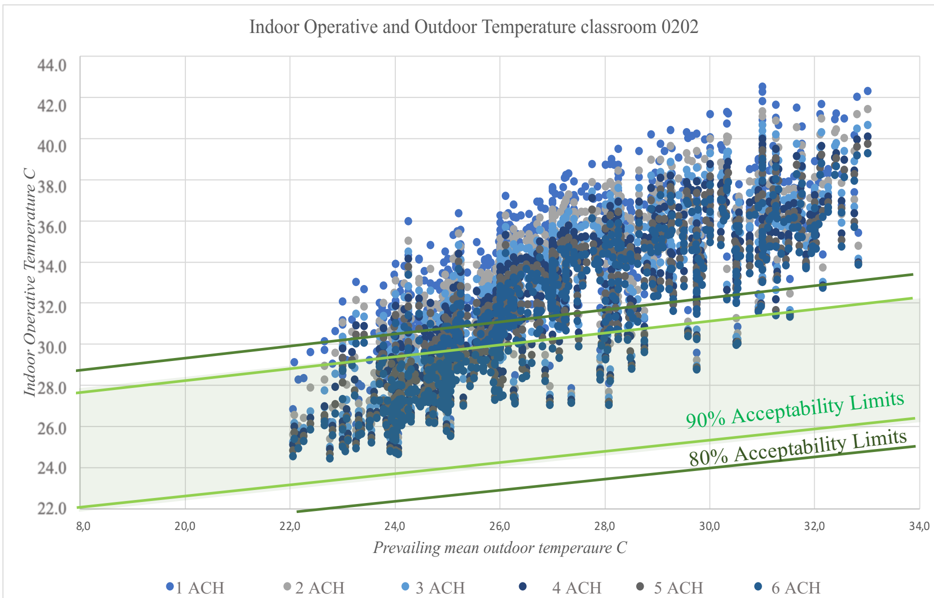


Figure 4.35. Effect of natural ventilation on the hourly indoor operative temperature November.

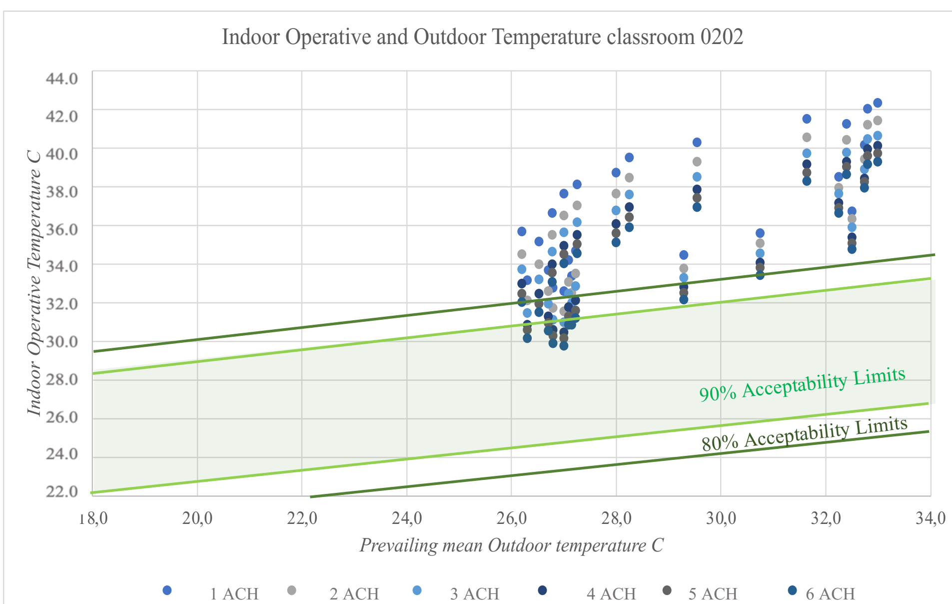


Figure 4.36. Effect of natural ventilation on the hourly indoor operative temperature on November 13th.

4.4. ROOF CONFIGURATION

The roof of the building has a sloping roof of 12° in galvanized steel tiles and a frame in a square metal tube. The tiles also have a zinc coating and fluoropolymer paint with a reflectivity of 0.85, the most common material used in the region, as shown in Figure 4.37. Each sheet has ridges reinforced, and fixing screws with a thickness of 0.45 mm and a width of 1070 mm without an insulation material layer contributes to overheating the upper floor.

Therefore, five roof configurations with different insulation types were selected to improve thermal conditions in a high range of prices and availability in the region, as shown in Table 4.1. In the first case, open-cell spray foam was selected. This type of insulation filled with air is very pliable, lightweight, with sound dampening qualities, and tends to be cheaper than closed-cell foam. The second case is the addition of R-12 block insulating fiberglass, resistant to fire and mold, effectively eliminating by convection and conduction. R-11 polystyrene and R-10 XPS-30 extrude polystyrene were selected in the third and fourth cases. These materials are moderately strong, though relatively low heat resistance. Expanded polystyrene is exceptionally lightweight, ideal for transporting and easy to install on-site, moisture resistance, and versatility. Finally, in the last case, an EPS Foamboard with 4 inches and a layer of concrete of 11 inches are selected to analyze as the option to improve the thermal conditions the minimum modification to the current conditions. All cases modify the existing roof configuration by adding plasterboard in the inner layer.

Figure 4.37. Current roof configuration detail

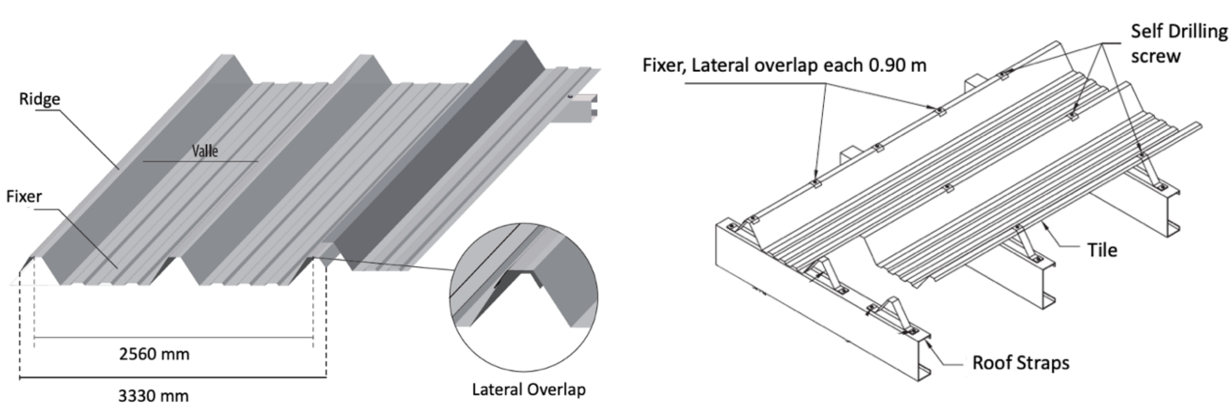


Figure 4.38. Wall/Roof Junction detail

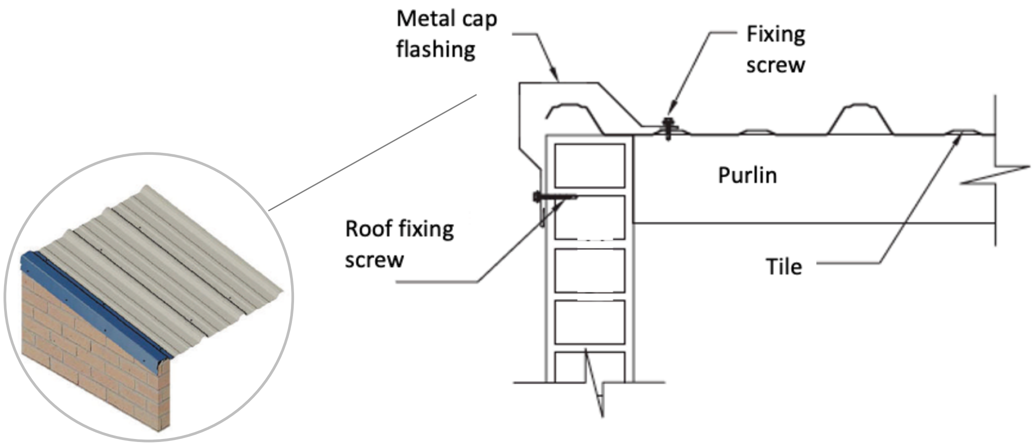
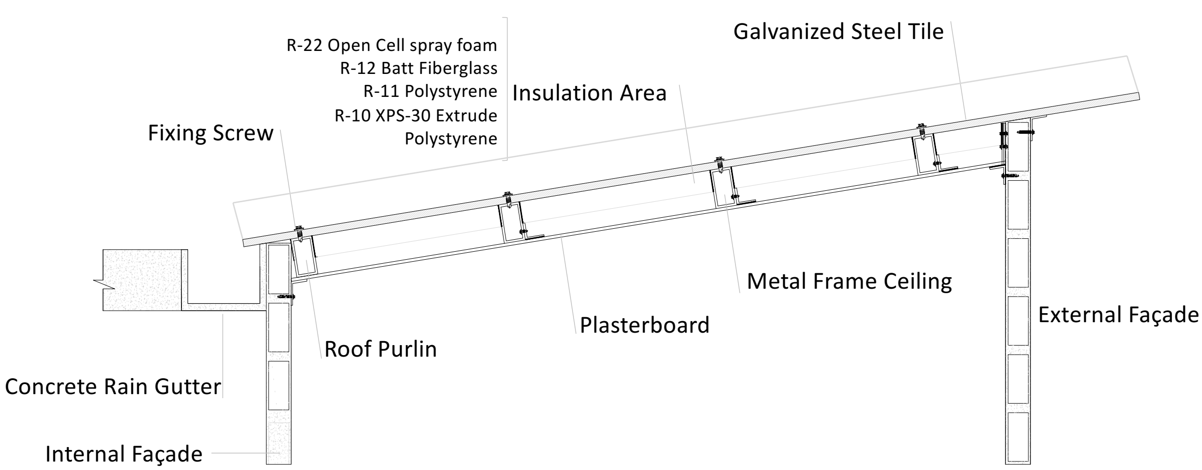


Table 4.1 Five cases of roof configuration

	Roof Confiuration	*ft*	*R Value F° ft2 h/BTU*	*U Value BTU/F° ft2 h*	*Total R Value*	*Total RSI Value*	*Total U Value*
	Galvanized painted tile	0.0017	0.22	4.50			
1	R-22 Open cell spray foam	0.5	22.80	0.04	23.47	4.13	0.24
	plasterboard	0.04	0.45	2.22			
	Galvanized painted tile	0.0017	0.22	4.50			
2	R-12 Batt Insulation Fiberglass	0.29	12.00	0.08	12.67	2.23	0.45
	plasterboard	0.04	0.45	2.22			
	Galvanized painted tile	0.0017	0.22	4.50			
3	R-11 Polystyrene	0.17	11.33	0.09	12.00	2.11	0.47
	plasterboard	0.04	0.45	2.22			
	teja eternit	0.0017	0.22	4.50			
4	R-10 XPS-30 Extrude Polystyrene	0.17	10.00	0.10	10.67	1.87	0.53
	plasterboard	0.04	0.45	2.22			
	Concrete 11 13/16"	0.98	1.28	0.78			
5	EPS Foamboard 4"	0.33	16.80	0.06	18.53	3.26	0.31
	plasterboard	0.04	0.45	2.22			

Figure 4.39. Cross section five insulation types roof configuration



4.4.1. Temperature

For dry bulb temperature results, R-11 polystyrene and R-10 XPS-30 Extrude Polystyrene cases resulted in a maximum of 60°C and a minimum of 30°C during November, as shown in figure 4.40. On November 13th, Figure 4.41 shows that higher temperatures were identified with polystyrene selected as isolation material. The curve presents similar behavior between the five configurations with a difference of up to 15°C in cases R-22 Open cell spray foam, R-12 Batt Insulation Fiberglass, and EPS Foamboard 4" with 12" concrete.

Two groups of results are identified in the graph, the first one with the highest values corresponds to R-11 Polystyrene, and R-10 XPS-30 Extrude Polystyrene, whit the lowest cover thickness of 2.52 inches with a min dry bulb temperature of 44.12°C and a max of 59.20°C In contrast, the second one of results corresponds to R-22 Open cell spray foam, R-10 XPS-30 Extrude Polystyrene and EPS Foamboard 4 "with flat cover in concrete with a maximum thickness of 12 inches a total R-value of 23.47 with a min dry bulb temperature of 31.60°C and a. max of 41.46°C. For this reason, it is identified the efficiency of the use of thermal insulation in this type of roof. Improving thermal comfort is the main objective for selecting the roof insulation, but the additional variables as additional cost to the construction budgets and the availability on site should be included.

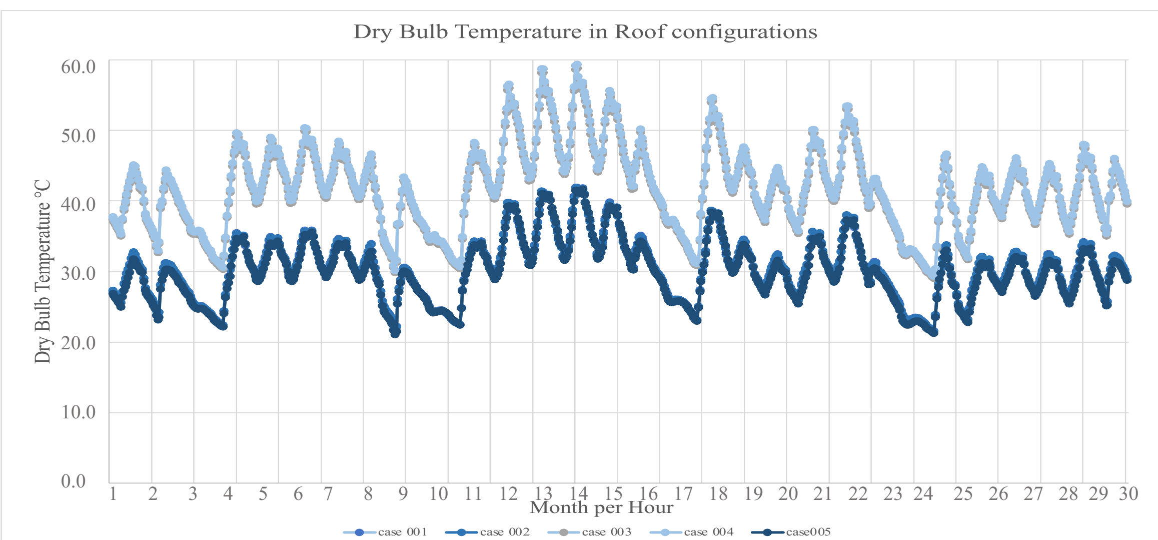


Figure 4.40. Dry Bulb temperature for five rof configuration cases on November

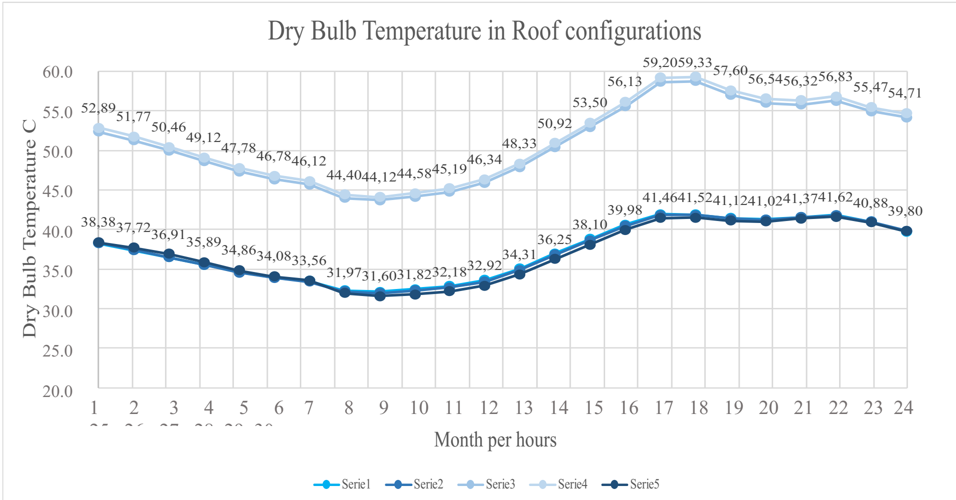


Figure 4.41. Dry Bulb temperature for five roof configuration cases on November 13th

4.4.2. Humidity

The humidity ratio results showed in Figure 4.43 a decrease at 11:00 hours from 23.3 g/kg to 21.2 g/kg at 18:00 hours. R-10 XPS-30 extrude polystyrene presented a value of 21.5 g/kg. minimum but one hour difference from EPS Foamboard with a concrete layer.

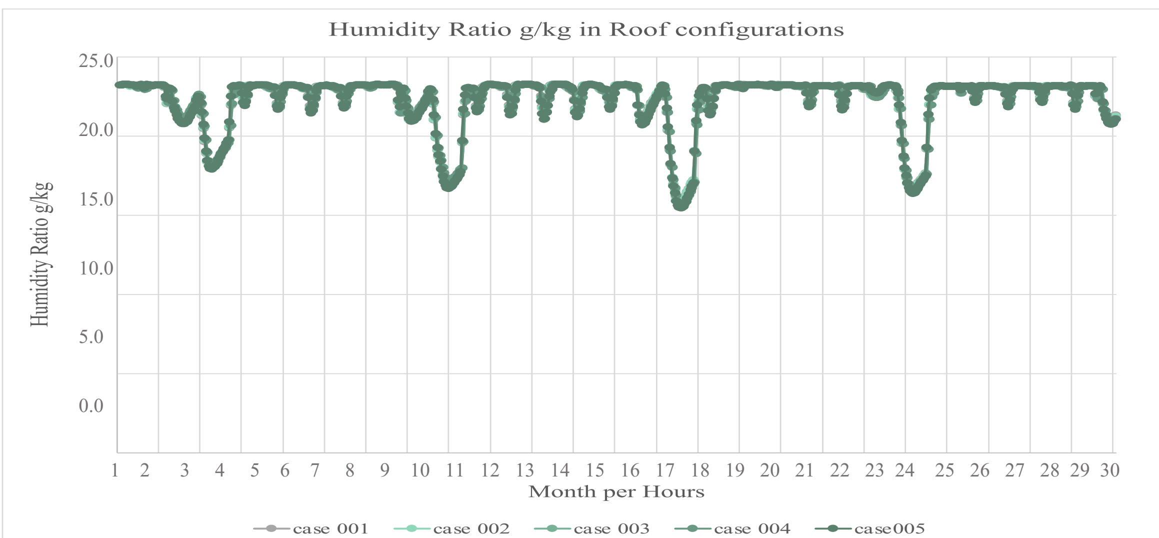


Figure 4.42. Humidity ratio for five roof configuration cases in November

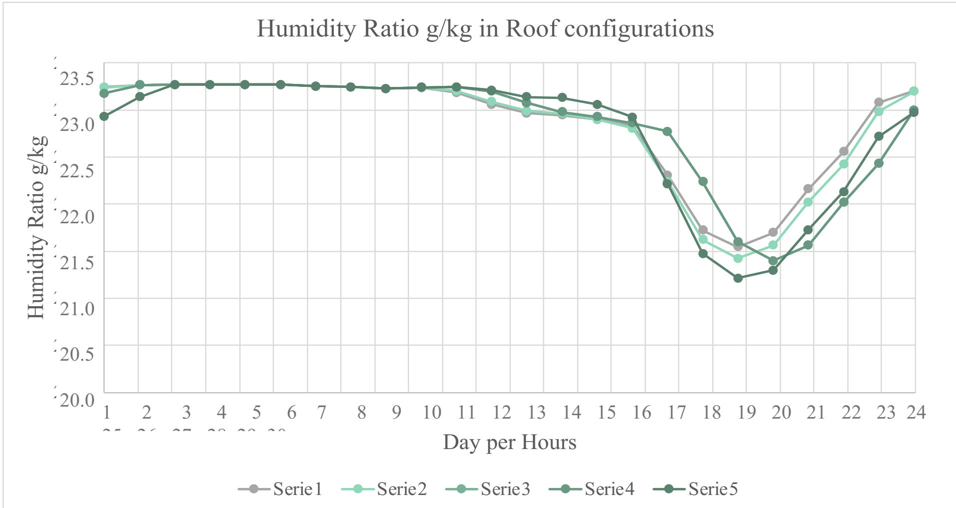


Figure 4.43. Humidity ratio for five roof configuration cases in November 13th.

Relative humidity presented a similar behavior as humidity ratio; concrete and EPS foamboard layer insulation case showed the lowest value with 91.4% at 19:00 hours and increased to 100% in all cases until 10:00 hours. R -11 polystyrene and R-10 XPS-30 extrude polystyrene cases showed the same humidity percentages with one hour difference. At the same time, open-cell spray foam insulation showed the highest humidity value compared to the other four cases of 83% on November 13th, as shown in Figure 4.45.

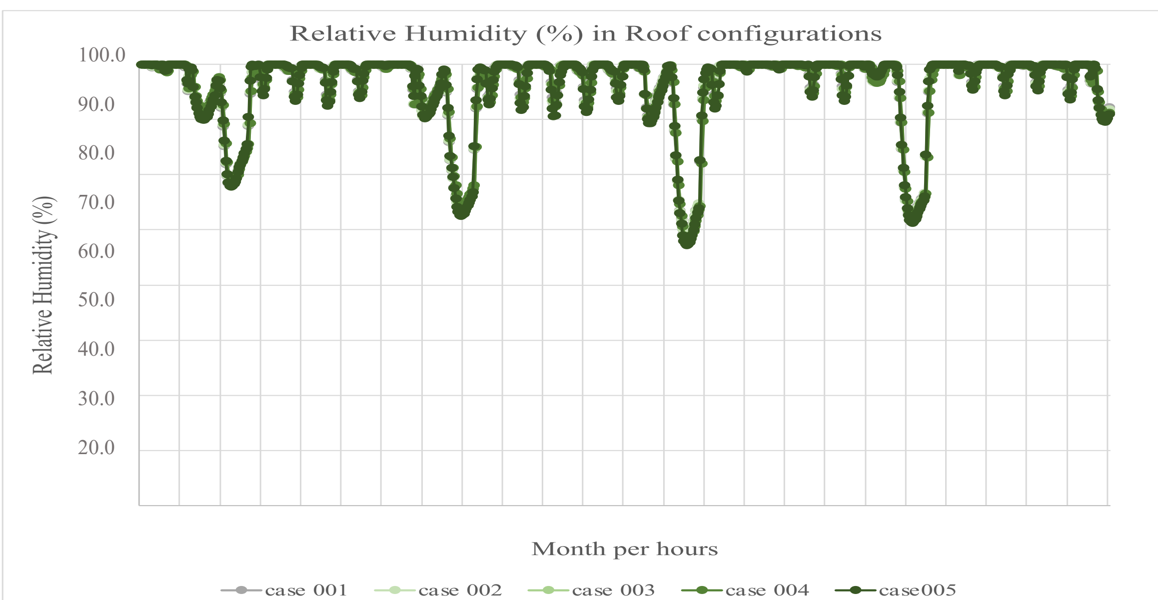


Figure 4.44. Relative Humidity for five roof configuration cases in November

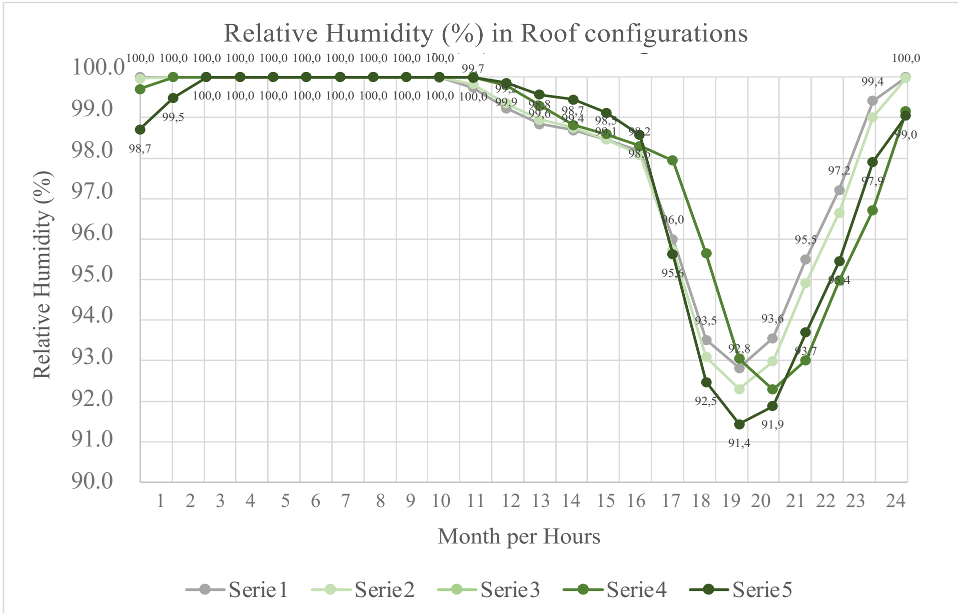


Figure 4.45. Relative Humidity for five roof configuration cases in November 13th

4.4.3 Adaptative thermal comfort

Figure 4.46, November shows that the temperature range is lower than in the current condition; the five cases reached a min of 29.2°C and maximum operative temperature of 40.5°C, and the thermal gain is longer by adding a thermal insulation layer. While in the current conditions, the minimum temperature is at 25.7°C, and the maximum is 44°C. Furthermore, as shown in Figure 4.47, the insulation thickness of 25 cm for R-11 polystyrene and 0.30 m for R-10 XPS-30 extrude polystyrene configurations show a 1.0°C lower operative temperature from 8:00 to 16:00 crucial period in school activities. Finally, R-12 fiberglass insulation is within the acceptability limits 14% of the time compared with 18% of the time open-cell spray and EPS foam board with a maximum of 18.5%.

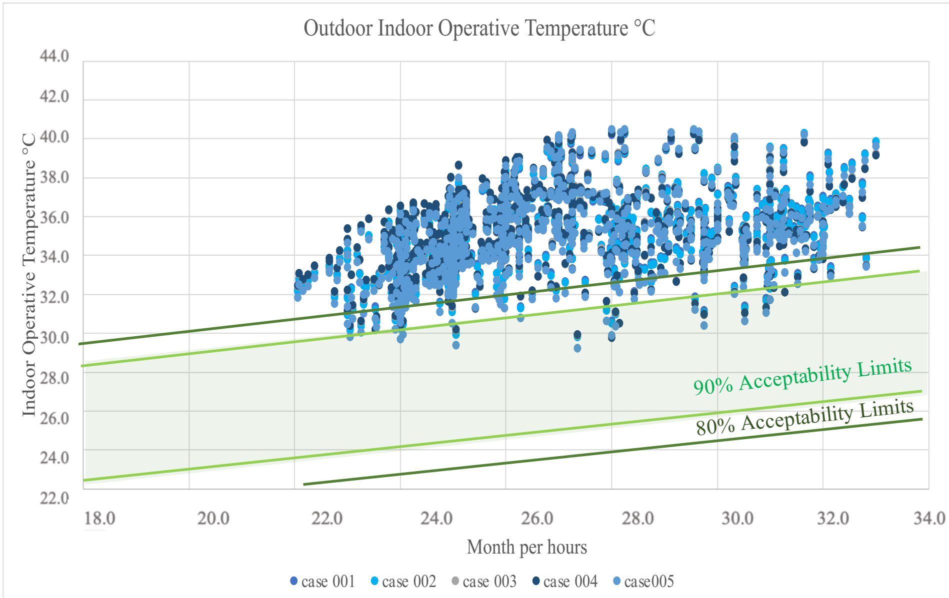


Figure 4.46. Effect of roof configurations on the hourly indoor operative temperature November

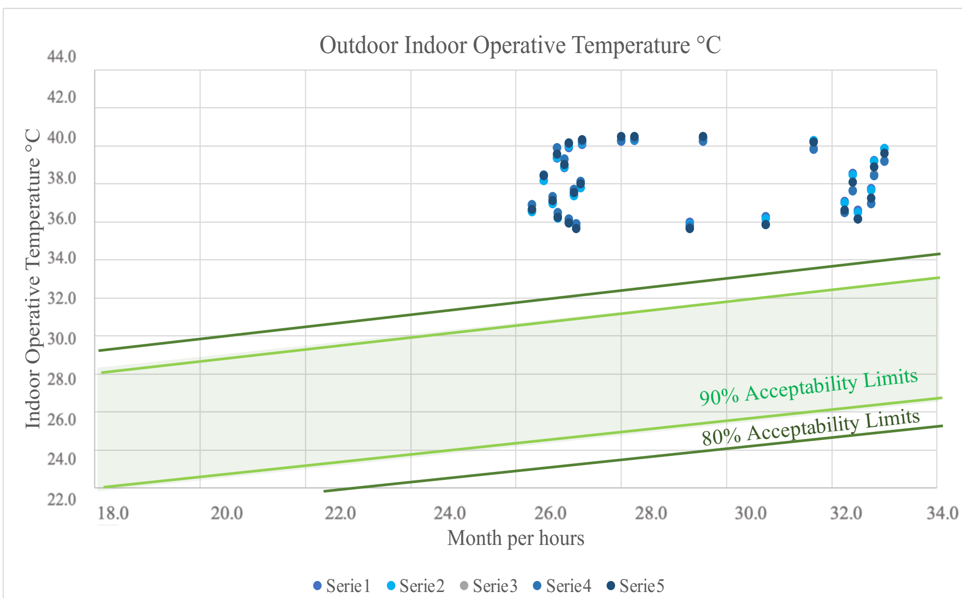


Figure 4.47. Impact of adding insulation in roof on the indoor operative temperature on November 13th

Chapter 5. CONCLUSIONS

The field study conducted in the educational building in hot and humid climate in Cucuta Colombia provided important insights into the thermal comfort performance according the local climatic conditions, Therefore, the following conclusions can be highlighted:

5.1 OCCUPANCY LEVELS

Overheating is the primary concern for a hot semi-humid climate. It is identified that just over a quarter of thermal variation (28.1%) in the period with the highest temperature record and establishing overheating as the main concern for a hot semi-humid climate.

It is found that occupancy has a significant impact on the indoor temperature and relative humidity, and thus the thermal comfort. The occupancy results showed the national standard NTC and ASHRAE refers to two different occupancy rates with a difference of 0,06°C indoor temperature and 2.5°C compared with the current indoor conditions but also decreased 36% the number of students per the classrooms.

According to the limited number of schools and the high percentage of the school-age child population, reducing the current occupancy per classroom is required in future educational building projects to accomplish the current regulations.

5.2 NATURAL VENTILATION

Natural ventilation significantly influences thermal conditions. The daily simulations results show the temperature fluctuates wildly during 24 hours. Mechanical ventilation methods as fans, besides the arrangement of external native vegetation, offer the flexibility to adjust the indoor conditions and control the effects of temperature variation. Improving air renewal by cross ventilation and achieving a renewal rate between 4.0 to 6.0 ACH keeps the operating temperature in the acceptability limits up to 46.5%. As a result, a decrease of 3.0° C was obtained due to the openings.

Occupants must have control of the thermal conditions, increasing the time of adaptation and increasing the range of thermal comfort. Besides increasing ventilation, there is more moisture evaporation in the skin and, therefore, a greater thermal comfort sensation and one of the challenges in hot and humid climate. In addition, lowest temperatures were registered between 21:00 to 3:00 passive cooling through a shading element besides a high level of night ventilation to flush cool air to the classrooms, natural ventilation from shaded openings is the key to thermal comfort.

The facades' orientation should prevail in the wind direction. Therefore, it is essential to know the orientation and location of north and southeast openings and grids in the angle between the 30 and 90° to increase the flowrate. Furthermore, the large openings maximize ventilation, while the overhangs and shutters protect from solar radiation and rain.

Extensive use of white or very light-colored surfaces minimizes heat gain. It is important to use native vegetation that adapts easily to the place conditions to avoid affectation to other species around it. As a passive strategy, some native plants are identified as shown in figures 5.1, 5.2, 5.3 and 5.4.

Description

Tree Type 01 Urapo
Crown diameter: 2.0 mt
Average height: 4.0 to 6.0 mt
Trunk height: 4.0 mt

Figure 5.1. Urapo Tree (Source: Carvajal,2015)

Tree Type 02 Habillo
Crown diameter: 8.0 m
Average height: 15.0 to 20.0 m
Trunk height: 8.0 m
Trunk diameter:1.20 m

Figure 5.2. Habillo Tree (Source: Carvajal,2015)

Tree Type 03 Tachuelo
Crown diameter: 5.0 m
Average height: 8.0 to 10.0 m
Trunk height: 5.0 m
Trunk diameter:1.30 m

Figure 5.3. Tachuelo Tree (Source: Carvajal,2015)

Figure 5.4. Small plants (Source: Carvajal,2015)

5.3 ROOF CONFIGURATION

Implementing an insulation layer in the roof configuration showed a reduction of up to 3.5°C in the indoor operating temperature between 7:00 to 19:00 hours. the use of insulation in the roof design should be with materials available in the zone without affecting the construction budget significantly.

Five insulation types increased the humidity percentage at 16:00 hours from 82.76% to 92.8% and delayed the maximum relative humidity percentage from 21:00 to 24:00. Open-cell spray foam, R-12 block insulating fiberglass, EPS Foamboard of 4 inches, and a layer of concrete of 11 inches reached the lowest indoor temperatures reaching the acceptability limits in 18.5% of the time during November.

5.4 CONTRIBUTION AND FUTURE WORK

This research represents a study of thermal performance in an educational building in a hot and humid climate in Colombia. The parameters analyzed were temperature, humidity, wind speed, activity, and clothing insulation under ASHRAE 55-10 standard. The elements identified in the case study building were high occupancy levels, roof configuration without an insulation layer, and low natural ventilation rate. Therefore, the results obtained could be generalized as the first approach in the thermal analysis for a hot and humid climate in Colombia.

The three variables were analyzed in a building energy simulation program. Classification according to age, gender, and a "clothes adjustment for a specific zone," and the furniture materials are not included. Natural ventilation and a roof configuration, including insulation layer and reflective values, reduce the operative temperature and relative humidity, reaching the limits proposed by the regulations ASHRAE 55-10, and should be between 3.0 to 5.00 ACH to increase the occupant's thermal comfort. Finally, occupancy levels increase significantly relative humidity and operative temperature, identifying that the occupancy ranges proposed by the national regulations and ASHRAE prevent discomfort conditions.

Therefore, passive design strategies are essential to optimize building design and meet ASHARE-55 requirements. Three strategies were proposed as the most effective:

- Improving air renewal by cross-ventilation through openings to the north and southeast
- Maintaining the occupancy percentage following current regulations
- Including insulation layer in the roof configuration

Further research and validation are needed to evaluate the proposed passive strategies' impacts. Besides, validate the current building as shading elements, arrangement of external native vegetation, or ventilated double-leaf construction, cross-ventilation, and fans to reduce the temperature and rh to identify possible effects and define the flow pattern within classrooms.

Analyze thermal requirements for children 7 to 12 years old and implement their thermal adaptation processes in the construction guidelines. Identified the occupants' age and gender influence the thermal comfort perception as well as the clothes adjustment

Additionally, enhance passive strategies to achieve thermal comfort in governmental building projects given social and economic limitations. More research is required to develop suitable strategies on all climatic variations in Colombia is suggested extrapolated to complement the national regulations and other building typologies as design guidelines to complement the national regulations.

REFERENCES

Allard & Santamouris, 1998, Natural ventilation in buildings: a design manual. UK: Cromwell Press).

Pepler, R.D., Warner, R.E., 1968. Temperature and learning: an experimental study. ASHRAE Trans. 74 (2), 211e224.

Ahrens, C. D. (2013). *Meteorology today: An introduction to weather, climate, and the environment*. Brooks/Cole.

ASHRAE, ANSI/ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy: Atlanta, Ga, 2010.

ASHRAE. (2013). *Ashrae pocket guide for Air Conditioning, heating, Ventilation, refrigeration Ashrae 62,1*. Atlanta, Ga, 2013.

ASHRAE. (2017). 2017 Ashrae Handbook: Fundamentals.

Buonocore, C., De Vecchi, R., Scalco, V., & Lamberts, R. (2018). Influence of relative air humidity and movement on human thermal perception in classrooms in a hot and humid climate. Building and Environment, 146, 98–106. https://doi.org/10.1016/j.buildenv.2018.09.036

Coley, D. A., Greeves, R., & Saxby, B. K. (2007). The effect of low ventilation rates on the cognitive function of a primary school class. International Journal of Ventilation,6(2), 107–112.

Digitized publications. Digitized publications | University of Toronto Archives & Records Management Services (UTARMS). (n.d.). Retrieved November 5, 2021, from https://utarms.library.utoronto.ca/archives/online/digitized-publications.

Enander, A. E., & Hygge, S. (1990). Thermal stress and human performance. *Scandinavian Journal of Work, Environment & Health*, *16*, 44–50. https://doi.org/10.5271/sjweh.1823

Fanger, P. O. (1970). Thermal comfort. Analysis and applications in environmental engineering. Copenhagen: Danish Technical Press.

Fisk, W. J. (2000). Health and productivity gains from better indoor environments and their relationship with building energy efficiency. Annual Review of Energy and the Environment, 25(1), 537–566.

Geng, Y., Ji, W., Lin, B., Hong, J., & Zhu, Y. (2018). Building Energy Performance diagnosis using energy bills and weather data. *Energy and Buildings*, *172*, 181–191. https://doi.org/10.1016/j.enbuild.2018.04.047 Mumovic, D., Palmer, J., Davies, M., Orme, M., Ridley, I., Oreszczyn, T., et al.(2009).

Geng, Y., Ji, W., Lin, B., & Zhu, Y. (2017). The impact of thermal environment on occupant IEQ perception and productivity. *Building and Environment*, *121*, 158–167. https://doi.org/10.1016/j.buildenv.2017.05.022

IDEAM, Atlas Climatológico de Colombia: Colombia, 2005.

ICONTEC. (2004). *Thermal Environmental Conditions For Human Occupancy*. NTC 5316.

ICONTEC (2006) Colombian Institute of Technical Standards and Certification. Civil Engineering And Architecture. Planning And Desing Of School Facilities And Environment. NTC 4595 Ministry of National Education, Republic of Colombia.

ICONTEC (2017). Colombian Institute of Technical Standards and Certification Planning And Design Of Environments For Initial Education In The Framework Of Integral Care Ntc 6199. Ministry of National Education, Republic of Colombia.

ISO, Ergonomic sof the Thermal Environment – _Determination of Metabolic Rate (ISO8996:2004),2004.

Koehn (E. Koehn, G. Brown, Climatic effects on construction, J. Constr. Eng. Manag. 111 (1985) 129e137).

Küller, R., & Lindsten, C. (1992). Health and behavior of children in classrooms with and without windows. *Journal of Environmental Psychology, 12*(4), 305–317.

López-Pérez, L. A., Flores-Prieto, J. J., & Ríos-Rojas, C. (2019). Adaptive thermal comfort model for educational buildings in a hot-humid climate. Building and Environment, 150, 181–194. https://doi.org/10.1016/j.buildenv.2018.12.011

MacNaughton, P., Satish, U., Laurent, J. G., Flanigan, S., Vallarino, J., Coull, B., Spengler, J. D., & Allen, J. G. (2017). The impact of working in a green certified building on cognitive function and health. *Building and Environment*, *114*, 178–186. https://doi.org/10.1016/j.buildenv.2016.11.041

McIntyre, D. (1973). A guide to thermal comfort. *Applied Ergonomics*, *4*(2), 66–72. https://doi.org/10.1016/0003-6870(73)90079-3

Ministery of Education (2016). School 10, Guidelines And Recommendations For The Design Of Schools. Governement of Colombia.

Ministery of Education (2010). Permanent advisory committee for the earthquake resistant construction regime., Colombian Construction Regulations for Earthquake Resistant Nsr-10. Ministry of Environment, Housing and Territorial Development

Montoya, O. L. Villegas, G. (2009). thermal comfort in school classrooms of the tropico, based on the application of passive bioclimatic design strategies. conference: thermal comfort in school classrooms in the tropico, based on the application of passive bioclimatic design strategies. San Buenaventura University Cali, Colombia.

Nicolas, M. H., & Bailey, G. B. (1997). Daylighting in schools: Energy costs reduced…student performance improved. *Strategic Planning for Energy and the Environment*, *17*(2), 41–61. https://doi.org/10.1080/10485236.1997.10530515

Ossama, A.A., Gamal, M.E.K., Amal, A.A., 2006. Correlation between indoor environmental.
(The atmospheric environment is a study of comfort and performance. Toronto: Department of Geography University of Toronto Press; 1972).

WHO,(1964). Research centre for the World Health Organization. *Nature*, *202*(4937), 1040–1060. https://doi.org/10.1038/2021060a0

Robert Bean, R. E. T. (n.d.). *Operative temperature: Indoor Environmental Quality with energy efficiency*. Online educational resource on achieving indoor environmental quality with radiant based HVAC systems. Retrieved November 5, 2021, from http://www.healthyheating.com/Definitions/Operative-temperature.htm#.YYTvYVNJ_0o.

SALONVIRTUAL Seguir. (n.d.). Threes y Plants in Cúcuta. SlideShare. Retrieved November 12, 2021, from https://es.slideshare.net/SALONVIRTUAL/rboles-y-plantas-de-ccuta.

Synnefa, A., Polichronaki, E., Papagiannopoulou, E., Santamouris, M., Mihalakakou, G., Doukas, P., et al. (2003). An experimental investigation of the indoor air quality in fifteen school buildings in Athens, Greece. International Journal of Ventilation, 2(3), 185–201.

Szokolay, S. V. (1985). Passive and low energy design for thermal and visual comfort. *Passive and Low Energy Ecotechniques*, 11–28. https://doi.org/10.1016/b978-0-08-031644-4.50007-2

Teli D, Jentsch MF, James PAB Naturally ventilated classrooms: an assessment of existing comfort models for predicting primary school children's thermal sensation and preference. EnergyBuild2012;53:166–82.

Vanessa, E. S. N., Calonge, H. R., Alberto, S. J. G., Alberto, T. J. L., Catalina, S. M. L., Alberto, C. R. J., Viegas, G. M., & María, Z. R. C. (2018). Environmental comfort in school classrooms: Incidence on teacher health and cognitive performance of students in public schools in Bogotá, Medellín and Cali. La Salle University

Appendix A

Figure A.1 Maximum monthly air temperature according to Cúcuta airport station

Year	*Anual average*	*Maximum Monthly Temperature*											
		Ene	*Feb*	*Mar*	*Abr*	*May*	*Jun*	*Jul*	*Ago*	*Sep*	*Oct*	*Nov*	*Dic*
1990	35.0	33.4	33.2	33.4	35,0	35.2	35.4	37.5	35.8	37.4	34,0	34,0	33.2
1991	37.0	34.8	35.2	35.2	36.7	37,0	36.4	36,0	36.3	37.3	35.6	34.4	32.5
1992	37.0	35.3	36.7	37,0	38.2	37,0	37,0	35.2	36,0	36,0	35.8	35.3	32,0
1993	37.0	34.2	34.2	34.6	37,0	36.8	36,0	36.4	37.6	36.3	36.4	33.7	33.7
1994	34.5	31.9	34.2	34.2	35.4	36.6	36.2	35.6	35.8	37.7	34.4	35.2	33.2
1995	34.0	35.8	36.2	34,0	36.8	36.2	36.2	36.6	35.5	36.4	36.6	34,0	33.2
1996	37.0	35.8	34.8	35.4	35.8	36,0	35.7	35,0	37,0	36.8	34.6	33.8	34.4
1997	37.0	29.4	34.2	33.8	35.8	36.8	36.6	36.1	38.7	38.4	38.2	36.8	37,0
1998	38.0	37,0	38,0	36.7	36.8	36.8	36.2	36.7	37.6	37.3	37.6	36.4	32.2
1999	36.0	30.8	33.2	34,0	34.8	36.4	35.4	36,0	35.6	36.8	35,0	33.6	30.4
2000	37.0	32.7	30.9	34,0	34.7	36.4	35.7	35.8	36.6	37,0	35.6	33.4	34.2
2001	36.0	35.6	34.8	36.5	34.8	37.9	36,0	36.8	37.8	37.6	36.5	34.6	34.2
2002	36.0	34.4	33.6	34,0	34.6	36,0	34.4	36.2	37.4	37.9	37.4	36.4	34.8
2003	36.8	37.2	35.5	37.4	35.6	36.4	35.4	36.8	37.2	37.6	37.1	34.6	34.4
2004	36.8	32.2	35,0	36,0	36.4	35.2	35,0	36.6	37.4	37.1	37.2	35.6	32.7
2005	35.2	33.7	33.4	35,0	37.9	34.3	35.3	36.4	37.5	37.4	36.6	35.3	31.4
2006	38.4	33.6	32.6	33.9	35.6	36.6	36.2	36.5	38,0	38.2	37.6	35.5	33.8
2007	36.8	35.5	36.5	37.3	35.3	37.2	36.3	36.7	37.1	36.9	36.1	33.9	32.3
2008	34.5	33.2	34,0	35.1	35.7	36.2	35.5	35.1	37.2	36.8	34.6	34.3	30.3
2009	36.2	31.8	31.5	31.2	32.6	36,0	35.8	35.8	36.2	38.2	37.4	35.2	35,0
2010	38.2	37.3	37.8	38,0	36.4	38.8	36.3	36.1	36.1	34.8	35,0	33.2	31.5
2011	37.6	32.6	32.1	34.7	36.1	34.5	35,0	36.1	37,0	37.2	35,0	35,0	33.4
2012	37.5	32,0	32.5	36.2	35.3	34.8	36.5	35.7	37.5	37.9	37,0	33.6	35.4
2013	37.2	35.2	34.3	36.7	37.2	35,0	36.8	37,0	38.2	37.9	37,0	34.8	34.2
2014	38.1	34.2	36,0	36.3	36.6	35,0	35.4	36.6	37.4	38,0	36.3	35.9	34.5
2015	37.6	34.4	34.8	33.8	36.8	37.4	37.2	36.3	37.2	(-)	(-)	(-)	(-)
2016	37.1	35,0	37.4	37,0	37.2	36.8	(-)	36.2	37.8	37.6	35.4	35,0	(-)
2017	35.2	35,0	34.9	35.7	35.2	37.0	36.8	36.0	35.4	34.7	35.8	33.2	30.7
2018	33.1	32.7	33.4	33.1	32.5	(-)	(-)	(-)	(-)	(-)	36.0	36.0	33.4

Figure A.2 Minimum monthly air temperature according to Cúcuta airport station

Minimum air temperature at the Camilo Daza airport station Cucuta, Period 1990 - 2018

Celsius Degrees (°C)

Year	Annual minimum temperat	*Minimum Monthly Temperature*											
		Ene	*Feb*	*Mar*	*Abr*	*May*	*Jun*	*Jul*	*Ago*	*Sep*	*Oct*	*Nov*	*Dic*
1990	16.6	17,0	16.6	18.4	20,0	19,0	17.4	20.2	20,0	21,0	20,0	19,0	19.2
1991	17.8	17.8	19.8	20.8	20.5	21,0	21.5	21.8	21.2	21.6	20.8	21.6	19.8
1992	19.4	19.4	19.4	21.2	21.3	22.3	22.8	21,0	22,0	20.4	20,0	21,0	19.8
1993	16.6	16.6	19.2	20.9	20.1	21.8	22.4	20.4	20.8	20.2	20.2	21,0	18.6
1994	17.6	17.6	20,0	20.4	20.2	21,0	20.9	20.2	20.6	20.2	20.7	19,0	18.2
1995	17.8	17.8	19.8	21,0	21.2	20.4	21.4	20.4	20.4	21,0	20.7	19.6	19.8
1996	19.2	19.2	20.6	20.8	20.7	20.8	20.3	21.4	20.1	21.2	20.8	21.4	20,0
1997	18.6	19,0	19.8	18.6	21.2	22.2	21.6	21.8	22.2	22.2	22.2	21.4	22,0
1998	18.8	20.6	21.6	21,0	23.4	22.6	22.2	20.5	21.4	21.6	22.2	20.6	18.8
1999	19.6	19.6	20.3	20.2	20.7	21.6	20.6	20.6	20.9	21,0	20.4	21.2	19.8
2000	18.0	18,0	18,0	19.1	19.8	21.2	19.4	20.6	21,0	20.7	21.8	20.8	19.2
2001	19.3	19.3	19.4	20,0	20.8	20.6	21,0	21.6	22.8	21.8	22,0	21,0	21.6
2002	19.0	19,0	19.8	20.5	20,0	21.2	21.2	22,0	20.8	21.3	21.4	21.6	21,0
2003	18.9	21.2	22,0	21.6	21.4	22.5	21,0	20.8	22,0	22.2	21.5	20.5	19.8
2004	18.5	18.5	19.5	20.2	21,0	21.8	19.7	20.3	22.7	20.8	21.6	20.2	20.2
2005	18.8	18.8	19,0	20.8	(-)	21,0	22.2	21.6	22,0	22.1	20.7	21.5	19.8
2006	17.5	17.5	17.6	18.5	19.6	20.6	20.3	19.8	22.4	19,0	20.2	21,0	20.8
2007	18.5	19.5	19,0	19.8	21.7	21,0	22,0	21.3	20.7	21,0	20.8	19.5	18.5
2008	16.9	16.9	18.6	19.2	20.1	20.8	22,0	21.5	19.8	20.8	20.2	20.6	18.8
2009	19.1	19.6	19.7	19.8	20.5	21,0	21,0	21.4	21.6	22.4	21,0	21,0	19.1
2010	18.8	18.9	21,0	22.6	21.4	22,0	21,0	20.5	21.8	20,0	21,0	19.5	18.8
2011	17.7	17.7	19.4	19.5	21,0	21.4	21.6	19.8	21.8	21.1	20.2	21,0	20.2
2012	19.1	19.9	18.8	20.8	20.2	21,0	21.9	22,0	21,0	21,0	20,0	21,0	19.8
2013	18.8	19.6	20,0	20.3	21.6	21.8	21.5	21.2	21.8	22,0	22,0	21.1	19.1
2014	18.5	18.8	19.8	21.4	22,0	21.3	20.8	22,0	22.1	21.3	21,0	21.2	21,0
2015	18.4	18.5	20.8	21,0	21.3	22,0	22.3	21,0	22.6	(-)	(-)	(-)	(-)
2016	16.8	18.4	19,0	19,0	19,0	21.6	22.8	20.2	20,0	21.9	19.2	20,0	19,0
2017	16.0	19,0	19,0	20,0	19.4	19.4	20.2	20.2	20,0	20.8	20.2	19,0	16.8
2018	16.2	17,0	16,0	18,0	18.8	20.2	19.8	20.8	19.2	19.6	18.8	19,0	17.4

Figure A.3 *Average relative humidity (%) Camilo Daza airport station Cucuta, Colombia in a period 1990-2018*

Year	*Relative humidity*	*Monthly relative humidity*											
		Ene	*Feb*	*Mar*	*Abr*	*May*	*Jun*	*Jul*	*Ago*	*Sep*	*Oct*	*Nov*	*Dic*
1990	75	82	85	81	80	72	60	65	65	67	80	77	84
1991	70	79	74	76	75	74	65	61	60	62	64	74	77
1992	67	68	68	66	68	66	60	61	60	64	64	74	81
1993	68	76	73	67	69	71	59	63	58	63	63	76	73
1994	69	76	71	74	77	66	57	61	58	59	75	76	75
1995	69	66	61	73	75	69	65	63	69	63	74	74	77
1996	69	72	74	72	69	70	62	61	59	58	70	76	80
1997	66	81	76	73	74	61	62	56	53	58	68	68	59
1998	66	62	67	67	73	66	58	58	58	63	66	73	80
1999	72	80	83	77	68	63	64	59	61	71	74	79	83
2000	71	83	81	80	75	68	63	61	58	65	66	78	68
2001	67	67	63	67	74	66	61	59	55	64	68	79	79
2002	70	74	74	77	82	73	67	61	57	61	66	71	71
2003	68	67	68	65	72	63	70	63	59	61	70	79	78
2004	72	81	74	77	79	73	60	62	58	68	74	79	83
2005	72	83	84	74	73	75	62	58	56	59	74	80	82
2006	72	83	79	83	82	70	64	61	59	60	71	77	77
2007	71	75	66	69	76	69	68	59	67	66	75	78	83
2008	74	78	78	79	74	73	65	63	70	64	74	80	84
2009	71	82	83	84	79	73	61	64	62	56	67	74	72
2010	72	62	67	70	75	71	67	68	64	76	76	82	84
2011	75	80	81	84	81	76	69	63	58	63	77	82	83
2012	69	83	77	77	78	66	54	58	60	53	71	79	74
2013	69	72	77	74	73	75	61	54	60	58	64	78	78
2014	66	71	66	70	65	75	61	54	54	59	68	76	75
2015	66	70	74	78	74	64	57	59	54	(-)	(-)	(-)	(-)
2016	72	71	68	74	72	72	62	65	65	71	81	81	78
2017	75	77	80	77	78	68	64	62	70	73	77	83	91
2018	77	88	82	85	80	72	69	65	66	72	75	80	84

Figure A.4. Relative Humidity Colombia, (Source: IDEAM)

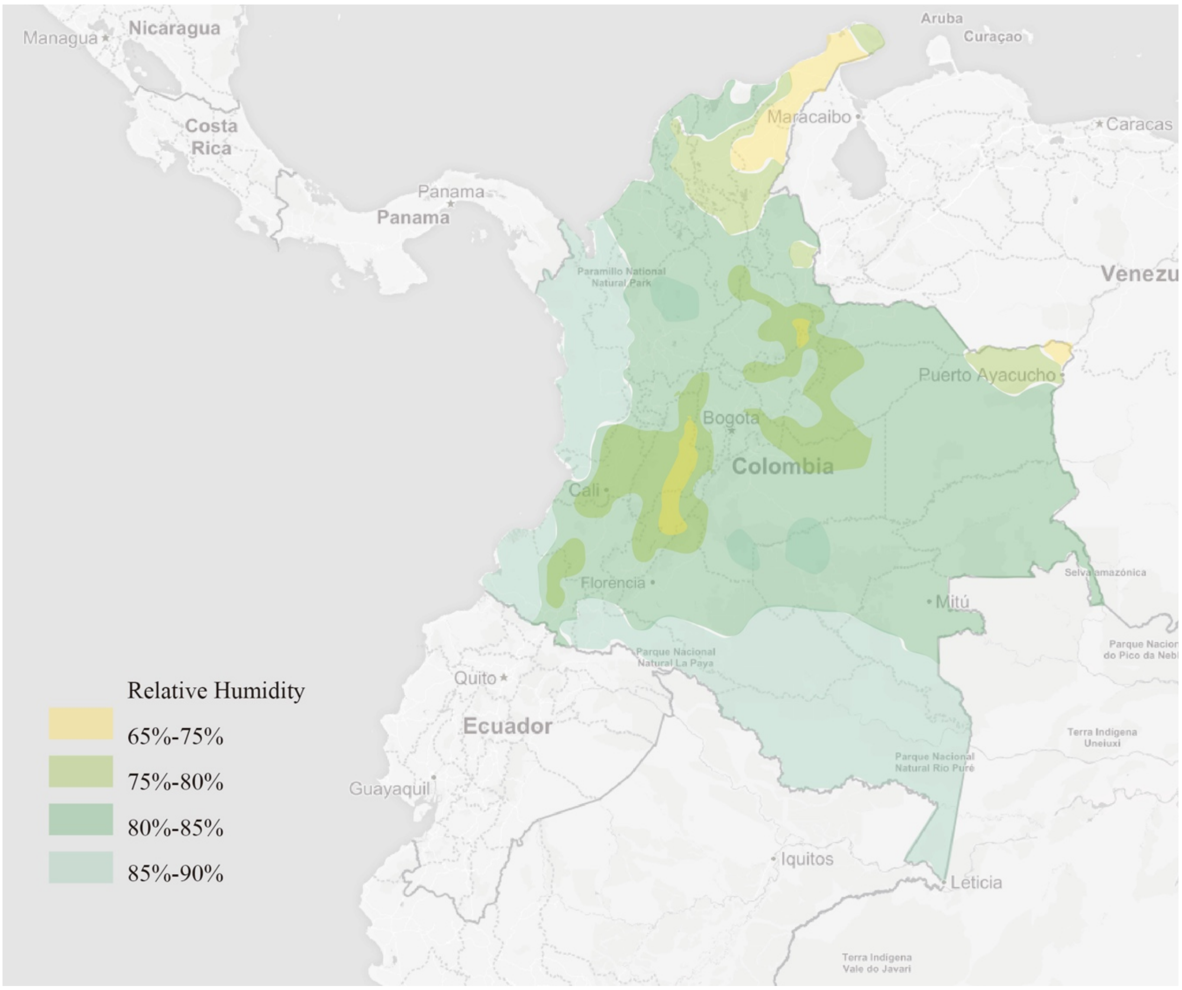
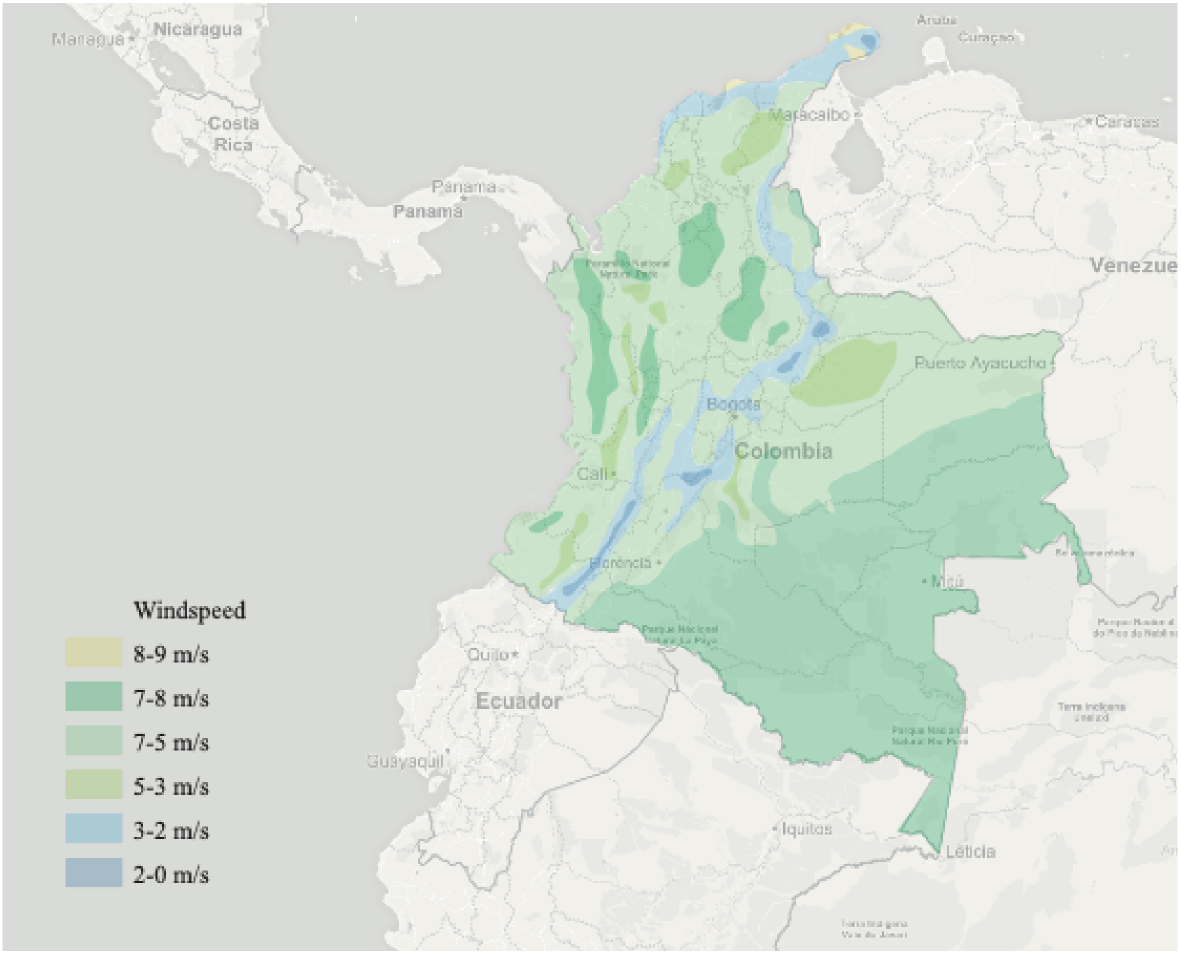


Figure A.5. Windspeed Colombia IDEAM



Appendix B

Figure B.1 General plan from the educational building (Non Scale)

Figure B.2. General plan Second Floor from the educational building (Non Scale)

Figure B.3. General plan First Floor from the educational building (Non Scale)

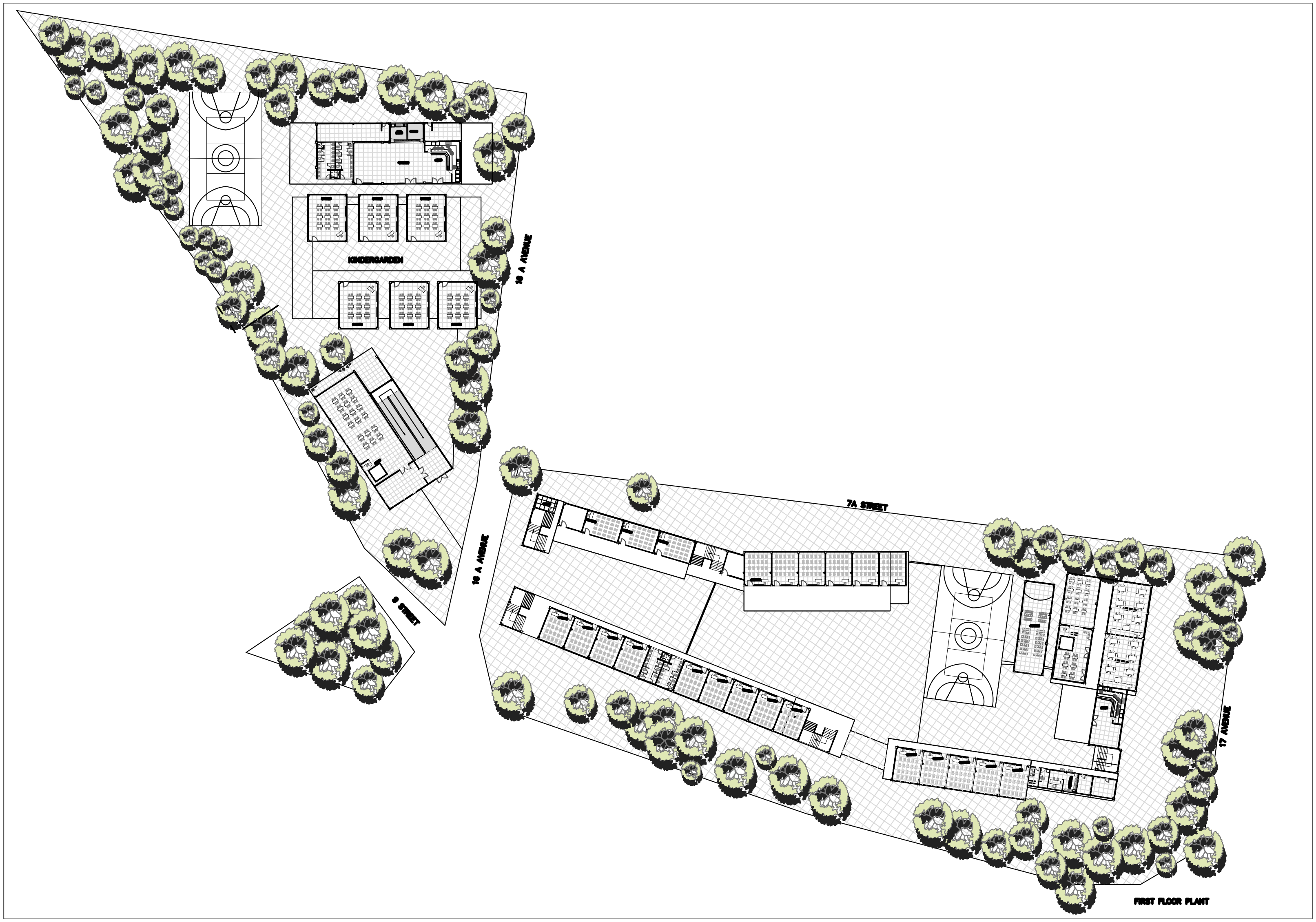
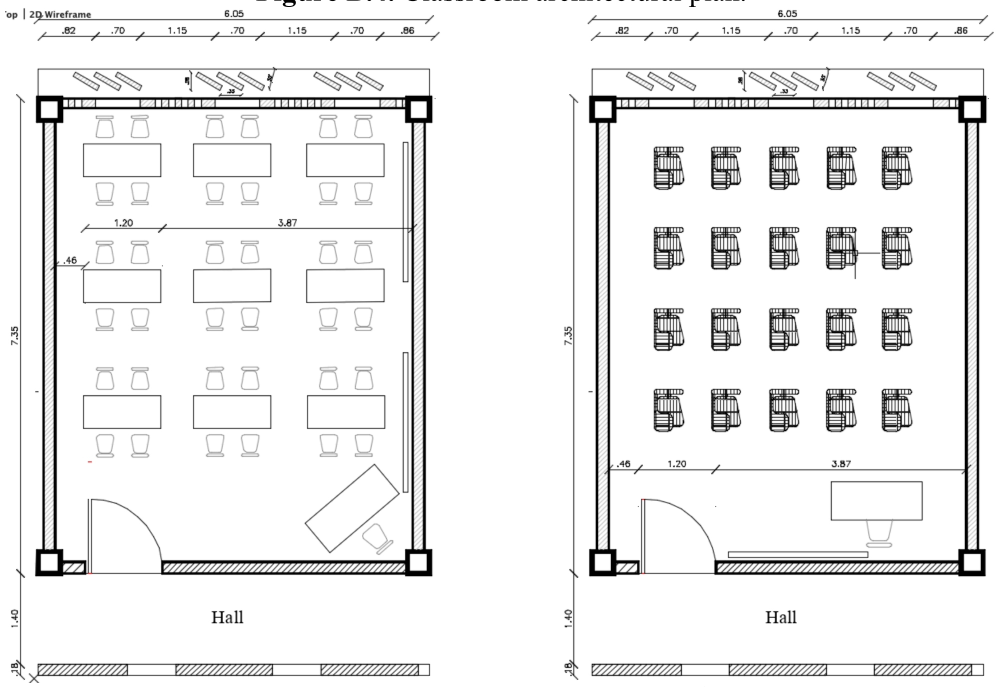
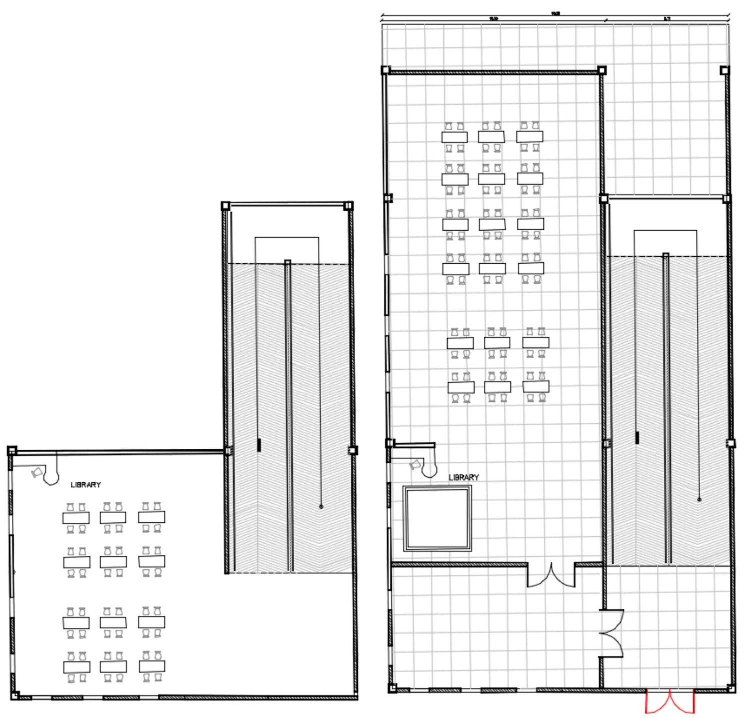


Figure B.4. Classroom architectural plan.



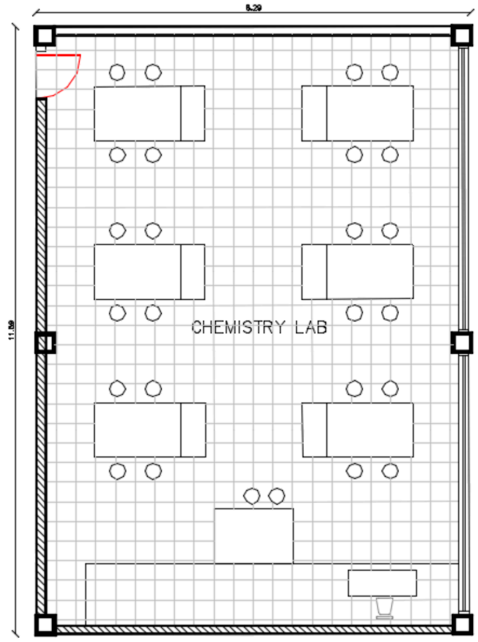
General dimensions: 8.30 mts x 5.1 mts, with an average area 42.31 m^2 and a capacity from 25 to 35 students.

Figure B.5. Library first and second floor architectural plan.



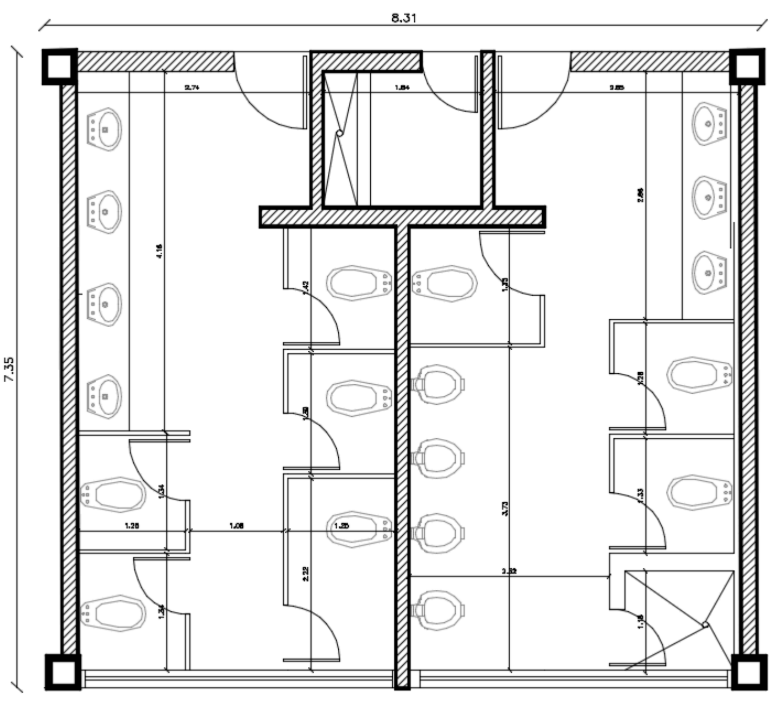
General dimensions: 31 mts x 16 mts, with an average area 497.23 m^2 and a capacity for 200 Students

Figure B.6. Chemistry laboratory architectural plan.



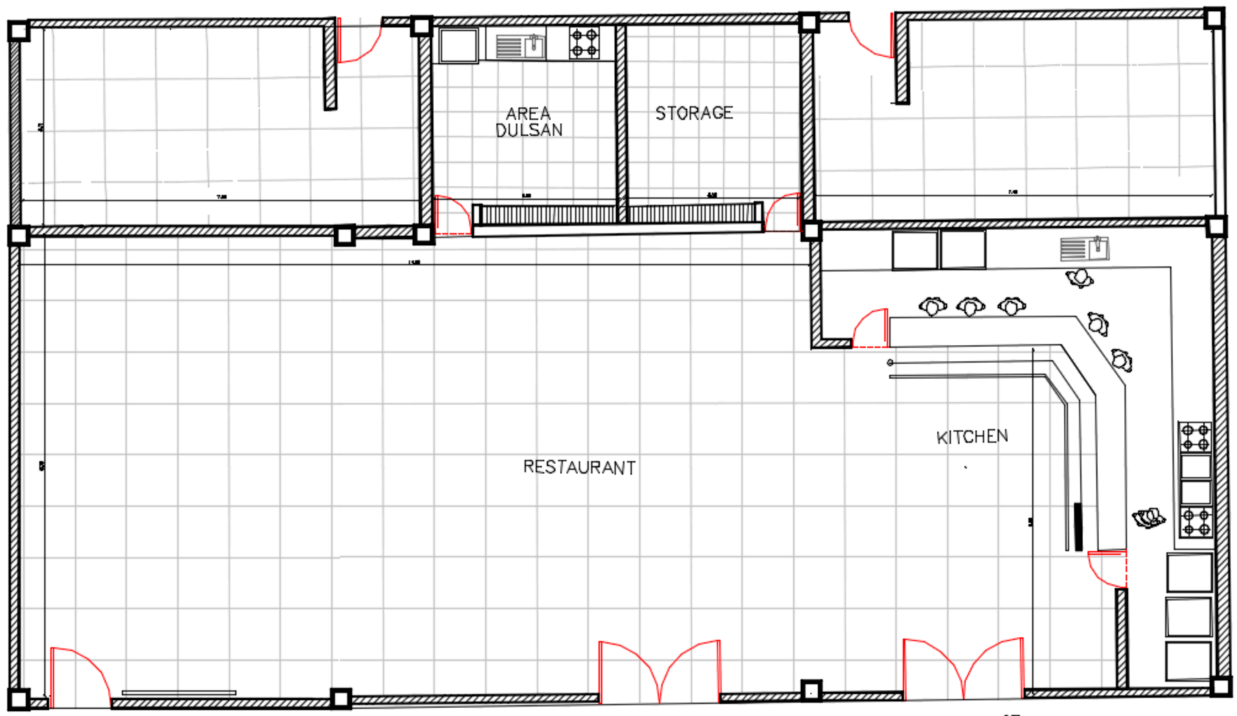
General dimensions: 8.3 mts x 12 mts, with an average area 96.0 m^2 and a capacity for 30 Students

Figure B.7. General bathrooms architectural plan.



General dimensions: 8.30 mts x 7.30 mts, with an average area 60.70 m^2 and a capacity for 12 Students

Figure B.8. Kitchen and restaurant architectural plan.



An average area 392.78 m^2 and a capacity for 14 workers and 60 students

Figure B.9. Sample Survey printed sample

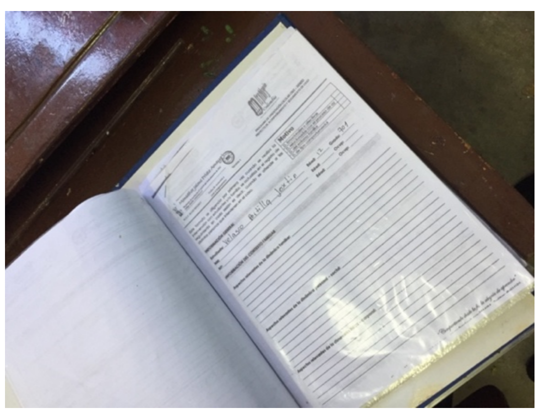


Figure B.9. *Survey Questionnaire according to ASHRAE 55-2010 (Source: Guerrero,2018)*

		Percentage			
	10	13%			
Range of Age	11	15%	***Gender***	M	75%
	12	15%		F	25%
	13	20%			
	14	20%			
	15	15%			
	16	2%%			

Noise

These are several sources of propagation, how often these sources interferes with your ability to hear in the classroom

a. Students speaking outside of the classroom

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	0	0	15	20	20	15	10	10	10	0	0	100

b. Studetns moving and mingling in the classroom

	0	1	2	3	4	5	6	7	8	9	10	Total
%	0	0	0	0	0	20	25	20	15	20	0	100

c.Noises from outside of the classroom

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	30	20	20	15	15	0	0	0	0	0	0	100

d. The noises in the classroom bother you?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	0	0	0	10	20	25	15	5	5	10	10	100

e. Indoor noises in the classroom interfiere with your concentration?

	0	1	2	3	4	5	6	7	8	9	10	Total
%	0	0	0	15	20	20	15	15	15	0	0	100

f. Are you free to choose your place to study in the classroom?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	0	0	20	20	20	15	15	10	0	0	0	100

Thermal Sensation

a.How could you describe best the indoor thermal sensation?

	Cold	Cool	Slightly neutral	Slightly warm	Warm	Hot	*Total*
%	0	0	17	40	43		100

b.How you rate your current thermal conditions?

	Cold	Cool	Slightly neutral	Slightly warm	Warm	Hot	*Total*
%	0	5	40	30	25		100

c.How do you perceive the indoor air quality?

	Acceptable	Just acceptable	Just unacceptable	Clearly unacceptable	*Total*
%	95	5	0	0	100

d.If you could modify the indoor temperature, how best describes your selection?

	Higher	No change	Lower	*Total*
%	0	13	87	100

Lighting Comfort

a. The lighting in the classroom can be described as:

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	0	35	15	20	10	15	5		0			100

b. the visual comfort in the classroom is:

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%		0		15	20	20	15	15	15	0		100

c. The lighting provided by the bulbs are:

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	0		20		15		10	15	10	0		100

d. How you describe the light in the areas of classroom?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	0		15	20			15		0			100

e. have you experience glare in the classroom?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	40	35	20	5			0					100

f. have you experience high contrast by excessive light in the corridors?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	40	35	20	5			0					100

g.have you perceive unpleasant color sensation?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	10	0	15	25	10	20			0			80

h.the daylight coming trough the windows is adequate for your activities?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	35	15	20	10	15	5		0				100

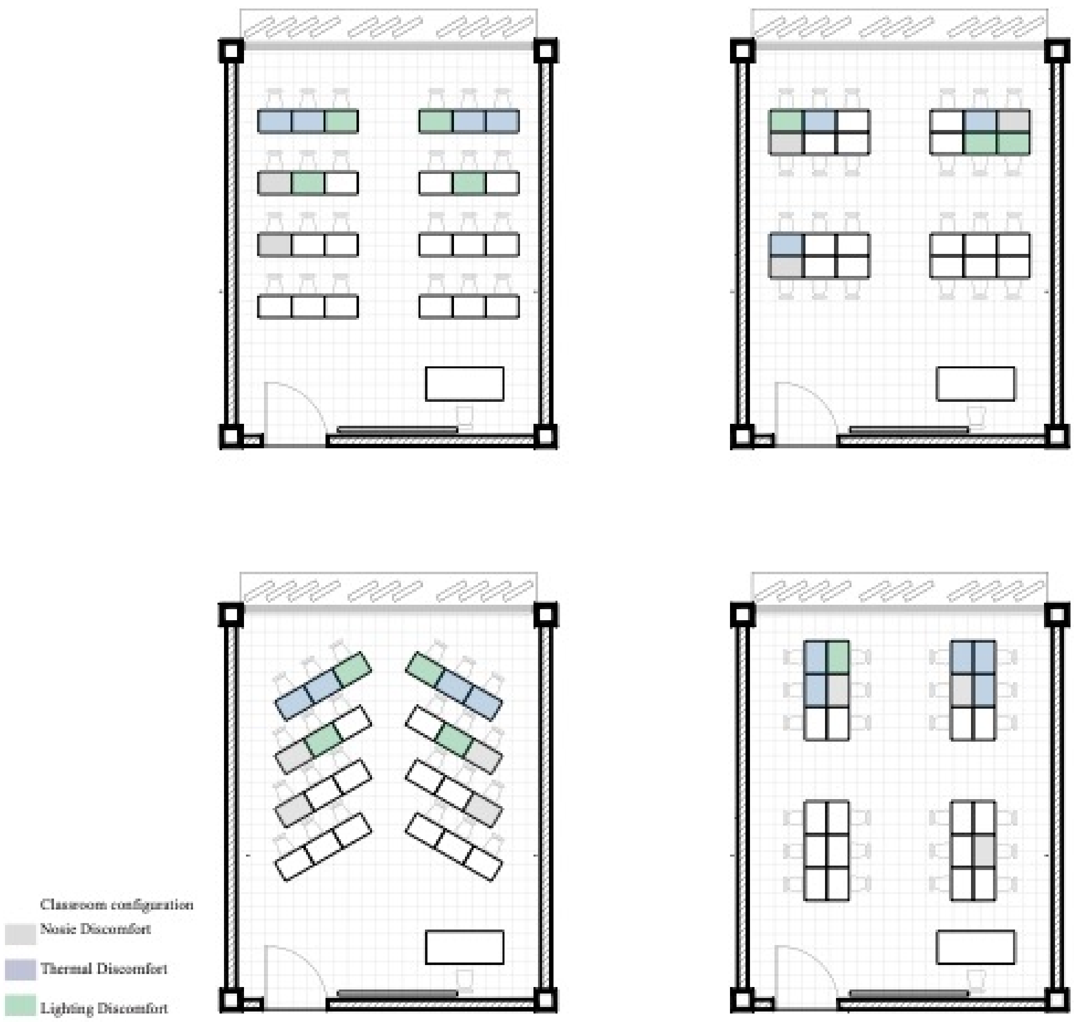
i. have you perceive annoying reflection on your desk?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%	40	35	20	5			0					100

j. Have you perceive dark areas in the classroom?

	0	1	2	3	4	5	6	7	8	9	10	*Total*
%		0			15	20		15			0	100

Figure B.10. Student's configuration in the elementary classrooms



Appendix C

Figure C.1 File .epw for San Antonio del Táchira. Source ASHRAE climatic design conditions station.

2009 ASHRAE Handbook - Foundamentals (SI)

SAN ANTONIO DEL TAC, VENEZUELA (WMO: 804470)

Lat:	Long:	Elev:	StdP:	Time zone:	Period:
7.85N	**72.45W**	**378**	**96.87**	**-4.00**	**83-05**

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR 99.6%			99%			Coldest month WS/MCDB 0.4%		1%		MCWS/PCWD to 99.6% DB	
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
1	**19.9**	**20.8**	**12.5**	**9.4**	**27.4**	**13.7**	**10.3**	**27.3**	**11.1**	**30.3**	**9.9**	**31.1**	**0.6**	**180**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB 0.4%		1%		2%		Evaporation WB/MCDB 0.4%		1%		2%		MCWS/PCWD to 0.4% DB	
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
9	**9.6**	**35.0**	**23.6**	**34.2**	**23.4**	**33.8**	**23.4**	**26.3**	**31.5**	**25.7**	**31.1**	**25.2**	**30.7**	**6.1**	**140**

Dehumidification DP/MCDB and HR 0.4%			1%			2%			Enthalpy/MCDB 0.4%		1%		2%		Hours 8 to 4 and 12.8/20.6
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
25.0	**21.1**	**28.8**	**24.2**	**20.0**	**27.8**	**23.7**	**19.5**	**27.4**	**84.6**	**31.6**	**81.5**	**31.4**	**79.3**	**30.7**	**16**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB Mean		Standard deviation		n-Year Return Period Values of Extreme DB n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
12.3	**10.8**	**9.9**	**32.9**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

Monthly Climatic Design Conditions

		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	Tavg	**27.3**	**26.1**	**26.6**	**26.7**	**27.2**	**27.9**	**27.9**	**27.5**	**28.0**	**28.2**	**27.9**	**27.2**	**26.4**
	Sd		**1.45**	**1.66**	**1.72**	**1.55**	**1.47**	**1.46**	**1.29**	**1.27**	**1.27**	**1.34**	**1.27**	**1.18**
	HDD10.0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	HDD18.3	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	CDD10.0	**6318**	**499**	**466**	**519**	**517**	**553**	**537**	**543**	**559**	**547**	**554**	**514**	**509**
	CDD18.3	**3276**	**241**	**233**	**261**	**267**	**295**	**287**	**285**	**301**	**297**	**296**	**264**	**251**
	CDH23.3	**31161**	**1940**	**2093**	**2332**	**2431**	**3031**	**3030**	**2826**	**3119**	**3118**	**2948**	**2292**	**2001**
	CDH26.7	**11955**	**751**	**818**	**921**	**933**	**1151**	**1076**	**962**	**1185**	**1314**	**1230**	**886**	**729**

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB	**34.1**	**35.0**	**35.2**	**35.0**	**35.0**	**34.8**	**34.1**	**35.0**	**35.4**	**35.2**	**34.8**	**34.0**
		MCWB	**22.3**	**22.7**	**24.8**	**23.3**	**23.5**	**23.2**	**22.9**	**24.1**	**23.9**	**23.7**	**24.0**	**23.4**
	2%	DB	**33.0**	**33.9**	**33.6**	**33.7**	**34.0**	**33.5**	**33.1**	**33.9**	**34.2**	**34.1**	**33.2**	**32.9**
		MCWB	**22.8**	**22.9**	**24.3**	**23.9**	**23.5**	**23.2**	**22.9**	**23.0**	**23.5**	**23.6**	**23.8**	**23.3**
	5%	DB	**31.9**	**32.8**	**32.5**	**32.4**	**33.0**	**32.7**	**32.1**	**32.9**	**33.5**	**33.2**	**32.2**	**31.8**
		MCWB	**22.7**	**23.0**	**23.8**	**23.4**	**23.2**	**22.9**	**22.6**	**22.9**	**23.2**	**23.4**	**23.6**	**23.2**
	10%	DB	**30.9**	**31.3**	**31.2**	**31.2**	**31.9**	**31.7**	**31.1**	**31.9**	**32.6**	**32.2**	**31.2**	**30.8**
		MCWB	**22.7**	**22.7**	**23.3**	**23.0**	**22.8**	**22.5**	**22.2**	**22.7**	**23.0**	**23.3**	**23.3**	**23.3**

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB	**25.2**	**25.6**	**27.2**	**26.9**	**26.3**	**26.3**	**25.6**	**25.8**	**26.2**	**26.1**	**26.3**	**25.8**
		MCDB	**30.9**	**31.4**	**32.9**	**31.4**	**31.1**	**31.0**	**31.3**	**32.2**	**32.2**	**32.2**	**31.8**	**31.0**
	2%	WB	**24.3**	**24.5**	**25.9**	**25.5**	**25.5**	**25.0**	**24.6**	**24.9**	**25.2**	**25.2**	**25.4**	**25.1**
		MCDB	**30.2**	**30.8**	**31.2**	**30.6**	**30.4**	**30.1**	**30.6**	**31.1**	**31.5**	**31.4**	**31.1**	**30.5**
	5%	WB	**23.7**	**23.7**	**24.9**	**24.8**	**24.8**	**24.1**	**23.7**	**24.1**	**24.5**	**24.6**	**24.7**	**24.5**
		MCDB	**29.5**	**29.7**	**30.3**	**29.6**	**29.3**	**29.7**	**29.4**	**29.9**	**30.6**	**30.5**	**30.1**	**29.4**
	10%	WB	**23.1**	**23.3**	**24.1**	**24.2**	**24.2**	**23.3**	**23.1**	**23.4**	**23.7**	**24.1**	**24.1**	**23.9**
		MCDB	**28.7**	**28.9**	**28.9**	**28.5**	**28.6**	**29.4**	**28.7**	**29.3**	**29.6**	**29.5**	**29.0**	**28.4**

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Temperature Range		MDBR	**9.8**	**9.1**	**9.1**	**8.7**	**8.5**	**7.8**	**8.0**	**8.4**	**9.6**	**9.6**	**9.3**	**9.2**
	5% DB	MCDBR	**11.4**	**11.4**	**11.0**	**10.2**	**10.0**	**9.3**	**9.3**	**9.8**	**10.6**	**10.6**	**10.5**	**10.8**
		MCWBR	**5.2**	**4.8**	**4.5**	**4.3**	**4.4**	**4.1**	**3.9**	**4.1**	**4.4**	**4.3**	**4.7**	**5.0**
	5% WB	MCDBR	**10.3**	**9.8**	**10.1**	**9.4**	**9.2**	**8.4**	**8.4**	**9.1**	**9.8**	**9.9**	**9.9**	**9.7**
		MCWBR	**5.2**	**4.7**	**4.8**	**4.7**	**4.7**	**4.5**	**4.4**	**4.7**	**4.4**	**4.3**	**4.7**	**5.0**

Figure C.2. File .epw for San Antonio del Táchira. Source ASHRAE climatic design conditions station.

Clear Sky Solar Irradiance	taub	**0.443**	**0.510**	**0.671**	**0.641**	**0.501**	**0.484**	**0.485**	**0.492**	**0.483**	**0.484**	**0.471**	**0.449**
	taud	**2.227**	**1.981**	**1.601**	**1.654**	**2.021**	**2.080**	**2.085**	**2.071**	**2.114**	**2.095**	**2.124**	**2.199**
	Ebn,noon	**871**	**822**	**701**	**713**	**802**	**805**	**809**	**817**	**834**	**834**	**838**	**857**
	Edn,noon	**143**	**187**	**276**	**259**	**175**	**162**	**163**	**168**	**163**	**165**	**157**	**145**

CDDn	Cooling degree-days base n°F, °F-day	Lat	Latitude, °	Period	Years used to calculate the design conditions
CDHn	Cooling degree-hours base n°F, °F-hour	Long	Longitude, °	Sd	Standard deviation of daily average temperature, °F
DB	Dry bulb temperature, °F	MCDB	Mean coincident dry bulb temperature, °F	StdP	Standard pressure at station elevation, psi
DP	Dew point temperature, °F	MCDBR	Mean coincident dry bulb temp. range, °F	taub	Clear sky optical depth for beam irradiance
Ebn,noon	Clear sky beam normal and diffuse horizontal irradiances at solar noon, Btu/h/ft2	MCDP	Mean coincident dew point temperature, °F	taud	Clear sky optical depth for diffuse irradiance
Edh,noon		MCWB	Mean coincident wet bulb temperature, °F	Tavg	Average temperature, °F
Elev	Elevation, ft	MCWBR	Mean coincident wet bulb temp. range, °F	Time Zone	Hours ahead or behind UTC
Enth	Enthalpy, Btu/lb	MCWS	Mean coincident wind speed, mph	WB	Wet bulb temperature, °F
HDDn	Heating degree-days base n°F, °F-day	MDBR	Mean dry bulb temp. range, °F	Hours 8/4 & 55/69	Number of hours between 8 a.m. and 4 p.m with DB between 55 and 69 °F
PCWD	Prevailing coincident wind direction, °,0 = North, 90 = East	WS	Wind speed, mph	HR	Humidity ratio, grains of moisture per lb of dry air

Appendix D

Figure D.1 Psychrometric chart with Dry bulb temperature and Humidity Ratio g/kg analysis for 2018

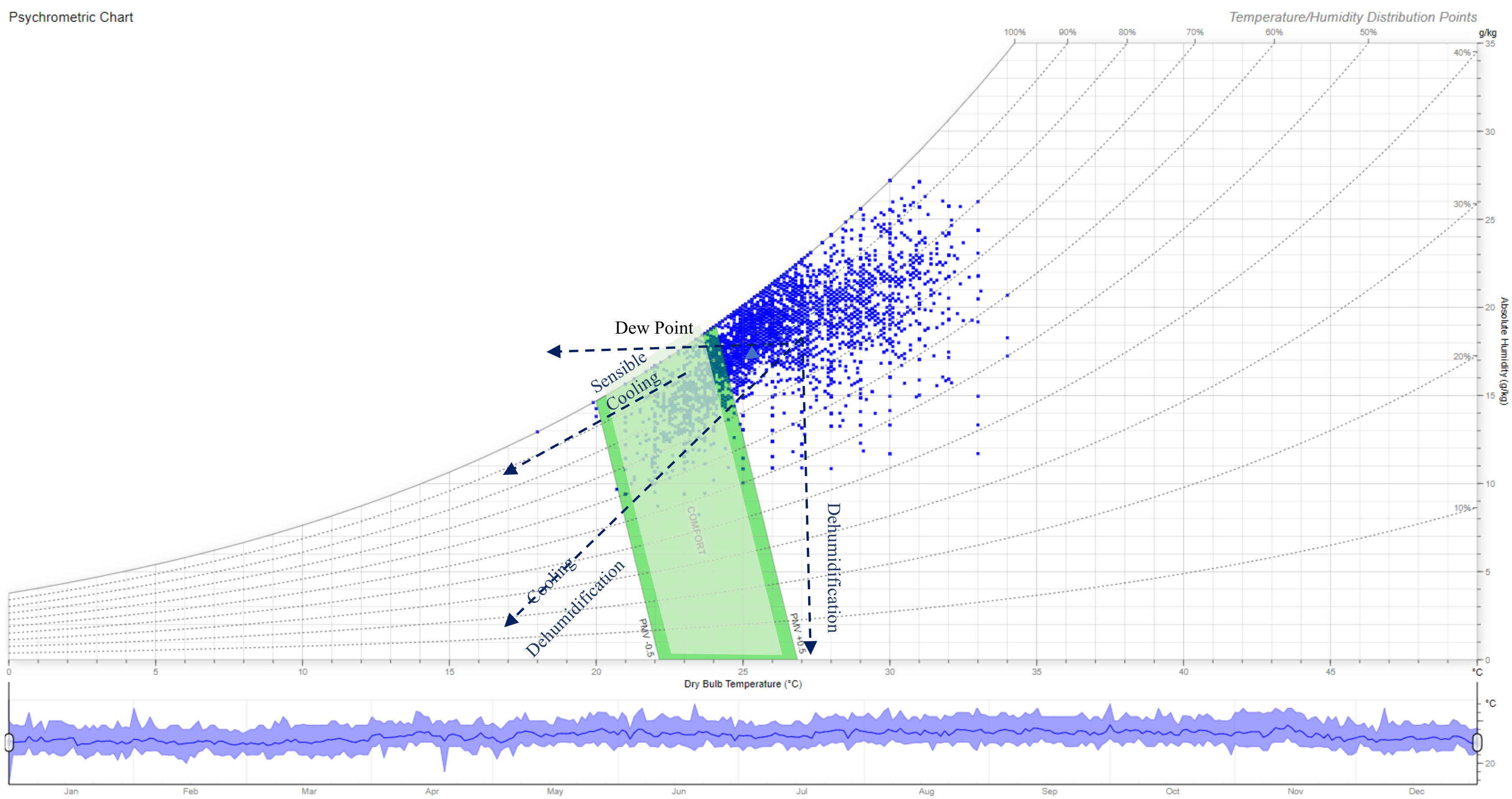


Figure D.2 Psychrometric chart with Dry bulb temperature and Humidity Ratio g/kg analysis for November 2018

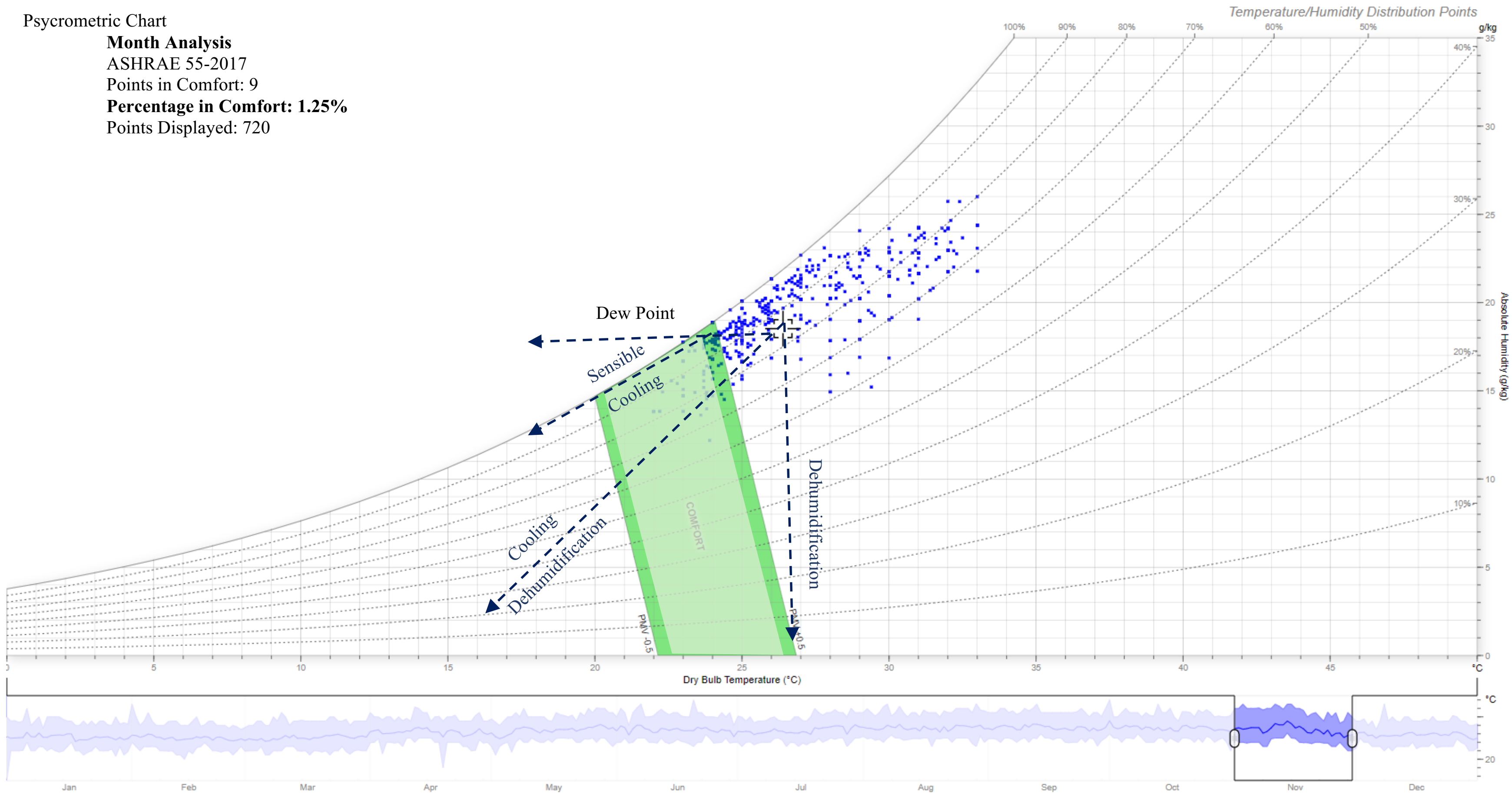


Figure D.3 Psychrometric chart with Dry bulb temperature and Humidity Ratio g/kg analysis for November 13th 2018