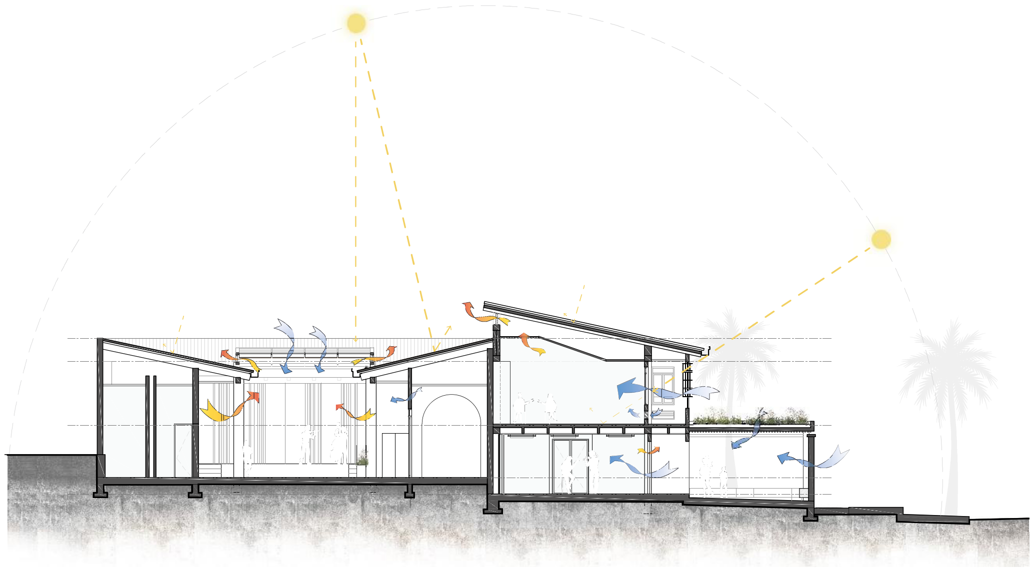
Passive design for hot - humid climate in the Tropics

"Casa de la música"
Building renovation in Villavicencio, Colombia



Politecnico di Torino

Architecture Department
Master´s Degree Architecture for Sustainable Design
AA 2021/2022

Passive design for hot - humid climate in the Tropics

“Casa de la música”
Building renovation in Villavicencio, Colombia

Tutor
Fabio Favoino
Co-Tutor
Roberto Giordano

Candidate
Catalina Godoy Mesa

July, 2022

CONTENT

ABSTRACT (ENG)

A building unaware of local climatic conditions and environmental factors not only leads to permanent physical deterioration but also generates discomfort affecting the health and social relations of those who inhabit it. Understanding the climate and environmental conditions of a place is the most important step to design and renovate architectural spaces with environmental and social responsibility, especially in hot-humid climate such as in the Tropics.
This work aims to provide the criteria for the passive design of buildings, whether new or existing, in correlation with its surrounding environment, particularly characterized by this climate. Also, aims to expose a method of indoor environmental assessment of an existing building to identify the impact of the environmental conditions on its infrastructure and the health of its users, and thus to determine appropriate strategies for improvement through passive design, and reducing energy consumption while contributing to the improvement of the environment. Providing balance between thermal, visual and acoustic comfort is a key to the development of sustainable building, and becomes the focus of study of the chosen existing building,: the "Casa de la música, Batuta Meta", a house dedicated to music education in Villavicencio, Colombia.

RESUMEN (ESP)

Un edificio poco consciente de las condiciones climáticas y factores ambientales locales no solo conduce a su permanente deterioro físico, sino también genera insatisfacción afectando la salud y las relaciones sociales de quienes lo habitan. Entender el clima y las condiciones ambientales de un lugar es el primer paso para diseñar y renovar espacios arquitectónicos con responsabilidad ambiental y social, especialmente en clima calido - humedo en el Tropico.
El objetivo de este trabajo es proporcionar los criterios del diseño pasivo de edificaciones, ya sean nuevas o existentes, en correlación con el medio ambiente local, particularmente caracterizado por este clima. Así como también exponer un método de evaluación ambiental de interiores de una edificación existente con este clima, que permita identificar el impacto de las condiciones ambientales sobre su infraestructura y la salud de sus usuarios, y así poder determinar las estrategias adecuadas de mejoramiento por medio del diseño pasivo, disminuyendo el consumo energético y a la vez contribuyendo al mejoramiento del medio ambiente. Brindar un balance entre confort interno térmico, visual y acústico es clave para el desarrollo de edificaciones sostenibles, y se convierte en el centro de estudio del edificio existente escogido, la "Casa de la música, Batuta Meta", una casa dedicada a la enseñanza musical en Villavicencio, Colombia.

KEYWORDS

- Hot-Humid Climate - Tropical Architecture - Passive Design - Thermal comfort - Adaptive comfort - Daylighting - Natural Ventilation - Acoustic Comfort

PALABRAS CLAVE

- Clima cálido-húmedo - Arquitectura tropical - Diseño pasivo - Confort térmico - Confort adaptativo - Iluminación natural - Ventilación natural - Confort acústico

I would like to dedicate this work and thank all those people who have been important for the development of this thesis and have been part of my experience in this master's program

- First of all, I dedicate this work to my father, who always believed in me and invited me to dream without limits, encouraging me to continue studying in unimaginable places
- To my family, my mother and siblings, and to Diego, I thank you for your essential support and love from distance during all these years
- To my Professors, Fabio Favoino and Roberto Giordano for their guidance and teachings to achieve this work in a professional manner with great results
- To "Casa de la mùsica, Batuta Meta" institution, all managers, students, and former classmates musicians who contributed to and inspired the development of this work.
- To my girlfriends Lina and Luisa, with whom I felt at home since the first day we met and lived together in Turin
- To my friends and colleagues in Turin from "Famiglia di Torino", that has become my second family during these years. Special thanks to Melis and Leo, with whom I have learned and enjoyed every project working together
- To my Colombian friends and colleagues spread all over the world, Laura, Jero, and Nata, for all the continuous support and advice from a distance

ACKNOWLEGDEMENTS

1.

INTRODUCTION

Generating comfort in extreme climates is one of the most significant challenges for architecture in cities located in the tropical zone, particularly in hot-humid climates. These are characterized by environmental conditions with high temperatures and relative humidity, leading to thermal stress, low productivity, health problems of the inhabitants , as well as the damaged structure of the building. In addition to the climate conditions, the inhabitants of these urban areas face social problems related to high levels of poverty and inequality caused, by weak urban development and rapid urban population growth. In many cases, these aspects of the territory have led to unplanned construction solutions resulting from a conflict between traditional and modern concepts[1].
Seeking harmony between architectural design and local environmental conditions, as well as social and cultural conditions, are vital to creating more comfortable spaces and reducing their environmental impact.

Victor Olgyay in his book "Design with climate", proposes 4 steps for building design to create a climate-balanced building. According to him, aesthetics should be the last goal of design, since understanding the main elements of climate and its interaction with the functioning of the human body is key to the success of buildings. "climate data evaluation, biological evaluation, technological solutions and finally, architectural expressions"[2].
Climate parameters such as temperature, humidity, wind and precipitation integrated with elements of the microclimate (local climate), proposed by Norbert Lechner, such as the shape of land, elevation above sea level, among others, give a place a character that must be evaluated in isolation to respond with architectural solutions that adapt[3].
Passive design seeks to respond to these environmental conditions by using natural strategies to achieve comfort. Ken Yeang, an architect

1 Bay, Jooh-Hwa ., On Boon-Lay g, 2006. Tropical sustainable architecture, Social an environmental dimensions.
2 Olgyay, V., Olgyay, A., Lyndon, D., Olgyay, V. W., Reynolds, J., & Yeang, K. 2015. Design with climate: Bioclimatic approach to architectural regionalism
3 Lechner, Norbert.2008. Heating, Cooling, Lighting: Design Methods for Architects. Third edition; p. 75

specializing in Eco-design calls this approach "Passive mode". According to him, "Passive mode requires an understanding of the climatic conditions of the locality, then designing not just to synchronize the built form`s design with the local meteorological conditions, but to optimize the ambient energy of the locality into a building design with improved internal comfort conditions without the use of any electro-mechanical systems"[4].The use of passive methods to achieve comfort, as well as reduce the use of mechanical systems such as air-conditioned is one of the pillars of tropical architecture. However, according to Tay Kheng Soon , "Tropical architecture as a discipline died because the architectural style seemed outdated and because the design of tropical buildings as individual buildings did not solve the problem of noise, dust, and heat, which are created by the city itself and which no particular building can aspire to solve other than with air conditioning"5. Moreover, it is that in these places often resort to the use of mechanical ventilation by pure style or fashion, where costs are no longer a problem and completely ignoring the local climatic conditions [6], which could be naturally addressed from the architecture design seeking the proper use of environmental resources.

Adapting to climatic conditions is one of the main characteristics of studying the internal comfort of buildings in the Tropics. According to the theory introduced by Michael Humphreys (1997), people tend to adapt because they have a range of acceptance of the environment in which they find themselves. "If change occurs such as to produce discomfort, people react in ways which tend to restore comfort" [7]. However, considering that in hot-humid climates they are strong and constant throughout the year, they can become intolerable for some of their occupants. That is why this work focuses on the evaluation of strategies for the thermal, visual and acoustic comfort, necessary for the responsible development of buildings. Although the application of the principles of tropical architecture for hot-humid climates presented in this work is open to any type of new or existing building, the house of music in Villavicencio, Colombia, has been chosen as a case study. A space for musical development is important not only for the city but also for the whole region. The objective is to determine the current design problems derived from the environmental conditions to propose an improvement of the internal comfort using passive design strategies. An educational building that is conscious and adapted to its microclimate is a great place for learning, that motivates students and teachers, lowers operating costs, and reduces environmental impact.

4 Yeang, Ken. Green design in the hot humid Tropical zone. Bay, Jooh-Hwa ., On Boon-Lay g, 2006. Tropical sustainable architecture, Social an environmental dimensions. P.49

5 Tay, Kheng Soon.Mega-cities in the tropics.Singapore 1989 : Institute of Southeast Asian Studies

6 Bay, Jooh-Hwa ., On Boon-Lay g, 2006. Tropical sustainable architecture, Social an environmental dimensions.p. 3

7 Humphreys, M ,1997. An adaptive approach to thermal comfort criteria, in clements.Croome.Naturally Ventilaed buildings for the senses.

1.1 PROBLEM

Sensation of thermal and visual discomfort, as well as damage to the infrastructure in most of the existing buildings and urban spaces located in the Tropics, specially characterized by an extreme hot and humid climate

- Could the comfort of a new or existing building in the Tropics, with hot-humid climate conditions, be performed mainly by passive sustainable design strategies?
- Is it possible to create an equilibrium between a thermal, visual and acoustic comfort in a building located in the Tropics with hot-humid climate conditions?

1.2 OBJECTIVES

GENERAL OBJECTIVE

To define the appropriate strategies for the design and renovation of buildings in cities with a hot-humid climate such as Villavicencio in Colombia, through an environmental analysis of the "Casa de la Musica" as a case study.

SPECIFIC OBJECTIVES

- To investigate the main characteristics of the hot-humid climate and its relationship with the built space and its users
- To analyze the different components of the microclimate, such as temperature, precipitation, relative humidity, winds, among others, at different scales. From the macro-scale, in the national territory, to the micro-scale, the context of the case study
- To investigate passive design strategies and their applications through international and national case studies with tropical climate
- To perform, through different software and manual calculations, a quantitative environmental evaluation of an existing house from 5 categories: Building design, thermal comfort, daylighting, natural ventilation and acoustic comfort.
- To determine through observation, consultation with users and calculations, the problems of the case study building with respect to its microclimate
- To consult the users of the case study building through interviews and surveys about their perception of the comfort of the spaces and the importance of the building for them and the region.
- To propose strategies for improvement through the development of a renovation proposal that adapts to the current situation without generating such a drastic impact and could be profitable.
- To carry out a comparative analysis of the current situation of the building against the proposal, to determine the effectiveness of the defined strategies
- To define low-impact technology and suitable materials that allow increasing the thermal comfort while improving acoustic performance in the building through minimal energy consumption and low maintenance costs

1.3 JUSTIFICATION

Long before I became an architect, I understood how important it is to design buildings and any urban space according to the microclimate, bringing comfort and shelter to societies while taking care of natural resources. In places with constant extreme climate conditions, especially in the Tropics with hot and humid characteristics, the designing process becomes a challenge to provide comfort. However, most of the existing buildings and public spaces in the cities with these climate conditions do not respond with an accurate design causing discomfort

The house of music, "Casa de la música, Batuta Meta" is a symbol of culture and integration for the department of Meta, which welcomes many children in situations of social vulnerability, offering them new opportunities through music. This house is a cultural landmark in the region and also for me. This has been like a second home for learning and loving music and Arts, which I was a part of for almost seven years through playing the violin. Being part of the music programs in that house positively transformed my life, not only in terms of playing an instrument, but also being more responsible and structured in my academic skills and improve social skills, especially developed in a group.

The musical, cultural and sporting educational institutions in Colombia have limited resources, and are often built in a traditional and gradual way, using temporary and non-climate adapted solutions. However, based on my experience growing up in such spaces, the thermal stresses certainly affected academic development. It is clear the need to understand how these spaces were developed and the current conditions of these types of buildings. "Casa de la Musica", represent a similar situation in many educational spaces. Therefore, it has been chosen to be evaluated for improvement through successful sustainable design solutions.

Fig 1.0: Anniversary concert 2012
Source: Batuta Meta

1.4 METHODOLOGY

The study is developed in different phases and by some research methods based on a qualitative and quantitative approaches. The organization of this study follows some general steps:

1. Understanding the climate conditions of the case study from a territorial scale to a building context scale (**Chapter 2**)

2. Doing research about the main concepts of passive design strategies specifically for Hot-Humid climate zones and its application in some project references located in the Tropics. As well as doing research of the theory of 4 categories developed in this document: Thermal comfort, Daylighting, Natural ventilation and Acoustic comfort (**Chapter 3**)

3. Analyzing the current design and environmental conditions of a building selected as a case study through a qualitative and quantitative method (**Chapter 4**)

4. Understanding the weaknesses and opportunities of the building, as well as its functional needs from a participatory study, through interviews and surveys to the local users (**Chapter 5**)

5. Developing a project proposal applying the concepts of passive strategies based on the conclusions of the analysis (**Chapter 6**)

6. Performing simulations of one room of the proposal from 5 categories: Building design, Thermal comfort, Daylighting, Natural ventilation and Acoustic comfort (**Chapter 7**)

7. Comparing the performance between the current and building proposal

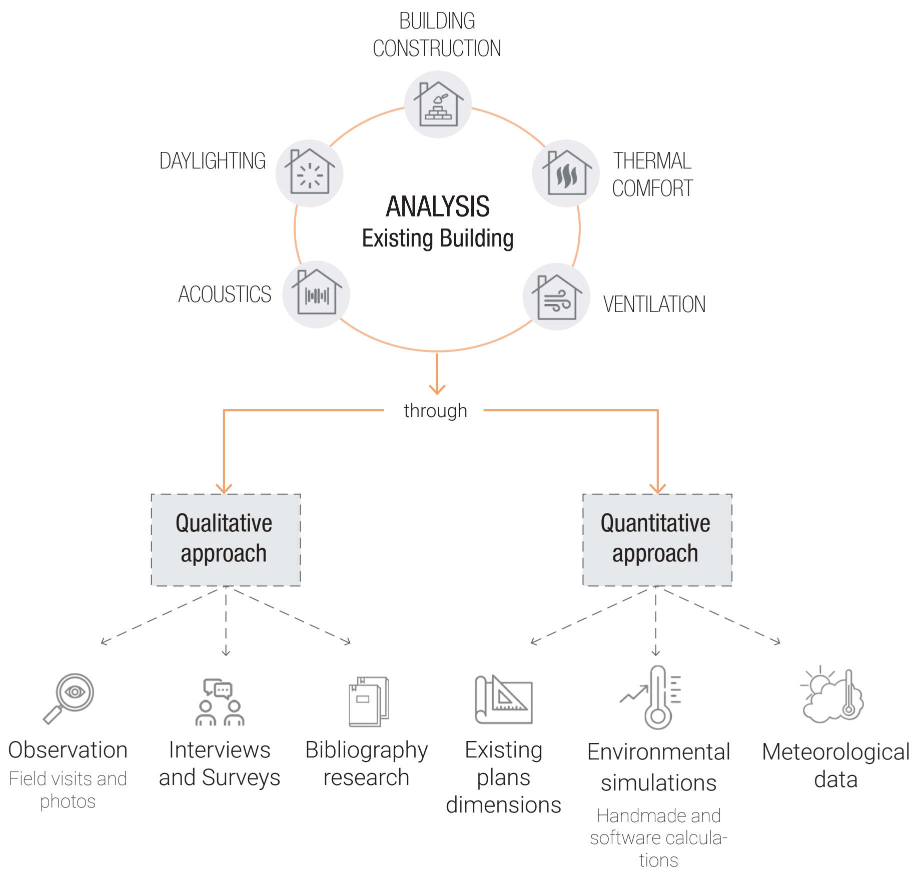


Fig 1.1: Methodology diagram
Source: Author`s elaboration

to conclude if exists an improvement with the new strategies (Chapter 8).

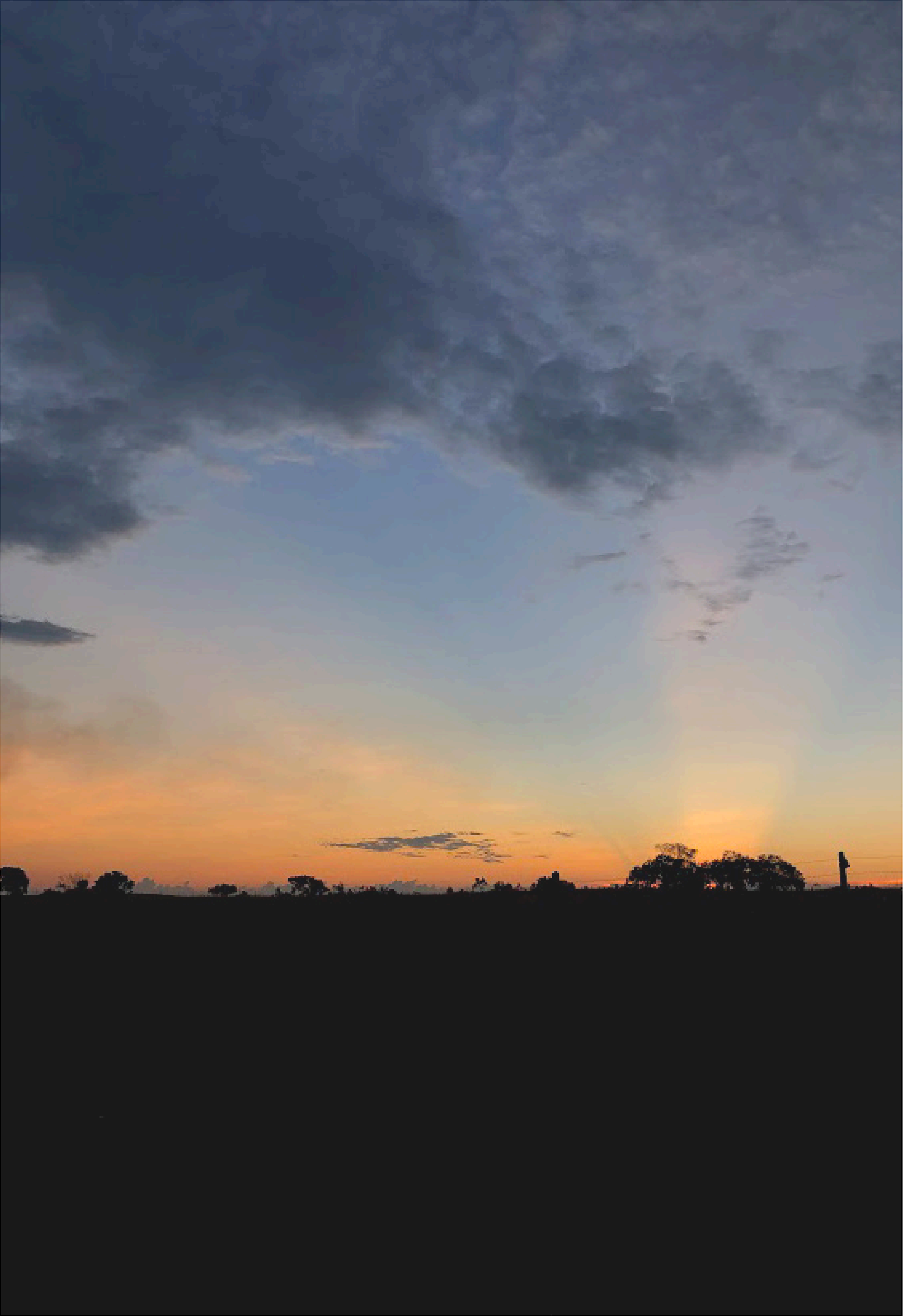
From a qualitative approach, one of the main methods used to do an analysis is by observation. Through field visits and photographies of the house and its context it is possible to know the design composition of the house, its construction materials and to discover the possible problems of the building from a physical point of view.
Additionally, through some field interviews and digital surveys to the current users and some former users from the past generations, it is possible to understand not also their opinion about the infrastructure and their needs as users, but also their desires and expectations of a music center.

From a quantitative method, the analysis starts from the study of basic existing plans and the data of the microclimate provided by meteorologic sources of the building location. Then, through simulations by hand calculations and the use of different softwares it is possible to do a deep analysis of the current conditions from different approaches.
This study is concentrated in four main systems: Thermal comfort, natural lighting, natural ventilation and acoustic. These would be analyzed for the current building, and then, for the proposal as well.

2. CONTEXT ANALYSIS

To understand the main characteristics of the hot-humid climate in the Tropics it has been taking into consideration the analysis of a city called Villavicencio, in Colombia for the development of this research work.
The following chapter aimed to carry out a general analysis of the environmental and physical conditions at different scales, as well as understand the state of development of projects within the framework of sustainable policies.

The chapter starts with the analysis of the climate conditions from a territorial scale, then to the city scale introducing also the main historic, economic, and social characteristics of it, until finally do a microclimate analysis of the selected building context area. Some of the climate parameters evaluated in all scales include solar radiation, dry bulb temperature, relative humidity, wind speed, and rainfall precipitation, among others.
In the end, there is an analysis of the local main constructive techniques from a territorial to the city scale, and an overview of the current situation of the country in terms of the implementation of sustainable certification in the construction area.



2.0 LOCATION CONTEXT

The Tropics is the region in the middle of the Earth planet located in between the Tropic of Cancer and the Tropic of Capricorn. It represents 36% of its landmass with countries from parts of South East Asia, Africa, Australia, and both, North America and South America[8].

Colombia is located in the equatorial zone (Latitude 0) in the Tropics. Therefore its climatic conditions as temperature, relative humidity, precipitation, and others, remain constant during the year without great changes. The country is divided into 5 regions, each one characterized by different climates due to their elevation above sea level, their topography, among other factors, as well as distinguished by diverse cultural traditions.

The case study of this work is part of the Orinoquia, one of the largest regions, and it is located in the city of Villavicencio, the capital of the Meta Department. The proximity to the capital of the country, Bogotà, as well as its plains landscapes and cultural expressions, among others, turns Villavicencio into an important economic and touristic center of the region.

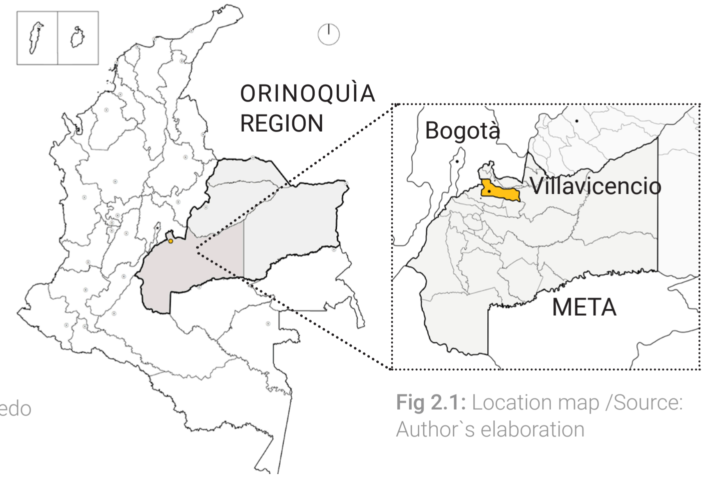


Fig 2.0: Orinoquia Plains Lansdcape / Source: Salcedo Juliana Photo

Fig 2.1: Location map /Source: Author`s elaboration

8 The Tropics. https://education.nationalgeographic.org/resource/tropics

2.1 CLIMATE CHARACTERISTICS IN COLOMBIA

According to the Koppen-Geiger climate classification map (1980-2010)[9], based on temperature and precipitation data and divided into 5 climate zones, Colombia is classified in Group A as Tropical.

The territories located in the equatorial zone have mean temperatures over 18 degrees. Villavicencio has a tropical monsoon which means warm temperature and more precipitation periods than dry in the year.

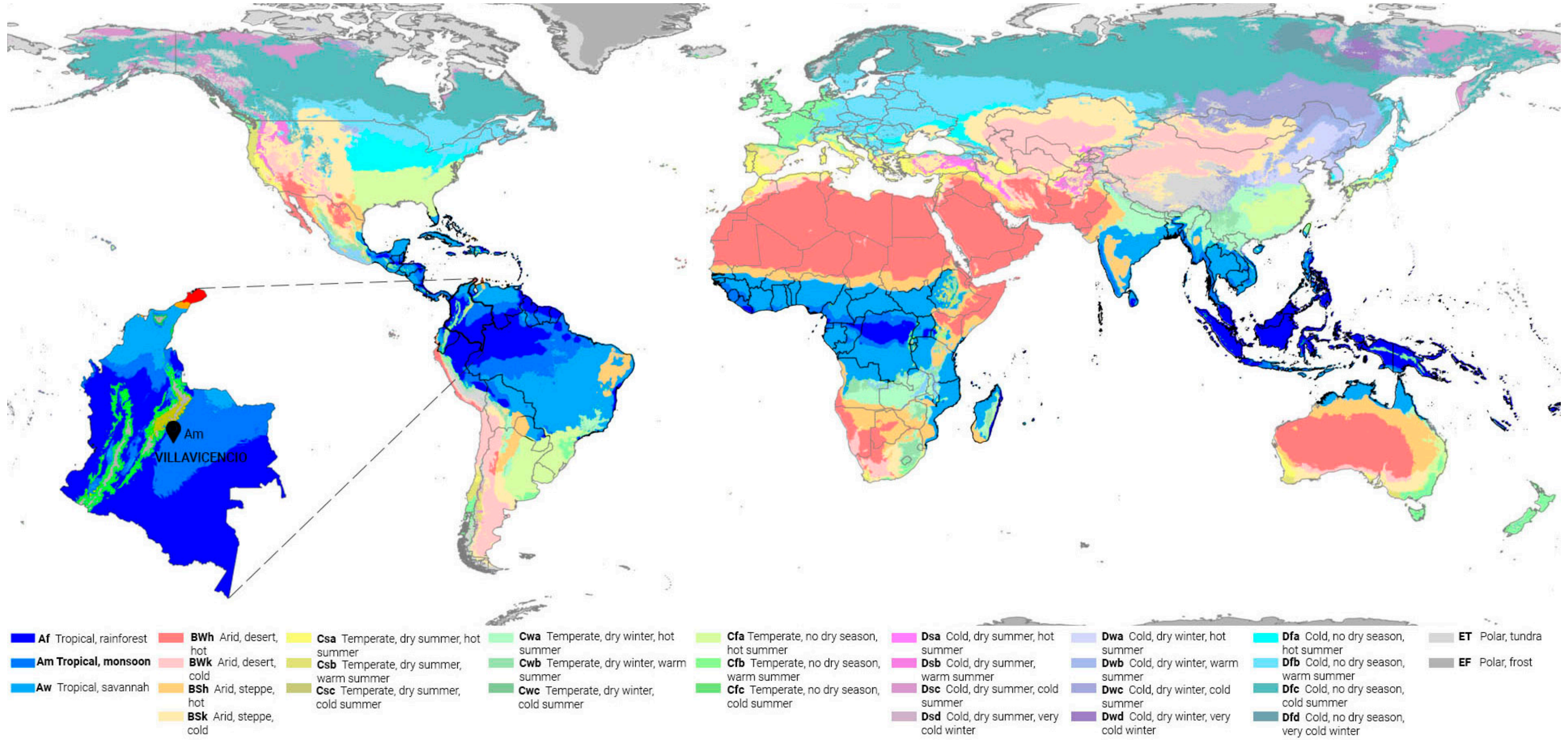


Fig 2.2:Koppen Geiger classification. Source: Beck, H. E. et al. Present and future Köppen-Geiger climate classification maps. Author`s edition

9 World maps of köppen-geiger climate classification. http://koeppen-geiger.vu-wien.ac.at/present.htm

According to the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM)[10], apart from the Koppen classification, the climate in the country is based on 3 classification systems: the first one is Caldas which is based on thermal factors and the relation between temperature and the elevation over sea level. The second one is Lang based on Humidity taking into account precipitation and temperature. The last one is Thorthwaite which is based also on the humidity factor involving the relation between excess water and the deficit of it.
According to the Caldas-Lang classification, there are 25 types of climate. The warm climate predominates in Colombia in its different levels of humidity with 67.4% of the territory, while over the Andes Mountain range the climate is cold and very cold.

The Department of Meta is part of the Orinoquia region that has similar climate characteristics. It is mainly warm humid with 70%, followed by warm semi-humid with 17.8%.

CALDAS-LANG CLASSIFICATION

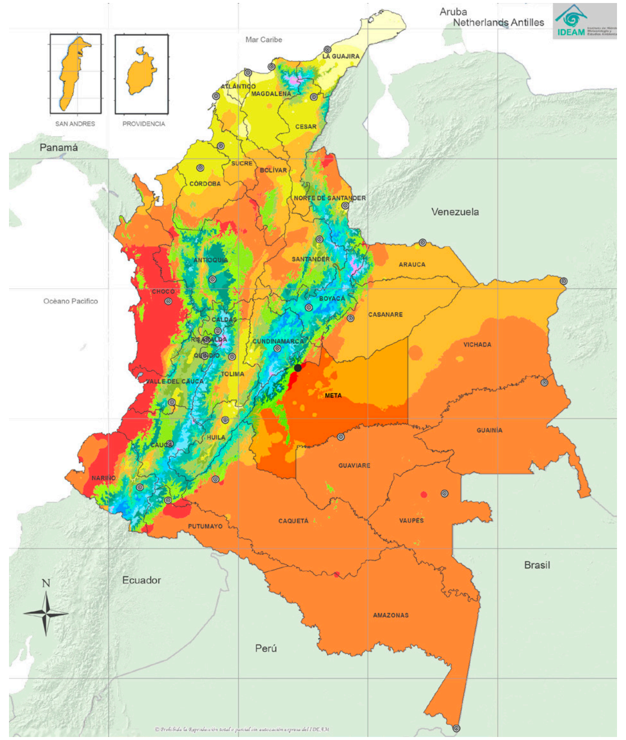


Fig 2.3: Caldas-Lang classification map/ Source: Atlas-IDEAM Colombia, Author´s edition

- Warm desertic
- Warm Dry
- Warm Semi-Dry
- Warm Semi-Humid
- Warm Humid
- Warm Super-Humid
- Temperate Desertic
- Temperate Dry
- Temperate Semi-Dry
- Temperate Semi-Humid
- Temperate Humid
- Temperate Super-Humid
- Cold Dry
- Cold Semi-Dry
- Cold Semi-Humid
- Cold Humid
- Cold Super-Humid
- Very Cold Semi-Dry
- Very Cold Semi-Humid
- Very Cold Humid
- Very Cold Super-Humid
- Extremely Cold Super-Humid
- Snow Super-Humid

SOLAR RADIATION

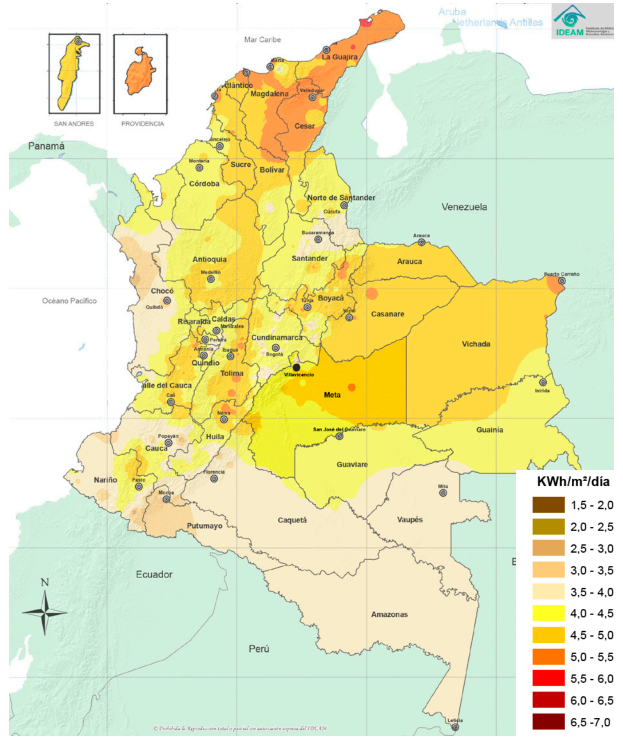


Fig 2.4: Solar radiation map /Source: Atlas-IDEAM Colombia, Author´s edition

The center and the northeast of Colombia have a higher amount of solar radiation than the southwest of the country.
The Orinoquia region ranges between 4.0 and 5.0 kWh/m2 per day.

RELATIVE HUMIDITY

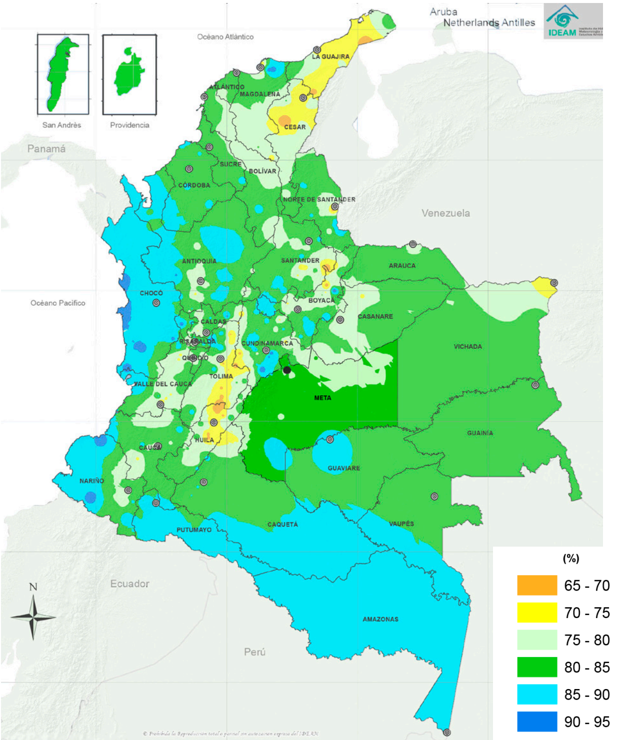


Fig 2.5: Relative humidity map/Source: Atlas-IDEAM Colombia, Author´s edition

Most of the territorial area presents a high percentage of humidity the whole year ranging from 75 to 90 %.
The department of Meta is one of those that has a high relative humidity with up to 85% mainly, with some areas below it like Villavicencio.

RAINFALL PRECIPITATION

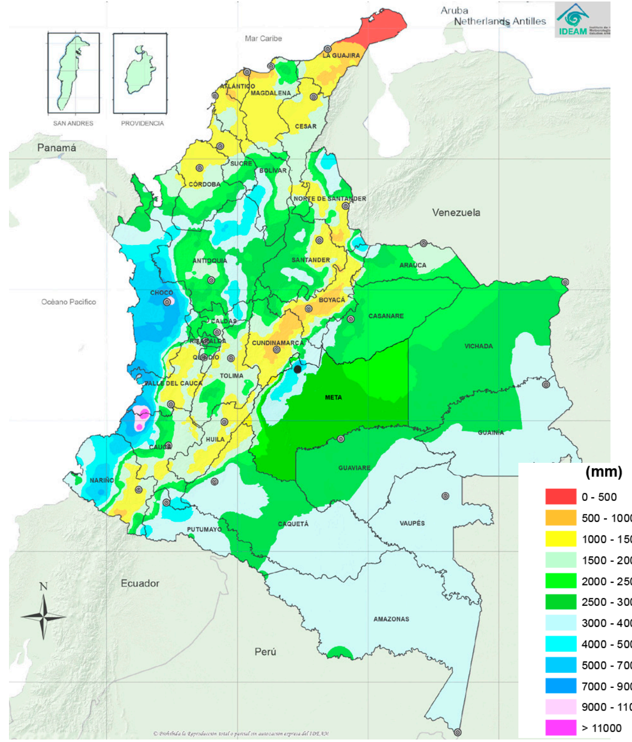


Fig 2.6: Rainfall precipitation map/ Source: Atlas-IDEAM Colombia, Author´s edition

The mean precipitation annual In the country is the highest in the Pacific region and the Amazonas with ranges from 3000 to 9000 mm.
The Orinoquìa region presents medium precipitation of 2000 to 3000 mm, except in the city of Villavicencio with an average of 4000 to 5000 mm

WIND SPEED

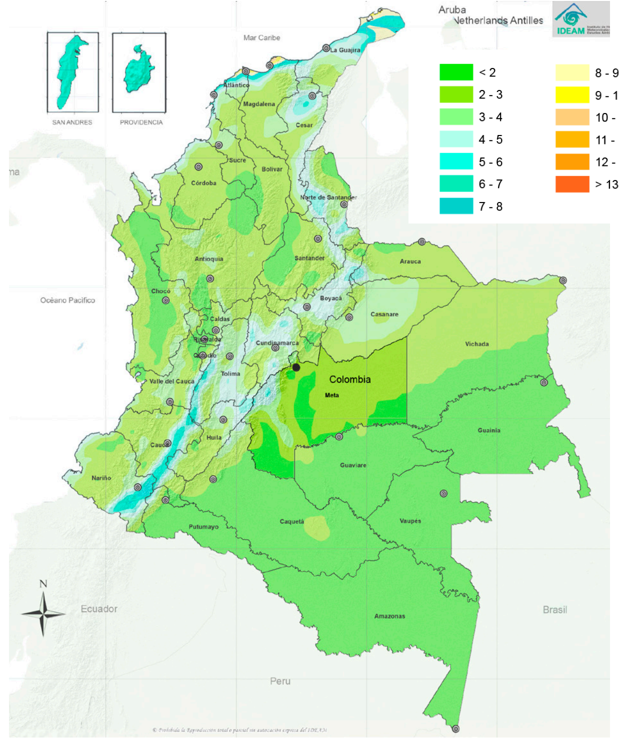


Fig 2.7: Windspeed map/ Source: Atlas-IDEAM Colombia, Author´s edition

The mean annual wind speed is similar in most of the national territory with a value from 0 to 4 m/s. The Andes mountains are characterized by a higher speed up to 6 m/s.
The Department of Meta has a speed range of 2 to 3 m/s

10 Interactive atlas IDEAM Colombia. http://atlas.ideam.gov.co/visorAtlasClimatologico.html

2.2 CITY CONTEXT

Fig 2.8: Villavicencio From the mountains to the Plains
Source: Salcedo Lina, 2020

VILLAVICENCIO
Meta

Villavicencio is the capital of the department of Meta, which is part of the Orinoquìa region, an extensive area between Colombia and Venezuela characterized by its landscape with plains and its ecosystem with endemic species. In Colombia, there are 4 departments (states) that are part of the llanos Orientales region, as it is also called: Meta, Vichada, Arauca, and Casanare

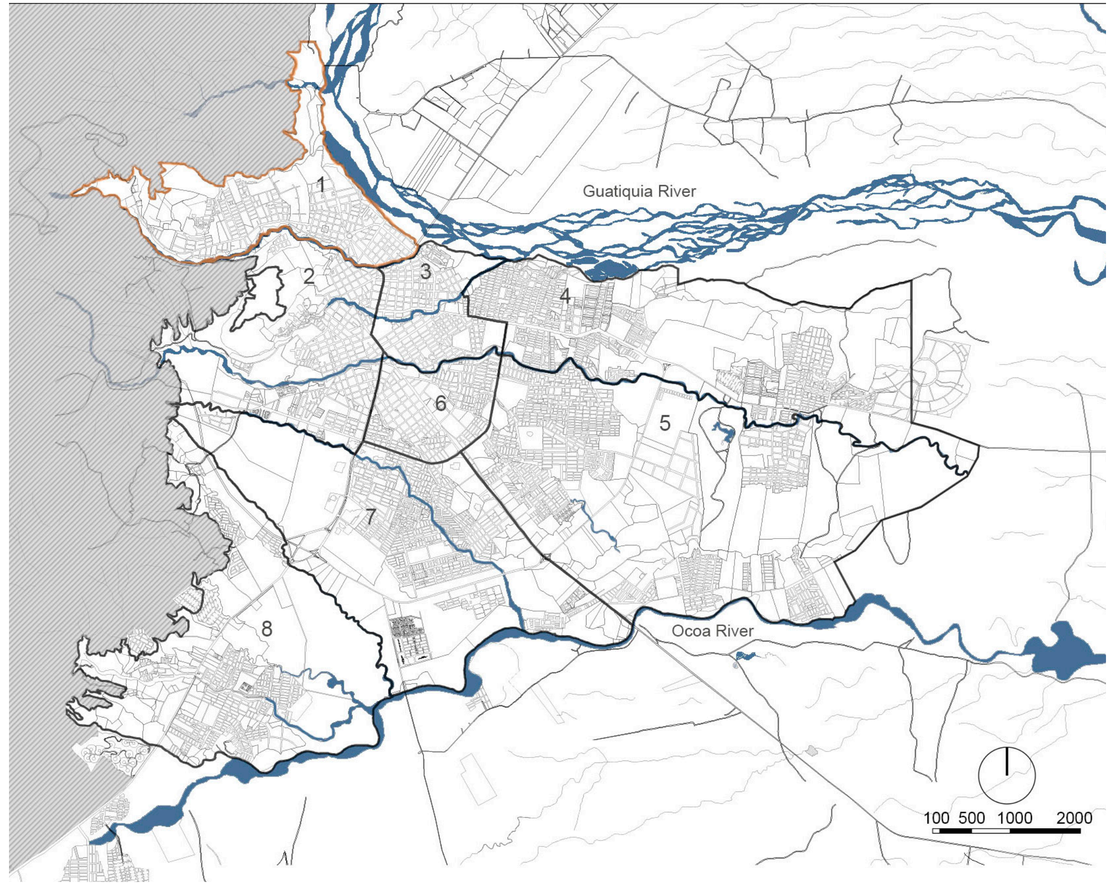


Fig 2.9: Villavicencio City Plan
Source: Author´s elaboration

CASE STUDY SITE:
Comuna 1

Inhabitants	452.472	Latitude	4.151382
Surface area	1.328 km²	Longitud	-73.637688
Elevation	467 m.a.s.l	Fundation year	1840

The city is located in the "Piedemonte llanero", which is the denomination of the limit area between the East Andes Mountain and the plains of the Orinoquìa region. The northeast limits with the Guatiquia river and in the south the Ocoa River. The city is crossed by numerous small streams and is divided into 8 zones called Comunas[11]. Comuna 1 is part of the study of this research.

According to Salamanca Uribe[12] the foundation of the city was on April 6, 1840, when it was called firstly Gramalote. Before the colonial period, the area was inhabited by indigenous people "Guayupes" from the region, until the expedition of the Spanish Pedro de Limpias in 1537 and then, the Jesuits.

Around 1740, the first ranch constructed by the Jesuits was located in an extended area called Apiay[13]. Stells the Jesuits worked with the indigenous in farming and cattle work while they taught them the Spanish language and new construction techniques. Then, in 1840, some merchants and cattle farmers Esteban Aguirre, Mateo Fernández, Libardo Hernández, Francisco Ruiz, Francisco Ardila y Silvestre Velásquez, who built some inns next to the river Gramalote while transporting cattle in the region.
The first settlement was planned with an orthogonal urban grid with the main place in between two rivers. Around it, there were built the cathedral, parish house, a school, the jail, and the municipality house Ten years later, in 1850, the settlement changed its name to Villavicencio, in honor of the Quito patriot Antonio Villavicencio. The following figure shows the historical

11 https://www.villavicencio.gov.co/
12 Salamanca Uribe, J, 2009. Villavicencio, la ciudad de las dos caras. Revista Credencial Historia, (231)
13 Espinel Riveros, N. 1989. Villavicencio, dos siglos de historia comunera. 1740-1940. Gráficas Juan XXIII.

growth in 100 years, from its beginnings until 1950 when arrived a lot of immigrants were displaced by the violence [14].

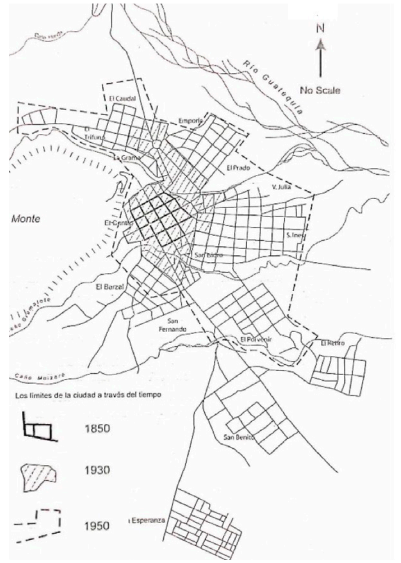


Fig 2.10:City Growth
Source: Rausch, J. M. (2011, pag 143)

Nowadays, due to the proximity to the capital of Colombia Bogotà (86 km), the city became an important economic and touristic pole since it allows the connection between the municipalities of the region and the center of the country. It has a strong economy around cattle ranching, agriculture, mining, and tourism.
The cultural expressions are characterized by typical music and dance called "Joropo" with native and special music instruments; the food with beef called " Mamona", rice, among others, and as well as the biodiversity and landscapes are part of the attractions of this region.

Fig 2.11: Villavicencio Central park
Source:Alcaldia Villavicencio @ villavoalcaldia[15]

Fig 2.12:Joropo Festival
Source: Salcedo Lina, 2019

Fig 2.13:Landscape of the plains
Source: Salcedo Juliana, 2020

14 Rausch, J. M. 2011. De pueblo de frontera a ciudad capital: la historia de Villavicencio, Colombia, desde 1842 (M. V. Mejía Duque, Trd.). Universidad de Los Llanos.

15 Alcaldìa Villavicencio, 6 April 2021, @villavoalcaldia. ¡Feliz Cumpleaños Villavicencio! La ciudad encantadora, de paisajes mágicos y gente pujante Twitter. https://twitter.com/villavoalcaldia/status/1379444256935448576/photo/1

2.3 MICROCLIMATE ANALYSIS OF THE CITY

To understand the microclimate of the city, it has been used mainly the tool Climate Consultant 6.0. All the data taken into consideration has been analyzed by graphs.

2.3.1TEMPERATURE

The city has a constant hot temperature during the whole year, with an average of 24°C degrees.
The warmest months with higher temperatures are January and February reaching an average of 32ºc degrees, while the coldest months are June and July with an average of 20ºc degrees.
The coldest months are in the comfort zone becoming quite pleasant, just in terms of temperature only

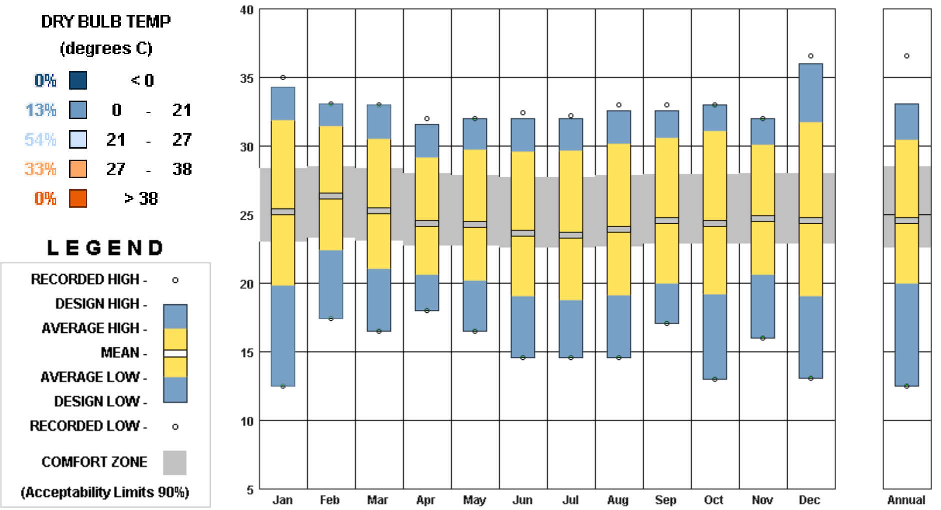


Fig 2.14: Dry bulb temperature
Source: Climate Consultant 6.0.Author´s edition

2.3.1 SOLAR RADIATION

The mean of total solar radiation, that is given by the Global horizontal is around 400 Wh/m2 hour on average per year in the city and the direct irradiance is approximately 250 Wh/m2. The annual total average is around 380 Wh/ m2.
The month with the highest solar radiation is September with around 420 Wh/m2 and the lowest is July with 300 Wh/m2 per day. The peak of the highest recorded value per hour of the Direct normal is around 950 Wh/m2 in October.

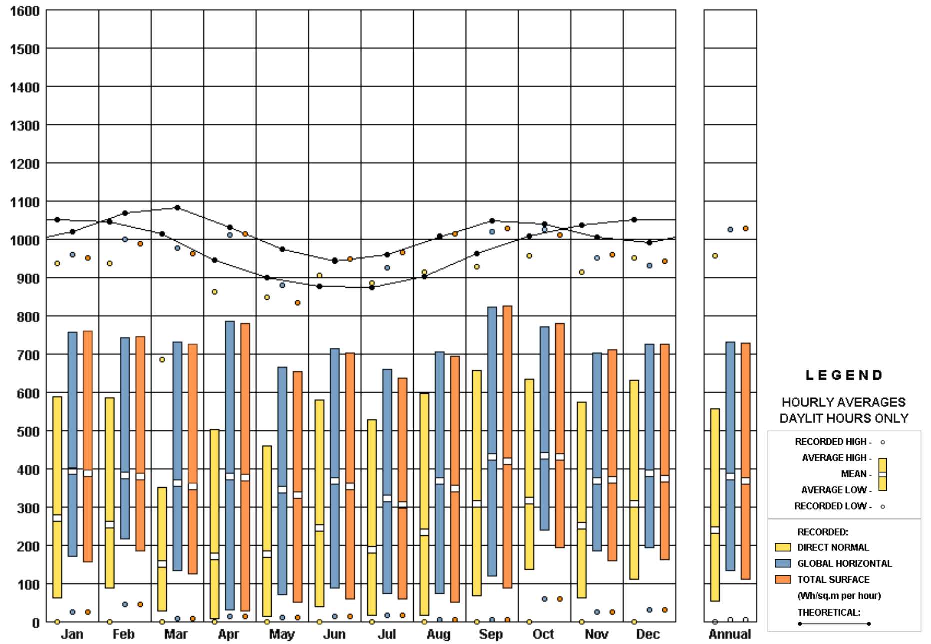


Fig 2.15: Solar radiation
Source: Climate Consultant 6.0.Author´s edition

2.3.3 SKY COVER

For more than half of the year, the sky is covered in Villavicencio. The cloudy months are April and May with almost 65% to 82% of the sky, while the less covered months are in summer January, and December with 40% to 45%.

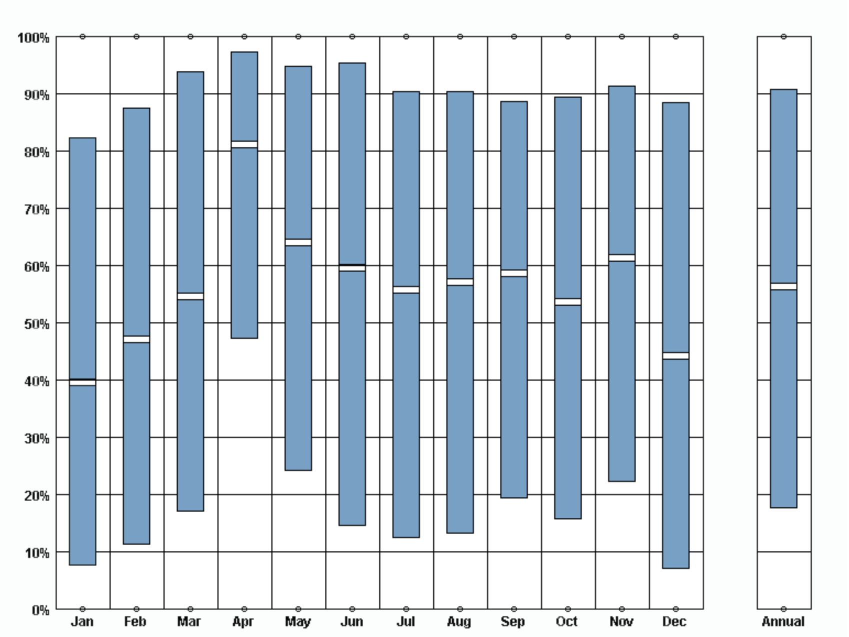


Fig 2.16: Sky cover
Source: Climate Consultant 6.0.Author`s edition

2.3.4 RELATIVE HUMIDITY

The annual relative humidity in the city is on average 80%, which is considerably high concerning other cities. The percentage decreases in summer when the temperatures are higher as in February, with relative humidity over 55% and less than 80%, while in the coldest month, July, the humidity is higher with a range of 70% to 100% in the day

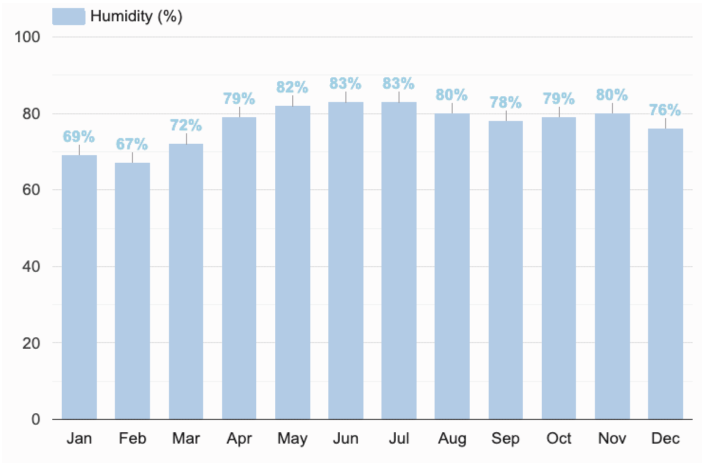


Fig 2.17: Relative humidity
Source: https://www.weather-atlas.com/es/colombia/villavicencio-clima-.Author`s edition

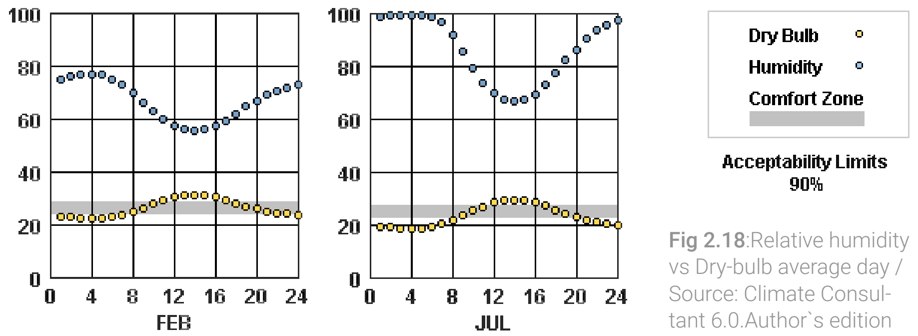


Fig 2.18:Relative humidity vs Dry-bulb average day / Source: Climate Consultant 6.0.Author`s edition

2.3.5 WIND

The annual average wind speed of the city is around 0.8 m/s, taken from 10 m height and based on historic analysis data from 2004 to 2018, with a maximum monthly average of 1.3 m/s in April. The recorded high average is in September with approximately 12.5 m/s.
However, according to current meteorologic platforms about the latest wind data analysis, the wind speed average of the city is 2 m/s[15].

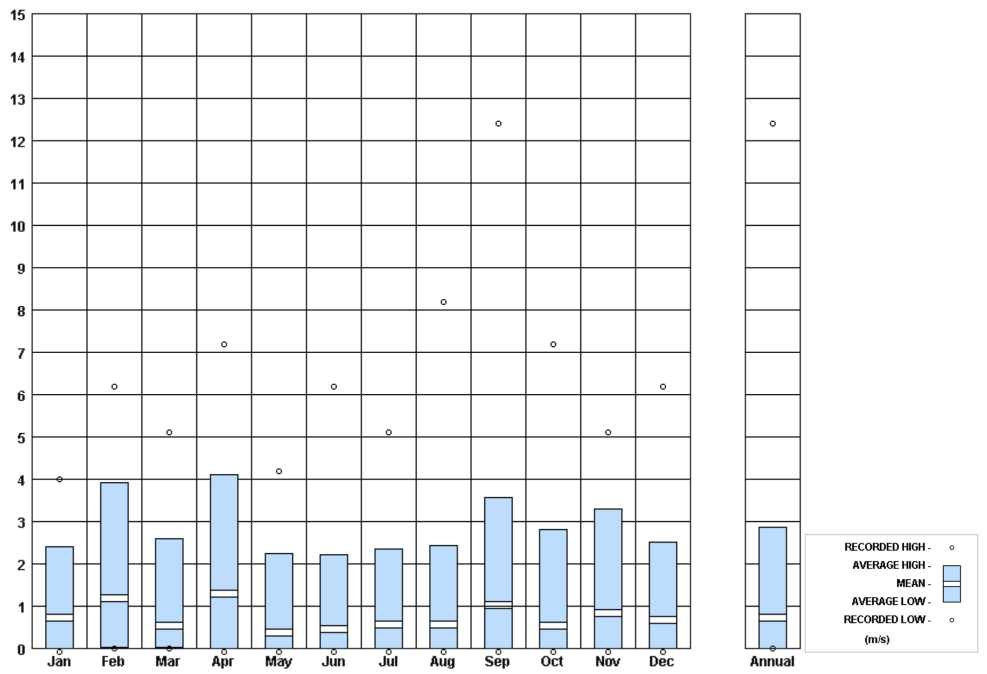


Fig 2.19: Wind speed
Source: Climate Consultant 6.0.Author`s edition

According to the wind rose of the city, the prevailing wind is coming from the East and South-East, with a monthly average speed (60%) between 1 to 4 m/s. The average wind direction is in a range of 90ºC to 105ºC degrees

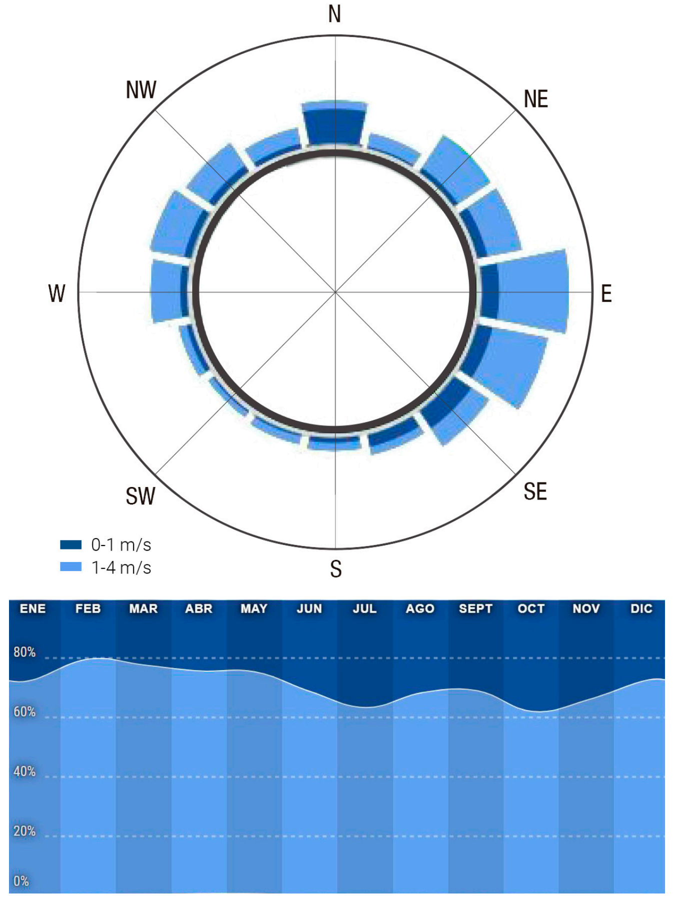


Fig 2.20: Wind direction
Source: Winfinder.Author`s edition

15 Windfinder-Wind map, wind forecast & weather reports: https://www.windfinder.com/windstatistics/villavicencio_la_vanguardia_aeropuerto

2.3.6 RAINFALL PRECIPITATION

The total annual rainfall precipitation is about 4000 to 5000 mm in the city. The month with higher precipitation is May with 627 mm while the lower is January with an amount of 64 mm.
The rainfall in the city is unimodal, which means there is just one large season peak of precipitation between April and November, followed by another short dry season.
In Villavicencio rains approximately 200- 250 days in a year, which means almost 71% of the time in the year

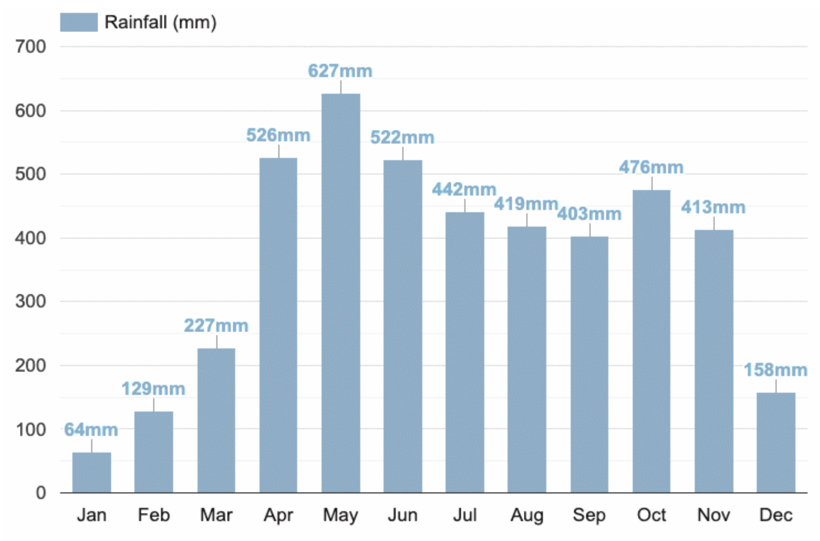


Fig 2.21: Rainfall precipitation/Source: https://www.weather-atlas.com/es/colombia/villavicencio-clima-.Author`s edition

2.3.7 COMFORT- PSYCHROMETRIC CHART

Based on the Adaptive Comfort Model of the ASHRAE Standard 55-2010, with a wider range of comfort zone between 22.6 ºC and 28.5 ºC, most of the year is not comfortable according to the Psychrometric Chart.
Using natural ventilation and a model of adaptability, and taking into account the outdoor climate, the percentage of comfortability is 31%, that is 2718 hours over 8760 hours in a year.

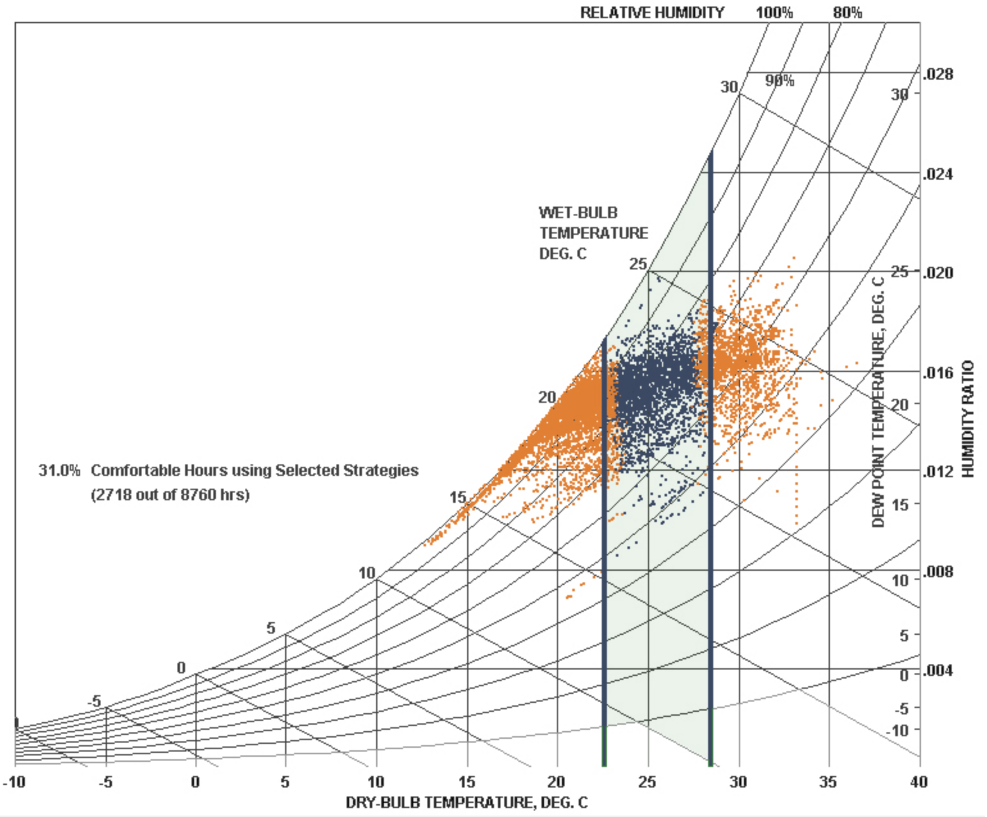


Fig 2.22: Psychrometric chart/ Source: Climate Consultant 6.0.Author`s edition

2.4 CASE STUDY CONTEXT

The case study is located in Comuna 1 of the city, composed of approximately 22 neighborhoods. The case study is part of the Caudal Neighborhood. The area is limited by the mountains to the West-South and by the River Guatiquia to the North-East. In terms of accessibility, it is well connected since it has near one of the main avenues of the city (Avenida del llano). However, in the area, there is not a good public transportation system to access the case study building.
Its proximity to the center of the city turns it into a dynamic area with a mix of activities mostly characterized by commerce, restaurants, and housing. There are also some types of equipment such as schools, churches, sports centers, and music school center, that has been pointed out in the plan.
The context of the case study has a low density, characterized mostly by buildings one-storey high, followed by two storeys buildings, and no more than three taller buildings up to 5 storeys.

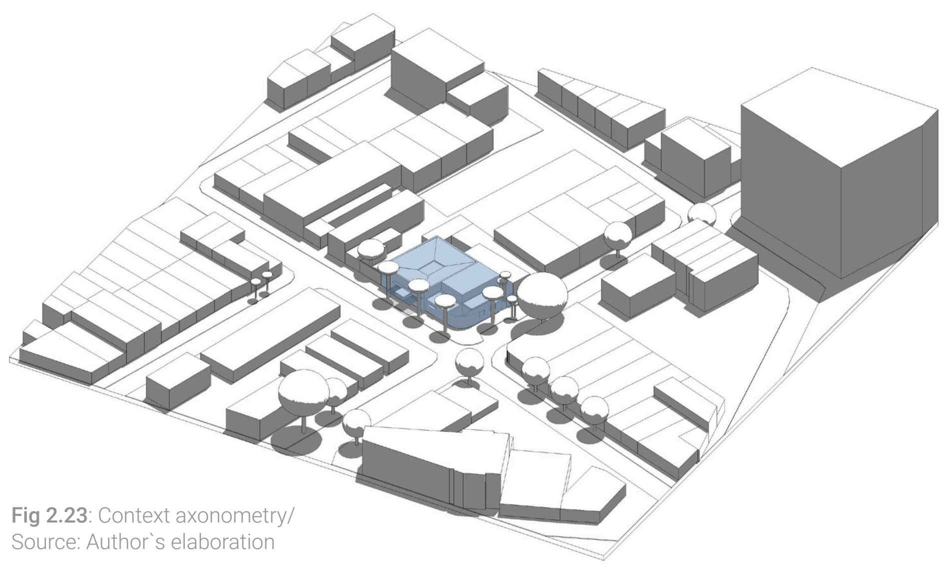


Fig 2.23: Context axonometric/ Source: Author`s elaboration

Fig 2.24: Context Uses plan
Source: Author`s elaboration

2.4.1 URBAN TREATMENT

According to the urban plan guide of the city, called P.O.T ("Plan de Ordenamiento Territorial") and described in the document " Acuerdo No 287 de 2015" [16], the house lot is located in an area determined as Consolidation Treatment. It means that it is an area that has the capacity and the potential to grow constructively in density according to the specific regulations defined by the context in this territorial model. This treatment is also subdivided into different ways of intervention: "Manzana", "Plataforma", and "Altura". The house location, according to the map is defined as a "Plataforma" treatment that allows the buildings to grow to a maximum of 5 floors.

Additionally, the land use and activities map show that the house lot is part of the A.A.R ("Area de Actividad Residencial") which means Residential activity area. According to the normative document described before, this activity area is also divided into different categories. The case study lot is in a commercial axis, called "Eje commercial", which means it is located in a low- medium traffic and, although the area is mainly a residential traffic zone, it is also allowed to be composed of commercial shops and complementary facilities as educative or cultural centers, among others[17].

CONSOLIDATION TREAMENT

- "Manzana" (CM)
- "Plataforma" (CP)
- "Altura" (CA)
- Other treatments

AREA OF ACTIVITY

A.A.R.: Residential, Commercial Axis, Housing Development

A.A.I.: Historical Centrality, Lineal Centrality, Peripherical Centrality

A.A.M.: "Corredor", Strategic area

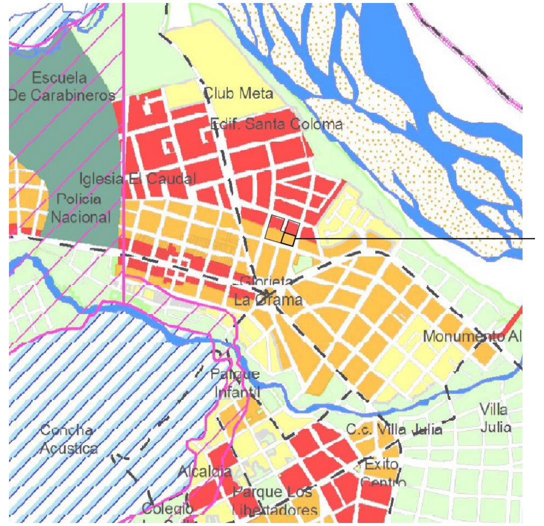


Fig 2.25: Consolidation Treatment

Source: Curaduria Segunda Villavicencio[18].
Edited by author

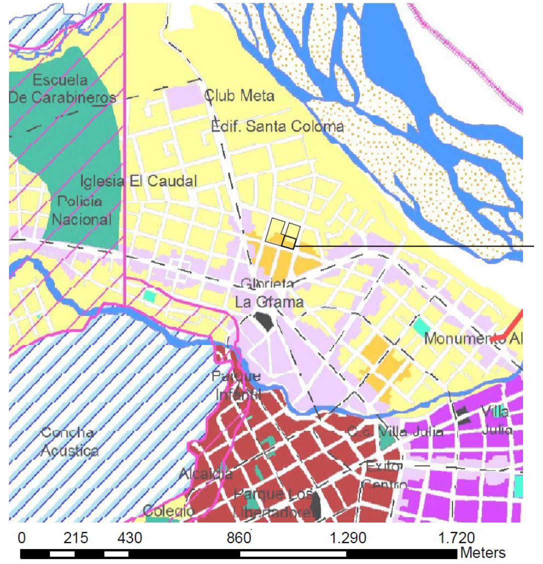


Fig 2.26: Area of Activity (Land use)

Source: Curaduria Segunda Villavicencio[18].
Edited by author

16 Acuerdo No 287.2015." Por medio del cual se adopta el nuevo plan de ordenamiento territorial del municipio de Villavicencio, y se dictan otras disposiciones". Consejo Municipal de Villavicencio. p.193

17 Acuerdo No 287. Articulo 233, "Area de actividad". Consejo Municipal de Villavicencio, 30 Diciembre 2015.Pag 167

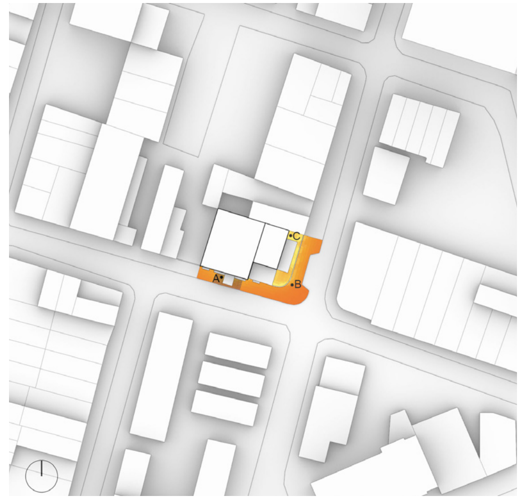
18 Curaduria Seguna Villavicencio. https://www.curaduriasegundavillavicencio.com.co/cartografia/

2.4.2 UTCI

To assess the thermal stress of a body in outdoor spaces the best method is through UTCI (Universal Thermal Climate Index) calculation. UTCI is an equivalent temperature and it is defined as "the air temperature of the reference environment which produces the same strain index value in comparison with the reference individual`s response to the real environment"[19]. In a few words, it is the thermophysiological reaction (thermal exchange)of a human body to an environment temperature reference. The environment reference considers, for the assessment, the meteorological parameters as dry bulb temperature, relative humidity, wind speed and mean radiant temperature as the main factors to produce tension in a certain atmospheric surrounding environment. Thermal stress for UTCI is categorized in a group of 10 levels in a range that varies from extreme cold stress (Below -40ºC degrees) to extreme heat stress (Above +46ºC degrees). It is considered as NO thermal stress when the UTCI resultant temperature is between +9 and +25ºC degrees. While Moderate Heat stress would be +26 to +32 ºC, and the Strong Heat stress is between +32 to 38 ºC.

For the outdoor comfort study of this present work, the tool used was an extension of Grasshopper called Lady bug, using the meteorological data of Villavicencio. It was taken into consideration for the assessment that the hottest day was February 9 and the coldest day was July 9. And there were evaluated 3 points in the immediate surrounding area of the case study. Points A and B were located in the entrance and public walk path outside the house and Point C was in the exterior courtyard in the private area of the house.

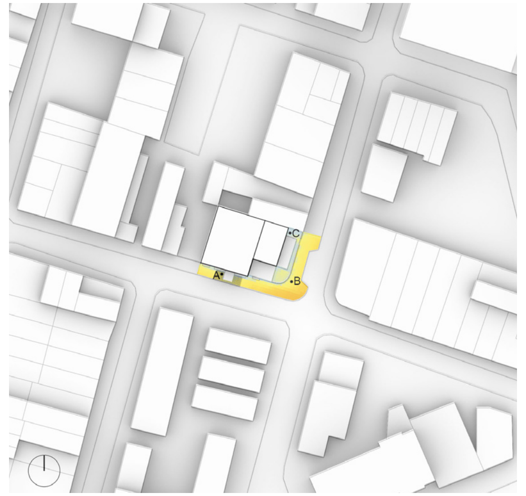
The UTCI temperature average for the hottest day, as it is shown in the



Feb 09 A: 34º B: 35º C: 31º

DRY SEASON
Hottest Day

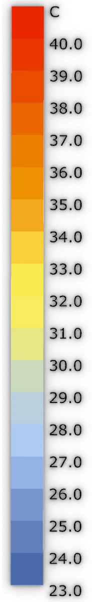
Fig 2.27: UTCI average plan of 3 points in February 09 (Hottest day)
Source: Author`s elaboration



Jul 09 A: 30º B: 31º C: 28º

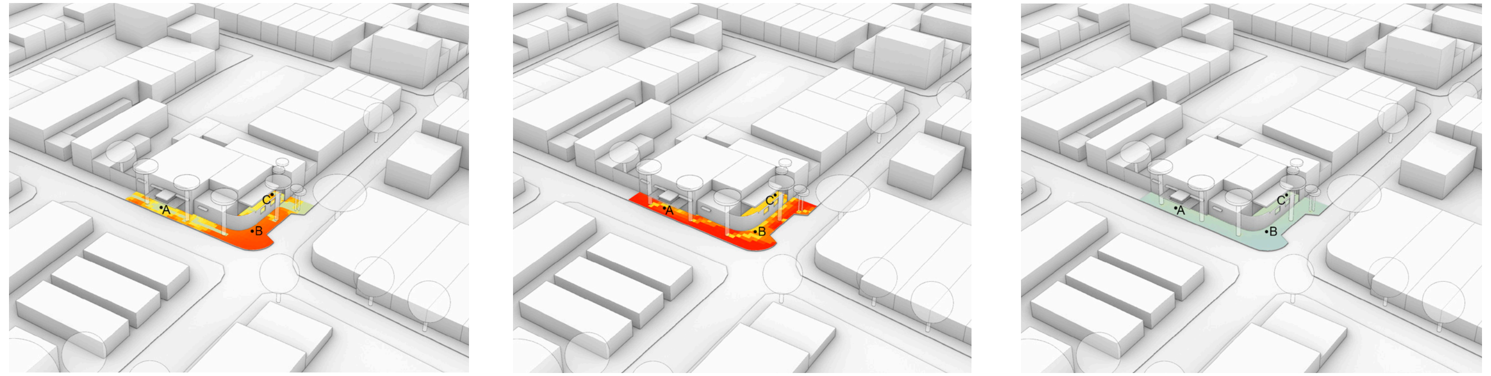
WET SEASON
Coldest Day

Fig 2.28: UTCI average plan of 3 points in July 09 (Coldest day)
Source: Author`s elaboration



19 Zare et al, 2018. Comparing Universal Thermal Climate Index (UTCI) with selected thermal indices environmental parameters during 12 months of the year

figure 2.27 represents strong heat stress in most of the points. At midday, the UTCI temperature reaches up to 37oC degrees with very strong heat stress. Both in the morning and at night the UTCI temperature is over 30oC degrees showing moderate heat stress in the entrance area, and strong heat stress in the courtyard. The coldest day in July is still in the range of Moderate heat stress according to the UTCI results. As it is shown in the graphs below the hour when there is No Thermal heat stress is in the afternoon and at some points in the morning (Exterior courtyard of the house. At midday, the UTCI is between 31ºC and 32ºC degrees representing moderate heat stress.

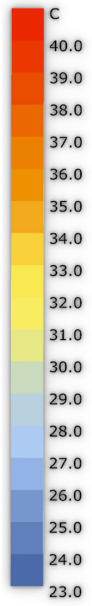


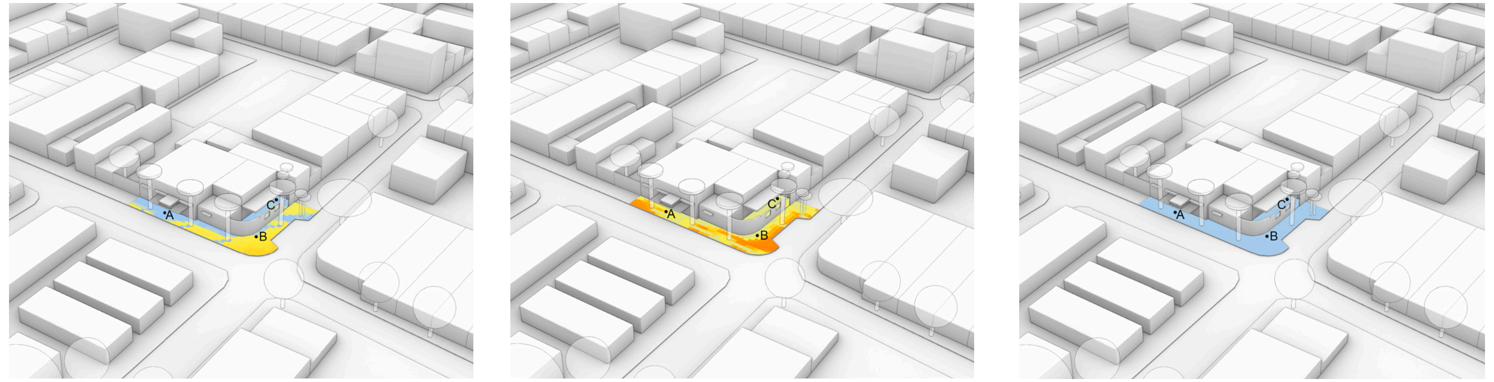
Feb 09_8:00 A: 30º B: 38º C: 34º

Feb 09_14:00 A: 37º B: 34º C: 32º

Feb 09_18:00 A: 30º B: 29º C: 31º

Fig 2.29: UTCI of 3 points
February 09 (Hottest day)
Source: Author´s elaboration





Jul 09_8:00 A: 29º B: 31º C: 28º

Jul 09_14:00 A: 31º B: 32º C: 31º

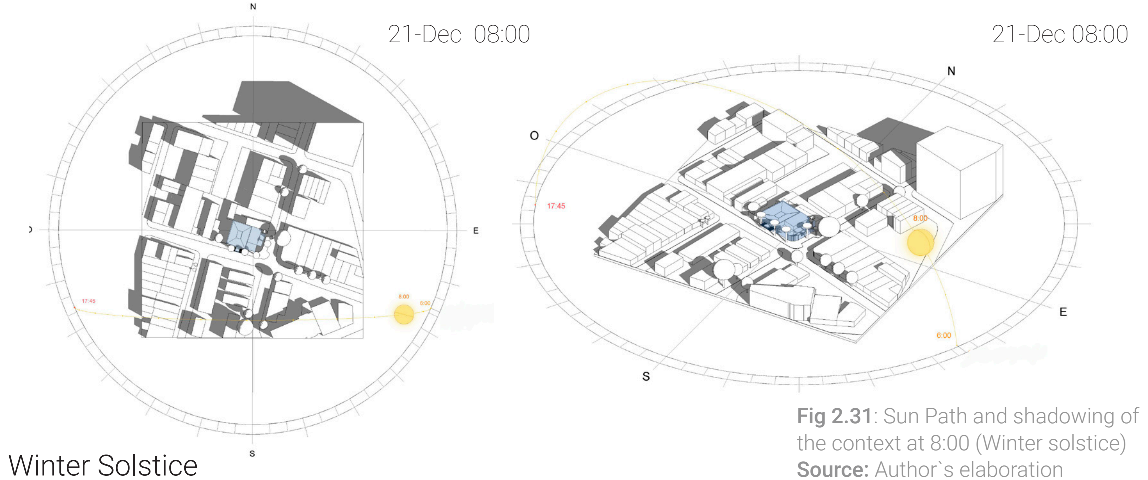
Jul 09_18:00 A: 27º B: 27º C: 27º

Fig 2.30: UTCI of 3 points
July 09 (Coldest day)
Source: Author´s elaboration

2.4.3 SHADOW ANALYSIS

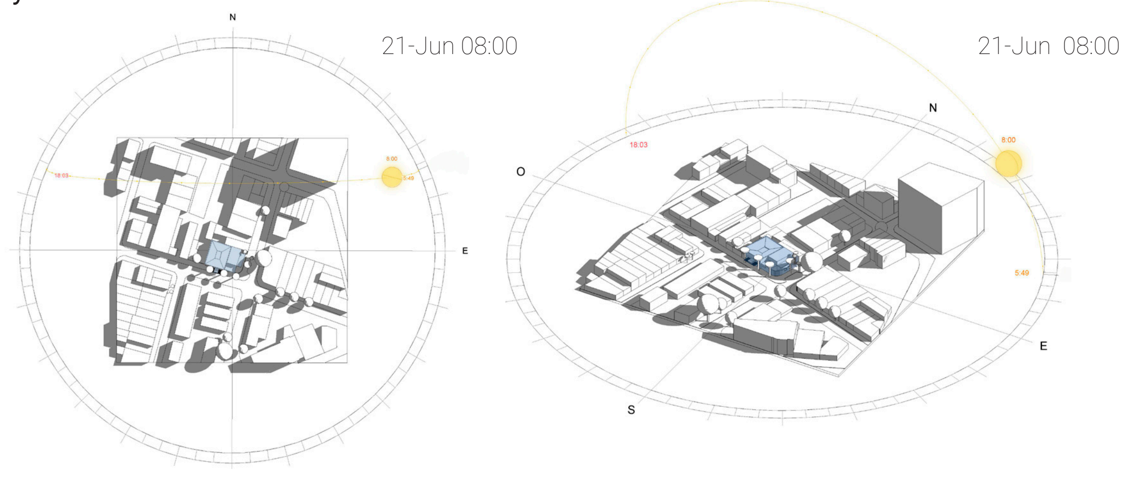
For the sun and shadow analysis of the context, it has taken into consideration some blocks adjacent to the project study case. The days chosen for the evaluation are December 21, which represents the winter solstice, and June 21, as the summer solstice. Because the Earth planet is an ellipse and is tilted fixed, the amount of sun that faces changes and varies between the hemisphere and the different latitudes. When the sun reaches the higher point along the Tropic of Cancer in the northern hemisphere, it is called the summer solstice, with the longest day. On the contrary, when the sun faces the southern hemisphere along the Tropic of Capricorn it represents the shortest day called the Winter solstice [20].
However, in the Equator line, where the case study is located, the variation in time of the day is not very considerable. The sun is overhead in March and September and with a lower tilt towards the north in the Summer solstice and towards the South in the Winter solstice.

As it is shown in the sun path axonometric of the context, although the area experienced the same amount of sunlight in both seasons, the incidence of the sun in summer solstice is higher, in this particular case study. It happens because of the height of the surrounding buildings. The north of the case study building is characterized by buildings with 2 or 3 storeys and more producing more shadows during the winter Solstice. While in the south the buildings are less compact and lower floors generate great sun exposure in June.



Winter Solstice
Dry Season

Fig 2.31: Sun Path and shadowing of the context at 8:00 (Winter solstice)
Source: Author´s elaboration



Summer Solstice
Wet Season

Fig 2.32: Sun Path and shadowing of the context at 8:00 (Summer solstice)
Source: Author´s elaboration

20 Lechner Norbert: Heating, Cooling, Lighting. 2008. Sustainable methods for architects, Third edition; p. 133

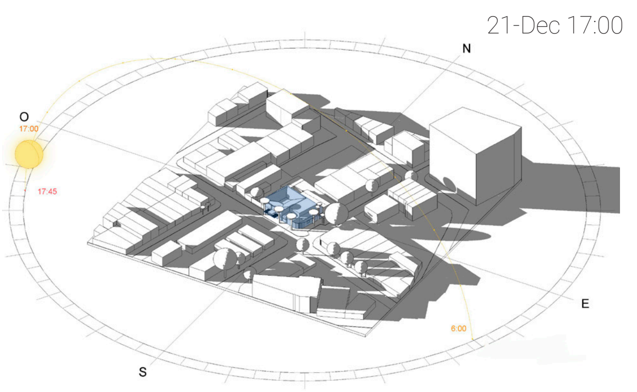


Fig 2.33: Sun Path and shadowing of the context at 17:00 (Winter solstice)
Source: Author´s elaboration

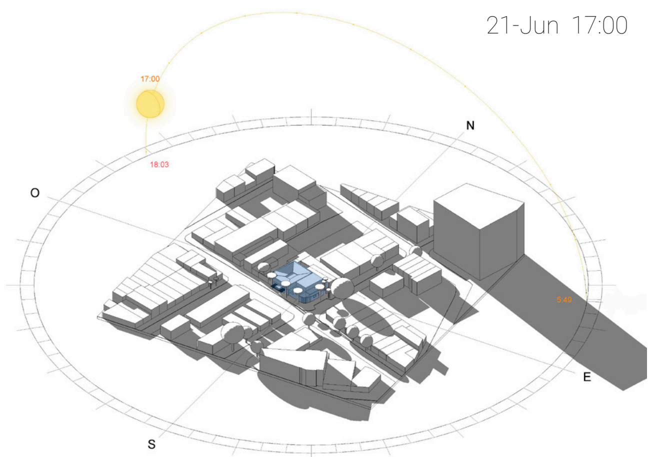


Fig 2.34: Sun Path and shadowing of the context at 17:00 (Summer solstice)
Source: Author´s elaboration

2.4.4 WIND ANALYSIS

The annual average Wind direction is 110º degrees. Both in Dry and Wet seasons the wind comes mostly from the East and South-East. The orientation of the case study could take into the advantage of the predominant wind.

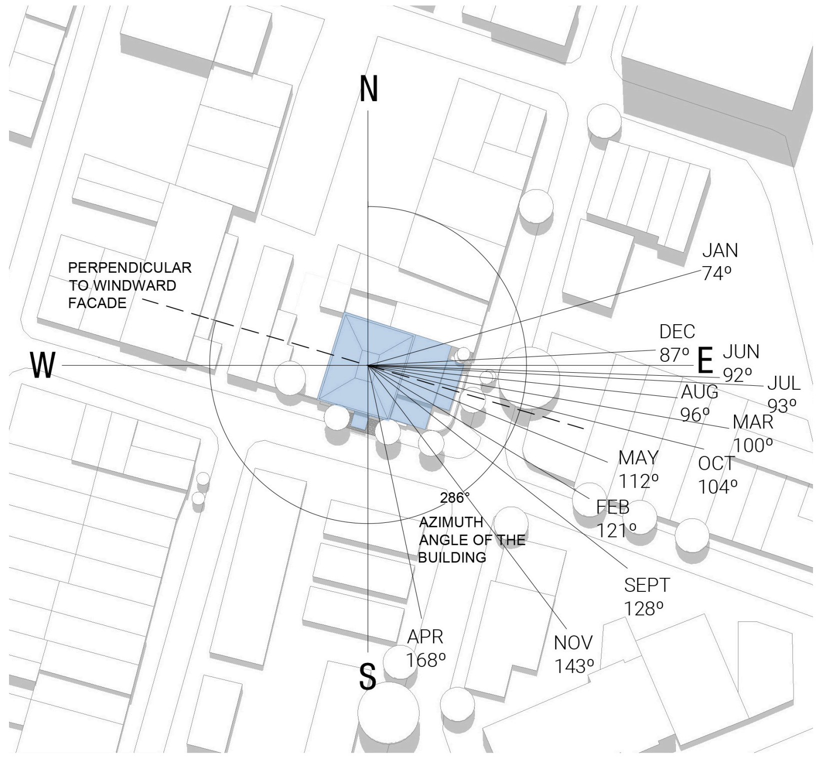


Fig 2.35: Wind Direction Montly average plan
Source: Author´s elaboration

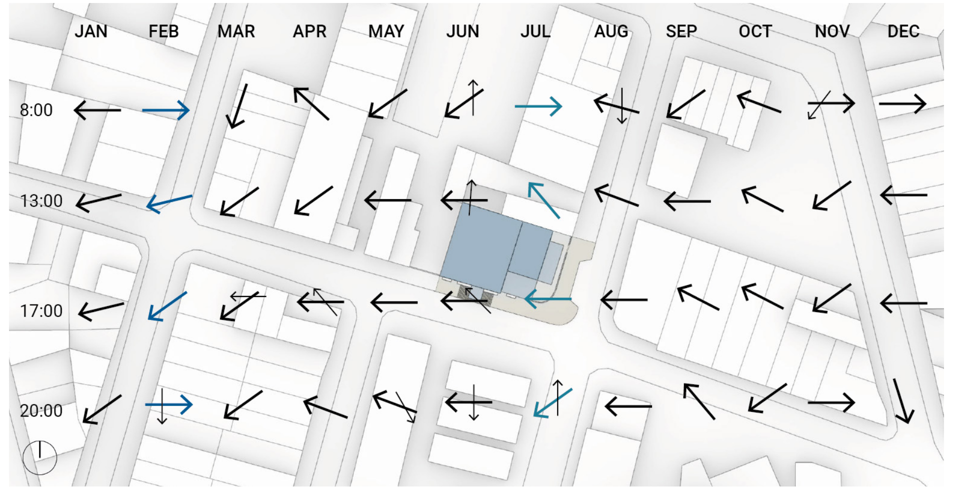


Fig 2.36: Wind Direction hourly average diagram
Source: Author´s elaboration

With an annual average wind speed is 0.8 m/s at 10 m height, based on meteorologic data, the speed does not vary too much since the surrounded buildings are mostly of 2-3 floors (max 10m).

2.4.5 TOPOGRAPHY

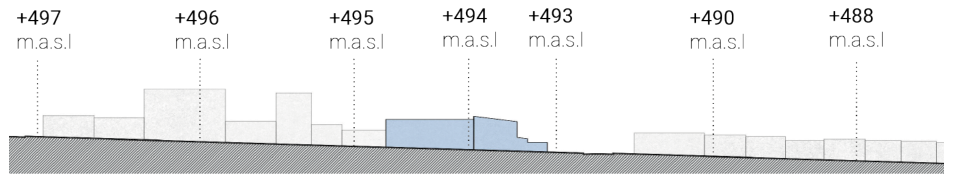


Fig 2.37: Elevation Section scheme
Source: Author´s elaboration

The block area in the city is located 494 meters above sea level (m.a.s.l). Due to its closeness to the River Guatiquia, the area has a medium risk level of flood. With an eventual rise of water flood, the probable water level would be 8 meters in the context area.

The context area is located on a slope of approximately 3% oriented to the West where it is located in the Cordillera oriental (Colombian Andes mountains).

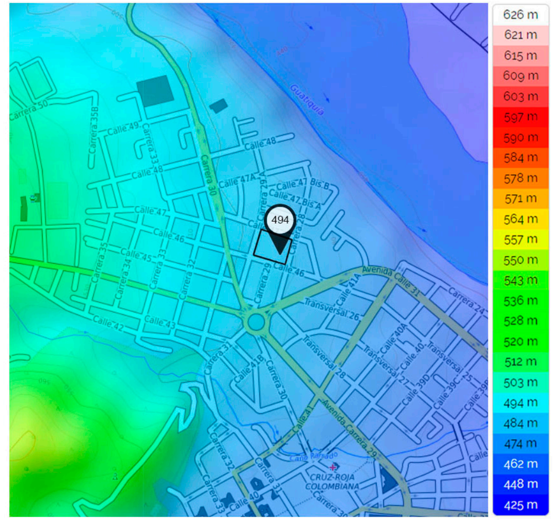


Fig 2.38: Elevation map
Source: Flood map.net

2.5 LOCAL CONSTRUCTION TECHNIQUES

Before colonization, in the middle of the XVI century, the architecture in Colombia has been characterized by the use of natural building techniques from the knowledge of the diverse indigenous groups that inhabited the territory. Nature was the key to the development of the community buildings in the different regions of the country. By using some natural materials such as earth, plant leaves, and trunks, and water, the indigenous cultures such as Muiscas, Tayronas, Quimbayas, among others, built their settlements looking for protection and adapting themselves to the microclimate conditions[21].

As a brief history of the architecture in Colombia, with the arrival of the conquerors from Spain, the traditional rural architecture based on nature started to change with the development of the cities characterized by large military and religious buildings. House typologies such as "Casa- Patio" with an inner courtyard were developed combined with the previous indigenous architecture style. And later, around the XVIII, it was marked by baroque and neo-classic styles full of decorative elements such as gold, paintings, and stained glass. By the middle of the XX century, it was established a milestone in architecture with the Modernism movement framed by the need for globalization. It was an era characterized by the phenomenon of industrialization, population growth, and a capitalist economy. With the modernism ideas of international architects such as Alvar Alto or Frank Loyd Wright and, then with the arrival of Le Corbusier, from the Bauhaus to Colombia, a new architecture was established in the country. With them, the orthogonal and rational shapes of the buildings, new skyscrapers, as well as the large serial social housing emerged in the urban areas losing a strong relationship with the natural context[21]. With modernism, materials such as brick and concrete blocks expanded and strengthened as the main construction technique of buildings in the country until today.

21 Garcìa, Beatriz, 1997."Arquitectura colombiana de la segunda mitad del siglo:entre la civilización y la cultura"
22 Silva, M. 2001. La vivienda a patios de origen hispánico y su difusión en Iberoamérica. Actas del III Congreso Internacional del Barroco Americano. Argentina: Universidad Nacional de Tucumán.

Despite the effects of industrialization, some of the traditional techniques with earth are still used in some areas of the country. Walls are mainly made by a process of rammed earth, with some techniques called, "Tapia pisada ", "bahareque" and "adobe". Nowadays this type of manual construction technique is more used in rural areas and some regions such as the Andina region and also in the Orinoquia region. In the cities, the most used material is industrialized clay bricks, concrete, and metal structures.

"CASA - PATIO" TYPOLOGY

From the XVI century, in the colonial period, new settlements were constructed throughout the national territory with new urban house typologies influenced by Spanish constructive techniques. But differing them by the use of local materials and other criteria such as the social structure of the families and the climate conditions of the site. The Spanish introduced the architectural model of " Casa - Patio" in Latin America, or House - Yard with typologies characteristics from the Andalucia region which in turn has oriental origins with the roman empire and Pompeian influences[22]. The "Patio" constitutes the main social space of the house where all the other functions converge and it represents the private and protected area of the house (Silva,2001). This typology is considered nowadays cultural and architectural heritage in the country. . This typology is considered nowadays cultural and architectural heritage in the country.

Although most of this type of house was designed with one floor, the families with a high social and economic level constructed a second floor. The internal "Patio" could be central or lateral surrounded by a covered corridor with columns and delimited by walls with doors and windows of the rooms. It has also a water reservoir to collect the water from the roof. The entrance, regularly lateral was composed of a large hall called "zaguan" the rooms and on the back was located the kitchen and services area. The walls were thicker and made of rammed earth (Tapia or Bahareque indigenous techniques) or stones and the external facades were designed with a low proportion of wooden windows due to security, but also environmental reasons. They were painted with a lime base with light colors such as white or earthy colors. And for the roof, the structure was composed of wood beams and covered firstly with a dry palm but then, evolved into ceramic clay tiles [23] (See figure 2.39). According to Silva, this type of house with an inner yard was intended to be adapted to the climate seasons in Europe, in summer the users were mainly on the first floor which was cooler and they moved to the upper floors in winter. But in America, since the weather was constant all year, the design was taken into account in terms of the functional program according to the needs of the families. Cecilia Lopez and David Sierra [24], from the Pontificia Universidad Javeriana, developed a bioclimatic study of two houses with the "Casa- patio" typology mentioned before but built in different cities in Colombia, one in Cartagena with an average of 26o degrees and the other in Bogotà with 13o. The study aimed to compare the two cases to find the differences and similarities between them in terms of architectural design and its uses, and their comfort performance according to the microclimate of each location. In conclusion, the design of an internal "Patio" for the house was an advantage in Cartagena allowing natural cross ventilation and shadowing with vegetation. While in bogotà it was not too accurate due to the use of high trees and plants that creates shadows lowing the temperature and increasing the humidity. The facade in Cartagena had long wooden windows with shutters, while in Bogotà the facade was more closed with smaller and squared metal windows to protect from cold at night. The wall thickness was over 30 cm in both cases made of rammed earth and painted with light colors that helped to increase the thermal comfort [24].

Just like these two examples, this model of the urban house was developed in different cities in Colombia. However, the most adaptive design responds to the warm climate regions, while the houses constructed in cities such as Bogotà, with a cold climate, required modifications to improve the internal comfort

Fig 2.39: Typology of "Casa -Patio" in Cartagena Colombia.
Source: Lopez, C -Sierra, D (2017). Magazine ESTOA Nº12.

23 Silva, M. 2001. La vivienda a patios de origen hispánico y su difusión en Iberoamérica. Actas del III Congreso Internacional del Barroco Americano. Argentina: Universidad Nacional de Tucumán.
24 Lopez, C & Sierra, D. 2018. Condicionantes bioclimáticos en la arquitectura colonial de Colombia: la casa-patio en Cartagena de Indias y Bogotá. Revista ESTOA Nº12.

Examples of "Casa-Patio" type in Colombia

Fig 2.40: Hostal Doña Manuela, Mompox.
Source: https://www.hostaldonamanuela.co/

Fig 2.41: Hostal Doña Manuela, Mompox.
Source: https://www.hostaldonamanuela.co/

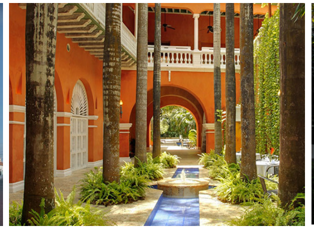


Fig 2.42: "Casa Pestagua" Hotel, Cartagena
Source: https://www.hotelboutiquecasapestagua.com/

Fig 2.43: "Casa de la moneda" Museum, Bogotà
Source: https://www.banrepcultural.org/bogota/casa-de-moneda

"MALOCA" HOUSE

The traditional architecture in the plains of the Orinoquìa region is characterized by large inns or ranches that come from the historical presence of the religious Jesuits during the conquest time combined with the indigenous techniques from the region as the typical house "Maloca". These places were dedicated to cattle and agriculture. (See figures 2.44)

In the rural areas characterized by landscape with plains, the traditional house of the "llaneros" (name of people from the region) is made of dry

Fig 2.44: "Soropo" and "Media pare"hosuing
Source: Photographies by Jairo Ruiz- http://canalllanero.blogspot.com/

palm in the roof, walls, and internal division, with rammed earth for the floor, columns with trunks, and cow leather for the doors. This house is called "Soropo" and is where the traditional dance "Joropo" took place. Another house called "Media pare" is constructed also with dry palm gabled roof and by perimeter half walls of painted rammed earth that allows natural ventilation protecting also from the raining. The traditional house is cool with wide corridors where the men are used to rest in hammocks or "chinchorros" (whose difference is in the fabric)[25].

CITY CONSTRUCTION TECHNIQUES: VILLAVICENCIO

In the city of Villavicencio, at the beginning of the XX century, the architecture was influenced by the traditional construction from the center of the country (Cundinamarca) when people from Chipaque and Quetame migrated to the city after the fire that destroyed a big area in 1890. Housing was made of rammed earth walls, dry palm roof or zinc roof tiles, wooden windows, and floors made with earth. Around half of the century, with the direct connection with the capital Bogotà, new materials such as brick, cement, marble, and ceramics started to replace the vernacular architecture of the city[26]. The "casa- patio", described before, was also introduced in the region with some adaptations and there are still some representative houses.
Nowadays, there are still some houses in the center of the city that keep the traditional construction techniques and are part of the local heritage.
The "casa- patio" was also introduced in the region with some adaptations. One of the original houses of the city became a museum. It is the " Casa Museo Cadavid", a house near the park " Parque de los periodistas" from around the year 1900 [27].

25 Martin, Miguel Àngel. 1979 Del folclor llanero. Lit. Juan XXIII.
26 Salamanca Uribe, J. 2009. Villavicencio, la ciudad de las dos caras. Revista Credencial Historia, (231)
27 Magazine: Agenda hoy. April 6 2018 ."Vestigios de una arquitectura vernácula".

Fig 2.45:Casa Museo Cadavid/ Source: Photographies by author

Managed by the artist Gerardo Cadavid who adapted the house to be a museum to show, not only his art pieces, but also to show colonial pieces from the city and the region such as weapons, cameras, telephones, furniture, and windows, among others. The original house was of one floor and is still with rammed earth walls and wooden doors and windows. Then, the artist extended it with one more floor but tried to keep the traditional housing details.
Some of the historical wooden windows from the late century XIX, collected over years, are exhibited as tables. They are made in layers with the possibility of different openings for natural ventilation, allowing to keep cool the houses.

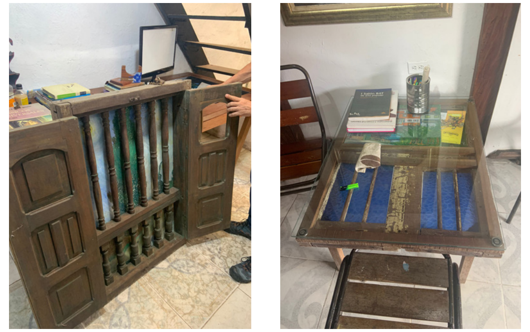


Fig 2.46: Wooden windows/ Source:Photographies by author

2.5 SUSTAINABLE GOALS AND CERTIFICATION SYSTEMS IN COLOMBIA

SUSTAINABLE DEVELOPMENT GOALS (SDG)

The Sustainable Development Goals (SDG) are part of the United Nations agreement taken on 25th September 2015 that seeks to take urgent actions over the main problems the world is facing. "They recognize that ending poverty must go hand-in-hand with strategies that build economic growth and address a range of social needs including education, health, social protection, and job opportunities while tackling climate change and environmental protection"[28]. By 2030, the member countries commit to take action to accomplish the 17 goals proposed to reduce poverty, and inequality, among others and to address current dramatic health problem: Covid 19.
Colombia has incorporated into the SDG agreement and in 2016 showed its first report of improvement results. By 2020, was reported 72% of the implementation of the goals with the achievement of eight new goal indicators. According to the Voluntary National Report 2021 presented to the members of the SDG, the country seeks to work with the SDG within the territories and looks for the participation of multiple actors. "This is a significant step forward in closing social and economic gaps in Colombia, especially when inequality in the country must not only be analyzed at the level of people but also between territories"[29]. As well as the elaboration of a state policy of acceleration of the achievement of the goals and the implementation of financial models. As for the rest of the world's members, future commitments seek to achieve more goals while recovering from the consequences of Covid.
The following list shows the 17 goals defined until now as SDG by 2030.

28 United Nattions: https://www.un.org/sustainabledevelopment/
29 Colombia ODS: accelerate the implementation for a sustainability. Voluntary National Report 202. https://sustainabledevelopment.un.org/memberstates/colombia

1 No poverty
2 No hunger
3 Good health and well-being
4 Quality Education
5 Gender Quality
6 Clean Water and sanitation
7 Affordable and clean energy
8 Decent work and economic growth
9 Industry, innovation and infraestructure
10 Reduced inequalities
11 Sustainable cities and communities
12 Responsable consumption and production
13 Climate action
14 Life below water
15 Life on LAND
16 Peace, justice and strong institutions
17 Partnerships for the goals

This research proposal will focus on achieving 6 of the Sustainable Development Goals (SDG). The application of the following global goals is focused on hot-humid climate regions in the Tropics and the infrastructure context of new and existing buildings.

To reduce and prevent environment and respiratory disseases, as well as mental problems, specially on youth population, by providing more naturally well ventilated and illuminated spaces.

To upgrade quality education, focused mainly on artistic programs for the children and youth of the region by providing accurate facilities and a good learning environment.

To upgrade infrastructure design and construction, accesible to all and well connected to the cities through the implementtion of an affordable but clean and innovative technology

To promote social and economic inclusion, through the free accessibility to quality and comfortable spaces for any kind of use to people from all the economic status, different age, gender, race and dissabilities.

To reduce the energy consumption and the waste of a building, by designing according to the microclimate, recycling existing materials and consuming local products.

To adapt to the climate change conditions and to mitigate the negative impact on the earth by promoting sustainable strategies based on local needs.

CONSTRUCTION SUSTAINABLE DEVELOPMENT IN COLOMBIA

According to a study conducted by the CCCS (Consejo Colombiano de Construccion Sostenible) that is the Colombian Green Building council, there are important advances and great trends from the construction sector in the country to the implementation of sustainable certifications. For the study developed, there were interviewed designers, building consultants, builders, product suppliers, operators, banks, and Universities allowing them to understand the current state of sustainable processes and evaluate future goals. The study found positively the vision "on the perspective of companies in this field indicates that the environmental interest of these has arisen more of his reflection than of the obligation to fulfill the commitments of trade unions and government regulation"[30].

In Colombia, the start of the implementation of sustainable certifications took place in 2008 with the international certification LEED (Leadership in Energy and Environmental Design). Since then, more and more companies and users have adopted the application of international certification systems and new national ones. As is shown in the graph below, LEED certification has been the most executed certification, followed by the international certification EDGE (Excellence in Design for Greater Efficiencies), and the national certification CASA from 2018, designed mainly for housing projects. Other new certifications in the country have been also performed in a small percentage as it is shown in the graph. The graph

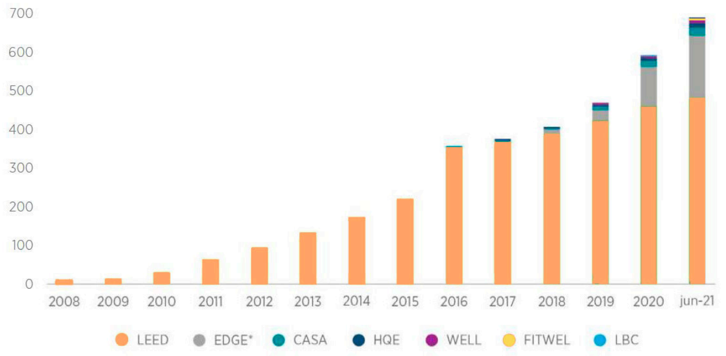


Fig 2.47: Evolution of certification systems in Colombia

Source: CCCS.[30]
Author`s Edition

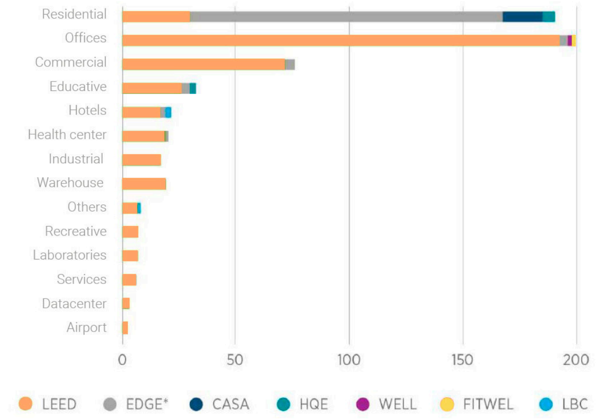


Figure 2.48: Number of projects by typologies with certifications

Source: CCCS[30]
Author`s Edition

above shows the number of projects performing a certification system by typology of building. The sector with more projects registered and already certified is offices using LEED certification with 32%, followed by Residential (21%) performing EDGE and CASA certifications, and then, the commercial area with 12%. The educative projects represented the fourth place performing LEED certification and it has been registered less than 50 projects until now. And in the city studied less than 5 projects follow a green certification, according to the same report.
Finally according to the report, "In 2020, although the world suffered the beginning of the crisis due to the COVID 19 pandemic, the largest total number of projects in all certification systems, which is in line with the evolution of the square meters that were registered in the country"[30].

30 Consejo Colombiano de Construccion Sostenible CCCS. 2021. "Estado de la construccion sostenible en Colombia". P. 6, 48

LEED CERTIFICATION

The certification LEED is a global rating system to recognize sustainable buildings that contribute to the protection of natural resources and peo-ple`s health while saving costs of construction. According to the U.S Green Building Council, the certified projects "are a critical part of addressing cli-mate change and meeting SDG goals, enhancing resilience, and support-ing more equitable communities[31]

The project is evaluated by a point system:

Certified (40-49 points)
Silver (50-59 points)
Gold (60-79 points)
Platinum (80+ points)

Fig 2.49: Logo LEED Source: https://www.usgbc.org/leed

The credit plan is defined in areas like Location and transportation, Water efficiency, Energy and atmosphere, Materials, Indoor Environmental Quali-ty, and innovation, among others. The following requirements are an exam-ple of some of the points related to this research paperwork.

SUSTAINBLE SITES: HEAT ISLAND REDUCTION
Schools (1-2 points)

• Installing plants that provide shade over paving areas .
• Providing shade with structures covered by energy generation systems, such as solar thermal collectors, photovoltaics, and wind turbines.
• Providing shade with architectural devices or structures that have a three-year aged solar reflectance (SR) value of at least 0.28.
• Providing shade with vegetated structures.

$$\frac{\text{Area of Nonroof Measures}}{0.5} + \frac{\text{Area of High-Reflectance Roof}}{0.75} + \frac{\text{Area of Vegetated Roof}}{0.75} \geq \text{Total Site Paving Area} + \text{Total Roof Area}$$

• High-Reflectance Roof for Steep-sloped roof : 39 (SR)
(LEED v4 for building design and construction_P. 38 [32])

MATERIAL AND RESOURCES: BUILDING LIFE-CYCLE IMPACT REDUCTION

Building and Material Reuse
• Reuse or salvage building materials from off site or on site as a percent-age of the surface area (LEED v4 for building design and construction.p.90) It includes the elements of the structure and interior elements as walls, ceilings, among others, but not the windows.

25 % Surface area Re-used (2 points)
50 % Surface area Re-used (3 points)
75 % Surface area Re-used (4 points)

INDOOR ENVIRONMENTAL QUALITY

To determine and calculate the minimum indoor air quality requirements, the certification asks to follow the standard ASHRAE Standard 62.1–2010 in the USA, but for cities out of this country, the suggestion is the European standard, EN 15251–2007 and EN 13779–2007.

_EQ: ENHANCED INDOOR AIR QUALITY STRATEGIES
Additional Enhanced IAQ Strategies (1 point)
B. Increased Ventilation: Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates as determined (LEED v4 for building design and construction_p.116).

31 U.S Green Building Council: https://www.usgbc.org/leed
32 LEED, 2019. LEED v4 for building design and construction

_EQ PREREQUISITE: MINIMUM ACOUSTIC PERFORMANCE

Design classrooms and other core learning spaces to include sufficient sound-absorptive finishes forcompliance with the reverberation time re-quirements specified in ANSI Standard S12.60–2010.
According to the standard, the maximum reververation time for a classro-om between 10,000 and 20,000 cubic feet (283-566 m³) should be 0.7 seconds[33].

_EQ: DAYLIGHT

• Demonstrate through simulations the accomplisment of Spatial Daylight Autonomy, Annual Sunlight Exposure and/or Illuminance.

Simulation: Spatial Daylight Autonomy (sDA300/50%):
55 % Spatial Daylight Autonomy (2 points)
75 % Spatial Daylight Autonomy (3 points)

Annual Sunlight Exposure (ASE1000,250): No more than 10%

Illuminance between 300 lux and 3,000 lux:
75 % Illuminance (1 point)
90 % Illuminance (2 point)

_EQ: QUALITY VIEWS

• Achieving a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area (LEED v4 for building design and con-struction_Page 134). For calculations must be excluded the obstructed windows and patterned or coated glazing.

33 Acoustical Society of America, 20120. Acoustical Performance Criteria, DesignRequirements, and Guidelines for Schools, Part 1: Permanent Schools. ANSI/ASA S12Part 1
34 Referencial CASA Colombia, 2016: https://www.cccs.org.co/wp/antecedentes-referencial-casa-colombia/

CASA COLOMBIA CERTIFICATION

The certification CASA is a recent national system that recognizes and rewards residential projects (Includes Low-cost housing called VIS/VIP) with sustainable and health solutions developed by the CCCS (Consejo Colombiano de Construccion Sostenible). The idea emerged in 2013 and it was based on the Brasilian similar certification but applied to the building needs of Colombia.
Although in the country the LEED certification has been applied before, CASA seeks to enlarge the coverage for low-income people. Until now 29 residential projects have been registered, of which 4 have already comple-ted the design certification[34].

According to the document Action Plan by the CCCS (Referencial CASA Colombia), the mecha-nism is composed of 7 categories and It is based on quantitative indicators with a maximum of 100 points.
The categories are Context sustainability, Sustai-nability in the construction area, Water efficiency, Energy efficiency, materials efficiency, Welfare, and social responsibility
This national certification could be applied in any region and becomes a good reference for projects characterized by extreme climate conditions, like hot-humid, typical of the tropical zone. However, it will be not taken into account in-depth since the case study is a music center, but not a residential one.

Fig 2.50: Logo CASA-Source: https://casa.cccs.org.co/

2.6 CONCLUSIONS

According to the analysis developed in this Chapter 2, the climate of this study, listed as Tropical monsoon by the Koppen-Geiger and Warm-Humid by Caldas Lang, from the territorial to the building context is characterized mainly by warm temperatures, high humidity, and high periods of rainfall. These conditions remain constant the whole year in the cities located in the tropical zone, along the Equator.

The data shows hard environment conditions set by the average of relative humidity up to 80%, lower wind speed of maximum 2 m/s coming from East and south-East, sky covered more than the half of the year, temperatures over 32oC degrees in the dry season (December to February), rainfall precipitation for almost the 70% of the year, moderate and strong heat stress of outdoor spaces (up to 31oC degrees), among others.

Despite the strong microclimate conditions mentioned before, the city of Villavicencio has become an attractive place to live and visit because of its other cultural, social, and economic characteristics. Although some cities of the country are strongly characterized by traditional techniques and the region of this study is characterized by vernacular architecture, the city of Villavicencio is mainly developed with modern construction architecture. It is a medium-size city growing faster but still characterized by lower buildings.
The microclimate condition
s, together with the progressive construction expansion of the city represent a challenge to be achieved to bring comfortability to the citizens and to reach sustainable goals. Some of the goals presented in this research work are the prevention of health problems, the access to quality education. Although there is an increase in the number of projects seeking green certifications in the country, there is still a low
interest from the studied city, as well as others in the region with the same climate characteristics. The LEED certification results in a great system to be accomplished since covers the main parameters for the typology of the case study.

3.

HOT-HUMID CLIMATE DESIGN

Having understood the main characteristics of the hot- humid climate in the previous chapter, the third chapter focuses on the introduction to the main design strategies and concepts to be taken into account to develop more accurately projects in this type of climate.
The chapter starts with a brief presentation of Tropical architecture and its main climate conditions, and then a description of the main microclimate elements to be taken into account before studying and designing any architecture project.
Since the aim of this work is on the analysis and the application mainly of passive design strategies, in this chapter these strategies are described in 5 categories: Building design, Thermal comfort, Daylighting, Natural ventilation, and Acoustic comfort.
Finally, there is an analysis of some international and national references located in the tropical zone and with similar climate characteristics, that have addressed well the challenge of the extreme environmental conditions through accurate passive design strategies.

3.0 TROPICAL ARCHITECTURE

In the tropics, the surrounded zone of the equator line of the Earth, the climate differs from temperate areas where the seasons are distinct with extreme temperatures. Near the Equator, the temperature remains constant all year tending to be Hot and dry or hot and humid. The summer, called the Dry season, is characterized by low rainfall precipitation, while the Winter, called the Wet season, precipitation is high.

As it was explained before, in Chapter 2, in the tropical zone the temperature varies according to the location and its microclimate elements. Also, it differs in a small proportion depending on the latitude. The Tropics are divided into 3 zones: the Equator, Tropic of Cancer (Latitude 23.5º north), and Tropic of Capricorn (Latitude 23.5º south). The difference between them is about the position of the sun path. In the Equator with a latitude 0 º the sun rays are direct overhead at midday in March 21 and September 21, and the movement is in the same proportion to the North (June 21) and South (December 21). In this zone, "the sun shines for half the year from the south and for the other half of the year from the north. Consequently, south and north facades experience the same sun angles but at different times of the year"[35](See figure 3.0). In the Tropic of Cancer, the sun is inclined to the South reaching the direct sun overhead on December 21, while in the Tropic of Capricornio is reached on June 21.

Although the climate is mainly warm, for dry and humid climates, the design approach should be different. While in a hot-dry climate, the comfort depends on thermal mass, shaded small windows, and night cooling strategies, the Hot-humid depends mainly on avoiding heat through shading devices, light color materials, and passive cooling strategies for both day and night. Achieving thermal comfort in the second one is a challenge since the high humidity makes it very hard for the body to cool itself through sweating"[35].

The design strategies topic for the hot-humid climate is extended in chapter 3.7, after introducing the main concepts of passive design.

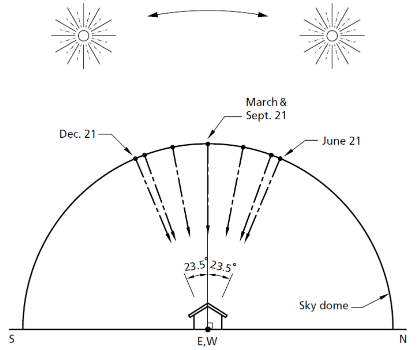


Fig 3.0: Equator Sun path
Source: Lechner, 2008

3.1 MICROCLIMATE MAIN ELEMENTS

To understand the principles of microclimate conditions is important to underline where the concept comes from and its main characteristics. Microclimate, as its name says " micro", is a smaller area of a climate and it varies according to the location in the world. " The word "climate" comes from the Greek klima, which means the slope of the earth in respect to the sun" [36]. Thus, the climate is associated with the sun angles in the different latitudes and its affection in a larger region for long periods.

Both, Climate and microclimate are related to weather conditions including temperature, wind, humidity, and precipitation on different scales. But the microclimate is affected by other elements of the local environment that could change completely the feeling of comfort on each site. For example, in Colombia, despite being under the same latitude, as the equator, there are several microclimates (Chapter 2.1) depending on the environmental conditions of each city.

[35] Lechner Norbert, 2014. Heating, Cooling, Lighting. Sustainable methods for architects, Fourth edition; 2008. p. 580;584.
[36] Lechner Norbert: Heating, 2008. Cooling, Lighting. Sustainable methods for architects, Third edition; p.72-76

Therefore, based on Norbert Lechner approach[37], these are the elements that should be taken into account when designing buildings or urban areas.

- Elevation above sea level (m.a.s.l): The higher the elevation from the sea, for example, a location over a mountain, the lower the temperature.

- Form of the land: Both a flat land or an inclined one, and its orientation affects thermal comfort. A north orientation in a mountain would be colder than the south due to the winds and the position of the sun. In the tropics, since the sun comes overhead always, the south and north have the lowest sunlight, being the east and west have the warmest orientation

- Proximity to water bodies: In warm places, the presence of a water body decreases the temperature by increasing air breezes and humidity.

- Soil Types: Some characteristics such as color, heat absorption, and water content affects the microclimate. The light color of sand reflects more of the sunlight decreasing heat, and soil with rocks absorbs more of the heat during the day

- Vegetation: Plants could lower temperatures of the air and ground and increases the humidity throught the Evapotranspiration, the process of loss of moisture by the evaporation from the soil and transpiration from the plants. Vegetation help also on noise and polluntants reduction.

- Man-made structures: Buildings and city structures can reach shade and cool areas, as well as increase temperatures depending on the shape, size and characteristics of the materials. In big cities, the urban heat island phenomenum increases with the man-made structures that rise the temperature in the metropolitan area against the rural areas. Materials as asphalt, with a dark color, could high the temperature drastically.

3.2 THERMAL COMFORT

The human body requires energy to develop most of its processes, it is then burnt becoming heat production. Since there is a temperature range acceptance for humans to live, the body can dissolve waste heat avoiding overheating. The body is capable of thermoregulates by sweating when there is an excess of heat or shivering when is too cold[37].

Heat loss occurs through Conduction, Convection, Evaporation, and Radiation mechanism. Conduction results when heat passes from one object to another by contact, and it occurs due to the closeness motion of its molecules. Convection is the heat transfer of a fluid, either liquid or gas when its molecules are in intense movement. The air tends to transfer heat by convection depending on the difference in temperatures. Hot air tends to go up and in the case of buildings, it goes to the ceiling roof. Radiation is energy transfer through electromagnetic waves. "Hot bodies lose heat

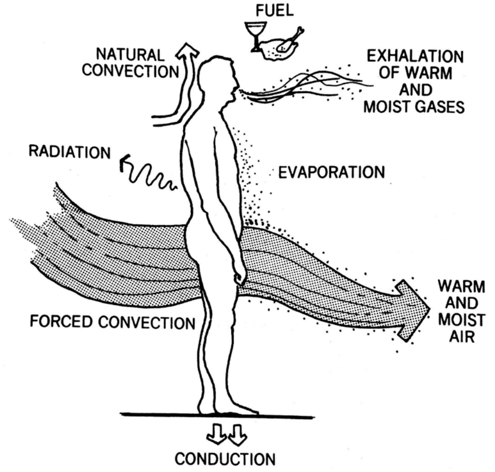


Fig 3.1: Methods of dissipating waste heat through a body
Source: Lechner, 2008

[37] Lechner Norbert: Heating, 2008. Cooling, Lighting. Sustainable methods for architects, Third edition; p.75; 56

by radiation because they emit more energy than they absorb"[38]. It is affected by the interaction between the energy and the matter through the emission, trasmission, absorption or reflectance. While there is heat gain when the external temperature is higher of a body through conduction, convection and radiation, the skin could loss heat through Evaporation, turning liquid into gas.
According to the standard from the American Society for Heating, Refrigerating and Air conditioning Engineers (ASHRAE) thermal comfort is " that condition of mind which expresses satisfaction with the thermal environment"[39] and it "occurs when a body does a minimum effort to balance the intern temperature. This balance results from a combination of some environmental factors such as air temperature, humidity, air movement and Mean radiant temperature (Fictitious uniform radiant temperature taken from a point in space). For indoors, Operative temperature, that is an average between mean radiant and the ambient temperature is also taken into account to measure thermal comfort.
Other variables that generate effects to the thermal equilibrium are the metabolic rate and clothing insulation. The metabolic rate is the heat production in one second from the different activities of a person such as sleeping, light activity, walking, running, seating, among others and its heat production is measure in Watts over m^2 with an unit called Met[38]. The more intense is the activity, the higher is the met. In the case of a music school, the activity taked into account is light activity that is about 1.6 met. On the other hand, clothing refers to the insulation provided by the amount of layers and type of clothing. The measurement is in m^2 .K/W and the unit is in Clo, whose range varies between 0 to 3, being 0 without clothing and 3 with 3 or more layers of clothing. One Clo i equal to 0.155 m^2 .K/W. In warm places, people tend to wear less layers, like T-shirt and shorts (1.5 met) and in Cold places, to wear thermojackets, cap, gloves and others (3 met).

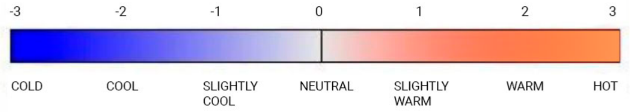


Fig 3.2: ASHRAE Thermal sensation scale
Source:. Haq Gilania, Khan, 2015. Author`s edition

To achieve thermal comfort two methods have been formulated and their use depends on the local environment where they would be analyzed. The first one is a thermal comfort prediction developed by Ole Fanger, who developed a method to evaluate indoor comfort conditions. The EN ISO 7730[40], and ASHRAE 55 [39] Standard included the two Fanger`s concepts: Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). Its calculations are based on the metabolic rate, clothing, and the environmental factors mentioned before and it has no big differences between age and gender. According to the ASHRAE 55, PMV is an index that predicts the average value in terms of votes of a group of people in a seven-point thermal scale from -3 to +3 points. Where -3 is too cold, 0 is neutral and +3 is too hot. And PPD is also based on PMV index and shows in terms of percentage an estimated amount of occupants that feel dissatisfied with the indoor thermal conditions. The more votes are into the extremes of the thermal scale, the higher the percentage of dissatisfaction.
The acceptance range for both PMV and PPD has been ruled by the International Organization Standardization (ISO 7730)and it has been classified into 3 different classes of satisfaction with indoor thermal conditions of a building (higher, moderate, and minimum levels of satisfaction).

Class	A	B	C
PMV	-0,2<PMV<+0,2	-0,5<PMV<+0,5	-0,7<PMV<+0,7
PPD (%)	<6	<10	<15

Fig 3.3Thermal acceptability criterion
Source: ISO 7730, 2005. Author`s edition

38 Lechner Norbert: Heating, 2008. Cooling, Lighting. Sustainable methods for architects, Third edition; p.45; p.65
39 ASHRAE, 2004. Standard 55 thermal environmental conditions for human occupancy.Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers

40 ISO 7730,2005. Thermal comfort using calculation of the PMV and PPD indices and local thermal consideration,International Organization Standardization.

ADAPTIVE COMFORT

The second method called Adaptive comfort is more suitable for microclimates characterized by a constant temperature the whole year. It is common to be used in tropical zone with mostly warm conditions. Since the case study of this research is focused on a building located in the Tropics with a hot-humid climate, adaptive comfort will be used as the best method for calculations.
This type of thermal comfort analysis, studied by Humphreys and Nicol [41], and also Dear and Brager [42] through surveys, has been integrated to the Standard AHSRAE 55 (2004). According to some studies, based on those authors research, the expectations of low temperatures result higher in an air conditioned building than in buildings with natural ventilation[43]. But since the studied house works mainly with natural ventilation, the adaptability and acceptance to the external temperature is higher.

Understanding the adaptive comfort as "the ability of human beings to adapt themselves to the environmental conditions (through conscious or unconscious changes in their metabolic rate or clothing level) and to interact with the environment in order to adapt it to their needs"[41], the analysis of the comfort limit it is based on assumptions. Thus, the range of acceptance of extreme temperatures is wider than the first method described before. According to the standard EN 15251 of the European Committee for Standardization (CEN), the limits of adaptive comfort acceptance are divided in 3 categories[43] (Fig 3.4), and it use depends on the expectations desired and the type of building project.

Class I: High level of expectations, for sensitive users (±2 ºC); High Comfort
Class II: Normal level of expectations, for new or building renovation (±3ºC). Good Comfort.
Class III: Moderate level of expectations, for new or renovation buildings (±4 ºC). Acceptable Comfort.

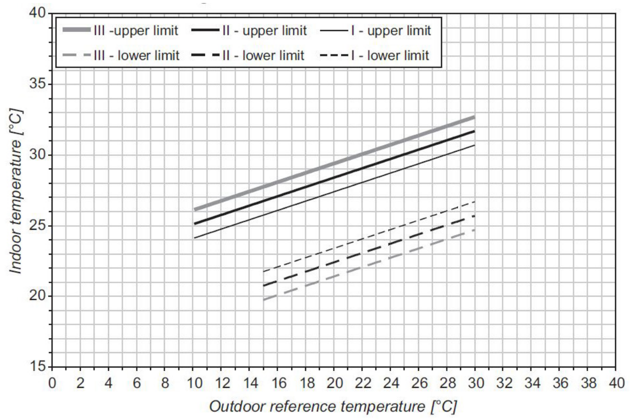


Fig 3.4: CEN Index comfort range.
Source: Article: Ferrari, Zanotto, 2011

3.3 DAYLIGHTING

Visual comfort is an essential component for biological needs of humans to be taked into account when desiging spaces.
When talking about illuminance is to refer to light, that "is defined as that portion of the electromagnetic spectrum to which our eyes are visually sensitive "[44]. As humans, we are not sensitive to see other electromagnetic wavelengths such as ultraviolet (UV)or infrared (IR). In fact, it would be dangerous to be exposed to them. The power of this visible spectrum portion is measure in Lumens (lm) and according to the International Sy-

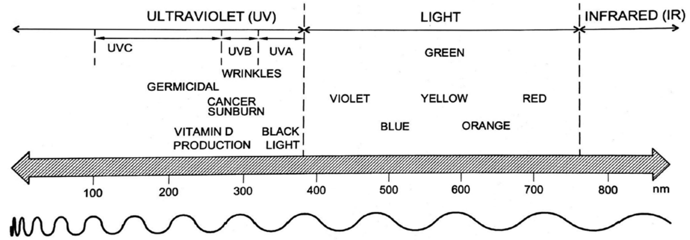


Fig. 3.5: Electromgnetic spectrum
Source: Lechner,2008.

41 Nicol JF, Humphreys MA. Adaptive thermal comfort and sustainable thermal standards for buildings.
42 deDear RJ, Brager GS. 1997 .ASHRAE RP-884 Final Report: developing an adaptive model of thermal comfort and preference.
43 Simone Ferrari*, Valentina Zanotto, 2011. Adaptive comfort: Analysis and application of the main

44 Lechner Norbert:, 2008. Heating, Cooling, Lighting. Sustainable methods for architects, Third edition; p. 346

stem (SI), the ratio between a quantity of lumens per 1 m² it is equivalent to Luxes (lx).
Indoor comfort is affected also by the color temperature (CT) of the light sources. A standard light is white and when it renders low CT with red colors, tends to be warm, while when it is high CT with blue color, its cooler. The white color normally accepted by people is form 3000 ºK to 4100ºK. In hot climates it is prefered to be used cool white light sources. As for the quantity of illuminance (lx), the color temperature must be applied differently between spaces according to it uses. For example, in a house it is preferable to have warm light, while in an office is better to use cold light in the morning and neutral one during the day.
Lighting harmony helps stimulating the body to do any daily activity and to manage correctly the circadian requirements, that regulates phsycological the sleep-wake cycles. According to William Lam, humans (applies also to most of the animals) have biological needs that could fullfill with lighting, such as the need for spatial orientation, need for time orientation, need for understanding physical forms of its surrounding, need to focus on activity, need for personal space, need for security, need for interesting visual points and cheerful spaces, and need for order [45].

Light from any source can also be transmitted, absorbed or reflected and it depends on the material of the surfaces that are exposed to the incident light. The reflected light it is called brightness and it is measure as a factor (RF), with a range between 0 and 1, where 1 is the total amount of illuminance. As for heating, white surfaces reflect more light than dark colors, that on the contrary have a high absorption property. The transmittance of light depends on the clarity of the surface and it could generates visual deformation, but not decreases the quantity of light. For example, in the case of the windows, a transparent glass allows to see the exact imagine without distortion, while a frosted glass deforms the image.
As our eyes are very sensitive to light, an excess of illuminance, either direct or indirect can cause discomfort and even pain. Norbert Lechner describes glare as "visual noise that interferes with visual performance"[46]. The closeness and angle of a position of a person respect to the light source can varies the glare exposition.

Despite lighting could be produced by electric sources, the most natural way to provide light into a building is with Daylighting, from the sunlight. Daylighting not only helps illuminating spaces, but also saves costs of energy demand by reducing the heating or cooling energy consumption. Sunlight is a source that is effective for almost the work hours of a day. Daylighting can be provided as direct or diffuse with clear sky and an overcast sky. With an overcast sky the quantity of illuminance decreases respect to the clear sky, but in a room with windows it is more than enough, depending on the position and size of the room and windows.

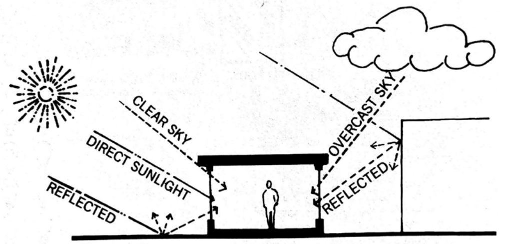


Fig. 3.6: Daylight sources.
Source: Lechner, 2008.. p. 218

Daylight design becomes a challenge because the amount of sunlight varies in the day and between places, and its indoors quality requires the understanding of the solar geometry of the site, and an accurate fenestration proposal. Some Sustainable building acreditation systems as LEED, have included some points for the contribution of 55% to 75% of the room for Illuminance and 75% to 90% of the room for Daylight Autonomy [47].

45 Lam, William M. C. 1977. Perception and lighting as formgivers for architecture. New York: McGraw-Hill.
46 Lechner Norbert: Heating, Cooling, Lighting. Sustainable methods for architects, Third edition; 2008.

47 LEED. https://www.usgbc.org/credits

3.4 NATURAL VENTILATION

To achieve indoor thermal comfort of a building, one important factor to take into account is the amount, direction and velocity of natural air movement or wind. The variation on wind characteristics between sites is caused on temperature and pressure differences in the atmosphere. " Desirable air movements should be utilized for cooling in hot periods, and as a relief from vapor pressure during times of high humidity. Conversely, air movements should be blocked and avoided during the cold season" [48]. When using natural ventilation as the main strategy of a building design, orientation and the shape of the building perform an important role to take advantage of the wind, among other strategies such as the used of windbreaks and openings in the opossite air pressure areas (Windward with positive pressure and leeward with negative pressure). Airflow performance depends also on the size of the buildings and their surrounding areas and could act differently outdoors and indoors.

Airflow from building`s outdoor is affected mainly by the geometry of the building, direction of the air and the surrounded landscaping. Wind barriers in the surroundings such as dense vegetation and solid ones like walls or another building could reduce the air speed and create calm zones in the windward area. This strategy is suggested mainly in cold or temperate zones to protect from the north wind, but for tropical areas iit could block the airflow needed. Also, It is not recommened to oriented a building exactly perpendicular to the wind direction.

The distribution of a community settlements in a city could also generate diverse effects of the wind. For example, in the hot humid climate the best position of a community should be an alternated location to take advantage of the wind, as it is shown in the (fig 3.7).
Inside a building the quantity of air and the velocity are more influenced by the quantity and location of the openings. Indoor air quality and air change

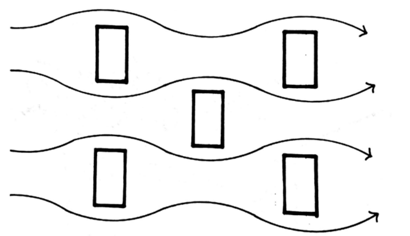


Fig 3.7: Buildings location in hot humid climate
Source: Lechner Norbert, Heating, Cooling, Lighting: Sustainable Design Methods for Architects, 3th Edition.

per hour are important requirements when providing ventilation either natural and mechanical method. According to Olgyay, single sided ventilated room tends to provide poor ventilation, unless the only window has a a higher outlet allowing to work as stack effect method[48]. Maximum airflow occurs when there are identical windows in the opposite facades. But if increasing air speed is the desire, the best way is to put a small inlet and a bigger outlet (Fig 3.8).

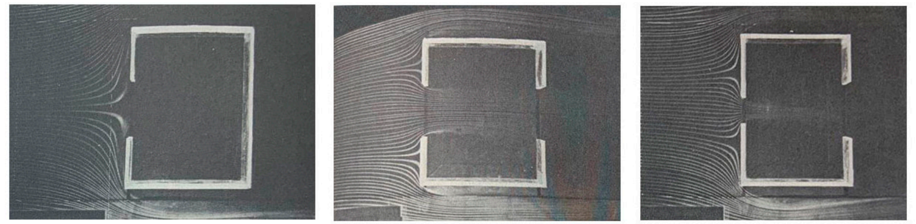


Fig 3.8: Airflow in room through the windows design
Source: Victor Olgyay. Design with climate. Bioclimatic approach to architectural regionalism. 1963 pag 104-

The third image shows a common strategy that could be apply to warm places with a smaller inlet and bigger outlet in the opposite side. "For summer cooling comfort sufficient speed is of more importance than the amount of air change, "Venturi effect" occurs, securing maximum air spe-

48 Olgyay, Victor, 1963. Design with climate. Bioclimatic approach to architectural regionalism. P.94;104.

eds within the structure"[49].
The calculations for the main requirements indexes as Indoor Air Quality (IAQ), Air Change per Hour (ACH), Air Quality for Cooling, among others for the different typologies of ventilation most used in tropical climates are described in the chapter 4.10 of this research.

3.5 ACOUSTIC COMFORT

Sound is a foundamental part of the acoustic study. Understanding the sound as oscilated waves that travel in a medium either through air or through objects and could be perceive through the ear by humans or animals. Then, according to Leo Beranek, expert on music, "Music is sound or combination of sounds that varies continuously or discontinuosly with time, usually rythmically, changing in pitch, timbre, and loudness in such a way as to comunicate something to listeners in its own terms. The composition and performance of music are arts" [50].

The phenomenum of sound is characterized by frecuency, clarity and pressure. Frecuency is the quantity of wave cycle in one second and its measure units is Hertz (Hz). In music the range of frecuencies more used are 125Hz, 250 Hz, 500Hz, 1000Hz, 2000Hz and 4000Hz. And the pressure measures the intensity of sound with decibels(dB).

There is a range that the human is capable to heard is from 20dB to 120dB and more, but from 75dB the noise could become on pain. According to the World Health Organization (WHO) humans could listened sounds below 70 dB during 24 hours and 75 dB during just 8 hours before generating possible deaf problems [51].

49 Olgyay, Victor, 1963. Design with climate. Bioclimatic approach to architectural regionalism. P.104.
50 Beranek, Leo.L. Music, acoustics & architecture. 1992, pag 31
51 https://www.cdc.gov/nceh/hearing_loss/what_noises_cause_hearing_loss

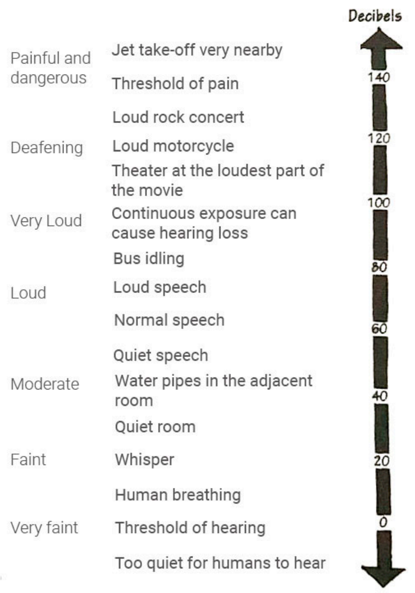


Fig 3.9. Loudness scale
Source: Erman, Michael.2015. p.5

The sound can be emmited, reflected and absorbed. Different sources can emmited sound, as in the case of music are the instruments and the human voice the sound producers. Materials have the properties of sound reflection and absorption. Absorption coefficient it is the quantity of energy of sound that it is absorbed or reflected from any material. This coefficient is important when calculating the reverberation time of the enclosure spaces, that is an important factor of performance buildings.

Reverberation is define as "the persistence of sound in a room after the sound source is suddenly stopped" [52] and it has been formulated by Wallace Clement Sabine in order to calculate the desired reverberation time. In the chapter 4.10 is described the Sabine`s formula that would be used to do the acoustic analysis.

52 Erman, Michael.2015. Architectoural acoustics illustrated. p 61

According to Antoni Carrión Isbert, in his acoustic design manual, "the success in the acoustic design of any type of enclosure, once its volume has been established and its shapes defined, lies first of all in the choice of the most suitable materials for use as coatings of the same in order to obtain reverberation times optimal"[53].Depending also on its form and dimensions each material could produces a different effect of the sound: Absorption, Reflection or Diffusion as it is shown in the fig 3.10. The absorptive material reflects less the energy of the sound, the reflective material has high reflection in one direction, while the diffusor reflects high uniformed energy in multiple directions.

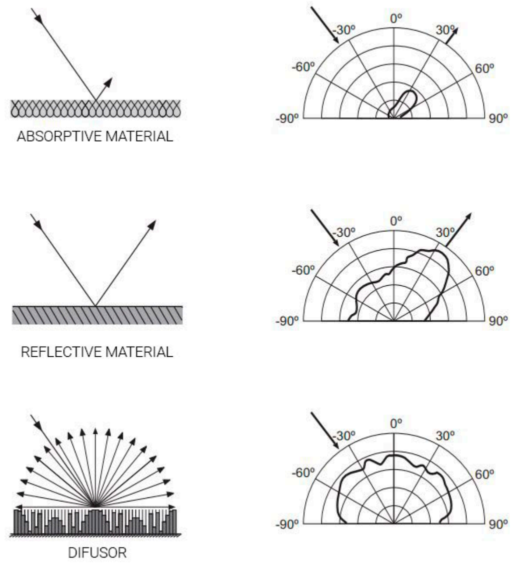


Fig 3.10 Effects of absorption, reflection and diffusion of sound
Source: Carrión, A .1998. P.123

In a building specially dedicated to music performance with long coursesschedules it is necessary to bring comfort from the acoustics. "Good room acoustics in a small music room enable a music teacher to more effectively teach subtle concepts such as intonation, articulation, balance, dynamics and tone production while a poor acoustical environment can adversely affect the development of basic musical skills of a music student"[54]. Since the case study of this reasearch is focous on a music school, the goal would be to improve the acoustic conditions, as well as to work with noise control between the rooms, seeking for comfortability inside the building.

53 Carrión, A . 1998. Diseño acústico de espacios arquitectónicos. Barcelona:Edicions UPC . P. 71
54 McCue, E., Rehearsal Room Acoustics, Acoustical Design of Music Education Facilities, E.McCue & R.H.Talaske Editors, Acoustical Society of America, New York, (1990) 36 - 41.

3.6 BUILDING DESIGN PARAMETERS

For all the climates, there are some parameters must be considered for a Sustainable design intervention. The first level approach is related to the design of the buildings. And it is suggested to take it into consideration from the beggining of a building design process, where the selection of the site, the urban context, the orientation and other parameters could bring a conscious and responsible solution not only for the environmental, but for the communities involved on it.

According to Norbert Lechner, the following are some of the basic parameters to reach a sustainable design [55]:

- Orientation
- Site selection
- Urban morphology and Topography
- Form and shape
- Colors
- Building materials
- Insulation materials
- Glazing- Transparent envelope
- Landscaping and Vegetation

55 Lechner Norbert: Heating, Cooling, Lighting. Sustainable methods for architects, Third edition; 2008.

3.7 PASSIVE DESIGN STRATEGIES FOR HOT-HUMID CLIMATE

The second level to follow when the basic building design does not manage to achieve comfort and reduction of energy consumption, is the use of Passive systems, consisting also of strategies based on natural energies.

PASSIVE COOLING SYSTEMS

In places where the microclimate conditions tend to be characterized by high temperatures, one of the main building design considerations should be oriented to avoid the heat gains, lowered the temperature and to cool the internal spaces in order to achieve thermal comfort.

To cool the buildings for hot climates, whether for humid or dry ones, there are some cooling systems called passive that are natural since they are not based on mechanical equipment to produce the energy needed to refresh. However, mechanical system is required in a small proportion where passive strategies are not sufficient to decrease the therml discomfort. According to Baruch Givoni, one of the most representative of the bioclimatic architecture, the passive cooling systems are classified like this [56]:

- Comfort Ventilation
- Night Flush Cooling
- Radiant Cooling (Direct- Indirect)
- Evaporative Cooling (Direct- Indirect)
- Earth Cooling (Direct Coupling- Indirect Coupling)

Taking into account the microclimate of the case study, just the strategies that works for a microclimate with hot temperatures, high percentage of humidity, long raining periods and partially cloudy the whole year will be described in detail. Strategy as Night Flush Cooling, where the building is open thw whole night but closed in the day, is not the best for the case study since
it will be used mainly in the afternoon where the temperatures are high.

Radiant Cooling system uses the roof and the sunlight to cool, but is not appropiate for microclimates characterized by a cloudy sky. That is the case of Villavicencio, the city of case study. And Earth Cooling uses the ground to bring cooling efect, but the excess of condensation could cause biological decays on the walls and structure in humid climates.

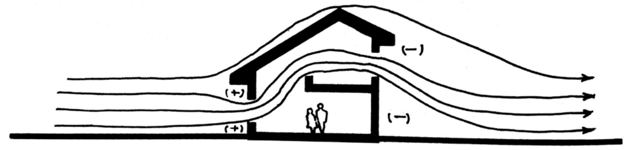
- Comfort ventilation

To increase the comfort in a building specially during the day, the more natural system is to allow the airflow passing over the occupants and through the skin of the building. Airflow crossing the building creates a cooling effect due to the capacity to control indoor humidity by evaporating the excess of moisture. Siting and orienting the building to the prevaling wind direction, but with an oblique angle (30-60º) than a perpendicular orientation [57].

For this, high ceilings and light mass of the building construction is appropiate, but a moderate insulation also could helps to reduce the heating from radiation that increase the indoor temperatures.

Fig. 3.11 Comfort ventilation

Source: Lechner. 2008. p. 280



56 Givoni, Baruch. 1994. Passive and low energy cooling of buildings. New York: Van Nostrand Reinhold
57 Lechner Norbert. 2008. Heating, Cooling, Lighting. Sustainable methods for architects, Third edition. p.282

The size and amount of windows are also important. The suggestion for a complete comfort ventilation system is to have operable windows with an area between 10 and 20% of the floor area. The use of shading devices in the windows, helps to protect the interior from overheating. When there is a raining period is recommened to keep opened the windows, to avoid the increase of humidity.
The use of cross-ventilation is the most recommended when it is possible. Having windows in the opposite sides allows the airflow to be pushed and pulled from a room. This type of ventilation depends on the difference of pressures of the wind between the windward (+) and leeward (-) sides. However, the stack ventilation could also works, since it does not depends on the wind, but on the temperature difference between indoor and outdoors. For this, the minimum temperature difference should be 1.7 ºC. With this the air is entering from the lower part and the hot air is going out from an upper part of the building.
Since this technique would be not enough when there is not good air velocity of at least up to 1 m/s, some fans, preferible exhaust ceiling fans, are recomended to increase the air movement.

- Indirect evaporative cooling

When a building uses water to cool it thought an evaporation process it is called evaporative Cooling. Contrary to a direct evaporative method, that implies the spread of water particles into the indoors, the Indirect evaporative system brings cooling efect evaporating water from outside the building [58].
Water ponds, in between a slab and an insulated roof that shades the pond from the sun, are an example of this method. The protection from the roof allows the water not to evaporate inmediately with the sunlight, but to be evaporated by the accumulated heating from the skin.

The advantage of this system is that it does not add humidity to the building as the Direct evaporative does. It just helps to increase comfort.

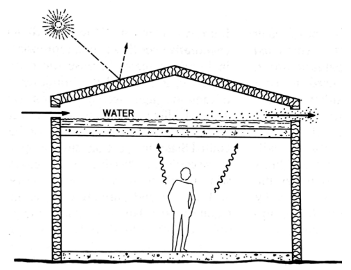


Fig 3.12 Indirect evaporative Cooling

Source: Lechner 2008. p.288

HUMIDITY CONTROL

- In areas where the humidity and the effet of condensation is high it is important to apply systems to dehumidificate the air. The best way to reduce the humidity is through natural ventilation. Having openings and windows, allows the constant airflow to control humidity. The use of exhaust fans also reduces the humidification, but if the Relative humidity is over 60% it would be necessary the use of dehumidifiers.

- The use of a wind barrier out of the skin of the building prevents the humid air entering and keeps the interior dry. A layer of insulation not porous acts as a vapor barrier or vapor retarder , but t is not recomended to use more than one. There is a variety of materials that works as vapor barriers, but the most common ones are polyethylene, polypropylene and bitumen.
- Materials with large hygric buffer properties are capable to storage moisture until Relative humidity decreases. Wood, brick and cellulose insulation are good examples.

58 Lechner Norbert. 2008. Heating, Cooling, Lighting. Sustainable methods for architects, Third edition. p.288

VEGETATION

ɷ Plants and trees around a building helps decreasing the temperature by transpiration, cooling the air of its sorroundings. Contrary to the concrete surfaces or man-made canopies, vegetation does not heat up. It is reccomended to use native species that are more adapted to the environment conditions.

ɷ To shade from direct sun, the strategy is to plant high canopy trees on East and West mainly. High trees allow to protect from the sun and also does not block the wind flow that is important for hot humid climates. Another way of shading is the use of Trellis or pergolas cover by vegetation.

ɷGreen roofs not are just able to reduce the heat loads from a building, but also to reduce the efect of urban heat island of the context in the city. The evotranspiration from the soil and plants produce cooling effects. Besides the cooling effect and noise reduction, "one of the great advantages of green roofs is the reduction os torm water runoff, which has both economic and environmental benefits"[59].

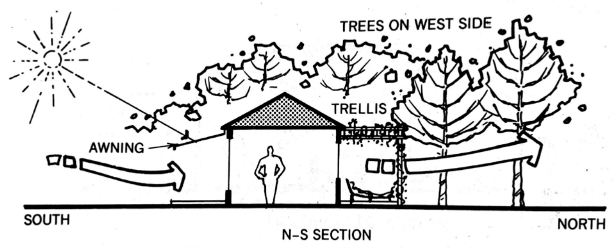


Fig 3.13 Vegetation for Hot humid climates
Source: Lechner ,2008. p. 336

59 Lechner Norbert. 2008. Heating, Cooling, Lighting. Sustainable methods for architects, Third edition. p.330

SOLAR CONTROL AND DAYLIGHTING

ɷ To reduce the quantity of direct and diffuse solar radiation and to improve the quality of natural lighting in a building must be considered some approaches. Improving the use of passive design also helps reducing the energy consumption regarding to the need of lights, therefore, the maintenance costs of the building.

ɷThe building should be oriented facing mainly south and north sides to avoid the direct sunlight. Glazing in East and West facades are less recommended to locate windows, unless they are deviated facing more South and North. This is because they receive all the direct sunlight.

ɷVertical and large windows are more effective if they are well shaded

ɷ Use of shading devices, mainly in the exteriors and not only to shade windows, but also the walls that receive more solar radiation as South. The shading devices should be located according to the sun path. On East and West facades works the implementation of vertical shading devices or mixed with horizontal ones, while for south the best choice is an horizontal one and they could be fixed or movable.
However, the design for buildings located in the tropics with a latitude 0º, with a sun path that passes overhead at midday, the facades that receive more sunlight are West and East, while South and North just receive it in the summer and winter equinoxes.

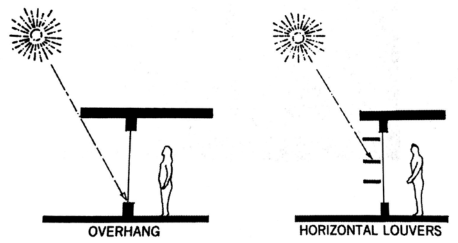


Fig 3.14 Horizontal shading devices
Source: Lechner, 2008.p. 400

Some of the examples of fixed or movable shanding devices are: Horizontal overhang, horizontal louvers and vertical fins, eggcrates (combination of horizontal- vertical) and mircoperforated panels.

ɷ Skylights provide good daylighting but it has to be shaded reduce glare effect, otherwise should be avoided. Instead of skylights, Clerestories are a better option.

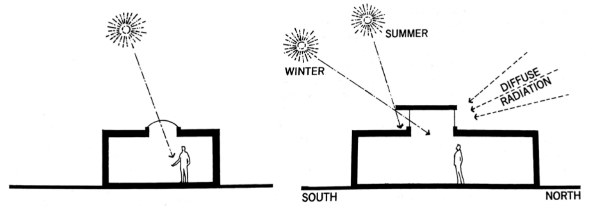


Fig 3.15 Skylight/ Clerestory
Source: Lechner 2008. p. 309

ɷTypology of glazing of the transparent envelope not only contributes to reduce heat gains, but also to protect the interiors from the sunlight by reducing that glare occurs. Just with a single clear glass the radiation is not totally transmited into the interiors, since it is partially absorbed and reflected. But the use of more layers of glass decrease the amount of sunlight.

Other glazing option is the tinted glass, commonly bluen green and brown, that are characterized by high solar absorbance. But has disadvantages such as bad light quality and thermal stress.
Reflective glazing is composed by a metal coating and is effective blocking solar radiation without decreasing the light and obstructing the view. The higher is the percentage of reflectance, the lower is the transmitance.With this type, has to be avoided the use of high percentage of reflectance because of the effect of glare to the exteriors.

To have good cool daylighting without having solar heating gains, the best solution is with a Spectrally Selective glass. It is a double glazing with a metaloxide coating that allows high transmission of Visible wavelengths of the solar spectrum, while rejecting the Infrared ones.

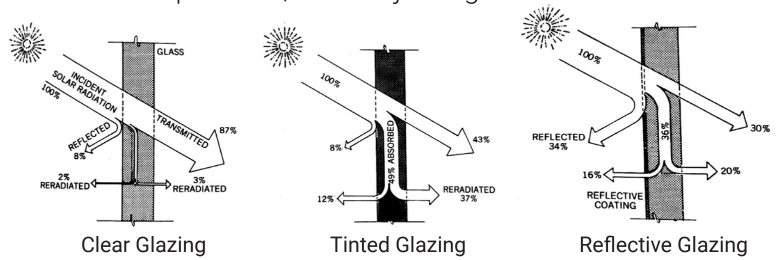


Fig. 3.16: Glazing type
Source:Lechner, 2008. p. 406

THERMAL PERFORMANCE

ɷAlthough for hot humid climate the structure should be light, the addition of a layer of insulation in walls and roof from the outside allows also to prevent the building from heating gains.

ɷ The time-lag of building materials can be use as thermal performance, but it is not as effective as the insulation. For hot season, and where the East and South facades receive more radiation, the building materials should have a very long time-lag up to eight hours, while in the West side could be less until the sunset. Materials such as adobe and brick have 10 hours of time lag.

ɷ Use of light colors with high SRI (Solar Reflective Index) for external walls and roof reduces high temperatures. The higher is the albedo of the materials, the more solar radiation is reflected, thus decrease the heating.

ɷ Avoid thermal mass in the case of full passive strategies design. If air-conditioning, thicken walls in order to prevent cool loss in the room from the mechanical equipment.

3.8 CASE STUDY REFERENCES

Much of the terms and concepts explained in this chapter can be understood through their application on many buildings with different uses from the past until now. Sustainable projects have been increased in the industry of construction expanding the consciousness of the use of design strategies according to the different microclimates and the need of contribute to save energy.

To analyze how to apply some of the parameters of design described before, some international references with a variety of uses have been selected, with a common factor: the location in the tropics. From educative and working to residential and healthcare buildings in some countries with the same or similar microclimate.
The selection of the projects has been determined by the climate conditions according to the koppen climate classification, in this case the ones are in the group A: Tropical. Much of them are classified as Am that means equatorial monsoon, that is, with high temperatures, long periods of precipitation and high relative humidity as average in the year [60]. There are others with Aw classification, that is equatorial with dry winter. It means warm temperatures with precipitations mainly in summer but not as much as the equatorial monsoon.

The design of the selected buildings are based mainly on passive strategies for hot-humid climate, that are main goal of this work. Some of the common strategies are related to solar control and passive cooling taking into account the need to reduce the levels of humidity that generate discomfort and to minimized the heating gain in the building. However, other important design features are taken into account as orientation, materials and colors of surfaces, vegetation as well as the particpation of the communities in the construction process.

60 World maps of köppen-geiger climate classification. http://koeppen-geiger.vu-wien.ac.at/present.htm

Taking into account that the study is focus on hot-humid climate conditions, it has been selected also a reference from Italy that although is not part of the equatorial zone, has some territories with summers with similar characteristics. The Cfa classification refers to temperate climate with fully humid hot summers. The north and north-west area of Italy presents these conditions.

The following building references show the main strategies of each project that are focus in different aspects such as ventilation, solar control, acoustics, recycling, among others, selected and catalogue by colors demonstrating the variety of possibilities when designing a sustainable project with these specific microclimate conditions.

3.8.1 INTERNATIONAL REFERENCES

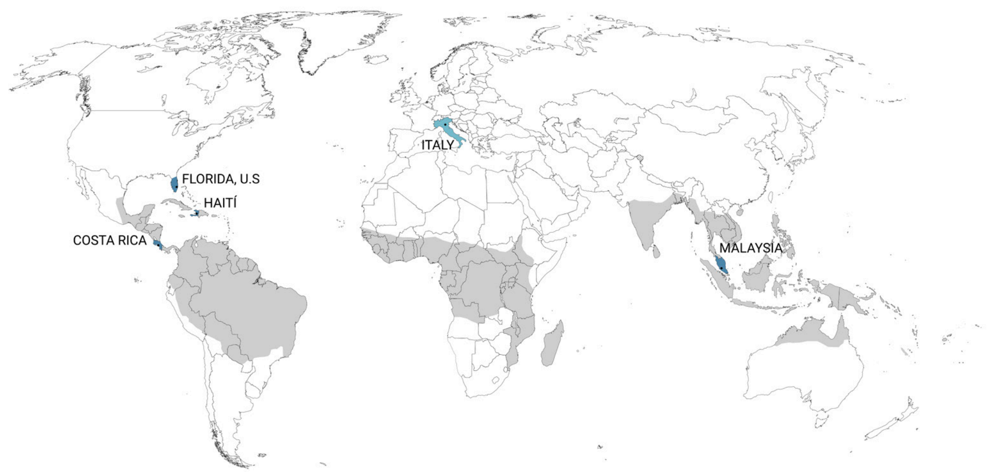


Fig 3.17: International references map
Source: Author´s elaboration

BRITISH AMERICAN TOBACCO COSTA RICA

"A great place to work" [61], was the moto to design this office building in Heredia - Costa Rica in 2006, by the architect Bruno Stagno. Its facade draws attention due to the large eaves that generate shade creating visual and thermal comfort inside the building. Some of the main environmental strategies are described below.

Fig 3.18: British American Tobacco Facade
Source: https://arquitecturapanamericana.com/british-american-tobacco/

- The design seaks to combine a open working and collaborative spaces with the natural context characterized by a tropical climate.
- Located next to the existing trees in order to keep the building fresh. Additionally, it was considered new types of vegetation as Hibiscus (Tropical plant) and bamboo trees to create more shadowing.
- The floor of the building is constructed elevated and separated from the ground level to decrease the temperature and reduce the humidity. The floor elevation helps on reducing the costs on mechanical ventilation equipments and saving energy.
- Horizontal light overhangs, oriented with a small ngle of slope, are placed over the facades for shadowing and to reduce the direct sun mainly in the sunset.
- Open inside spaces and permeable ceilings allow the air to flow without obstacles.
- Saving rainwater through the construction of a deep water tank that collects the water and reuses it to irrigate the gardens. It also releases the water in a dosed way to the urban rainwater system.

Fig 3.19: British American Tobacco interior and exterior photos
Source: https://arquitecturapanamericana.com/british-american-tobacco/

61 https://arquitecturapanamericana.com/british-american-tobacco/

GHESKIO TUBERCULOSIS HOSPITAL

This hospital has been designed in Port-au-prince, Haiti in 2015, by MASS Design group, and it is an innovative center for tuberculosis treatment "focused on minimizing the risk of transmission, while creating a more comfortable and supportive space to receive care" [62]. The key of the project is the cross ventilation design that is totally required for the isolated conditions of the treatment, as well as the design of a white exterior envelope for thermal comfort. Among other environmental strategies described below.

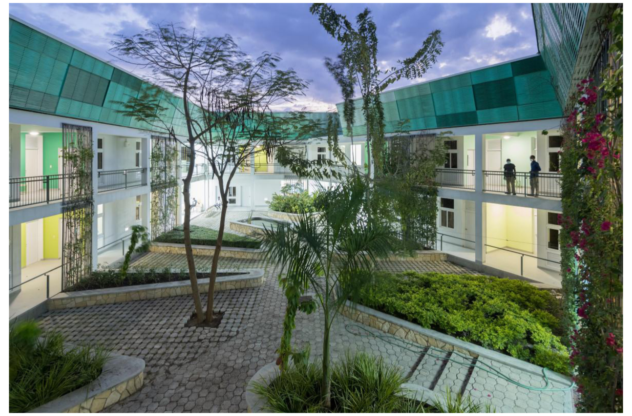


Fig 3.20: Interior courtyard Gheskio Tuberculosis Hospital
Source: https://massdesigngroup.org

- The building creates a green open central coutyard with interior corridors allowing sharing community spaces.
- Passive ventilation strategies as cross ventilation reducing the high risk of transmission of the disease.
- Fixed and directional metalic louvers in the down part of the windows allowing correct airflow through the isolated rooms.
- Fixed vertical and horizontal fins in the exterior facade to avoid the re-entry of the polluted air.
- Extraction of polluted air through exhaust fans into the exterior walls.
- Vertical bamboo porous screens in the interior facades for visual privacy and reducing glare of the direct sun.
- One high slope roof with an open air trust to decrease the heat in the building.
- Reflective white colored roof to control the hight temperatures. Permeable soffit and ceiling for great airflow

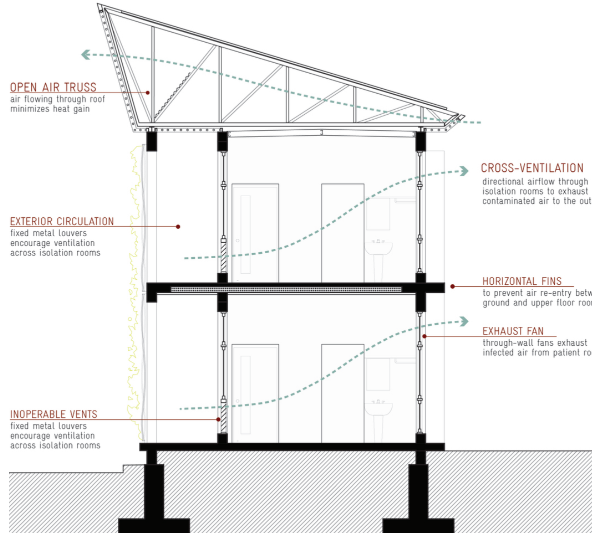


Fig 3.21: Cross ventilation section scheme
Source: https://massdesigngroup.org

Fig 3.22: Roof and hall Photos
Source: https://massdesigngroup.org

62 https://massdesigngroup.org/work/design/gheskio-tuberculosis-hospital

"DESA MAHKOTA" SCHOOL

This school has been designed in Kuala Lumpur - Malaysia in 2013, by the architect Eleena Jamil. In the design "the linked spaces are considered an 'architectural promenade' where a lot of informal teaching and interaction between students will take place"[63]. The open corridors and its cooling night system allows the building to be thermally regulated. Among other environmental strategies described below.

Fig 3.23: Desa Dakota School
Source: https://www.archdaily.com/470704/desa-mahkota-school-eleena-jamil-architect

- Linear buildings with different scale separated by coutyards with local vegetation.
- Facade openings oriented North and South to avoid direct sun from East and West.
- Cross ventilation in the classrooms with louvered windows on windward and leeward sides. Ceiling fans inside the classrooms.
- Vertical fins and horizontal and slab overhangs on North side allow shading and reduce glare.
- Open corridors on south facade for shading and ventilate
- Prefabricated structure assembled on site reducing time and costs
- Floors and ceilings in concrete allowing the absorption of heat during the day and its release in the night.

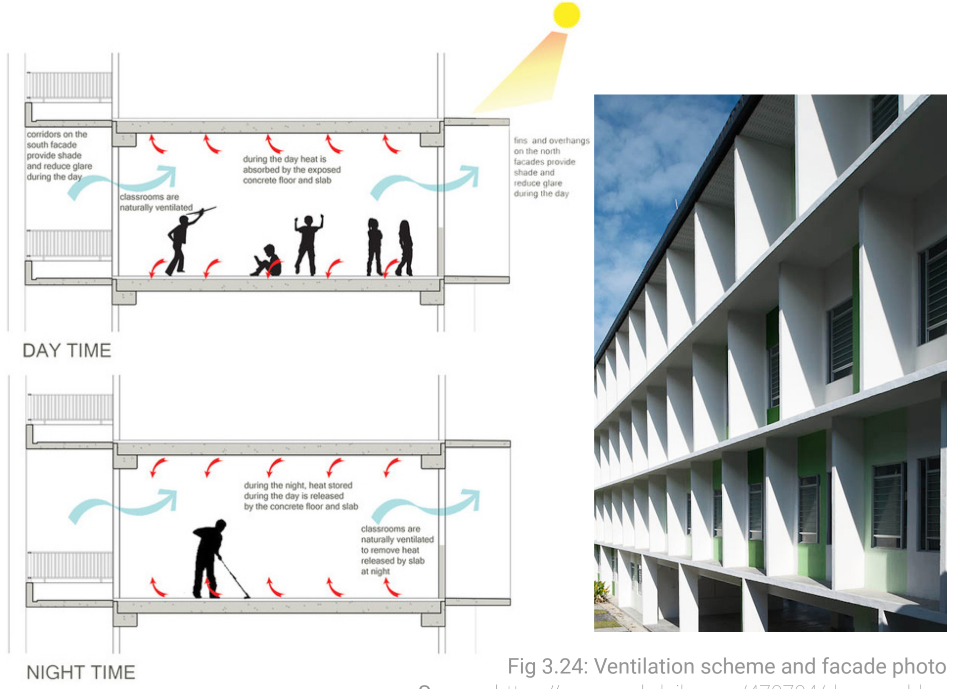


Fig 3.24: Ventilation scheme and facade photo
Source: https://www.archdaily.com/470704/desa-mahkota-school-eleena-jamil-architect

63 https://www.archdaily.com/470704/desa-mahkota-school-eleena-jamil-architect

BRILLHART HOUSE

The house designed in Miami - United States in 2014, by Jacob and Melissa Brillhart, is based on the principles of Tropical Modernism mixed with "the seemingly forgotten American Vernacular, and more specifically, the Dog Trot"[64]. The central breezeway links the 2 main spaces and allows continous natural ventilation thanks to the shutters on facade.

Fig 3.25: Brillhart house Exterior
Source: https://brillhartarchitecture.com

- The house is built elevated from the ground arround 13 cm refreshing the interior and reducing the humidity.
- Sliding glass door-windows along the front and back side and movable door shutters on the porches allow a cross ventilation.

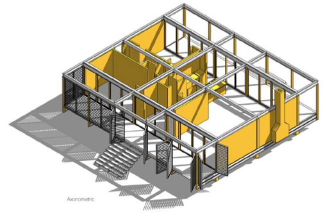


Fig 3.26: Axonometry Brillhart house
Source: https://brillhartarchi-tecture.com

64 https://brillhartarchitecture.com/gallery/brillhart-house-3/

- The six sides of the building are insulated with rigid and icyne spray insulation and thermal glass (14mm) increased the R-value for better comfort.

MUSIC SCHOOL OF PIEVE DI CENTO

Inspired on the music tradition of the city and " the theme of the soul of musical instruments, in particular refering to the sound box"[65], the italian architect Mario Cuccinella has designed this music school in Pieve di Cento-Italy in 2017. Its double roof and wooden envelope material create acoustic, but also thermal comfort, both at the interior and exterior.

Fig 3.27: Music school Pieve di Cento image
Source: https://www.mcarchitects.it

The building iluminated at night works a "lantern" for the city. The school has become a landmark because of implementation of a lot of environmental strategies described below.

- Located in a urban and social transformed area of the city that is connected by a cycle route to the historical center. Thus, is a meeting place for the community, not only for music field.
- The exterior and interior envelope are in curved oak wood panels that help amplifying the sounds. The ceiling is made by accoustic pannels.
- System of double roof. The external one is curve an elevated allowing the circulation of the air and the extraction of the interiors heating in summer.
- The extension of the roofs creates shadows around the building.
- 28% of the energy is produced by solar panels located in the roofs.
- Elevated albedo of the material of the roof reducing overheating inside.

65 https://www.mcarchitects.it/project/the-music-school-of-pieve-di-cento

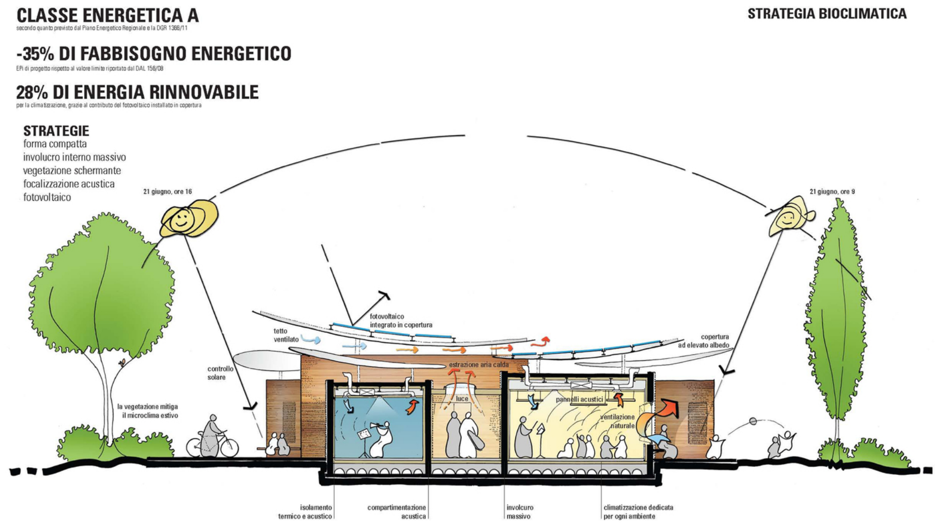


Fig 3.28: National references map
Source: https://www.mcarchitects.it

3.8.2 NATIONAL REFERENCES

As it was explained before in the chapter 2, Colombia has a variety of climates eventhough it is located in the latitude 0. Thus, there are region with hot and dry or humid climate, and cold climate as well near to the mountains. To analize some case tudies of the country, it has been selected some projects that are located in a region that is chatacterized by hot- super humid, and hot - semi- humid climate. The two cases are good references on the use of passive environmental strategies in this specific type of climate from a national sustainable construction context.

Fig 3.29: National references map
Source: Author's elaboration

“MINGA” PROTOTYPE HOUSE (Solar Decathlon 2019)

For the Solar decathlon 2019, an international student contest for sustainable housing design, the winner project was the “MINGA” House, in Buenaventura- Valle del cauca and designed by an alliance between the Pontificia Universidad Javeriana Cali (Colombia), Universidad Federal de Santa Catarina and Instituto Federal de Santa Catarina (Brasil). The aim of the project was to solve the “problem of human settlements located on the maritime fronts of the tropical region of the planet, which are at risk of flooding as a result of the rise in sea level, a product of global warming”[66]. Some of the strategies to achieve it are described below.

Fig 3.30: MINGA house
Source: https://www.archdaily.co/co/938809/propuesta-de-vivienda-para-comunidades-sostenibles-en-la-costa-de-buenaventura-colombia

- Co-housing prototype buildings based con adaptability as a main concept with the possibilty to accommodate 1 or 2 families on each house and constructed it by modules.
- The house is elevated from the ground taking into account the rise of the sea level of approximately 2% by 2050 due to climate crisis.

- The modularity allows to build towers of 6 floors with the co-housing prototype. The ground floor is over a flexible platform with afloat system.

66 MINGA HOUSE.https://www.archdaily.co/co/938809/propuesta-de-vivienda-para-comunidades-sostenibles-en-la-costa-de-buena-ventura-colombia

- Use of double skin facade ventilated. One for the private modules with horizontal panels, and the general one with a permeable wood design.

- Insulated rooms. The wall is composed by 2 wooden panels with a fiberglass layer in between.
- Surfaces with color painting with lower albedo and representative of pacific traditions.

- Use of local materials for the structure and elements of the facade as cultivated laminated wood and reycled materials as recolected Tetra pak (Carton packaging).
- Passive cooling strategies as cross ventilation in private rooms and common spaces through open facades and shutters.
- Active systems with low comsuption in the private rooms as air conditioning and extraction fans supported by solar panel energy

- Designed with a double roof, one flat covering the private areas, and a second gable roof over it to protect the open common areas and the whole house of the solar radiation, rain and to allow good airflow in between.

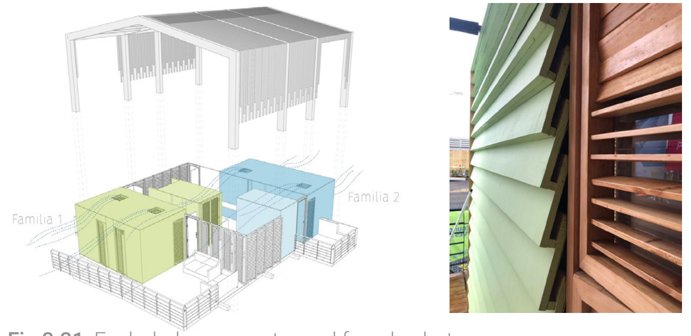


Fig 3.31: Exploded axonometry and facade photo
Source: https://www.archdaily.co/co/938809/propuesta-de-vivienda-para-comunidades-sostenibles-en-la-costa-de-buenaventura-colombia

“CDI EL GUADUAL” KINDERGARTEN

“El Guadual” is a kindergarten located in Puerto Tejada-Cauca and designed in 2013, by Daniel Joseph Feldman Mowerman and Iván Dario Quiñones Sanchez. The building is a result of a participatory process that “has been a victim and witness of the conflict and violence that have plagued much of the rural areas of our country” [67]. Its design is characterized by the use of natural local material such as the guadua for the solar control and natural ventilation system, as well as its insulated envelope. Among other environmental strategies described below.

Fig 3.32: CDI El Guadual Courtyard
Source: https://www.plataformaarquitectura.cl/cl/625198/centro-de-desarrollo-infantil-el-guadual-daniel-joseph-feldman-mowerman-ivan-dario-quinones-sanchez

- The design was a participatory process between architects, citizens, professors and students

- Constuction was made by the local people and the participation of artisans of the region

67 https://www.revistaaxxis.com.co/arquitectura/la-sostenibilidad-como-necesidad/l

- Insulated envelope for thermal control: Thick walls insulated with icopor and thermoacustic roof with fiberglass.

- Overhangs and shutters made with Guadua, a natural resource of the region. Their distribution allows the continuous entrance of natural ventilation while protecting from sun.

- Ceiling made with natural cane as a traditional material of the region

Rainwater colletion through exposed tanks and a man-made stream that are vissible to teach the kids

Fig 3.33: Corridors and Interior of a classroom photos
Source: https://www.plataformaarquitectura.cl/cl/625198/centro-de-desarrollo-infantil-el-guadual-daniel-joseph-feldman-mowerman-ivan-dario-quinones-sanchez

2.6 CONCLUSIONS

Tropical architecture focuses mainly on hot climate conditions that could be dry or humid, however, the microclimate could vary depending on many elements such as the elevation above sea level, and the form of the land, among others, that should be evaluated before starting a project. Although in this climate a greater capacity for adaptation by citizens to high temperatures or high levels of humidity, it is important to improve the thermal, visual, and acoustic comfort in the buildings

As a summary of the concepts described in the chapter, the best strategies to be taken into account when designing or renovating any building in a place with a hot - humid climate include solar control and avoiding heat avoidance, as well as the appliance of passive cooling systems.
Thermal comfort depends mostly on the appliance of natural ventilation. For this specific climate, the most recommended system is comfort ventilation through Cross- ventilation, which depends on air pressure or Stack-ventilation, on temperature differences. Besides cooling from a ventilation strategy, another way to increase comfort is by reducing the heat gains from solar radiation. During the design phase, it is important to orient the building avoiding long facades on the east and west, as well as locating windows there, because of the high and direct sun exposure. For this, it is important to shade, not just the windows, but the walls by using shading devices, preferably fixed overhangs and deep eaves to protect from midday solar radiation, and some vertical fins or shutters (Operable if possible) to protect it in the morning and evening. Type of glazing is also important to reduce heat gains by transmission, so it is recommended to design at least with a double-glass window, or a Spectral selective glass for better performance. This strategy is also applied to improve visual comfort by reducing glare while taking advantage of as much as possible the daylight. Additionally, to increase indoor comfort is it useful to add insulation on roofs and walls when exposed to direct solar radiation. Mineral materials help not only to decrease temperature but also to improve acoustic performance and noise control. However, massive walls are not recommended in this type of climate where is better to design lightweight structures buildings and elevated from the ground, if possible.
High levels of humidity increase thermal discomfort, thus the main strategy to control it should be by increasing natural ventilation. Fans could help to increase the speed of air when there is no wind. Vapor barrier membranes or coatings on exterior walls and in between the roof can also help to reduce the risks of condensation. In this type of climate should be also avoided any water source, such as fountains, as well as the addition of extensive vegetation would increase the humidity level by the evaporation mechanism. However, high canopy trees are recommended to cool temperatures while allowing constant airflow.

Light-colored opaque envelopes are useful to avoid heat gains from solar radiation and to reduce temperatures in hot climates. It is recommended to propose roofs, exterior walls, and surrounded surfaces with reflective materials and/or color coatings with a high SRI (Solar Reflective Index). White color is the best reflective option. To cool temperatures it is also suggested to design intensive or extensive green roofs while improving air quality and allowing to reduce the heat urban island effect of the city. From the international and national case study references presented in the chapter, it is possible to conclude that many passive strategies could be used when designing properly any building in a hot-humid climate. The most recurring strategies in those reference buildings are solar control by providing multiple horizontal and vertical shading devices, light-colored envelopes to avoid heat gaining, naturally ventilated spaces with a cross-ventilation system, use of local and natural materials for finishing and the exterior envelope, elevated floors and rainwater collection, among others. All these strategies and others mentioned in the chapter are the keys to proposing well-designed and comfortable buildings for users and respectfully with the environment.

4.

CASE STUDY BUILDING ANALYSIS

To understand and apply all the concepts about tropical architecture for the hot- humid climate described before, it has been selected a house of music in Villavicencio as a case study. This fourth chapter aims to do a qualitative and quantitative environmental evaluation of the current building and then propose an improvement through a renovation design.

The chapter starts with the main characteristics of the music foundation that takes place in the house called "Casa de la musica". Then, the house is analyzed from its current design, from the physical characteristics of the spaces to the functional program through plans and photos of the place.

The first evaluation is about the building design (first category), which is carried out by a general qualitative analysis of the materials, constructive system, and decays through observation and current plans of the entire building. On the other hand, it is developed a quantitative evaluation of different elements, such as the transparent and opaque envelope of the building. Then, to extend the evaluation, to understand the current performance of the interior spaces of the building, it has been selected 8 rooms. Each room has been evaluated in 4 categories: Thermal comfort, Daylighting, Natural ventilation, and Acoustic comfort. The evaluation has been executed through different calculation systems and software that are explained in the chapter.

Finally, after all the analysis is done, the results of the current performance of the different spaces will allow identifying the problems and some opportunities to consider for an improvement proposal

"CASA DE LA MÚSICA"

"Batuta Meta"

Fig 4.0:Exterior "Casa de la Musica"
Source: Author´s Photography

4.0 HISTORICAL AND SOCIAL CONTEXT OF THE INSTITUTION

Corporaciòn Batuta Meta was founded in 1997 and is part of the Fundaciòn Nacional Batuta. A non-profit national foundation that seeks "to contribute to the improvement of the quality of life of children, adolescents and young people in Colombia, through musical education of excellence, focused on collective practice, from a perspective of social inclusion, rights and cultural diversity"[68]. With the support of the national government, local governments, and some private companies, the foundation has been able to expand, achieving coverage in many cities and vulnerable areas of the national territory.

In Villavicencio, capital of Meta Department, Batuta Meta was created with the collaboration of Casa de la Cultura Jorge Eliecer Gaitan and the Inem Luis Lopez de Mesa School. The first Pre-orchestra classes made up of 50 children and the subsequent creation of the Batuta Meta Experimental youth symphony Orchestra were held in the classrooms of these buildings, until 1998 when a house was rented for some years. However, the lessons were held in different parts of the city, due to the lack of space, until 2000 when the center worked in the current building thanks to the collaboration of the local government.

Fig 4.1: First generation of students 1997/ Source: Batuta Meta Foundation

68 https://www.fundacionbatuta.org

4.0.1 THE HOUSE

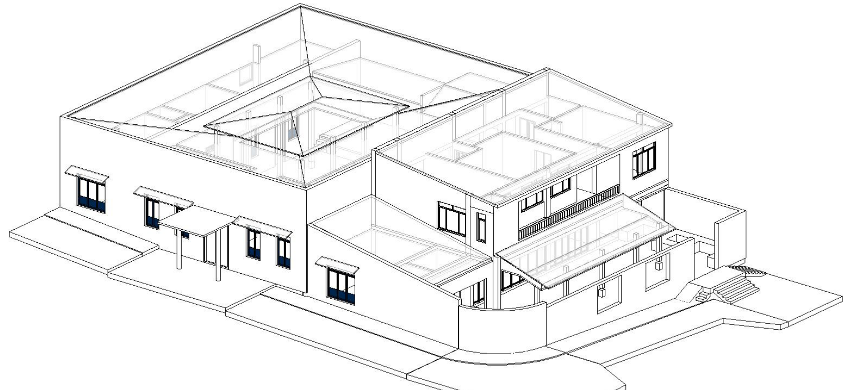


Fig 4.2: Current house axonometry/ Source: Author´s elaboration

The current house, the object of this work, corresponds to a donation made in 2000 by former Governor Alan Jara Urzola (1998-2000), which was set up as the main center of Batuta Meta for musical training in this region.

The house was constructed and adapted to the function of a music school. It has individual and group classrooms, services areas, administrative offices, resting places, and a small scenario for their musical performances

There is a lack of information about the original house, thus there is no certainty of the year of construction of the house, nor are there original plans. However, it can be presumed that it should not have been built before 1950, according to the historical plans of the city. Before the current renovation, there was carried out an architectural survey of the house by the designers. By analyzing the survey plan, it is also possible to assume that the original design of the house had the design emulated the appearance and main characteristics of colonial architecture (described in chapter 2.5), despite not being exactly built at that time. Exterior walls without windows, an interior courtyard with corridors and rooms with high wooden windows and doors, thick walls of 25 cm, and a big entrance with a "zaguan", are some of the characteristics that could more or less be appreciated through the plan below.

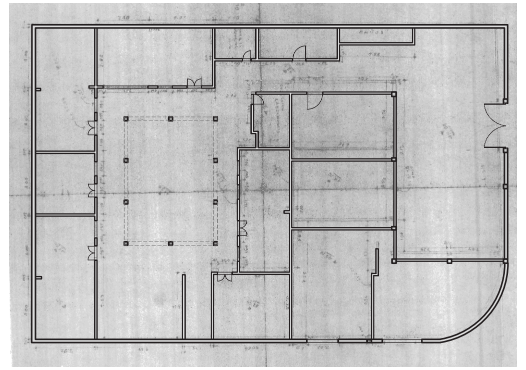


Fig 4.3: Survey plan Original house scale 1:500/ Source: Batuta Meta. Author´s edition

In 2012, there were some architectural interventions of the house due to the degradation of some materials. The skylight of the scenario and main entrance was replaced, as well as some tiles of the roof. The facade and furniture inside the hose were painted again. And the walls of the orchestra room were changed and adapted to improve acoustics.

After some economic and administrative issues within the corporative center, during the last years, the infrastructure of the building was abandoned and degraded. Today, with a new administration, the house has been recovering through some quick solutions to mitigate the negative impact of the microclimate due to some problems with the materials and construction.

4.0.2 USERS

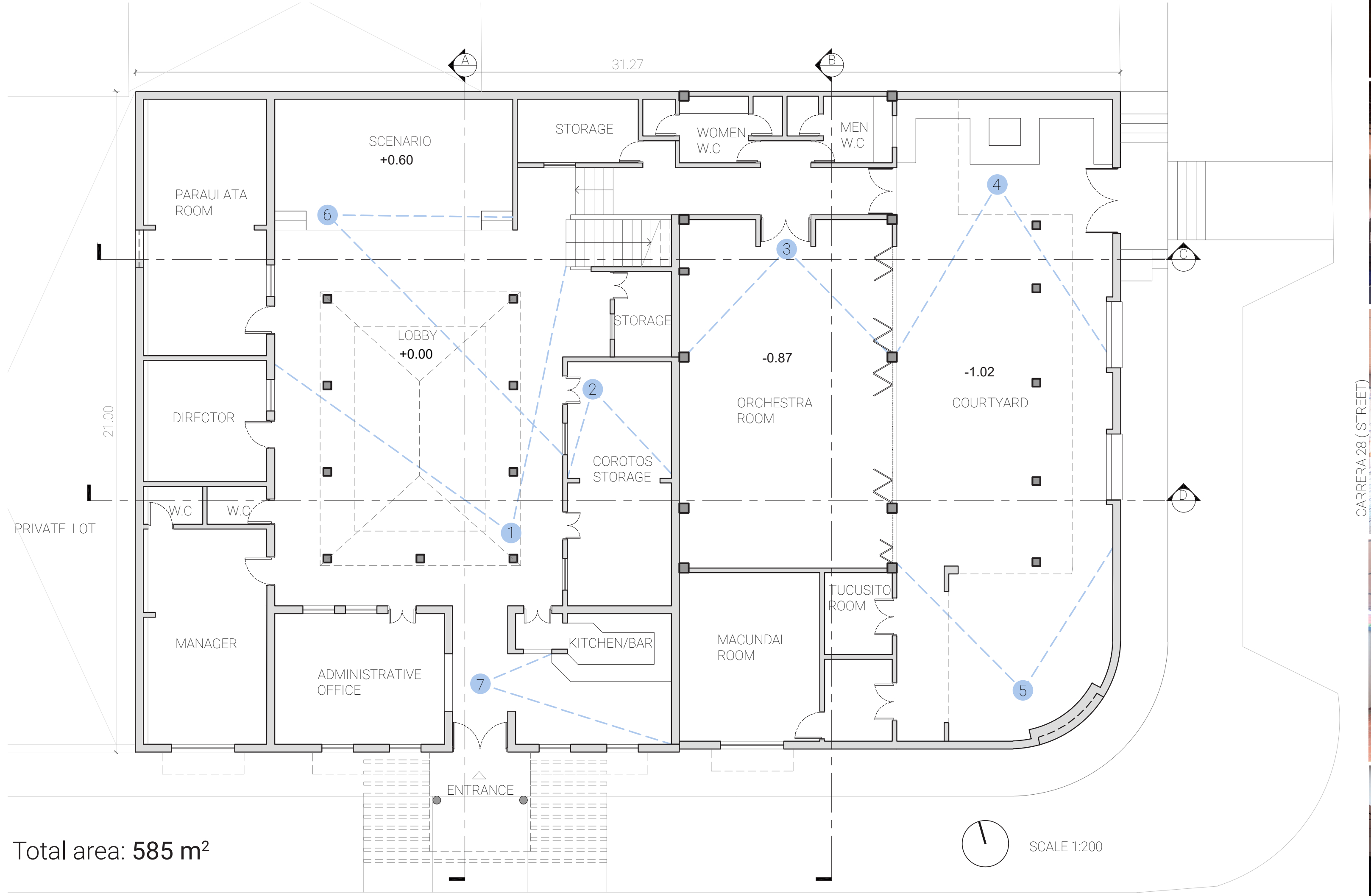
Since its foundation, until today, the musical center and its different centers in the Meta department, have participated thousands of children and young people, aged between 3 years (Kindergarten) to 18 years old (High School). They have taken part in programs such as Pre-orchestra, Batubebes, Choirs, symphonic bands, Chamber orchestras, and children`s and youth symphony Orchestra, among others. Its musical groups, mainly the youth symphony orchestra, were outstanding in different periods for the development of symphonic concerts not only classical music but also typical folk music of the "Llanos Orientales" culture.
The students were part of many workshops with special guests coming from important orchestras from Bogotà, and also international professors. Some of them had the opportunity to travel and play in different cities of the country and even international invitations.
Nowadays, starting on the 30th of October 2021, it has been created the OSJM Orchestra (Orquesta Sinfònica de las juventudes del Meta), which results from the union between the music students from Batuta Meta and the Orchestra of the Inem Luis Lopez de Mesa School and students coming from the different cities within the Department of Meta.
This musical center has allowed the integral training of children and young people, increasing their social welfare, their cognitive and communication skills, promoting their participatory power and their love for culture, as well as preventing negative behaviors in situations of vulnerability.
For many young people who have been part of the center, this space has been the base for professional training as musicians. Some former students are already part of important national and even international orchestras, as well as they, have also returned to the Casa de la Mùsica as music teachers. However, the possibility for the students to continue with their professional music studies, once they have finished high school, is low due to the lack of financial resources and the lack of universities with faculty of music for professional studies in the Department of Meta.

MEMORIES 1997-2021

Fig 4.4: Collage memories Batuta Meta/ Source: Author´s elaboration

BUILDING CONSTRUCTION

4.1 CURRENT PLANS



Total area: 585 m²

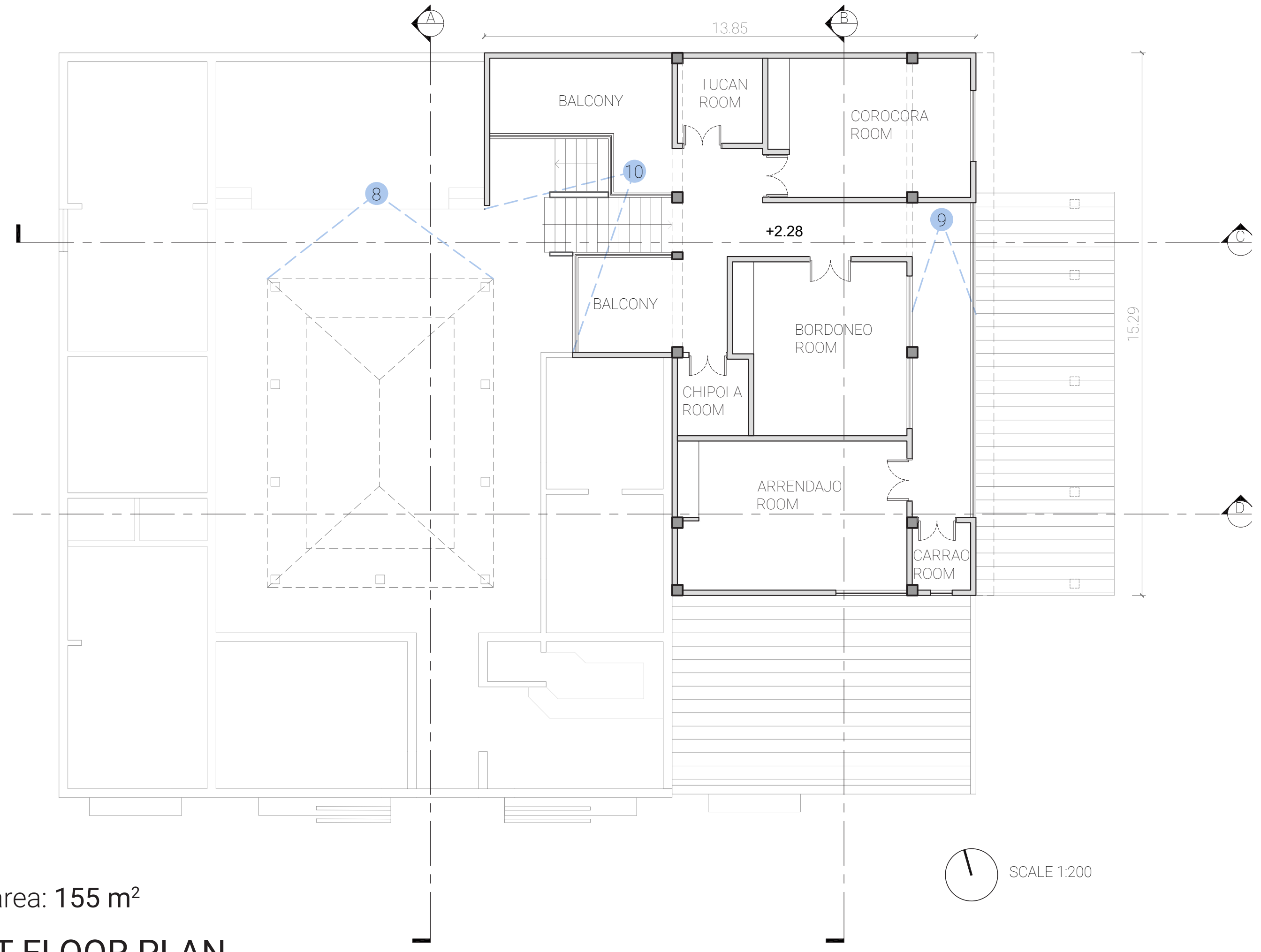
GROUND FLOOR PLAN

Fig 4.5: Ground floor plan of existing building/Source: Batuta Meta PDF drawing .Author´s edition

2% SLOPE

CALLE 46 (STREET)

Fig 4.6: Photos of the house / Source: Author´s Photos

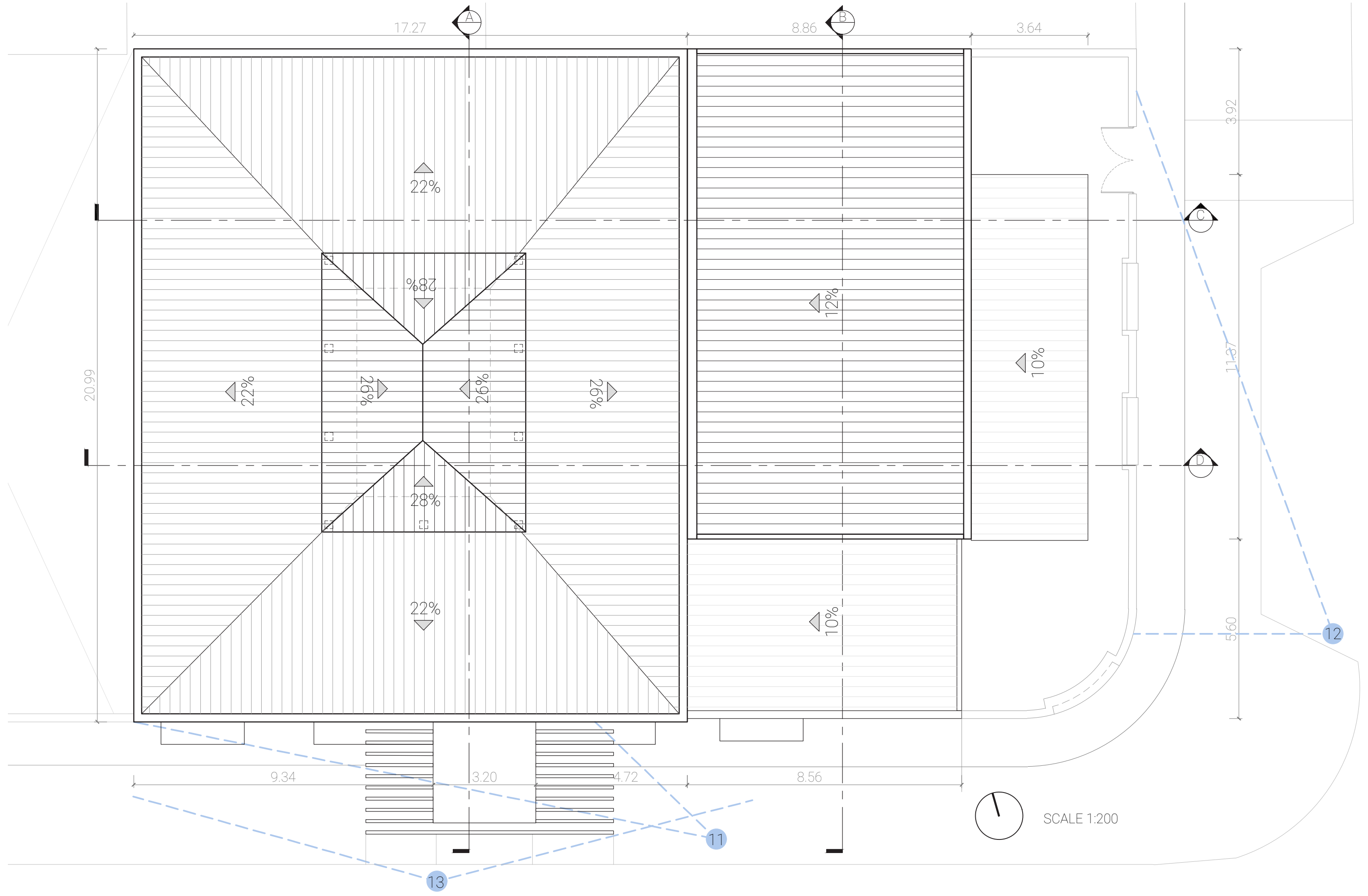


Total area: 155 m²

FIRST FLOOR PLAN

Fig 4.7: First floor plan of existing building /Source: Batuta Meta PDF drawing .Author´s edition

Fig 4.8 Photos of the house / Source: Author´s Photos



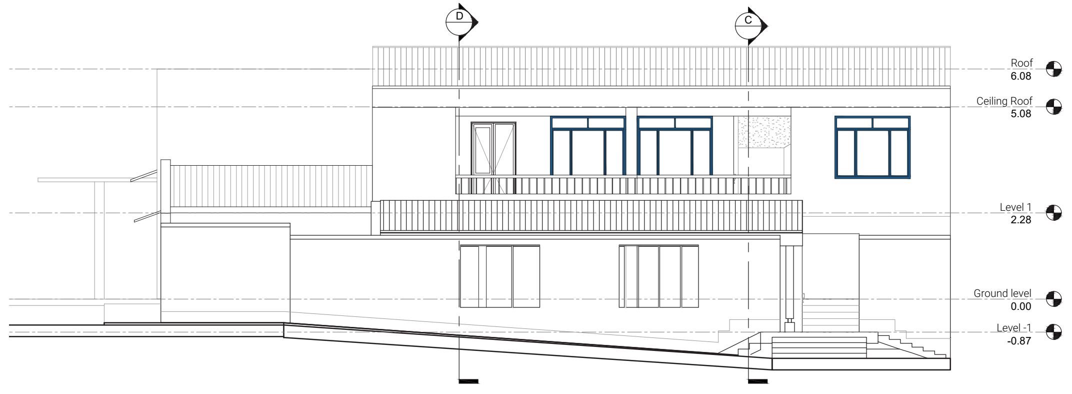
ROOF PLAN

Fig 4.9: Roof plan of existing building/Source: Batuta Meta PDF drawing .Author´s edition

Fig 4.10 Photos of the house /Source: Author´s Photos

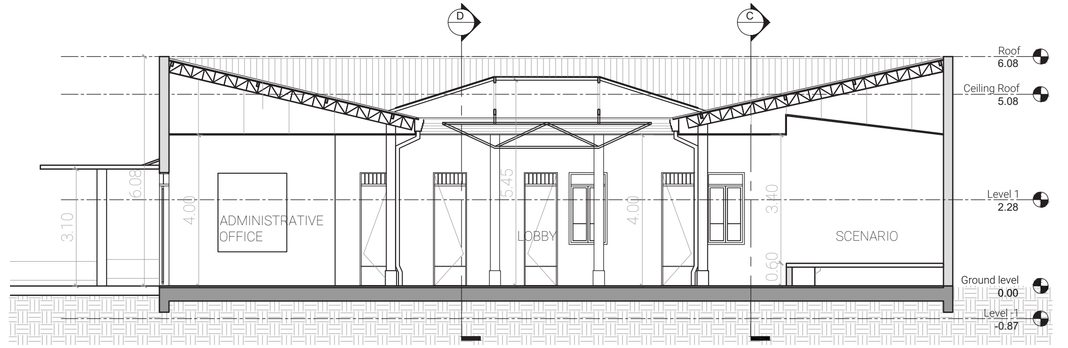
FACADE SOUTH-WEST

Fig 4.11: Facade South West_Scale 1:200 / Source: Batuta Meta PDF drawing .Author´s edition



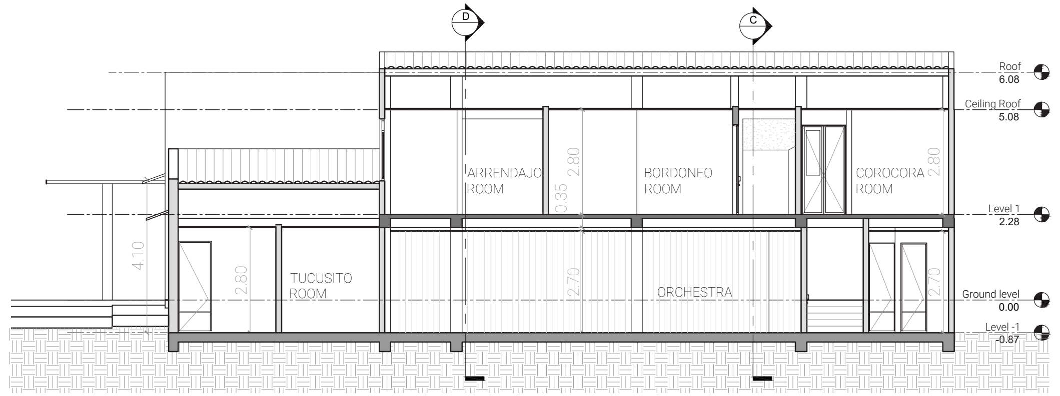
FACADE SOUTH-EAST

Fig 4.12: Facade South East_Scale 1:200 / Source: Batuta Meta PDF drawing .Author´s edition



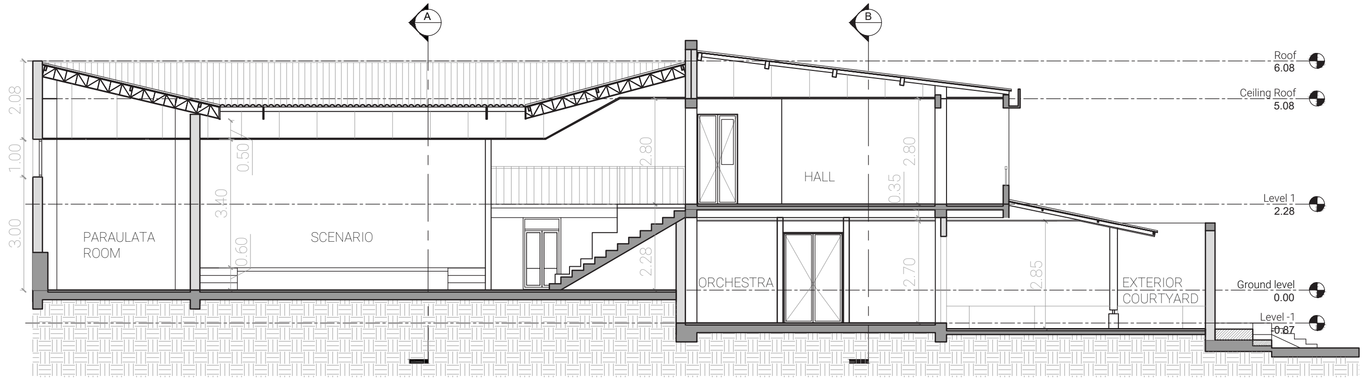
SECTION A

Fig 4.13: Section A_Scale 1:200 /Source: Batuta Meta PDF drawing .Author´s edition



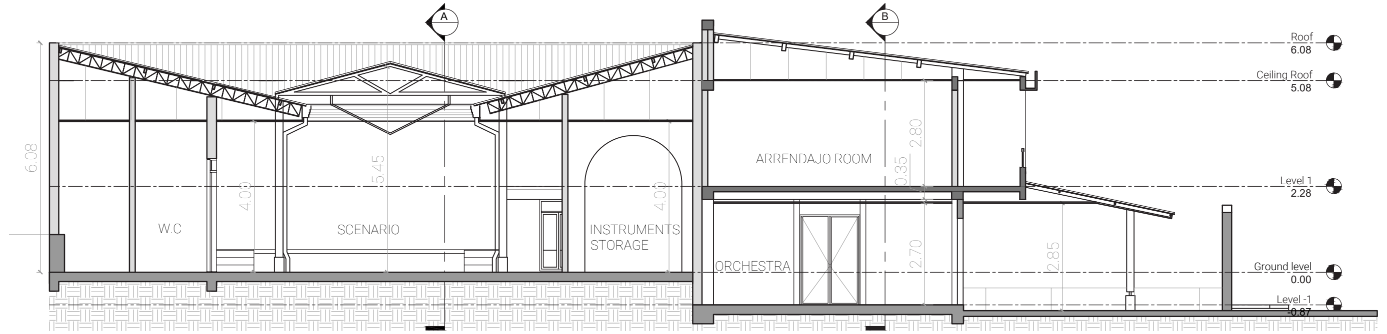
SECTION B

Fig 4.14: Section B_Scale 1:200 /Source: Batuta Meta PDF drawing .Author´s edition



SECTION C

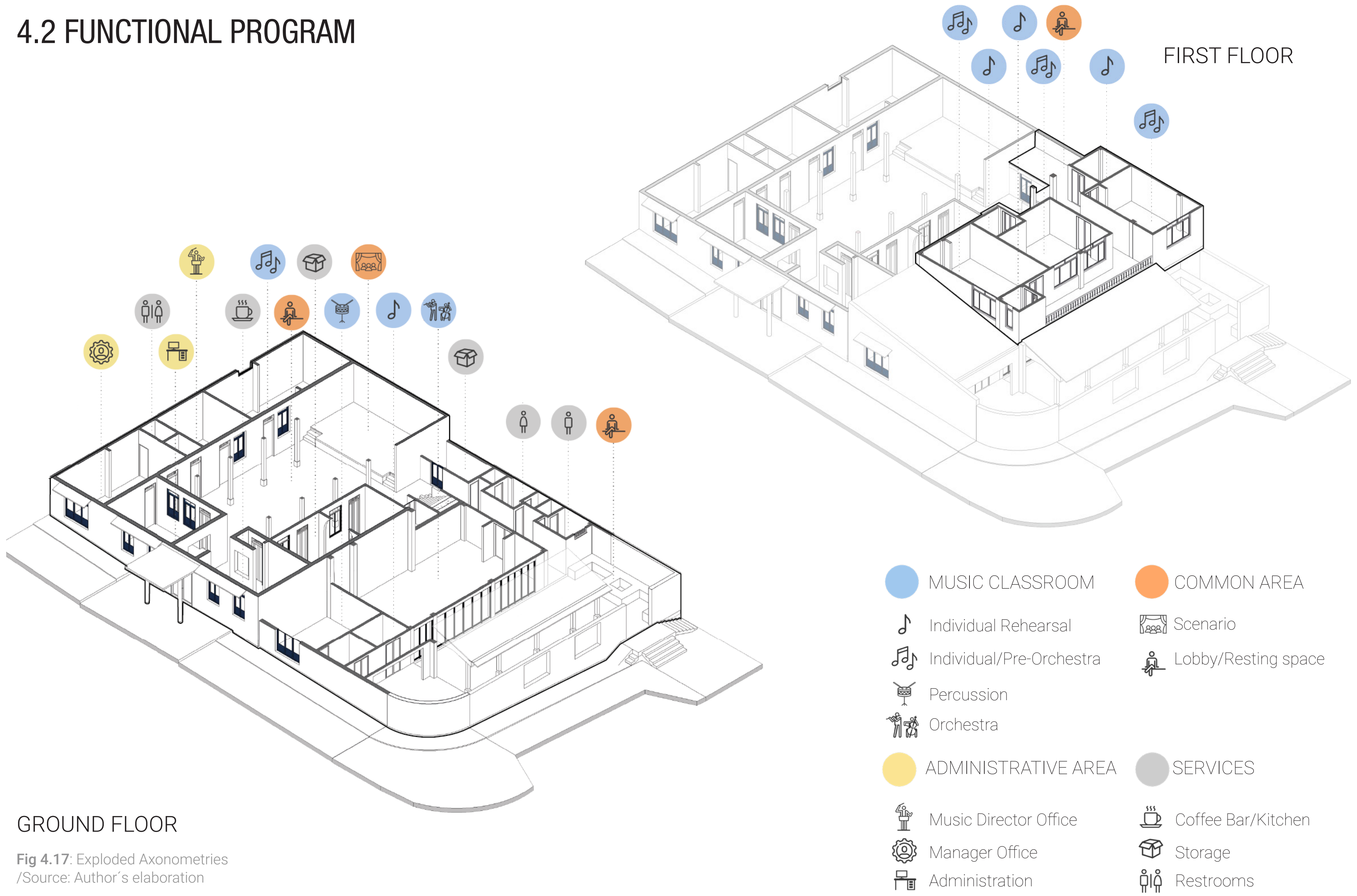
Fig 4.15: Section C_Scale 1:200 /Source: Batuta Meta PDF drawing .Author´s edition



SECTION D

Fig 4.16: Section D_Scale 1:200 /Source: Batuta Meta PDF drawing .Author´s edition

4.2 FUNCTIONAL PROGRAM



GROUND FLOOR

Fig 4.17: Exploded Axonometries /Source: Author´s elaboration

	ROOM				DIMENSIONS			WINDOWS									REQUIREMENTS		
	Name	Function	Level	N° Users	H	Area	Volume	Type	Nº	W	H	Area	Parapet Height	Location	Shading device	Frame Material	IAQ	DF	T_{60}
MUSIC CLASSROOMS	MACUNDAL*	Individual-Preorchestra Rehearsal	-0,87	4	2,8	23,86	66,81	W-3	1	2,00	1,90	3,80	0,9	Exterior - SW	Overhang	Timber Dark blue	42 m^3/h	3%	0.8s - 0.9 s
	TUCUSITO	Individual Rehearsal	-0,87	1	2,8	7,10	19,88	Door wind. Closed	1	0,30	0,80	0,24	1,0	Exterior -E	Overhang	Timber Dark blue	10,5 m^3/h	3%	0.8s - 0.9 s
	ORCHESTRA*	Rehearsal	-0,87	40	2,7	75,79	204,63	/ Open area	/	/	/	26,60	/	Exterior - SE	Overhang	/	420 m^3/h	3%	0.8s - 0.9 s
	PARAULATA*	Individual-Preorchestra Rehearsal	0,00	15	4	31,95	127,80	W-2	1	1,00	1,90	1,90	1,1	Interior -E	/	Timber Dark blue	157,5 m3/h	3%	0.8s - 0.9 s
								W-4	1	1,20	1,00	1,20	3,0	Exterior - NW	/	Aluminum White			
	TUCAN	Individual Rehearsal	2,28	1	2,8	7,29	20,41	Door wind. Closed	1	0,30	0,80	0,24	0,9	Interior	/	Timber Dark blue	10,5 m^3/h	3%	0.8s - 0.9 s
	CHIPOLA	Individual Rehearsal	2,28	1	2,8	5,66	15,85	Door wind. Closed	1	0,30	0,80	0,24	0,9	Interior	/	Timber Dark blue	10,5 m^3/h	3%	0.8s - 0.9 s
	COROCORA*	Individual-Preorchestra Rehearsal	2,28	15	2,8	22,38	62,66	W-1	1	2,00	1,65	3,30	0,9	Exterior -E	/	Aluminum Dark blue	157,5 m^3/h	3%	0.8s - 0.9 s
								Door wind. Closed	1	2,00	1,65	3,30	0,9	Exterior -E	/	Aluminum Dark blue			
	ARRENDAJO*	Individual-Preorchestra Rehearsal	2,28	15	2,8	27,13	75,96	W-1	1	2,00	1,65	3,30	0,9	Exterior - SW	/	Aluminum Color Dark blue	157,5 m^3/h	3%	0.8s - 0.9 s
								Door wind. Closed	1	2,00	1,65	3,30	0,9	Exterior -E	/	Aluminum Dark blue			
	BORDONEO	Individual Rehearsal	2,28	6	2,8	25,70	71,96	W-1	2	2,00	1,65	3,30	0,9	Exterior - SE	Overhang	Aluminum Color Dark blue	63 m^3/h	3%	0.8s - 0.9 s
	CARRAO	Individual Rehearsal	2,28	1	2,8	4,29	12,01	W-6	1	0,60	1,65	0,99	0,9	Exterior - SE	/	/	10,5 m^3/h	3%	0.8s - 0.9 s

	ROOM				DIMENSIONS			WINDOWS									REQUIREMENTS		
	Name	Function	Level	N° Users	H	Area	Volume	Type	Nº	W	H	Area	Parapet Height	Location	Shading device	Frame Material	IAQ	DF	T_{60}
ADMINISTRATION	DIRECTOR OFFICE	Office	2,28	1	4	18,34	73,36	W-2A	1	1,00	1,90	1,90	1,1	Interior	/	Aluminum Dark blue	12 m^3/h	1%	0.6s - 0.7s
	MANAGER OFFICE*	Office	2,28	1	4	26,81	107,24	W-3	1	2,00	1,90	3,80	1,1	Exterior - SW	Overhang	Aluminum Dark blue	12 m^3/h	1%	0.6s - 0.7s
	ADMINISTRATIVE OFFICE*	Office	-0,87	5	4	22,41	89,64	W-2	2	1,00	1,90	1,90	1,1	Exterior - SW	Overhang	Timber Dark blue	60 m^3/h	1%	0.6s - 0.7s
								W-2A	2	1,00	1,90	1,90	1,1	Interior	/	Timber Dark blue			
COMMON AREAS	SCENARIO*	Concerts/ Resting	0,00	70	4	142,50	570	Sky light	1	/	/	/	/	Roof	/	PVC_ White	787,5 m^3/h	2%	1.2s - 1.4s
	COURTYARD	Resting_ Outdoor	-1,02	/	/	60,70	/	/	/	/	/	/	/	/	/	/	/	/	/
		Resting_ Covered	-1,02	/	2,85	68,40	194,94	/	/	/	/	/	/	/	/	/	/	/	/
SERVICES	COROTOS STORAGE	Instruments Storage	0,00	2	4	30,15	120,60	W-2A	2	1,00	1,90	1,90	0,9	Interior	/	Aluminum Dark blue	18 m^3/h	/	0.6s - 0.7s
	CAFETERIA	Kitchen/ Snack Bar	0,00	10	4	25,30	101,20	W-2	2	1,00	1,90	1,90	0,9	Interior	Overhang	Aluminum Dark blue	133 m^3/h	2%	0,7s-1s
	STORAGE	Office Storage	-0,87	0	2,8	8,64	24,19	W-2A	1	1,00	1,90	1,90	0,9	Interior	/	Timber Dark blue	/	/	/
	RESTROOMS	Public W.C (x2)	-0,87	6	2,8	17,50	49,00	Louver	2	1,00	0,50	0,50	2,0	Exterior -E, Interior	Overhang	Aluminum Dark blue	15-30 m^3/h toilet	/	/
		Private W.C(x2)	0,00	2	2,8	6,25	17,50	/	/	/	/	/	/	/	/	/	15-30 m^3/h	/	/

Table 4.0: Progam Analysis Table. Author´s elaboration. * Rooms that will be analyzed in detail

4.3 MATERIALS AND CONSTRUCTION

According to the architectural plans, and by observation through photographs, it is possible to identify two types of structural systems. Half of the house (Main entrance with one floor) is built with structural walls of 25 cm in width, composed of double blocks. And the other part, composed of 2 floors, is constructed with a column system in concrete. The walls are built with clay blocks masonry system. The west perimetral walls are built with a structural wall in concrete 35 cm of 1 m in height from the ground floor, due to the difference in levels between the house and the private lot beside it. The roof is made of fibercement and is supported by wooden columns on concrete blocks.The structure is composed by metal trusses and joists. The main lobby and scenario has a skylight that is built with a metal structure as a hip roof.

Fig 4.18.1
Expanded Polystyrene Board

ρ 10
μ 1.8
c 1300
λ 0.036

Fig 4.18.2
Wooden columns-Concrete block

ρ 350
μ 45
c 2400
λ 0.12

Fig 4.18.3
Concrete columns and beams

ρ 2000
μ 69
c 880
λ 1.16

Fig 4.18.4
Clay Blocks
White painted walls

ρ 800
μ 18
c 840
λ 0.36

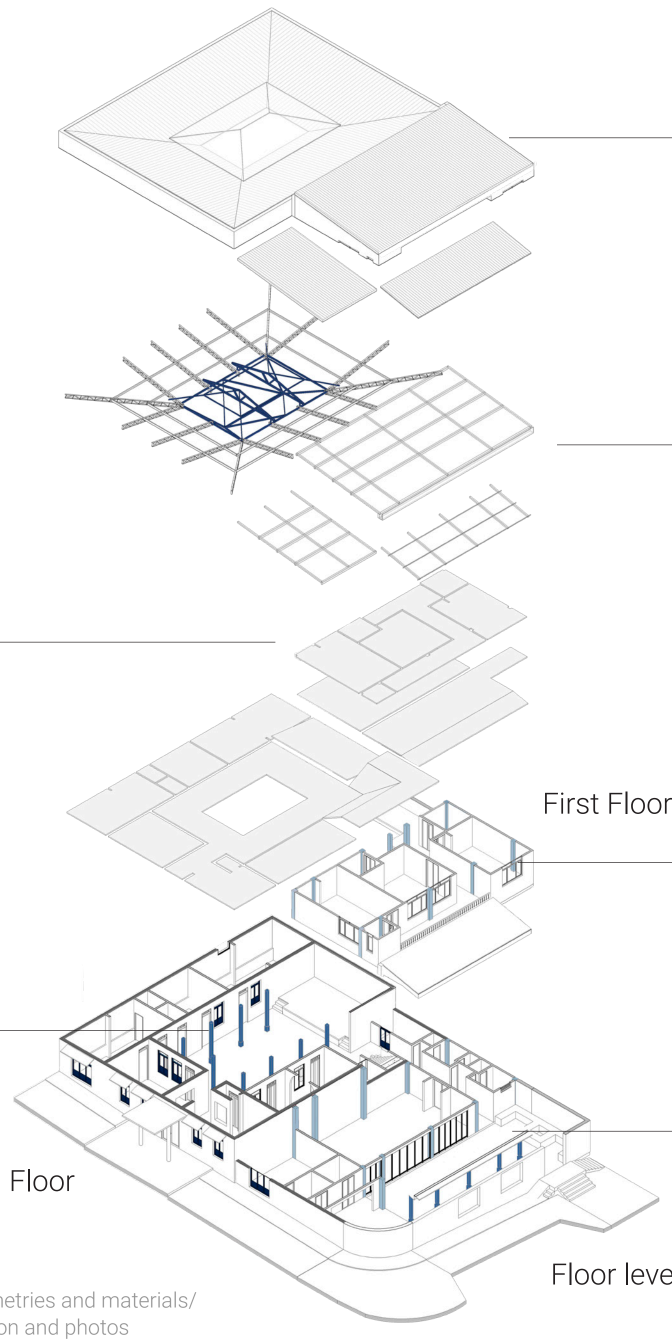


Fig 4.18 Exploded axonometries and materials/ Source: Author´s elaboration and photos

Fig 4.18.5
Fibercement Tiles

ρ 1350
μ 22.6
c 840
λ 0.21

Skylight

Fig 4.18.11
PVC White ondulated panels

ρ 1400
μ 10.7
c 1300
λ 0.16

Fig 4.18.6
Metal Trusses and Joists

ρ 2700
μ 2.1
c 960
λ 220

Fig 4.18.7
Metal Windows

ρ 2700
μ 2.1
c 960
λ 220

Fig 4.18.8
Wooden Windows

ρ 2700
μ 2.1
c 960
λ 220

Fig 4.18.9
Clay Tiles-Terracota

ρ 1900
μ 36
c 840
λ 0.36

Fig 4.18.10
Ceramic Tiles (W.C)

ρ 1900
μ 36
c 840
λ 0.36

LEGEND

ρ Density_kg/cm3
μ Water vapour resistance factor
c Specific heat capacity_ J/Kg°C
λ Thermal conductivity_ W/m°C

Note: Thermal data taked from book: Roberto Giordano, 2013, *I prodotti per l'edilizia sostenibile*.

4.4 GENERAL DECAYS

MOISTURE GENERATED BY CONDENSATION

MOISTURE IN EXTERNAL WALLS

_Presence of vegetation
_Biological Patina: Thin and homogeneous layer, mainly consisting of micro-organisms.
_Lack: Loss of continuity in a surface
_Stain: Localized color variation of the surface related to the presence of water or micro-organisms
_Swelling: Localized surface lifting of the material with variable shape and consistency.
The presence of these decays is mainly due to the direct exposition to climate conditions.
LOCATION: Est perimetral walls, next to the courtyard. The North-West facade is next to the neighboring lot

Fig 4.19.0

Fig 4.19.1

MOISTURE IN INTERNAL WALLS

Stain
Swelling

LOCATION: West and South-West perimetral walls. Walls adjacent to West neighboring lot: Administrative rooms and Paraulata Classroom.
Due to the slope of the terrain, the pedestrian path and neighbor lot are elevated 1 meter, causing humidity issues

Fig 4.19.2

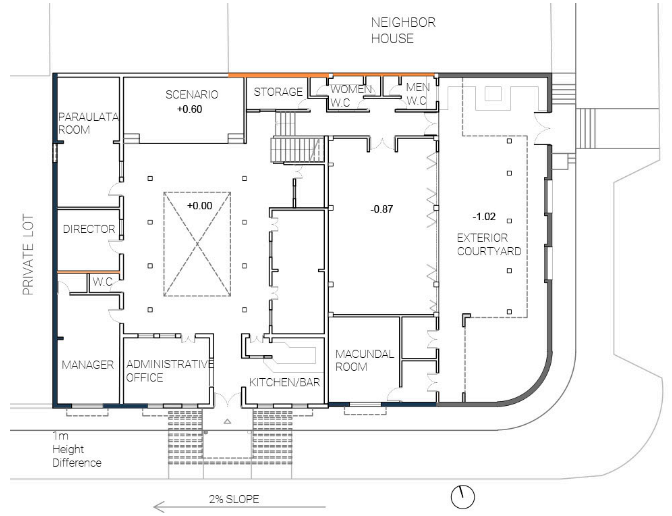


Fig 4.19 Decays photos/ Autor´s Photos

0 External Wall Courtyard
1 External Wall Courtyard
2 Manager office
3 Courtyard beam
4 First floor door
5 Balcony exterior wall
6 Clay floor classroom
7 Interior balcony
8 "Patio"
9 Courtyard furniture

Fig 4.20 Type of walls scheme plan/ Author´s elaboration

MOISTURE ON BEAMS

Presence of mold and disconnection of plaster of beams due to leaks of the roof when raining and high humidity.

LOCATION: Beams of courtyard`s overhang roof

Fig 4.19.3

MOISTURE IN WOODEN DOOR

Discoloration and Disconnection of parts from the bottom of the door due to the presence of water.

LOCATION: External wooden door in the firts floor. Room Carrao

Fig 4.19.4

CRACKING WALLS

Discontinuity in material that implies the mutual displacement of the parts. Structure damage.

LOCATION: South-West and South-Est perimetral walls.

Fig 4.19.5

BROKEN FLOOR TILES

Disconnection of parts from clay tiles of the floor.

LOCATION: Some classrooms mainly in the first floor and the orchestra classroom.

Fig 4.19.6

STACKED INSTRUMENTS_LACK OF STORAGE SPACE

Instruments piled up in resting places due to the lack of enough storage space. Some instruments are in bad contidions due to the high exposition to humidity. When they are stacked, the decay increases.

LOCATION: Resting places as the interior balcony of second floor and Corotos room

Fig 4.19.7

LEAKS ON THE ROOF

Leaks on some parts of the roof due to broken and displaced tiles, and to blocked drainage gutters next to the columns.

LOCATION: Lobby and Scenario

Fig 4.19.8

DAMAGED FURNITURE

Broken and stained chairs due to the exposition to sun, water and bad use. Lack of seating furniture.

LOCATION: Resting places, Lobby.

Fig 4.19.9

LACK AND SWELLING CEILING

Missing parts of the ceiling in Expanded Polysterene. Parts of the ceiling lifted due to the presence of water or heating conditions.

LOCATION: Ceiling of the courtyard overhang, interior resting places, and main lobby.

Fig 4.19.10

4.5 SHADOWS ANALYSIS

The main two facades of the building are oriented to the South-Est and South-West. With a location in the Tropics, the sun path is overhead all year, as it has been exposed in chapter 3.0, thus, those facades receive constante and homogeneus sunlight for both seasons, Dry and Wet, but they differs on the amount according to the sun position.

In the Dry season, from December to March, and taking into consideration the winter solstice on December 21 for the study, the sunlight comes from 05:56 in the morning to 5:48 p.m. The Wet season, from April to November, has a similar schedule, with sunlight coming from 05:45 to 18:06 on June 21 the Summer solstice.

In December, both the South Est, and South West receive the morning sun, but in the evening, the most affected one is the South-West facade. In the morning the rooms with high exposition to the sunlight are mainly classrooms, while in the evening, the exposed rooms are administrative areas and the main entrance.

On the contrary, in June, the morning direct sunlight affects only the South-Est facade, while in the evening, the exposed facade is North-West. The North-West facade is mainly closed because the house is adjacent to a private lot. There is just one classroom that receives sunlight at that time. The house has some shadowing devices like overhangs to protect it from the direct sunlight in both main facades. They will be analyzed to define their effectiveness.

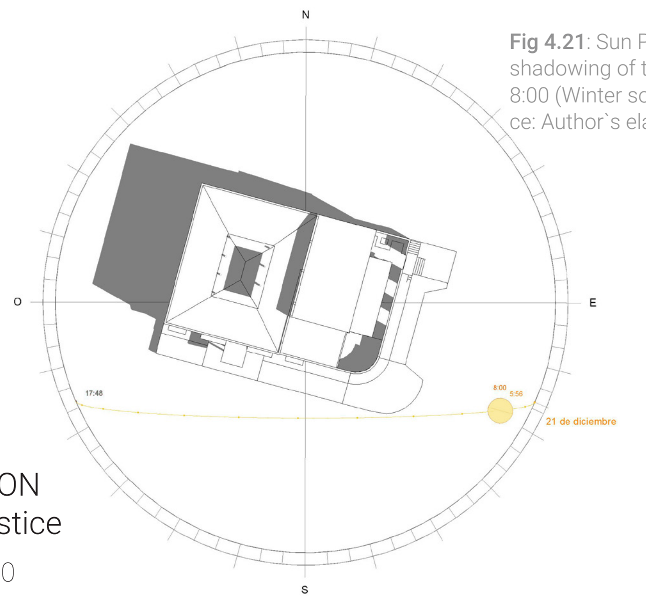


Fig 4.21: Sun Path and shadowing of the context at 8:00 (Winter solstice)/ Source: Author´s elaboration

DRY SEASON
Winter Solstice

21-DEC 08:00

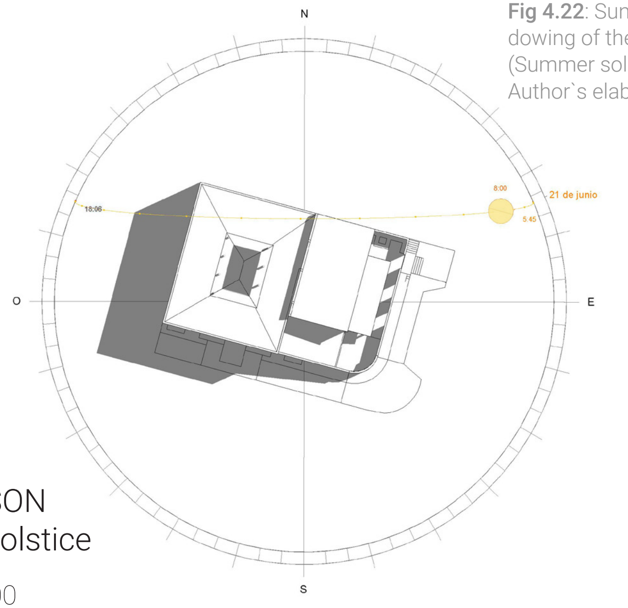
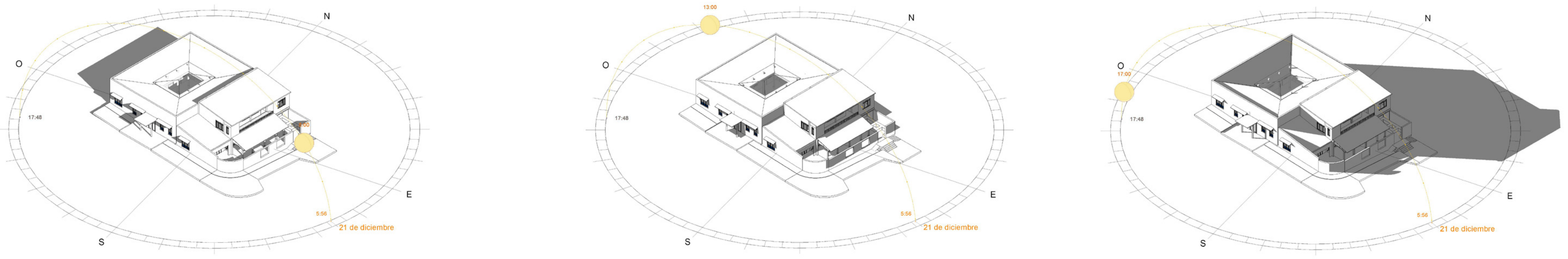


Fig 4.22: Sun Path and shadowing of the context at 8:00 (Summer solstice)/ Source: Author´s elaboration

WET SEASON
Summer Solstice

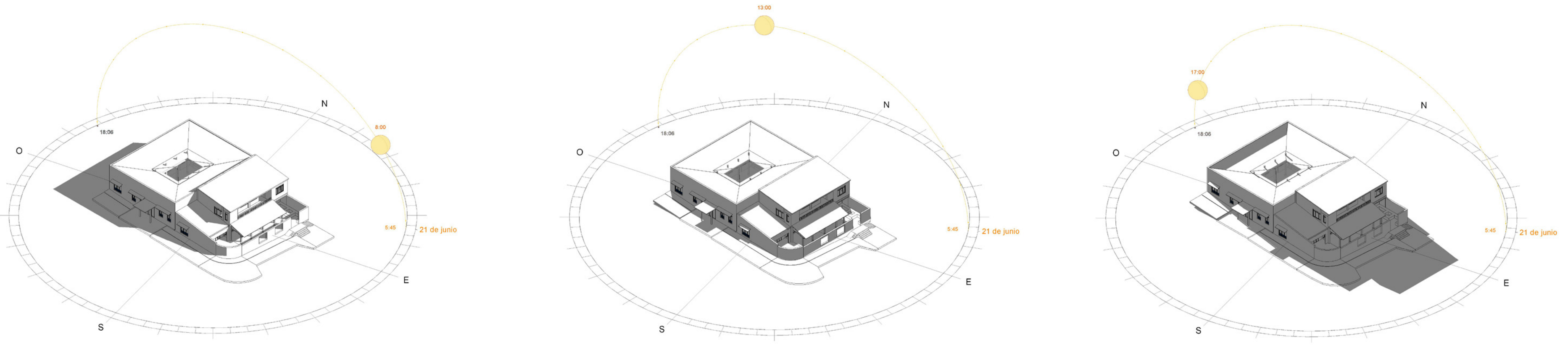
21-JUN 08:00

Fig 4.23: Sun Path and shadowing of the house at 8:00, 13:00, 17:00 (Winter solstice)/ Source: Author´s elaboration



21-DEC 08:00 | 21-DEC 13:00 | 21-DEC 17:00

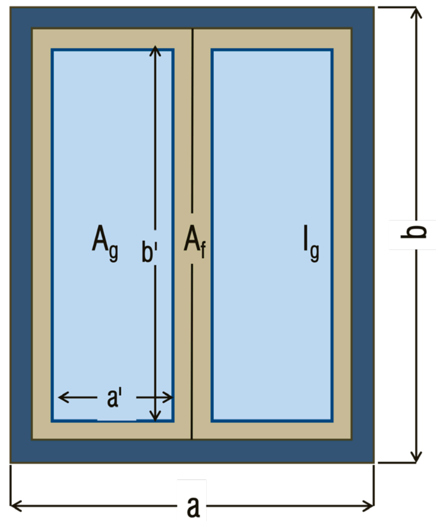
Fig 4.24: Sun Path and shadowing of the house at 8:00, 13:00, 17:00 (Summer solstice)/ Source: Author´s elaboration



21-JUN 08:00 | 21-JUN 13:00 | 21-JUN 17:00

4.6 TRANSPARENT ENVELOPE

For the evaluation of the transparent envelope, it has been taking into account the typologies of windows, mainly involved in the specific analysis of the case study.
The analysis of the thermal transmittance value of each window has been developed through a numerical calculation by following the formula of the standard EN ISO 10077-1 [69].



$$U_w = \frac{A_g U_g + A_f U_f + l_g \Psi_g}{A_g + A_f}$$

U_g Glazing Thermal transmitance [W/m² K]
U_f Frame Thermal transmitance [W/m ² K]
U_w Total Thermal transmitance [W/m ² K]
Ψ_g Linear thermal transmittance of glazing spacer bar

A_g Area of the glass
A_f Area of the frame
l_g Perimeter of the glass

69 EN ISO 10077-1, 2017. Thermal performance of windows, doors and shutters — Calculation of thermal transmittance

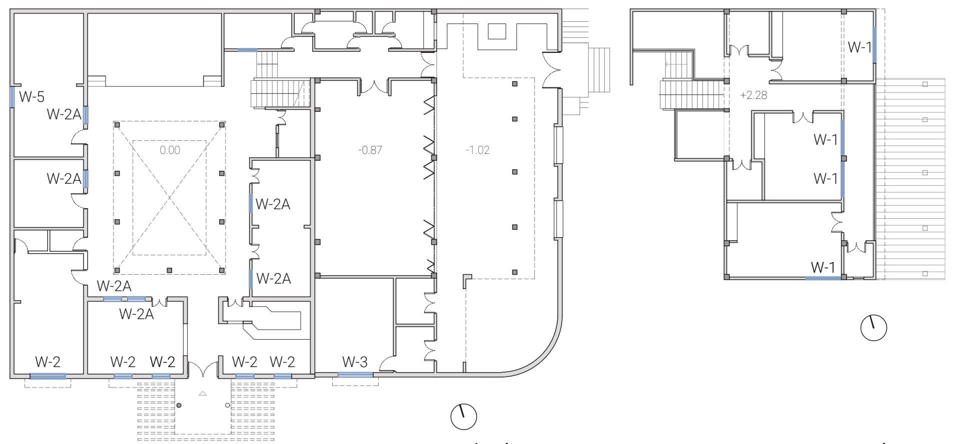


Fig 4.25 Windows Scheme plan / Source: Author´s elaboration

IMPUT DATA

Type of glass
Single Clear Glazing_ U_g: 5.8 W/m²K

Type of Frame
Ground Floor: Wood _2 W/m²K
First Floor: Aluminum _5 W/m²K

ψ_g There is not consider a spacer bar since is a single glass

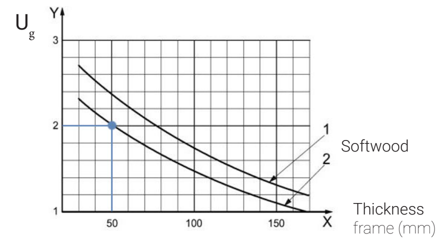


Fig 4.26 Wood frame Ug reference / Source: EN ISO 10077-1, 2017

W1-External

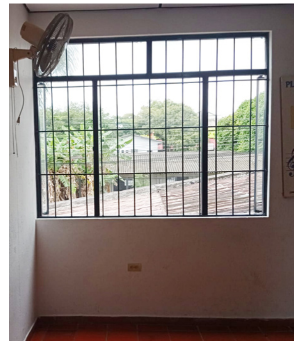


Fig 4.27 First floor window / Source: Author´s Photo

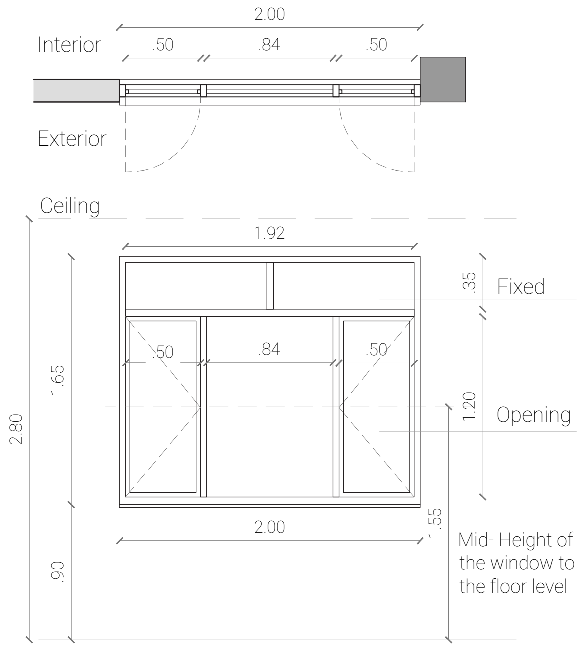


Fig 4.28 Window W1plan and facade _Scale 1:50/Source: Author´s elaboration

WINDOW THERMAL TRANSMITTANCE _ TYPE: W-1					
GEOMETRICAL DATA					
a [m]	2,00	A_g [m²]	2,76	A_{tot} [m²]	3,30
b [m]	1,65	A_f [m²]	0,54		
a' [m]	0,50	l_g [m]	9,26		
b' [m]	1,20	number of glasses	2		
FRAME AND GLASS					
Material [-]	Aluminum	U_f [W/m²K]	5,00	U_g [W/m²K]	5,80
				ψ_g [W/mK]	0
RESULTS		U_w [W/m²K]	5,67		

Table 4.1: Window Thermal transmittance Type W-1/ Author´s elaboration

W2-External
W2A Internal

W2A-Internal without the overhang

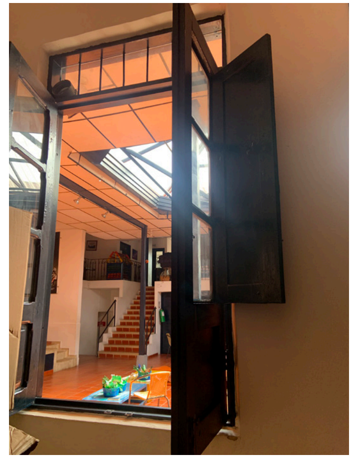


Fig 4.29 Ground floor window / Source: Author´s Photo

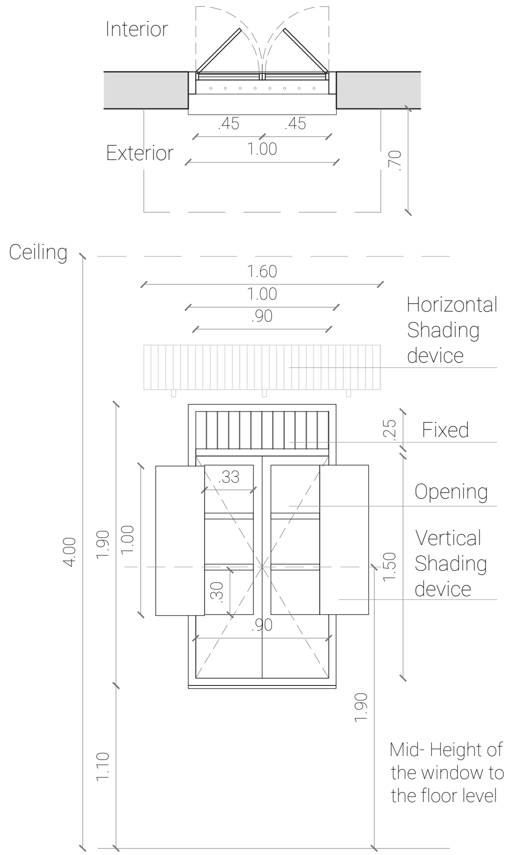


Fig 4.30 Window W2 plan and facade _Scale 1:50/Source: Author´s elaboration

WINDOW THERMAL TRANSMITTANCE _ TYPE: W-2, W-2A					
GEOMETRICAL DATA					
a [m]	1,00	A_g [m²]	0,81	A_{tot} [m²]	1,90
b [m]	1,90	A_f [m²]	1,09		
a' [m]	0,33	l_g [m]	8,71		
b' [m]	0,30	number of glasses	6		
FRAME AND GLASS					
Material [-]	Wood	U_f [W/m²K]	2,00	U_g [W/m²K]	5,80
				ψ_g [W/mK]	0
RESULTS		U_w [W/m²K]	3,63		

Table 4.2: Window Thermal transmittance Type W-2, 2A/ Author´s elaboration

W3-External

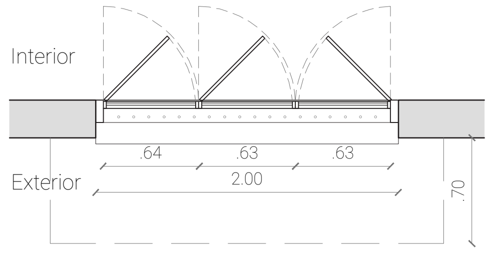


Fig 4.31 Window W3 plan and facade _Scale 1:50/Source: Author´s elaboration

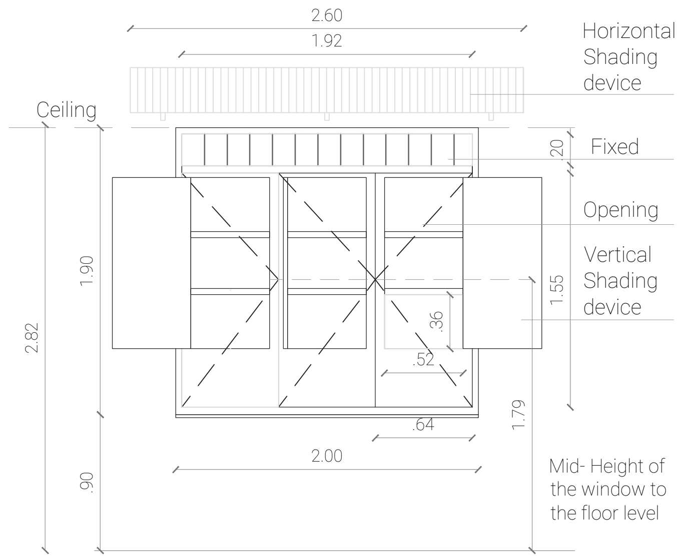


Fig 4.32 Photo exterior facade window /Source: Author´s Photo

WINDOW THERMAL TRANSMITTANCE _ TYPE: W-3					
GEOMETRICAL DATA					
a [m]	2,00	A_g [m^2]	2,085	A_{tot} [m^2]	3,8
b [m]	1,90	A_f [m^2]	1,715		
a' [m]	0,52	l_g [m]	17,960		
b' [m]	0,36	number of glasses	9		
FRAME AND GLASS					
Material [-]	Wood	U_f [W/m^2K]	2,00	U_g [W/m^2K]	5,80
				ψ_g [W/mK]	0
RESULTS		U_w [W/m^2K]	4,08		

Table 4.3: Window Thermal transmittance Type W-3.Author´s elaboration

W4-External

This typology of the window is unglazed. It is a solid casement window in aluminum that is operated by a long stick to open it. Its value is not been calculated since there is no thermal insulation when the window is opened

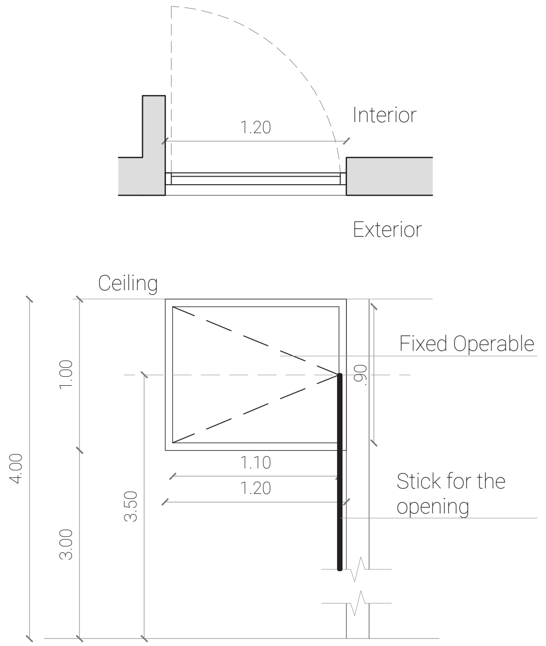


Fig 4.33 Window W4 plan and facade _Scale 1:50/Source: Author´s elaboration

SECTION TYPE W2-W3

External windows with external horizontal shading device and internal movable vertical shading device.

The wooden windows have a double layer, one glass, and one panel of wood

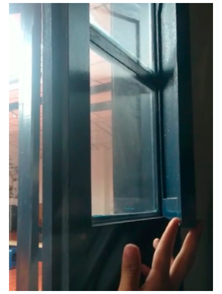


Fig 4.34 Double frame- layer window./ Source: Author´s Photos

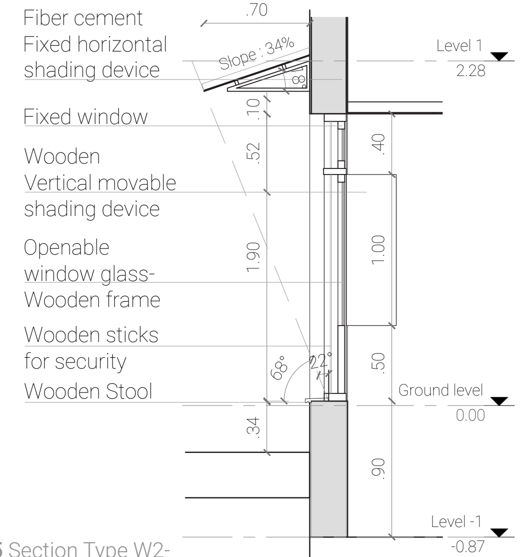


Fig 4.35 Section Type W2-W3 _Scale 1:50/ Source: Author´s elaboration

4.7 SHADING DEVICES

The analysis of the existing shading devices has been simulated using the software OMBRE, developed by the Dipartimento di Energetica Politecnico di Torino (Italy) in 2004. It is a tool to evaluate the energy performance between the windows and shading device systems in a simple way.

By adding the input data of one of the windows types (W3) and its shadow device, the simulation was run on the opposite sun path days, 21st December and 21st June. The results are different between both days, showing a high percentage of solar factor (SF) from Direct Irradiance in December, but no value in June, due to the position of the sun. The Solar factor in the Wet season depends just on the diffuse daylight.

The critical hour is at 17:00 in December, when the shading device is not able to shade 0.99% from the direct sun.

All the internal and external windows Type W2-W2A-W3 are composed of 2 layers, one for airflow through the window, and a second that acts as a vertical shading device. The last one can be open or close in the interiors blocking the direct sunlight 50 or 100%, depending on the opening angle. The simulation has been taking into account just the exterior horizontal shading devices and the following input data.

- Latitude: **4.15º**
- Albedo (Sorrounding): **30%**
- Exposure: **-16º South-West**

Window (W3)

- Width: **2.00m**
- Height:**1.90m**

Shading Device

- Horizontal Overhang Tilt: **18º**
- Distance between Overhang and window: **0.45m**
- Depth of Overhang: **0.70m**
- Lateral projection of Overhang: **0.30**

Fig 4.36 Hourly Solar Irradiance (W) December

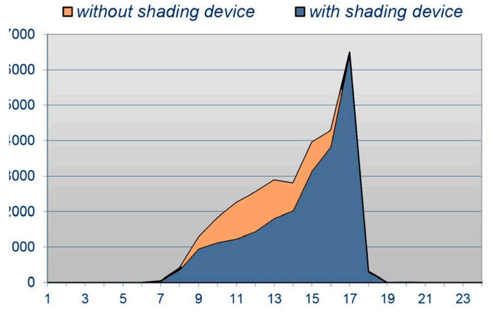
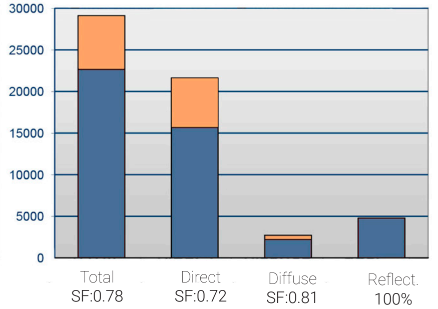
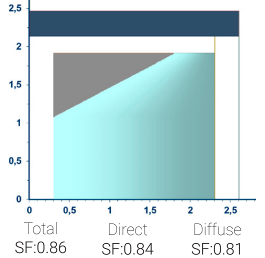


Fig 4.37 Solar Irradiance (Wh)December

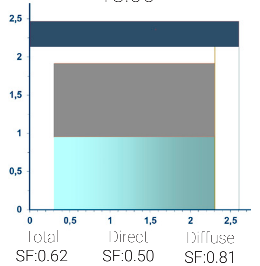


21 DECEMBER

8:00



13:00



17:00

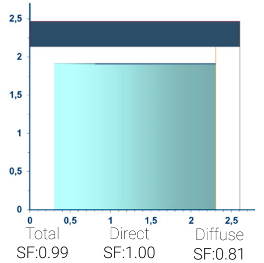


Fig 4.38 Hourly Solar Irradiance (W) June

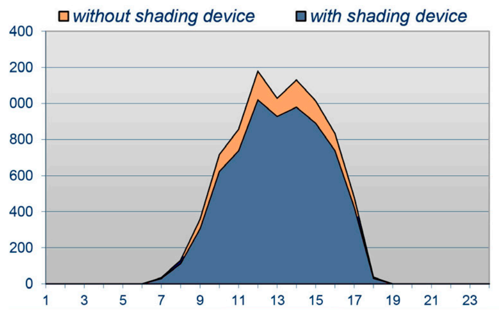
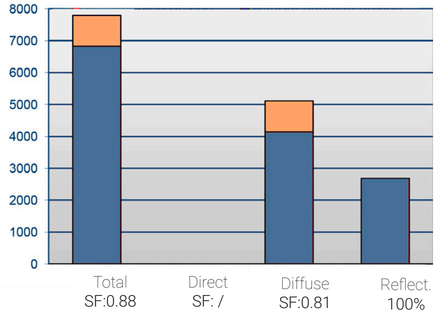
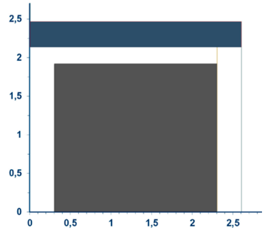


Fig 4.39 Solar Irradiance (Wh) June



21 JUNE

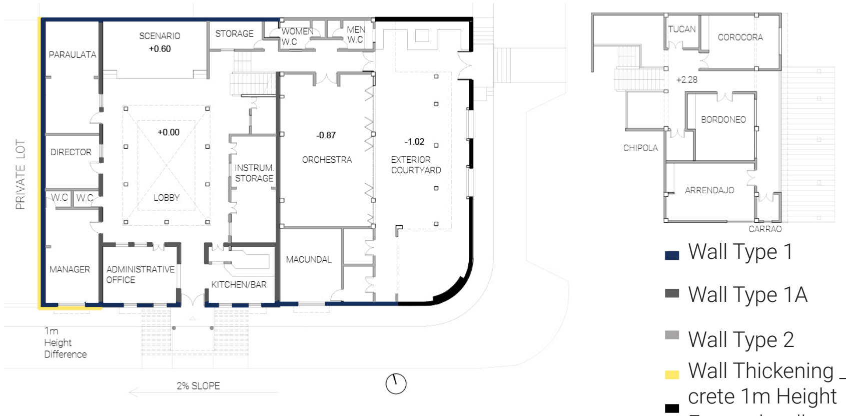
	Total	Direct	Diffuse
8:00	SF:0.85	SF: /	SF:0.81
13:00	SF:0.90	SF: /	SF:0.81
17:00	SF:0.88	SF: /	SF:0.81



4.8 OPAQUE ENVELOPE

The opaque envelope performs an important role in the building becoming the thermal protector from the external environment conditions. Miminimizing the heat transfer through the envelope could help to increase the comfort and save energy needed to heat or cool the building. The analysis of the Heat transfer through the main vertical and horizontal building components as walls, floor, and roof, has been developed by using the calculator INVOLUCRO OPACO. It is an italian tool created by the Dipartimento di Energetica Politecnico di Torino (DENERG) by Vincenzo Corrado. The calculation of the thermal properties and hygrothermal performance of the elements are based on two standards: UNI EN ISO 13786:2018 and UNI EN ISO 13788:2013

For the case study, the calculation has been done for external and internal walls, one type of floor, and the roof. The results show high thermal transmittance values from the walls and floor, but mainly the wall W2. All values are over 1W/m2K which is high against an insulated wall.



- Wall Type 1
- Wall Type 1A
- Wall Type 2
- Wall Thickening _Concrete 1m Height
- External wall

Fig 4.40 Scheme plans Wall type location/ Source: Author´s elaboration

d Thickness
ρ Density
μ Water vapour resistance factor
c Specific heat capacity
λ Thermal conductivity
R Thermal Resistance
U Thermal transmittance

WALL 1 - Facade

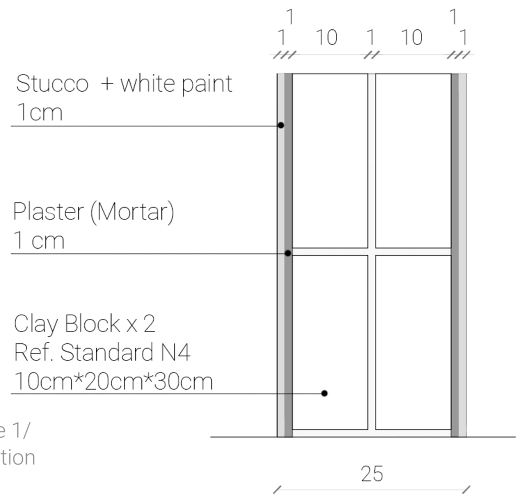


Fig 4.41 Section wall type 1/ Source: Author´s elaboration

OPAQUE ENVELOPE PERFORMANCE : Wall type 1							
N	Layers Interior to Exterior	*d* cm	*ρ* kg/cm^3	μ (-)	*c* J/Kg°C	λ W/m°C	*R* m^2°C/W
	Internal Surface						0,13
1	Stucco-Painting	1	1800	24	840	0,9	
2	Cement Plaster	1	2000	24	840	1,4	
3	Clay Block	10	800	18	840	0,36	
4	Cement Plaster	1	2000	24	840	1,4	
5	Clay Block	10	800	18	840	0,36	
6	Cement Plaster	1	2000	24	840	1,4	
7	Stucco-Painting	1	1800	24	840	0,9	
	External Surface						0,04

THERMAL TRANSMITTANCE ANALYSIS			
Parameter	Unit	Value	Required
Thermal Transmittance (*U*)	$W/(m^2K)$	1,3	
Thermal Resistance (*R*)	$(m^2k)/W$	0,769	
Decrement Factor (*f*)	-	0,56	
Periodic thermal transmittance (Y_{ie})	$W/(m^2K)$	0,738	
Internal aereal heat capacity (K_{ie})	$kJ(m^2K)$	58,4	

Total Thickness (*s*)	25 cm
Areal Mass (*m*)	256 kg/m^2
Time lag (φ)	6,59 h

U value
1.3 W/m^2K

Table 4.4: Opaque envelope thermal transmitance.Wall 1/ Source: Author´s elaboration

WALL 1A - Internal

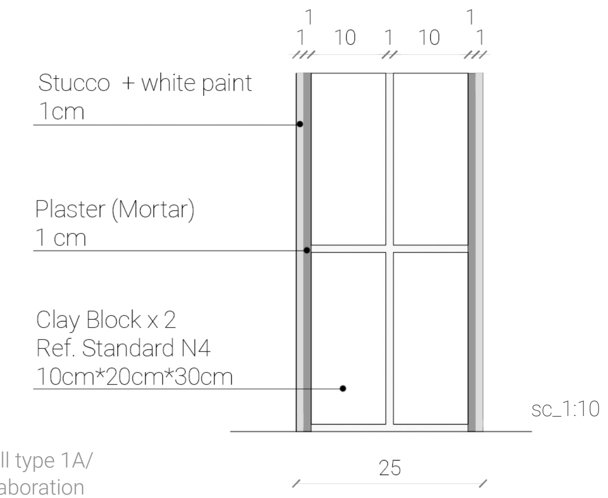


Fig 4.42 Section wall type 1A/ Source: Author´s elaboration

OPAQUE ENVELOPE PERFORMANCE : Wall type 1A							
N	Layers Interior to Exterior	*d* cm	*ρ* kg/cm^3	μ (-)	*c* J/Kg°C	λ W/m°C	*R* m^2°C/W
	Internal Surface						0,13
1	Stucco-Painting	1	1800	24	840	0,9	
2	Cement Plaster	1	2000	24	840	1,4	
3	Clay Block	10	800	18	840	0,36	
4	Cement Plaster	1	2000	24	840	1,4	
5	Clay Block	10	800	18	840	0,36	
6	Cement Plaster	1	2000	24	840	1,4	
7	Stucco-Painting	1	1800	24	840	0,9	
	External Surface						0,13

THERMAL TRANSMITTANCE ANALYSIS			
Parameter	Unit	Value	Required
Thermal Transmittance (*U*)	$W/(m^2K)$	1,164	
Thermal Resistance (*R*)	$(m^2k)/W$	0,859	
Decrement Factor (*f*)	-	0,469	
Periodic thermal transmittance (Y_{ie})	$W/(m^2K)$	0,545	
Internal aereal heat capacity (K_{ie})	$kJ(m^2K)$	57,7	

Total Thickness (*s*)	25 cm
Areal Mass (*m*)	256 kg/m^2
Time lag (φ)	7,53 h

U value
1.16 W/m^2K

Table 4.5: Opaque envelope thermal transmitance.Wall 1-A /Source Author´s elaboration

WALL 2 - External, Internal

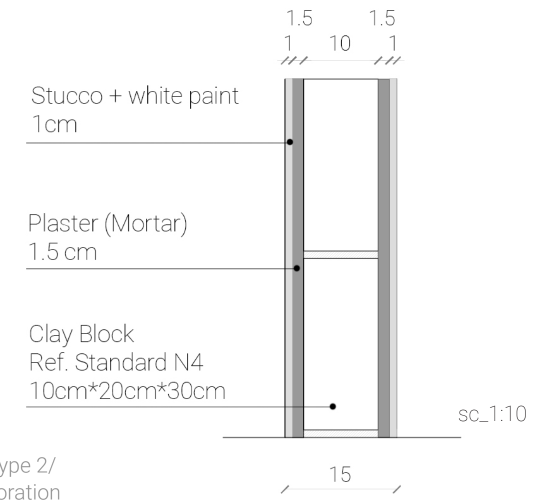


Fig 4.43 Section wall type 2/ Source: Author´s elaboration

OPAQUE ENVELOPE PERFORMANCE : Wall type 2							
N	Layers Interior to Exterior	*d* cm	*ρ* kg/cm^3	μ (-)	*c* J/Kg°C	λ W/m°C	*R* m^2°C/W
	Internal Surface						0,13
1	Stucco-Painting	1	1800	24	840	0,9	
2	Cement Plaster	1,5	2000	24	840	1,4	
3	Clay Block	10	800	18	840	0,36	
4	Cement Plaster	1,5	2000	24	840	1,4	
5	Stucco-Painting	1	1800	24	840	0,9	
	External Surface						0,13

THERMAL TRANSMITTANCE ANALYSIS			
Parameter	Unit	Value	Required
Thermal Transmittance (*U*)	$W/(m^2K)$	**1,72**	
Thermal Resistance (*R*)	$(m^2k)/W$	0,581	
Decrement Factor (*f*)	-	0,74	
Periodic thermal transmittance (Y_{ie})	$W/(m^2K)$	1,274	
Internal aereal heat capacity (K_{ie})	$kJ(m^2K)$	56,9	

Total Thickness (*s*)	15 cm
Areal Mass (*m*)	176 kg/m^2
Time lag (φ)	4,36 h

U value
1.72 W/m^2K

Table 4.6: Opaque envelope thermal transmitance.Wall 2/Source: Author´s elaboration

Floor

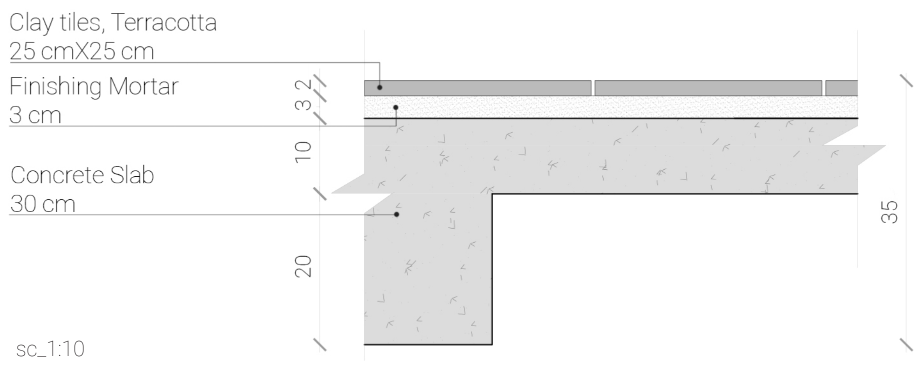


Fig 4.44 Section Floor/ Source: Author´s elaboration

OPAQUE ENVELOPE PERFORMANCE : **Floor**_External and Internal							
N	Layers Interior to Exterior	*d* cm	*ρ* kg/cm³	μ (-)	*c* J/Kg°C	λ W/m°C	*R* m²°C/W
	Internal Surface						0,17
1	Concrete Slab	30	2000	69	880	1,16	
2	Cement Plaster	3	2000	24	840	1,4	
3	Terracota Tiles	2	1900	36	840	0,8	
	External Surface						0,04

THERMAL TRANSMITTANCE ANALYSIS			
Parameter	Unit	Value	Required
Thermal Transmittance (U)	W/(m²K)	**1,94**	
Thermal Resistance (R)	(m²k)/W	0,515	
Decrement Factor (f)	-	0,229	
Periodic thermal transmittance (Y_{ie})	W/(m²K)	0,445	
Internal aereal heat capacity (K_{ie})	kJ(m²K)	64,4	

Total Thickness (s)	35 cm
Areal Mass (m)	698 kg/m²
Time lag (φ)	9,95 h

U value
1.94 W/m²K

Table 4.7: Opaque envelope thermal transmitance.FloorAuthor´s elaboration

Roof

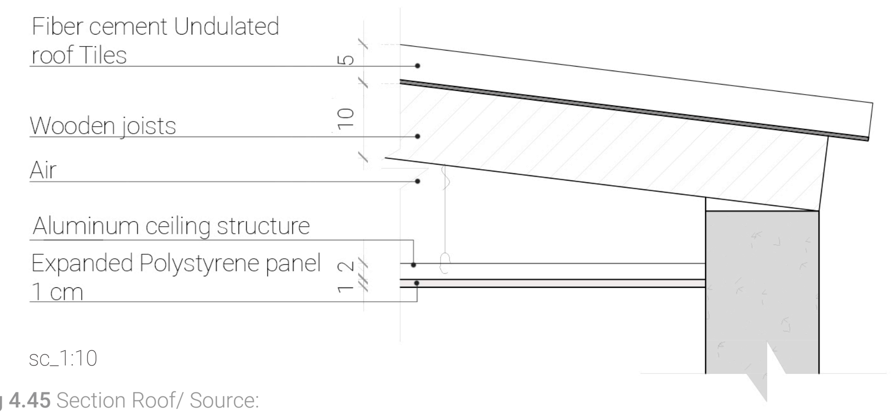


Fig 4.45 Section Roof/ Source: Author´s elaboration

OPAQUE ENVELOPE PERFORMANCE : **Roof**							
N	Layers Interior to Exterior	*d* cm	*ρ* kg/cm³	μ (-)	*c* J/Kg°C	λ W/m°C	*R* m²°C/W
	Internal Surface						0,1
1	Expanded Polystyrene Panel	3	10	1	1300	0,026	
2	Air	30*	1	24	1000	1400	
3	Wooden Joist	10	350	45	2400	0,12	
4	Polyvinyl Cloruro (PVC)Ondulated panel	5	1400	11	1300	0,16	
	External Surface						0,04

* Air space and total thickness depends on the slope

THERMAL TRANSMITTANCE ANALYSIS			
Parameter	Unit	Value	Required
Thermal Transmittance (U)	W/(m²K)	**0,377**	
Thermal Resistance (R)	(m²k)/W	2,654	
Decrement Factor (f)	-	0,251	
Periodic thermal transmittance (Y_{ie})	W/(m²K)	0,094	
Internal aereal heat capacity (K_{ie})	kJ(m²K)	9,1	

Total Thickness (s)	48 cm*
Areal Mass (m)	106 kg/m²
Time lag (φ)	9,84 h

U value
0.37 W/m²K

Table 4.8: Opaque envelope thermal transmitance. Roof. Author´s elaboration

4.9 CONDENSATION

In hot-humid climates one of the main building problems it is caused by condensation, that occurs due to temperature differences. The warm water vapour contained in the air becomes into liquid when it is in contact with a cold surface reaching the dew point. Condensation could be superficial, visible on the external surfaces, or Interstitial that occurs inside the layers of walls, roof or floor. Since the interstitial affects more the building construction and produces more health risks, it has been analyzed through the calculator INVOLUCRO OPACO described before in the Opaque envelope section.

	Temperature Exterior [°C]	Dew Point Temp. [°C]	Saturation vapour pressure [Pa]	Relative Humidity [%]	Vapour Pressure [Pa]
JAN	28,73	18,6	3778	68	2569,04
FEB	29,01	19,3	4003	67	2682,01
MAR	27,93	20,15	3563	75	2672,25
APR	26,86	20,49	3359	80	2687,2
MAY	27,16	21,35	3563	84	2992,92
JUN	26,73	20,25	3359	83	2787,97
JUL	26,72	20,68	3359	86	2888,74
AUG	27,2	20,5	3563	83	2957,29
SEPT	27,6	20,47	3563	79	2814,77
OCT	27,8	20,13	3563	79	2814,77
NOV	27,5	20,91	3563	80	2850,4
DEC	28,3	21,35	3778	77	2909,06

Table 4.9: Climate environmental data /Source: Author´s elaboration

Mass of condensed water (kg/m²)

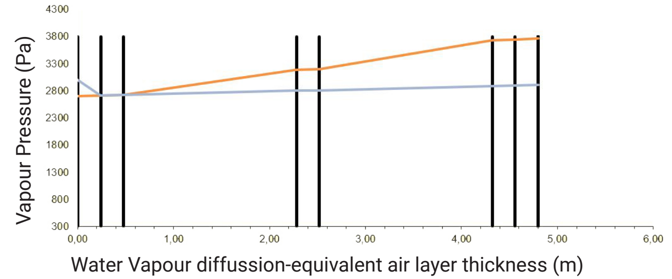
xterior [°C]	Temp. [°C]	pressure [Pa]	Humidity [%]	Pressure [Pa]
28,73	18,6	3778	68	2569,04
29,01	19,3	4003	67	2682,01
27,93	20,15	3563	75	2672,25
26,86	20,49	3359	80	2687,2
27,16	21,35	3563	84	2992,92
26,73	20,25	3359	83	2787,97
26,72	20,68	3359	86	2888,74
27,2	20,5	3563	83	2957,29
27,6	20,47	3563	79	2814,77
27,8	20,13	3563	79	2814,77
27,5	20,91	3563	80	2850,4
28,3	21,35	3778	77	2909,06

Table 4.10: Interstitial condensation / Source: Author´s elaboration

To calculate vapour pressure (Pa) it has been taken into account the local climate conditions of the city for each month, mainly relative humidity data (See figure 4.9). Additionally, internal against external vapour pressure has been shown by the following graphs in December for the walls, floor and roof types. According to the table of insterstitial condensation and the graphs, single (15cm) and double (25cm) wall have risks of interstitial condensation mainly in December and from Feburary to April for the single one. To prevent condesation in these construction elements, the best solution would be improving natural ventilation, and also adding vapour barries in the warmer layer area of the walls.

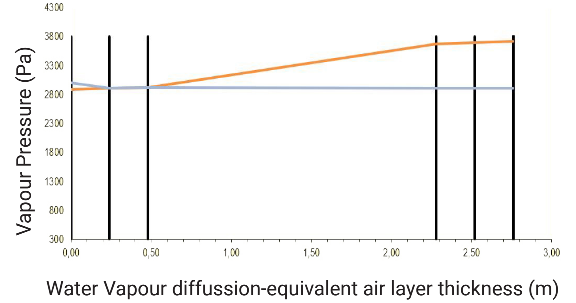
WALL 1 - 1A_
December

Fig 4.46 Source: Edited from simulation INVOLUCRO OPACO



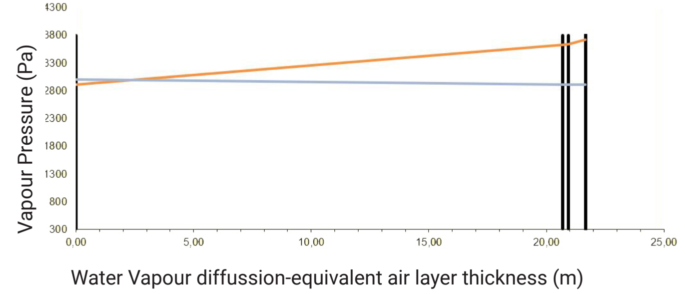
WALL 2_
December

Fig 4.47 Source: Edited from simulation INVOLUCRO OPACO



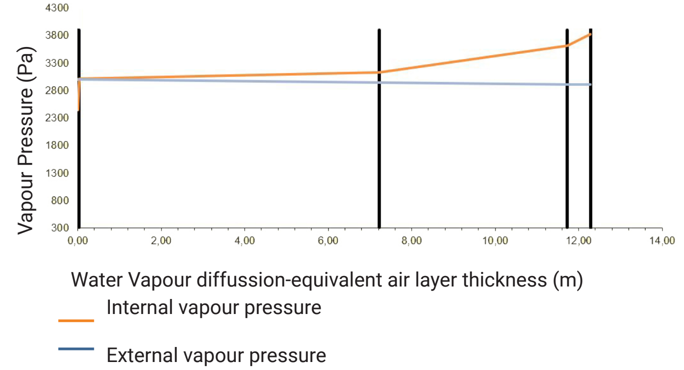
FlOOR_
December

Fig 4.48 Source: Edited from simulation INVOLUCRO OPACO



ROOF_
December

Fig 4.49 Source: Edited from simulation INVOLUCRO OPACO



4.10 ENVIRONMENTAL ANALYSIS OF SELECTED ROOMS

For the evaluation, 8 rooms have been selected taking into account their function, level, dimensions, capacity, and orientation to collect as much information as possible about the total building for the development of the next step regarding the design approach. Each room has been evaluated in 4 categories: Thermal comfort analysis, Daylight analysis, Ventilation analysis, and Acoustic comfort analysis.

For each room, the evaluation has been taking into consideration an assumed maximum capacity and the same schedule for the whole year. So, for the classrooms (named as the typical birds of the region), the amount of students is 12 for the pre-orchestra courses. Most of these rooms are also used for individual or small group classes, but for calculation purposes, the maximum capacity will be taken into account. The orchestra room and the scenario area consider between 30 and 50 people, corresponding to the audience and students. In the case of the office area, the administrative room contemplates 5 people and 1 person for the manager room, although in this room could be an eventual meeting with 3-5 people.

The schedule of the simulations is programmed with 10 hours per day on weekdays and 4 hours on Saturday for the music classrooms, while in the office case, it works with 9 hours on weekdays and 4 on weekends. For some simulations, the year has been separated by seasons. The dry season is from December to March, and the Wet season is from April to November.

Each simulation has been developed with different methods. from the use of international software to the use of traditional calculations that will be described separately.

Before going into detail about the calculations and methods of evaluation, it would be necessary to know the following concepts that are listed below

[70] IUPS Thermal Commission.2001. Glossary of terms for thermal physiology
[71] Nicol JF, Humphreys MA. Adaptive thermal comfort and sustainable thermal standards for buildings.
[72] https://www.corrosionpedia.com/definition/5226/solar-reflective-index

GLOSSARY OF MAIN CONCEPTS

- Temperature, operative (To): The temperature of a uniform (isothermal) “black” enclosure in which a solid body or occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment. [°C] [70]
- Relative humidity:(φ) The ratio of the mol fraction of water vapor present in a volume of air to the mol frac tion present in saturated air, both at the same tempera- ture and pressure. [70]
- Adaptive comfort: the ability of human beings to adapt themselves to the environmental conditions (through conscious or unconscious changes in their metabolic rate or clothing level) and to interact with the environment in order to adapt it to their needs. [71]
- Heat transfer: Process of heat flow [W], i.e., the rate at which heat energy is transferred from one part of an organism to another especially between body core and shell. [70]
- Heat loss: The sum of heat flows or heat fluxes by radiation, convection, and conduction from a body to the environment. [W] or [W · m−2] Synonyms: sen- sible heat loss; heat loss, Newtonian. [70]
- Thermal insulation, clothing (Icl): The intrinsic insu- lation of a clothing assembly. The effective insulation of clothing is (Icl + Ia) where Ia is the reciprocal of the thermal conductance of the ambient environment. [70]
- Solar reflective index (SRI): is a measure of the solar radiation that is reflected back by a rooftop surface (or any other surface in question) and the emissivity of the surface. [72]
- Solar Factor (G-Value): the quantity of heat penetrating into an interior through the glazing and the solar radiant energy incident on that glazing.[73]
- Daylight Factor:Ratio of the illuminance at a point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky, excluding the contribution of direct sunlight to both illuminances. [74]
- Daylight autonomy (DA): is a daylight availability metric that corresponds to the percentage of the occupied time when the target illuminance at a point in a space is met by daylight. [75]
- Useful daylight illuminance (UDI) is a daylight availability metric that corresponds to the percentage of the occupied time when a target range of illuminances at a point in a space is met by daylight. [75]
- Glare: condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme luminance contrasts [73]
- Indoor Air Quality (IAQ) refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants [76]
- Single sided ventilation: airing with windows located on only one side of the ventilation zone. The projections on the horizontal plane of the normal vectors of the windows are within a 90° angle or less [77]
- Stack ventilation: Refers to passive air movement throughout a building due to variances in vertical pressure initiated by thermal buoyancy. If the air within a building grows warmer than the temperature of the surrounding outdoor air, the warmer and lower-density air will rise. [77]
- Cross ventilation: airing with windows located on several sides of the ventilation zone. The projections on the horizontal plane of the normal vectors of the windows are not within a 90° angle or less. [77]
- Reverberation: persistence of sound decreasing with time in an enclosed or partly enclosed space after the signal from an acoustic source is interrupted. [73]
- Reverberation time (T_{60}):of an enclosure, for a sound of a given frequency or frequency band, time that would be required for the sound pressure level in the enclosure to decrease by 60 decibels, after the source has been stopped. [73]

[73] website: https://www.electropedia.org/
[74] ANSI-ASA_2010_part_1_acoustic standard

[75] website: https://www.velux.com
[76] website: https://www.epa.gov/indoor-air-quality-iaq ANSI-ASA_2010_part_1_acoustic standard
[77] BSI, 2015. Draft BS EN 16798-7 Energy performance of buildings. Part 7: Ventilation for buildings

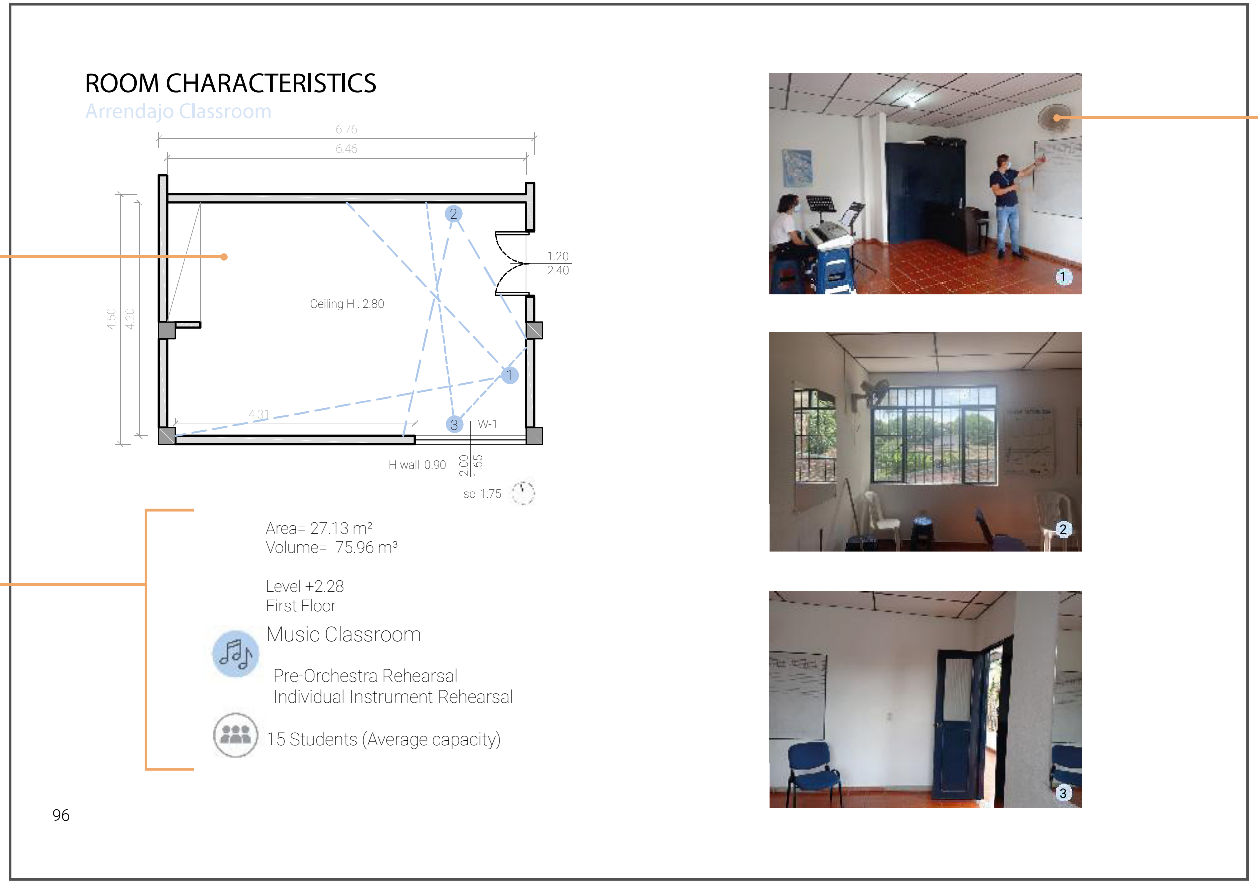
4.11 EVALUATION FORM GUIDE ROOM ANALYSIS

The 8 rooms selected have been evaluated from 4 categories of analysis: Thermal comfort, Daylight, Airflow referring to natural ventilation, and Acoustic comfort. They have been chosen according to their function and location trying to cover a large part of the building for an overall analysis.

Before showing the results of the internal environmental evaluation, it has been developed a form guide where it is explained the content of each evaluation sheet repeated room by room, and its methods of calculations. Some of the evaluations have been developed by software, digital tools, and manual calculations.

At the end of the last room evaluation, it is possible to find a summary of the quantitative results and the respective conclusions.

For each room, there are 6 sheets. The first one corresponds to an image of the location of the room in the building. The second one is an introductive sheet with the main dimensional characteristics and input data for the following evaluations. And the last ones are Thermal, Daylight, Airflow, and Acoustic comfort, in that respective order. The following evaluation form guide sheets it has been taken as an example of the “Arrendajo” room analysis.



1 Plan of the room
2 Specific data
3 Photos survey

Fig 4.50 Evaluation form guide room characteristics/ Source: Author´s elaboration

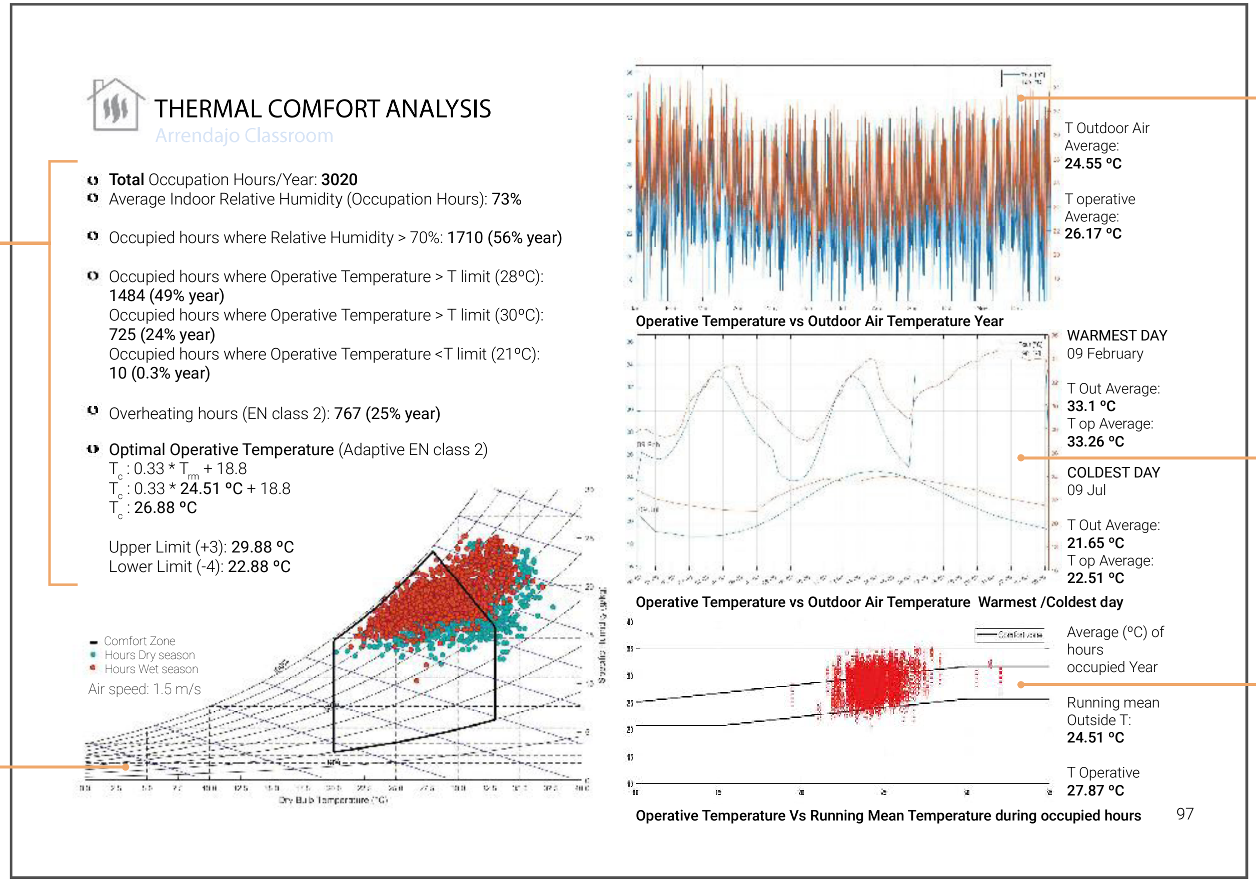
The first sheet contains the main geometric characteristics and the program of the room. It is divided into 3 parts, as it is shown in the image.

1. Plan of the room: It shows the general dimensions, the location and dimensions of the windows and doors, and the location of the photo view.

2. Specific data: It refers to the geometric characteristics such as area and volume, and it indicates the level where the room is located. It also specified the function and its occupancy, taking into account an average of students per course.

3. Photos survey: Some photographs are shown to understand by observation the main elements of the room. They have been taken through some surveys on site

4.11.1 THERMAL EVALUATION FORM GUIDE



4 Thermal performance of occupied hours
5 Givoni Diagram
6 Operative temperature vs Outdoor temperature graph
7 Warmest day/Coldest day graph
8 Operative temperature vs Running mean temperature graph

Fig 4.51 Evaluation form guide thermal comfort/ Source: Author´s elaboration

The interior thermal comfort data of the rooms, as well as the daylighting evaluation, has been calculated through the simulator EnergyVer [78]. It is a software created in France, that is based on normative as French RE2020 DIES, the EN 15251 and ASHRAE 55, and that uses EnergyPlus[79] as a base for energy consumption calculation. The imput data that has been inserted in the software for the thermal and daylighting is described after the chapter 4.11.2, about daylight.

The Thermal evaluation sheet is divided in 5 parts. (The numbers are successive from the previous evaluation sheet)

4. Thermal performance of occupied hours: It indicates some data related to the elements of the environment that affects comfort during the hours of occupation of the house. The results show the hours of discomfort. The maximum hours

78 EnergyVer. Computer software. https://www.energyver.com/
79 EnergyPlus™. Computer software.https://energyplus.net/

varies between the rooms accoring to their function.
The thermal analysis has been simulated following the Adaptive Comfort method, initially proposed by deDear RJ, Brager with the ASHRAE american Standard, and then introduced by the European Committee for Standardization (CEN) with the standard EN 15251 in 2007[80] As this is an existing building, with a further renovation proposal, the Class II category for adaptive comfort has been used for the simulations following the formula developed by Nicol JF, Humphreys in the standard EN 15251[81] It has been applied taking into account the average of the Running mean temperature of occupied hours

Optimal	$T_c : 0.33 * T_{rm} + 18.8$
Upper Limit	$T_c : 0.33 * T_{rm} + 18.8 + 3$
Lower Limit	$T_c : 0.33 * T_{rm} + 18.8 - 4$

The indoor environment parameters evaluated are Relative humidity (assumming a limit of acceptability of 70%), Operative temperature when is over 28°C, and 30°C, also when it is below the minimum acceptable 21°C. Also, there is shown the number of overheating hours according to the adapting approach mentioned above.

5. Givoni diagram: It has been calculated with an average of airspeed of 1.5 m/s, taking into account the climate data of the city where the wind speedvaries in arange between 1 to 2 m/s.

6. Operative temperatura vs Outdoor temperature graph: It represents a graph that shows a comparison between the Outdoor temperature and the Operative Temperature of the room. The evaluation is about the average value of a year (2019).

7. Warmest day vs Coldest day graph: Comparison between the Warmest day on 09 February and the coldest day on 09 July according to the evaluation fo that the specific year 2019. Both the hottest and coldest data are also shown by the comparison between the Outdoor temperature and the Operative Temperature for that day. The results showed are the mean temperature of that day.
8. Operative temperature vs Running mean temperature:It shows the average operative temperature against the running mean temperature of the occupied hours. This graph shows the number of occupied hours (points) during the year in the band which corresponds to the comfort zone for adaptive class 2.

4.11.2 DAYLIGHT EVALUATION FORM GUIDE

As for thermal comfort analysis, the daylight has been calculated using EnergyVer. Considering the required data of the existing room, but mainly the information about windows materials and their position, shading devices, and adding the climate data coming from the EPW file, it has been possible to identify the areas more illuminated and the ones that lack natural illumination.
The Daylight evaluation sheet is divided into 4 parts. (The numbers are successive from the previous evaluation sheet)

9. Average year illuminance plan: It shows through a room plan the amount of illuminance from daylight in terms of Luxes and its distribution in the room according to the location of the windows. The legen also shows the Daylight factor value (DF)
10. Current daylight vs threshold value: The data listed shows the 3 main parameters to calculate daylighting. The first one is about the main Daylight Factor (DF) value against its threshold for schools according to its function. And the area of the room that meets the requirement. The second one is about the mean Daylight Autonomy (DA) value with a requirements of at least 50% of the room. And the third one shows the value of the Useful Daylight Illuminance (UDI), with a range between 300 lx and 3000 lx. For school the value of UDI (Percentage of occupied hours) should be 80%[82]. The value shows the percentage of the room that meets that requirement, as well as the percentage of the room with glared area (Over 3000 lx).
10. Analysis per hour during dry season: : it shows the amount of illuminance in the dry season distributed in the room plan and the average percentage of the room that is below and over the threshold values. It has been taken into consideration three hours of the day for the calculation.
11. Analysis per hour during wet season: it shows the amount of illuminance in the wet season distributed in the room plan and the average percentage of the room that is below and over the threshold values. It has been taken into consideration three hours of the day for the calculation.

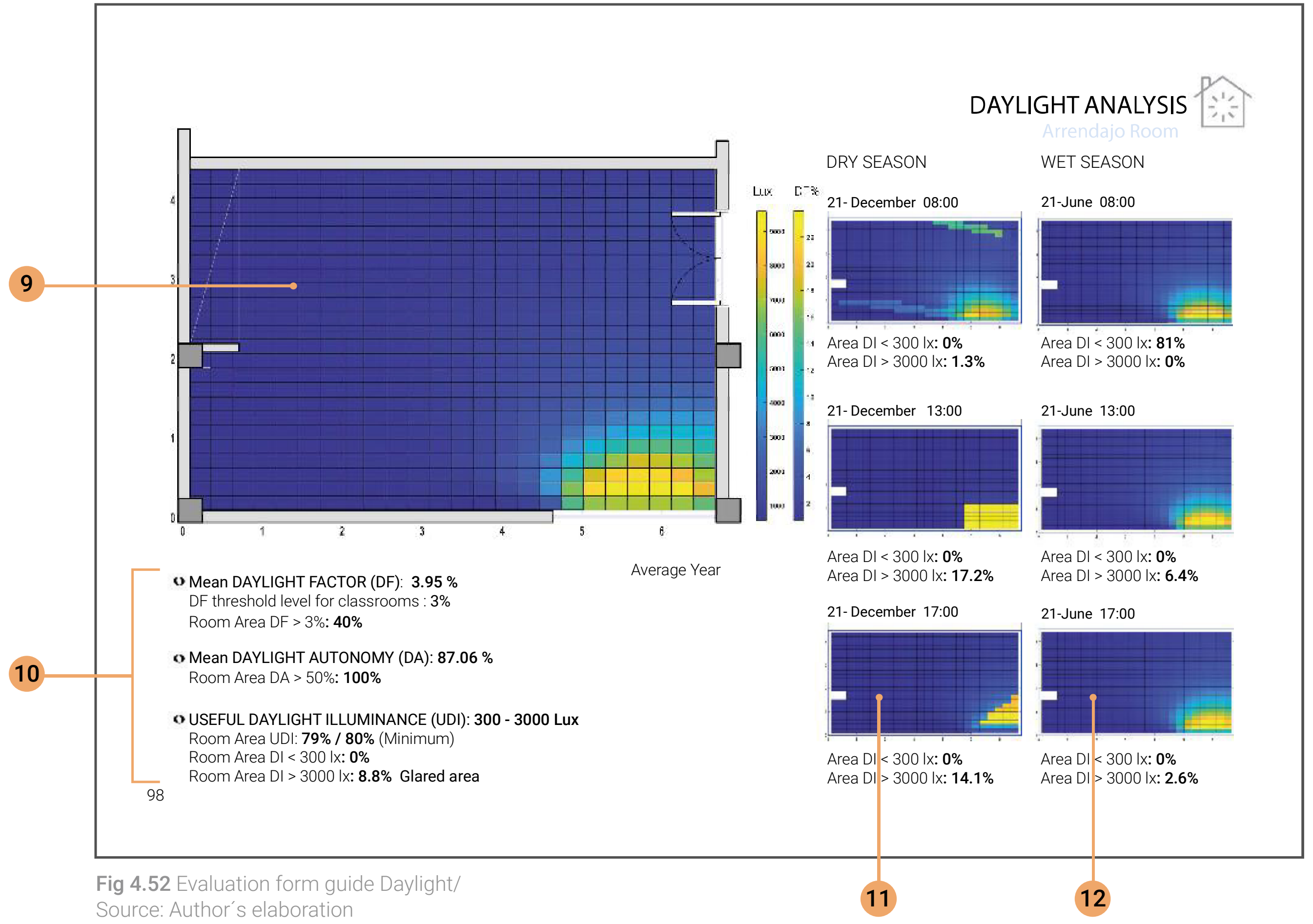


Fig 4.52 Evaluation form guide Daylight/
Source: Author´s elaboration

9 Average year Daylight Illuminance plan
10 Current Daylight vs threshold value
11 Analysis per hour during dry season
12 Analysis per hour during wet season

80 Simone Ferrari, Valentina Zanotto, 2011.Adaptive comfort: Analysis and application of the main indices
81 Nicol JF, Humphreys MA. 2010. Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN15251. Build Environ 45:11e7.
82 EN 17037:2018. Daylighting in buildings

IMPUT DATA FOR THERMAL COMFORT AND DAYLIGHT ANALYSIS

The software EnergyVer is a tool for building physics simulations based on EnergyPlus calculations design by the Université Côte-d'Azur and performed by Professor Ibrahim Mohamad. The following general data has been used to run simulations for thermal comfort and daylighting analysis

Simulation Running Time: **1 year (2019)**

Geometry

- Latitude: **4.15°**
- North: **-16° South-West**
- Ceiling Height: **4 m / 2.80 m**
- Zone elevation: 0 m / -0.87m / +2.28 m
- Zone type: Secondary school (similar to Music school)

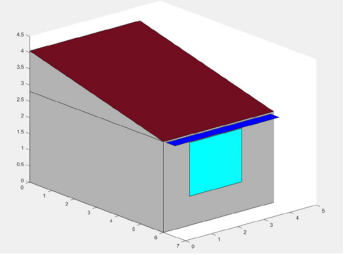


Fig 4.53: Axonometry of geometry/ Source: EnergyVer simulation

Windows data

For the data of windows it has been inserted the results from the windows analysis described in Chapter 4 (4.5).

U-value: **4.08 / 5.67 / 3.643** [W/m^2 K]

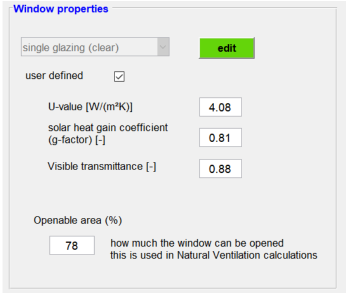


Fig 4.54: Windows properties/ Source: EnergyVer simulation

Construction imput data

The main materials and typlogies of construction of the walls and their location are part of the input data. Each material has been inserted with its thermal characteristics and the thickness.

- Type 1 (Wall single block): Mineral Stucco- Clay blocks 10x20x30cm (2)- Mineral Stucco
- Type 2 (Roof): Fibercement panel - Air layer
- Type 3 (Floor): Concrete slab- Cement plaster- Terracota Tiles
- Type 4 (ceiling roof): Polystylene expanded panel

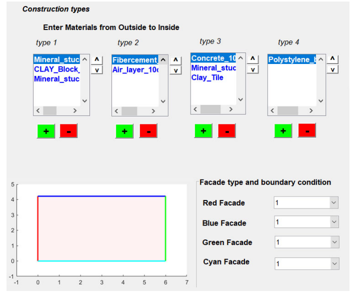
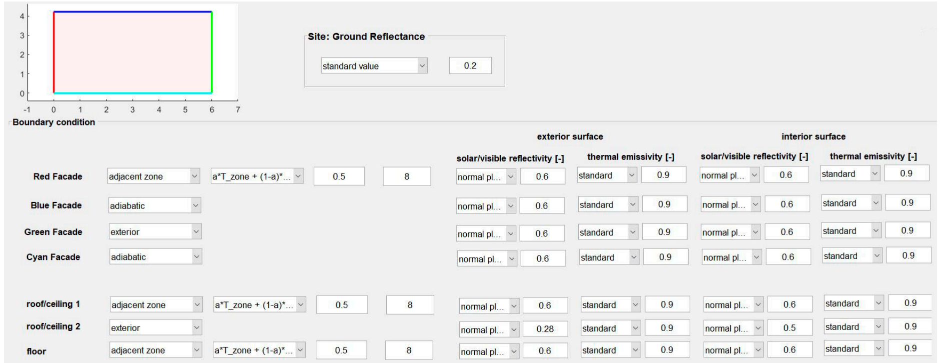


Fig 4.55: Construction imput data/ Source: EnergyVer simulation



Boundaries:

It refers to the boundary conditions of each wall, as well as the emissivity and reflective values of the wall material . The value varies from room to room.

Schedules

The occupancy schedules for running simulations have been divided by functions and spaces for the whole year.

- Music spaces: 9 Hours of use
- Offices: 8 Hours of use

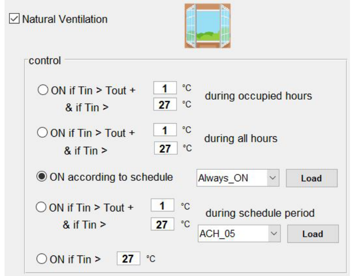


Fig 4.56: Natural ventilation/Source: EnergyVer simulation

System and load

Although ome of the rooms have fans, the simulations have been run as Natural ventilated always ON.

Has been added the number of occupants, the activity as light and quantity of lights in terms of watts. It varies from room to room.

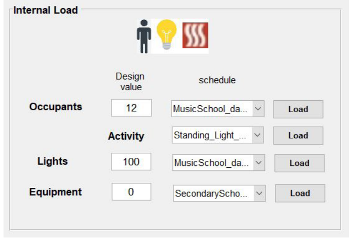


Fig 4.57: Internal loads/ Source: EnergyVer simulation

4.11.3 AIRFLOW EVALUATION FORM GUIDE

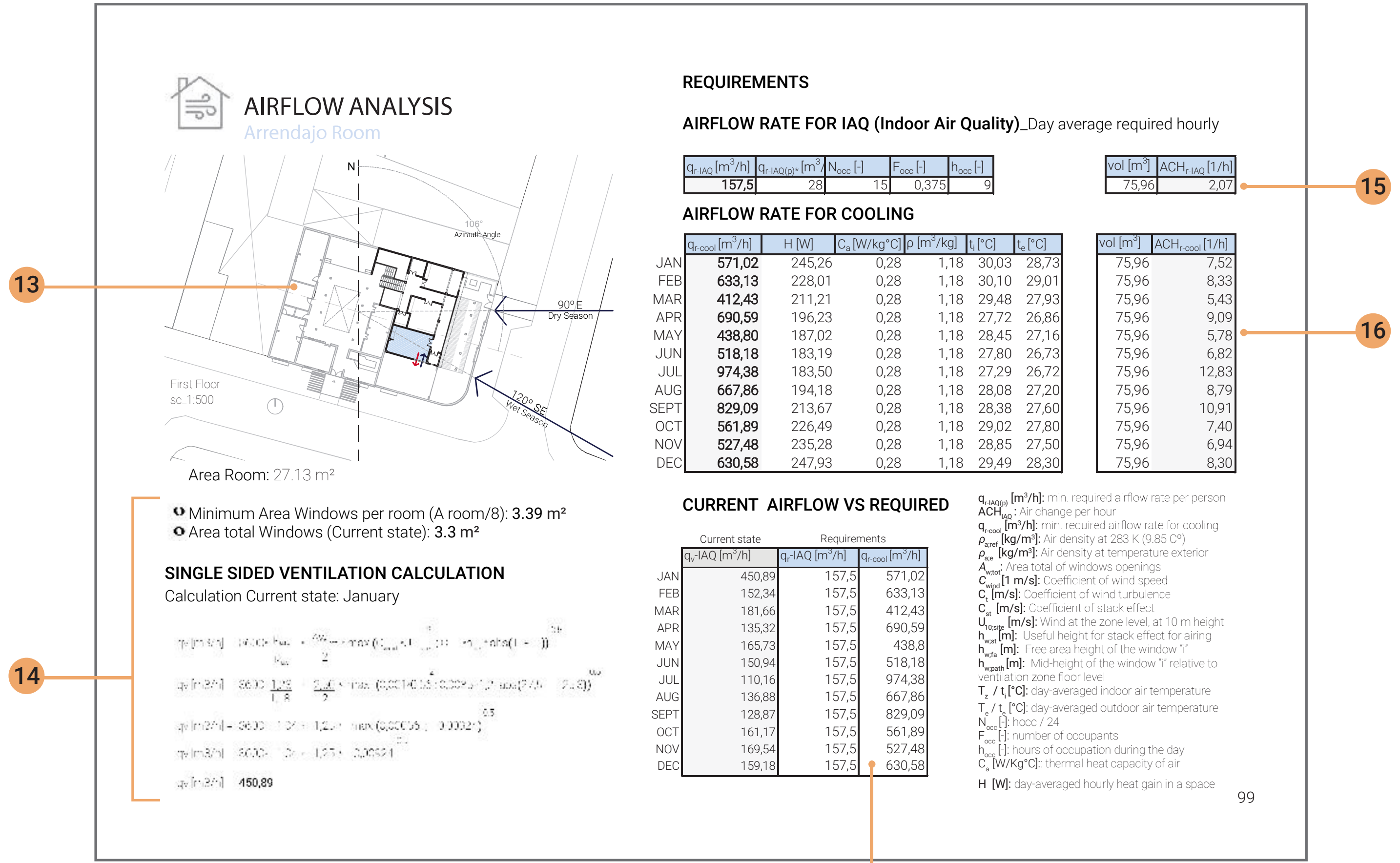


Fig 4.58 Evaluation form guide Airflow/ Source: Author´s elaboration

17

- **13** Wind direction site plan
- **14** Ventilation calculation
- **15** Indoor Air Quality Values
- **16** Monthly airflow rate for cooling required
- **17** Current state VS required airflow values

Based on stantards from ASHRAE and EN-16798-7:2017, the calculations have been done manually following the main formulas to know the actual airflow performance compared to the requirements for each room. For the requirements, a simplified empirical method has been used for calculating natural ventilation airflow through buildings developed by the architect and professor Mario Grosso from the Politecnico di Torino[83].

The Airflow evaluation sheet is divided into 5 parts. (The numbers are successive from the previous evaluation sheet)

13. **Wind direction site plan:** The plan shows the location of the room in the building with its windows location and the main wind direction pointed

14. **Ventilation calculation:** It is divided into two calculations. The first one is the formula to define the minimum window dimension required. It is shown the current dimension of the window for each room against the threshold value given by Italian regulation

83 Grosso, Mario.2017. Il raffrescamento passivo degli edifici in zone a clima temperato

84 DM 5 luglio 1975, DECRETO MINISTERIALE 5 LUGLIO. Requisiti igienico sanitari dei locali d'abitazione. art 5.

Ministerial decree 25-07-75[84]. On the other hand there is an example of the applied formula for the case of January depending on the type of ventilation of the room. If is single sided ventilation, stack ventilation or cross ventilation. The formulas have been taken from the Standard EN 16798-7:2017 [85]

$$q_{V;\arg} = 3600 \times \frac{\rho_{a;ref}}{\rho_{a;e}} \cdot \frac{A_{w;tot}}{2} \cdot \max\left(C_{wind} \cdot u_{10;site}^2; C_{st} \cdot h_{w;st} \cdot abs(T_z - T_e)\right)^{0.5}$$

For the Single-sided ventilation calculation has been used this formula :

a applied was:

$$q_s = C_d \cdot A \cdot \sqrt{2 \cdot g \cdot H \cdot \frac{(T_i - T_e)}{T}} \qquad [\mathrm{m^3/s}]$$

Although there is not considered **cross-ventilation** for any room of the current building, the following is the formula for its calculation:

$$q_v = v_{(z)} \times \sqrt{\frac{C_p^+ - C_p^-}{\frac{1}{C_{d_1}^2 \cdot A_1^2} + \frac{1}{C_{d_2}^2 \cdot A_2^2} + \dots \frac{1}{C_{d_n}^2 \cdot A_1^2}}} \qquad [\mathrm{m^3/s}]$$

$$v_{(z)} = v_{(z_{sm})} \left(\frac{\delta_{sm}}{z_{sm}}\right)^{\upsilon_{sm}} \left(\frac{z_{se}}{\delta_{se}}\right)^{\upsilon_{se}} \qquad [m/s]$$

85 Standard EN 16798-7:2017 Energy performance of buildings - Part 7: Ventilation for buildings - Modules M5-1, M5-5, M5-6, M5-8 - Calculation methods for the determination of air flow rates in buildings including infiltration

NOMENCLATURE

$\rho_{a;ref}$ [kg/m³]: Air density at 283 K (9.85 Cº)and dry air
$\rho_{a;e}$ [kg/m³]: Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} [1 m/s]: Coefficient taking into account wind speed
C_t [m/s]: Coefficient taking into account wind turbulence
C_{st} [m/s]: Coefficient taking into account stack effect
$u_{10;site}$ [m/s]: Wind at the zone level, taking into account meteo wind at 10 m height
$h_{w;st}$ [m]: Useful height for stack effect for airing
$h_{w;fa}$ [m]: Free area height of the window "i"
$h_{w;path}$ [m]: Mid-height of the window "i" relative to ventilation zone floor level
T_z/T_i [°C]: day-averaged indoor air temperature
T_e [°C]: day-averaged outdoor air temperature
q_v [m3/s]: Volume Instant Wind-Driven Airflow
V_z [m/s]: Average wind velocity at the barycentre of openings
C_p^+: Average value of Coeficcient Pressure at windward side
C_p^-: Average value of Coeficcient Pressure at windward side
C_d: Discharge coefficient of the openings

15. Indoor air quality values: It shows a table with the required average hourly volume airflow rate and the value of air changes per hour needed. The formulas has been taken from the Standard EN 16798-7:2017[83]

Day-average Indoor Air Quality Requirements (IAQ):

$q_{r\text{-}IAQ} = q_{r\text{-}IAQ(p)} \times N_{occ} \times F_{occ}$ [m³/h]

Day-average Air Change per Hour (ACH_{IAQ})

$ACH_{r\text{-}IAQ} = q_{r\text{-}IAQ} / Vol$ [1/h]

16. Monthly airflow rate for cooling required: It shows the required average hourly volume airflow rate and the value of air changes per hour needed. The formulas has been taken from the Standard EN 16798-7:2017 [83]

Day-average Indoor Air Quality for Cooling Requirements (Cool) / **Day-average average Air Change per Hour for Cooling (ACH_{Cool})**:From the Standard EN 16798-7:2017

$$q_{r\text{-}cool} = \frac{H}{c_a \cdot \rho \cdot (t_i - t_e)} \quad [\mathrm{m^3/h}] \qquad ACH_{r\text{-}cool} = q_{r\text{-}cool} / Vol \quad [1/h]$$

$H = (H_{sol} + H_{int}) \times F_{mass}$ [W]

$H_{sol} = \sum_1^w (I_{sol.w} \times F_{sol.w} \times A_w)$ [W] Solar Gains

IMPUT DATA FOR THE CALCULATIONS

The following table shows the data needed to do the calculations was: Climate data of Villavicencio from the EPW, that is given by the meteorological station of thecity and the radiation data specifically from the house location, taked from the Photovoltaic Geographical Information system (PVGIS).

	Dew Point Temperature [°C]	Relative Humidity (%)	Global Horizontal Radiation (Wh/m2)	Direct Normal Radiation (Wh/m2)	Horizontal Radiation (Wh/m2)	Wind Direction (Degrees)	Wind Speed (m/s)	Temperature Interior (Ti)	Temperature Exterior (Te)
JAN	18,6	68	142,38	105,47	76,88	74	0,7	27,5	25,3
FEB	19,3	67	127,72	77,92	72,8	121	1,2	28	26,4
MAR	20,15	75	132,84	68,2	82,36	100	0,5	27,3	25,4
APR	20,49	80	130,17	69,57	79,4	168	1,3	25,7	24,4
MAY	21,35	84	132,41	74,98	80,71	112	0,3	26,2	24,4
JUN	20,25	83	121,43	73,13	72,85	92	0,4	25,4	23,7
JUL	20,68	86	127,17	75,43	75,03	93	0,5	24,9	23,6
AUG	20,5	83	134,57	78,85	78,05	96	0,6	25,6	24
SEP	20,47	79	145,32	98,4	74,11	128	1	26,1	24,7
OCT	20,13	79	150,26	95,62	81,14	104	0,5	26,5	24,5
NOV	20,91	80	131,90	83,12	76,5	143	1,3	26,7	24,8
DEC	21,35	77	139,60	107,04	71,96	87	0,8	26,8	24,7

NOMENCLATURE for IAQ and IAQ_{-Cool}

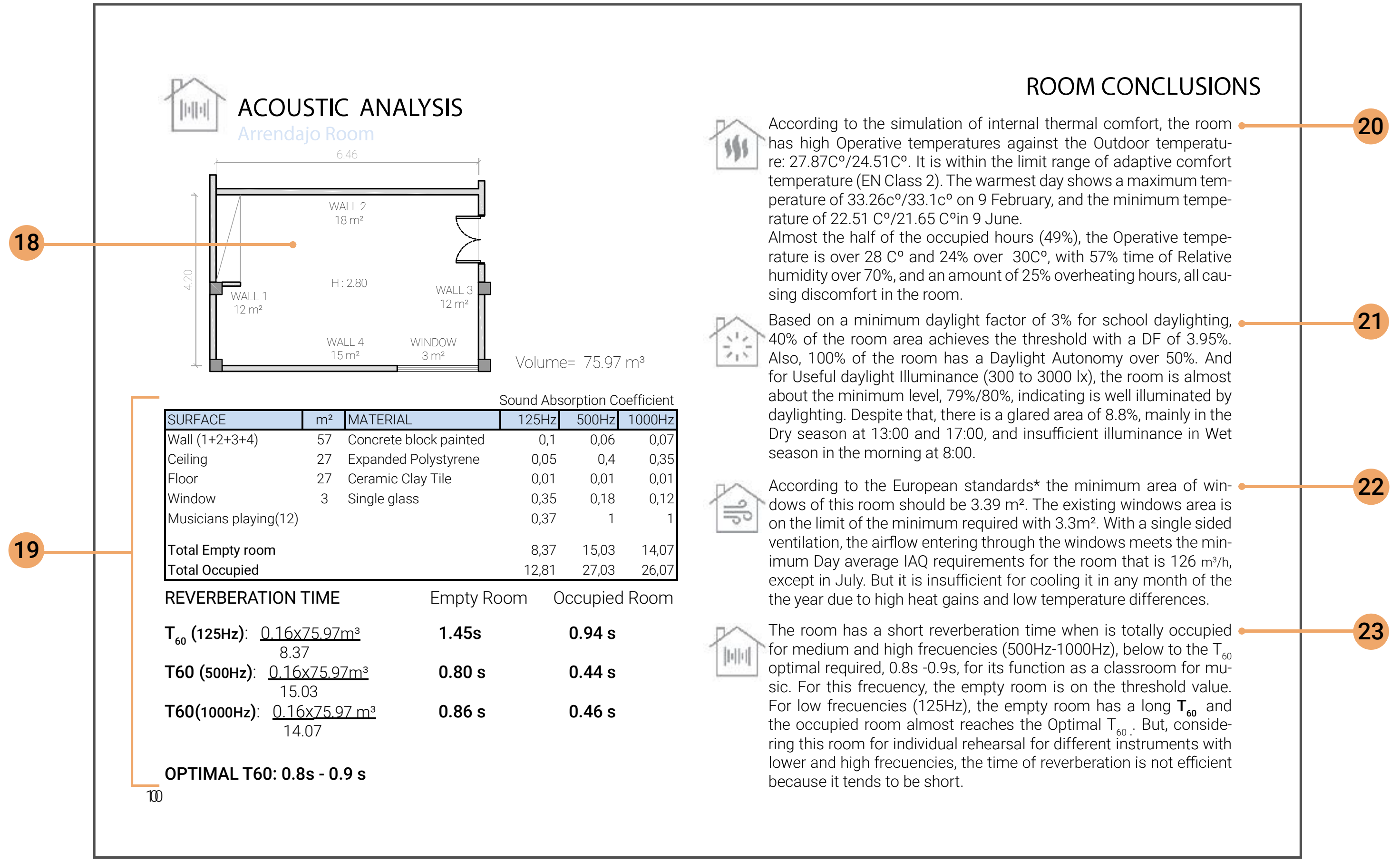
$q_{r\text{-}IAQ(p)}$ [m³/h]: minimum required airflow rate per person related to the considered space unit
A_w: Area total of windows glass
T_z / t_i [°C]: day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
$q_{r\text{-}IAQ(p)}$ [m³/h]: minimum required airflow rate per person related to the considered space unit
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
H [W]: day-averaged hourly heat gain in the space unit [W]

17. Current state VS required airflow required: The table shows the values of the current state from the formula applied (step 14) against the required values. From it, it is possible to identify the months that meet the requirement of minimum airflow.

Note: For temperature data has been taken as a reference the Room Arrendajo. The values for each room comesfrom the thermal comfort simulation from EnergyVer.

Table 4.10: Climate Data base of Villavicencio. Taked from EPW file Villavicencio data 2012-2018.

4.11.4 ACOUSTIC EVALUATION FORM GUIDE



ACOUSTIC ANALYSIS
Arrendajo Room

Volume= 75.97 m³

Sound Absorption Coefficient

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4)	57	Concrete block painted	0,1	0,06	0,07
Ceiling	27	Expanded Polystyrene	0,05	0,4	0,35
Floor	27	Ceramic Clay Tile	0,01	0,01	0,01
Window	3	Single glass	0,35	0,18	0,12
Musicians playing(12)			0,37	1	1
Total Empty room			8,37	15,03	14,07
Total Occupied			12,81	27,03	26,07

REVERBERATION TIME	Empty Room	Occupied Room
T_{60} (125Hz): $\frac{0.16 \times 75.97 m^3}{8.37}$	**1.45s**	**0.94 s**
T60 (500Hz): $\frac{0.16 \times 75.97 m^3}{15.03}$	**0.80 s**	**0.44 s**
T60(1000Hz): $\frac{0.16 \times 75.97 m^3}{14.07}$	**0.86 s**	**0.46 s**

OPTIMAL T60: 0.8s - 0.9 s

100

ROOM CONCLUSIONS

According to the simulation of internal thermal comfort, the room has high Operative temperatures against the Outdoor temperature: 27.87Cº/24.51Cº. It is within the limit range of adaptive comfort temperature (EN Class 2). The warmest day shows a maximum temperature of 33.26cº/33.1cº on 9 February, and the minimum temperature of 22.51 Cº/21.65 Cºin 9 June.
Almost the half of the occupied hours (49%), the Operative temperature is over 28 Cº and 24% over 30Cº, with 57% time of Relative humidity over 70%, and an amount of 25% overheating hours, all causing discomfort in the room.

Based on a minimum daylight factor of 3% for school daylighting, 40% of the room area achieves the threshold with a DF of 3.95%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room is almost about the minimum level, 79%/80%, indicating is well illuminated by daylighting. Despite that, there is a glared area of 8.8%, mainly in the Dry season at 13:00 and 17:00, and insufficient illuminance in Wet season in the morning at 8:00.

According to the European standards* the minimum area of windows of this room should be 3.39 m². The existing windows area is on the limit of the minimum required with 3.3m². With a single sided ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 126 m³/h, except in July. But it is insufficient for cooling it in any month of the the year due to high heat gains and low temperature differences.

The room has a short reverberation time when is totally occupied for medium and high frecuencies (500Hz-1000Hz), below to the T_{60} optimal required, 0.8s -0.9s, for its function as a classroom for music. For this frecuency, the empty room is on the threshold value. For low frecuencies (125Hz), the empty room has a long $\mathbf{T_{60}}$ and the occupied room almost reaches the Optimal T_{60}. But, considering this room for individual rehearsal for different instruments with lower and high frecuencies, the time of reverberation is not efficient because it tends to be short.

Fig 4.59 Evaluation form guide Daylight/ Source: Author´s elaboration

18 Room plan
19 Material values - Reverberation time
20 Thermal comfort conclusion
21 Daylight conclusion
22 Airflow conclusion
23 Acoustic conclusion

Being the case study a building for music education, evaluating the acoustic of its spaces becomes important. For this evaluation, it has been taking into consideration the calculation of the reverberation time of each room.
The Acoustic evaluation sheet is divided into 2 parts. (The numbers are successive from the previous evaluation sheet)

18. Room plan: The plan shows the area of each wall and the height of the room. This data is neccesary for the following calculation.

19. Material values and reverberation time calculation: The table includes the materials for each wall, ceiling, and floor with the sound absorption properties in 3 frequencies (125Hz,500 Hz, 1000Hz), the number of people when occupied, and the area of the room. Then, it was applied for the calculation the Sabine`s Formula [86]

$$T_{60}: \frac{0.16V}{A^*}$$

A* : S (Area of surfaces) . α (Coefficient of absorption)

86 McCue, E., Rehearsal Room Acoustics, Acoustical Design of Music Education Facilities, E.McCue & R.H.Talaske Editors, Acoustical Society of America, New York, (1990) 36 - 41.

To know if the actual conditions are effective to provide acoustic comfort, it has been use as a reference for optimal time (Optimal T_{60})of reverberation from the table of Harris[87]. The value of music has been taking into consideration to be compare with the actual values of each room.

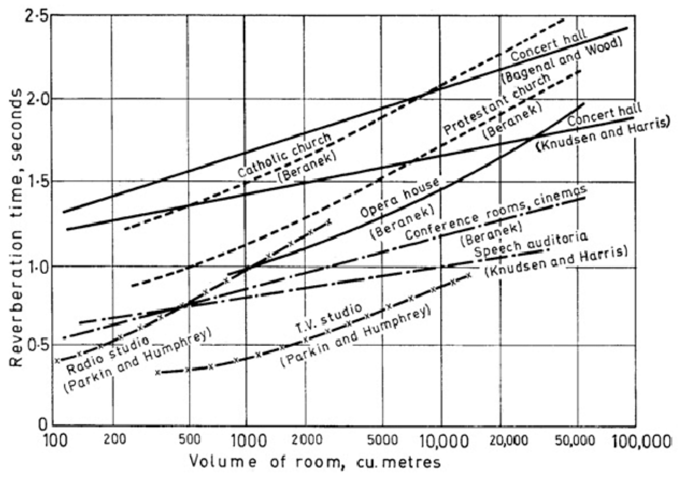


Fig 4.60 Reverberation time / Source: AHarris,C.1997. M. Handbook of Noise Control.

For rooms 50m³ to 500m³

T_{60} Normal Classroom: 0.4 - 0.6 s

T_{60} Chamber music- concert hall: 1.2 s- 1.4s

T_{60} Music Classroom: **0.8s - 0.9s**

87 AHarris,C.1997. M. Handbook of Noise Control.

ROOM CONCLUSIONS

Finally, the last evaluation form guide shows also the main written conclusions of the current state of room-by-room evaluation. After all the 8 rooms analysis there will be an extensive conclusion comparison between the rooms.

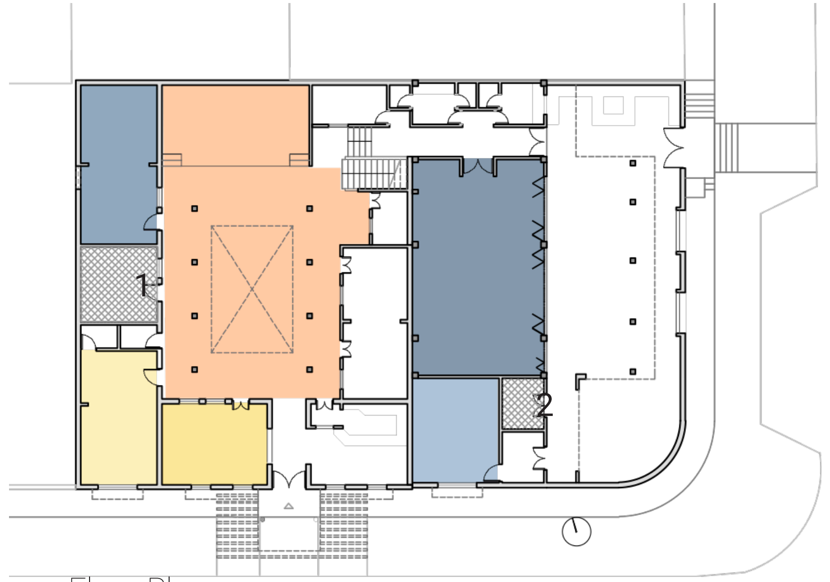
20. Thermal comfort conclusions
21. Daylight conclusions
22. Airflow conclusions
24. Acoustic comfort conclusions

4.11.5 SELECTED ROOMS

Functional rooms with reduce natural ventilation and daylighting.

1 Director office

2 Tucusito classroom Individual



Floor Plan

MUSIC CLASSROOM

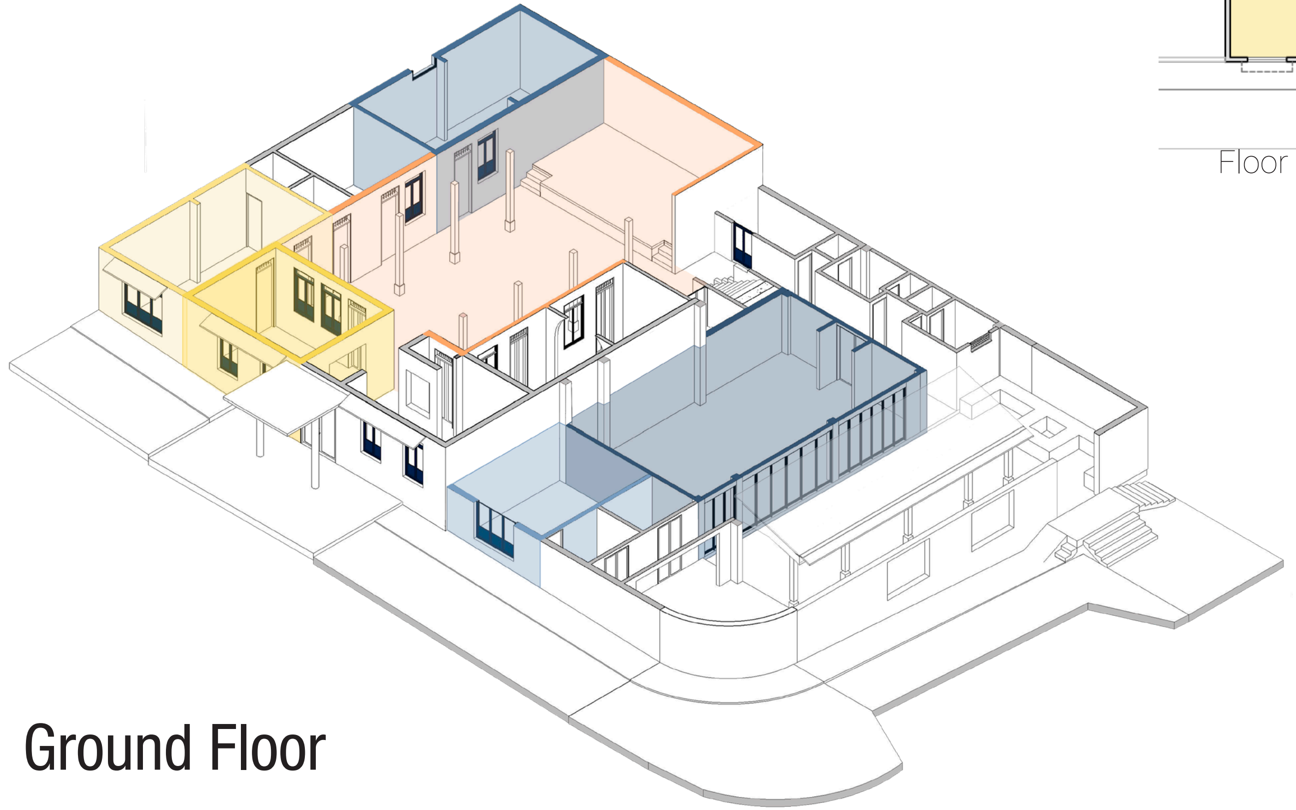
- “Macundal” Classroom — Percussion
- “Paraulata” Classroom — Individual/ Pre-Orchestra
- Orchestra Classroom — Orchestra

COMMON AREA

- Scenario/Lobby — Scenario

ADMINISTRATION

- Administrative Office — Administration
- Manager Office — Manager



Ground Floor

Fig 4.61 Axonometry and floor plan Ground Floor selected rooms Source: Author´s elaboration

Functional rooms with reduce natural ventilation and daylighting

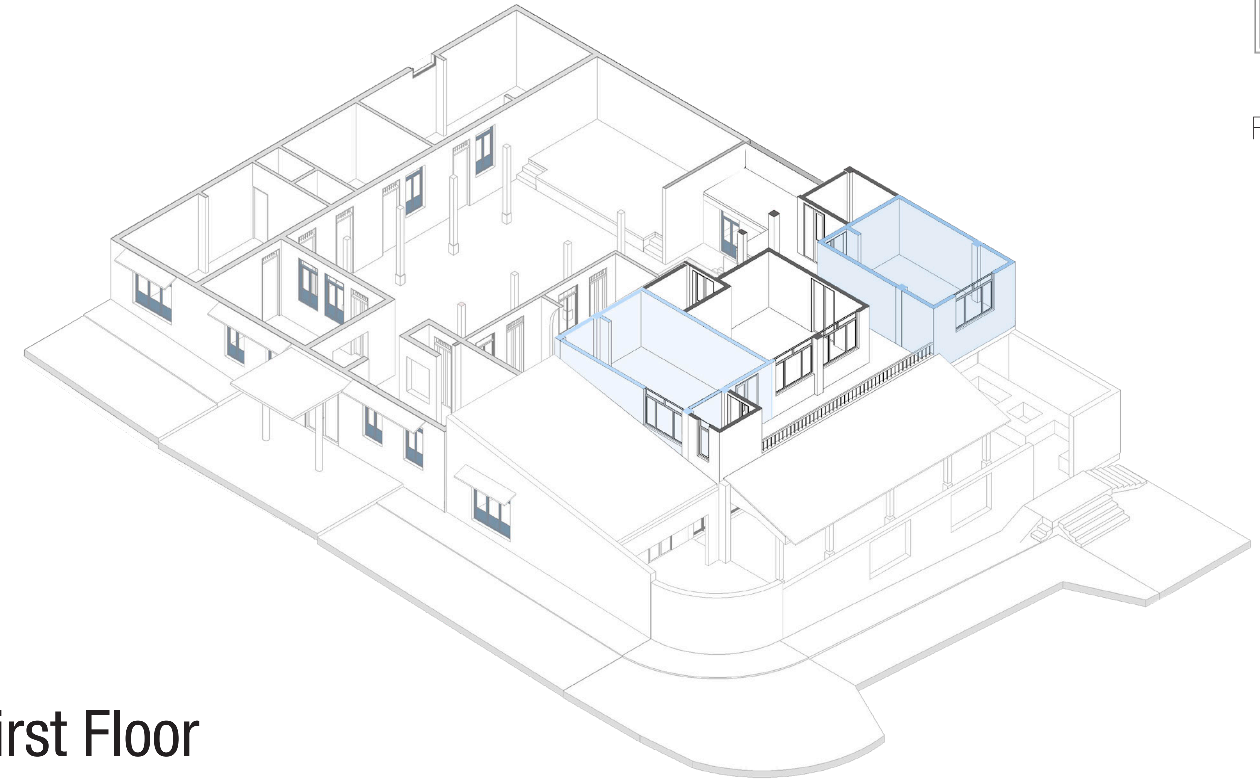
3 Tucan Classroom Individual

4 Chipola Classroom Individual

Floor Plan

MUSIC CLASSROOM

- “Arrendajo” Classroom — Individual/ Pre-Orchestra
- “Corocora” Classroom — Individual/ Pre-Orchestra



First Floor

Fig 4.62 Axonometry and floor plan First floor selected rooms Source: Author´s elaboration

“ARRENDAJO”

ROOM ANALYSIS

Fig 4.63 Axonometry “Arrendajo” location// Source: Author´s elaboration

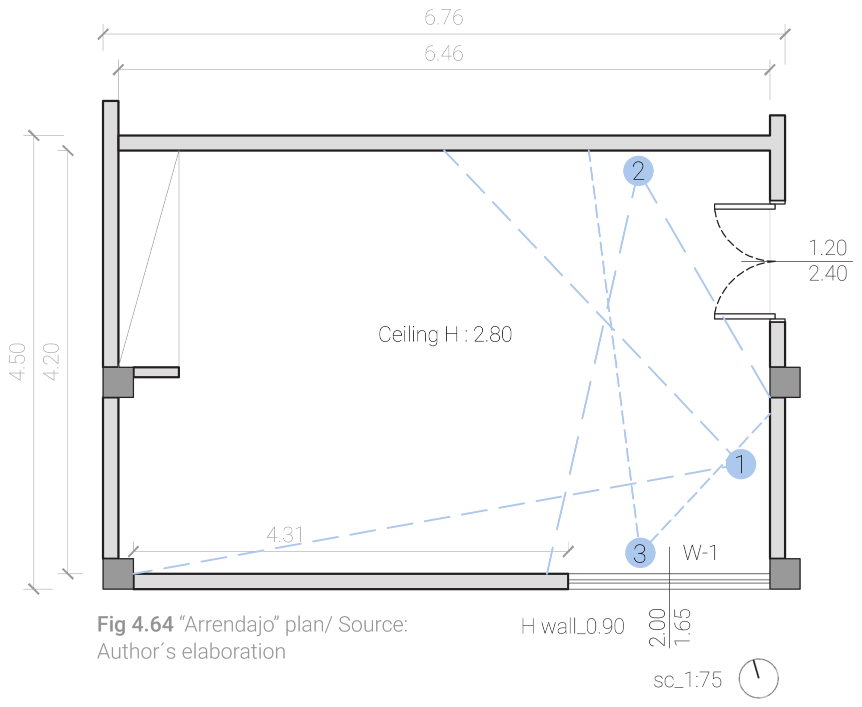


Fig 4.64 “Arrendajo” plan/ Source: Author´s elaboration

Area= 27.13 m²
Volume= 75.96 m³

Level +2.28
First Floor

Music Classroom

_Pre-Orchestra Rehearsal
_Individual Instrument Rehearsal

15 Students (Average capacity)

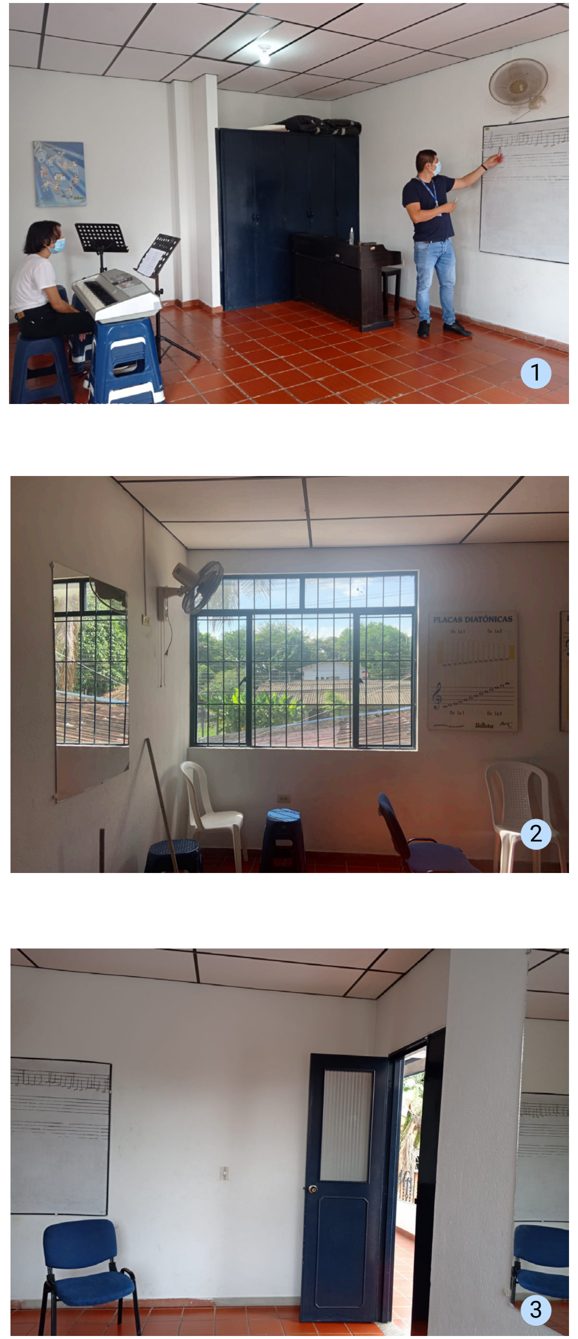


Fig 4.65 “Arrendajo” photos/ Source: Author´s photos

THERMAL COMFORT ANALYSIS

"Arrendajo" Classroom

- **Total** Occupation Hours/Year: **3020**
- Average Indoor Relative Humidity (Occupation Hours): **73%**

- Occupied hours where Relative Humidity > 70%: **1710 (56% year)**

- Occupied hours where Operative Temperature > T limit (28ºC): **1484 (49% year)**
  Occupied hours where Operative Temperature > T limit (30ºC): **725 (24% year)**
  Occupied hours where Operative Temperature <T limit (21ºC): **10 (0.3% year)**

- Overheating hours (EN class 2): **767 (25% year)**

- **Optimal Operative Temperature** (Adaptive EN class 2)
  T_c : 0.33 * T_{rm} + 18.8
  T_c : 0.33 * **24.51 ºC** + 18.8
  T_c : **26.88 ºC**

  Upper Limit (+3): **29.88 ºC**
  Lower Limit (-4): **22.88 ºC**

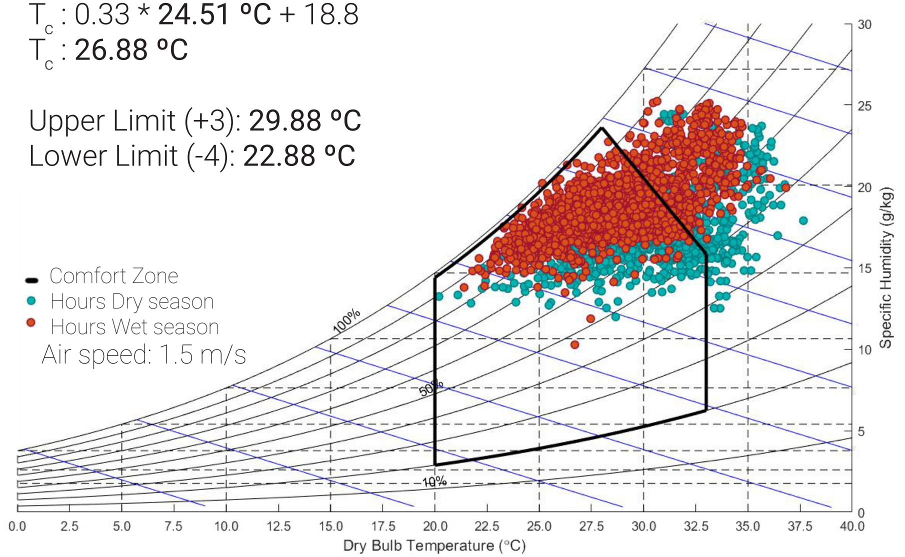


Fig 4.66 Givoni diagram/ Source: EnergyVER

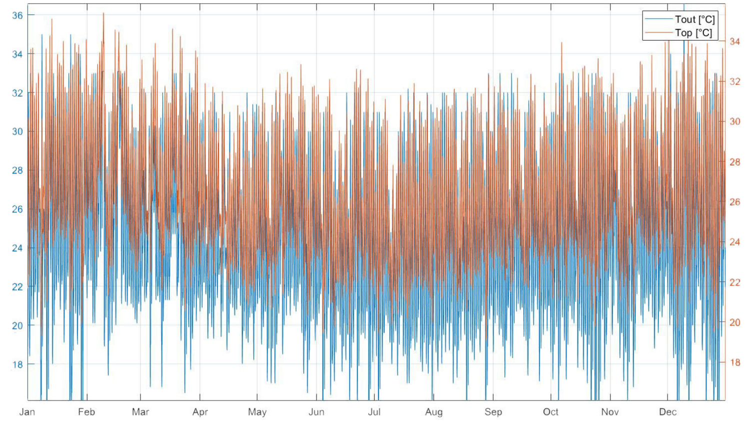


Fig 4.67 Operative Temperature vs Outdoor Air Temperature Year

T Outdoor Air Average: **24.55 ºC**

T operative Average: **26.17 ºC**

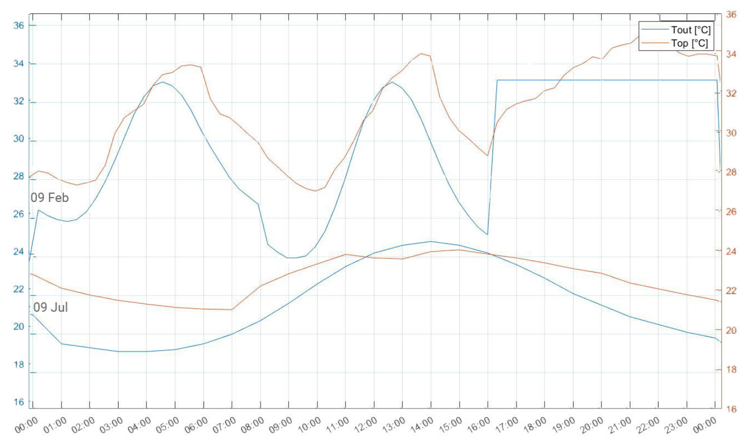


Fig 4.68 Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day

WARMEST DAY
09 February

T Out Average: **33.1 ºC**
T op Average: **33.26 ºC**

COLDEST DAY
09 Jul

T Out Average: **21.65 ºC**
T op Average: **22.51 ºC**

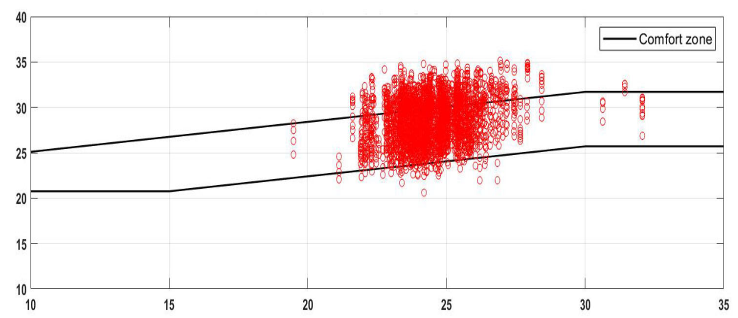


Fig 4.69 Operative Temperature Vs Running Mean Temperature during occupied hours

Average (ºC) of hours occupied Year

Running mean Outside T: **24.51 ºC**

T Operative **27.87 ºC**

DAYLIGHT ANALYSIS

"Arrendajo" Room

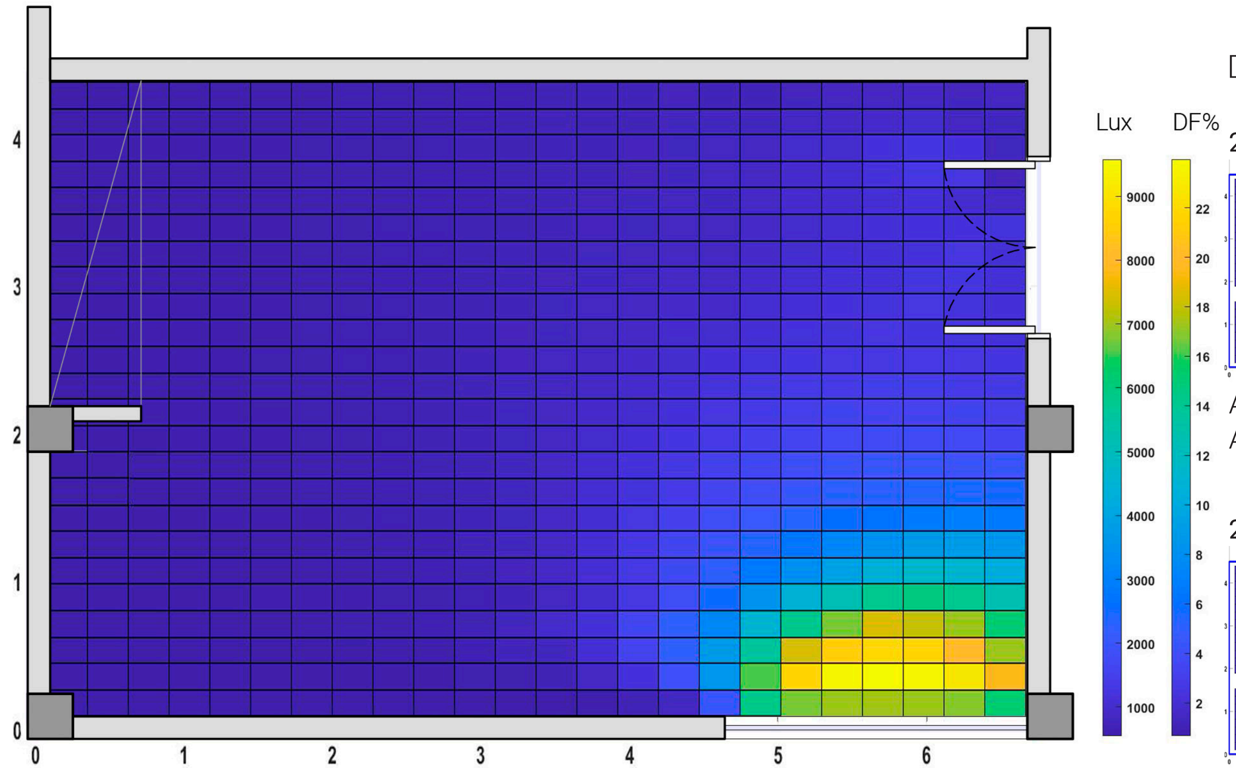


Fig 4.70 Illuminance plan/ Source: EnergyVER

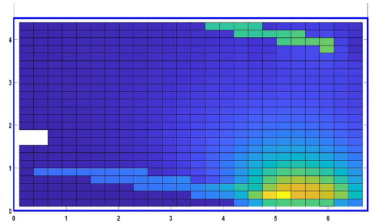
Average Year

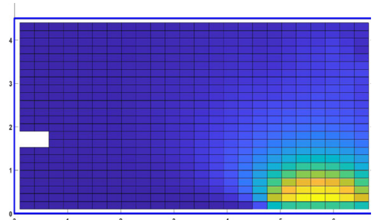
- Mean **DAYLIGHT FACTOR** (DF): **3.95 %**
  DF threshold level for classrooms : 3%
  Room Area DF > 3%: **40%**

- Mean **DAYLIGHT AUTONOMY** (DA): **87.06 %**
  Room Area DA > 50%: **100%**

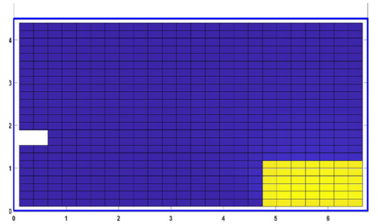
- **USEFUL DAYLIGHT ILLUMINANCE (UDI): 300 - 3000 Lux**
  Room Area UDI: **79% / 80%** (Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **8.8%** Glared area

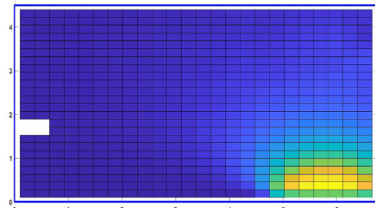
DRY SEASON	WET SEASON
21- December 08:00	21-June 08:00



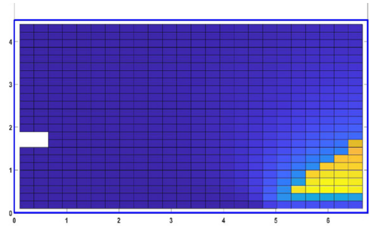


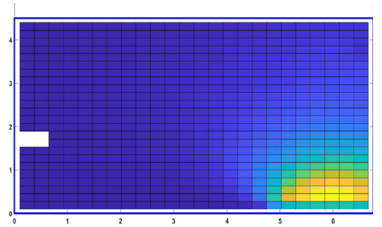
DRY SEASON	WET SEASON
Area DI < 300 lx: **0%** Area DI > 3000 lx: **1.3%**	Area DI < 300 lx: **81%** Area DI > 3000 lx: **0%**
21- December 13:00	21-June 13:00





DRY SEASON	WET SEASON
Area DI < 300 lx: **0%** Area DI > 3000 lx: **17.2%**	Area DI < 300 lx: **0%** Area DI > 3000 lx: **6.4%**
21- December 17:00	21-June 17:00





DRY SEASON	WET SEASON
Area DI < 300 lx: **0%** Area DI > 3000 lx: **14.1%**	Area DI < 300 lx: **0%** Area DI > 3000 lx: **2.6%**

Fig 4.71 Illuminance Hours plan Dry season / Source: EnergyVER

Fig 4.72 Illuminance Hours plan Wet season / Source: EnergyVER

AIRFLOW ANALYSIS

"Arrendajo" Room

Fig 4.73 wind direction plan/ Source: Author´s elaboration

Area Room: 27.13 m²

- Minimum Area Windows per room (A room/8): **3.39 m²**
- Area total Windows (Current state): **3.3 m²**

SINGLE SIDED VENTILATION CALCULATION

Calculation Current state: January

$$qv\ [m3/h] = 3600 * \frac{\rho_{a;ref}}{\rho_{a;e}} * \frac{Aw_{;tot}}{2} * \max\left(C_{wind} * U_{10;site}^{2} ; C_{st} * h_{w;st} * abs(T_z - T_e)\right)^{0,5}$$

$$qv\ [m3/h] = 3600 * \frac{1,23}{1,18} * \frac{2,50}{2} * \max\left(0,001 * 0,56^{2} ; 0,0035 * 1,2 * abs(27,5 - 25,3)\right)^{0,5}$$

$$qv\ [m3/h] = 3600 * 1,04 * 1,25 * \max(0,00056 ; 0,00924)^{0,5}$$

$$qv\ [m3/h] = 3600 * 1,04 * 1,25 * 0,00924^{0,5}$$

$$qv\ [m3/h] = \mathbf{450,89}$$

REQUIREMENTS

Table 4.11 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}IAQ(p)}$ [m³/h]	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
157,5	28	15	0,375	9

vol [m³]	$ACH_{r\text{-}IAQ}$ [1/h]
75,96	2,07

Table 4.12 **AIRFLOW RATE FOR COOLING**

	$q_{r\text{-}cool}$ [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]
JAN	571,02	245,26	0,28	1,18	30,03	28,73
FEB	633,13	228,01	0,28	1,18	30,10	29,01
MAR	412,43	211,21	0,28	1,18	29,48	27,93
APR	690,59	196,23	0,28	1,18	27,72	26,86
MAY	438,80	187,02	0,28	1,18	28,45	27,16
JUN	518,18	183,19	0,28	1,18	27,80	26,73
JUL	974,38	183,50	0,28	1,18	27,29	26,72
AUG	667,86	194,18	0,28	1,18	28,08	27,20
SEPT	829,09	213,67	0,28	1,18	28,38	27,60
OCT	561,89	226,49	0,28	1,18	29,02	27,80
NOV	527,48	235,28	0,28	1,18	28,85	27,50
DEC	630,58	247,93	0,28	1,18	29,49	28,30

vol [m³]	$ACH_{r\text{-}cool}$ [1/h]
75,96	7,52
75,96	8,33
75,96	5,43
75,96	9,09
75,96	5,78
75,96	6,82
75,96	12,83
75,96	8,79
75,96	10,91
75,96	7,40
75,96	6,94
75,96	8,30

Table 4.13 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	q_v-IAQ [m³/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	450,89	157,5	571,02
FEB	152,34	157,5	633,13
MAR	181,66	157,5	412,43
APR	135,32	157,5	690,59
MAY	165,73	157,5	438,8
JUN	150,94	157,5	518,18
JUL	110,16	157,5	974,38
AUG	136,88	157,5	667,86
SEPT	128,87	157,5	829,09
OCT	161,17	157,5	561,89
NOV	169,54	157,5	527,48
DEC	159,18	157,5	630,58

$q_{r\text{-}IAQ(p)}$ [m³/h]: min. required airflow rate per person
ACH_{IAQ}: Air change per hour
$q_{r\text{-}cool}$ [m³/h]: min. required airflow rate for cooling
$\rho_{a;ref}$ [kg/m³]: Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ [kg/m³]: Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} [1 m/s]: Coefficient of wind speed
C_t [m/s]: Coefficient of wind turbulence
C_{st} [m/s]: Coefficient of stack effect
$u_{10;site}$ [m/s]: Wind at the zone level, at 10 m height
$h_{w;st}$ [m]: Useful height for stack effect for airing
$h_{w;fa}$ [m]: Free area height of the window "i"
$h_{w;path}$ [m]: Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i [°C]: day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air

H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS

"Arrendajo" Room

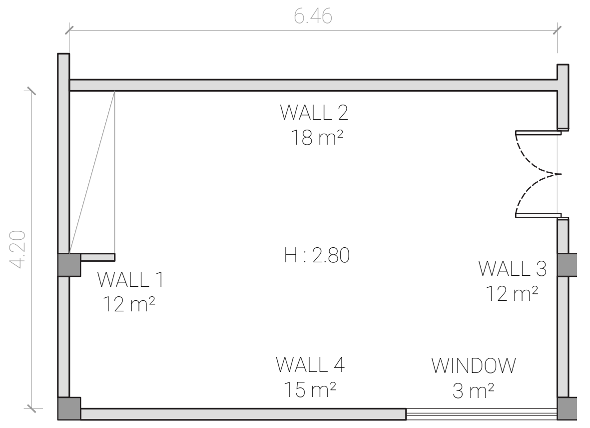


Fig 4.74 Acoustic plan/Source: EnergyVer simulation

Volume= 75.97 m³

Table 4.14 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4)	57	Concrete block painted	0,1	0,06	0,07
Ceiling	27	Expanded Polystyrene	0,05	0,4	0,35
Floor	27	Ceramic Clay Tile	0,01	0,01	0,01
Window	3	Single glass	0,35	0,18	0,12
Musicians playing(12)			0,37	1	1
Total Empty room			8,37	15,03	14,07
Total Occupied			12,81	27,03	26,07

REVERBERATION TIME		Empty Room	Occupied Room
T_{60} (125Hz):	$\frac{0.16x75.97m^3}{8.37}$	**1.45s**	**0.94 s**
T60 (500Hz):	$\frac{0.16x75.97m^3}{15.03}$	**0.80 s**	**0.44 s**
T60(1000Hz):	$\frac{0.16x75.97\ m^3}{14.07}$	**0.86 s**	**0.46 s**

OPTIMAL T60: 0.8s - 0.9 s

ROOM CONCLUSIONS

According to the simulation of internal thermal comfort, the room has high Operative temperatures against the Outdoor temperature: 27.87Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is out of this limit with 25% year. The warmest day shows a maximum temperature of 33.26cº/33.1cº on 9 February, and the minimum temperature of 22.51 Cº/21.65 Cºin 9 June. Almost half of the occupied hours (49%), the Operative temperature is over 28 Cº and 24% over 30Cº, with 57% time of Relative humidity over 70%, and an amount of 25% overheating hours, all causing discomfort in the room.

Based on a minimum daylight factor of 3% for school daylighting, 40% of the room area achieves the threshold with a DF of 3.95%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room is almost about the minimum level, 79%/80%, indicating is well illuminated by daylighting. Despite that, there is a glared area of 8.8%, mainly in the Dry season at 13:00 and 17:00, and insufficient illuminance in Wet season in the morning at 8:00.

According to the Italian decree DM 05-07-75, the minimum area of windows of this room should be 3.39 m². The existing windows area is on the limit of the minimum required with 3.3m². With a single sided ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 157 m3/h, except in July. But it is insufficient for cooling it in any month of the the year due to high heat gains and low temperature differences.

The room has a short reverberation time when is totally occupied for medium and high frecuencies (500Hz-1000Hz), below to the T60 optimal required, 0.8s -0.9s, for its function as a classroom for music. For this frecuency, the empty room is on the threshold value. For low frecuencies (125Hz), the empty room has a long T60 and the occupied room almost reaches the Optimal T60 .. But, considering this room for individual reharsal for different instruments with lower and high frecuencies, the time of reverberation is not efficient because it tends to be short.

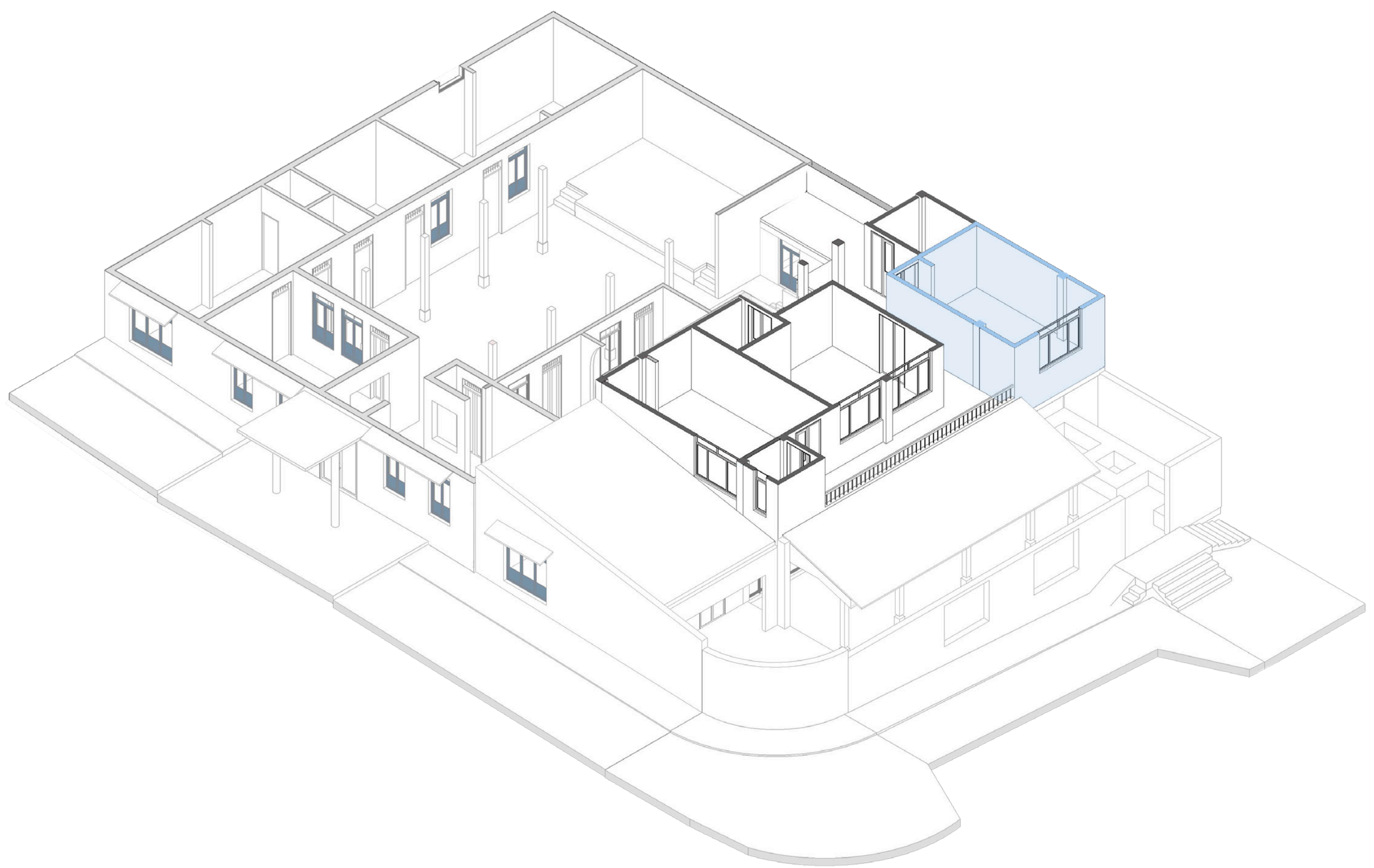


Fig 4.75 Axonometry "Corocora" location/ Source: Author´s elaboration

"COROCORA"

ROOM ANALYSIS

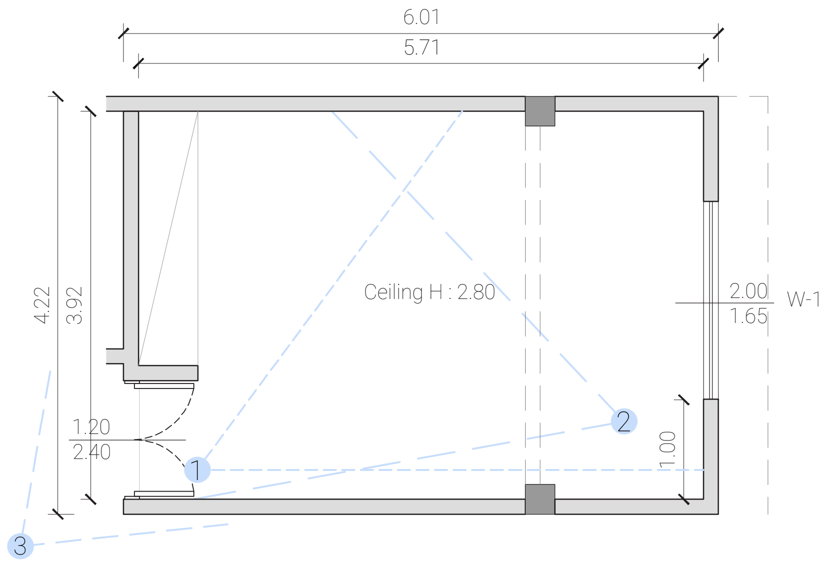


Fig 4.76 "Corocora" plan/ Source: Author´s elaboration

sc_1:75

Area= 22.38 m²
Volume= 62.67 m³

Level +2.28
First Floor

Music Classroom

_Pre-Orchestra Rehearsal
_Individual Instrument Rehearsal

15 Students (Average capacity)

Fig 4.77 "Corocora" photos/ Source: Author´s photos

THERMAL COMFORT ANALYSIS
Corocora Room

- **Total** Occupation Hours/Year: **3020**
- Average Indoor Relative Humidity (Occupation Hours): 77%

- Occupied hours where Relative Humidity > 70%: 1749 (57% year)

- Occupied hours where Operative Temperature > T limit (28°C): 1774 (58% year)
- Occupied hours where Operative Temperature > T limit (30°C): 906 (30% year)
- Occupied hours where Operative Temperature <T limit (21°C): 9 (0.3% year)

- Overheating hours (EN class 2): 1306 (31% year)

- Optimal Operative Temperature (Adaptive EN class 2)

T_c : 0.33 * T_{rm} + 18.8
T_c : 0.33 * **24.51 °C** + 18.8
T_c : **26.88 °C**

Upper Limit (+3): **29.88 °C**
Lower Limit (-4): **22.88 °C**

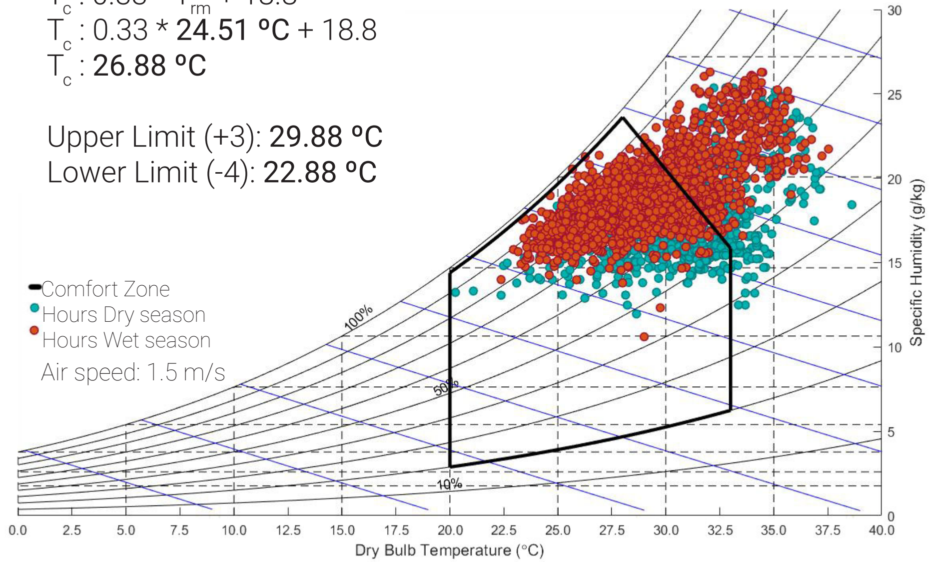


Fig 4.78 Givoni diagram/ Source: EnergyVER

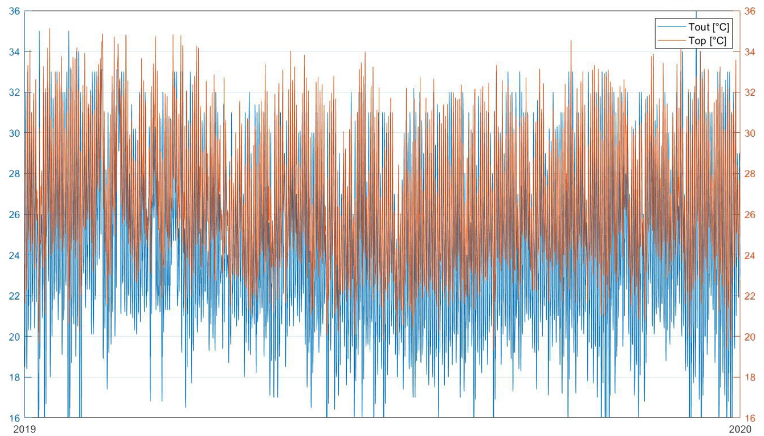


Fig 4.79 **Operative Temperature vs Outdoor Air Temperature Year**

T Outdoor Air Average: **24.55 °C**

T operative Average: **26.63 °C**

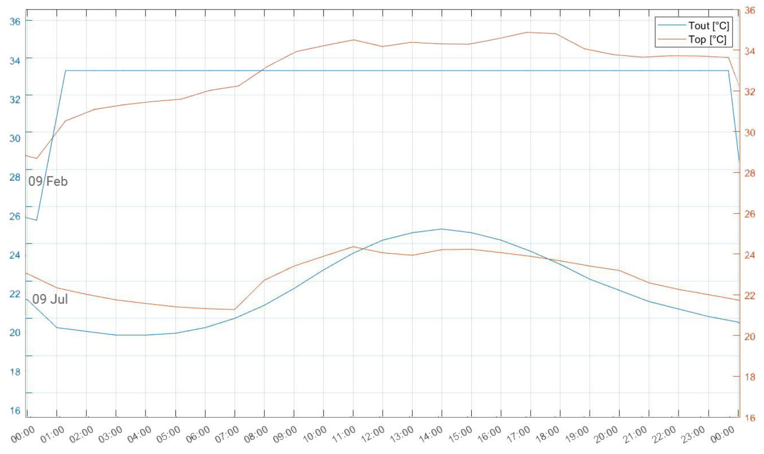


Fig 4.80 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**

WARMEST DAY
09 February

T Out Average: **33.1 °C**
T op Average: **33.20 °C**

COLDEST DAY
09 Jul

T Out Average: **21.65 °C**
T op Average: **22.91 °C**

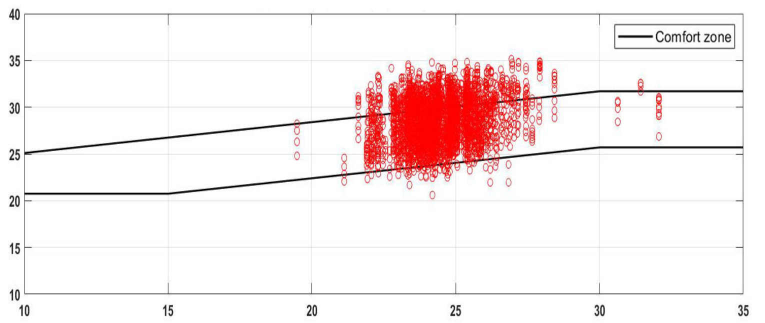


Fig 4.82 **Operative Temperature Vs Running Mean Temperature during occupied hours**

Average (°C) of hours occupied

Running mean Outside T: **24.51 °C**

T Operative **28.53 °C**

DAYLIGHT ANALYSIS
Corocora Room

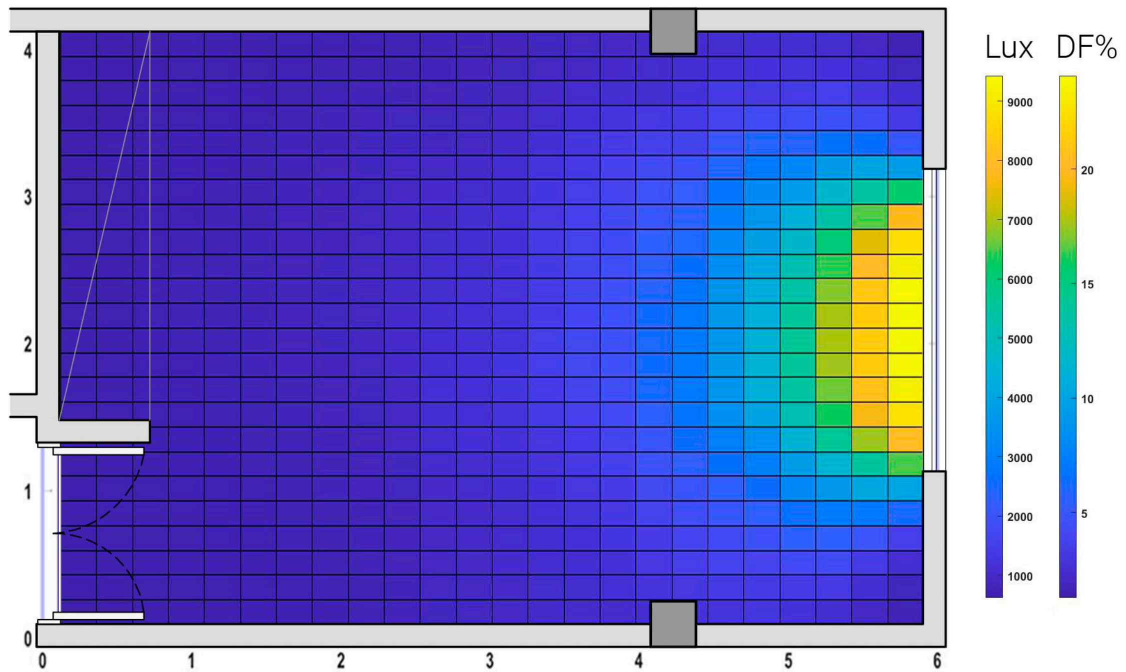


Fig 4.83 Illuminance plan/ Source: EnergyVER

Average Year

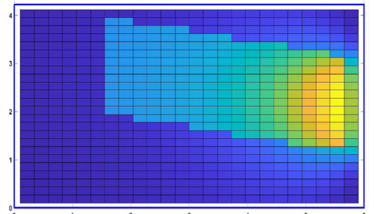
- Mean DAYLIGHT FACTOR (DF): **5.01 %**
  DF threshold level for classrooms : **3%**
  Room Area DF > 3%: **48.5%**

- Mean DAYLIGHT AUTONOMY (DA): **88.29%**
  Room Area DA > 50%: **100%**

- USEFUL DAYLIGHT ILLUMINANCE (uDI): **300 - 3000 Lux**
  Room Area UDI: **36% / 80% UDI**(Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **14.1%** Glared area

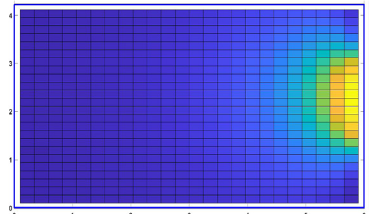
DRY SEASON

21- December 08:00



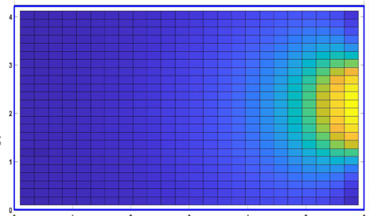
Area DI < 300 lx: **0%**
Area DI > 3000 lx: **21.4%**

21- December 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **2.2%**

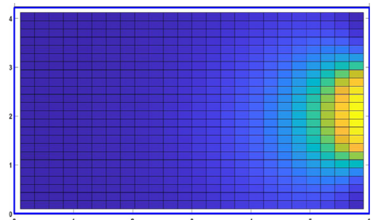
21- December 17:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0%**

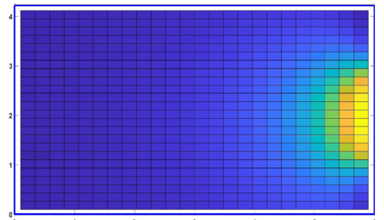
WET SEASON

21-June 08:00



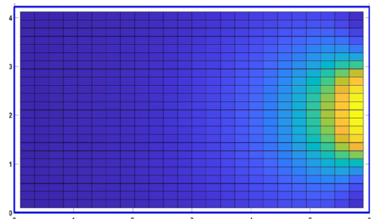
Area DI < 300 lx: **53%**
Area DI > 3000 lx: **0%**

21-June 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **9.1%**

21-June 17:00



Area DI < 300 lx: **7%**
Area DI > 3000 lx: **0%**

Fig 4.84 Illuminance Hours plan Dry season / Source: EnergyVER

Fig 4.85 Illuminance Hours plan Wet season / Source: EnergyVER

AIRFLOW ANALYSIS

"Corocora" Room

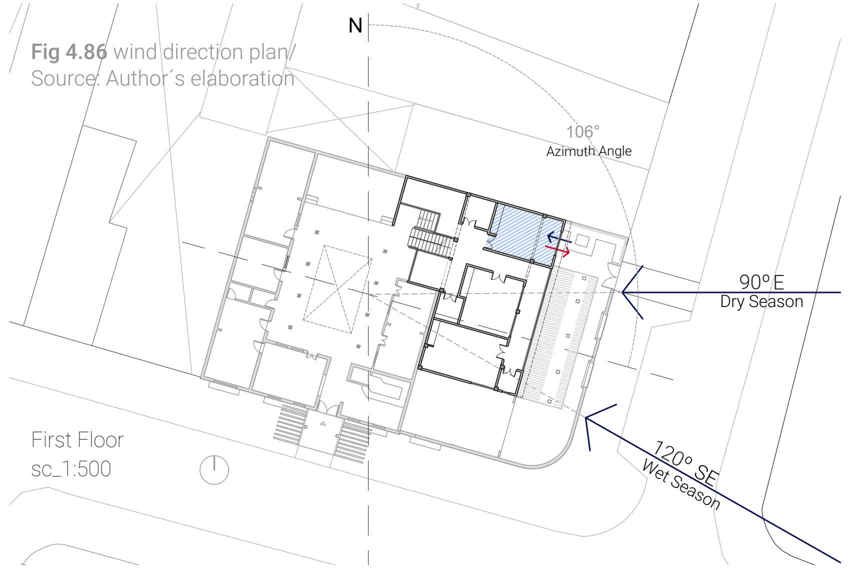


Fig 4.86 wind direction plan/ Source: Author´s elaboration

Area Room: 22.38 m²

- Minimum Area Windows per room (A room/8): **2.79m²**
- Area total Windows (Current state): **3.3 m²**

SINGLE SIDED VENTILATION CALCULATION

Calculation Current state: January

$$qv\,[m3/h] = 3600 * \frac{\rho_{a;ref}}{\rho_{a;e}} * \frac{Aw_{;tot}}{2} * \max\left(C_{wind} * U_{10;site}^{2} ; C_{st} * h_{w;st} * abs(T_z - T_e)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * \frac{1,23}{1,18} * \frac{1,20}{2} * \max\left(0,001 * 0,56^{2} ; 0,0035 * 1,2 * abs(27,5 - 25,3)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 0,6 * \max(0,00056 ; 0,00924)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 0,6 * 0,00924^{0,5}$$

qv [m3/h] = **216.43**

REQUIREMENTS

Table 4.15 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

q_{r-IAQ} [m³/h]	$q_{r-IAQ(p)*}$ [m³/	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
157,5	28	15	0,375	

vol [m³]	ACH_{r-IAQ} [1/h]
62,66	2,51

Table 4.16 **AIRFLOW RATE FOR COOLING**

	q_{r-cool} [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]	vol [m³]	ACH_{r-cool} [1/h]
JAN	473,43	167,37	0,28	1,18	29,8	28,7	62,66	7,56
FEB	598,47	168,07	0,28	1,18	29,9	29,0	62,66	9,55
MAR	294,16	161,34	0,28	1,18	29,6	27,9	62,66	4,69
APR	514,83	156,49	0,28	1,18	27,8	26,9	62,66	8,22
MAY	304,48	152,91	0,28	1,18	28,7	27,2	62,66	4,86
JUN	348,75	150,95	0,28	1,18	28,0	26,7	62,66	5,57
JUL	716,85	151,58	0,28	1,18	27,4	26,7	62,66	11,44
AUG	453,01	155,66	0,28	1,18	28,2	27,2	62,66	7,23
SEPT	662,51	161,98	0,28	1,18	28,3	27,6	62,66	10,57
OCT	361,09	167,03	0,28	1,18	29,2	27,8	62,66	5,76
NOV	376,37	165,39	0,28	1,18	28,8	27,5	62,66	6,01
DEC	598,87	164,23	0,28	1,18	29,1	28,3	62,66	9,56

Table 4.17 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	q_v-IAQ [m³/h]	q_r-IAQ [m³/h]	q_{r-cool} [m³/h]
JAN	216,43	157,5	473,43
FEB	134,53	157,5	598,47
MAR	188,00	157,5	294,16
APR	139,96	157,5	514,83
MAY	179,90	157,5	304,48
JUN	167,01	157,5	348,75
JUL	116,73	157,5	716,85
AUG	148,81	157,5	453,01
SEPT	125,52	157,5	662,51
OCT	172,65	157,5	361,09
NOV	168,28	157,5	376,37
DEC	132,94	157,5	598,87

$q_{r-IAQ(p)}$ [m³/h]: min. required airflow rate per person
ACH_{IAQ} : Air change per hour
q_{r-cool} [m³/h]: min. required airflow rate for cooling
$\rho_{a;ref}$ [kg/m³]: Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ [kg/m³]: Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} [1 m/s]: Coefficient of wind speed
C_t [m/s]: Coefficient of wind turbulence
C_{st} [m/s]: Coefficient of stack effect
$u_{10;site}$ [m/s]: Wind at the zone level, at 10 m height
$h_{w;st}$ [m]: Useful height for stack effect for airing
$h_{w;fa}$ [m]: Free area height of the window "i"
$h_{w;path}$ [m]: Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i [°C]: day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air
H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS

"Corocora" Room

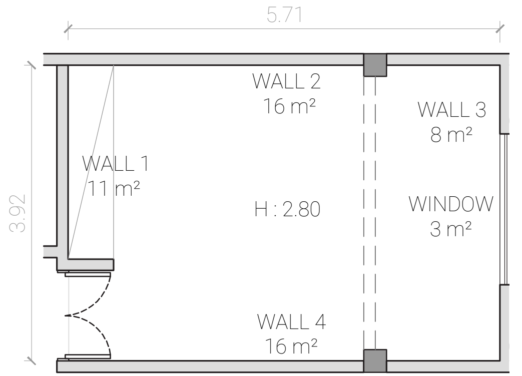


Fig 4.87 Acoustic plan/Source: EnergyVer simulation

Volume= 62.67 m³

Table 4.18 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4)	51	Concrete block painted	0,1	0,06	0,07
Ceiling	22	Expanded Polystyrene	0,05	0,4	0,35
Floor	22	Ceramic Clay Tile	0,01	0,01	0,01
Window	3	Single glass	0,35	0,18	0,12
Musicians playing(12)			0,37	1	1
Total Empty room			7,47	12,62	11,85
Total Occupied			11,91	24,62	23,85

REVERBERATION TIME	Empty Room	Occupied Room
T60 (125Hz): $\frac{0.16x62.67\ m^3}{7.47}$	**1.34 s**	**0.84 s**
T60 (500Hz): $\frac{0.16x62.67\ m^3}{12.62}$	**0.79 s**	**0.40 s**
T60 (1000Hz): $\frac{0.16x62.67\ m^3}{11.85}$	**0.84 s**	**0.42 s**

OPTIMAL T60: 0.8s - 0.9 s

CONCLUSIONS

According to the simulation of internal thermal comfort, the room has high Operative temperatures against the Outdoor temperature: 28.53Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is out of this limit with 31% year.The warmest day shows a maximum temperature of 33.20cº/33.1cº on 9 February, and the minimum temperature of 22.91 Cº/21.65 Cºin 9 June. More than the half of the occupied hours (58%), the Operative temperature is over 28 Cº and 30% over 30Cº, with 49% time of Relative humidity over 70%, and an amount of 31% overheating hours, all causing discomfort in the room.

Based on a minimum daylight factor of 3% for school daylighting, 48.5% of the room area meets the threshold with a DF of 5.01%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room reaches the minimum level, 85%/80%, indicating is well illuminated by daylighting. Despite that, there is a glared area of 14.1%, in the Dry season in the morning at 8:00.and in Wet season at 13:00 but it has insufficient illuminance in Wet season at 8:00.

According to Italian decree DM 05-07-75, the minimum area of windows of this room should be 2.79 m². The existing windows area is up to the minimum required with 3.3m².
With a single sided ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 157 m3/h, except for July and September. But it is insufficient for cooling it in any month of the year due to high heat gains and low temperature differences.

The room has a short reverberation time when is totally occupied for medium and high frecuencies (500Hz-1000Hz), below to the T60 optimal required, 0.8s -0.9s, for its function as a classroom for music. For this frecuency, the empty room is on the threshold value. For low frecuencies (125Hz), the empty room has a long T60 and the occupied room reaches the Optimal T60 .. But, considering this room for individual rehearsal for different instruments with lower and high frecuencies, the time of reverberation is not efficient because it tends to be short.

“MACUNDAL”

ROOM ANALYSIS

Fig 4.88 Axonometry "Macundal" location/
Source: Author´s elaboration

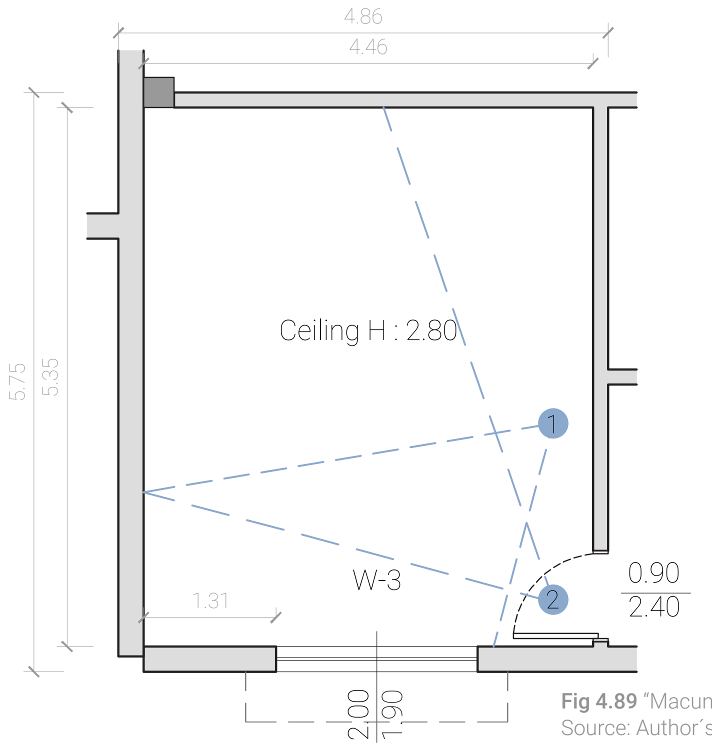


Fig 4.89 "Macundal" plan/
Source: Author´s elaboration

H wall_0.90

sc_1:75

Area= 23.86 m²
Volume= 66.81 m³

Level -0.87
Ground Floor

Music Classroom

_Percusion Rehearsal

4 Students (Average capacity)

Fig 4.90 "Macundal" photos/
Source: Author´s photos

THERMAL COMFORT ANALYSIS
"Macundal" Room

- **Total** Occupation Hours/Year: **3020**
- Average Indoor Relative Humidity (Occupation Hours): 78%

- Occupied hours where Relative Humidity > 70%: 2378 (78% year)

- Occupied hours where Operative Temperature > T limit (28ºC): 337 (11% year)
- Occupied hours where Operative Temperature > T limit (30ºC): 34 (1% year)
- Occupied hours where Operative Temperature <T limit (21ºC): 41 (1% year)

- Overheating hours (EN class 2): 21 (0.6% year)

- **Optimal Operative Temperature** (Adaptive EN class 2)

T_c : 0.33 * T_{rm} + 18.8
T_c : 0.33 * **24.51 ºC** + 18.8
T_c : **26.88 ºC**

Upper Limit (+3): **29.88 ºC**
Lower Limit (-4): **22.88 ºC**

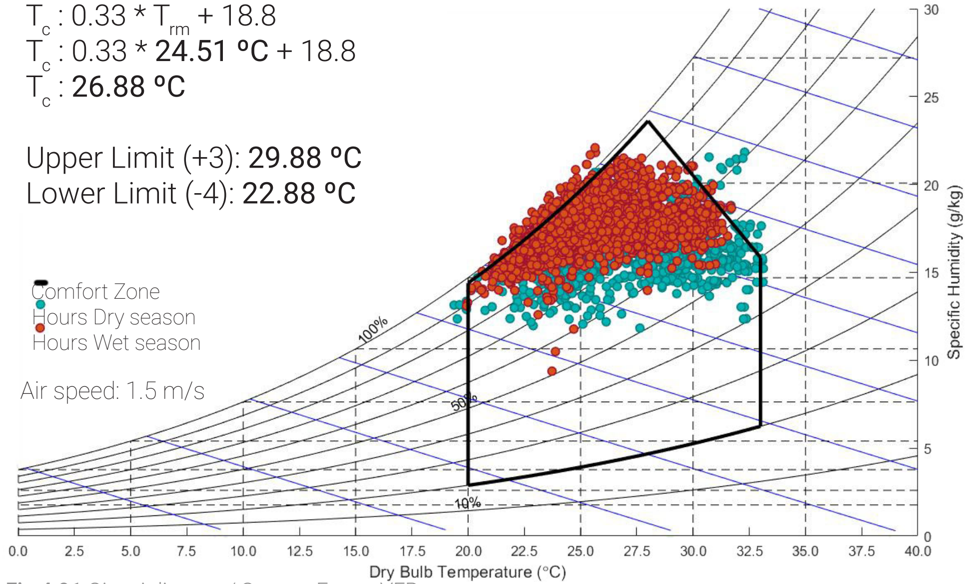
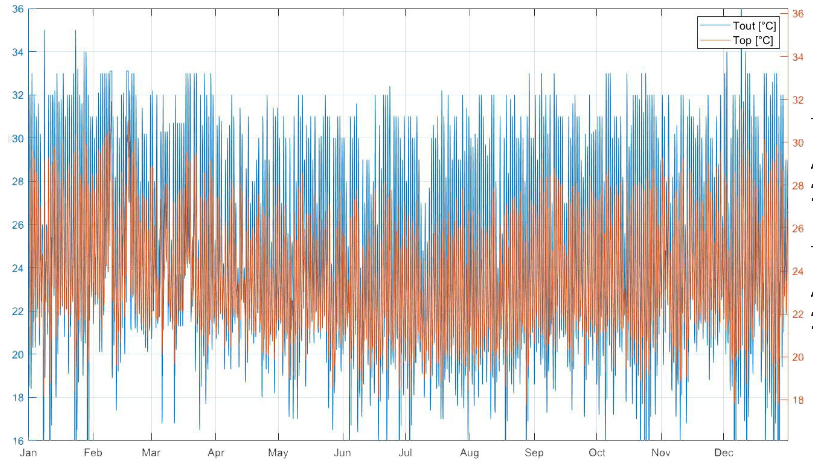


Fig 4.91 Givoni diagram/ Source: EnergyVER



T Outdoor Air Average: **24.55 ºC**

T operative Average: **23.66 ºC**

Fig 4.92 **Operative Temperature vs Outdoor Air Temperature Year**

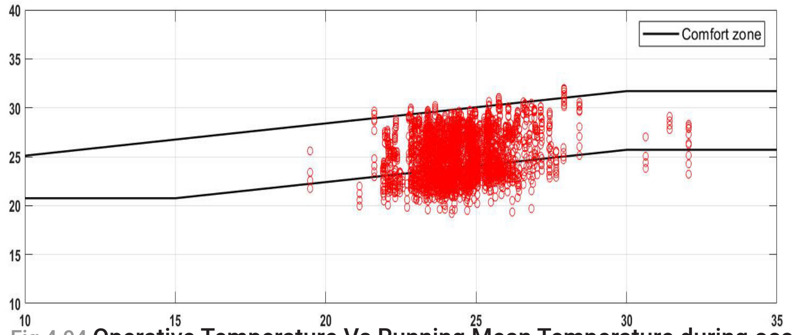
WARMEST DAY
09 February

T Out Average: **33.1 ºC**
T op Average: **30.18 ºC**

COLDEST DAY
09 Jul

T Out Average: **21.65 ºC**
T op Average: **21.09 ºC**

Fig 4.93 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**



Average (ºC) of hours occupied

Running mean Outside T: **24.51 ºC**

Operative T **25.26 ºC**

Fig 4.94 **Operative Temperature Vs Running Mean Temperature during occupied hours**

DAYLIGHT ANALYSIS
"Macundal" Room

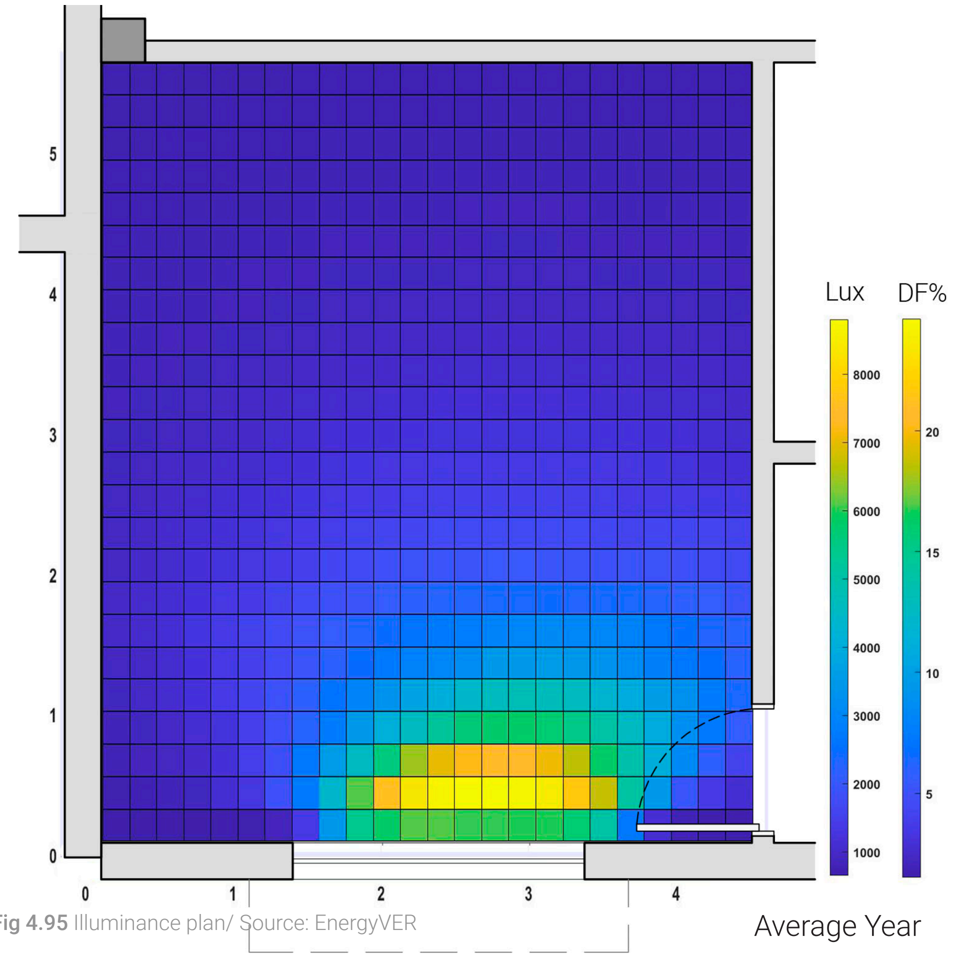


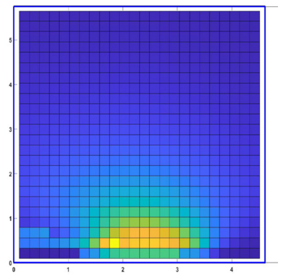
Fig 4.95 Illuminance plan/ Source: EnergyVER

- Mean DAYLIGHT FACTOR (DF): **5.12 %**
  DF threshold level for classrooms : 3%
  Room Area DF > 3%: **54%**
- Mean DAYLIGHT AUTONOMY (DA): **91.18%**
  Room Area DA > 50%: **100%**

- USEFUL DAYLIGHT ILLUMINANCE (uDI): **300 - 3000 Lux**
  Room Area UDI: **88% / 80%** (Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **10.9%** Glared area

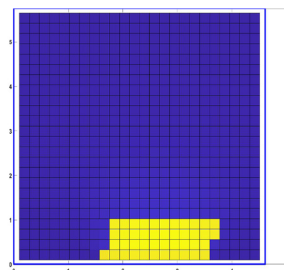
DRY SEASON

21- December 08:00



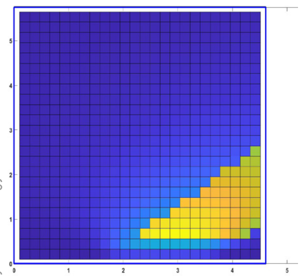
Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0.6%**

21- December 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **25.8%**

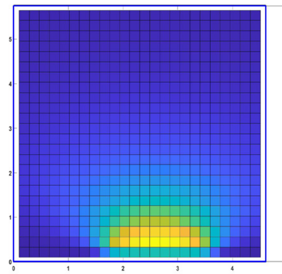
21- December 17:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **30.2%**

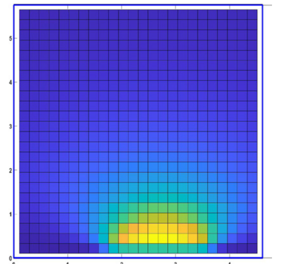
WET SEASON

21-June 08:00



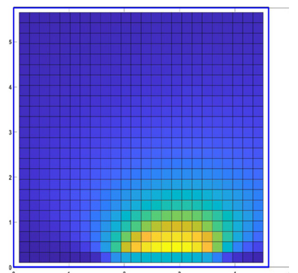
Area DI < 300 lx: **72%**
Area DI > 3000 lx: **0%**

21-June 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **6.9%**

21-June 17:00



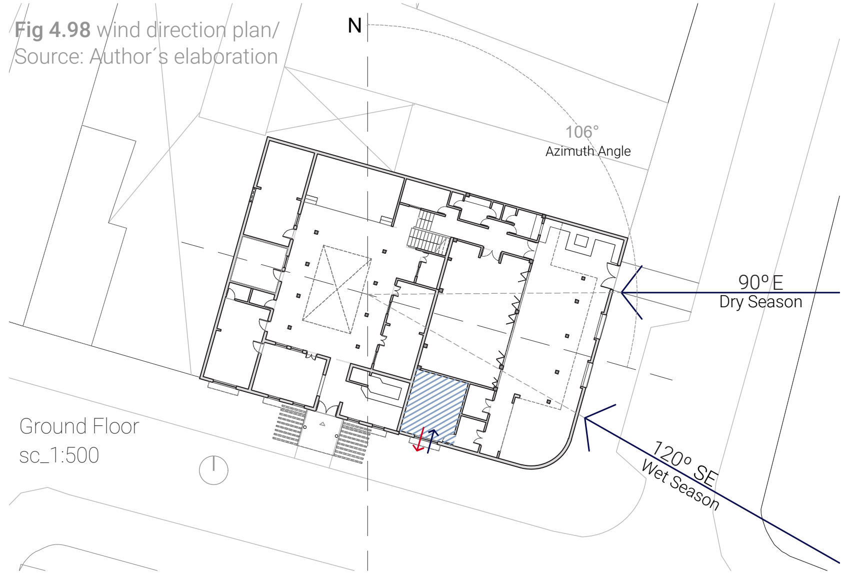
Area DI < 300 lx: **0%**
Area DI > 3000 lx: **2.4%**

Fig 4.96 Illuminance Hours plan Dry season / Source: EnergyVER

Fig 4.97 Illuminance Hours plan Wet season / Source: EnergyVER

AIRFLOW ANALYSIS
"Macundal" Room

Fig 4.98 wind direction plan/ Source: Author´s elaboration



Area Room: 23.86 m²

- Minimum Area Windows per room (A room/8): **2.98m²**
- Area total Windows (Current state): **3.8 m²**

SINGLE SIDED VENTILATION CALCULATION

Calculation Current state: January

$$qv\,[m3/h] = 3600 * \frac{\rho_{a;ref}}{\rho_{a;e}} * \frac{Aw_{;tot}}{2} * \max\left(C_{wind} * U_{10;site}^{2} \,;\, C_{st} * h_{w;st} * abs(T_z - T_e)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * \frac{1,23}{1,18} * \frac{2,97}{2} * \max\left(0,001 * 0,56^{2} \,;\, 0,0035 * 1,5 * abs(25,28 - 25,3)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 1.5 * \max(0,00056 \,;\, 0,0001)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 1.5 * 0,00056^{0,5}$$

$$qv\,[m3/h] = \mathbf{131.87}$$

REQUIREMENTS

Table 4.19 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}IAQ(p)*}$ [m³/	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
52,5	28	5	0,375	9

vol [m³]	$ACH_{r\text{-}IAQ}$ [1/h]
75,96	0,69

Table 4.20 **AIRFLOW RATE FOR COOLING**

	$q_{r\text{-}cool}$ [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]	vol [m³]	$ACH_{r\text{-}cool}$ [1/h]
JAN	741,25	227,76	0,28	1,18	27,80	28,73	75,96	9,76
FEB	937,58	213,75	0,28	1,18	28,32	29,01	75,96	12,34
MAR	597,04	191,34	0,28	1,18	26,96	27,93	75,96	7,86
APR	779,13	187,92	0,28	1,18	26,13	26,86	75,96	10,26
MAY	374,07	180,44	0,28	1,18	25,70	27,16	75,96	4,92
JUN	386,12	177,33	0,28	1,18	25,34	26,73	75,96	5,08
JUL	331,78	177,58	0,28	1,18	25,10	26,72	75,96	4,37
AUG	399,82	186,26	0,28	1,18	25,79	27,20	75,96	5,26
SEPT	902,68	190,88	0,28	1,18	26,96	27,60	75,96	11,88
OCT	564,21	212,51	0,28	1,18	26,66	27,80	75,96	7,43
NOV	1208,72	219,65	0,28	1,18	26,95	27,50	75,96	15,91
DEC	621,35	229,93	0,28	1,18	27,18	28,30	75,96	8,18

Table 4.21 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	q_v-IAQ [m³/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	131,87	52,5	741,25
FEB	335,39	52,5	937,58
MAR	397,67	52,5	597,04
APR	344,98	52,5	779,13
MAY	487,87	52,5	374,07
JUN	476,04	52,5	386,12
JUL	513,91	52,5	331,78
AUG	479,45	52,5	399,82
SEPT	323,01	52,5	902,68
OCT	431,11	52,5	564,21
NOV	299,44	52,5	1208,72
DEC	427,31	52,5	621,35

$q_{r\text{-}IAQ(p)}$ **[m³/h]:** min. required airflow rate per person
ACH_{IAQ} **:** Air change per hour
$q_{r\text{-}cool}$ **[m³/h]:** min. required airflow rate for cooling
$\rho_{a;ref}$ **[kg/m³]:** Air density at 283 K (9.85 C°)
$\rho_{a;e}$ **[kg/m³]:** Air density at temperature exterior
$A_{w;tot}$**:** Area total of windows openings
C_{wind} **[1 m/s]:** Coefficient of wind speed
C_t **[m/s]:** Coefficient of wind turbulence
C_{st} **[m/s]:** Coefficient of stack effect
$u_{10;site}$ **[m/s]:** Wind at the zone level, at 10 m height
$h_{w;st}$ **[m]:** Useful height for stack effect for airing
$h_{w;fa}$ **[m]:** Free area height of the window "i"
$h_{w;path}$ **[m]:** Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i **[°C]:** day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air

H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS
"Macundal" Room

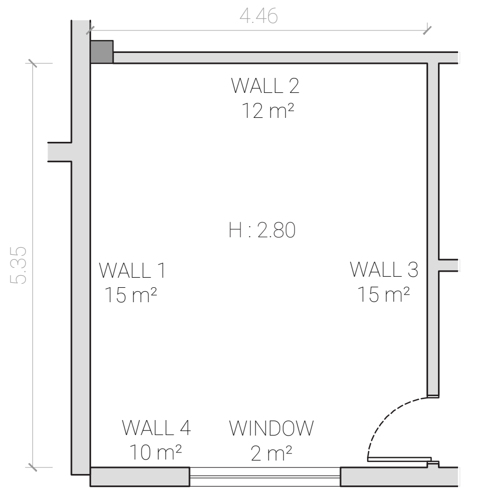


Fig 4.99 Acoustic plan/Source: EnergyVer simulation

Volume= 66.81 m³

Table 4.22 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4)	52	Concrete block painted	0,1	0,06	0,07
Ceiling	24	Expanded Polystyrene	0,05	0,4	0,35
Floor	24	Ceramic Clay Tile	0,01	0,01	0,01
Window	2	Single glass	0,35	0,18	0,12
Musicians playing(4)			0,37	1	1
Total Empty room			7,34	13,32	12,52
Total Occupied			8,82	17,32	16,52

REVERBERATION TIME		Empty Room	Occupied Room
T60 (125Hz):	$\frac{0.16 \times 66.81\ m^3}{7.34}$	**1.45 s**	**1.21 s**
T60 (500Hz):	$\frac{0.16 \times 66.81\ m^3}{13.32}$	**0.80 s**	**0.61 s**
T60 (1000Hz):	$\frac{0.16 \times 66.81\ m^3}{12.52}$	**0.85 s**	**0.64 s**

OPTIMAL T60: 0.8s - 0.9 s

CONCLUSIONS

According to the simulation of internal thermal comfort, the room has an average of Operative temperature over the Outdoor temperature: 25.15Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is within this limit with 0.6% year. The warmest day shows a maximum temperature of 30.18cº/33.1cº on 9 February, and the minimum temperature of 21.09 Cº/21.65 Cºin 9 June. A small percentage of the occupied hours (11%), has an Operative temperature over 28 Cº and just 1% over 30Cº. But, 78% of the time has a Relative humidity over 70%, causing discomfort .

Based on a minimum daylight factor of 3% for school daylighting, 54% of the room area achieves the threshold with a DF of 5.12%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room reaches the minimum level, 88%/80%, indicating is well illuminated by daylighting. Despite that, there is a glared area of 10.9%, mainly in the Dry season at 13:00 and 17:00, and high percentage (72% of the room) of insufficient illuminance in Wet season in the morning at 8:00.

According to the Italian decree DM 05-07-75, the minimum area of windows of this room should be 2.98 m². The existing windows area is up to the minimum required with 3.8m². With a single sided ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 52.5 m3/h, but it is insufficient for cooling it in some months of the year due to high heat gains and low temperature differences. From May to August, the current airflow manages to cool the room.

The room has a short reverberation time when is totally occupied for medium and high frecuencies (500Hz-1000Hz), below to the T60 optimal required, 0.8s -0.9s, for its function as a classroom for music. For this frecuency, the empty room is on the threshold value. For low frecuencies (125Hz), the empty room and, also occupied has a long T60 over the Optimal T60 .. But, considering this room for individual rehearsal instruments with a lower frecuency (Percusion instruments), the time of reverberation is not efficient because it tends is long for 125Hz .

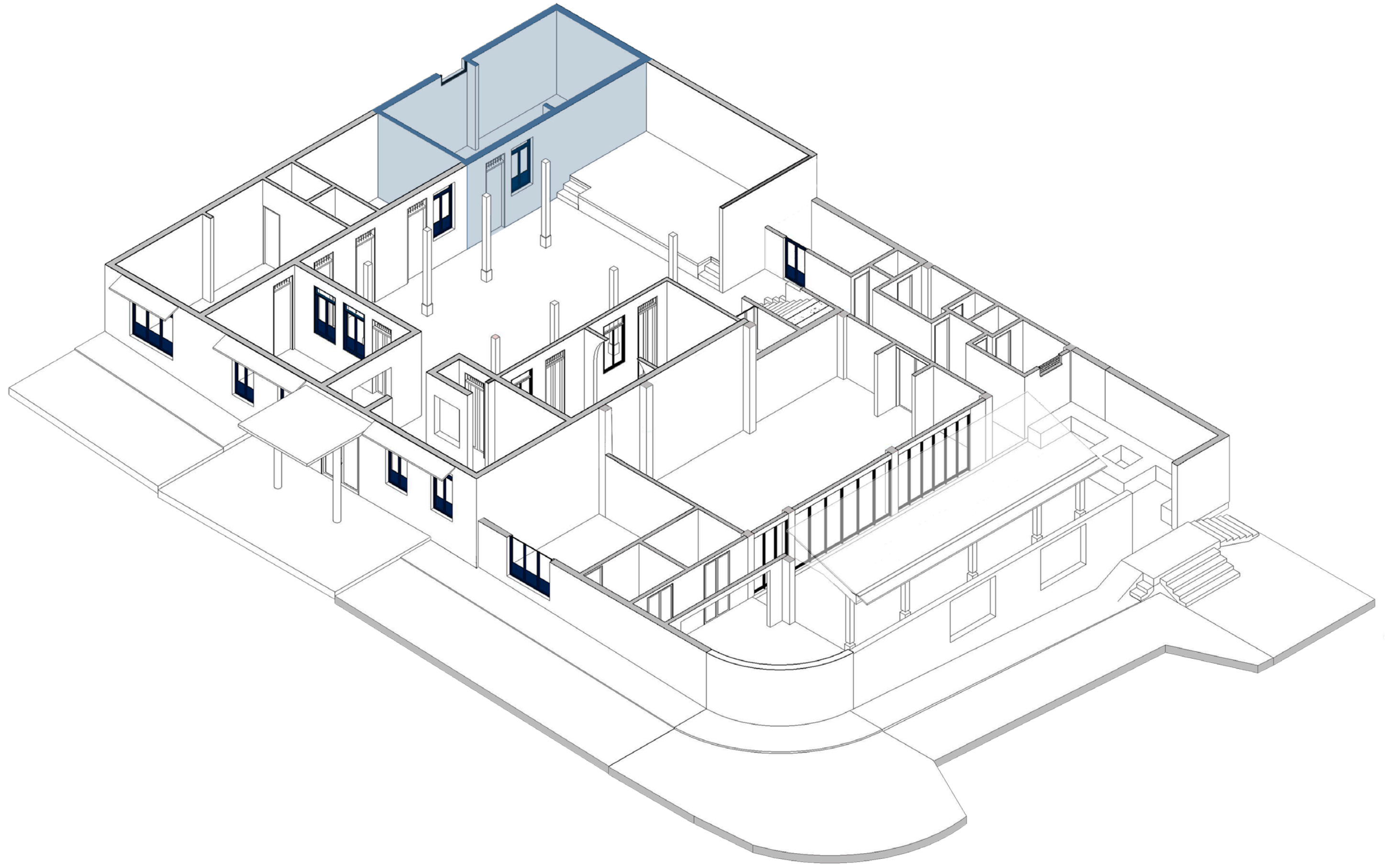
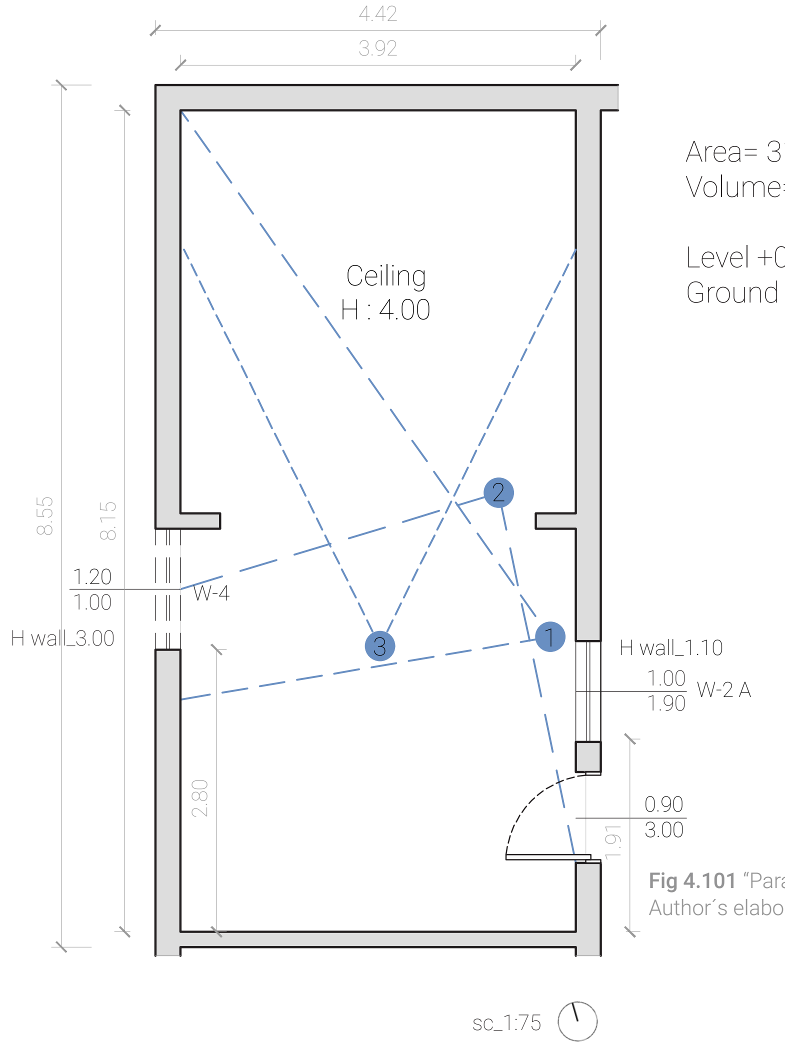


Fig 4.100 Axonometry "Paraulata" location/ Source: Author´s elaboration

"PARAULATA"

ROOM ANALYSIS



Area= 31.95 m²
Volume= 127.79 m³

Level +0.00
Ground Floor

Fig 4.101 "Paraulata" plan/ Source: Author´s elaboration

Music Classroom

_Pre-Orchestra Rehearsal
_Individual Instrument Rehearsal

15 Students (Average capacity)

Fig 4.102 "Paraulata" photos/ Source: Author´s photos

THERMAL COMFORT ANALYSIS
"Paraulata" Room

- **Total** Occupation Hours/Year: **3020**
- Average Indoor Relative Humidity (Occupation Hours): 71%

- Occupied hours where Relative Humidity > 70%: 2678 (88% year)

- Occupied hours where Operative Temperature > T limit (28ºC): 174 (5% year)
- Occupied hours where Operative Temperature > T limit (30ºC): 12 (0.3% year)
- Occupied hours where Operative Temperature <T limit (21ºC): 20 (0.6% year)

- Overheating hours (EN class 2): 6 (0.1% year)

- **Optimal Operative Temperature** (Adaptive EN class 2)
  T_c : 0.33 * T_{rm} + 18.8
  T_c : 0.33 * **24.51 ºC** + 18.8
  T_c : **26.88 ºC**

  Upper Limit (+3): **29.88 ºC**
  Lower Limit (-4): **22.88 ºC**

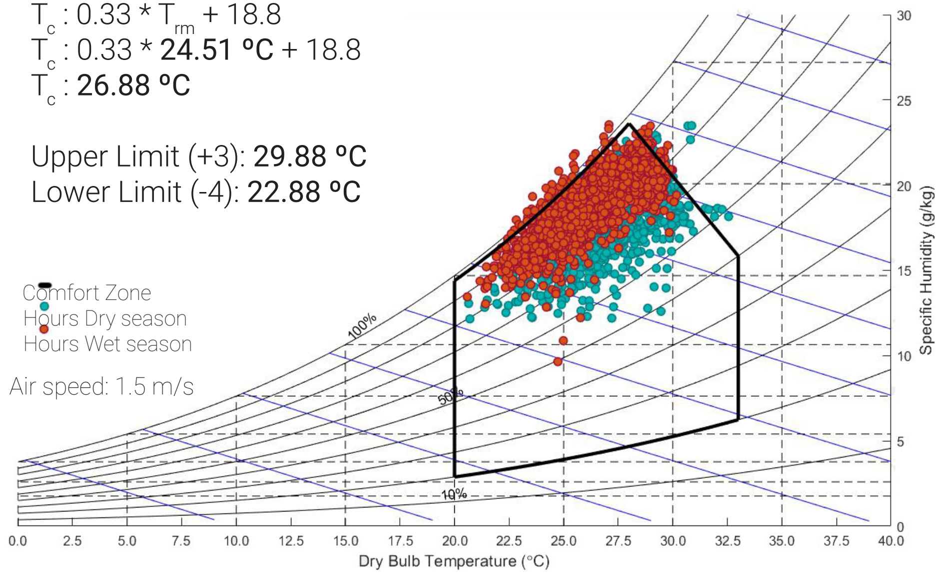


Fig 4.103 Givoni diagram/ Source: EnergyVER

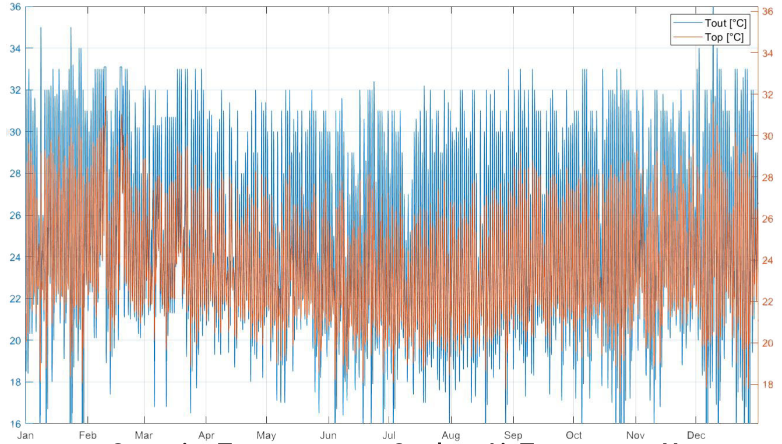


Fig 4.104 **Operative Temperature vs Outdoor Air Temperature Year**

T Outdoor Air Average: **24.55 ºC**

T operative Average: **23.83 ºC**

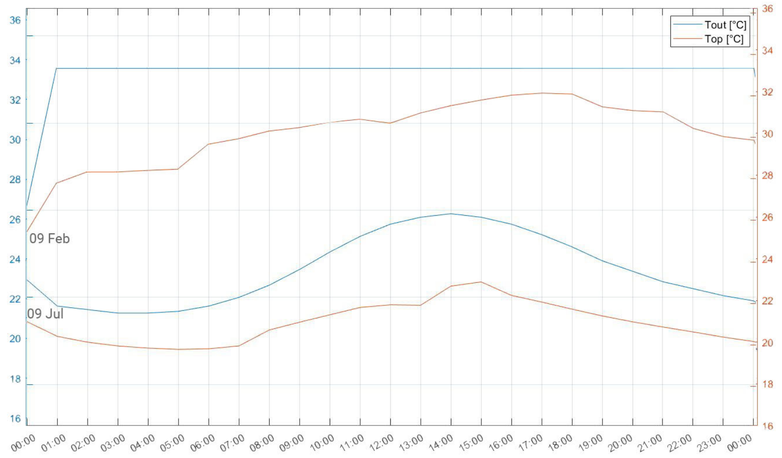


Fig 4.105 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**

WARMEST DAY
09 February

T Out Average: **33.1 ºC**
T op Average: **29.50 ºC**

COLDEST DAY
09 Jul

T Out Average: **21.65 ºC**
T op Average: **21.12 ºC**

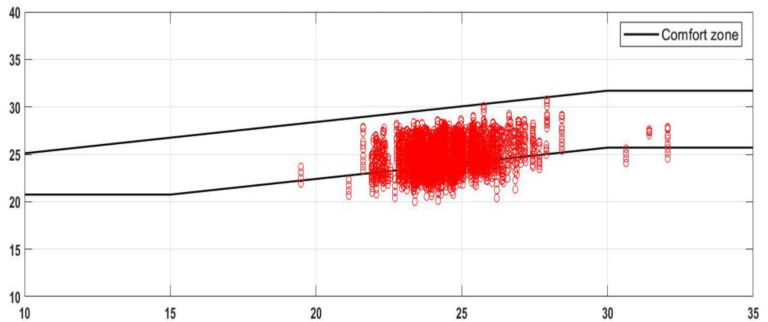


Fig 4.106 **Operative Temperature Vs Running Mean Temperature during occupied hours**

Average (ºC) of hours occupied

Running mean Outside T: **24.51 ºC**

Operative T **25.18 ºC**

DAYLIGHT ANALYSIS
Paraulata Room

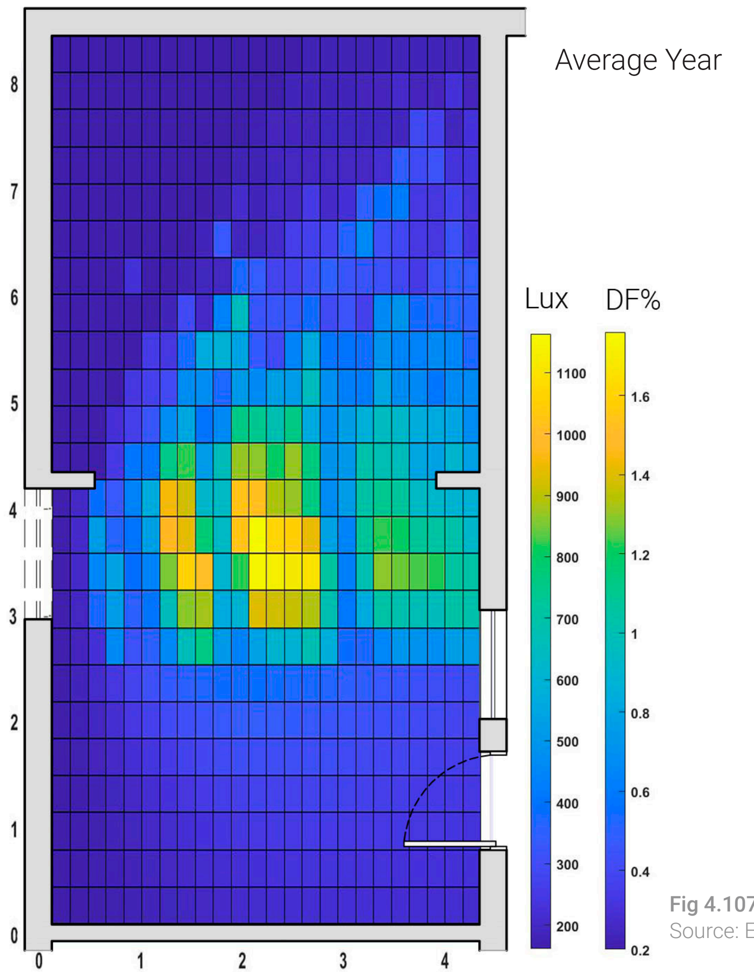
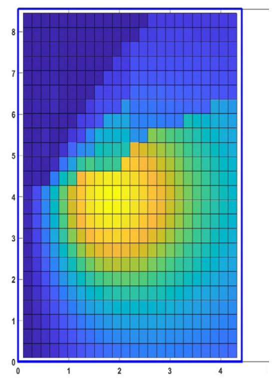
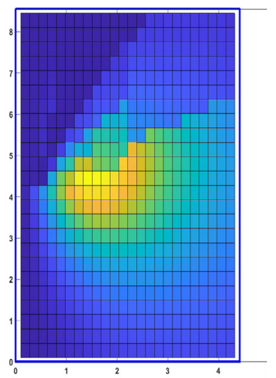
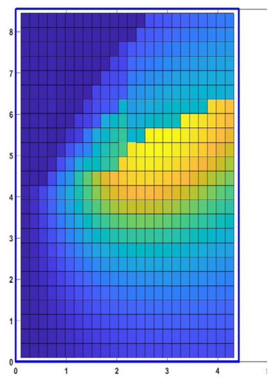


Fig 4.107 Illuminance plan/ Source: EnergyVER

- Mean **DAYLIGHT FACTOR (DF): 0.96 %**
  DF threshold level for classrooms : **3%**
  Room Area DF > 3%: **0%**
- Mean **DAYLIGHT AUTONOMY (DA): 37.85%**
  Room Area DA > 50%: **19.2%**
- **USEFUL DAYLIGHT ILLUMINANCE (uDI): 300 - 3000 Lux**
  Room Area UDI: **46% / 80%** (Minimum)
  Room Area DI < 300 lx: **54%**
  Room Area DI > 3000 lx: **0%** Glared area

DRY SEASON

21- December 08:00	21- December 13:00	21- December 17:00
		
Area DI < 300 lx:**100%** Area DI > 3000 lx: **0%**	Area DI < 300 lx: **95%** Area DI > 3000 lx: **0%**	Area DI < 300 lx: **0%** Area DI > 3000 lx: **0%**

WET SEASON

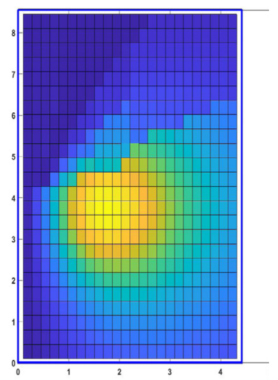
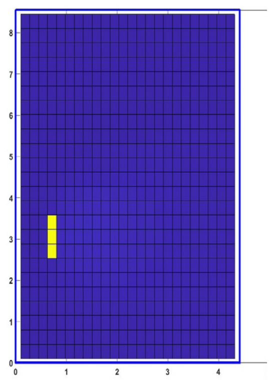
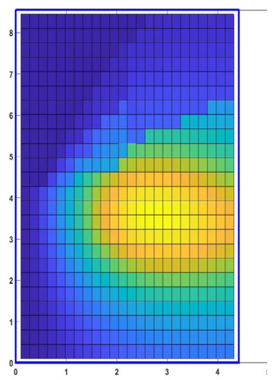
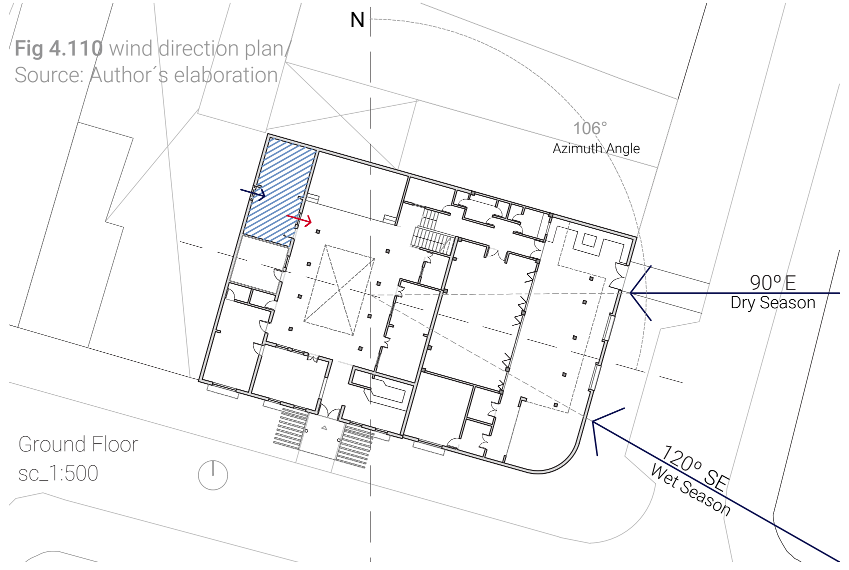
21-June 08:00	21-June 13:00	21-June 17:00
		
Area DI < 300 lx: **100%** Area DI > 3000 lx: **0%**	Area DI < 300 lx: **18%** Area DI > 3000 lx: **0.5%**	Area DI < 300 lx: **0%** Area DI > 3000 lx: **0%**

Fig 4.108 Illuminance Hours plan Dry season / Source: EnergyVER

Fig 4.109 Illuminance Hours plan Wet season / Source: EnergyVER

AIRFLOW ANALYSIS
"Paraulata" Room

Fig 4.110 wind direction plan/ Source: Author´s elaboration



Area Room: 31.95 m²

- Minimum Area Windows per room (A room/8): **3.99m²**
- Area total Windows (Current state): **1.20 m²**

SINGLE SIDED VENTILATION

Despite the room has an internal window, the airflow is considered as single sided ventilation due to the position and size of the windows.

$$qv\,[m3/h] = 3600 * \frac{\rho_{a;ref}}{\rho_{a;e}} * \frac{Aw_{;tot}}{2} * \max\left(C_{wind} * U_{10;site}^{2} ; C_{st} * h_{w;st} * abs(T_z - T_e)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * \frac{1,23}{1,18} * \frac{0,99}{2} * \max\left(0,001 * 0,56^{2} ; 0,0035 * 1 * abs(27,70 - 28,7)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 0,495 * \max(0,00056 ; 0,00361)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 0,495 * 0,00361^{0,5}$$

$$qv\,[m3/h] = \mathbf{111,53}$$

REQUIREMENTS

Table 4.23 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}IAQ(p)}$ [m³/	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
157,5	28	15	0,375	9

vol [m³]	$ACH_{r\text{-}IAQ}$ [1/h]
127,80	1,23

Table 4.24 **AIRFLOW RATE FOR COOLING**

	$q_{r\text{-}cool}$ [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]
JAN	573,90	195,31	0,28	1,18	27,7	28,7
FEB	787,21	197,67	0,28	1,18	28,3	29,0
MAR	1021,75	199,18	0,28	1,18	27,3	27,9
APR	1183,27	203,29	0,28	1,18	26,3	26,9
MAY	798,30	205,73	0,28	1,18	26,4	27,2
JUN	886,93	205,13	0,28	1,18	26,0	26,7
JUL	590,62	204,90	0,28	1,18	25,7	26,7
AUG	686,12	204,02	0,28	1,18	26,3	27,2
SEPT	937,81	201,40	0,28	1,18	27,0	27,6
OCT	638,68	198,36	0,28	1,18	26,9	27,8
NOV	1096,14	195,57	0,28	1,18	27,0	27,5
DEC	494,60	194,46	0,28	1,18	27,1	28,3

vol [m³]	$ACH_{r\text{-}cool}$ [1/h]
127,80	4,49
127,80	6,16
127,80	7,99
127,80	9,26
127,80	6,25
127,80	6,94
127,80	4,62
127,80	5,37
127,80	7,34
127,80	5,00
127,80	8,58
127,80	3,87

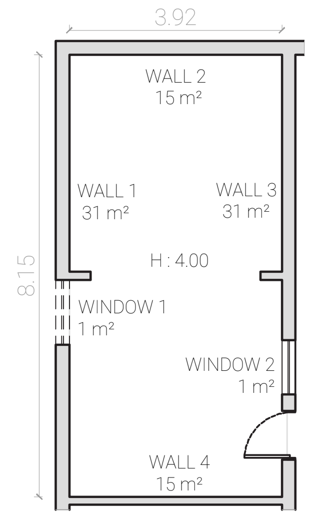
Table 4.25 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	q_v-IAQ [m³/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	111,53	157,5	573,9
FEB	95,80	157,5	787,21
MAR	84,41	157,5	1021,75
APR	79,24	157,5	1183,27
MAY	97,05	157,5	798,3
JUN	91,94	157,5	886,93
JUL	112,61	157,5	590,62
AUG	104,25	157,5	686,12
SEPT	88,60	157,5	937,81
OCT	106,54	157,5	638,68
NOV	80,75	157,5	1096,14
DEC	119,88	157,5	494,6

$q_{r\text{-}IAQ(p)}$ [m³/h]: min. required airflow rate per person
ACH_{IAQ} : Air change per hour
$q_{r\text{-}cool}$ [m³/h]: min. required airflow rate for cooling
$\rho_{a;ref}$ [kg/m³]: Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ [kg/m³]: Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} [1 m/s]: Coefficient of wind speed
C_t [m/s]: Coefficient of wind turbulence
C_{st} [m/s]: Coefficient of stack effect
$u_{10;site}$ [m/s]: Wind at the zone level, at 10 m height
$h_{w;st}$ [m]: Useful height for stack effect for airing
$h_{w;fa}$ [m]: Free area height of the window "i"
$h_{w;path}$ [m]: Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i [°C]: day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air

H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS
Paraulata Room



Volume= 127.79 m³

Fig 4.111 Acoustic plan/Source: EnergyVer simulation

Table 4.26 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4)	52	Concrete block painted	0,1	0,06	0,07
Ceiling	24	Expanded Polystyrene	0,05	0,4	0,35
Floor	24	Ceramic Clay Tile	0,01	0,01	0,01
Window 1	2	Single glass	0,35	0,18	0,12
Window 2	2	Metalic solid panel	0,01	0,01	0,01
Musicians playing(12)			0,37	1	1
Total Empty room			7,36	13,34	12,54
Total Occupied			11,8	25,34	24,54

REVERBERATION TIME	Empty Room	Occupied Room
T60(125Hz): $\frac{0.16x127.79\ m^3}{7.36}$	**2.77 s**	**1.73 s**
T60(500Hz): $\frac{0.16x127.79\ m^3}{13.34}$	**1.53 s**	**0.80 s**
T60(1000Hz): $\frac{0.16x127.79\ m^3}{12.54}$	**1.63 s**	**0.83 s**

OPTIMAL T60: 0.8s - 0.9 s

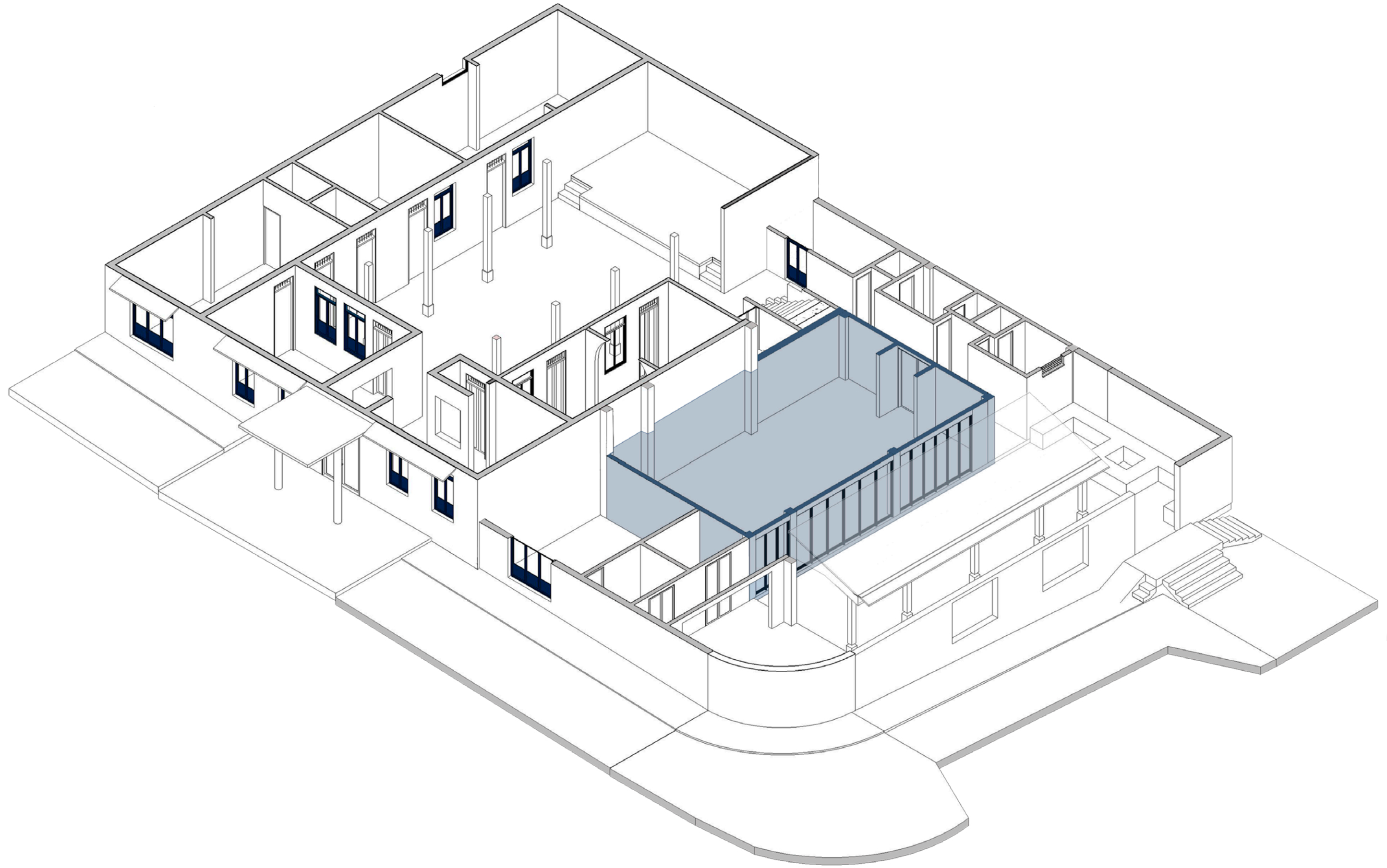
CONCLUSIONS

According to the simulation of internal thermal comfort, the room has an average of Operative temperature over the Outdoor temperature: 25.18Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is within this limit with 0.1% year. The warmest day shows a maximum temperature of 29.50Cº/33.1Cº on 9 February, and the minimum temperature of 21.12 Cº/21.65 Cº in 9 June. A small percentage of the occupied hours (5%), has an Operative temperature over 28 Cº and just 0.3% over 30Cº. But, 88% of the time has a Relative humidity over 70%, causing discomfort .

Based on a minimum daylight factor of 3% for school daylighting, 0% of the room area achieves the threshold with a deficient DF of 0.96%. Also, just 19.2% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room does not reach the minimum level, 46%/80%, indicating it is poorly illuminated by daylighting. There is not a glared area, but insufficient illumination mainly in the morning at 8:00 for both seasons with 100% of the area, and also, in the Dry season at 13:00 with 95%.

According to the Italian decree DM 05-07-75, the minimum area of windows of this room should be 3.99 m². The existing windows area is not meeting the minimum required with 1.20 m². Also the window does not bring daylight or natural ventilation when it is closed. With a single sided ventilation, the airflow entering through the windows does not meets the minimum Day average IAQ requirements for the room that is 157,5 m3/h, neither for the cooling requirements.

The room has a good reverberation time when is totally occupied for medium and high frecuencies (500Hz-1000Hz), achieving the T60 optimal required, 0.8s -0.9s, for its function as a classroom for music. For this frecuency, the empty room is long, over the threshold value. For low frecuencies (125Hz), the empty room and, also occupied has a long T60 over the Optimal T60 .. But, considering this room for individual rehearsal instruments with a lower and higher frecuencies, the time of reverberation is not enought because it is long for 125Hz .



ORCHESTRA

ROOM ANALYSIS

Fig 4.112 Axonometry "Orchestra" location/ Source: Author´s elaboration

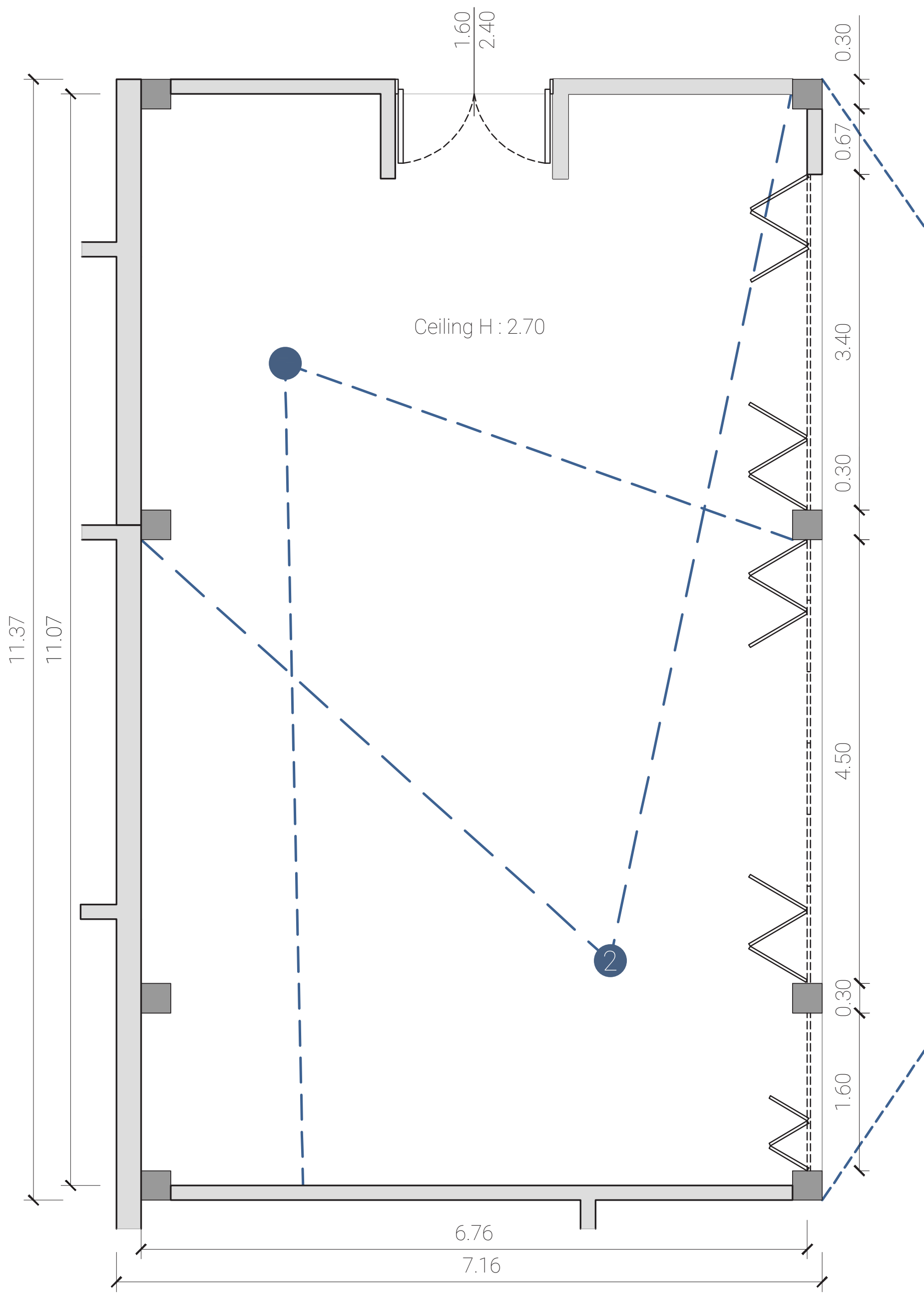


Fig 4.113 "Orchestra" plan/ Source: Author´s elaboration

Area= 75.79 m²
Volume= 204.63 m³

Level -0.87
Ground Floor

Music Classroom
_Orchestra Rehearsal

40 Students (Average capacity)

Fig 4.114 "Orchestra" photos/ Source: Author´s photos

THERMAL COMFORT ANALYSIS
Orchestra Room

- **Total** Occupation Hours/Year: **3020**
- Average Indoor Relative Humidity (Occupation Hours): 69%
- Occupied hours where Relative Humidity > 70%: 1803 (59% year)
- Occupied hours where Operative Temperature > T limit (28°C): 1093 (36% year)
- Occupied hours where Operative Temperature > T limit (30°C): 217 (7% year)
- Occupied hours where Operative Temperature <T limit (21°C): 21 (0.6% year)
- Overheating hours (EN class 2): 250 (8% year)
- Optimal Operative Temperature (Adaptive EN class 2)

T_c : 0.33 * T_{rm} + 18.8
T_c : 0.33 * **24.51 °C** + 18.8
T_c : **26.88 °C**

Upper Limit (+3): **29.88 °C**
Lower Limit (-4): **22.88 °C**

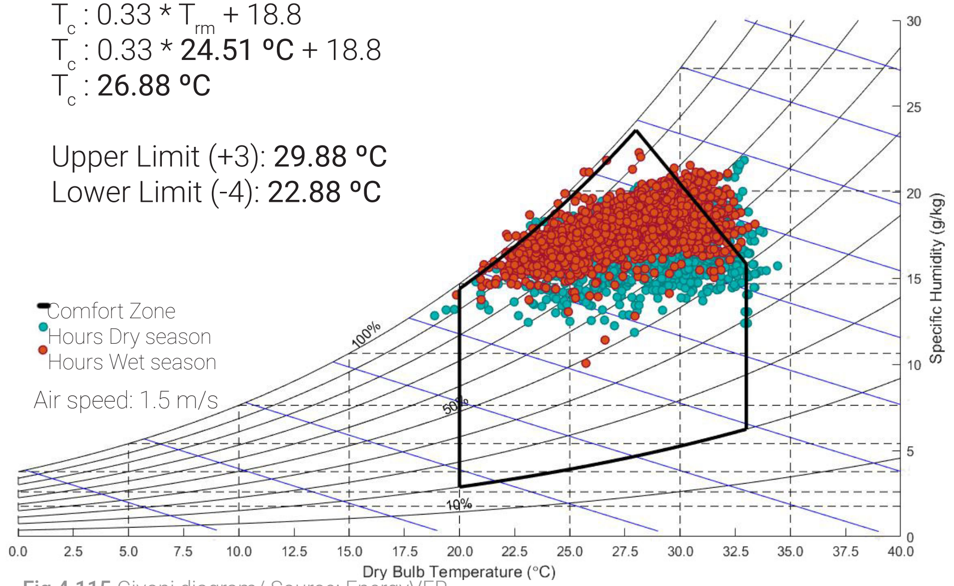
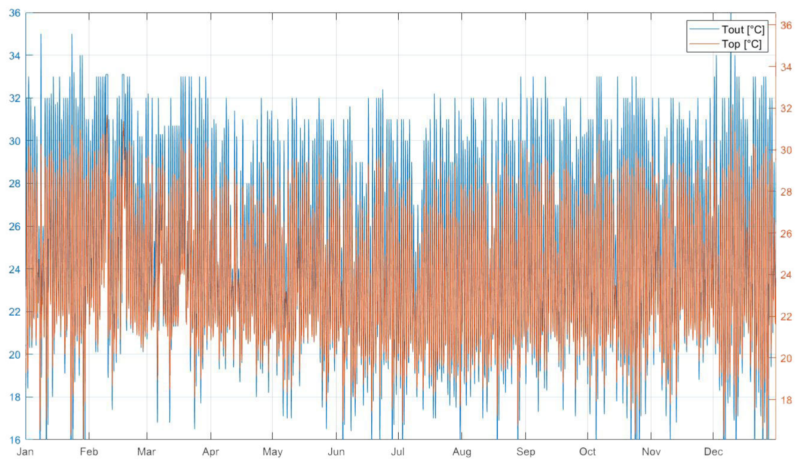


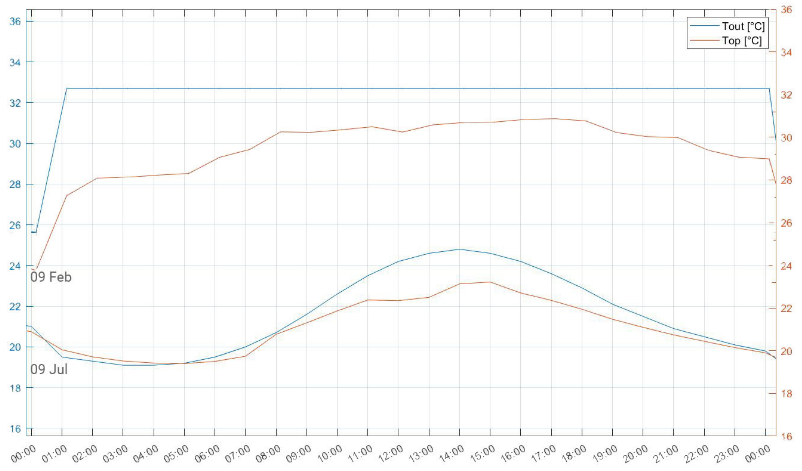
Fig 4.115 Givoni diagram/ Source: EnergyVER



T Outdoor Air Average: **24.55 °C**

T operative Average: **23.89 °C**

Fig 4.116 **Operative Temperature vs Outdoor Air Temperature Year**



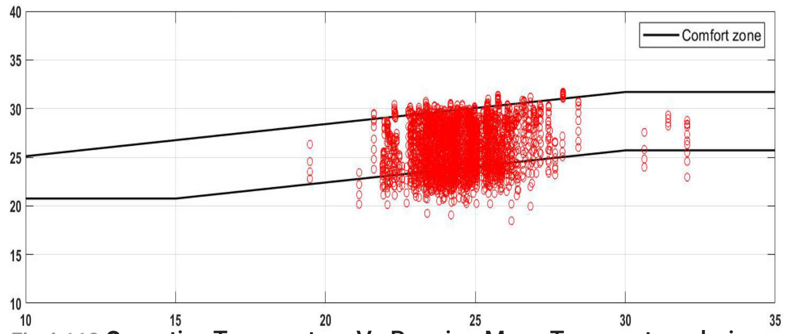
WARMEST DAY
09 February

T Out Average: **33.1 °C**
T op Average: **30.52 °C**

COLDEST DAY
09 Jul

T Out Average: **21.65 °C**
T op Average: **21.12 °C**

Fig 4.117 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**



ADAPTIVE EN-2
Average (°C) of hours occupied

T Running mean Outside: **24.51 °C**

T operative: **26.75 °C**

Fig 4.118 **Operative Temperature Vs Running Mean Temperature during occupied hours**

DAYLIGHT ANALYSIS
Orchestra Room

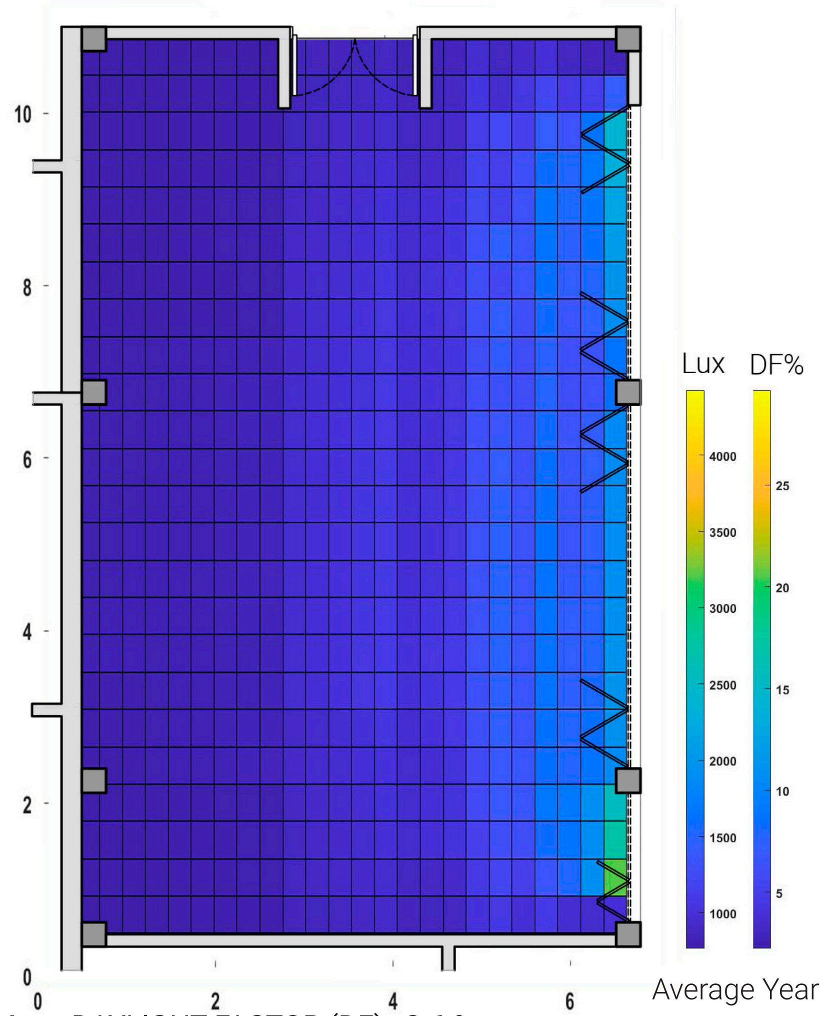
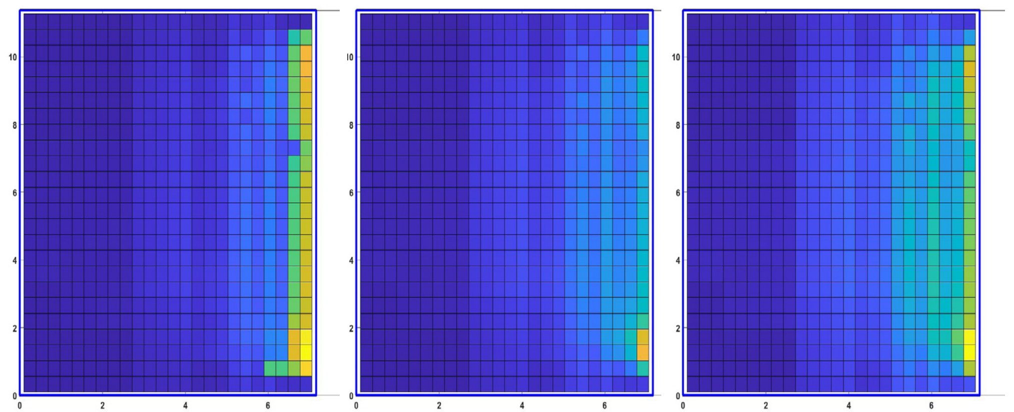


Fig 4.119 Illuminance plan/ Source: Energy-VER

- Mean DAYLIGHT FACTOR (DF): 8.6 %
  DF threshold level for classrooms : 3%
  Room Area DF > 3%: **92%**
- Mean DAYLIGHT AUTONOMY (DA): 89.32%
  Room Area DA > 50%: **100%**
- USEFUL DAYLIGHT ILLUMINANCE (uDI): 300 - 3000 Lux
  Room Area UDI: **99% / 80%** (Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **0.3%** Glared area

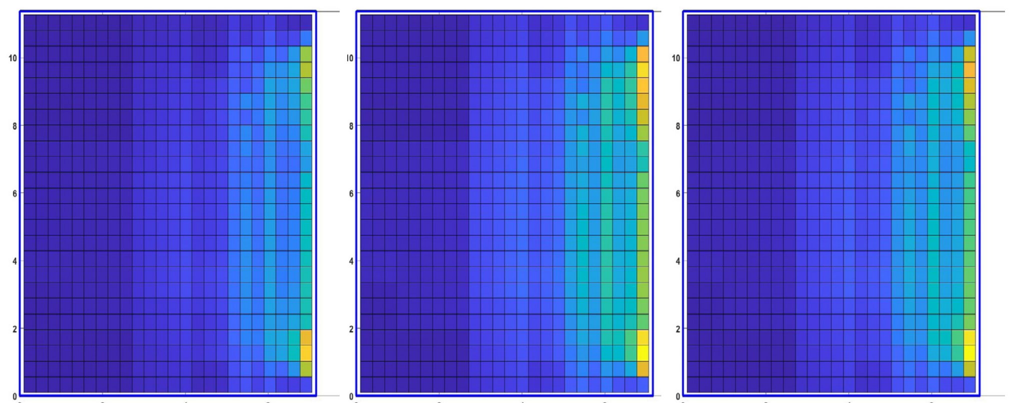
DRY SEASON



21- December 08:00	21- December 13:00	21- December 17:00
Area DI < 300 lx:**0%**	Area DI < 300 lx: **0%**	Area DI < 300 lx: **0%**
Area DI > 3000 lx: **8.3%**	Area DI > 3000 lx: **0.3%**	Area DI > 3000 lx: **0%**

Fig 4.120 Illuminance Hours plan Dry season / Source: EnergyVER

WET SEASON

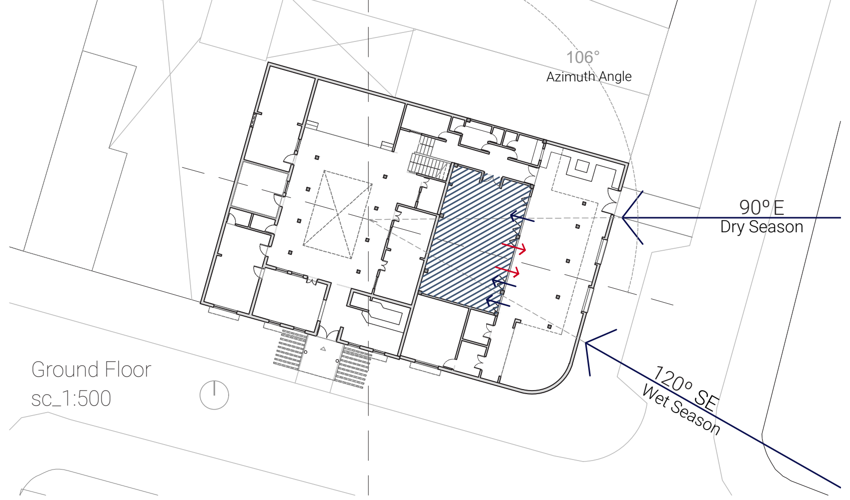


21-June 08:00	21-June 13:00	21-June 17:00
Area DI < 300 lx:**0%**	Area DI < 300 lx: **0%**	Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0%**	Area DI > 3000 lx: **1.3%**	Area DI > 3000 lx: **0%**

Fig 4.121 Illuminance Hours plan Dry season / Source: EnergyVER

AIRFLOW ANALYSIS
Orchestra Room

Fig 4.115 wind direction plan/ Source/ EnergyVer simulation



Area Room: 75.79 m²

- Minimum Area Windows per room (A room/8): **9.47m²**
- Area total Windows (Current state): **25.75 m²**

SINGLE SIDED VENTILATION CALCULATION

Calculation Current state: January

$$qv\,[m3/h] = 3600 * \frac{\rho_{a;ref}}{\rho_{a;e}} * \frac{Aw_{;tot}}{2} * \max\left(C_{wind} * U_{10;site}^{2} ; C_{st} * h_{w;st} * abs(T_z - T_e)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * \frac{1,23}{1,18} * \frac{25,75}{2} * \max\left(0,001 * 0,56^{2} ; 0,0035 * 2,7 * abs(29,4-28,7)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 12,88 * \max(0,00056 ; 0,000595)^{0,5}$$

$$qv\,[m3/h] = 3600 * 1,04 * 12,88 * 0,000595^{0,5}$$

$$qv\,[m3/h] = \mathbf{3727,86}$$

REQUIREMENTS

Table 4.27 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

q_{r-IAQ} [m³/h]	$q_{r-IAQ(p)*}$ [m³/	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
420	28	40	0,375	9

vol [m³]	ACH_{r-IAQ} [1/h]
204,63	2,05

Table 4.28 **AIRFLOW RATE FOR COOLING**

	q_{r-cool} [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]
JAN	2549,87	530,76	0,28	1,18	29,4	28,7
FEB	3606,60	536,23	0,28	1,18	29,5	29,0
MAR	1715,55	527,14	0,28	1,18	28,9	27,9
APR	2931,29	522,99	0,28	1,18	27,4	26,9
MAY	1775,19	522,00	0,28	1,18	28,1	27,2
JUN	1835,73	515,55	0,28	1,18	27,6	26,7
JUL	2447,24	517,48	0,28	1,18	27,4	26,7
AUG	1789,69	520,36	0,28	1,18	28,1	27,2
SEPT	2894,05	525,91	0,28	1,18	28,2	27,6
OCT	1990,60	532,73	0,28	1,18	28,6	27,8
NOV	2353,41	528,75	0,28	1,18	28,2	27,5
DEC	2637,27	522,81	0,28	1,18	28,9	28,3

vol [m³]	ACH_{r-cool} [1/h]
204,63	12,46
204,63	17,62
204,63	8,38
204,63	14,32
204,63	8,67
204,63	8,97
204,63	11,96
204,63	8,75
204,63	14,14
204,63	9,73
204,63	11,50
204,63	12,89

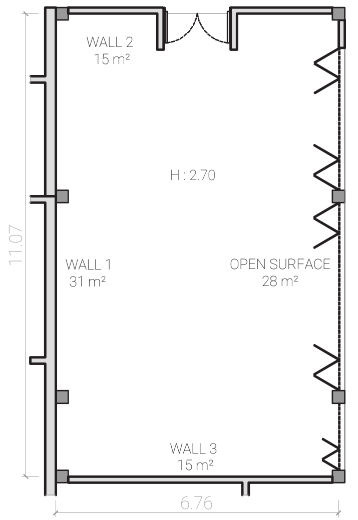
Table 4.29 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	q_r-IAQ [m³/h]	q_r-IAQ [m³/h]	q_{r-cool} [m³/h]
JAN	3727,86	420	2549,87
FEB	1496,95	420	3606,6
MAR	4529,29	420	1715,55
APR	3451,32	420	2931,29
MAY	4430,82	420	1775,19
JUN	4330,10	420	1835,73
JUL	3757,32	420	2447,24
AUG	4405,85	420	1789,69
SEPT	3483,13	420	2894,05
OCT	4226,99	420	1990,6
NOV	3872,96	420	2353,41
DEC	3638,01	420	2637,27

$q_{r-IAQ(p)}$ **[m³/h]:** min. required airflow rate per person
ACH_{IAQ} **:** Air change per hour
q_{r-cool} **[m³/h]:** min. required airflow rate for cooling
$\rho_{a;ref}$ **[kg/m³]:** Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ **[kg/m³]:** Air density at temperature exterior
$A_{w;tot}$**:** Area total of windows openings
C_{wind} **[1 m/s]:** Coefficient of wind speed
C_t **[m/s]:** Coefficient of wind turbulence
C_{st} **[m/s]:** Coefficient of stack effect
$u_{10;site}$ **[m/s]:** Wind at the zone level, at 10 m height
$h_{w;st}$ **[m]:** Useful height for stack effect for airing
$h_{w;fa}$ **[m]:** Free area height of the window "i"
$h_{w;path}$ **[m]:** Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i **[°C]:** day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air

H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS
Orchestra Room



Volume= 204.63 m³

Fig 4.116 Acoustic plan/Source: EnergyVer simulation

Table 4.30 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3)	91	Concrete block painted	0,1	0,06	0,07
Ceiling	74	Expanded Polystyrene	0,05	0,4	0,35
Floor	74	Ceramic Clay Tile	0,01	0,01	0,01
Open surfaces	28	Air	0	0	0
Musicians playing(40)			0,37	1	1
Total Empty room			13,54	35,8	33,01
Total Occupied			28,34	75,8	73,01

REVERBERATION TIME	Empty Room	Occupied Room
T60(125Hz): $\frac{0.16 \times 204.63\ m^3}{13.54}$	**2.41 s**	**1.15 s**
T60 (500Hz): $\frac{0.16 \times 204.63\ m^3}{35.8}$	**0.91 s**	**0.43 s**
T60 (1000Hz): $\frac{0.16 \times 204.63\ m^3}{33.01}$	**0.99 s**	**0.44 s**

OPTIMAL T60: 0.8s - 0.9 s

CONCLUSIONS

According to the simulation of internal thermal comfort, the room has an average of higher Operative temperature over the Outdoor temperature: 26.75Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is out of this limit with 8% year. The warmest day shows a maximum temperature of 30.52cº/33.1cº on 9 February, and the minimum temperature of 21.12 Cº/21.65 Cºin 9 June.
The room, with 36% of the occupied hours, has an Operative temperature over 28 Cº and just 7% over 30Cº. More than the half of hours (60%),the room has a Relative humidity over 70%. Despite the high RH, most of the hours are within the comfort zone.

Based on a minimum daylight factor of 3% for school daylighting, 92% of the room area achieves the threshold with a high DF of 8.6%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room exceeds the minimum level, 99%/80%, indicating it is well illuminated by daylighting. There is not a considerable glared area, just in dry season at 8:00 with 8.3%. In general, the room has good quality of daylighting in the occupied hours.

According to the Italian decree DM 05-07-75, the minimum area of windows of this room should be 9.47m². Since the room has an open facade instead of windows, it up to minimum required with 25.75m². With a single sided ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 420 m3/h. The current airflow also meets the requirements for cooling in the year, except for February.
The room has a short reverberation time when is totally occupied for medium and high frecuencies (500Hz-1000Hz), below to the T60 optimal required, 0.8s -0.9s, for its function as a classroom for music. For this frecuency, the empty room is over the threshold value. For low frecuencies (125Hz), the empty room and lso occupied, has a long T60 over the Optimal T60 .. But, considering this room for groupal rehearsal for all the orchestra`s instruments with lower and high frecuencies, the time of reverberation is not efficient because it tends to be mostly short.

SCENARIO/LOBBY

ROOM ANALYSIS

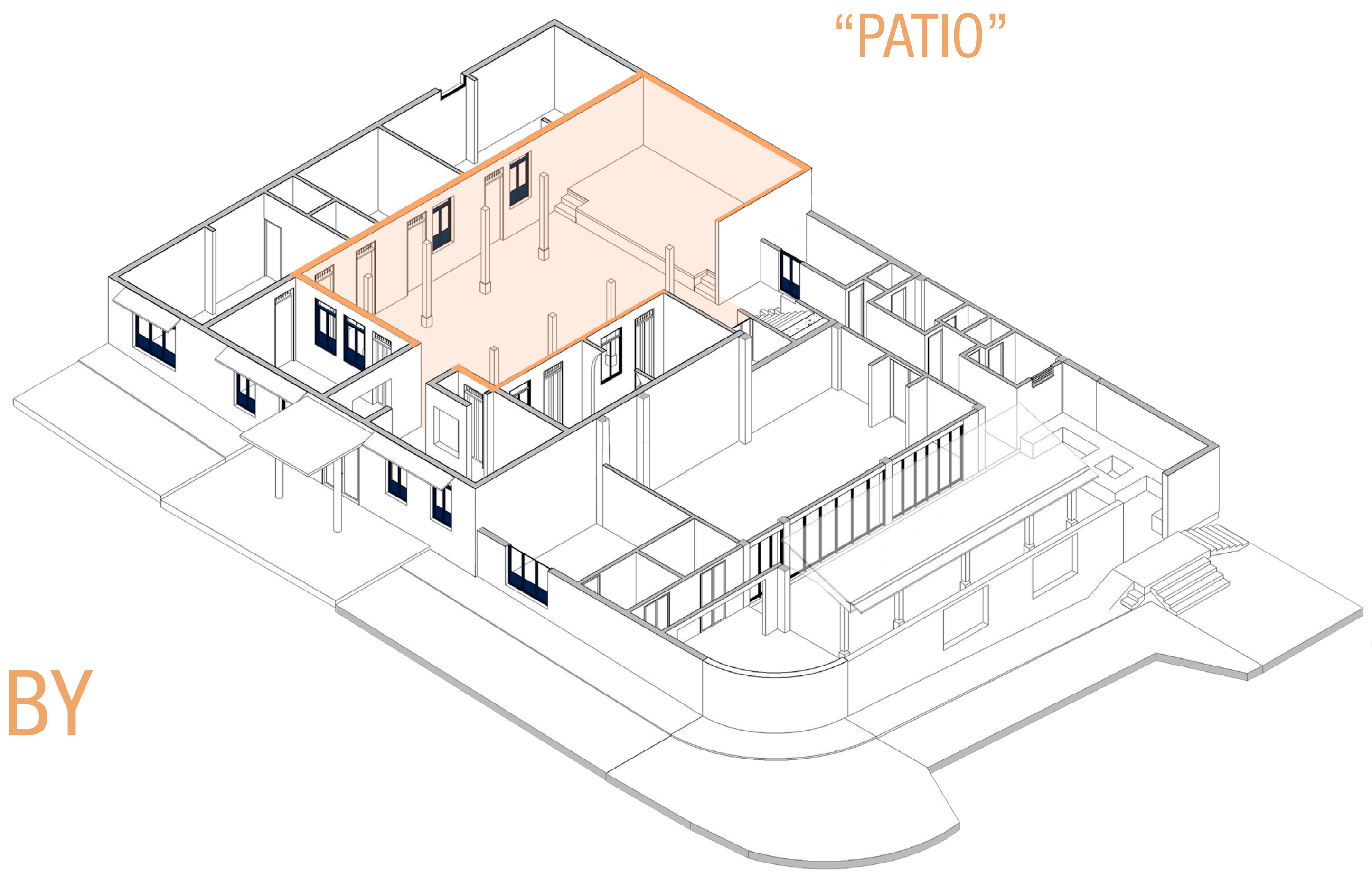


Fig 4.117 Axonometry "Scenario" location/ Source: Author´s elaboration

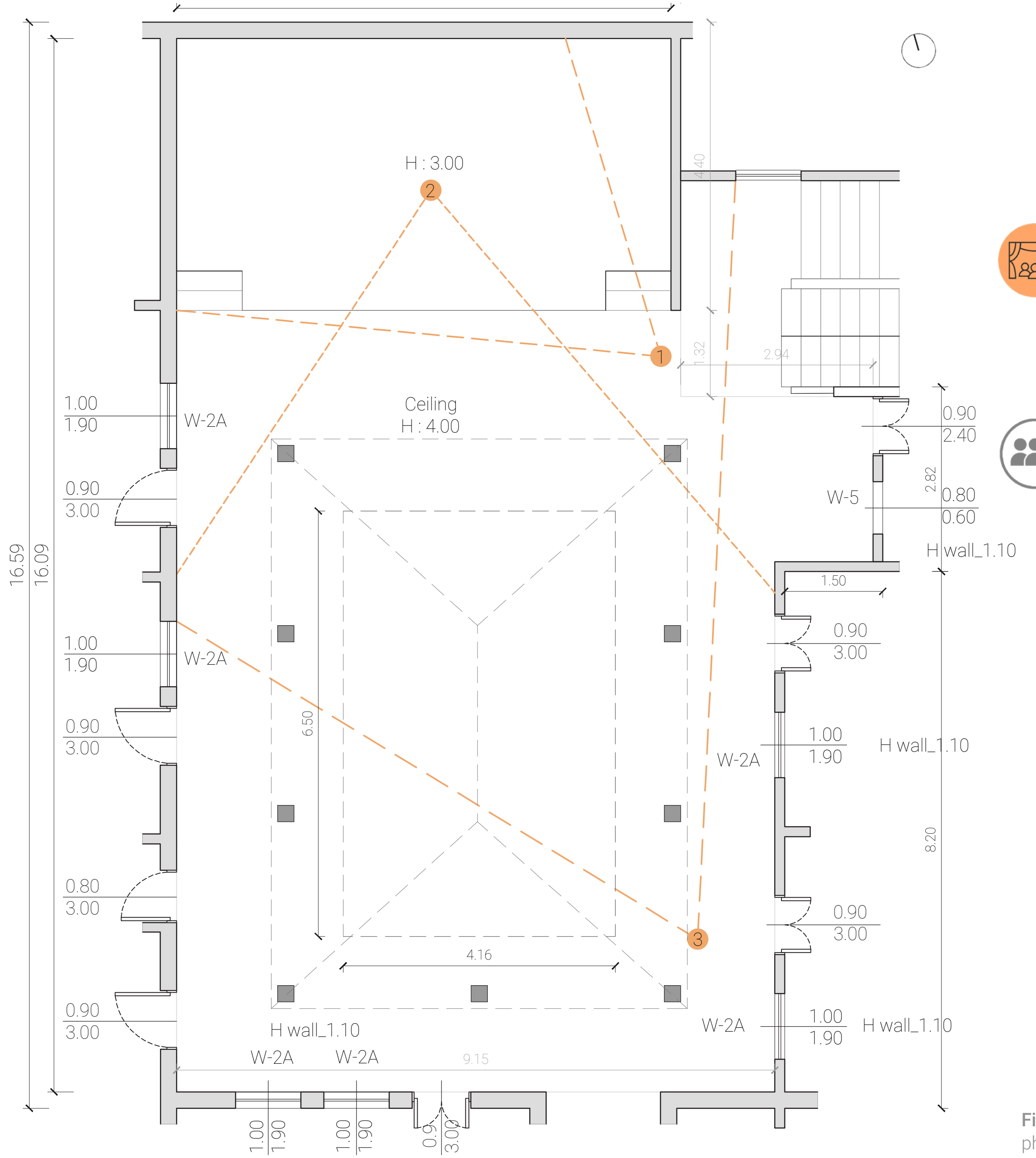


Fig 4.118 "Scenario" plan/ Source: Author´s elaboration

Area= 142.50 m²
Volume= 551.17 m³

Level 0.00
Ground Floor

Music Concert/ Lobby

_Pre-Orchestra and orchestra concerts
_Main Lobby

70 people (Average capacity)

Fig 4.119 "Scenario" photos/ Source: Author´s photos

THERMAL COMFORT ANALYSIS
Scenario/Lobby

- **Total** Occupation Hours/Year: **3375**
- Average Indoor Relative Humidity (Occupation Hours): 69%

- Occupied hours where Relative Humidity > 70%: 2092(61% year)

- Occupied hours where Operative Temperature > T limit (28ºC): 1732 (51% year)
- Occupied hours where Operative Temperature > T limit (30ºC): 1353 (40% year)
- Occupied hours where Operative Temperature <T limit (21ºC): 36 (1% year)

- Overheating hours (EN class 2): 1343 (39% year)

- Optimal Operative Temperature (Adaptive EN class 2)

T_c : 0.33 * T_{rm} + 18.8
T_c : 0.33 * 24.51 ºC + 18.8
T_c : 26.88 ºC

Upper Limit (+3): 29.88 ºC
Lower Limit (-4): 22.88 ºC

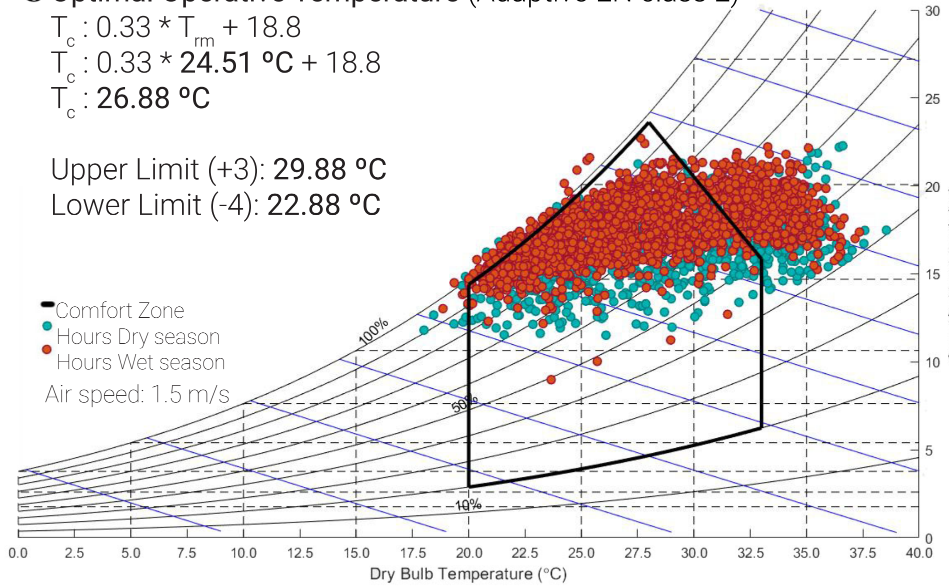


Fig 4.120 Givoni diagram/ Source: EnergyVER

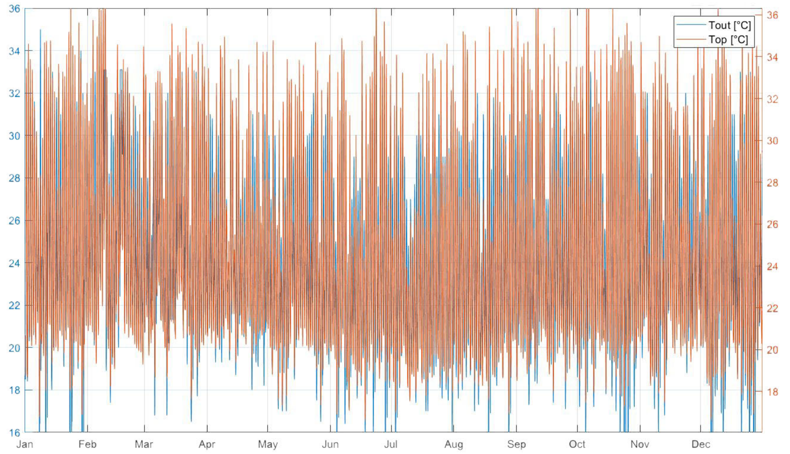


Fig 4.121 **Operative Temperature vs Outdoor Air Temperature Year**

T Outdoor Air Average: **24.55 ºC**

T operative Average: **24.93 ºC**

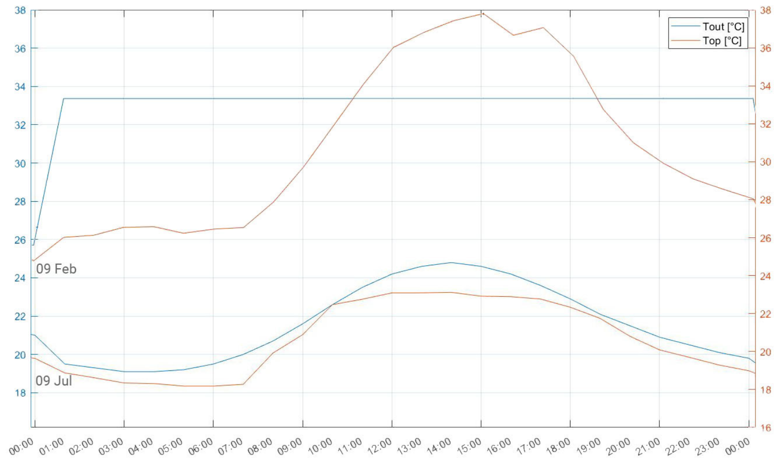


Fig 4.122 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**

WARMEST DAY
09 February

T Out Average: **33.1 ºC**
T op Average: **31.16 ºC**

COLDEST DAY
09 Jul

T Out Average: **21.65 ºC**
T op Average: **20.72 ºC**

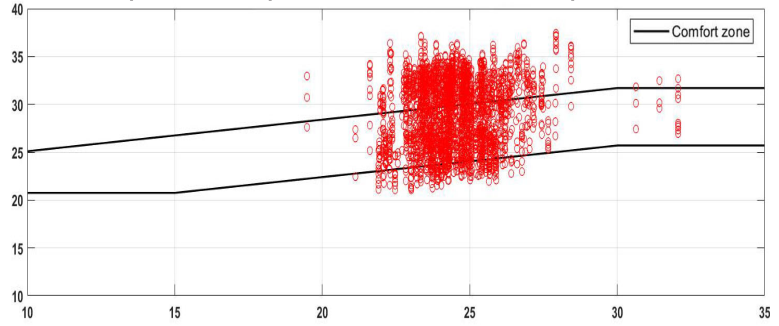


Fig 4.123 **Operative Temperature Vs Running Mean Temperature during occupied hours**

Average (ºC) of occupied hours Year

Running mean Outside T: **24.51 ºC**

T Operative **28.31 ºC**

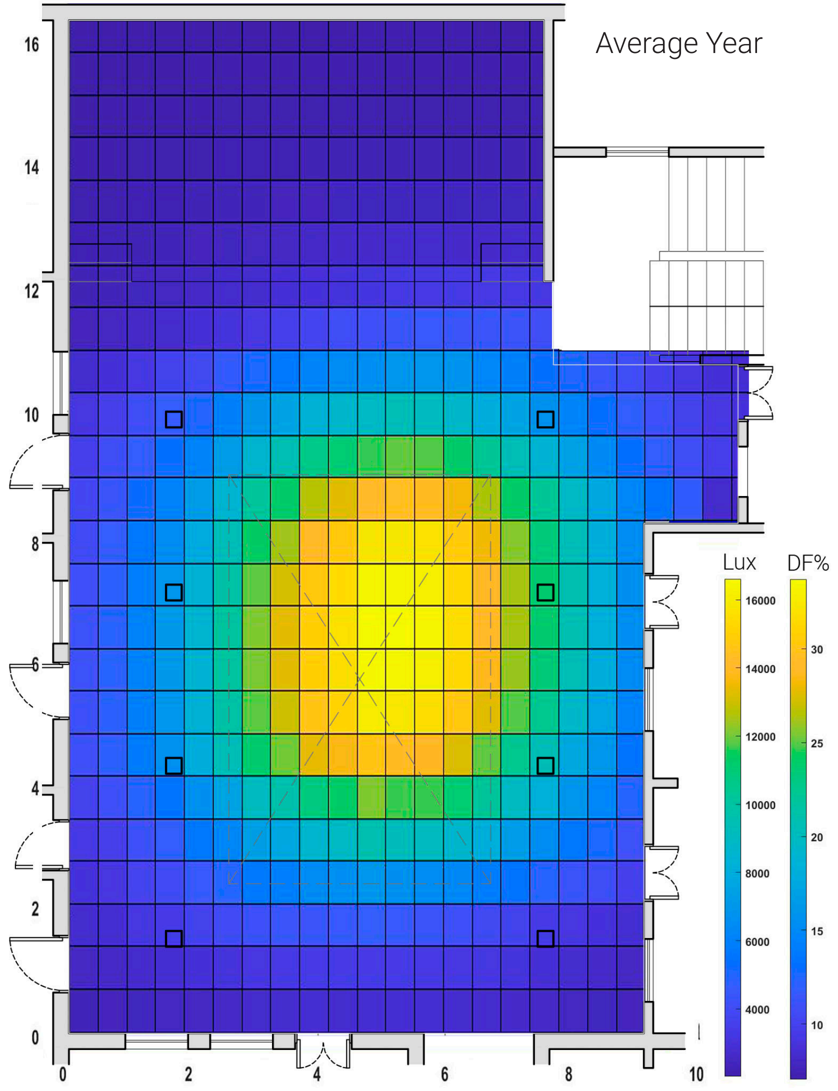
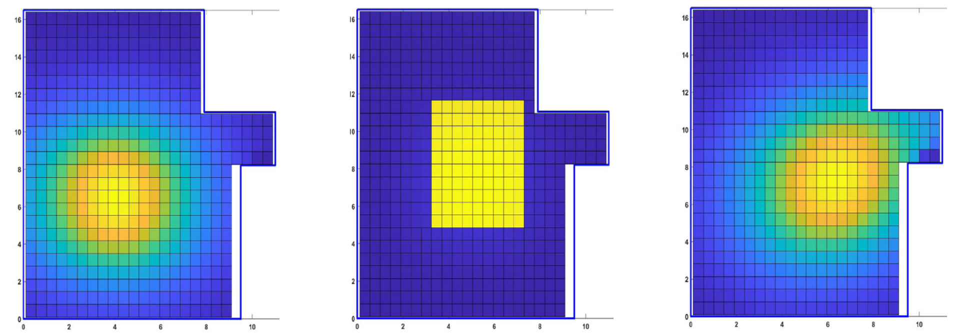


Fig 4.124 Illuminance plan/ Source: EnergyVER

- Mean DAYLIGHT FACTOR (DF): **19.21%**
DF threshold level for Meeting spaces : 2%
Room Area DF > 2%: **100%**
- Mean DAYLIGHT AUTONOMY (DA): **96.07%**
Room Area DA > 50%: **100%**

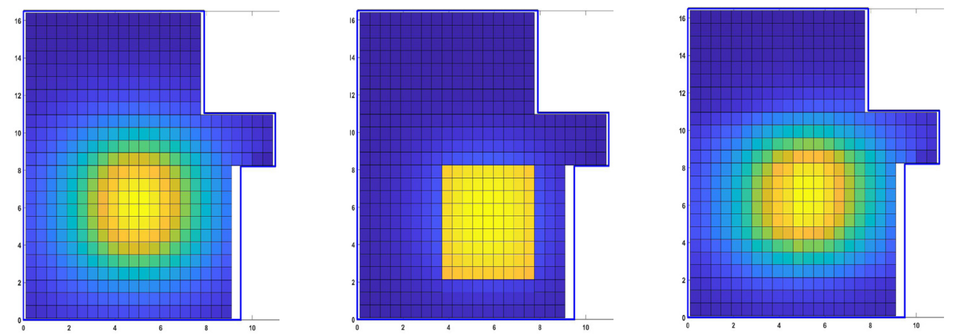
DAYLIGHT ANALYSIS
Scenario/Lobby

DRY SEASON



21- December 08:00	21- December 13:00	21- December 17:00
Area DI < 300 lx:**0%**	Area DI < 300 lx: **0%**	Area DI < 300 lx: **0%**
Area DI > 3000 lx: **8.3%**	Area DI > 3000 lx: **100%**	Area DI > 3000 lx: **8.8%**

WET SEASON



21-June 08:00	21-June 13:00	21-June 17:00
Area DI < 300 lx: **22%**	Area DI < 300 lx: **0%**	Area DI < 300 lx: **0%**
Area DI > 3000 lx: **8.3%**	Area DI > 3000 lx: **100%**	Area DI > 3000 lx:**12.5%**

Fig 4.125 Illuminance Hours plan Dry season / Source: EnergyVER

Fig 4.126 Illuminance Hours plan Dry season / Source: EnergyVER

- USEFUL DAYLIGHT ILLUMINANCE (uDI): **300 - 3000 Lux**
Room Area UDI: **62% / 80%** (Minimum)
Room Area DI < 300 lx: **0%**
Room Area DI > 3000 lx: **44.5%** Glared area

AIRFLOW ANALYSIS
Scenario/Lobby

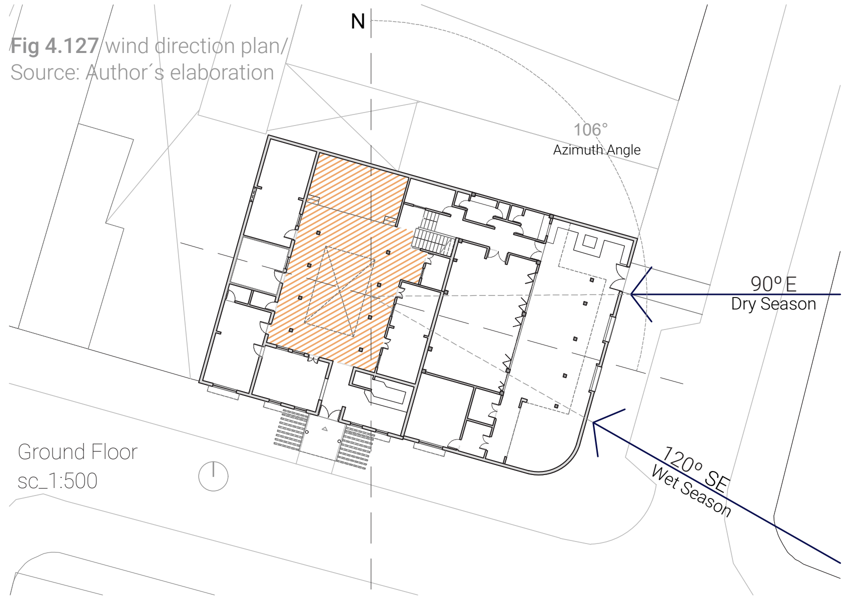


Fig 4.127 wind direction plan/ Source: Author´s elaboration

Area Room: 142.50 m²

- Minimum Area Windows per room (A room/8): **17.81 m²**
- Area total Windows (Current state): **27.06 m²**

STACK VENTILATION

Calculation Current state: January

$$q_s\,[m^3/s] = C_d * A * \sqrt{2 * g * H * \text{abs}\frac{(T_z - T_e)}{T}}$$

$$q_s\,[m^3/s] = 0,6 * 4 * \sqrt{2 * 9.8 * 2,2 * \text{abs}\frac{(29,91 - 28,73)}{29,32}}$$

$$q_s\,[m^3/s] = 3,16$$

$$q_s\,[m^3/s] = 3,16 * 3600$$

$q_{s,h}$ [m³/h] = **11381,83**

REQUIREMENTS

Table 4.31 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}IAQ(p)}$ [m³/]	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
787,5	30	70	0,375	9

vol [m³]	$ACH_{r\text{-}IAQ}$ [1/h]
551,17	1,43

Table 4.32 **AIRFLOW RATE FOR COOLING**

	$q_{r\text{-}cool}$ [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]	vol [m³]	$ACH_{r\text{-}cool}$ [1/h]
JAN	6898,75	2689,63	0,28	1,18	29,91	28,73	551,17	12,52
FEB	8118,41	2601,85	0,28	1,18	29,98	29,01	551,17	14,73
MAR	4781,71	2496,20	0,28	1,18	29,51	27,93	551,17	8,68
APR	6714,30	2684,27	0,28	1,18	28,07	26,86	551,17	12,18
MAY	8951,74	2750,62	0,28	1,18	28,09	27,16	551,17	16,24
JUN	4675,69	2348,17	0,28	1,18	28,25	26,73	551,17	8,48
JUL	14444,53	2720,31	0,28	1,18	27,29	26,72	551,17	26,21
AUG	9743,86	2704,27	0,28	1,18	28,04	27,20	551,17	17,68
SEPT	6220,52	3041,79	0,28	1,18	29,08	27,60	551,17	11,29
OCT	4072,12	3027,22	0,28	1,18	30,05	27,80	551,17	7,39
NOV	6178,59	2674,24	0,28	1,18	28,81	27,50	551,17	11,21
DEC	7931,99	2777,97	0,28	1,18	29,36	28,30	551,17	14,39

Table 4.33 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	$q_{s,h}$ [m³/h]	$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	11381,83	787,5	6898,75
FEB	10288,80	787,5	8118,41
MAR	13307,28	787,5	4781,71
APR	11908,47	787,5	6714,30
MAY	10409,83	787,5	8951,74
JUN	13340,97	787,5	4675,69
JUL	8242,68	787,5	14444,53
AUG	9894,21	787,5	9743,86
SEPT	12965,34	787,5	6220,52
OCT	15823,69	787,5	4072,12
NOV	12238,02	787,5	6178,59
DEC	10878,27	787,5	7931,99

$q_{r\text{-}IAQ(p)}$ [m³/h]: min. required airflow rate per person
ACH_{IAQ}: Air change per hour
$q_{r\text{-}cool}$ [m³/h]: min. required airflow rate for cooling
$\rho_{a;ref}$ [kg/m³]: Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ [kg/m³]: Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} [1 m/s]: Coefficient of wind speed
C_t [m/s]: Coefficient of wind turbulence
C_{st} [m/s]: Coefficient of stack effect
$u_{10;site}$ [m/s]: Wind at the zone level, at 10 m height
$h_{w;st}$ [m]: Useful height for stack effect for airing
$h_{w;fa}$ [m]: Free area height of the window "i"
$h_{w;path}$ [m]: Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i [°C]: day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air

H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS
Scenario/Lobby

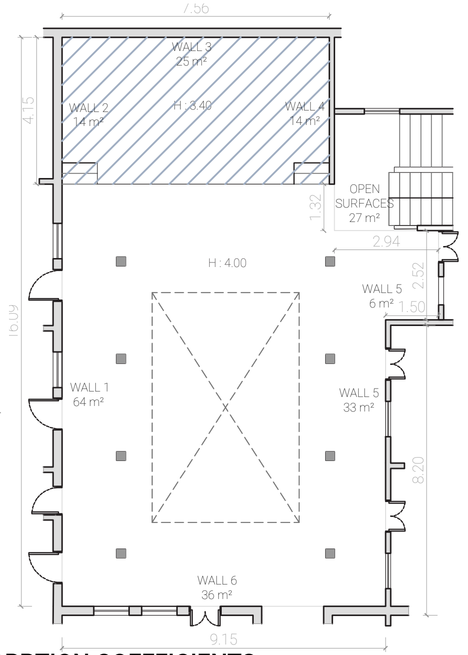


Fig 4.128 Acoustic plan/Source: Energy-Ver simulation

Volume= 551.17 m³

OPTIMAL T60: 1.2s to 1.4s

Table 4.34 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4+5+6)	192	Concrete block painted	0,1	0,06	0,07
Ceiling	115	Expanded Polystyrene	0,05	0,4	0,35
Floor	142	Ceramic Clay Tile	0,01	0,01	0,01
Skylight	27	Polycarbonate/glass	0,35	0,18	0,12
Open surfaces	27	Air	0	0	0
Musicians playing(20)			0,37	1	1
Adults seated(50)			0,33	0,44	0,42
Total Empty room			35,82	63,8	58,35
Total Occupied			59,72	105,8	99,35

REVERBERATION TIME		Empty Room	Occupied Room
T60 (125Hz):	$\frac{0.16 \times 551.17\ m^3}{35.82}$	**2.46s**	**1.47 s**
T60(500Hz):	$\frac{0.16 \times 551.17\ m^3}{63.8}$	**1.38 s**	**0.83 s**
T60 (1000Hz):	$\frac{0.16 \times 551.17\ m^3}{58.35}$	**1.51 s**	**0.88 s**

CONCLUSIONS

According to the simulation of internal thermal comfort, the room has high Operative temperatures against the Outdoor temperature: 28.31Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is out of this limit with 39% year. The warmest day shows a maximum temperature of 31.16Cº/33.1Cº on 9 February, and the minimum temperature of 20.72 Cº/21.65 Cº in 9 June.
Almost the half of the occupied hours (51%), the Operative temperature is over 28 Cº and 40% over 30Cº, with 61% time of Relative humidity over 70%, and a high amount of 39% overheating hours, all causing discomfort in the room.

Based on a minimum daylight factor of 2% for meeting rooms of schools, 100% of the room area achieves the threshold with a DF of 19.21%. Also, 100% of the room has a Daylight Autonomy over 50%. But, for Useful daylight Illuminance (300 to 3000 lx), the room does not reach the minimum level with 69%/80%, due to the high percentage of glared area of 44.5%. The glare occurs mainly at 13:00 with 100% of the area both seasons. On the contrary, the area of the stage platform has insufficient illuminance in Wet season in the morning at 8:00.

According to the Italian decree DM 05-07-75, the minimum area of windows of this room should be 17.81 m². Taking into account the skylight as the main window, the area is up to the minimum required with 27.06 m².With a stack ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 787.5m3/h (70 people). The current airflow also meets the requirements for cooling in almost all months, except in july.
The room has a short reverberation time when is totally occupied for medium and high frecuencies (500Hz-1000Hz), below to the T60 optimal required, 1.2s -1.4s, for its function as an scenariofor music performances. For this frecuency, the empty room is almost on the threshold value. For low frecuencies (125Hz), the empty room and also occupied, has a long T60 over the Optimal T60 .. Since this room is for the eventual orchestra and pre-orchestras performances with lower and high frecuencies, the time of reverberation has to be longer to reach the Optimal value.

ADMINISTRATIVE OFFICE

ROOM ANALYSIS

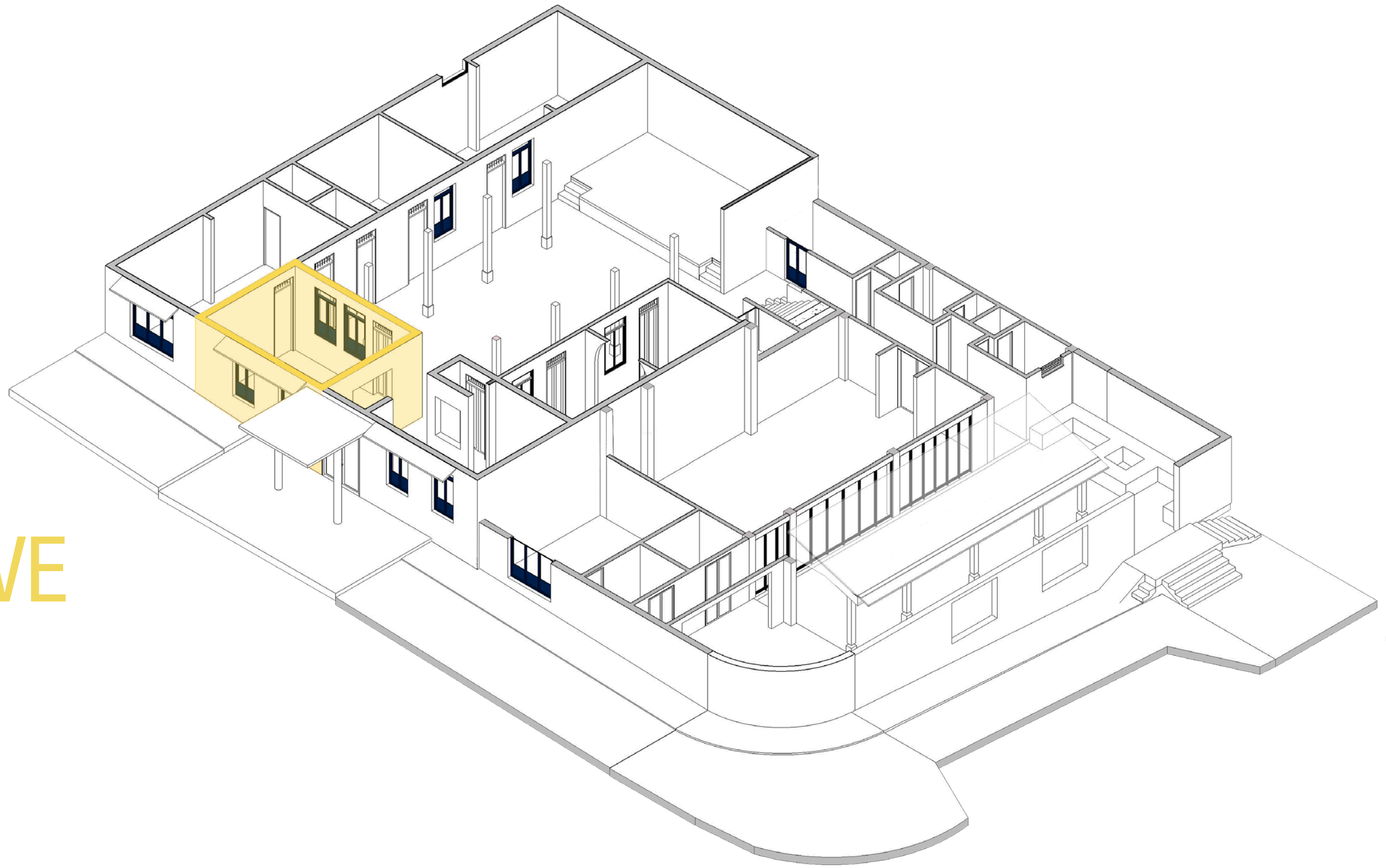


Fig 4.129 Axonometry "A.Office" location/ Source: Author´s elaboration

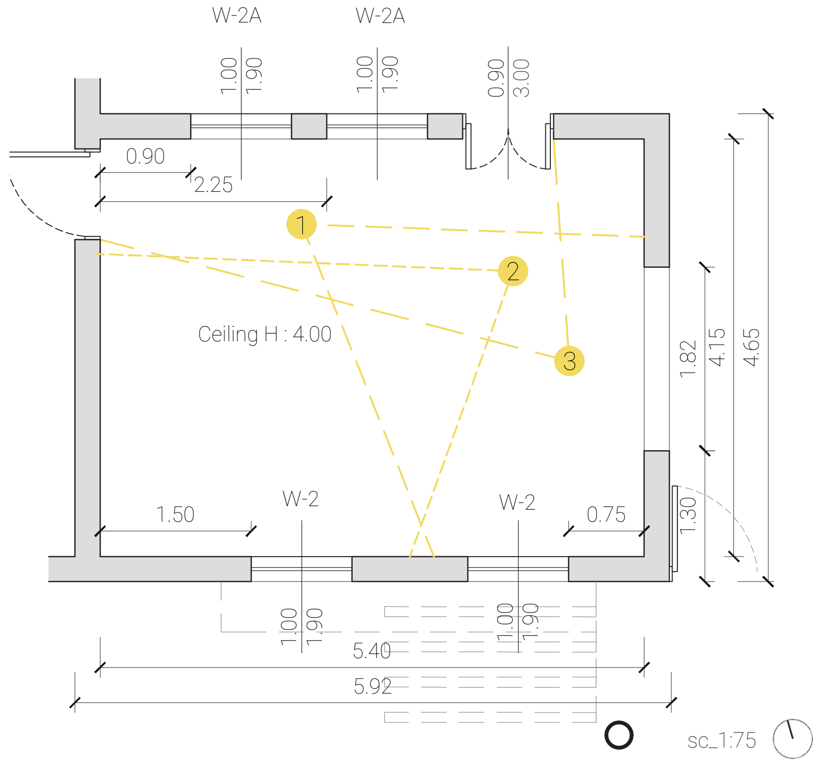


Fig 4.130 "A.Office" plan/ Source: Author´s elaboration

Area= 22.41 m²
Volume= 89.64 m³

Level 0.00
Ground Floor

Office

_Administrative Offices

5 People (Average capacity)

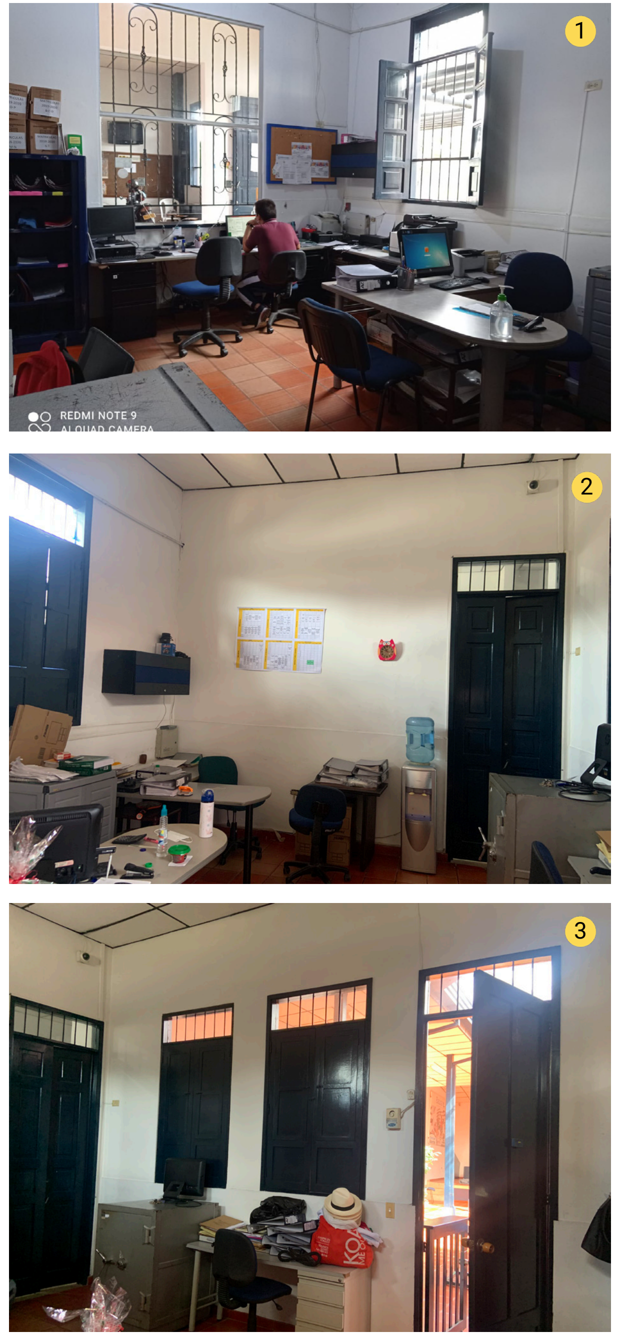


Fig 4.131 "A.Office" photos/ Source: Author´s photos

THERMAL COMFORT ANALYSIS
Administrative Office

- **Total** Occupation Hours/Year: **2492**
- Average Indoor Relative Humidity (Occupation Hours): 69%
- Occupied hours where Relative Humidity > 70%: 2091 (75% year)
- Occupied hours where Operative Temperature > T limit (28ºC): 450 (18% year)
- Occupied hours where Operative Temperature > T limit (30ºC): 55 (2% year)
- Occupied hours where Operative Temperature <T limit (21ºC): 21(0.8% year)
- Overheating hours (EN class 2): 53 (2% year)
- Optimal Operative Temperature (Adaptive EN class 2)

T_c : 0.33 * T_{rm} + 18.8
T_c : 0.33 * 24.51 ºC + 18.8
T_c : 26.88 ºC

Upper Limit (+3): 29.88 ºC
Lower Limit (-4): 22.88 ºC

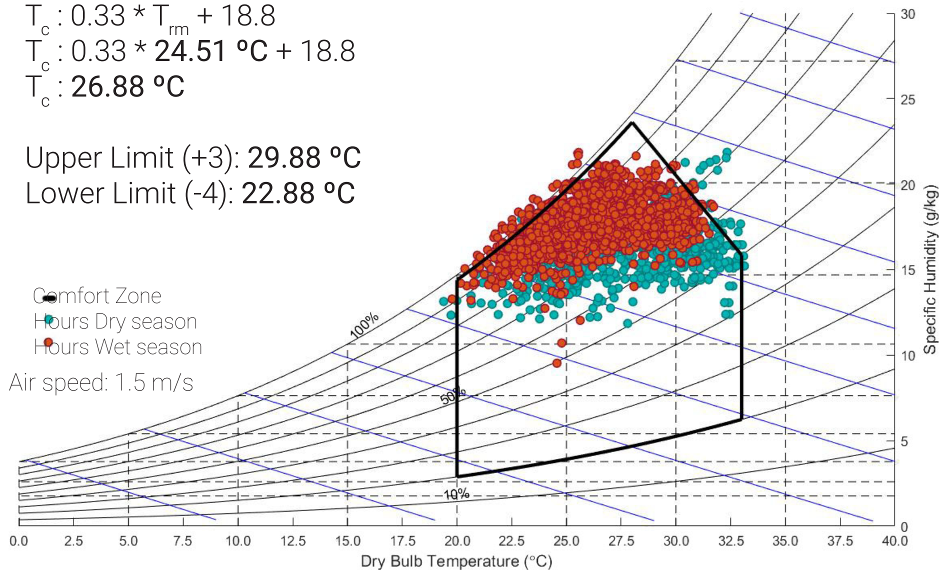


Fig 4.132 Givoni diagram/ Source: EnergyVER

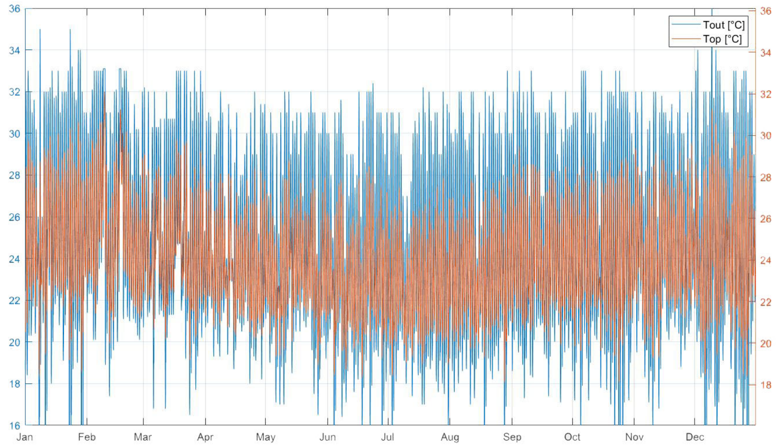


Fig 4.133 **Operative Temperature vs Outdoor Air Temperature Year**

T Outdoor Air Average: **24.55 °C**

T operative Average: **24.02 °C**

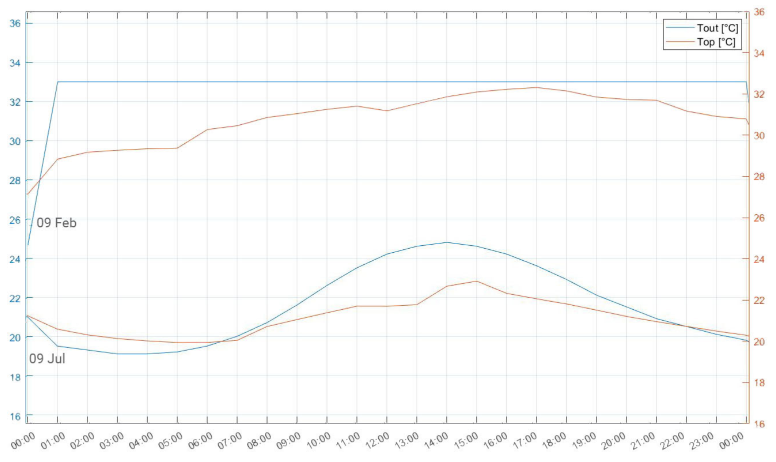


Fig 4.134 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**

WARMEST DAY
09 February

T Out Average: **33.1 ºC**
T op Average: **30.48 ºC**

COLDEST DAY
09 Jul

T Out Average: **21.65 ºC**
T op Average: **21.12 ºC**

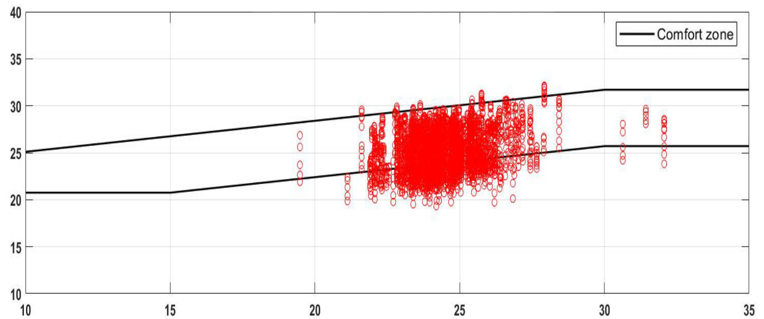


Fig 4.135 **Operative Temperature Vs Running Mean Temperature during occupied hours**

Average (ºC) of hours occupied year

Running mean Outside T: **24.51 ºC**

T Operative **25.52 ºC**

DAYLIGHT ANALYSIS
Administrative Office

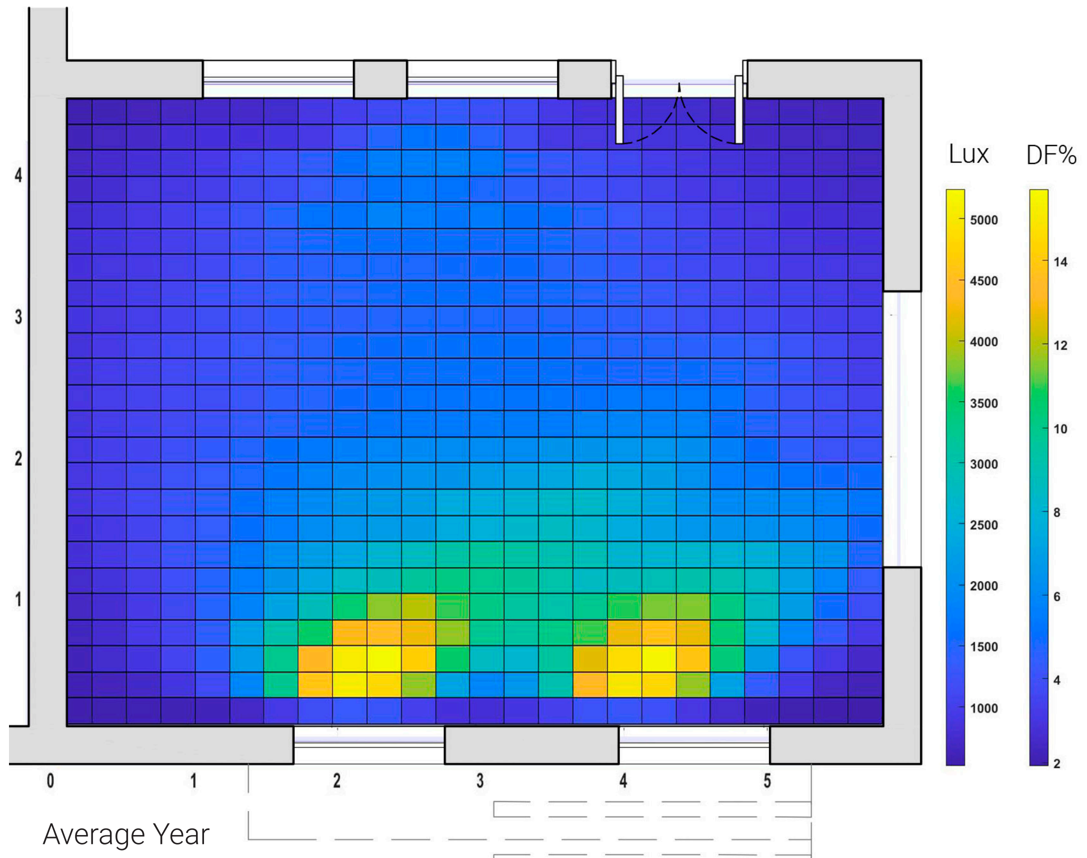
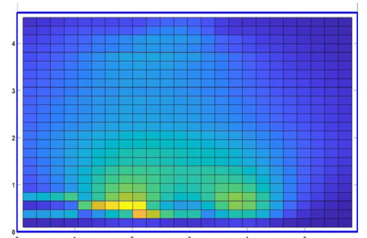
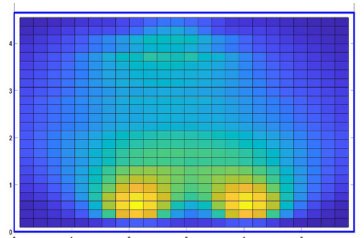


Fig 4.136 Illuminance plan/ Source: EnergyVER

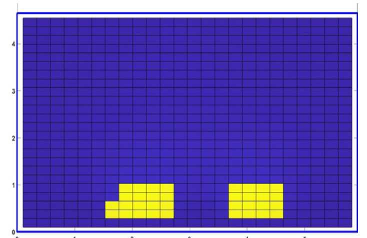
- Mean DAYLIGHT FACTOR (DF): **9.3 %**
  DF threshold level for Office : **1%**
  Room Area DF > 1%**: 100%**
- Mean DAYLIGHT AUTONOMY (DA): **95.97%**
  Room Area DA > 50%**: 100%**
- USEFUL DAYLIGHT ILLUMINANCE (uDI): **300 - 3000 Lux**
  Room Area UDI: **89% / 80%** (Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **0.3%** Glared area

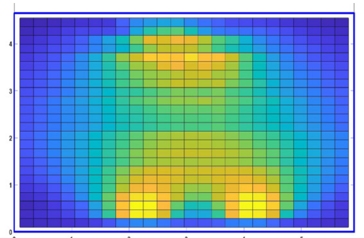
DRY SEASON	WET SEASON
21- December 08:00	21-June 08:00



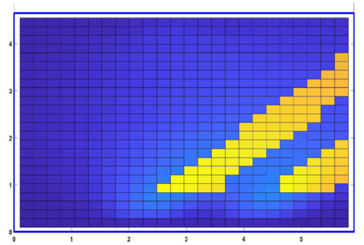


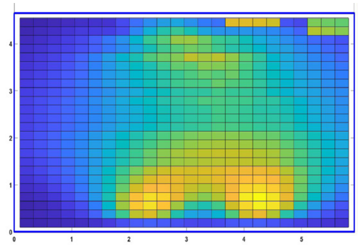
DRY SEASON	WET SEASON
Area DI < 300 lx: **0%** Area DI > 3000 lx: **0%**	Area DI < 300 lx: **39%** Area DI > 3000 lx: **0%**
21- December 13:00	21-June 13:00





DRY SEASON	WET SEASON
Area DI < 300 lx: **0%** Area DI > 3000 lx: **27.2%**	Area DI < 300 lx: **0%** Area DI > 3000 lx: **6.4%**
21- December 17:00	21-June 17:00





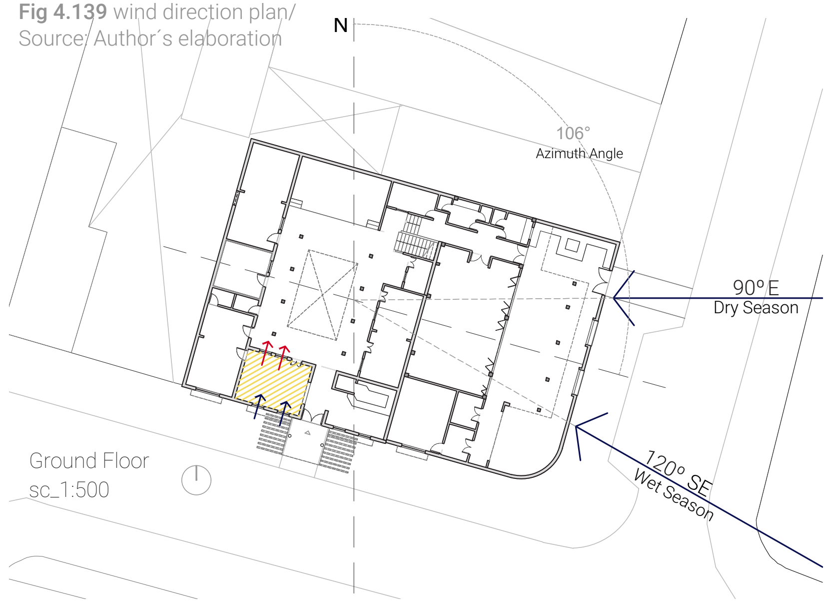
DRY SEASON	WET SEASON
Area DI < 300 lx: **0%** Area DI > 3000 lx: **37.9%**	Area DI < 300 lx: **0%** Area DI > 3000 lx: **0%**

Fig 4.137 Illuminance Hours plan Dry season / Source: EnergyVER

Fig 4.138 Illuminance Hours plan Dry season / Source: EnergyVER

AIRFLOW ANALYSIS
Administrative Office

Fig 4.139 wind direction plan/ Source: Author´s elaboration



Area Room: 22.41 m²

- Minimum Area Windows per room (A room/8): **2.80 m²**
- Area total Windows (Current state): **3.80 m²**

STACK VENTILATION

Calculation Current state: January

$$q_s\,[m^3/s] = C_d * A * \sqrt{2 * g * H * abs\left(\frac{T_z - T_e}{T}\right)}$$

$$q_s\,[m^3/s] = 0{,}6 * 2{,}35 * \sqrt{2 * 9.8 * 2{,}55 * abs\left(\frac{26{,}60 - 28{,}73}{27{,}67}\right)}$$

$$q_s\,[m^3/s] = 2{,}77$$

$$q_s\,[m^3/s] = 2{,}77 * 3600$$

$$q_{s,h}\,[m^3/h] = \mathbf{9957{,}36}$$

REQUIREMENTS

Table 4.35 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}IAQ(p)*}$ [m³/	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
60	36	5	0,33333	8

vol [m³]	$ACH_{r\text{-}IAQ}$ [1/h]
89,64	0,67

Table 4.36 **AIRFLOW RATE FOR COOLING**

	$q_{r\text{-}cool}$ [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]	vol [m³]	$ACH_{r\text{-}cool}$ [1/h]
JAN	189,83	133,59	0,28	1,18	26,60	28,73	89,64	2,12
FEB	207,74	133,16	0,28	1,18	27,07	29,01	89,64	2,32
MAR	189,20	123,15	0,28	1,18	25,96	27,93	89,64	2,11
APR	202,74	119,23	0,28	1,18	25,08	26,86	89,64	2,26
MAY	150,04	114,02	0,28	1,18	24,86	27,16	89,64	1,67
JUN	151,12	111,84	0,28	1,18	24,49	26,73	89,64	1,69
JUL	134,54	112,02	0,28	1,18	24,20	26,72	89,64	1,50
AUG	148,29	118,08	0,28	1,18	24,79	27,20	89,64	1,65
SEPT	195,31	123,25	0,28	1,18	25,69	27,60	89,64	2,18
OCT	182,75	132,23	0,28	1,18	25,61	27,80	89,64	2,04
NOV	248,64	130,62	0,28	1,18	25,91	27,50	89,64	2,77
DEC	187,41	134,36	0,28	1,18	26,13	28,30	89,64	2,09

Table 4.37 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	$q_{s,h}$ [m3/h]	q_{r}-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	9957,36	60	189,83
FEB	9439,12	60	207,74
MAR	9703,17	60	189,20
APR	9394,93	60	202,74
MAY	10671,21	60	150,04
JUN	10613,02	60	151,12
JUL	11289,92	60	134,54
AUG	10926,56	60	148,29
SEPT	9607,90	60	195,31
OCT	10276,51	60	182,75
NOV	8756,33	60	248,64
DEC	10133,17	60	187,41

$q_{r\text{-}IAQ(p)}$ **[m³/h]:** min. required airflow rate per person
ACH_{IAQ} **:** Air change per hour
$q_{r\text{-}cool}$ **[m³/h]:** min. required airflow rate for cooling
$\rho_{a;ref}$ **[kg/m³]:** Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ **[kg/m³]:** Air density at temperature exterior
$A_{w;tot}$**:** Area total of windows openings
C_{wind} **[1 m/s]:** Coefficient of wind speed
C_t **[m/s]:** Coefficient of wind turbulence
C_{st} **[m/s]:** Coefficient of stack effect
$u_{10;site}$ **[m/s]:** Wind at the zone level, at 10 m height
$h_{w;st}$ **[m]:** Useful height for stack effect for airing
$h_{w;fa}$ **[m]:** Free area height of the window "i"
$h_{w;path}$ **[m]:** Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i **[°C]:** day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air

H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS
Administrative Office

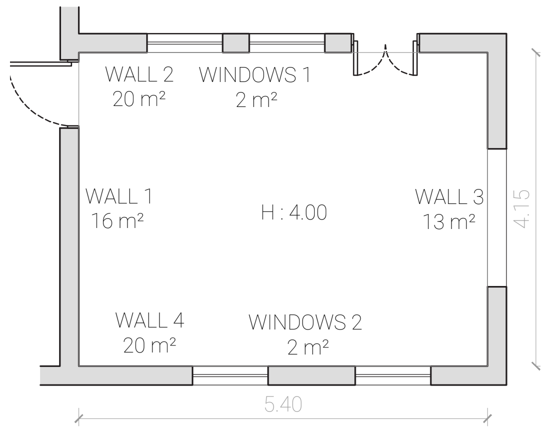


Fig 4.140 Acoustic plan/Source: EnergyVer simulation

Volume= 89.64 m³

Table 4.38 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4)	73	Concrete block painted	0,1	0,06	0,07
Ceiling	22	Expanded Polystyrene	0,05	0,4	0,35
Floor	22	Ceramic Clay Tile	0,01	0,01	0,01
Windows (1+2)	4	Single glass	0,35	0,18	0,12
Office furniture (5)			0,5	0,45	0,45
Adults seated (5)			0,33	0,44	0,42
Total Empty room			10,02	14,12	13,51
Total Occupied			14,17	18,57	17,86

REVERBERATION TIME		Empty Room	Occupied Room
T60 (125Hz):	$\frac{0.16x89.64\ m^3}{10.02}$	**1.43 s**	**1.01 s**
T60 (500Hz):	$\frac{0.16x89.64m^3}{14.12}$	**1.01 s**	**0.77 s**
T60 (1000Hz):	$\frac{0.16x89.64m^3}{13.51}$	**1.06 s**	**0.80 s**

OPTIMAL T60: 0.6s - 0.7s

CONCLUSIONS

According to the simulation of internal thermal comfort, the room has an average of almost similar Operative temperature over the Outdoor temperature: 25.52Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is within this limit with 2% year. The warmest day shows a maximum temperature of 30.48Cº/33.1Cº on 9 February, and the minimum temperature of 21.12 Cº/21.65 Cº in 9 June. A small percentage of the occupied hours (18%), has an Operative temperature over 28 Cº and just 2% over 30Cº. But more than the half of hours (75%),the room has a Relative humidity over 70%, causing discomfort in the room.

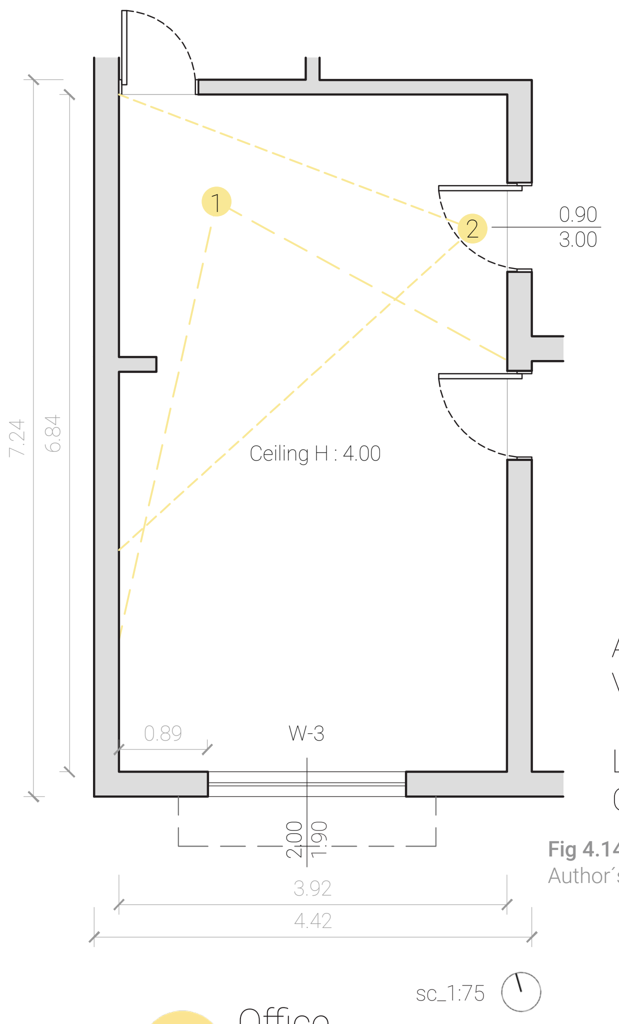
Based on a minimum daylight factor of 1% for office of school daylighting, 100% of the room area achieves the threshold with a high DF of 9.3%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room achieves the minimum level, 89%/80%, indicating it is well illuminated by daylighting. There is a glared area, mainly in Dry season at 13:00 and 17:00 with maximum 37.9%.
In general, the room has good daylighting in the occupied hours, but the glared hours causes discomfort.

According to the Italian decree DM 05-07-75, the minimum area of windows of this room should be 2.80 m². The existing windows area is up to the minimum required with 3.80m². With a stack ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 60m3/h (5 people). The current airflow also meets the requirements for cooling in any month of the year.
The room has a long reverberation time when is totally occupied and empty for all frecuencies, over to the T60 optimal required, 0.6s -0.7s, for its function as offices. For medium and high frecuencies (500Hz-1000Hz), the T60 almost reaches the Optimal value. But, since the room is an office where people should speak, the time of reverberation has to be shorter to reach the Optimal value.

MANAGER OFFICE

ROOM ANALYSIS

Fig 4.141 Axonometry "A.Office" location/ Source: Author´s elaboration



Area= 26.81 m²
Volume= 107.24 m³

Level 0.00
Ground Floor

Fig 4.142 "A.Office" plan/ Source: Author´s elaboration

Office

_Manager Office
_Meeting Room

1 Person (Regularly)
5 People (Average capacity)

Fig 4.143 "A.Office" photos/ Source: Author´s photos

THERMAL COMFORT ANALYSIS
Manager Office

- **Total** Occupation Hours/Year: **2492**
- Average Indoor Relative Humidity (Occupation Hours): 77%

- Occupied hours where Relative Humidity > 70%: 2037 (81% year)

- Occupied hours where Operative Temperature > T limit (28ºC): 133 (5% year)
- Occupied hours where Operative Temperature > T limit (30ºC): 11 (0.4% year)
- Occupied hours where Operative Temperature <T limit (21ºC): 58(2% year)

- Overheating hours (EN class 2): 6 (0.2% year)

- Optimal Operative Temperature (Adaptive EN class 2)

T_c : 0.33 * T_{rm} + 18.8
T_c : 0.33 * 24.51 ºC + 18.8
T_c : 26.88 ºC

Upper Limit (+3): 29.88 ºC
Lower Limit (-4): 22.88 ºC

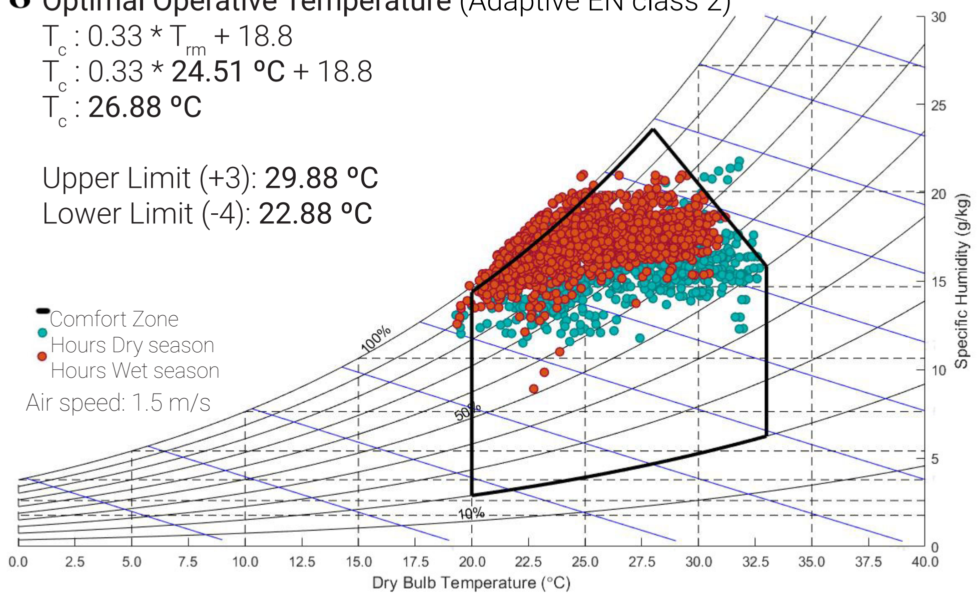
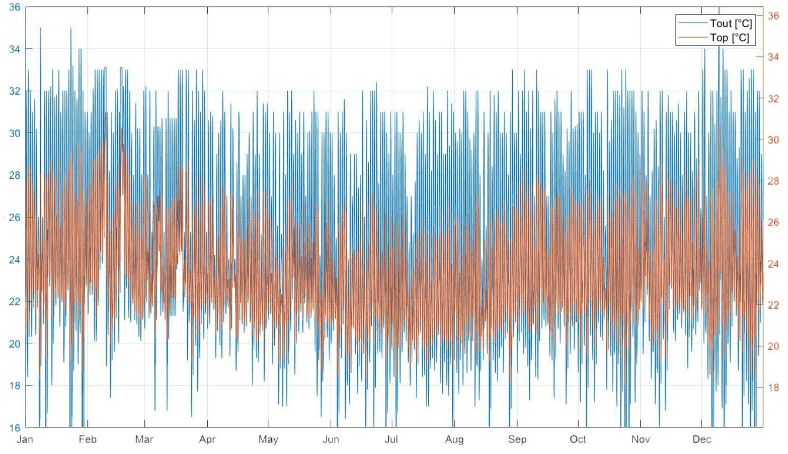


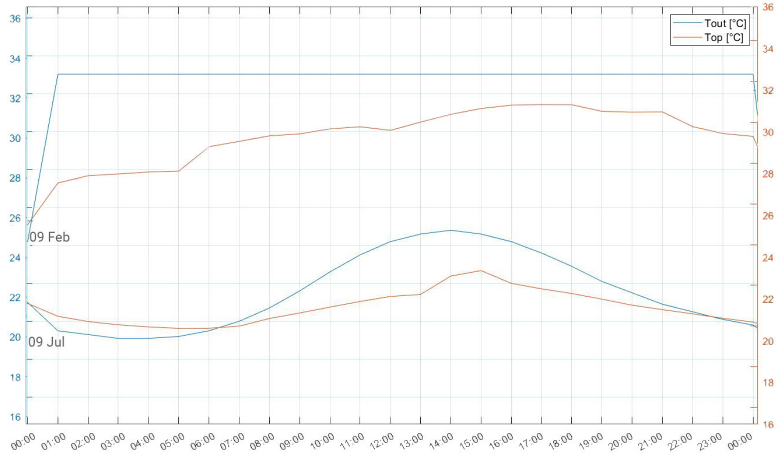
Fig 4.144 Givoni diagram/ Source: EnergyVER



T Outdoor Air Average year: **24.55 ºC**

T operative Average year: **23.45 ºC**

Fig 4.145 **Operative Temperature vs Outdoor Air Temperature Year**



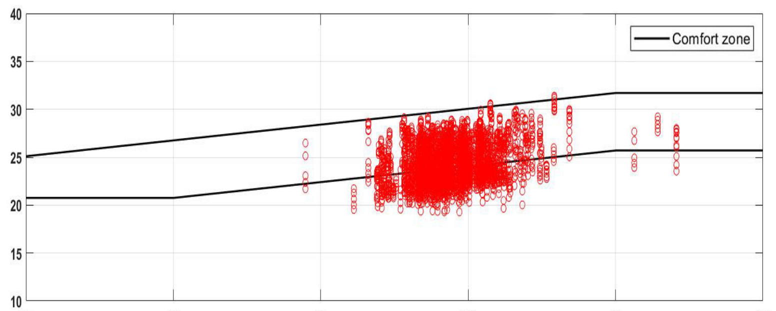
WARMEST DAY
09 February

T Out Average: **33.1 ºC**
T op Average: **29.9 ºC**

COLDEST DAY
09 Jul

T Out Average: **21.65 ºC**
T op Average: **20.93 ºC**

Fig 4.146 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**



Average (ºC) of occupied hours year

Running mean Outside T: **24.51 ºC**

T Operative **24.24 ºC**

Fig 4.147 **Operative Temperature Vs Running Mean Temperature during occupied hours**

DAYLIGHT ANALYSIS
Manager Office

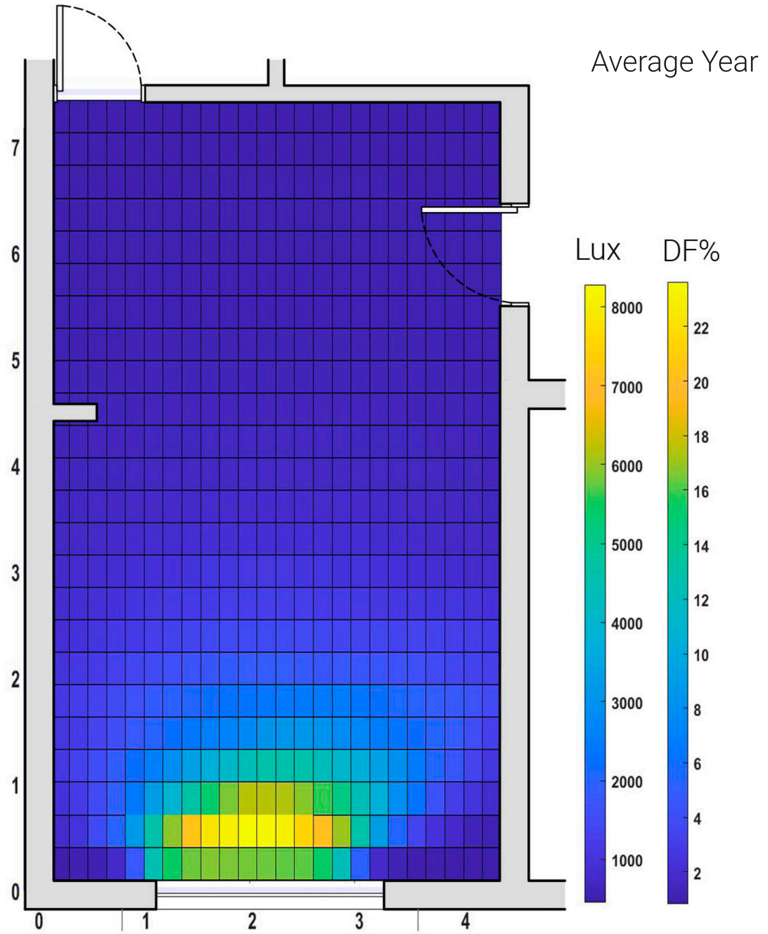


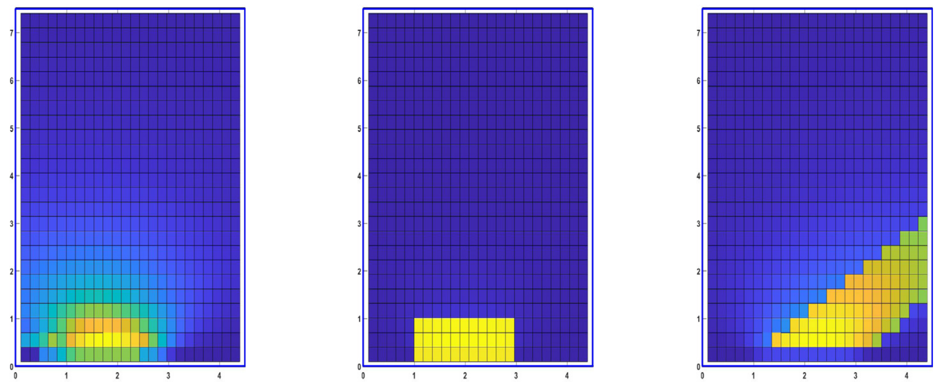
Fig 4.148 Illuminance plan/ Source: EnergyVER

- Mean DAYLIGHT FACTOR (DF): 3.78 %
  DF threshold level for Office : 1%
  Room Area DF > 1%: **86%**
- Mean DAYLIGHT AUTONOMY (DA): 85.5%
  Room Area DA > 50%: **100%**
- USEFUL DAYLIGHT ILLUMINANCE (uDI): 300 - 3000 Lux
  Room Area UDI: **93% / 80%** (Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **8%** Glared area

Fig 4.149 Illuminance Hours plan Dry season / Source: EnergyVER

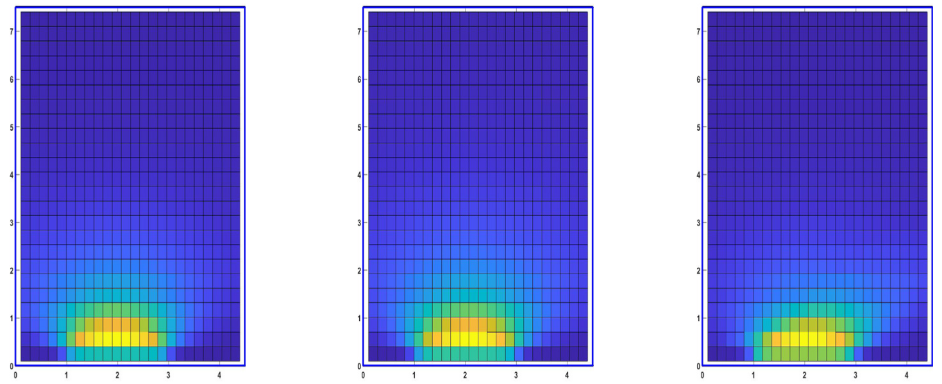
Fig 4.150 Illuminance Hours plan Dry season / Source: EnergyVER

DRY SEASON



21- December 08:00	21- December 13:00	21- December 17:00
Area DI < 300 lx:**36%**	Area DI < 300 lx: **0%**	Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0%**	Area DI > 3000 lx: **12.6%**	Area DI > 3000 lx:**19.2%**

WET SEASON

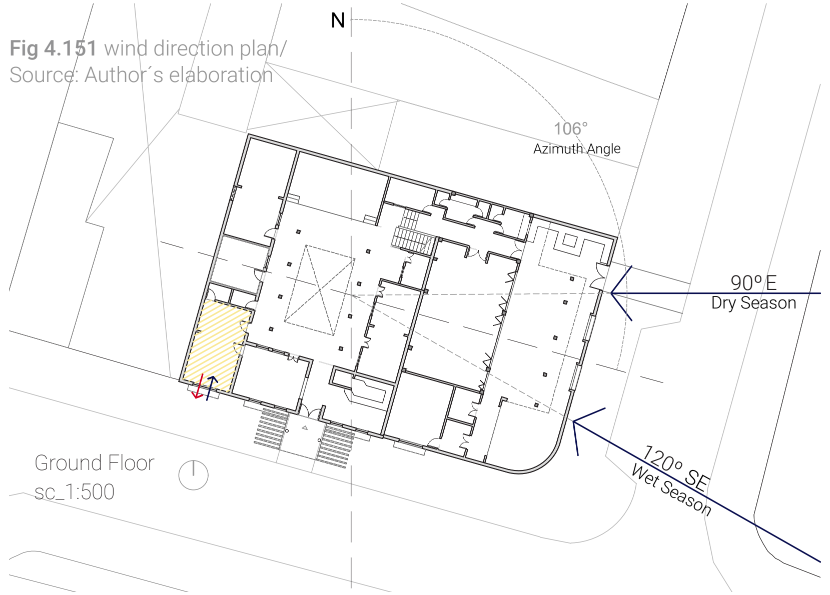


21-June 08:00	21-June 13:00	21-June 17:00
Area DI < 300 lx:**81%**	Area DI < 300 lx: **0%**	Area DI < 300 lx: **0.8%**
Area DI > 3000 lx: **0%**	Area DI > 3000 lx: **3.8%**	Area DI > 3000 lx: **1.4%**

AIRFLOW ANALYSIS

Manager Office

Fig 4.151 wind direction plan/ Source: Author´s elaboration



Area Room: 26.81 m²

- Minimum Area Windows per room (A room/8): **3.35 m²**
- Area total Windows (Current state): **3.8 m²**

SINGLE SIDED VENTILATION CALCULATION

Calculation Current state: January

$$qv\,[m3/h] = 3600 \ast \frac{\rho_{a;ref}}{\rho_{a;e}} \ast \frac{Aw_{;tot}}{2} \ast \max\left(C_{wind} \ast U_{10;site}^{2} ; C_{st} \ast h_{w;st} \ast abs(T_z - T_e)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 \ast \frac{1,23}{1,18} \ast \frac{2,97}{2} \ast \max\left(0,001 \ast 0,56^{2} ; 0,0035 \ast 1,5 \ast abs(27,12-28,7)\right)^{0,5}$$

$$qv\,[m3/h] = 3600 \ast 1,04 \ast 1,485 \ast \max(0,00056 ; 0,000845)^{0,5}$$

$$qv\,[m3/h] = 3600 \ast 1,04 \ast 1,485 \ast 0,000845^{0,5}$$

$$qv\,[m3/h] = \mathbf{512,32}$$

REQUIREMENTS

Table 4.39 **AIRFLOW RATE FOR IAQ (Indoor Air Quality)**_Day average required hourly

q_{r-IAQ} [m³/h]	$q_{r-IAQ(p)*}$ [m³/h]	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
12	36	1	0,33333	8

vol [m³]	ACH_{r-IAQ} [1/h]
107,24	0,11

q_{r-IAQ} [m³/h]	$q_{r-IAQ(p)*}$ [m³/h]	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
60	36	5	0,33333	8

vol [m³]	ACH_{r-IAQ} [1/h]
107,24	0,56

Table 4.40 **AIRFLOW RATE FOR COOLING**

	q_{r-cool} [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]	vol [m³]	ACH_{r-cool} [1/h]
JAN	348,30	185,28	0,28	1,18	27,12	28,73	107,24	3,25
FEB	409,54	171,84	0,28	1,18	27,74	29,01	107,24	3,82
MAR	280,94	150,37	0,28	1,18	26,31	27,93	107,24	2,62
APR	332,24	147,10	0,28	1,18	25,52	26,86	107,24	3,10
MAY	193,39	139,93	0,28	1,18	24,97	27,16	107,24	1,80
JUN	203,18	136,94	0,28	1,18	24,69	26,73	107,24	1,89
JUL	180,53	137,19	0,28	1,18	24,42	26,72	107,24	1,68
AUG	202,01	145,50	0,28	1,18	25,02	27,20	107,24	1,88
SEPT	354,52	149,93	0,28	1,18	26,32	27,60	107,24	3,31
OCT	285,38	170,66	0,28	1,18	25,99	27,80	107,24	2,66
NOV	447,69	177,50	0,28	1,18	26,30	27,50	107,24	4,17
DEC	308,18	187,35	0,28	1,18	26,46	28,30	107,24	2,87

Table 4.41 **CURRENT AIRFLOW VS REQUIRED**

	Current state	Requirements	
	q_v-IAQ [m³/h]	q_r-IAQ [m³/h]	q_{r-cool} [m³/h]
JAN	512,32	60	348,3
FEB	455,02	60	409,54
MAR	513,91	60	280,94
APR	467,40	60	332,24
MAY	597,52	60	193,39
JUN	576,70	60	203,18
JUL	612,34	60	180,53
AUG	596,16	60	202,01
SEPT	456,81	60	354,52
OCT	543,21	60	285,38
NOV	442,31	60	447,69
DEC	547,70	60	308,18

$q_{r-IAQ(p)}$ [m³/h]: min. required airflow rate per person
ACH_{IAQ} : Air change per hour
q_{r-cool} [m³/h]: min. required airflow rate for cooling
$\rho_{a;ref}$ [kg/m³]: Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ [kg/m³]: Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} [1 m/s]: Coefficient of wind speed
C_t [m/s]: Coefficient of wind turbulence
C_{st} [m/s]: Coefficient of stack effect
$u_{10;site}$ [m/s]: Wind at the zone level, at 10 m height
$h_{w;st}$ [m]: Useful height for stack effect for airing
$h_{w;fa}$ [m]: Free area height of the window "i"
$h_{w;path}$ [m]: Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i [°C]: day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air
H [W]: day-averaged hourly heat gain in a space

ACOUSTIC ANALYSIS

Manager Office

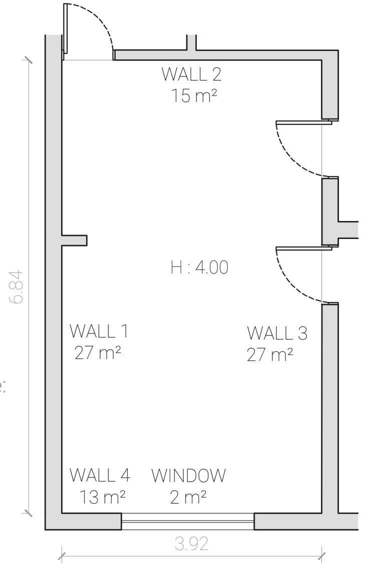


Fig 4.152 Acoustic plan/Source: EnergyVer simulation

Volume= 107.24 m³

Table 4.42 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+3+4)	82	Concrete block painted	0,1	0,06	0,07
Ceiling	27	Expanded Polystyrene	0,05	0,4	0,35
Floor	27	Ceramic Clay Tile	0,01	0,01	0,01
Windows	2	Single glass	0,35	0,18	0,12
Office furniture (1)			0,5	0,45	0,45
Adults seated (1)			0,33	0,44	0,42
Total Empty room			10,52	16,35	15,7
Total Occupied			14,67	20,8	20,05

REVERBERATION TIME		Empty Room	Occupied Room
T60 (125Hz):	$\frac{0.16x107.24\ m^3}{10.52}$	**1.63 s**	**1.16 s**
T60 (500Hz):	$\frac{0.16x107.24\ m^3}{16.35}$	**1.04 s**	**1.04 s**
T60(1000Hz):	$\frac{0.16x107.24\ m^3}{15.7}$	**1.09 s**	**0.85 s**

OPTIMAL T60: 0.6s - 0.7s

CONCLUSIONS

According to the simulation of internal thermal comfort, the room has an average of almost similar Operative temperature over the Outdoor temperature: 24.24Cº/24.51Cº. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the current value is within this limit with 0.2% year. The warmest day shows a maximum temperature of 29.9Cº/33.1Cº on 9 February, and the minimum temperature of 20.93 Cº/21.65 Cº in 9 June. A small percentage of the occupied hours (5%), has an Operative temperature over 28 Cº and just 0.4% over 30Cº. But more than the half of hours (81%),the room has a high Relative humidity over 70%, causing discomfort in the room.

Based on a minimum daylight factor of 1% for office of school daylighting, 86% of the room area achieves the threshold with a high DF of 3.78%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room achieves the minimum level, 93%/80%, indicating it is well illuminated by daylighting. There is a small glared area of 8% year, mainly in Dry season at 13:00 and 17:00. But, in the morning there is insufficient illuminance at 8:00, with 36% of room area for Dry season and 81% for Wet season.

According to the Italian decree DM 05-07-75, European standards* the minimum area of windows of this room should be 3.35 m². The existing windows area is up to the minimum required with 3.8m². With a single sided ventilation, the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 12m3/h or 60m3/h (5 people). The current airflow also meets the requirements for cooling in any month of the year.

The room has a long reverberation time when is totally occupied and empty for all frecuencies (125Hz-500Hz-1000Hz), over to the T60 optimal required, 0.6s -0.7s, for its function as office. Since the room is an office for the manager, the simulation has been calculating for 1 person. Considering more people, for eventual meetings could lower the T60. However, the time of reverberation has to be shorter to reach the Optimal value.

4.11 CONCLUSIONS OF SELECTED ROOMS ANALYSIS

The following table shows a quantitative summary of the results from the analysis of the current situation of each room. The general conclusions of the rooms for each category, Thermal Comfrot, Daylighting, Airflow (natural ventilation) and Acoustic comfort will be explained below this table

Table 4.43 numeric anaylsis results

	ROOMS	THERMAL COMFORT	DAYLIGHTING	AIRFLOW	ACOUSTIC COMFORT
Music Classroom	Arrendajo	_ Occupied hours T Operative / T mean outside: 27,87 Cº / 24,51 ºC _Adaptive Comfort Limits 22.88ºC< 27,87 ºC <29.88 ºC. _Warmest day(9 feb):33,26Cº/33,1ºC _Coldest day(9 jul): 22,51Cº/21,65 ºC _Occupied hours T op >28 Cº: 1484/3020 hours year (49%) _T op<21 Cº: 10/3020 (0,3%) _ RH >70 %: 1710/3020 (56%). _Overheating hours :767/3020 (25%)	_DF: 3,95% / 3% Threshold _Area DF > 3%: 40% _DA: 87% _Area DA > 50%: 100% _Area UDI (300-3000 Lx): 91% / 80% _Area DI < 300 lx: 0% _Glared Area DI > 3000 lx: 8.8% _Critical Hour/day Area DI < 3000 lx: 81% 21 Jun 8:00 h Wet season _Critical Hour/day Area DI > 3000 lx: 17.2% 21 Dic 13:00 h Dry season	_Area windows/Required: 3.3m^2 /3.39m^2 _q_r-IAQ: 157,5 [m3/h] _ACH$_{r\text{-}IAQ}$: 1.66 Current airflow Single sided Vent. _Current q_v-IAQ /qr-IAQ [m3/h] 91/100 % Total months year (All except July) _Current q_v-IAQ /$q_{r\text{-}cool}$ [m3/h] 0/100 % Total months year	Empty room: _T60 (125Hz): 1.45s/ 0,8s-0,9s (T60 optimal) _T60 (500Hz): 0,8s/ 0,8s-0,9s _T60 (1000Hz): 0,86s/ 0,8s-0,9s Occupied room: _T60 (125Hz): 0,94s/ 0,8s-0,9s _T60 (500Hz): 0,44s/ 0,8s-0,9s _T60 (1000Hz): 0,46s/ 0,8s-0,9s
	Corocora	_ Occupied hours T Operative / T mean outside : 28,53 Cº / 24,51 ºC _Adaptive Comfort Limits 22.88ºC< 28,53 ºC <29.88 ºC _Warmest day(9 feb):33,20Cº/33,1ºC _Coldest day(9 jul):22,91 Cº/21,65ºC _Occupied hours T op >28 ºC: 1774/3020 hours year (58%) _T op<21 ºC: 9/3020 (0,3%) _ RH >70 %: 1487/3020 (49%). _Overheating hours :937/3020 (31%)	_DF: 5,01% / 3% Threshold _Area DF > 3%: 48,5% _DA: 88,29% _Area DA > 50%: 100% _Area UDI (300-3000 Lx):85% / 80% _Area DI < 300 lx: 0% _Glared Area DI > 3000 lx: 14,1% _Critical Hour/day Area DI < 300 lx: 53% 21 Jun 8:00 h Wet season _Critical Hour/day Area DI > 3000 lx: 21,4% 21 Dic 08:00 h Dry season	_Area windows/Required: 3,3m^2 /2,79m^2 _q_r-IAQ: 157,5 [m3/h] _ACH$_{r\text{-}IAQ}$: 1.66 Current airflow Single sided Vent. _Current q_v-IAQ /qr-IAQ [m3/h] 83/100 % Total months year (All except July and Sept) _Current q_v-IAQ /$q_{r\text{-}cool}$ [m3/h] 0/100 % Total months year	Empty room: _T60 (125Hz): 1.34s/ 0,8s-0,9s (T60 optimal) _T60 (500Hz): 0,79s/ 0,8s-0,9s _T60 (1000Hz): 0,84s/ 0,8s-0,9s Occupied room: _T60 (125Hz): 0,84s/ 0,8s-0,9s _T60 (500Hz): 0,40s/ 0,8s-0,9s _T60 (1000Hz): 0,42s/ 0,8s-0,9s

T op Operative Temperature, **T Out** Outdoor temperature, **RH** Relative Humidity, **DF** Daylight Factor, **DA** Daylight Autonomy, **UDI** Useful Daylight Illuminance, **T60** Reverberation Time

	ROOMS	THERMAL COMFORT	DAYLIGHTING	AIRFLOW	ACOUSTIC COMFORT
Music Classroom	Macundal	_ Occupied hours T Operative / T mean outside : 25,15 Cº / 24,51 ºC _Adaptive Comfort Limits 22.88ºC< 25,15 ºC <29.88 ºC. _Warmest day(9 feb):30,18ºC/33,1ºC _Coldest day(9 jul): 21,09 ºC/21,65ºC _Occupied hours T op >28 ºC: 337/3020 hours year (11%) _T op<21 ºC: 41/3020 (1%) _ RH >70 %: 2378/3020 (78%). _Overheating hours :21/3020 (0,6%)	_DF: 5,12% / 3% Threshold _Area DF > 3%: 54% _DA: 91,18% _Area DA > 50%: 100% _Area UDI (300-3000 Lx):88% / 80% _Area DI < 300 lx: 0% _Glared Area DI > 3000 lx: 10,9% _Critical Hour/day Area DI < 300 lx: 72% 21 Jun 8:00 h Wet season _Critical Hour/day Area DI > 3000 lx: 30,2% 21 Dic 17:00 h Dry season	_Area windows/Required: 3,8m^2 /2,8m^2 _q_r-IAQ: 52,5 [m3/h] _ACH$_{r\text{-}IAQ}$: 0,69 Single sided Ventilation: _Current q_v-IAQ /qr-IAQ [m3/h] 100/100 % Total months year _Current q_v-IAQ /$q_{r\text{-}cool}$ [m3/h] 33/100 % Total months year (From May to Aug)	Empty room: _T60 (125Hz): 1.45s/ 0,8s-0,9s (T60 optimal) _T60 (500Hz): 0,8s/ 0,8s-0,9s _T60 (1000Hz): 0,85s/ 0,8s-0,9s Occupied room: _T60 (125Hz): 1,21s/ 0,8s-0,9s _T60 (500Hz): 0,61s/ 0,8s-0,9s _T60 (1000Hz): 0,64s/ 0,8s-0,9s
	Paraulata	_ Occupied hours T Operative / T mean outside : 25,18 ºC / 24,51 ºC _Adaptive Comfort Limits 22.88ºC< 25,18 ºC <29.88 ºC _Warmest day(9 feb):29,50ºC/33,1ºC _Coldest day(9 jul): 21,12 ºC/21,65ºC _Occupied hours T op >28 ºC: 174/3020 hours year (5%) _T op<21 ºC: 20/3020 (0,6%) _ RH >70 %: 2678/3020 (88%). _Overheating hours :6/3020 (0,1%)	_DF: 0,96% / 3% Threshold _Area DF > 3%: 37,85% _DA: 87% _Area DA > 50%: 19,2% _Area UDI (300-3000 Lx):46% / 80% _Area DI < 300 lx: 54% _Glared Area DI > 3000 lx: 0% _Critical Hour/day Area DI < 300 lx: 100% 21 Dic/Jun 8:00 h _Critical Hour/day Area DI > 3000 lx: 0%	_Area windows/Required: 1,2m^2 /3,99m^2 _q_r-IAQ: 157,5 [m3/h] _ACH$_{r\text{-}IAQ}$: 0,99 Current airflow Single sided Vent. _Current qv-IAQ /qr-IAQ [m3/h] 0/100 % Total months year _Current qv-IAQ /qr-cool [m3/h] 0/100 % Total months year (All except Feb)	Empty room: _T60 (125Hz): 2,77s/ 0,8s-0,9s (T60 optimal) _T60 (500Hz): 1,53s/ 0,8s-0,9s _T60 (1000Hz): 1,63s/ 0,8s-0,9s Occupied room: _T60 (125Hz): 1,73s/ 0,8s-0,9s _T60 (500Hz): 0,80s/ 0,8s-0,9s _T60 (1000Hz): 0,83s/ 0,8s-0,9s
	Orchestra	_ Occupied hours T Operative / T mean outside : 26,75ºC / 24,51 ºC _Adaptive Comfort Limits 22.88ºC< 26,75 ºC <29.88 ºC _Warmest day(9 feb):30,52ºC/33,1ºC _Coldest day(9 jul): 21,12 ºC/21,65ºC _Occupied hours T op >28 ºC: 1093/3020 hours year (36%) _T op<21 ºC: 21/3020 (0,6%) _ RH >70 %: 1803/3020 (59%). _Overheating hours :250/3020 (8%)	_DF: 8,6% / 3% Threshold _Area DF > 3%: 92% _DA: 89,32% _Area DA > 50%: 100% _Area UDI (300-3000 Lx):99% / 80% _Area DI < 300 lx: 0% _Glared Area DI > 3000 lx: 0% _Critical Hour/day Area DI < 300 lx:0% _Critical Hour/day Area DI > 3000 lx: 8,3% 21 Dic 8:00 h Dry season	_Area windows/Required: 25,75m^2 /9,47m^2 _q_r-IAQ: 420 [m3/h] _ACH$_{r\text{-}IAQ}$: 2,05 Current airflow Single sided Vent. _Current q_v-IAQ /qr-IAQ [m3/h] 100/100 % Total months year _Current q_v-IAQ /$q_{r\text{-}cool}$ [m3/h] 91/100 % Total months year (All except Feb)	Empty room: _T60 (125Hz): 2,41s/ 0,8s-0,9s (T60 optimal) _T60 (500Hz): 0,91s/ 0,8s-0,9s _T60 (1000Hz): 0,99s/ 0,8s-0,9s Occupied room: _T60 (125Hz): 1,15s/ 0,8s-0,9s _T60 (500Hz): 0,43s/ 0,8s-0,9s _T60 (1000Hz): 0,44s/ 0,8s-0,9s

T op Operative Temperature, **T Out** Outdoor temperature, **RH** Relative Humidity, **DF** Daylight Factor, **DA** Daylight Autonomy, **UDI** Useful Daylight Illuminance, **T60** Reverberation Time

	ROOMS	THERMAL COMFORT	DAYLIGHTING	AIRFLOW	ACOUSTIC COMFORT
Common Area	Scenario/ Lobby	_ Occupied hours T Operative / T mean outside : **28,31 ºC / 24,51 ºC** _Adaptive Comfort Limits 22.88ºC**<** **28,31 ºC** <29.88 ºC _Warmest day(9 feb):**31,16ºC/33,1ºC** _Coldest day(9 jul): **20,72 ºC/21,65ºC** _Occupied hours T op >28 ºC: **1732/3375** hours year **(51%)** _T op<21 ºC: **36/3375 (1%)** _ RH >70 %: **2092/3375 (61%)**. _Overheating h:**1343/3375 (39%)**	_DF: **19,21% / 2%** Threshold _Area DF > 2%: **100%** _DA: **96,07%** _Area DA > 50%: **100%** _Area UDI (300-3000 Lx): **62% / 80%** _Area DI < 300 lx: **0%** _Glared Area DI > 3000 lx: **44,5%** _Critical Hour/day Area DI < 300 lx: **22%** **21 Jun 8:00 h Wet season** _Critical Hour/day Area DI > 3000 lx: **100% 21 Dic/ Jun 13:00 h**	_Area windows/Required: **27,06m^2** **/17,81m^2** _q_r-IAQ: **787,5 [m3/h]** _$ACH_{r\text{-}IAQ}$: **1,43** **Current airflow**_Stack Ventilation: _Current $q_{s,h}$-IAQ /qr-IAQ [m3/h] **100/100 %** Total months year _Current $q_{s,h}$-IAQ /qr-cool [m3/h] **91/100 %** Total months year (All except Jul)	**Empty room**: _T60 (125Hz): **2,46s/ 1,2s-1,4s** (T60 optimal) _T60 (500Hz): **1,38s/ 1,2s-1,4s** _T60 (1000Hz): **1,51s/ 1,2s-1,4s** **Occupied room**: _T60 (125Hz): **1,47s/ 1,2s-1,4s** _T60 (500Hz): **0,83s/ 1,2s-1,4s** _T60 (1000Hz): **0,88s/ 1,2s-1,4s**
Administrative area	Administrative Office	_ Occupied hours T Operative / T mean outside : **25,52ºC / 24,51 ºC** _Adaptive Comfort Limits 22.88ºC**<** **25,52 ºC** <29.88 ºC _Warmest day(9 feb):**30,48Cº/33,1ºC** _Coldest day: **21,12 ºC / 21,65 ºC** _Occupied hours T op >28 ºC: **450/2492** hours year **(18%)** _T op<21 ºC: **21/2492 (0,8%)** _ RH >70 %: **2091/2492 (61%)**. _Overheating hours:**53/2492 (2%)**	_DF: **9,3% / 1%** Threshold _Area DF > 1%: **100%** _DA: **95,97%** _Area DA > 50%: **100%** _Area UDI (300-3000 Lx): **89% / 80%** _Area DI < 300 lx: **0%** _Glared Area DI > 3000 lx: **0,3%** _Critical Hour/day Area DI < 300 lx: **39%** **21 Jun 8:00 h Wet season** _Critical Hour/day Area DI > 3000 lx: **37,9% 21 Dic 17:00 h Dry season**	_Area windows/Required: **3,80m^2** **/2,80m^2** _q_r-IAQ: **60 [m3/h]** _$ACH_{r\text{-}IAQ}$: **0,80** **Current airflow** Stack Ventilation: _Current qs,h-IAQ /qr-IAQ [m3/h] **100/100 %** Total months year _Current qs,h-IAQ /qr-cool [m3/h] **100/100 %** Total months year	**Empty room**: _T60 (125Hz): **1,43s/ 0,6s-0,7s** (T60 optimal) _T60 (500Hz): **1,38s/ 0,6s-0,7s** _T60 (1000Hz): **1,51s/ 0,6s-0,7s** **Occupied room**: _T60 (125Hz): **1,47s/ 0,6s-0,7s** _T60 (500Hz): **0,83s/ 0,6s-0,7s** _T60 (1000Hz): **0,88s/ 0,6s-0,7s**
	Manager Office	_ Occupied hours T Operative / T mean outside : **24,24 ºC / 24,51 ºC** _Adaptive Comfort Limits 22.88ºC**<** **24,24 ºC** <29.88 ºC _Warmest day(9 feb):**29,9 ºC/33,1ºC** _Coldest day(9 jun):**20,93ºC/21,65ºC** _Occupied hours T op >28 ºC: **133/2492** hours year **(5%)** _T op<21 ºC: **58/2492 (2%)** _ RH >70 %: **2037/2492 (81%)**. _Overheating hours:**6/3020 (1%)**	_DF: **3,78% / 1%** Threshold _Area DF > 1%: **86%** _DA: **85,5%** _Area DA > 50%: **100%** _Area UDI (300-3000 Lx): **93% / 80%** _Area DI < 300 lx: **0%** _Glared Area DI > 3000 lx: **8%** _Critical Hour/day Area DI < 300 lx: **81%** **21 Jun 8:00 h Wet season** _Critical Hour/day Area DI > 3000 lx: **19,29% 21 Dic 17:00 h Dry season**	_Area windows/Required: **3,8m^2** **/3,35m^2** _q_r-IAQ (1 / 5 people): **12 / 60 [m3/h]** _$ACH_{r\text{-}IAQ}$ (1 / 5 people): **0,11/0.56** **Current airflow** Single sided Vent. _Current q_v-IAQ /qr-IAQ [m3/h] **100/100 %** Total months year _Current qr-coo **100/100 %** Total months year	**Empty room**: _T60 (125Hz): **1,63s/ 0,6s-0,7s** (T60 optimal) _T60 (500Hz): **1,04s/ 0,6s-0,7s** _T60 (1000Hz): **1,09s/ 0,6s-0,7s** **Occupied room**: _T60 (125Hz): **1,16s/ 0,6s-0,7s** _T60 (500Hz): **1,04s/ 0,6s-0,7s** _T60 (1000Hz): **0,85s/ 0,6s-0,7s**

T op Operative Temperature, **T Out** Outdoor temperature, **RH** Relative Humidity, **DF** Daylight Factor, **DA** Daylight Autonomy, **UDI** Useful Daylight Illuminance, **T60** Reverberation Time

THERMAL COMFORT CONCLUSIONS

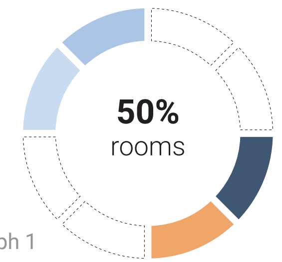
The following graphs are an overall result of the evaluation of the thermal comfort done to the 8 selected rooms. Some of the data includes average operative temperatures, relative humidity, overheating hours, among others. With these results it is possible to conclude:

Graph 1: Following the standard EN 16798 with a level of expectation Class 2, the results show that 50% the rooms have overheating hours that exceeds 5% of occupied hours without the limits of Adaptive comfort. According to the formula for adaptive comfort applied, the limits of acceptable temperature are between 22,881C and maximum 29.88ºC taking into account an average of Running mean Outside Temperature of 24.51ºC. The overheated rooms are "Arrendajo" ,"Corocora" classrooms in the first floor, and the Orchestra classroom and Scenario /Lobby room in ground floor.

Graph 2: 75% rooms have Operative temperatures over 28ºC of more than 5% of the occupied hours.

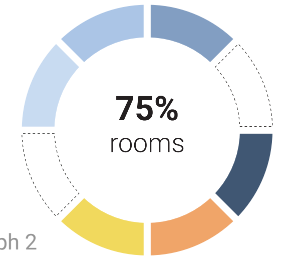
Graph 3 and 4: The room with the highest operative temperature the warmest day analyzed, that is February 9, is "Arrendajo" classroom located in the first floor with 33.26ºC.

Graph 4: On the contrary, the coldest day, that is July 9, the room with the lowest operative temperature is the Scenario/Lobby.



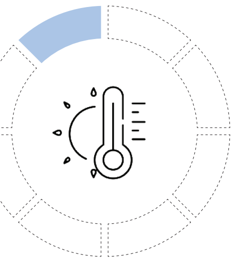
Graph 1

Overheating hours > 5% occupied hours Adaptive comfort En class 2 limits (22,88°C < x < 29,88°C)



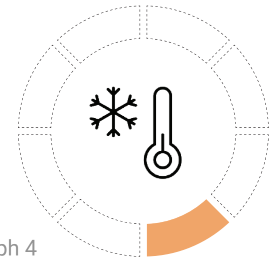
Graph 2

T_{op} > 28°C = More than 5% occupied hours



Graph 3

Warmest day
Highest Temp.
T_{op} vs T_{out}



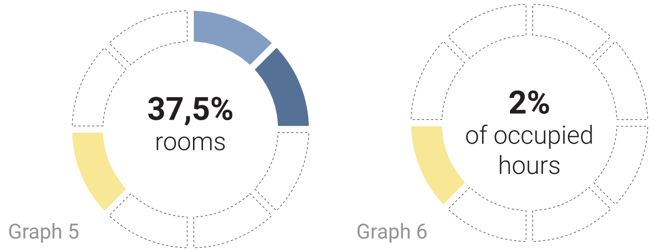
Graph 4

Coldest day
Lowest Temp.
T_{op} vs T_{out}

"ARRENDAJO" classroom
"COROCORA" classroom
"MACUNDAL" classroom
"PARAULATA" classroom
ORCHESTRA classroom
SCENARIO/LOBBY
ADMINISTRATIVE OFFICES
MANAGER

T_{op} OPERATIVE TEMPERATURE
T_{out} OUTDOOR TEMPERATURE
RH RELATIVE HUMIDITY

Fig 4.153 Thermal Comfort results/
Source: Author´s elaboration



RH > 70% = More than 70% occupied hours

max occupied hours
T_{op} < 21°C

Graph 5: : Taking into account 70% as an acceptable limit of relative humidity the results have shown 37.5% of the rooms are over this limit average in more than 70% of the occupied hours in the year. The rooms with lower indoor temperatures presented high levels of relative humidity: Manager office, "Macundal" classroom and "Paraulata" room.

Graph 6: In general, the percentage of occupied hours were the operative temperature is below 21ºC is lower. Most of the rooms present less than 1%. The Manager office is the only one that reaches 2% of the occupied hours with an operative temperature under 21ºC.

In terms of thermal comfort, most of the rooms analized are having high operative temperatures over 28ºC and, according to the Adaptive comfort limits for En class 2, half of the rooms are overheated more than 5% Occupied hours . There are also high percentages of relative humidity during the year over 70% in 37.65% of the rooms. The rooms with more thermal discomfort hours according to the results are "Arrendajo" classroom, "Corocora" classroom and the Scenario/Lobby.

- "ARRENDAJO" classroom
- "COROCORA" classroom
- "MACUNDAL" classroom
- "PARAULATA" classroom
- ORCHESTRA classroom
- SCENARIO/LOBBY
- ADMINISTRATIVE OFFICES
- MANAGER

T_{op} OPERATIVE TEMPERATURE
T_{out} OUTDOOR TEMPERATURE
RH RELATIVE HUMIDITY

Fig 4.154 Thermal Comfort results 2 /Source: Author´s elaboration

DAYLIGHT CONCLUSIONS

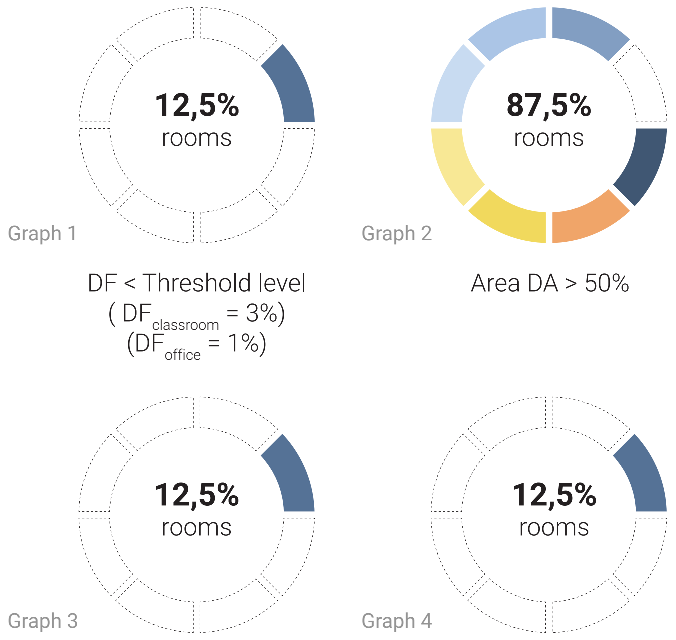
The following graphs are an overall result of the evaluation of the daylight done to the 8 selected rooms. Some of the data includes the accomplishment of Daylight factor for a classroom, Daylight autonomy, Useful Daylight illumination, glared areas, among others. With these results it is possible to conclude:

Graph 1: Based on international standards the minimum daylight factor for school, that stablish a threshold levels of 3% for classrooms, 1% for offices and 2% for meeting rooms, the results of the analysis shows that "Paraulata" classroom is the only room that does not meet this requierement

Graph 2: Almost 87.5% of the evaluated rooms has a mean Daylight Autonomy that covers at least the 50% of the room area. "Paraulata" classroom is the only room that does not meet this requierement.

Graph 3: Just the 12.5% of the analyzed rooms does not meets the minimum area (80%) of a Useful Daylight Illuminance between 300 - 3000 lx "Paraulata" classroom is the only room.

Graph 4: Just the 12.5% of the analyzed rooms does not meets the minimum area (50%) of a Daylight Illuminance over 300 lx. "Paraulata" classroom is the only room.



DF < Threshold level
($DF_{classroom}$ = 3%)
(DF_{office} = 1%)

Area DA > 50%

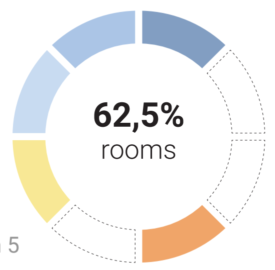
UDI (300-3000 lx)
< 80% (minimum area)

DI < 300 lx
(more than 50% of area)

- "ARRENDAJO" classroom
- "COROCORA" classroom
- "MACUNDAL" classroom
- "PARAULATA" classroom
- ORCHESTRA classroom
- SCENARIO/LOBBY
- ADMINISTRATIVE OFFICES
- MANAGER

DF DAYLIGHT FACTOR
DA DAYLIGHT AUTONOMY
UDI USEFULL DAYLIGHT ILLUMINANCE

Fig 4.155 Daylight results/ Source: Author´s elaboration



Graph 5

Glared area
DI > 3000 lx

Graph 6

Critical hour
Area DI < 3000 lx
(total rooms)

Graph 7

Critical hour
Area DI > 3000 lx
(glared area,
total rooms)

- "ARRENDAJO" classroom
- "COROCORA" classroom
- "MACUNDAL" classroom
- "PARAULATA" classroom
- ORCHESTRA classroom
- SCENARIO/LOBBY
- ADMINISTRATIVE OFFICES
- MANAGER

DF DAYLIGHT FACTOR
DA DAYLIGHT AUTONOMY
UDI USEFULL DAYLIGHT ILLUMINANCE

Fig 4.152 Daylight results

Graph 5: When the Daylight Illuminance is over 3000 luxes, glare occurs that generates visual discomfort. 62.5% of the rooms have a percentage of glared area. The room with the highest percentage of glared area is the Scenario/lobby with 44.5%.

Graph 6: In average between the analyzed rooms, the critical hour where there is a high percentage of area that has a Daylight illluminace below 300 lx is in the morning at 8:00, mainly in wet season. In the case of "Paraulata" classroom, the room does not meet the requirement at that hour in both seasons, dry and wet.

Graph 7: In the case of the amount of glared area of the rooms, that means a Daylight illuminance over 3000 lx, there are two critical hours mostly in the dry season, at 13:00 when the sun is overhead, and 17:00 in the afternoon.

In general, most of the rooms are meeting the requirements for school building in terms of Daylight factor and Daylight Autononmy of the room area. However, there is a high percentage of glared area in many rooms, specially in the Scenario/lobby where there is located a skylight. On the contrary, there is one room, "Paraulata", that has a lower average of daylighting that does not meet the any requirement of Daylight factor, Daylight Autonomy and Useful Daylight Illuminance. The wet season is when there is a lower illuminance in the mornings, while in dry season are the critical hours with more glared area. The critical hour most important is the one at 17:00 hour because it is when there is more occupancy of students in class.

AIRFLOW CONCLUSIONS
NATURAL VENTILATION

The following graphs are an overall result of the evaluation of the airflow of 8 selected rooms. The data includes the accomplishment of minimum area windows requirement, Type of airflow, Indoor air quality and airflow for cooling requirements. With these results it is possible to conclude:

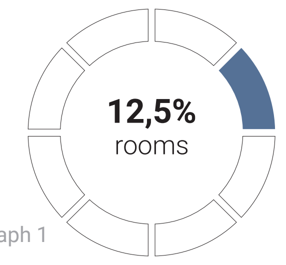
Graph 1:According to the formula about the minimum area of windows of a room, 12,5% of the rooms is not meeting the requirement. "Paraulata" room has 1.2 m^2 over 3.99 m^2 required.

Graph 2: 62.5% of the rooms have a singled sided ventilation, that correspond mostly to the classrooms, while the others, the Scenario and Administrative offices works with stack ventilation.

Graph 3: There are 3 rooms (37.5%) that are not meeting the requirement of minimum airflow rate according to their occupancy and type of space. These rooms are the classrooms "Arrendajo" and "Corocora" with a higher but not total percentage of compliance (around 80% of the year) and "Paraulata", that has a 0% of compliance in the year.

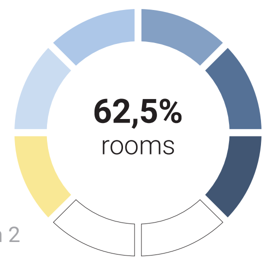
Graph 4: For cooling the room in all months of the year 50% of the rooms are not meeting the minimum airflow required. These four classrooms have 0% of months that fulfill the compliance.

In general, most of the rooms are meeting the requirement of the minimum windows area, except of "Paraulata" room. Although the other rooms meet that requirement, some of them, specially the classrooms are not fully meeting the minimum of airflow rate per person, and the airflow necessary for Cooling mainly due to the single sided ventilation system.



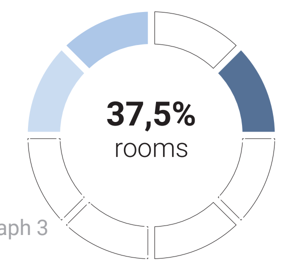
Graph 1

Area Windows
requirement
($A_w = A_{room}/8$)
A_w < min A_w required



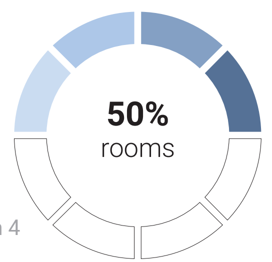
Graph 2

Single Sided
Ventilation
(Airflow)



Graph 3

IAQ Compliance
q_v-IAQ < q_r-IAQ (m^3/h)
Total months per year



Graph 4

COOLING Compliance
q_v-IAQ < q_r-COOL (m^3/h)
Total months per year

- "ARRENDAJO" classroom
- "COROCORA" classroom
- "MACUNDAL" classroom
- "PARAULATA" classroom
- ORCHESTRA classroom
- SCENARIO/LOBBY
- ADMINISTRATIVE OFFICES
- MANAGER

A_w WINDOW AREA
q_v-IAQ CURRENT AIRFLOW RATE
q_r-IAQ MINIMUM REQUIRED AIRFLOW RAT
q_r-COOL MINIMUM REQUIRED AIRFLOW FOR COOLING

Fig 4.153 Ariflow results

ACOUSTIC COMFORT CONCLUSIONS

The following graphs are an overall result of the evaluation of the airflow of 8 selected rooms. The data includes the acoustic evaluation relative only to reverberation time T_{60} of the room when is empty and occupied in the different sound frequencies. Although the T_{60} of each room depends on its function, it has been analyzed all of them together.

Graph 1: When the room is empty, for lower frequencies of 125 Hz, the current reverberation time is over the Optimal time in all the rooms.

Graph 2: When the room is empty, for medium frequencies of 500 Hz and 1000 Hz, half of the rooms have a reverberation time over the optimal value.

Graph 3: When the room is occupied, for medium frequencies of 500 Hz and 1000 Hz, 25% of the rooms have a reverberation time over the optimal value.

Graph 4: When the room is occupied, for lower frequencies of 125 Hz, mostly all of the room (87.5%) have a reverberation time over the optimal value.

Graph 5: When the room is empty, for all frequencies (125 Hz, 500 Hz and 1000 Hz), no room has a reverberation time below the optimal value.

Graph 6: When the room is occupied, for all frequencies (125 Hz, 500 Hz and 1000 Hz), 62.5% of the room has a reverberation time below the optimal value.

In general, most of the rooms does not meet the optimal reverberation for their functionality when is occupied. Most of the music classrooms have a short reverberation in the medium and high frecuencies becoming discomfortable when it is used for different type of instruments. For low frecuencies, most of the rooms, including the offices and the percussion room, have a long reverberation.

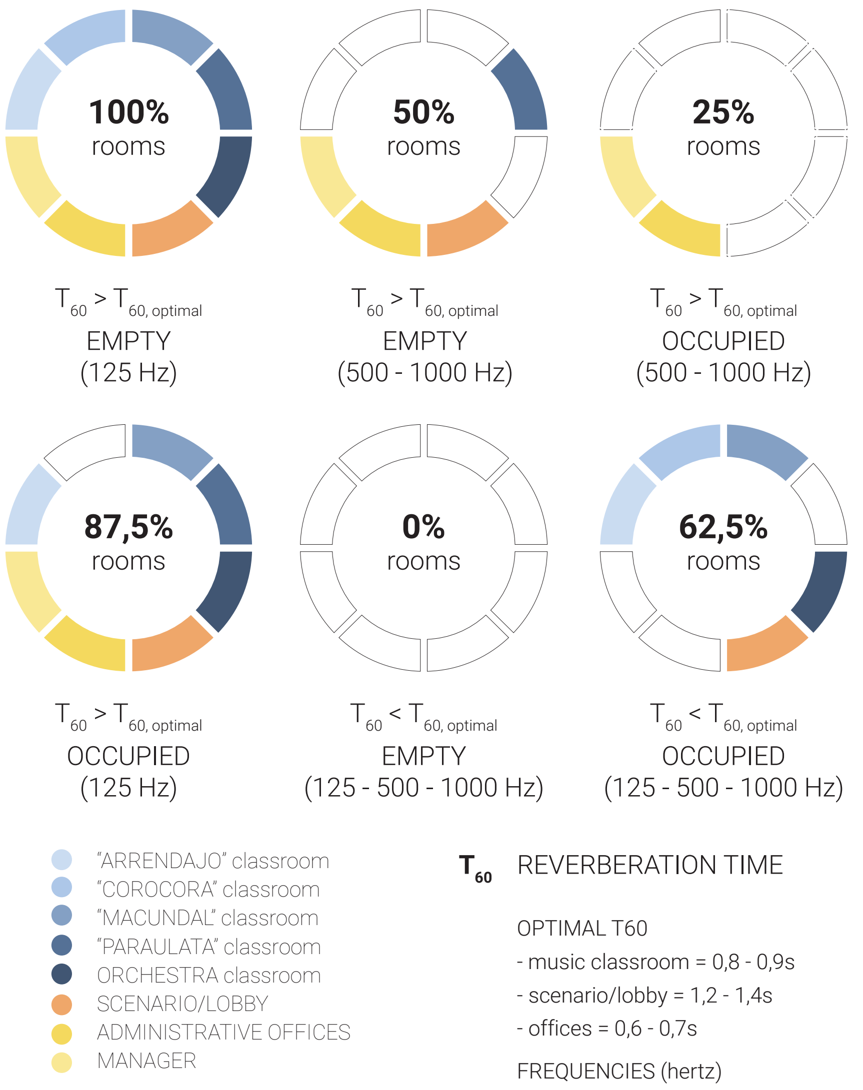


Fig 4.154 Acoustic comfort results

4.11 GENERAL CONCLUSIONS

Although the conditions of the current house have allowed the development of its successful operation in musical practices for many years, it has been evident through the analysis developed, the need for improvement from an architectural point of view.

After all the general and specific environmental analysis done of the building "Casa de la music", from the 5 categories of evaluation, Building design, thermal comfort, daylighting, airflow (natural ventilation) and Acoustic comfort, it is possible to understand the impact that the house has had due to the microclimatic conditions and its relationship with the layout of its spaces. This impact not only results in physical damage to the building but also in increased discomfort for its users.

In summary, the main problems found from the general analysis of the building design are listed below.

- Moisture on external and internal walls due to condensation, mostly in wet season and to the outdoor exposition to microclimate conditions.
- Structure affected by high levels of humidity and daylight. Cracking walls on the perimeter of the house.
- Presence of vegetation and mold on walls that, mainly in the courtyard and the administrative zone causing risks on the health of users.
- Inadequate distribution of the functional program with respect to the location of the building. Limited external exposition of the facades (South East and South West)
- Functional rooms as classrooms and administrative rooms with reduce natural ventilation and daylighting.
- Lack of storage space and high levels of humidity in the existing rooms for instruments storaging. The stacked instruments are easily damaged causing also problems on the health of the students.
- Poor accesibility for disabled people and to transport all the instruments.
- Damaged doors and wooden elements exposed to open spaces due to floods and leaks from the roof.
- Lack of furniture for the resting places. Damaged furniture due to misuse and weather conditions.
- Missing parts of ceiling and some parts affected by the heating with extreme temperatures and exposition to water. Despite the polystyrene has acoustic properties, is higly polluty for the environment and flamable becoming a high risk for the users.
- High value of thermal and solar transmitance of the existing windows. The thermal transmitance (u-value) of the walls and floors are high, due to the lack of insulation layers.
- Noise from the exterior and in between the classrooms.

The specific analysis carried out on 8 selected rooms, allowed us to identify the rooms that require more attention and to understand the starting point when proposing solutions from the building design, thermal comfort, daylighting, airflow (natural ventilation), and acoustic comfort parameters.

- Thermal and visual discomfort in first floor rooms ("Arrendajo" and "Corocora").High operative temperatures and glared area, due to the direct exposure to the exterior conditions, the performance of its materials and also, due to their location facing the East.

- Excessive overheating hours, and a high percentage of glared area in the internal "Patio" where is located the Scenario and lobby due to materials and form of the skylight.

- Several thermal and visual problems in the classroom "Paraulata" in the ground floor, which not meets most of the requirements. Poor airflow in almost half of the rooms, mainly because they worked with single-sided ventilation.It is also because of the context of the building that forces it to receive natural ventilation only through two of its facades, South West and East.
- Long reverberation time over the Optimal value in low frequencies 87% of the rooms and too short reverberation of half of the room mainly in medium and high frecuencies. Need of an evaluation of absorptive and reflective materials in each case.

5.

USERS PARTICIPATION

Involving the different users in a participatory way during a building analysis process is as important as the spatial and environmental analysis it has been done in the previous chapters. Asking direct users helps to understand
their sensations and needs, and their relationship with the built spaces.

That is why chapter 5 is focus on interviews and surveys made to current students, former students, professors, and administrative users as direct participation. It starts with a face-to-face interview made with the current manager of the institution Batuta Meta, who explains how music programs work there, as well as the current challenges of the building construction. Then, it has been carried out an open electronic survey of some current students, former students, and professors with final participation of 29 people. The survey includes questions not only about the building spaces but also about their thermal sensation inside the building, as well as the important value of that house for them and the region. Both the interview and the survey were conducted in Spanish, and then translated to English for this document.

5.0 INTERVIEW MANAGER
“Casa de la mùsica”

Luis Ibarra
Current Manager
Interview day: 30 December 2021

How long have you been part of the music house?

-Well, I have known the house since 2009 when I started working here as a teacher and as a musical coordinator since Porfia (Barrio), but I came here to work as a teacher. I spent 8 years working, then I fell apart. And since last year I took over the management, in November more or less.

In Covid period, how and with what frequency are musical classes being developed?

-For the classes, we have adequate biosafety topics, such as gel, everything that is required in terms of law. And the groups are not numerous groups as they used to work before, but rather they are groups that depend on space. For example, there is a room there for batubebes, who cannot have more than 5 children. In the orchestra hall, we do rehearsals for a maximum of 15 students, and when we do large rehearsals we do them outside on the Courtyard.

And in the orchestra, how much is the maximum number of students that you manage?

-Maximum 30 people. That is, we do as sectionals. And we do large rehearsals but we look for other spaces such as the school INEM.

In the event that the pandemic does not exist, how many people handle in the orchestra and in the pre-orchestra?

-Orchestra around 40-45. And pre-orchestra is between 20 and 30 students

Ah, there are quite a few. And with the pandemic, how many students there are??

-No more than 10 or 15..

Do you currently use all the spaces for musical teaching?

At this moment yes. There are some rooms that are with implements, but because the previous management was using them as a warehouse. So I'm trying to get that out of there because they are spaces that I need for teaching. They are some small rooms

What are the current needs of the house, in terms of infrastructure for the development of the classes?

-First, is to recover it. Well, it is deteriorating in some places. Leave it recovered in every way, in terms of humidity, roof, ceiling. There are many things to recover. From then on it is important to soundproof some spaces for rehearsals. How to adapt it more for what is musical training. This is a house where we do music training, but we don't have any adequate space as it should be for music training according to quality standards for a music rehearsal. With soundproof spaces, larger spaces, ventilation. For example, in Granada, in the music classrooms of Priest Georg Schachner. He was a person who made a symphonic band from church. He did some very cool processes. There he adapted them and made some special rooms, soundproofed and the idea would be to have something like this here. Although the priest has already died, and that is already abandoned! But that would be a second stage of adaptation

Do you think there is a lack of spaces for teaching or services?

-Yes, there is a lack. **Sometimes we find ourselves in trouble, because there is nowhere to accommodate them**, and there are days when classes are simultaneous, so we have to see if the teacher teaches in the hall.

What kind of physical problems does the house have?

-Yes

And in which spaces have you most frequently experienced this discomfort?

As I was saying, in terms of humidity, in these rooms, on this side of the house (western side). **When it is very sunny there is a smell like mold, and the atmosphere becomes heavy.** Well, when it gets very hot in the dome area, as it is transparent, it is wasted for testing because it is awfully hot and sunny! **And behind, it is like the most pleasant space, of the courtyard, that the air circulates**

I have seen that they have quite a few instruments stacked in different areas, why is that?

-It is due to lack of space for a storaging. At the end of the year, we almost always receive the inventories from the other orchestral centers (in the region) so we have to keep instruments and elements from Porfia, from the Reliquia or Castilla. But there is no space to store so much instrument. Of course those instruments will be taken there later.

And does it have any specific damage due to those conditions?

-Of course, these instruments are not accommodated in the best environmental conditions for their good care.

How do you think Casa de la Música could improve in terms of infrastructure and space?

-I think it is important to generate another storage space. I imagine the most adapted rooms for the musical study. Basically that, adequacy for the functionality that is music, and second spaces to store important elements. **And improving the way for the air to circulate more. We are very locked up**.

How valuable is the house for you and / or for the Region?

-Casa de la musica, the importance that it has, in addition to the city, is for all the Department. **It is a focus of an incredible social transformation, and it has always been historically known. Every family in Villavicencio, in the department knows about Batuta**, and when they enter the house they evoke memories when they were there. This space is very important for the history of Villavicenses (name of people from the city) and Metenses due to the transformation it has made through music. And for me, this is a challenge and a purpose, because this was something that was in decline. I was in another job as a department's music consultant. I was fine, but when I saw that this was going downhill, this is part of my life because I started here. And I resigned and decided to come here against all the odds!

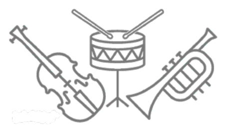
5.1 SURVEY USERS

Casa de la mùsica

Users: 29 People

-Administrative and professors 4
-Former students 11
-Current students 14

Instruments of surveyed users



Violin
Cello
Double bass
Saxofon
Flute
Oboe
Trumpet
Trombone
Clarinet
Piano

1.What are the spaces or rooms that most used to use within the house?

-Orchestra Room
-Individual classrooms
-External Courtyard
-Pre-Orchestra
-Offices

2.Have you experienced thermal discomfort due to internal environmental conditions?

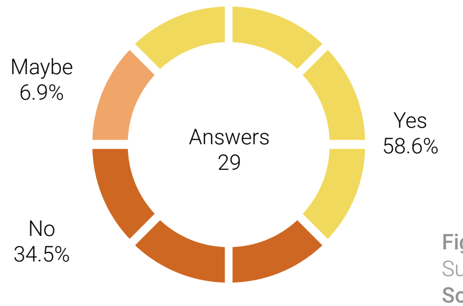


Fig. 5.0 Results Question 2 Survey
Source: Author´s elaboration

3.Where have you experienced more thermal discomfort due to internal environmental conditions?

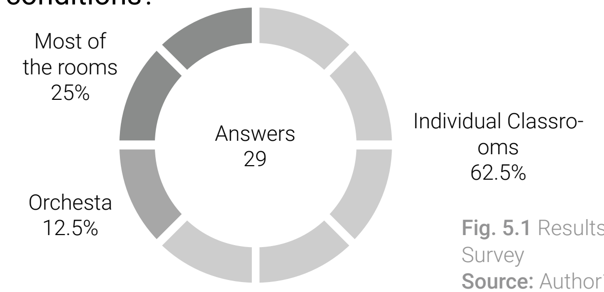


Fig. 5.1 Results Question 3 Survey
Source: Author´s elaboration

4.Do you think there is a need of spaces for music education or services?

Fig. 5.2 Results Question 4 Survey
Source: Author´s elaboration

5.What type of spaces do you think would be needed?

- More Individual classrooms
- More Groupal classrooms
- More Storage for instruments
- An Auditorium
- A recording studio

6.How do you think the building could improve in terms of infrastructure?

- Expanding the house with more floors
- Adding bigger classrooms for individual and small groups class
- Improving the existing classrooms with natural ventilation
- Improving service areas, such as bathrooms
- Adding more space for Orchestra room
- Adding space for storaging
- Replacing the roof and old structures of the house
- Adding acoustic treatment of the rooms

How valuable is the house for you and / or for the Region?

"Ha sido la cuna de muchos profesionales en la música, y ha sido uno de los más importantes espacios para llevar arte, generar encuentros, reunir personas al rededor de la música en muchos lugares del departamento del Meta"

It has been the cradle of many professionals in music, and it has been one of the most important spaces to bring art, generate meetings, gather people around music in many places in the department of Meta

WOLGANG ORDOÑEZ

"Es un espacio muy importante para los jóvenes de la región,es una oportunidad de vida para muchos jóvenes que no tiene posibilidades de estudiar carreras ,y otros que viven en espacios de alta delincuencia"

It is a very important space for the young people of the region, it is a life opportunity for many young people who do not have the possibility of studying careers, and others who live in areas of high crime

ANONYMOUS

"Es un espacio de transformación social. Cambia positivamente a las familias y a los niños que hacen parte de sus programas

It is a space for social transformation. It positively changes the families and children who are part of its programs

CAMILO BUSTAMANTE REYES

"Es prácticamente mi segundo hogar y mi espacio seguro para ser yo mismo"

It is practically my second home and my safe space to be myself

ANONYMOUS

"Tiene mucha importancia ya que en esta podemos aprender a tocar instrumentos y cantar, además de también poder divertirnos mientras lo hacemos y poder formarnos como personas, así como formar nuevos vínculos sociales y afectuosos con los demás asistentes de esta"

"It is very important because we can learn to play instruments and sing, and we can also have fun while we do it and learn as people, as well as form new social and affectionate bonds with the other attendees".

MARIA ALEJANDRA ESCOBAR

"Considero que tanto para mi como para la región es bastante importante debido a que es una de las pocas escuelas de música en general, y que da oportunidad a nuevos talentos a darse a conocer en múltiples ocasiones formando parte de lso diferentes procesos que se encuentran en batuta"

I consider that both for me and for the region it is quite important because it is one of the few music schools in general, and that it gives the opportunity for new talents to make themselves known on multiple occasions as part of the different processes that are in Batuta

STIVEN TORRES

"La casa de la música es un lugar donde los sueños y las metas no tienen límites, dónde se puede cambiar la sociedad por medio de la música, es un lugar que nunca debería desaparecer y que se debería apoyar mucho más"

"Casa de la Música" is a place where dreams and goals have no limits, where you can change society through music, it is a place that should never disappear and should be supported much more."

ANGELICA FABRA

"Fue el espacio en el cual amé la musica"

It was the place in which I loved music

ANONYMOUS

5.2 CONCLUSIONS

According to the current manager of the institution, one of the biggest challenges of the building is to adapt it for music training, while recovering it from all the decays from the past, mainly due to the hard microclimate conditions. Although it has been made a great effort to solve some of the problems, the high levels of humidity and high indoor temperatures not only affect the infrastructure but also hinder the learning process of the students with high levels of discomfort.
When asking about the thermal sensation of the rooms, up to 58% of the surveyed people have felt thermal discomfort when teaching or playing music. However, a great percentage of 34.5% of the surveyed people say they have never felt discomfort. These last results correspond to current students, which have high levels of expectation of high temperatures. The rooms associated with this discomfort are the small individual rooms with 62.5% , as well as the group classrooms on the first floor.

Among the suggestions that users gave from their needs are, improving the existing spaces and adding more for individual rehearsals by expanding the building with more floors. To improve the services areas, as well as the storage space that it is not enough. To add acoustic treatment and soundproofing to the classrooms, and to replace structures and materials such as the roof.

For all of the surveyed users, the house and its musical programs is not just important for the children and young people of the city, but also for the cultural development of the entire region since it is the greatest music program there. As some of them have said, the music programs help with social transformation, reinforce cultural values and become an opportunity for many students to continue with music as a lifestyle. For many of them, that house has become like a second home to love arts and music.

6. RENOVATION PROPOSAL

This chapter focuses on the development of a proposal for comfort improvement through partial renovation. The project is based on the results of the analysis carried out in the previous chapters and the survey done to its users.
A matrix is developed to combine the problems from the analysis done and their possible solutions through the design criteria presented in Chapter 3. As would be detailed in the chapter through schemes and plans, the renovation proposal seeks to improve the thermal, visual, and acoustic comfort by doing a re-distribution of some spaces, opening the “Patio” for natural ventilation, adding upper louvers, replacing some materials, changing the roof and ceilings, adding shading devices, among other strategies. The strategies are divided into 3 groups. The first one corresponds to the building design approach, the second one is related to passive design strategies, although both are connected, and the third one to some active strategies as a supplement when the other strategies are not enough to solve the problems.
Design schemes, plans, sections, facades, axonometries, and details, among others, are the material included in this chapter to explain the proposal.

Fig.6.0 Image Perspective Proposal-
Source: Author´s elaboration

6.0 DESIGN APPROACH

The proposal is a partial renovation of the existing building design for the improvement of its thermal, visual, and acoustic comfort through a natural low-impact design method.
Understanding the results of the building evaluation from each category, building construction, thermal comfort, daylighting, airflow/natural ventilation, and acoustic comfort, has been the starting point to define the design method for a further architecture intervention.
It was necessary to establish the main problems and then the specific ones to prioritize the required solutions. The data was cross-checked with the different environmental strategies, which, in turn, are divided into 3 levels of solutions to minimize the energy consumption. See the matrix below (Chapter 6.1).
The first level is building design (A), which refers to the spatial configuration and dimensions of the elements that are defined from the beginning of the design process, such as orientation, site selection, urban morphology and topography, form and shape, colors, among others (See chapter 3.6). These first architectural decisions are important to reduce the heat gains or heat loss depending on the climate. Since the case study is an existing building, this level of intervention takes into consideration some elements to produce the lower possible impact of the current construction.
The second level refers to the passive strategies (B), which refers mainly to the use of natural resources for heating or cooling. But it could also include all the elements of the first approach mentioned before. For the proposal, it is taken into account strategies to improve the natural ventilation as the main method for cooling and to increase thermal comfort. As well as the appliance of other strategies.
The last level of design approach is the use of low active systems (C) which implies the use of energy when the other two methods result not enough to meet the requirements. Although there are complex HVAC mechanical systems for cooling or heating, this work is not considering its uses but some low mechanical elements, such as fans and dehumidifiers would be considered as needed.

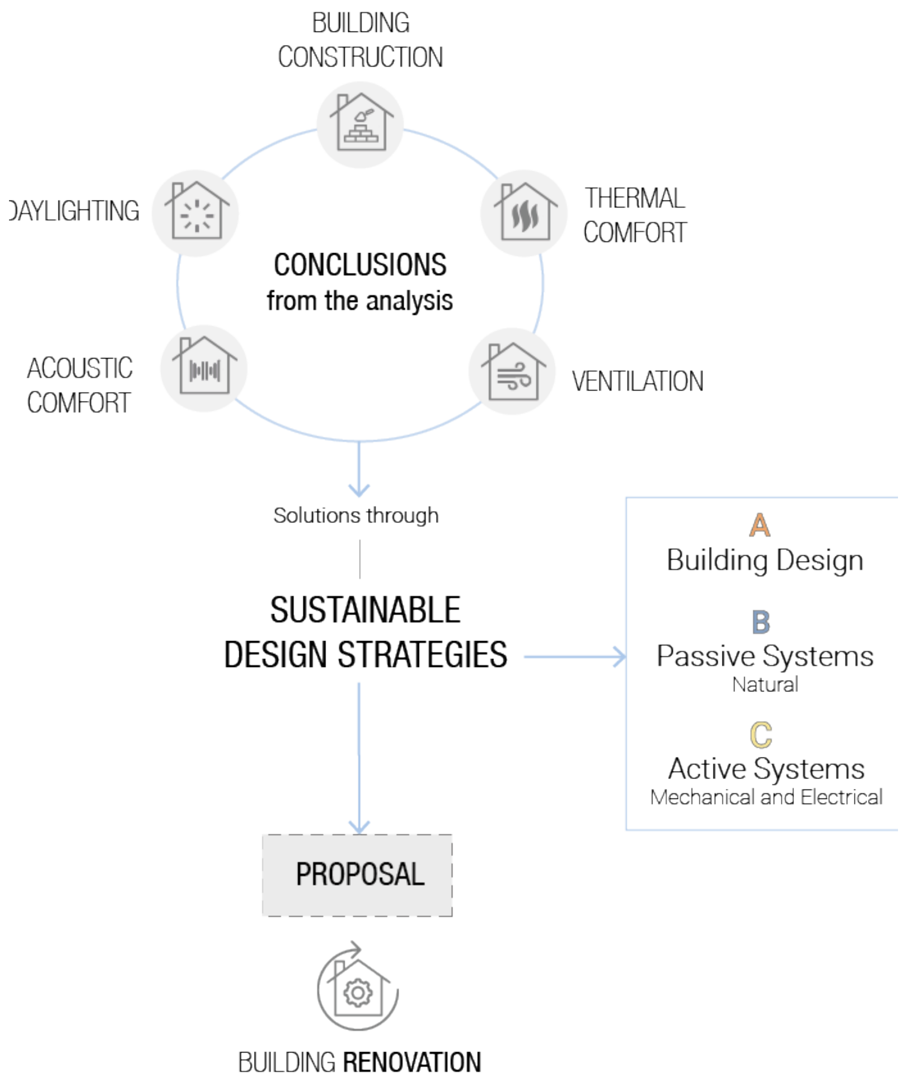


Fig.6.1 Diagram methodology proposal/ Source: Author´s elaboration

6.1 PROBLEMS VS SOLUTIONS MATRIX

		PROBLEMS														
		BUILDING DESIGN			THERMAL COMFORT				VENTILATION		DAYLIGHTING		ACOUSTICS			
		Inadequate Functional distribution			Excess of moisture and condensation		High indoor temperatures		Poor quantity of airflow		Poor quality of illuminance		Inadequate acoustics of rooms			
		Poor accesibility for disable people	Reduced area for storage and services	Deficient rooms with reduced areas and ventilation for individual and small groupal classes	Mold on walls and structure	Instruments damages and people health issues	High thermal transmission (U Value) and solar factor (G value) of windows and material	Overheating rooms over 5% of occupied hours for Adaptive comfort limits (EN class 2) (50%)	Rooms with airflow rate Indoor Air Quality (IAQ) below the minimum required (37,5%)	Rooms with Airflow rate for Cooling (qr-cool) below to the minimum required (50%)	Rooms with Daylight factor (DF) and Daylight illuminance (DI) below to the minimum required <300lx (12,5%)	Rooms with glared areas. Daylight illuminance (DI) over the maximum required >3000lx (62,5%)	Background noise between rooms	Rooms with long Reverberation Time (T60) over the optimal required for low frecuencies (87%)	Rooms with short Reverberation Time (T60) below the optimal required for high frecuencies (62%)	
SOLUTIONS – Building design and Passive strategies	Spatial Redistribution of the functional program	■	■	■				■	■	■	■	■				A
	Extension and addition of new spaces		■	■					■							A
	Increasing height of the ceilings and skylight			■				■	■	■	■	■				A
	Implementation of Comfort ventilation with cross and/or stack ventilation			■				■	■	■						A
	Resize and Relocate windows			■			■	■	■	■	■	■				A
	Redesign and addition of shading devices							■			■	■				B
	Use of light colors and materials with higher albedo						■	■								B
	Implementation of sound absorption and reflective materials												■	■	■	B
	Adding louvers on windows and replacing glass with high VT and low U-Value glazing			■			■	■	■		■	■				B
	Replacement of building materials by low U-value materials															B
	Adding Insulation to walls, floors and roof						■	■								B
	Adding mass + Insulation layer to internal walls												■			B
	Use of ceiling fans			■				■	■	■						B
	Adding vapor barriers				■	■										B
Active systems	Use of exhaust fans							■	■	■						C
	Use of dehumidifiers				■	■										C

Table 6.0: Problems vs Solutions. Environmental strategies./Source: Author´s elaboration

6.2 BUILDING RENOVATION

Re-designing the building through a spatial re-distribution and addition of new spaces with a reinforcement of the current structure and replacement of materials in order to mitigate the impact of the microclimate. It seeks to adapt the existing building to the local environmental conditions through passive design strategies which include the use of surrounding natural resources to improve comfort while reducing the consumption of non-renewable energies, and in turn the economic expense that this generates.

This proposal approaches the design from levels A, B and C (explained before) with the following strategies:

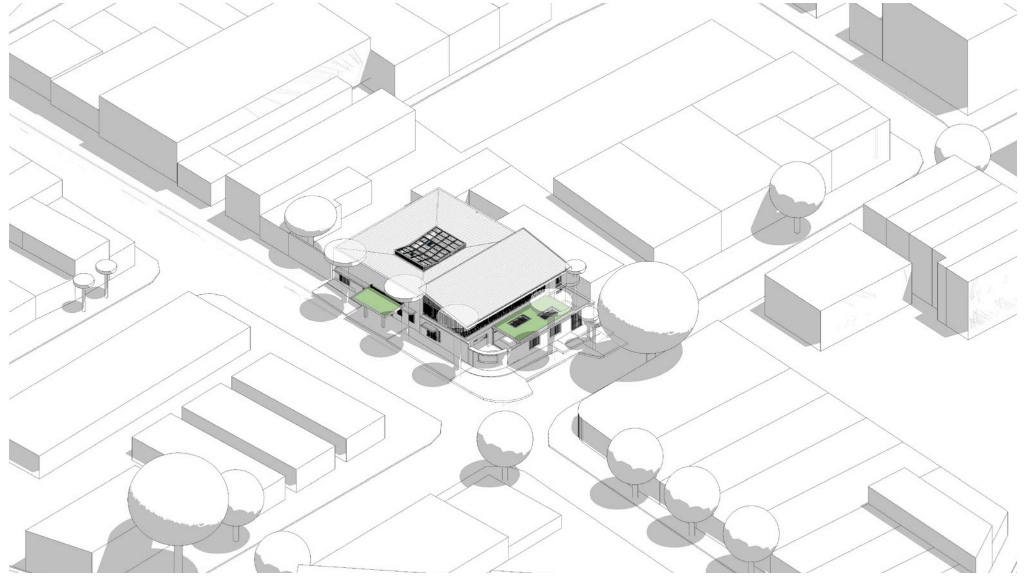


Fig.6.2 Axonometry Proposal/
Source: Author´s elaboration

A Building Design

-Spatial Redistribution o the functional program
-Extension and addition of new spaces
-Increasing the height of the roof, ceilings and replacing the skylight
-Implementation of comfort ventilation with cross and stack ventilation
-Resize and relocate windows

B Passive Systems

-Redesign and addition of shading devices
-Use of light colors and materials with higher albedo
-Implementation of sound absorption materials
-Adding louvers on windows and replacing glass with high Vissibility Transmittance and Low U-value glazing
-Replacement of building materials by low U-value materials
-Adding insulation of walls, floors and roof
-Use of ceiling fans
-Adding vapor barriers

C Active Systems

-Use of exhaust fans
-Use of dehumidifiers

6.2.1 CONCEPT DESIGN

Increasing interior **COMFORT** by creating a **balance** between a permeable and protected building with a synergy of its spaces

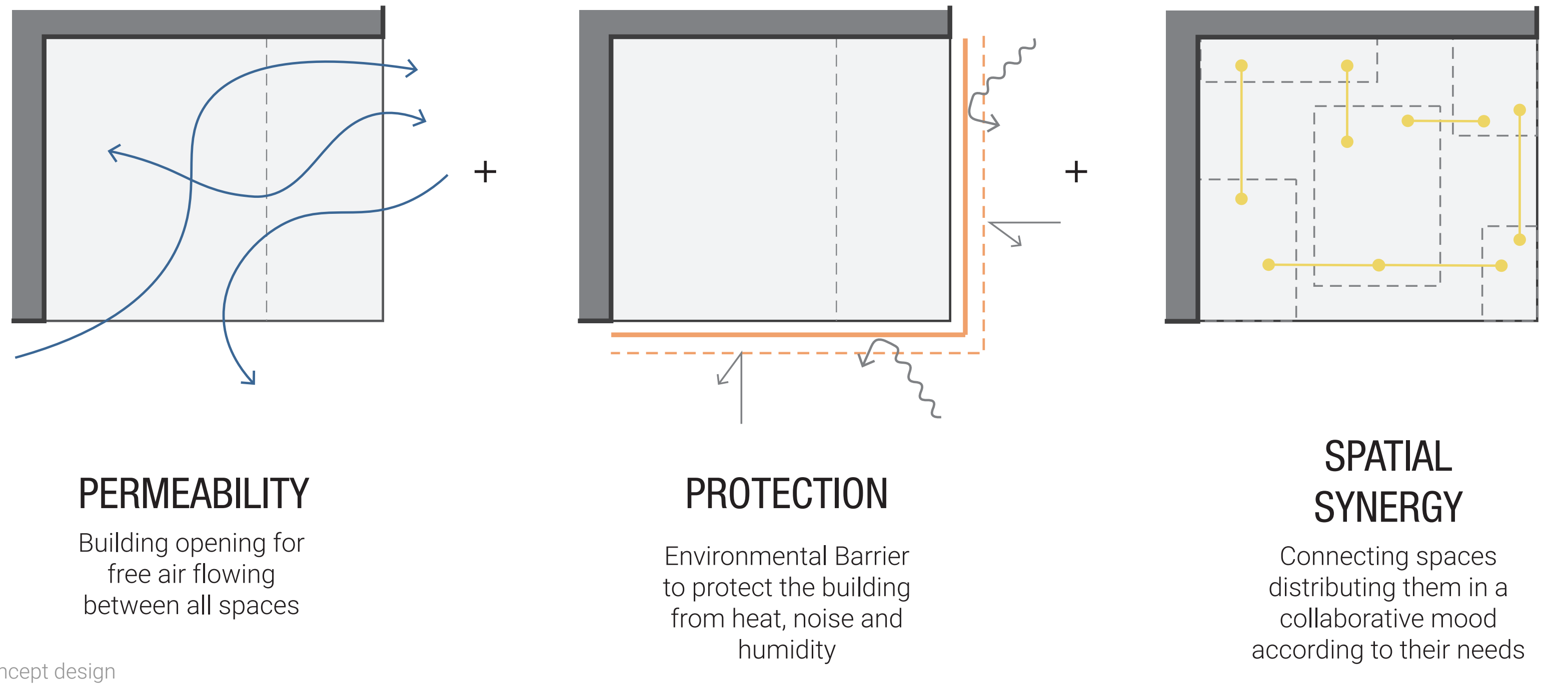
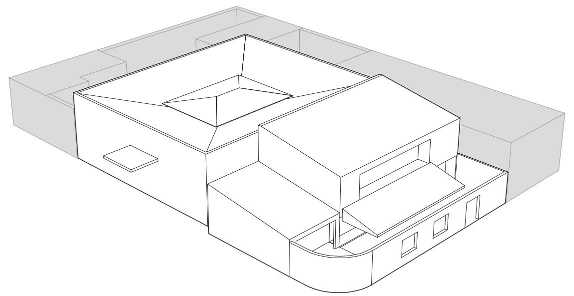


Fig.6.3 Diagram concept design
Source: Author´s elaboration

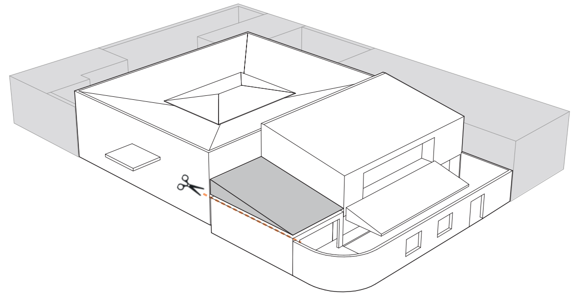
As a result of the analysis carried out, 3 main needs stand out as the starting point for the design concept of this renovation. The need for continuous ventilation for cooling, the need for protection from extreme climate conditions, and the need to connect spaces coherently according to activities and the surrounded environment. Those needs have been defined as the 3 main concepts of the building design: PERMEABILITY, PROTECTION, AND SPATIAL SYNERGY. Creating a balance between their strategies to bring thermal, visual and acoustic comfort is the aim of this work.

6.2.2 DESIGN STEPS



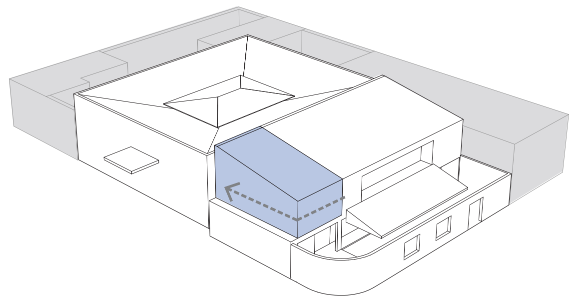
1. Original Building

"Casa de la musica" current design



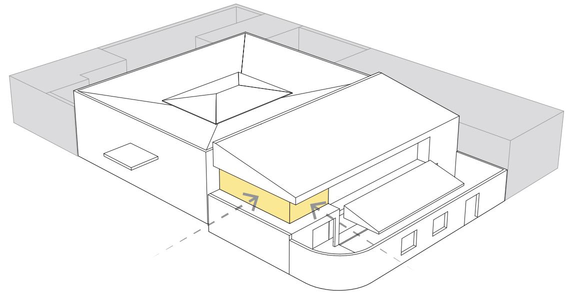
2. Cutting the roof

Removing the sloped roof from level - 1



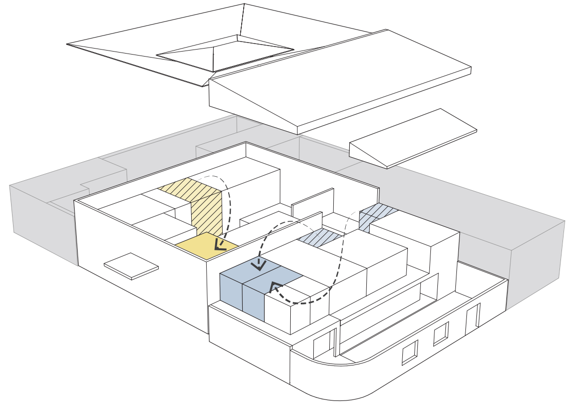
3. Floor addition

Extension of First floor



4. Pushing back the walls

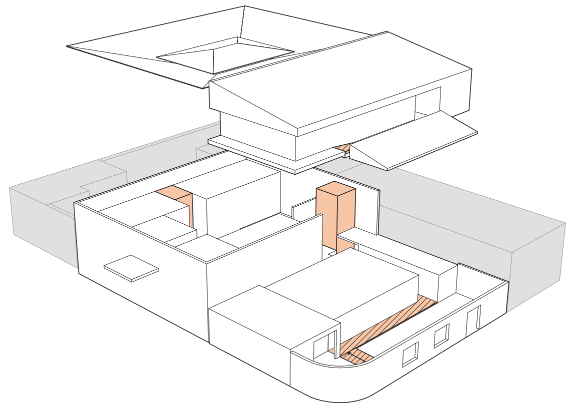
New exterior hall and balcony



5. Re organizing spaces

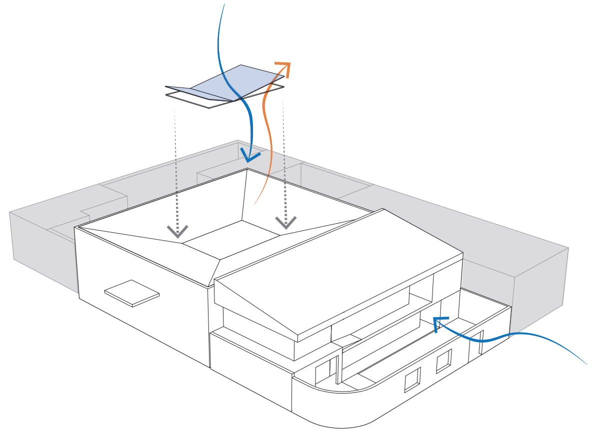
Redistributing rooms an adding new ones

Fig.6.4 Design steps schemes.
Source: Author´s elaboration



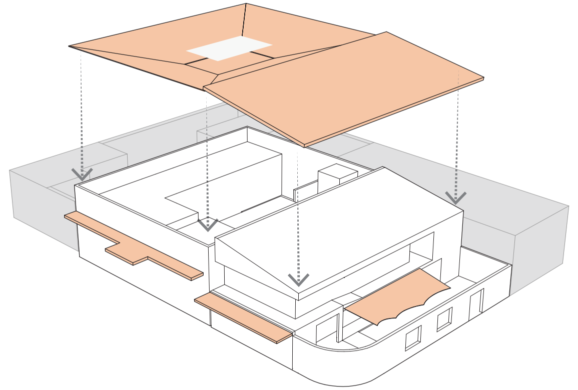
6. Improving Accesibility

Adding an elevator and ramps for disabled people acces



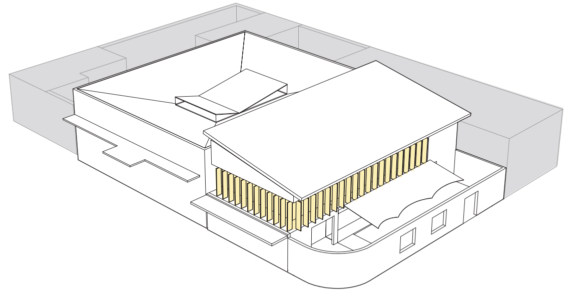
7. Opening the courtyard

Replacing the skylight by a opena-ble roof for natural ventilation



8. Horizontal protection

Replacing the roofs and overhangs with accurate materials



9. Dynamic facade

Addition of movable vertical shading devices

6.2.3 FUNCTIONAL PROGRAM

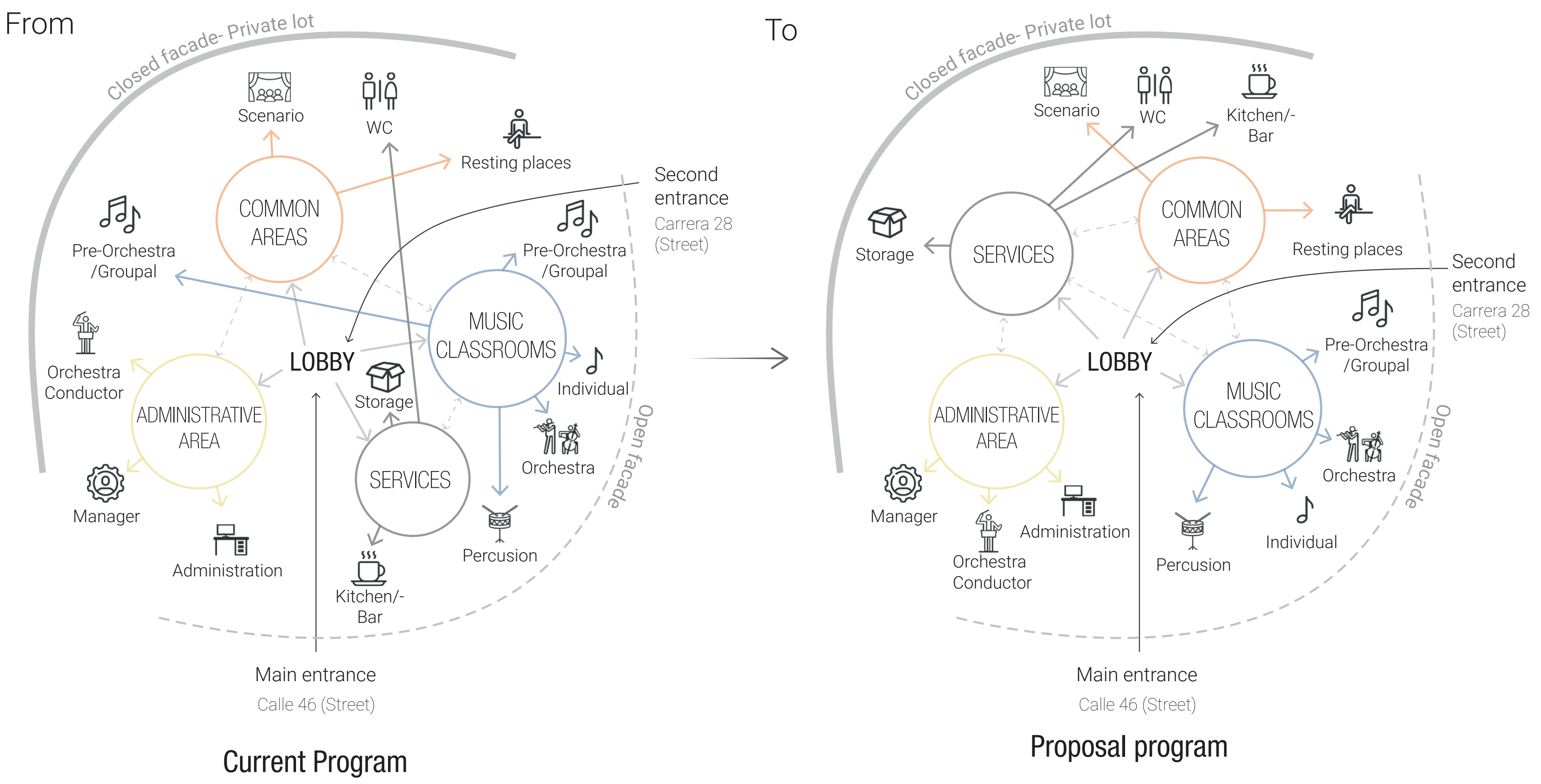


Fig.6.5: Diagram Comparison program Current vs proposal/Source: Author´s elaboration

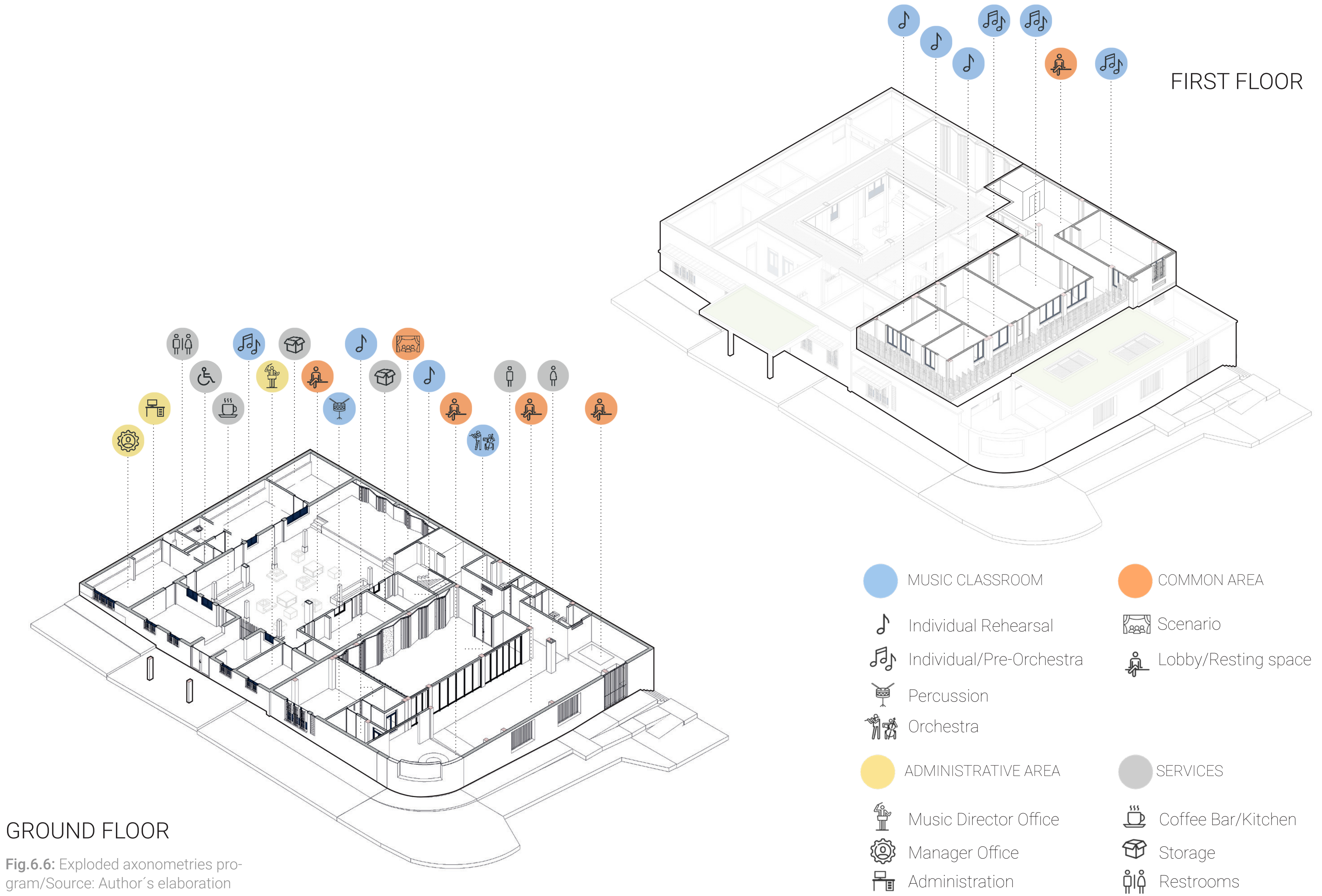
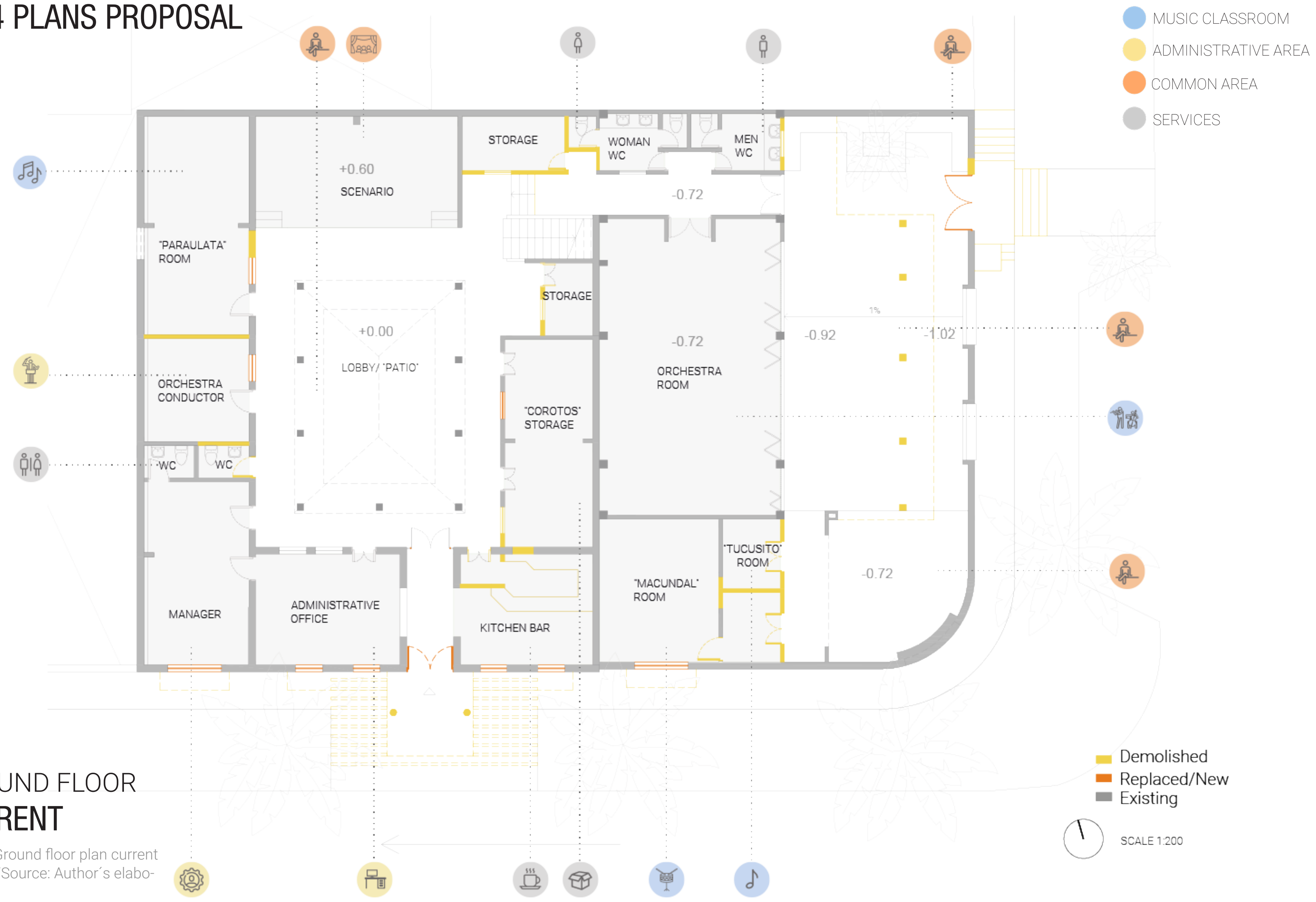


Fig.6.6: Exploded axonometries program/Source: Author´s elaboration

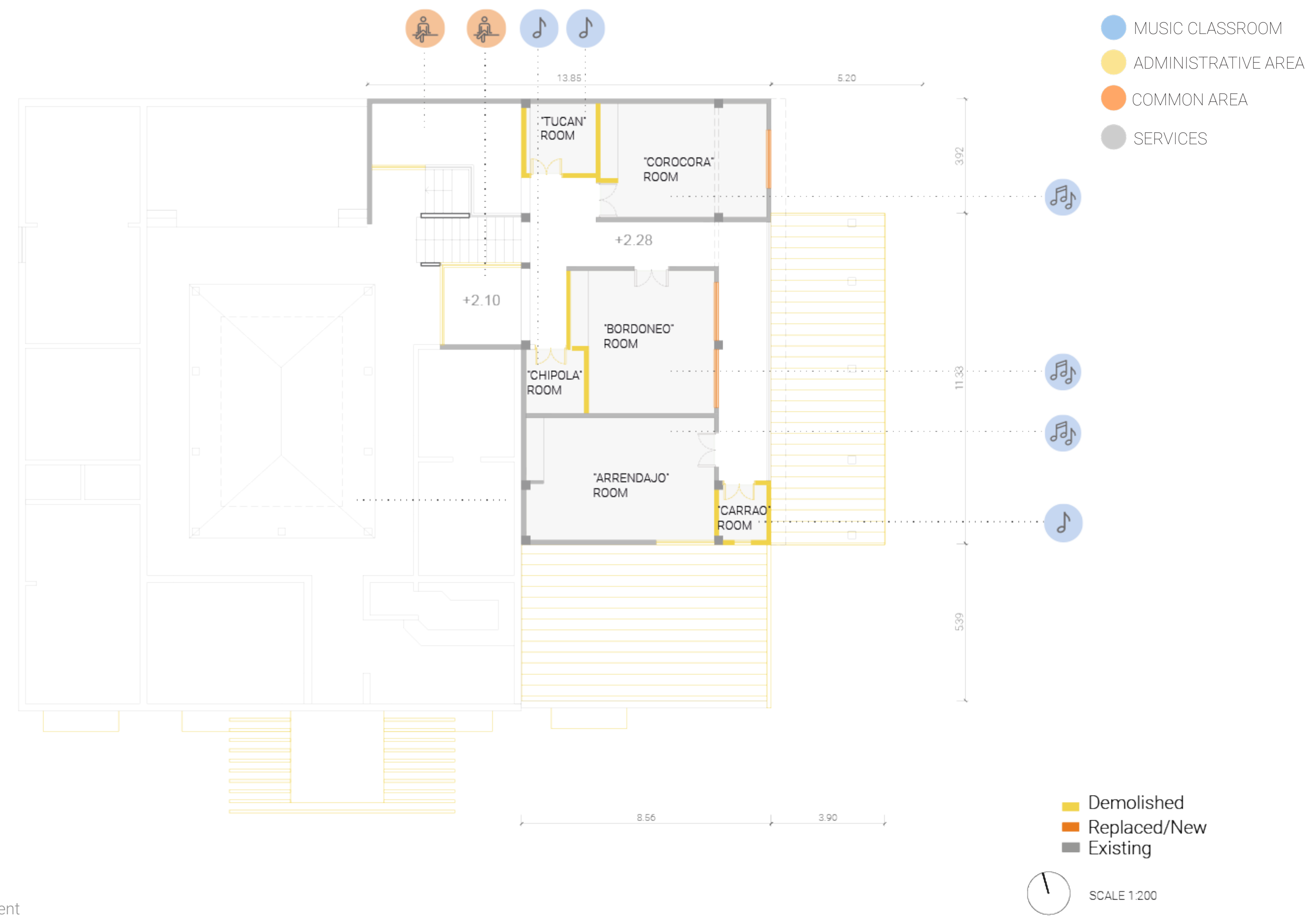


GROUND FLOOR
CURRENT

Fig 6.7: Ground floor plan current building/Source: Author´s elaboration

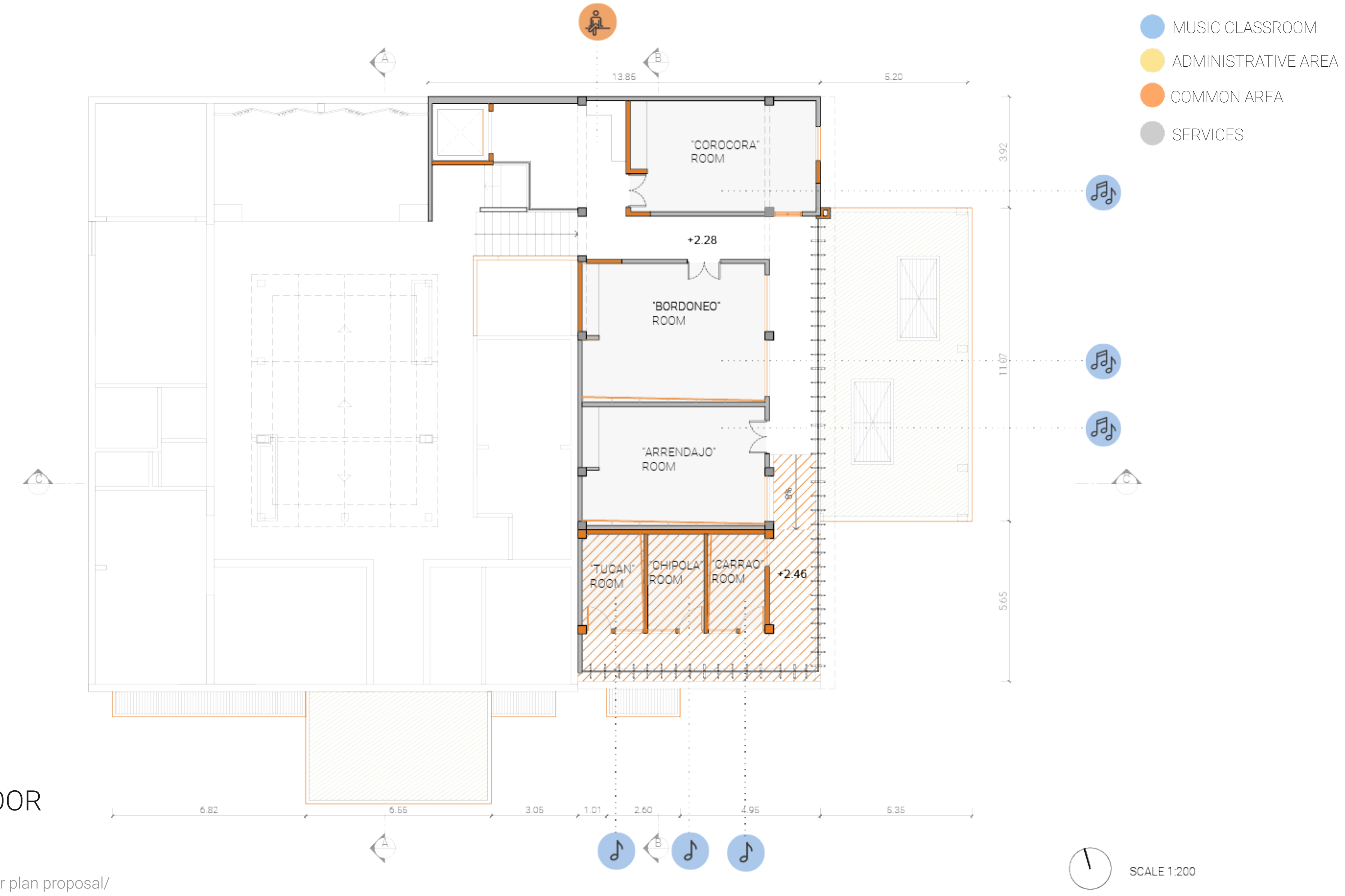
GROUND FLOOR
PROPOSAL

Fig.6.8: Ground floor plan proposal/ Source: Author´s elaboration



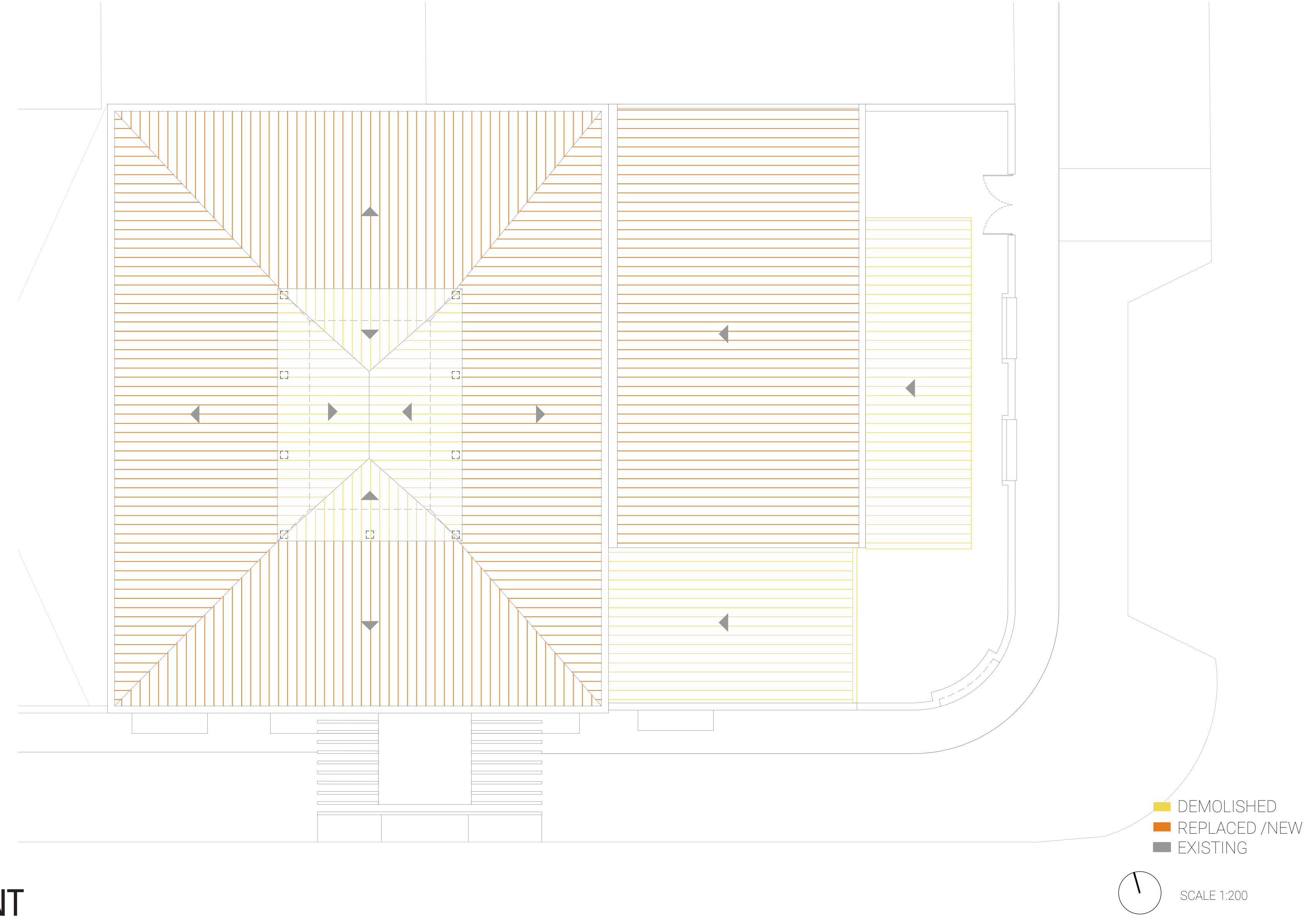
FIRST FLOOR
Current

Fig 6.9:First floor plan current building/Source: Author´s elaboration



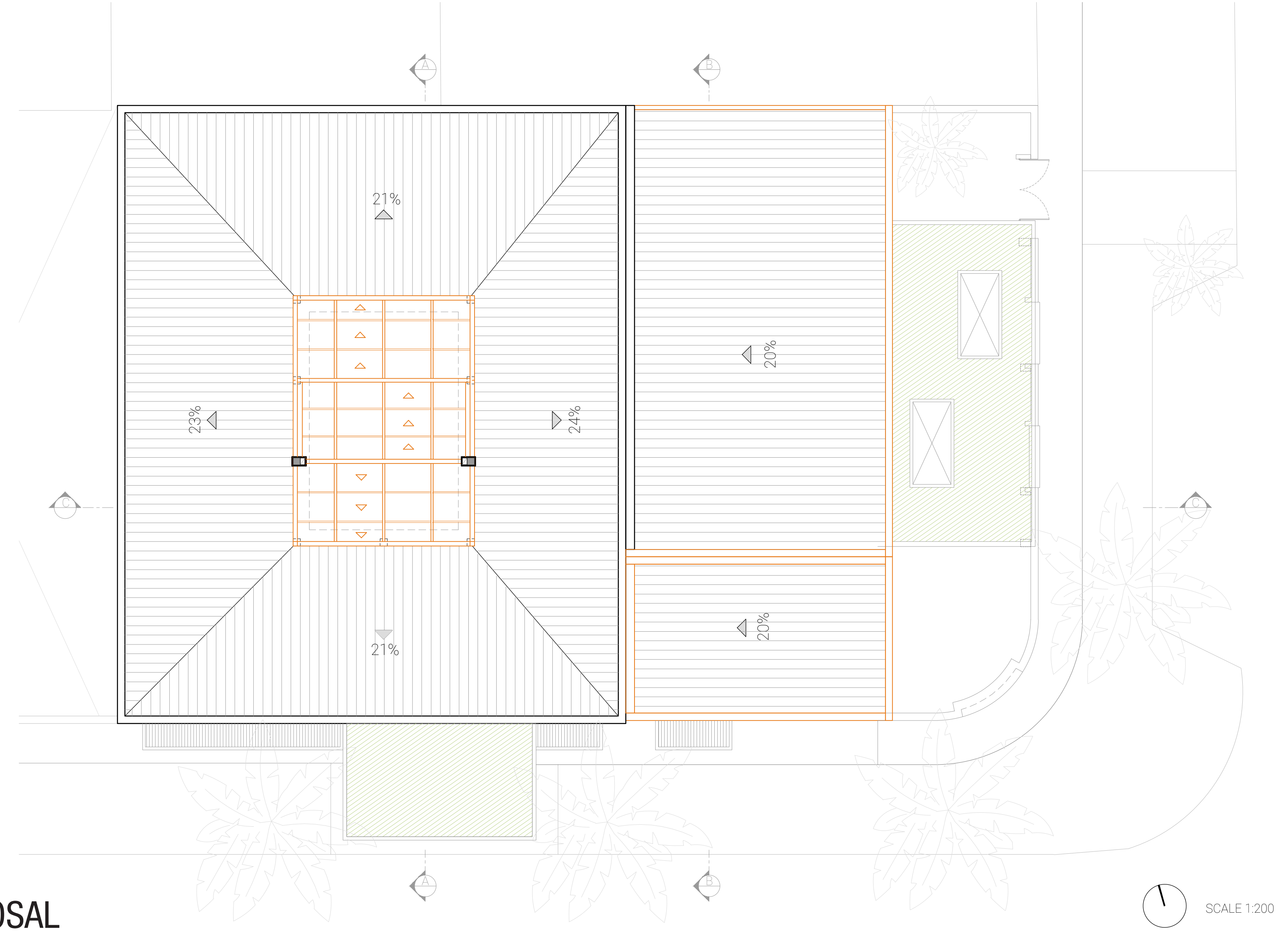
FIRST FLOOR
Proposal

Fig.6.10:First floor plan proposal/ Source: Author´s elaboration



ROOF
CURRENT

Fig 6.11: Roof plan current building/Source: Author´s elaboration



ROOF
PROPOSAL

Fig.6.12:Roof plan proposal/Source: Author´s elaboration

6.2.5 FACADES

FACADE SOUTH- WEST

Fig 6.13: Facade South-West / Source: Author´s elaboration

FACADE SOUTH-EAST

Fig 6.14: Facade South-East / Source: Author´s elaboration

6.2.6 ENVIRONMENTAL DESIGN STRATEGIES

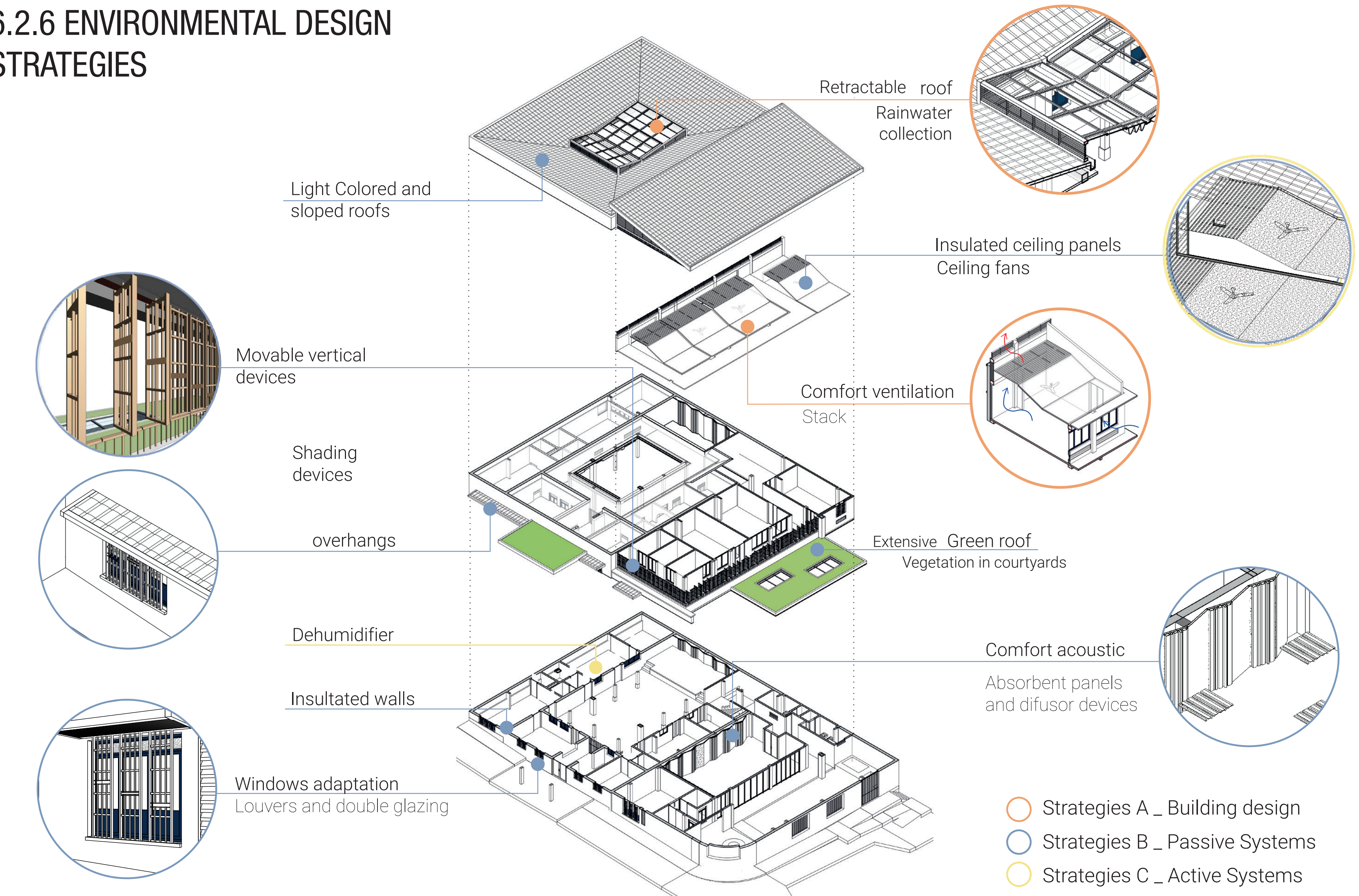


Fig 6.33 Exploded axonometry environmental strategies/ Source: Author´s elaboration

Based on the matrix of problems and solutions, and taking into account the design criteria for hot-humid climate discussed in the chapter 3, the proposal has been designed with strategies from 3 different approaches: Building design, Passive systems and Active systems.
Most of the strategies are focus on reducing interior heating from solar radiation by adding insulation layers on roof and walls, using light colors for the surfaces, or by improving the shading devices on facades. Small vegetation, as well as the extensive green roofs in the entrance and the courtyard help also to cool the building. Other strategies also focus on adding comfort ventilation by increasing roof height and proposing stack ventilation system to all the rooms. Due to the interior high temperatures and relative humidity, working just with passive design strategies result hard to accomplish thermal comfort, thus it is suggested the addition of mechanical fans in classrooms and exhausted fans in service rooms. To control excess of humidity in the storage rooms it is suggested to add a dehumidifier device as mechanical system due to the lack of natural ventilation in there.
The following strategies described are the most used in the different building spaces.

HORIZONTAL DEVICES: OVERHANGS

For solar control it has been replaced the existing sloped overhangs in fibercement by longer overhangs in metal light colored roofing with a small slope. Two extensive green roofs act as horizontal shading systems. In the Tropics, with a latitude near to 0º, horizontal shading iis important because the sun is overhead most of the day throughout the year.

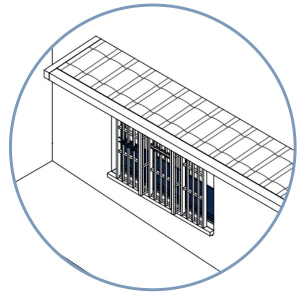


Fig 6.34 Horizontal shading strategy/ Source: Author´s elaboration

Strategies A_ Building Design
Strategies B_Passive Systems
Strategies C_Active Systems

RETRACTABLE ROOF

The existing fixed skylight located over the internal "patio" has been replaced by a metal-frame retractable roof with opal multiwall polycarbonate panels. It consists on an inverted canopy system divided in 3 sections with retractable panels that collects rainwater in 2 gutters located in reinforced columns inside the room. The panels could be moved manually or motorized depending on the environmental conditions, and they are additionally shaded by fabric retractable velums for glare control. The horizontal openings, as well as the vertical louvers proposed, improves the ventilation system.

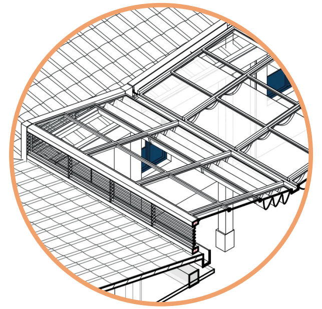


Fig 6.35 Retractable roof strategy/ Source: Author´s elaboration

MOVABLE VERTICAL SHADING DEVICES

To shade the facades from east and southeast sun rays in the morning and afternoon it has been proposed immunized timber permeable and operable vertical louvers. The louvers can be manually rotated up to 90º degrees depending on the shadowing needs. The louvers design have been inspired from the music scale that creates a dynamic facade of the music center.

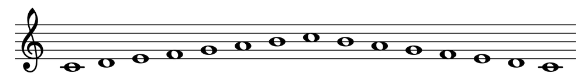


Fig 6.36 Music scale pentagram./ Source: https://promocionmusical.es

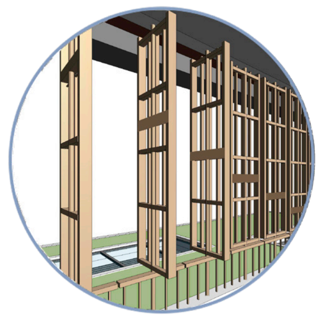


Fig 6.37 Vertical Shading strategy/ Source: Author´s elaboration

INSULATED/ACOUSTIC CEILING PANELS

For both, acoustics and thermal performance it has been designed a variety of ceiling materials depending on the functions of the room. In some spaces ceiling is composed by fiberglass panels covered with fabric when an absorptive material is needed, while in others the main material is gypsum board which acts as a reflective acoustic material and in turn avoids internal heat gains. In the first floor, the ceiling has been design at different heights to increase stack ventilation effect through permeable timber slats.

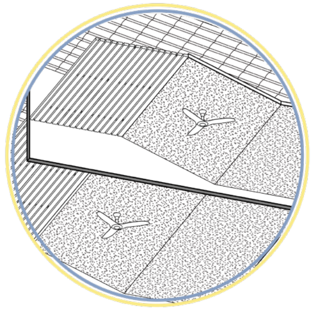


Fig 6.38 Acoustic Ceiling strategy/ Source: Author´s elaboration

COMFORT VENTILATION

To improve natural ventilation of the internal spaces of the building, comfort ventilation is the best strategy solution. For this case, most of the rooms have been adapted to manage airflow through stack ventilation system. To accomplish it, it has been necessary to increase the height of the first floor roof and to add louvers in the North-West facade. Also on each room, it has been added metal acoustic louvers under or over the windows to improve the internal ventilation even when the rooms are closed without losing acoustic properties.

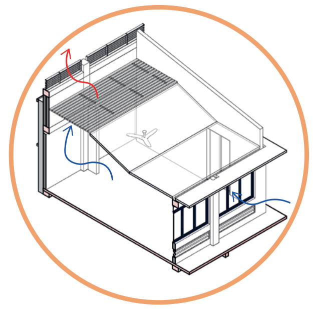


Fig 6.39 Comfort ventilation strategy/ Source: Author´s elaboration

- Strategies A_Building Design
- Strategies B_Passive Systems
- Strategies C_Active Systems

ACOUSTIC COMFORT

To improve the acoustic performance of the rooms, have been proposed different materials according to the analysis done in chapter 4 and depending on the type of room and its occupancy. Acoustic comfort has been reached through two strategies in the building. The first one is to improve the acoustic conditions of a room, including the reverberation time T_{60} as the main factor of evaluation. Timber smooth floors, reflective or absorptive ceilings, suspended timber clouds and angled timber slated and gypsum walls are part of the design. The second one is soundproofing the walls in between the rooms and floor of first floor in order to limit background noises.

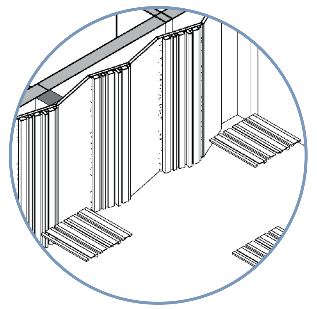


Fig 6.40 Acoustic comfort strategies/ Source: Author´s elaboration

WINDOWS ADAPTATION

The original wooden windows of the building has been kept because of its thermal performance for the interiors, as well as its historical and cultural value. However, they have been modified and adapted to improve indoor comfort. New type of glazing, louvers in the interior frame layer and vertical fixed permeable shutters on the exterior facade allows controlled daylighting. For the first floor, the windows have been designed with the same characteristics but with more glass area.

Fig 6.41 Windows adaptation strategy/ Source: Author´s elaboration

The original wooden window has been adapted by replacing the glass by a double uncoated glass or double low emissivity coated glass. Additionally, replacing the interior solid frame area of the windows by wooden louvers to avoid heating, but adding more natural illumination and airflow through it. The thermal transmittance decreases from 3,63 to 2,83-2,53 according to the following tables showing a performance improvement for thermal comfort, as well as for daylighting by reducing glare.

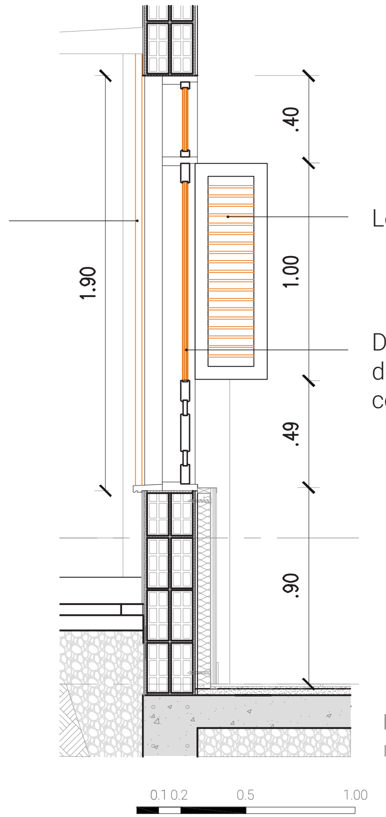


Fig 6.42 Window section "Macundal" room / Source: Author´s elaboration

Table 6.1 **Double glazing (Uncoated glass)**

WINDOW THERMAL TRANSMITTANCE _ TYPE: W-2, W-2A					
GEOMETRICAL DATA					
a [m]	1,00	A_g [m²]	0,81	A_{tot} [m²]	1,90
b [m]	1,90	A_f [m²]	1,09		
a' [m]	0,33	l_g [m]	8,71		
b' [m]	0,30	number of glasses	6		
FRAME AND GLASS					
Material [-]	Wood	U_f [W/m²K]	2,00	U_g [W/m²K]	3,30
				ψ_g [W/mK]	0,06
RESULTS		U_w [W/m²K]	2,83		

Table 6.2 **Double glazing (Low emissivity coated glass)**

WINDOW THERMAL TRANSMITTANCE _ TYPE: W-2, W-2A					
GEOMETRICAL DATA					
a [m]	1,00	A_g [m²]	0,81	A_{tot} [m²]	1,90
b [m]	1,90	A_f [m²]	1,09		
a' [m]	0,33	l_g [m]	8,71		
b' [m]	0,30	number of glasses	6		
FRAME AND GLASS					
Material [-]	Wood	U_f [W/m²K]	2,00	U_g [W/m²K]	2,60
				ψ_g [W/mK]	0,06
RESULTS		U_w [W/m²K]	2,53		

6.2.7 Sections Proposal

MUSIC CLASSROOM

2 "Macundal" Percussion room
3 Orchestra room
4 "Chipola individual room
5 "Arrendajo" room (groupal)
6 "Bordoneo" room (groupal)
7 "Corocora" room (groupal)

ADMINISTRATIVE AREA

1 Administration

COMMON AREA

1 Lobby
2 Scenario

SERVICES

1 W.C Men

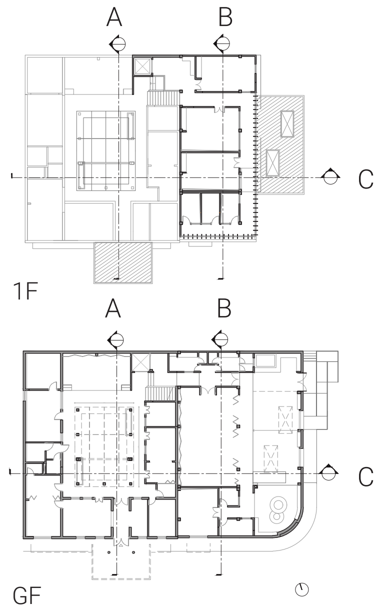
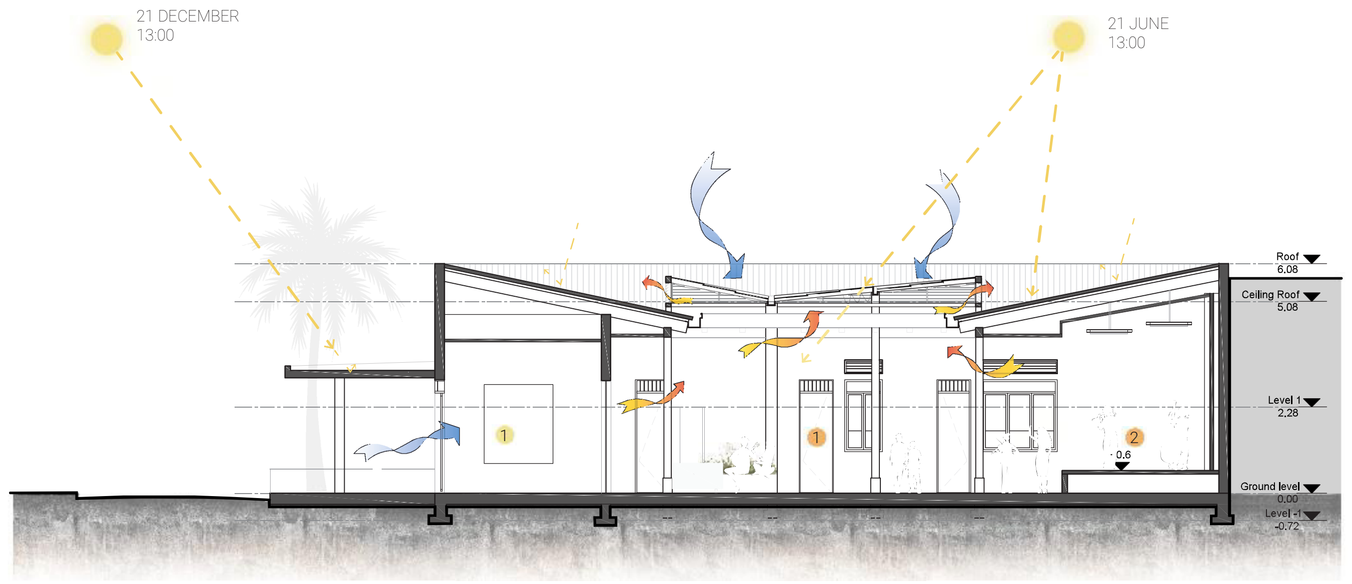
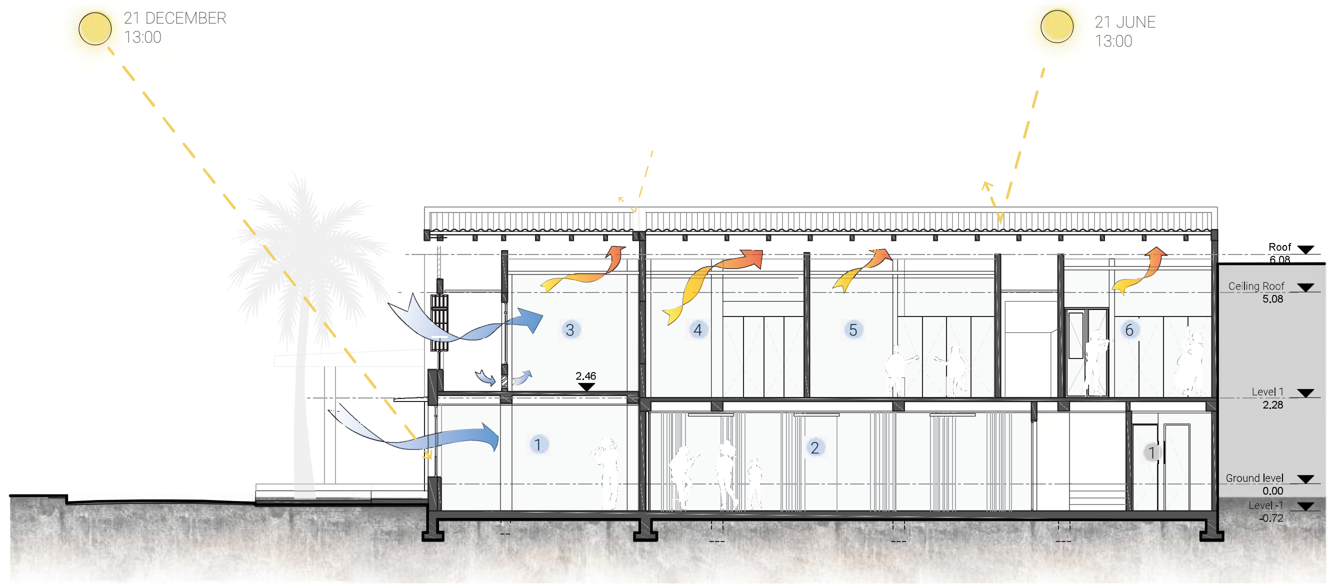


Fig 6.15: Schematic plan /Source: Author´s elaboration



SECTION A

Fig 6.16: Section A 1:200 / Source: Author´s elaboration



SECTION B

Fig 6.17: Section B 1:200 / Source: Author´s elaboration

MUSIC CLASSROOM

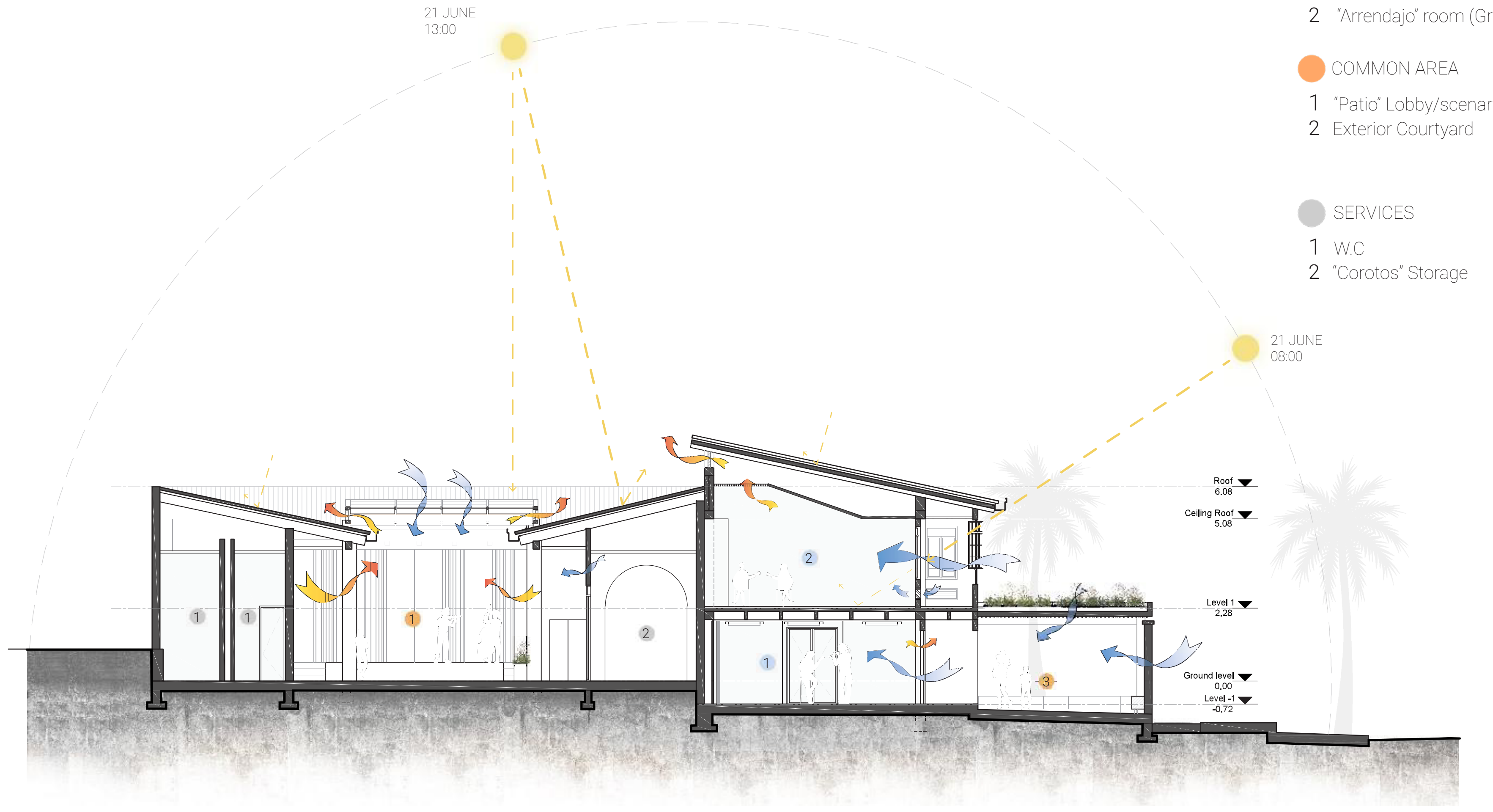
1 Orchestra room
2 "Arrendajo" room (Groupal)

COMMON AREA

1 "Patio" Lobby/scenario
2 Exterior Courtyard

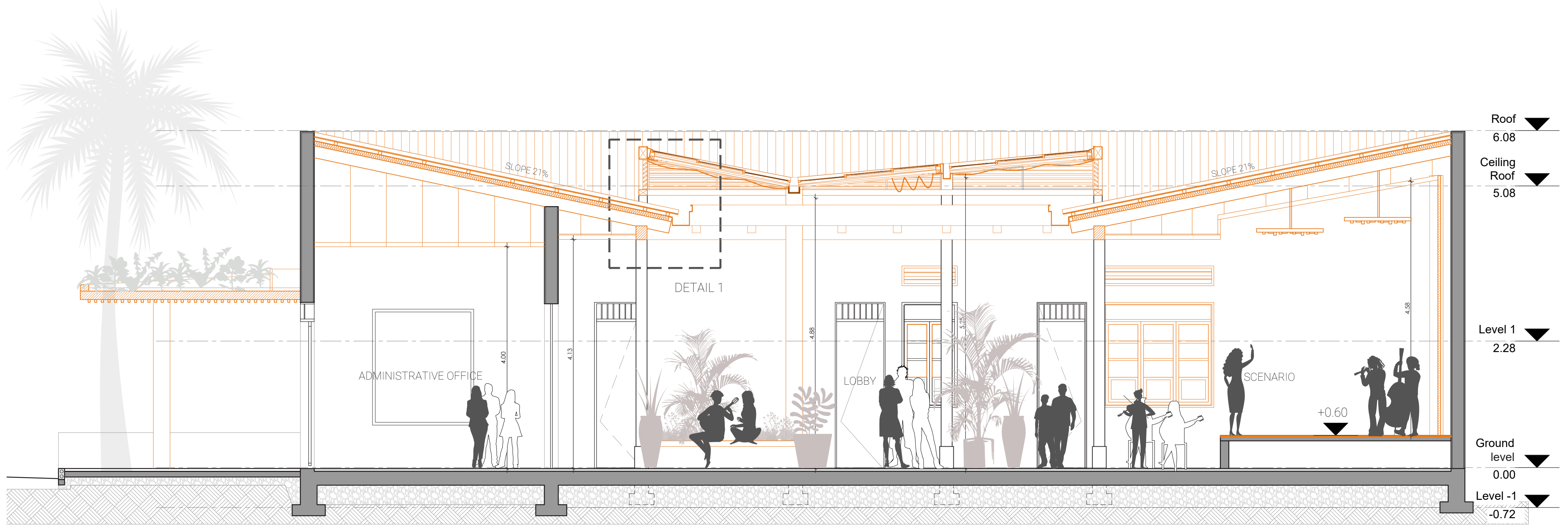
SERVICES

1 W.C
2 "Corotos" Storage



SECTION C

Fig 6.18: Section C 1:200 / Source: Author´s elaboration



Existing construction
New construction

SECTION A

Fig 6.19: Section A 1:100 /
Source: Author´s elaboration

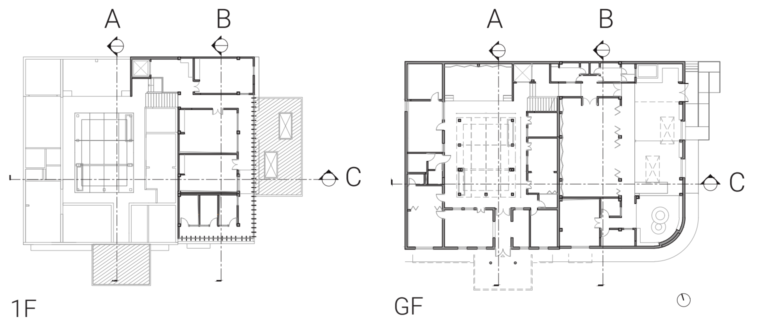
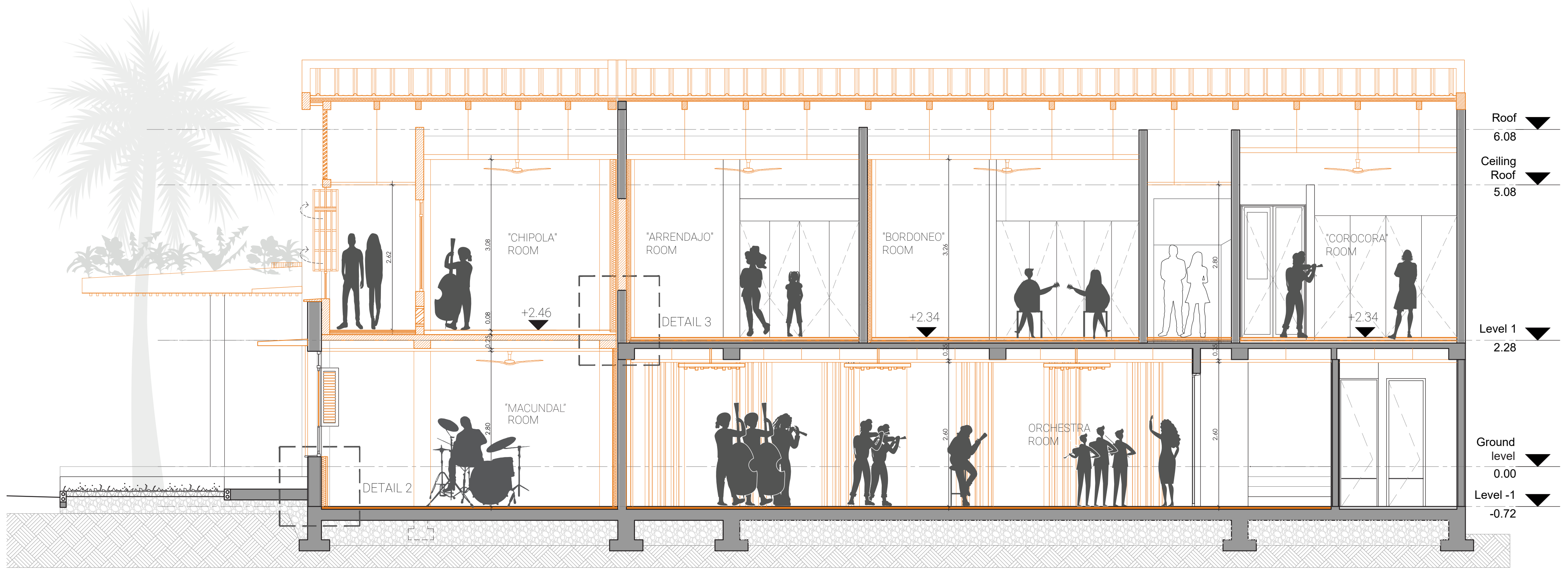


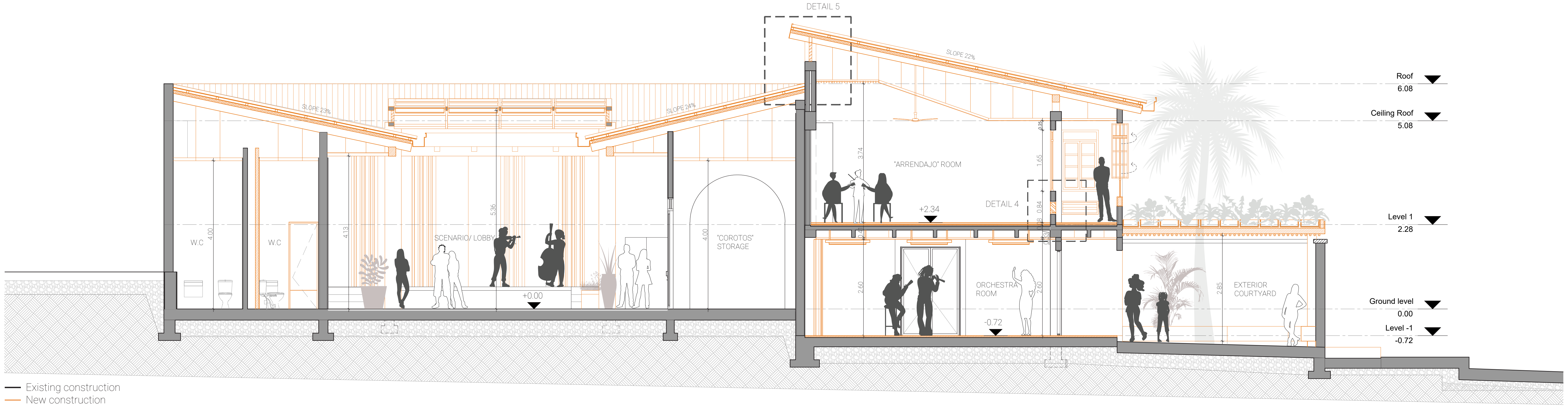
Fig 6.20: Schematic section plan /
Source: Author´s elaboration



Existing construction
New construction

SECTION B

Fig 6.21: Section B 1:100 /
Source: Author´s elaboration



— Existing construction
— New construction

SECTION C

Fig 6.22: Section C 1:100 /
Source: Author´s elaboration

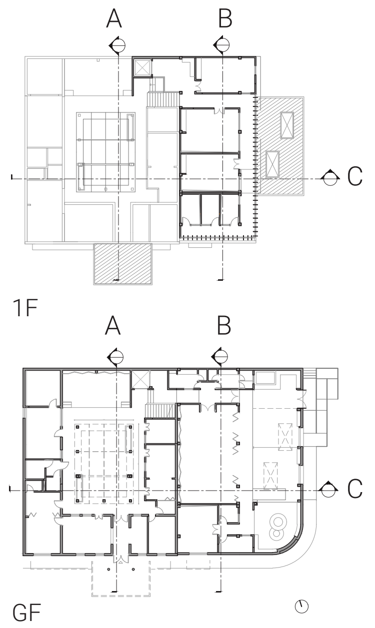


Fig 6.23: Schematic section plan /
Source: Author´s elaboration

6.2.8 Images

Fig 6.24 Interior image. "Patio"/ Source: Author´s elaboration

Fig 6.25 Exterior image. "Courtyard"/ Source: Author´s elaboration

6.2.9 Axonometries

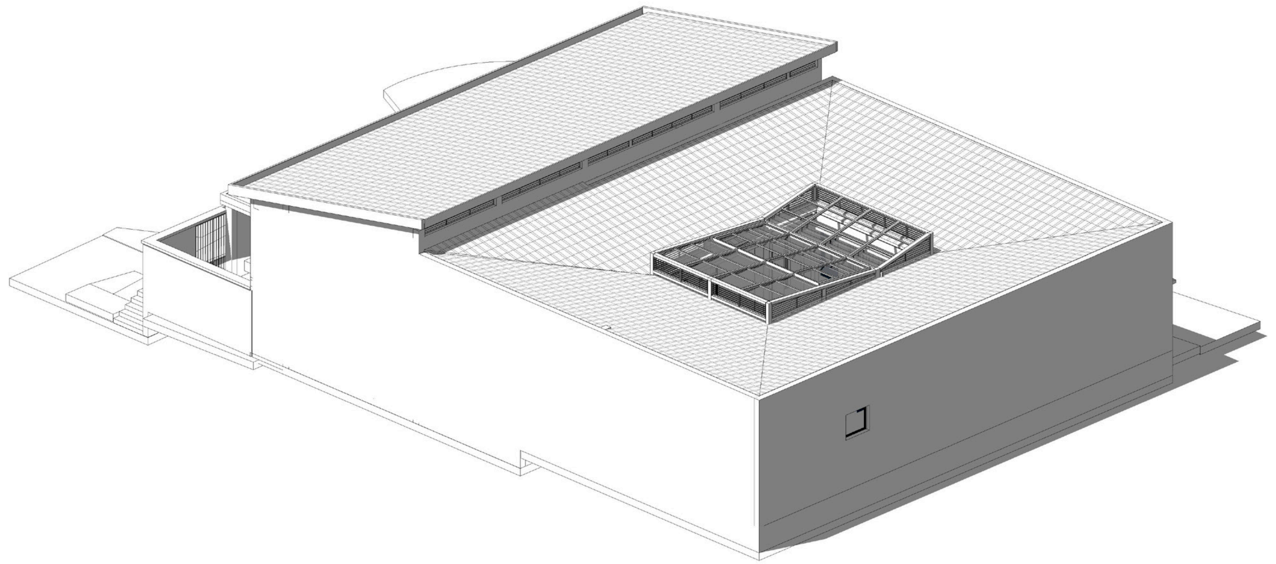


Fig 6.27 Axonometry/ Source: Author´s elaboration

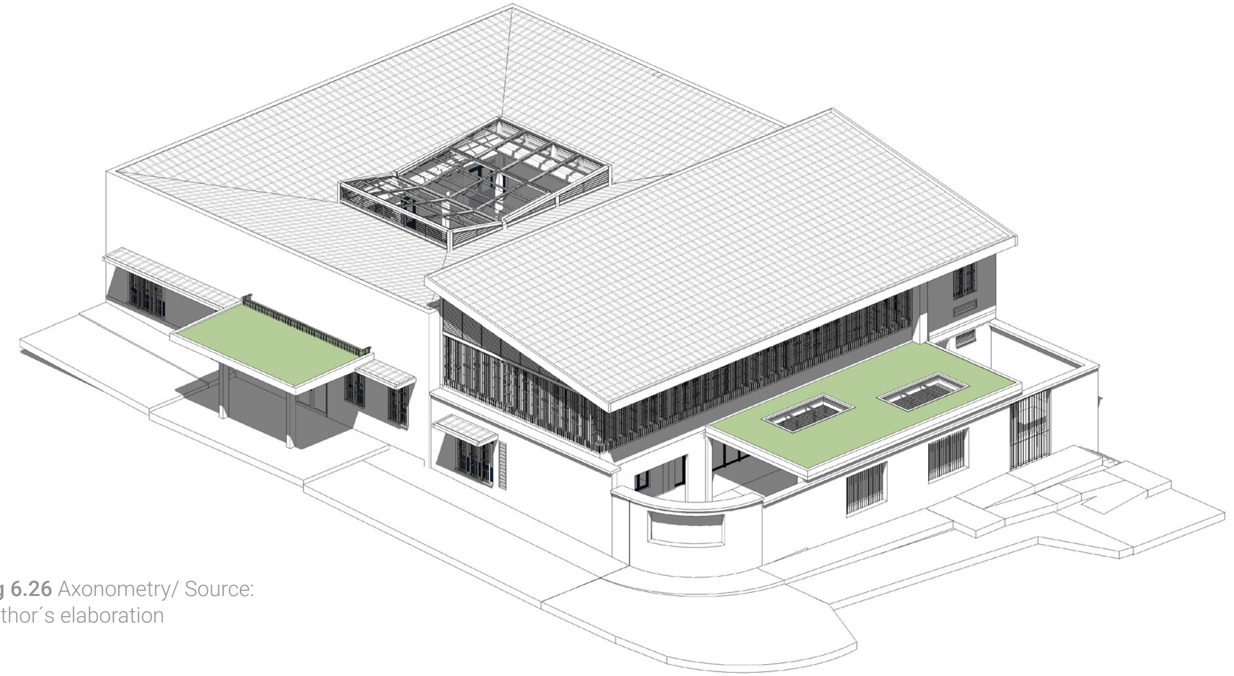
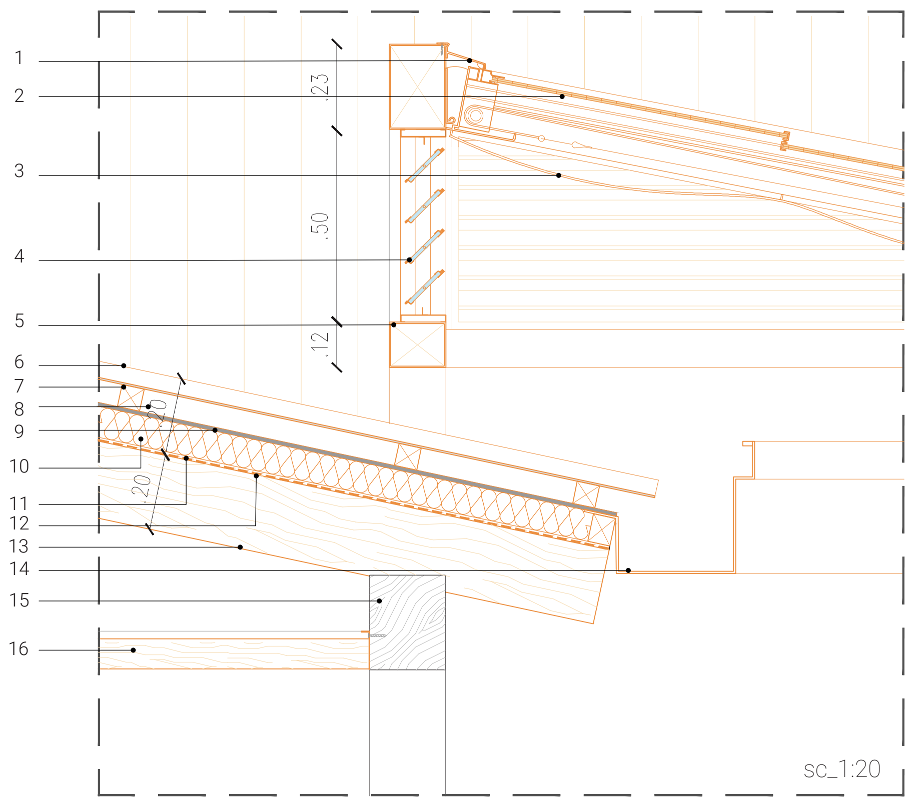
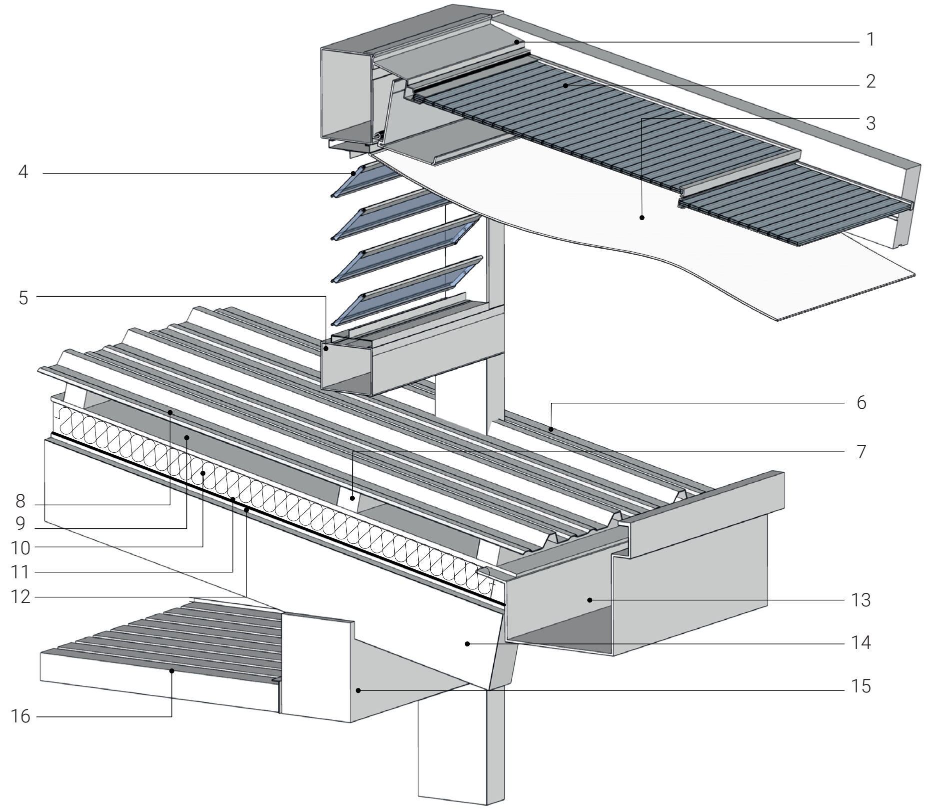


Fig 6.26 Axonometry/ Source: Author´s elaboration

6.2.10 Details



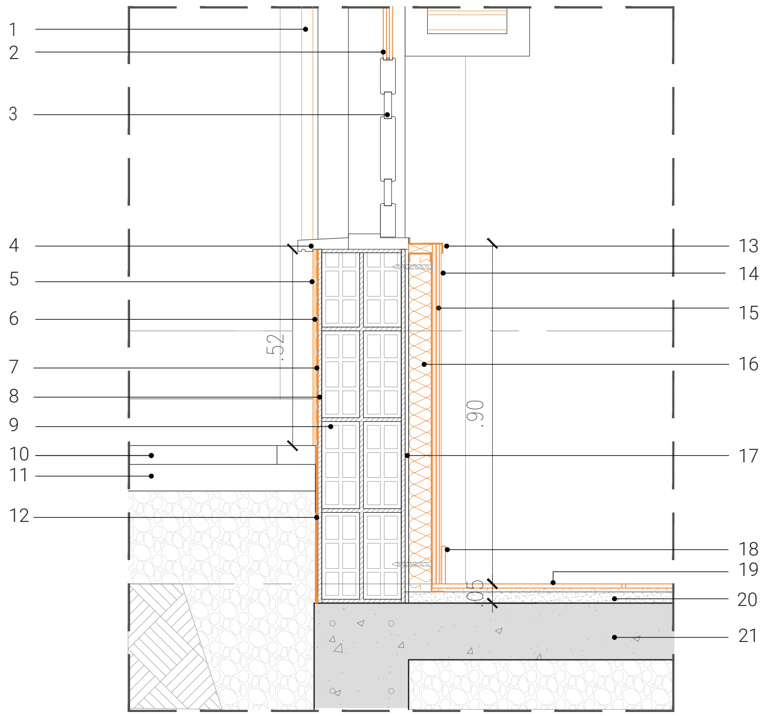


1 Metal Flashing
2 Retractable Multiwall polycarbonate Panels (Rail system) with metalic frame
3 Fabric rectractable Velums- Light color
4 Fixed Glass Louvers with metalic frame
5 Metal structure
6 Metal roof panel_White/Almond/ Light gray
7 Timber framing Purlins
8 Air layer
9 Polyethylene waterproof membrane
10 Fiber glass/ Rock wool Insulation 8cm
11 Polypropylene vapor barrier sheet
12 Timber deck
13 Timber beam structure
14 Metal roof gutter
15 Timber beam structure
16 Timber slatted acoustic ceiling panels

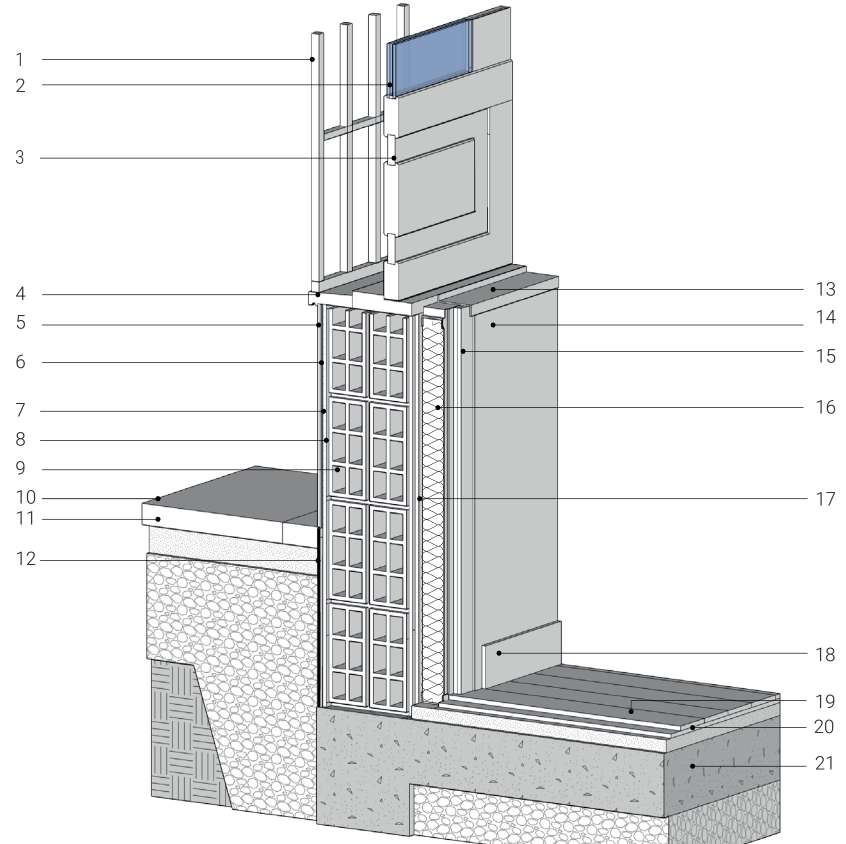
Existing construction elements
Proposal construction addition

DETAIL 1

Fig 6.28 Section detail and axonometry Detail 1/ Source: Author´s elaboration



sc_1:20

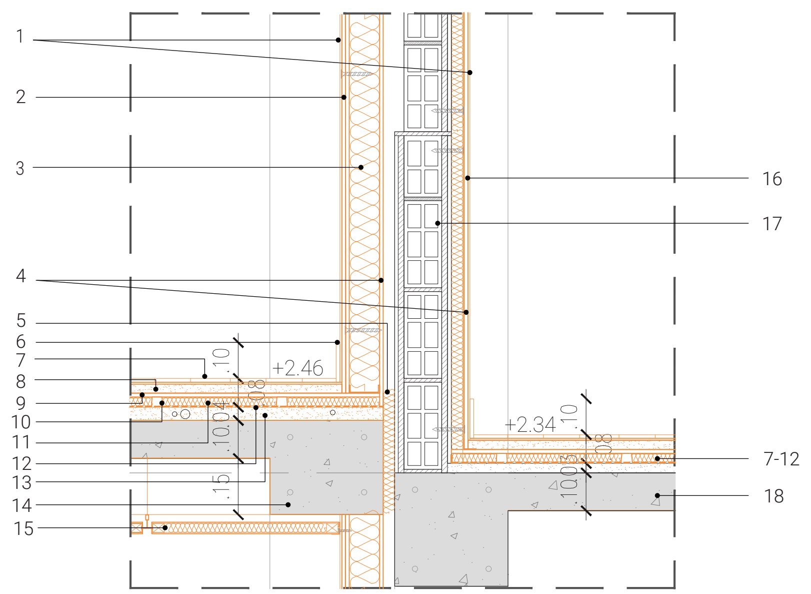


1 Fixed timber shutters
2 Double glazing openable window
3 Timber window frame
4 Timber window sill
5 Stucco + Waterproof Exterior White Painted finish (1cm)
6 Plaster_Cement Mortar
7 Vapour barrier
8 Stucco
9 Existing wall_ Double Clay blocks Ref. N 10cm*20cm*30cm
10 Precast tiles / cobblestone
11 Sand substrate
12 Waterproof membrane
13 Flashing
14 Stucco + White Painted finish (1cm)
15 Gypsum board_Double (2.5 cm)
16 Glass wool/ Rock wool insulation panel (6 cm)
17 Existing Mortar
18 Timber skirting
19 Laminated Timber floor finishes + Adhesive
20 Mortar
21 Existing concrete slab

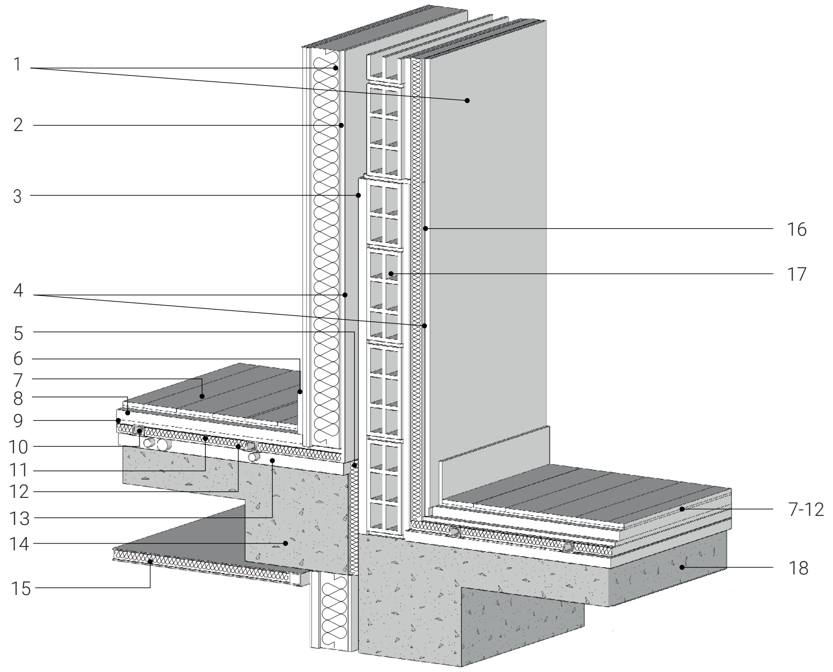
Existing construction elements
Proposal construction addition

DETAIL 2

Fig 6.29 Section detail and axonometry Detail 2/ Source: Author´s elaboration



sc_1:20

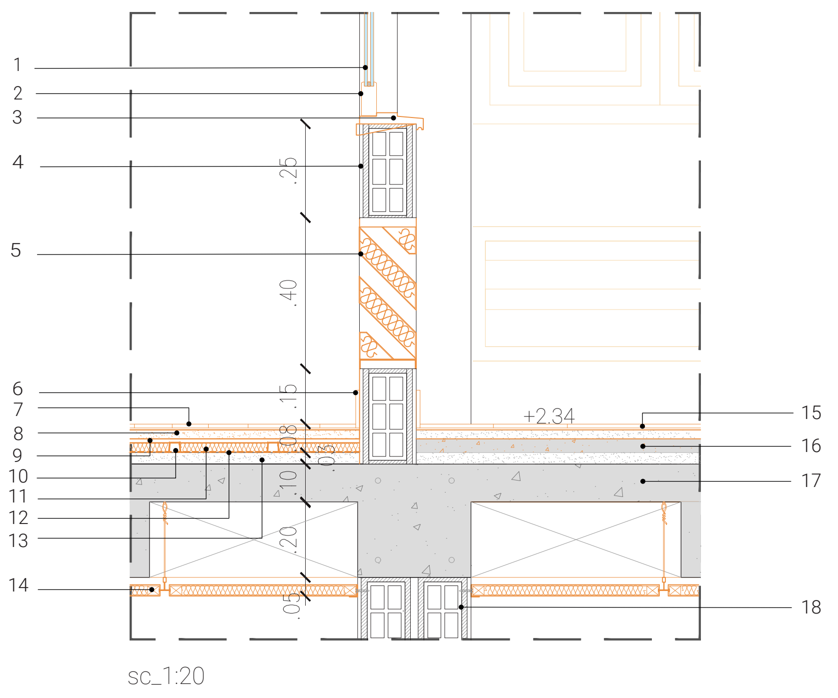


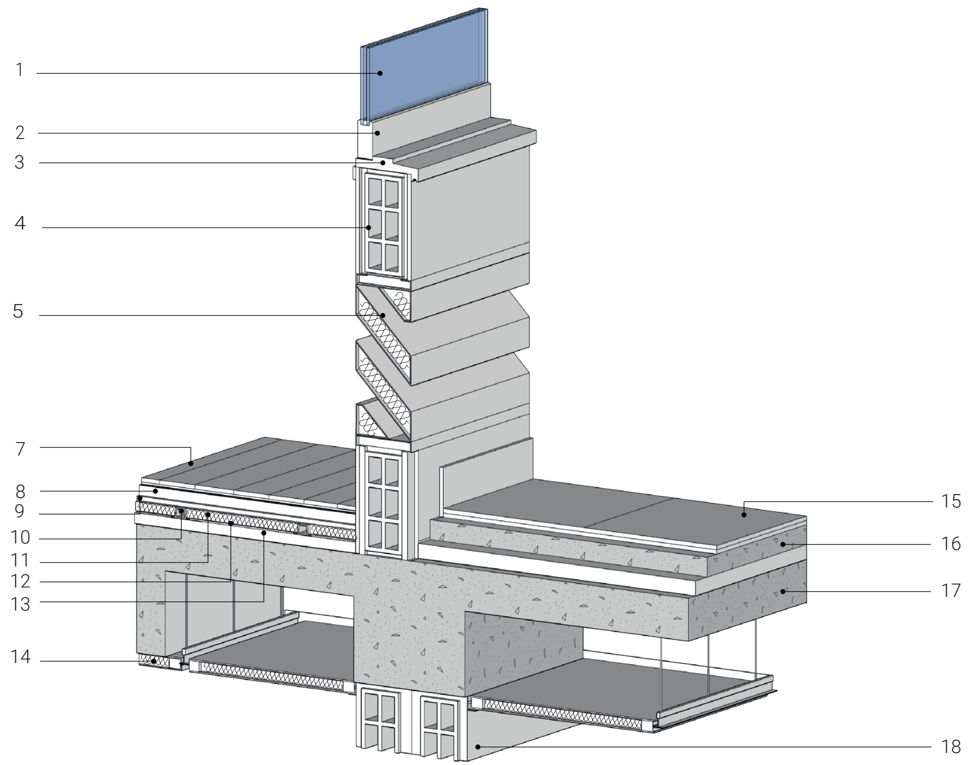
1 Stucco + White Painted finish (1cm)
2 Gypsum board_Double (2.54 cm)
3 Fiber glass insulation panel (8 cm)
4 Gypsum board_Single (1.27 cm)
5 Polyurethane spray foam insulation
6 Timber skirting
7 Laminated Timber floor finishes + Adhesive
8 Mortar
9 Superboard panel (1 cm)
10 Neoprene mount floor
11 Glass wool insulation (6 cm)
12 Acoustic membrane
13 Concrete substrate for conduit pipes (4 cm)
14 New concrete slab
15 Fabric acoustic ceiling panel filled with fiber glass / Gypsum board ceiling
16 Gypsum board_Single (1.27 cm)
17 Existing wall_ Clay blocks Ref. N 10cm*20cm*30cm
18 Existing "Waffle" concrete slab

Existing construction elements
Proposal construction addition

DETAIL 3

Fig 6.30 Section detail and axonometry Detail 3/ Source: Author´s elaboration



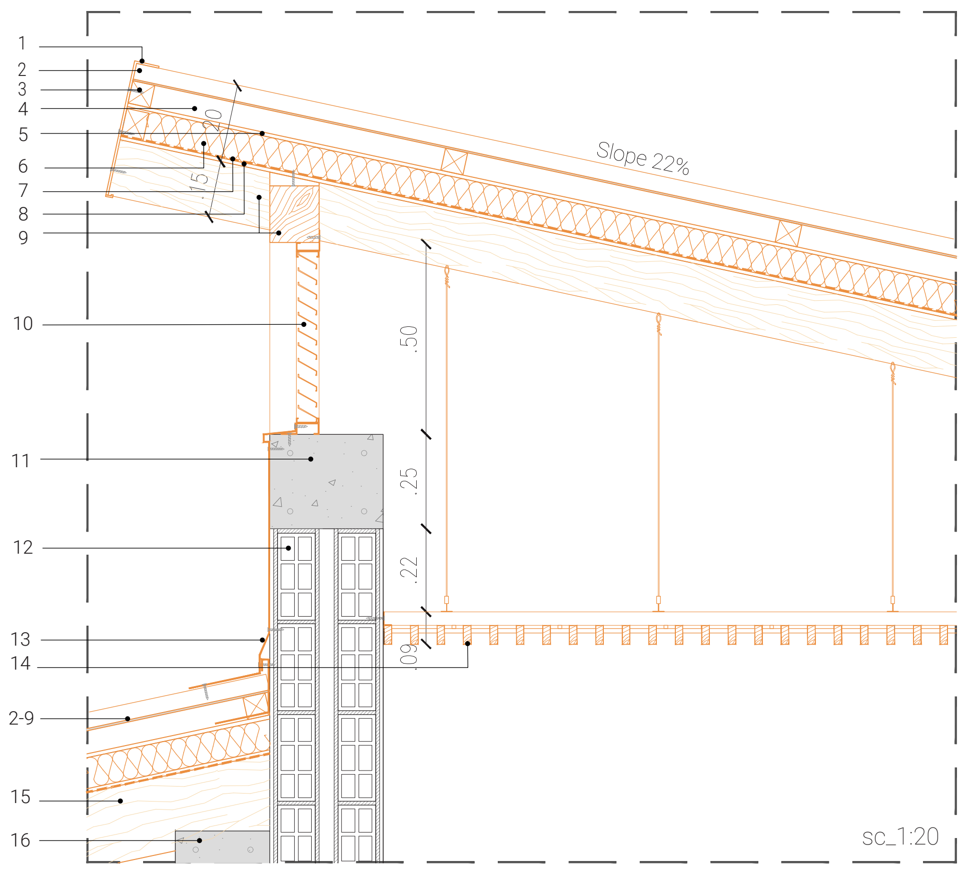


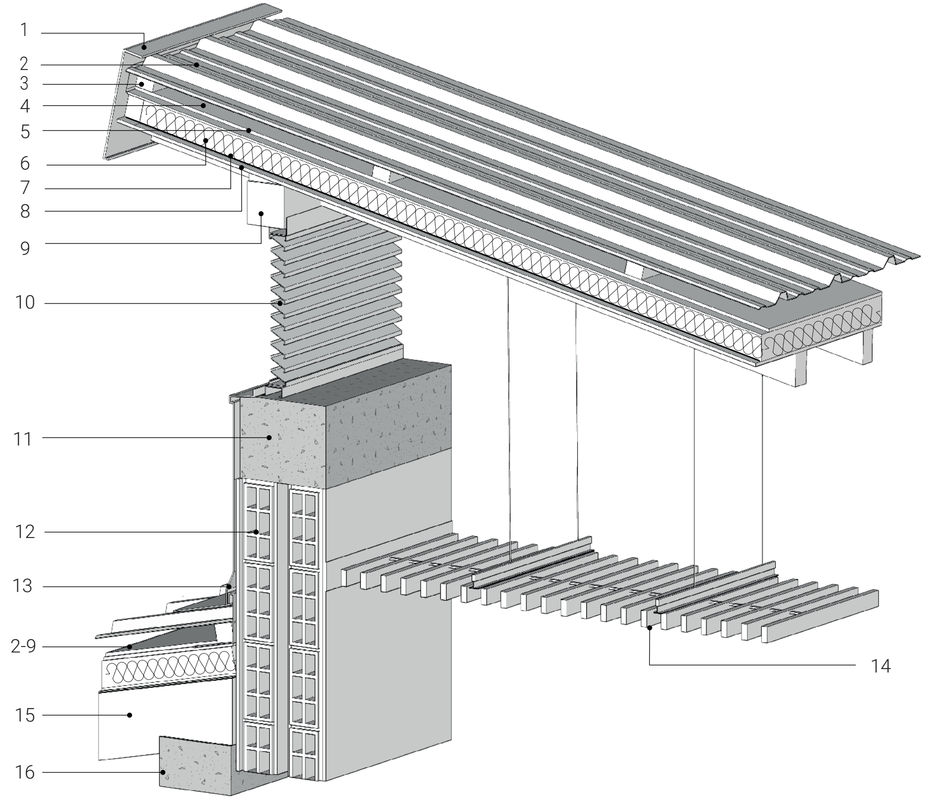
1 Double glass openable window
2 Timber window frame
3 Timber window sill
4 Existing wall_Clay blocks + stucco+ Paint
5 Metal acoustic louver with fiber glass
6 Timber skirting
7 Timber floor finishing + Adhesive
8 Mortar
9 Superboard panel (1cm)
10 Neoprene mounts floor
11 Glass wool (2.5 cm)
12 Acoustic membrane
13 Existing Mortar layer
14 Fabric acoustic ceiling panel filled with fiber glass / Gypsum board ceiling
15 Clay tiles floor
16 Leveling concrete overlay
17 Existing "Waffle" concrete slab
18 Existing double wall_Clay blocks + stucco+ Paint

Existing construction elements
Proposal construction addition

DETAIL 4

Fig 6.31 Section detail and axonometry Detail 4/ Source: Author's elaboration





1 Metal Flashing
2 Metal roof panel_White/Almond / Light gray
3 Timber framing Purlins
4 Air layer
5 Polyethylene waterproof membrane
6 Fiber glass/ Rock wool Insulation 8cm
7 Polyethylene vapor barrier sheet
8 Timber deck
9 Timber beam structure 15 cm Height
10 Metal louver
11 Existing concrete beam
12 Existing wall_Clay blocks + stucco + Paint
13 Metal flashing
14 Solid timber slats ceiling with air gap at the side
15 Timber beam structure 20 cm Height
16 Existing concrete beam

Existing construction elements
Proposal construction addition

DETAIL 5

Fig 6.32 Section detail and axonometry Detail 5/ Source: Author's elaboration

6.3 Conclusions

Based on the problems evidenced through the general and specific analysis of the house, the main objective is to seek passive strategies that mitigate these problems and adapt to current environmental conditions, reducing the need to resort to solutions with a high environmental and economic impact.
According to research on hot humid climate design, the primary strategy for improving comfort is cooling through natural ventilation, among other strategies. That is why the proposal integrates many strategies around ventilation, as well as avoiding heat gain since there is constant high exposure to solar radiation.

Among the strategies adopted for the renovation that represents a great change are: the expansion of the first floor to relocate the individual classrooms that currently do not have ventilation. Also the change of the entire roof due to its materiality of low environmental quality and considered dangerous for health. Adjusting the height of the roof would help reduce overheating in the rooms most exposed to solar radiation, as well as improve the quantity and quality of air through natural ventilation systems. By adding louvers in the upper part, it is possible to apply comfort ventilation through the mechanism stack ventilation in all the first-floor rooms. Additionally, the proposed opening of the skylight of the internal courtyard and increasing its height would help increase ventilation through the stack effect. as well as give greater use to the space as a meeting place. However, elements of horizontal protection against the sun must be located to avoid greater glare. For this, cloth velums are proposed, preferably white or warm colors to increase the reflectivity of the sun rays. To reduce internal heat, other solutions are proposed, such as the implementation of thermal insulation on facades, the addition of shading devices, both horizontal and vertical, and green roofs over communal open areas. the use of these and other implemented strategies also helps to improve the acoustic and visual comfort required especially for the type of use of the building. Being an educational building for children and young people, a lot of attention should be paid to developing spaces that promote learning and social and cultural development.

7 PROPOSAL ROOM ANALYSIS

This chapter aims to check the effectiveness of the renovation proposal through the environmental evaluation of some rooms from the renovation proposal. The rooms will be evaluated again using the same method of the analysis of selected rooms on the chapter 4.
The chosen rooms are “Corocora” classroom in the first floor, and the Scenario /Lobby room that are placed in the internal “Patio” of the house. Those rooms have been chosen according to the results that showed a high degree of thermal and visual discomfort in the analysis carried out for the current design.
In addition to the each evaluation, it has been developed a comparison between the current results and the proposal ones to understand if the applied strategies worked. For the first evaluations, carried out with the same software EnergyVer, it has been simulated different options of the proposal in order to define the best solution regarding mainly to the materials proposed.
As it was done in the evaluation of the current building, this chapter contains 4 categories of analysis: Thermal comfort, Daylight, Airflow and Acoustic comfort.

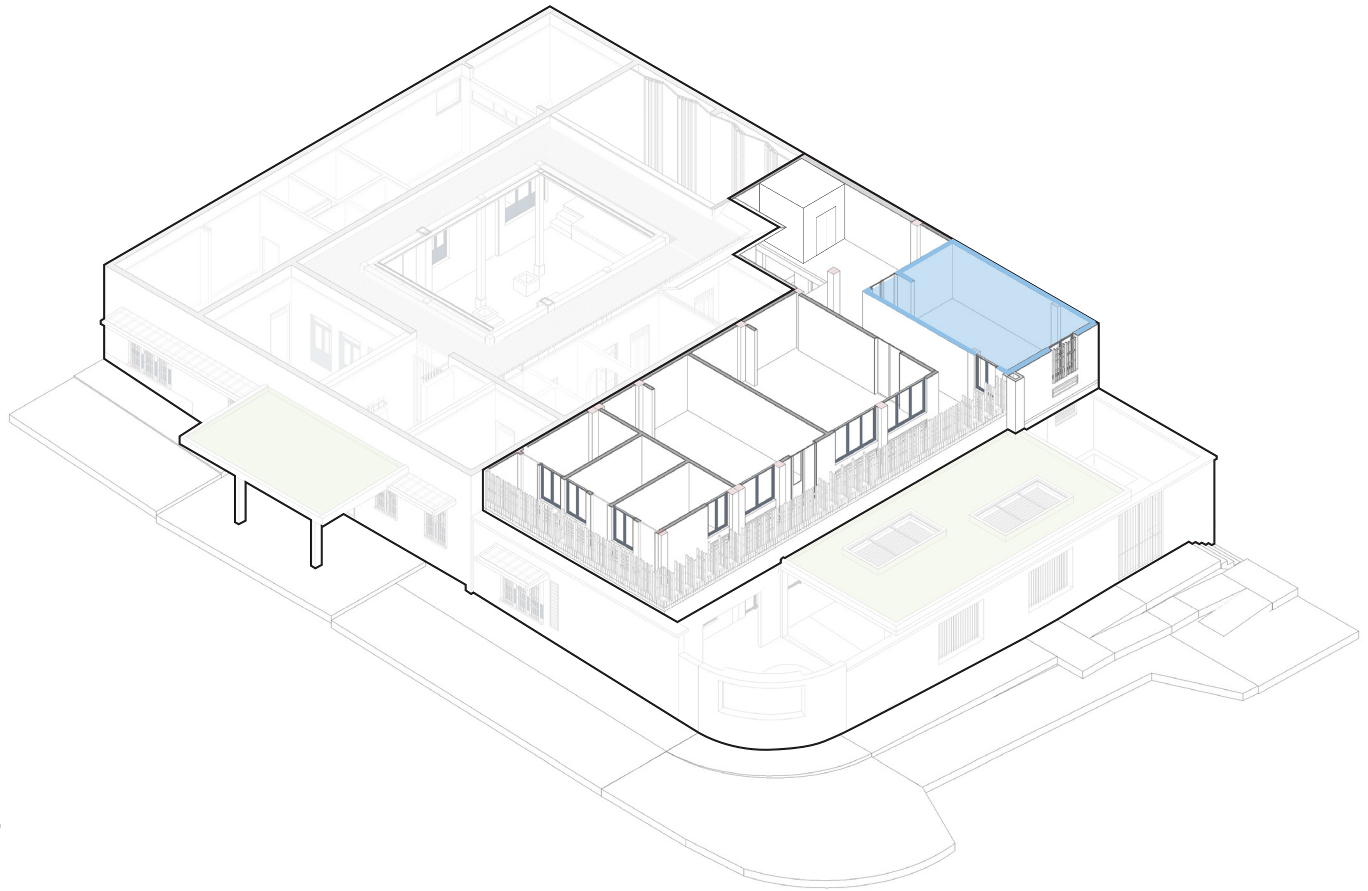


Fig 7.0 Axonometry "Corocora" proposal location/ Source: Author´s elaboration

"COROCORA"

ROOM PROPOSAL ANALYSIS

7.0 ROOM PROPOSAL ANALYSIS: "Corocora" Room

Music Classroom

_Pre-Orchestra Rehearsal (Group)
_Individual Instrument Rehearsal

15 Students (Average capacity)

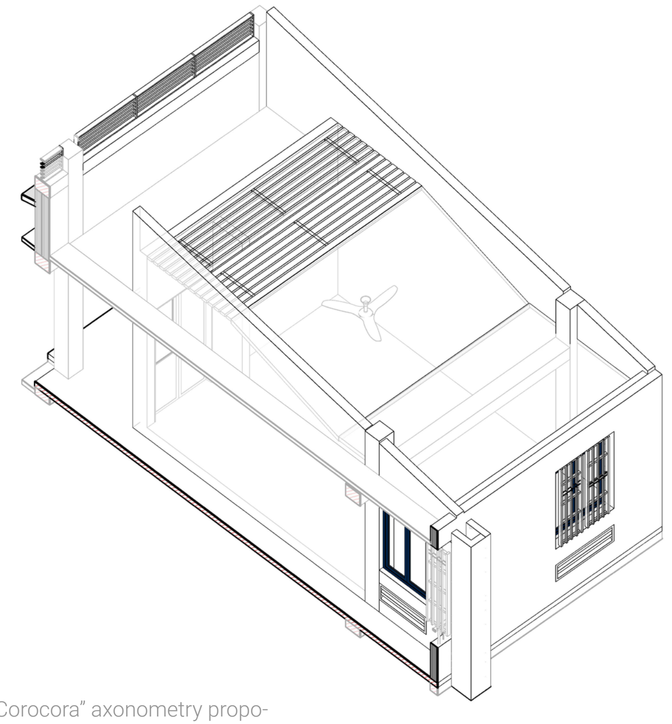
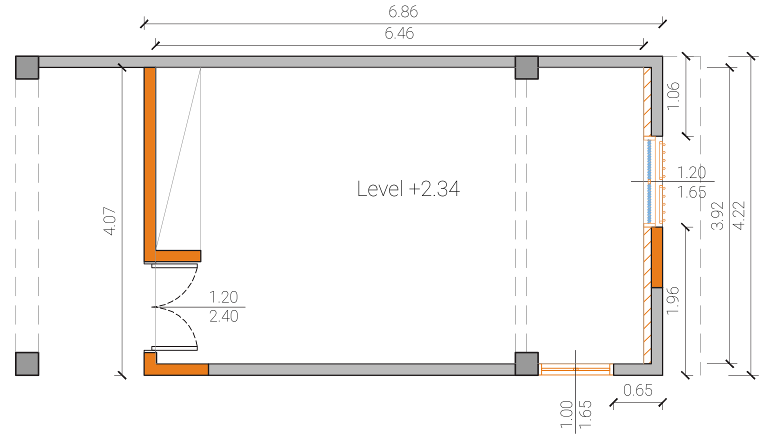
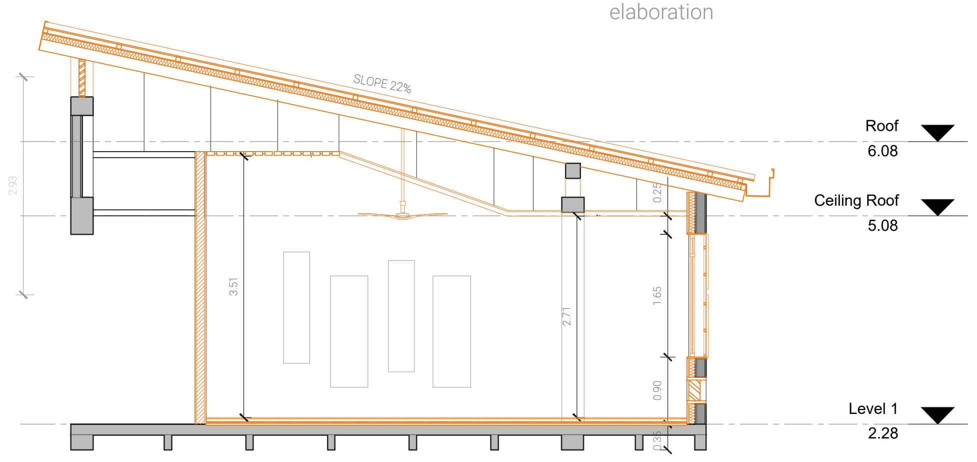


Fig 7.1: "Corocora" axonometry proposal /Source: Author´s elaboration



FLOOR PLAN

Fig 7.2: Floor plan proposal "Corocora" Scale 1:100 /Source: Author´s elaboration



SECTION

Fig 7.3: Section proposal "Corocora" Scale 1:100 /Source: Author´s elaboration

7.1 IMPUT DATA PROPOSAL
“Corocora” Room

Thermal and Daylighting Analysis SIMULATION

To carry out the evaluation, both for Thermal and Daylighting, the software used was EnergyVer. The imput data has been change from the current design according to the new dimensions and characteristics of the proposal.

The room has been simulated with 5 options with different materials. The data shown below corresponds to the option 4, that shows better performance results.

EnergyVer Imput Data

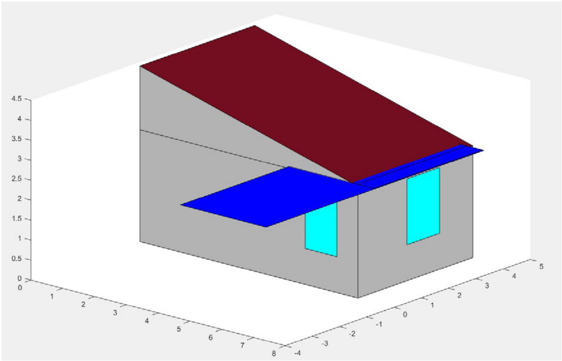


Fig 7.4: Axonometry of the room simulated
Source: EnergyVer simulation

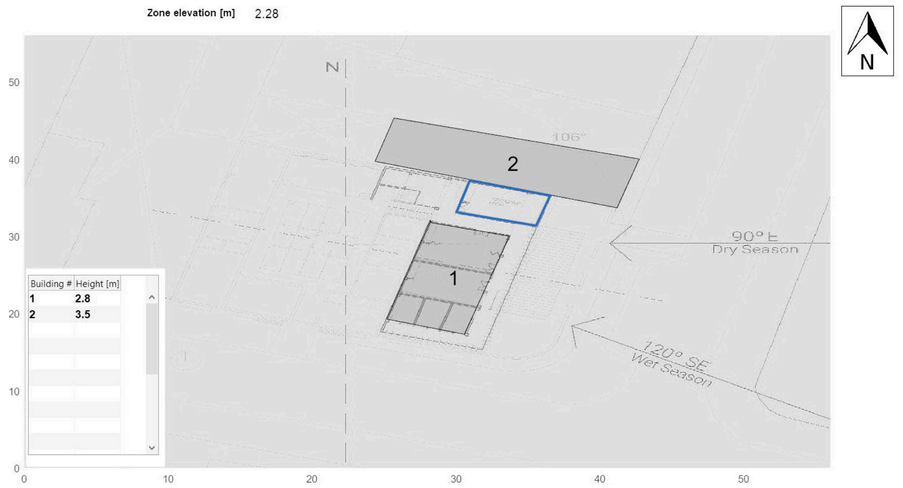


Fig 7.5: Site context
Source: EnergyVer simulation

To calculate the context for shadowing mainly, it has been include the neighbor building and the other classrooms next to it.

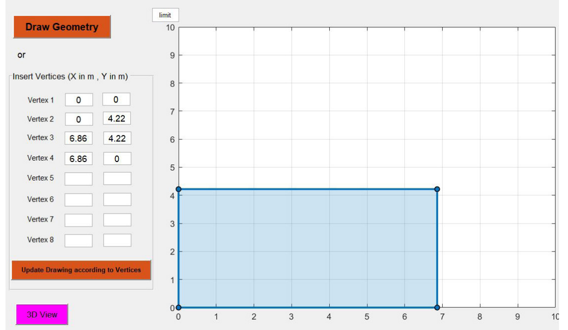


Fig 7.6: Draw geometry
Source: EnergyVer simulation

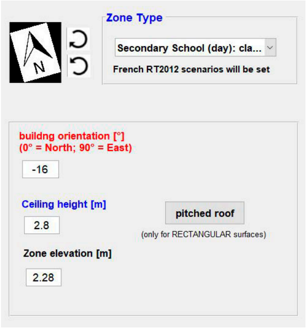


Fig 7.7: Geometry. Zone type
Source: EnergyVer simulation

Drawing Geometry and Function
The dimensions have been adjusted to 6.86 m x 4.22 m. For the ceiling the height remains as 2.8m although the proposal has a variation in the half of the room. The existing window has been modified decreasing its width dimensions and there is a new window in the South-West facade

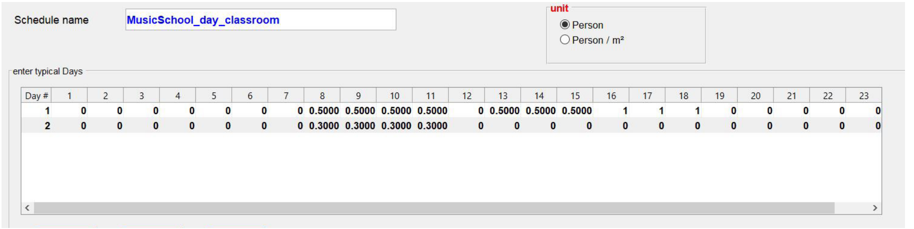


Fig 7.8: Schedule
Source: EnergyVer simulation

Music classroom schedule
The schedule created responds to the school classes that starts at 8:00 and finishes at 19:00, and it works just half day on weekends.

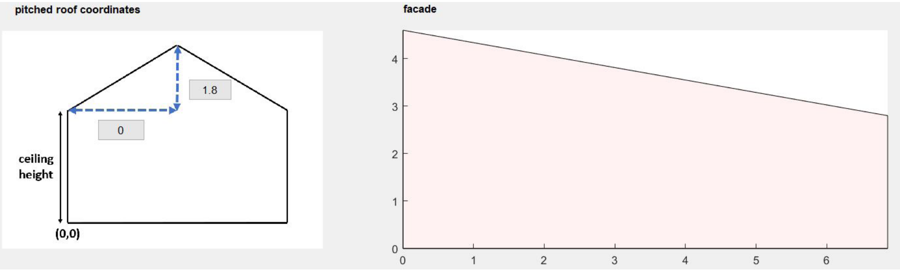


Fig 7.9: Rood data
Source: EnergyVer simulation

Pitched roof characteristics
The height of the pitched roof has been increased from 1.2m to 1.8m where it is located a louver

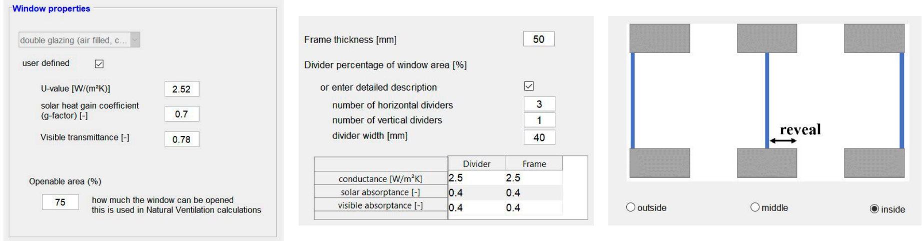


Fig 7.10: Windows properties. Glass and frame
Source: EnergyVer simulation

Window properties
The U-value of the new window is now 2.52 since the glass has been changed to a double-glazing. The solar factor has decreased as well, from 0.8 to 0.7 with the glazing proposal

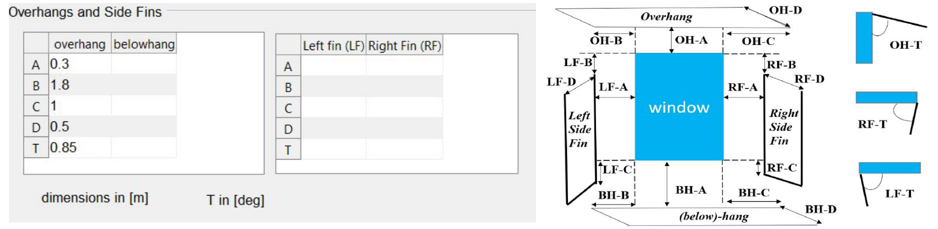


Fig 7.11: Overhangs and side fins
Source: EnergyVer simulation

Shading device dimensions
For each window it has been added a horizontal overhang 0.5 deep that represents the eaves of the roof. The vertical permeable and movable shutters in front of the windows have not been considered due to their complexity in design.

Construction materials:
The room proposal chosen has been simulated with the following materials. Metal roof (Steel) + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder (**Type 2**)+ glasswool ceiling (**Type 4**) + Floor replacement laminated board (**Type 3**)+ East External wall with insulation: Glass wool and gypsum boards (**Type 4**)

Facade type and Boundary conditions
The number on the colored facades corresponds to the material type described before. The boundary conditions have been change. In order to simulate the upper louvers, the wall has been change to Exterior. The reflection of the roof is 0.75 that refers to the SRI of the steel light colored roof.

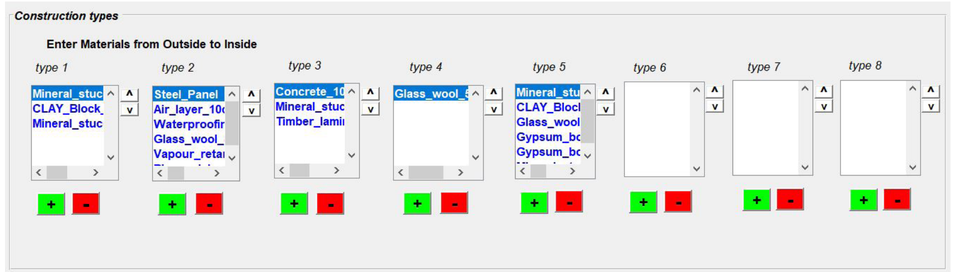


Fig 7.12: Construction types and materials
Source: EnergyVer simulation

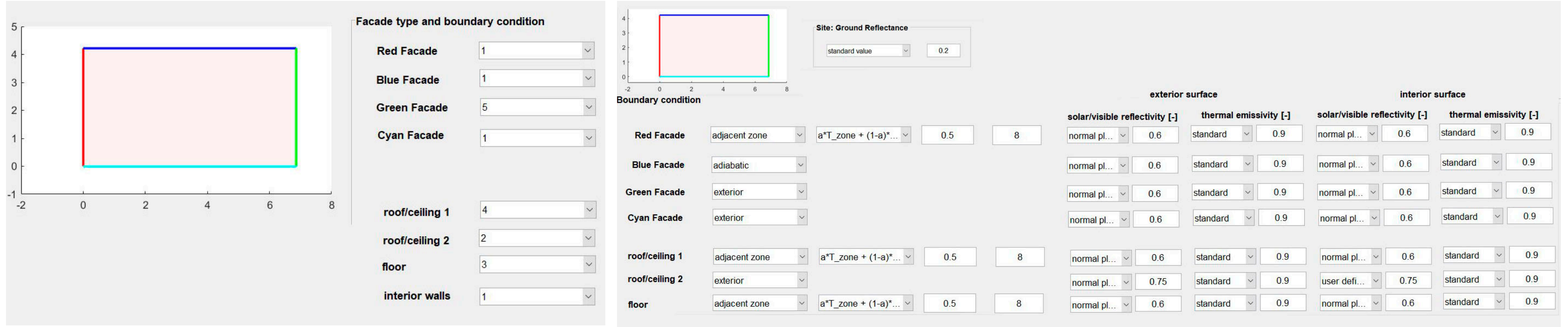


Fig 7.13:Boundary conditions of facades/
Source: EnergyVer simulation

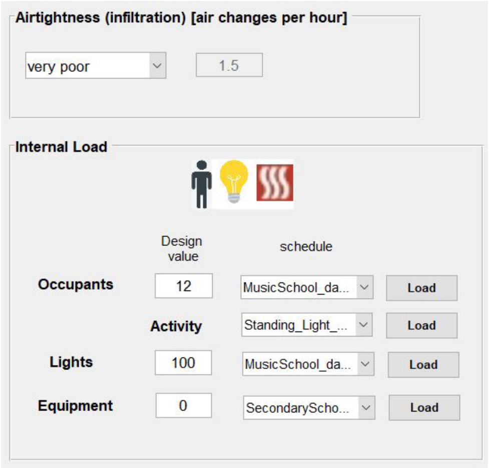


Fig 7.14 Airtighness and occupancy/ Source: EnergyVer simulation

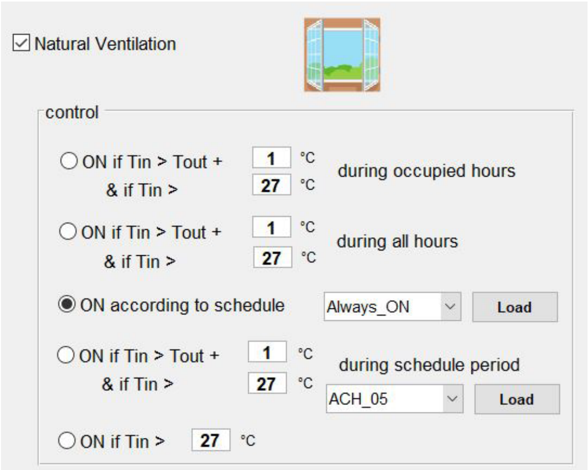


Fig 7.15:Natural ventilation /Source: EnergyVer simulation

Systems and loads:
For the simulation of this room it has been considered always ON the natural ventilation. Another option (Option 5) has been simulated by activating the natural ventilation if the interior temperratur (Tin) is over 27ºC. But the result was an increasment of discomfort hours.
The airtightness is still considered as very poor since the case study has a constant warm and humid climate. The simulation increasing the value has been negative
The values of occupants and lighting remain equal to the proposal imput data, with 12 students in average.

7.2 THERMAL COMFORT ANALYSIS PROPOSAL

"Corocora" Room

- **Total** Occupation Hours/Year: **3020**
- Average Indoor Relative Humidity (Occupation Hours): **76%**

- Occupied hours where Relative Humidity > 70%: **1650 (54% year)**

- Occupied hours where Operative Temperature > T limit (28°C): **1324 (44% year)**
  Occupied hours where Operative Temperature > T limit (30°C): **728(24% year)**
  Occupied hours where Operative Temperature <T limit (21°C): **4 (0.1% year)**

- Overheating hours (EN class 2): **767 (25% year)**

- **Optimal Operative Temperature** (Adaptive EN class 2)
  T_c : 0.33 * T_{rm} + 18.8
  T_c : 0.33 * **24.51 °C** + 18.8
  T_c : **26.88 °C**

  Upper Limit (+3): **29.88 °C**
  Lower Limit (-4): **22.88 °C**

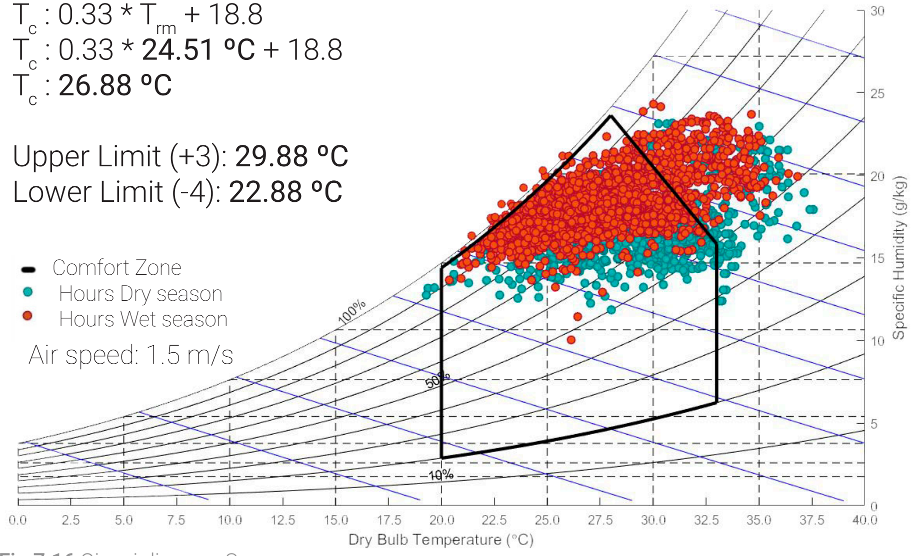
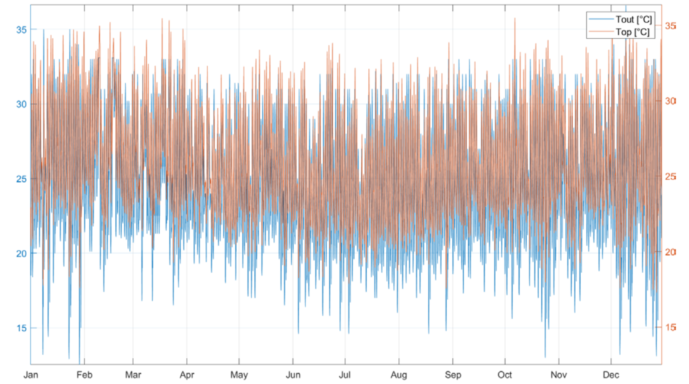


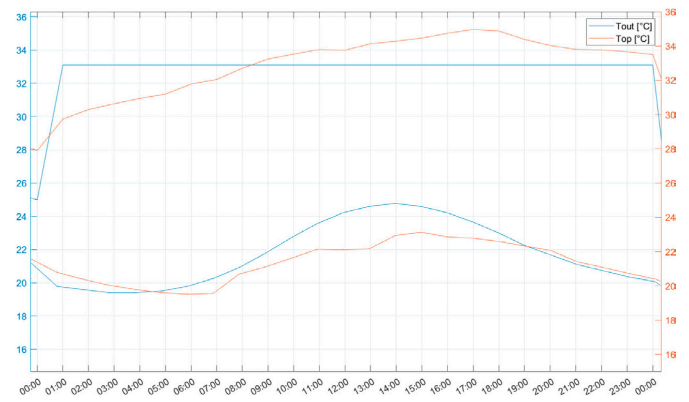
Fig 7.16:Givoni diagram Source: EnergyVer simulation



T Outdoor Air Average: **24.55 °C**

T operative Average: **25.78 °C**

Fig 7.17 **Operative Temperature vs Outdoor Air Temperature Year**



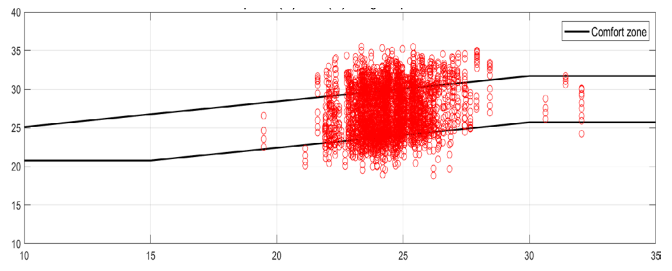
WARMEST DAY
09 February

T Out Average: **33.1 °C**
T op Average: **33.07 °C**

COLDEST DAY
09 Jul

T Out Average: **21.65 °C**
T op Average: **22.00 °C**

Fig 7.18 **Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day**



Average (°C) of hours occupied Year

Running mean Outside T: **24.51 °C**
T Operative **27.38 °C**

Fig 7.19 **Operative Temperature Vs Running Mean Temperature during occupied hours**

According to the simulation of internal thermal comfort, the room still has high Operative temperatures against the Outdoor temperature: 27.38C°/24.51C° of occupied hours. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the proposal value is still out of this limit with 25%year. The warmest day shows a maximum temperature of 33.07c°/33.1c° on 9 February, and the minimum temperature of 22.0 C°/21.65 C°in 9 June. Almost the half of the occupied hours (44%), the Operative temperature is over 28 C° and 24% over 30C°. 54% of occupied hours the relative humidity is over 70%.

7.2.1 COMPARISON THERMAL PERFORMANCE

Current vs Proposal

To find the best solution for thermal comfort improvement, the analysis has been carried out with the simulation of 5 proposal options. Each option varies in the number of new materials and architectural adjustments. The following chart shows the thermal comfort performance of all the options including the base case (current room). For the simulation has been selected a normal level of expectations of Adaptive comfort (EN class 2). In this chart, it is possible to see the more strategies and material layers are, the more decreases the hours of discomfort due to overheating hours. The first option (Op1) maintains the same materials as the current proposal, which are fibercement roof, a Polystyrene foam ceiling, white-painted clay block walls, and clay tiles floor. But it differs from the existing one with the addition of one window in the south-east facade, and the reduction of the existing window dimensions in the east facade. Both windows are proposed with a double-glazing. And also, the enlargement of the room area. For this option and the following 3 options, the simulation takes into consideration the use of natural ventilation always "ON". In the chart, it is possible to see that just with the geometry adaptation the number of discomfort hours is reduced.
The second option (op2) starts from the improvement of the option 1, with the architectural adjustments, but in addition, there is a roof replacement

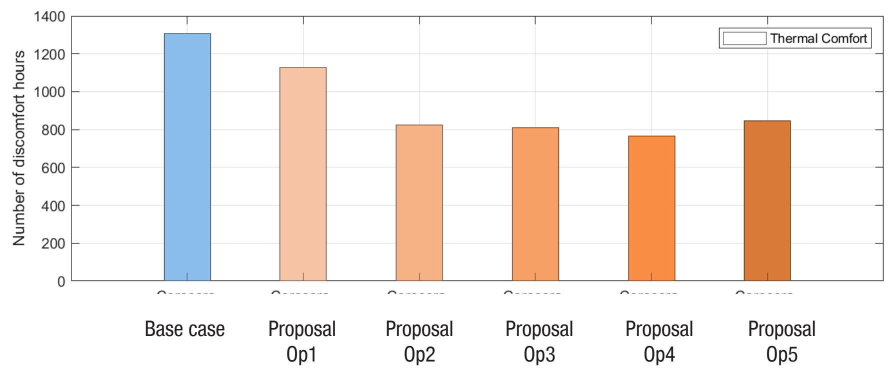


Fig 7.20:Thermal comparison chart-
Source: EnergyVer simulation

BASE CASE (Current state)
Fibercement-Roof + Clay tiles floor + Polystyrene foam ceiling
PROPOSAL Op 1
Fibercement-Roof + Clay tiles floor + Polystyrene foam ceiling + New south window and adjusment of existing one (Double glazing)

PROPOSAL Op 2
New south window and adjusment of existing one (Double glazing) + **Roof Replacement: Terracota tiles + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + Glass wool ceiling +Floor replacement:Timber laminated board**

PROPOSAL Op 3
New south window and adjusment of existing one (Double glazing) + **Roof Replacement: Metal roof (Steel)** + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + Glass wool ceiling + Floor replacement:Timber laminated board.

PROPOSAL Op 4
New south window and adjusment of existing one (Double glazing) + Roof Replacement: Metal roof (Steel) + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + Glass wool ceiling +Floor replacement:Timber laminated board **+ -East External wall with insulation: Glass wool**

PROPOSAL Op 5
New south window and adjusment of existing one (Double glazing) + Roof Replacement: Metal roof (Steel) + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + Floor replacement:Timber laminated board.+ -East External wall with insulation: **Glass wool_ With NATURAL VENTILATION ON only if Tin 27°C**

for cooling the building. In this proposal, it has been changed the height of the roof by increasing its slope and using clay tiles ("colonial style") for the simulation. The altitude growth has allowed the room to have some louvers on the West facade for natural ventilation. Additionally, the ceiling has been replaced by glass wool panels and the floor with a timber parquet.
With all these new materials proposed, there is a great thermal comfort improvement. The number of discomfort hours has decreased by almost 500 hours from the current state of the room.

The third option (Op 3) has almost the same material characteristics as option 2 described before. But differs from the roof material. For this simulation, it has been selected a metal roof, using the properties of steel and with a high Solar Reflectance Index (SRI) color. It has been assumed a SRI of 0.75, is an average between white, almond, and light gray color panels. In the chart of the total comparison, it is possible to see a small reduction in discomfort hours.
For the fourth option (Op 4), the proposal has used the same parameters as Option 3, with the metal roof, but with an addition of an insulated wall. To avoid heat gains from solar radiation, the external wall, which faces the east, has been increased with an addition of mineral insulation of about 8 cm. The results show a thermal comfort improvement against the last options.
The simulation has been also done applying this strategy to all the walls, but the results tend to increase the discomfort because of the climate conditions. According to the simulations, the only facade that needs insulation is the east one.

Finally, the last option (Op 5) has been considered with the same characteristics as option 4 but applies a different method of natural ventilation. For this case, it has been used the mode of active natural ventilation just only if the temperature is above 27ºC or one degree above the outdoor temperature. However, with this option, the result was an increase in discomfort hours because the average temperature is still high, up to 25ºC.
The following chart shows a comparison of operative temperature during the year (2019) between the current room and proposal one (Option 4). According to it, it is possible to see a decrease of higher temperatures with the proposal. The new operative temperatures in the room have an average of 25.78ºC, while the current room has an average of 26.63ºC.

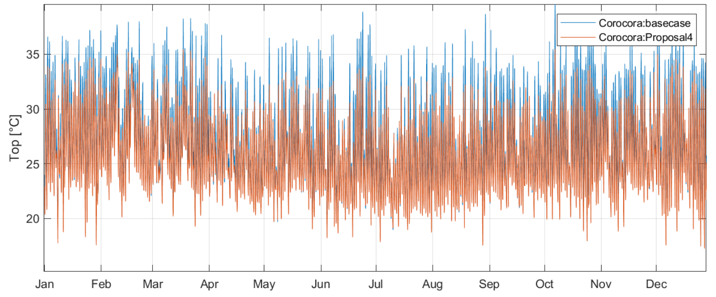


Fig 7.21:Thermal comparison char. Operative temperature. Source: EnergyVer simulation

Despite the operative temperature decrease of almost 1ºC degree, the temperatures remain high, as it is possible to seen in the figue 7.18 below. The chart shows the number of discomfort hours when the operative temperature is over 28ºC in occupied hours. Even with the renewal proposal, the number of discomfort hours at this temperature is over 1300 hours. The average operative temperature when occupied is 27.38ºC. Therefore it is necessary to add other strategies, probably mechanical, to achieve better performance.

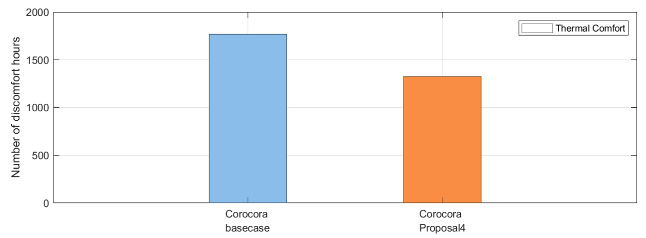


Fig 7.22:Thermal comparison char. Operative temperature. Source: EnergyVer simulation

7.3 DAYLIGHT ANALYSIS PROPOSAL

"Corocora" Room

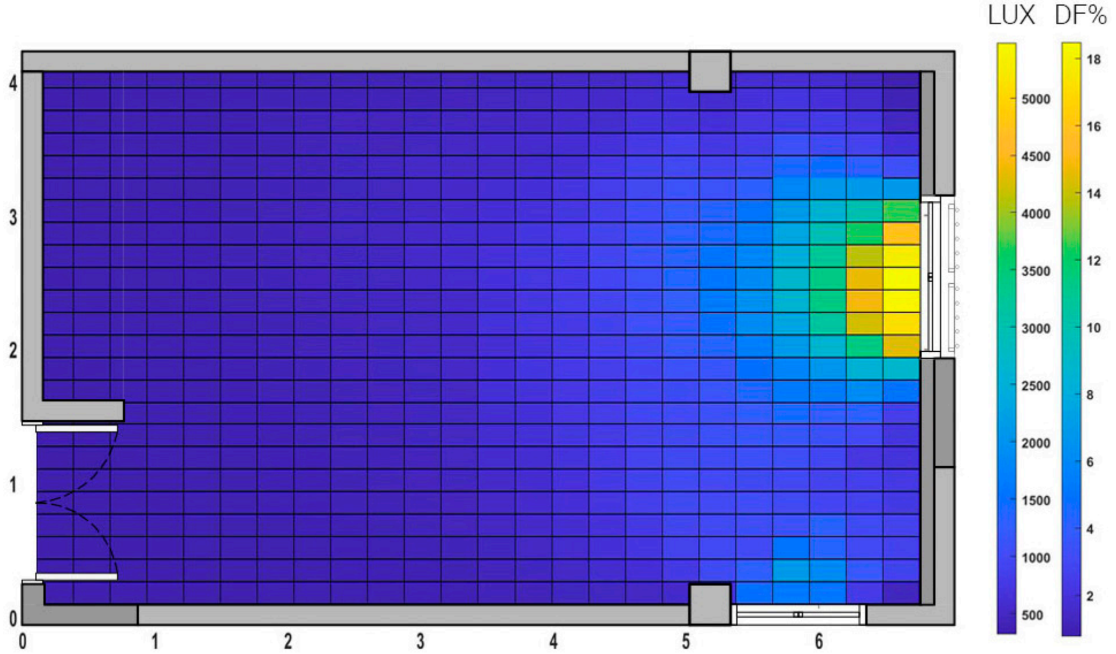


Fig 7.23:Illuminance plan/Source: EnergyVer simulation

Average Year

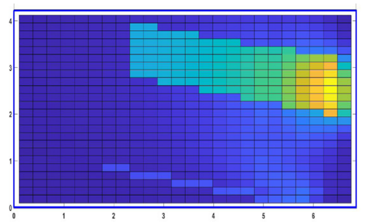
- Mean DAYLIGHT FACTOR (DF): **4.07 %**
  DF threshold level for classrooms : **3%**
  Room Area DF > 3%: **39.4%**
- Mean DAYLIGHT AUTONOMY (DA): **77.08%**
  Room Area DA > 50%: **100%**
- USEFUL DAYLIGHT ILLUMINANCE (uDI): **300 - 3000 Lux**
  Room Area UDI: **30.6% / 80%UDI** (Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **2.7%** Glared area

Fig 7.24:Illuminance plan per hour and season (Dry)/Source: EnergyVer simulation

Fig 7.25:Illuminance plan per hour and season (wet)/ Source: EnergyVer simulation

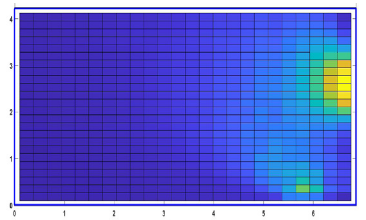
DRY SEASON

21- December 08:00



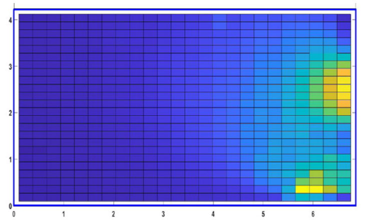
Area DI < 300 lx: **0%**
Area DI > 3000 lx: **3.8%**

21- December 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0%**

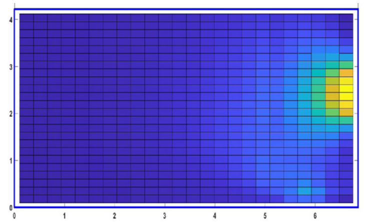
21- December 17:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0%**

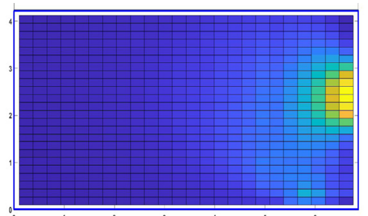
WET SEASON

21-June 08:00



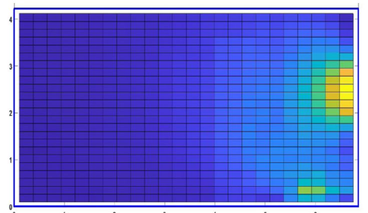
Area DI < 300 lx: **88%**
Area DI > 3000 lx: **0%**

21-June 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0.5%**

21-June 17:00



Area DI < 300 lx: **70%**
Area DI > 3000 lx: **0%**

Based on a minimum daylight factor of 3% for school daylighting, 39.4% of the room area achieves the threshold with a DF of 4.07%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room has lowered the room area requirement with 30.6%/80%. Despite that, the glared area has reduced with mean value 2.7%, in the Wet season in the morning at 8:00.and at 17:00 the room has insufficient illuminance, but meets all the requirements in the dry season.

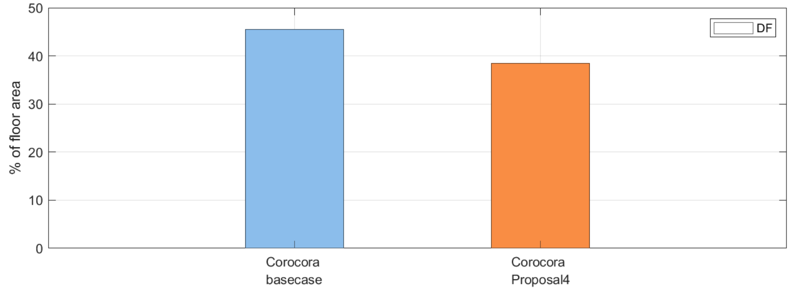


Fig 7.26:Area room of Daylight factor.
Source: EnergyVer simulation

7.3.1 COMPARISON DAYLIGHT PERFORMANCE

Current vs Proposal

According to the analysis of the current room of the building and the proposed one, there are some positive and negative results when comparing both options. As it has been explained in the last analysis about thermal comfort, the simulation has been carried out with 4 proposal options changing their materials. However, the architectural design parameters regarding the dimensions of the room, as well as the location and dimension of its window. Therefore, the simulations show similar results between all the options. Option 4 has been selected for the comparison between the existing building and the proposed one.

In the case of Daylight Factor (DF) in the following graph, the proposal reduces the mean DF room area in the year with 39.4% against the current one that is 48.5%. But the proposal is still meeting the DF required for classooms that should be at least an average of 3% DF of the room area. this could have happened because the area of the room was increased by extending the depth of the room. Also because the width of the window on the east façade was reduced to reduce the glare and the amount of solar radiation. Although a new window has been located in the south-east façade, the results show a daylighting decrease.

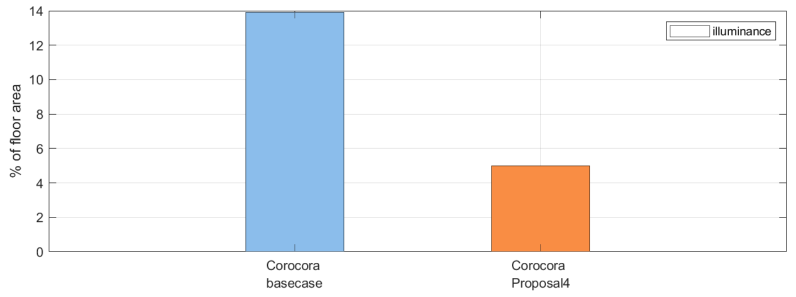


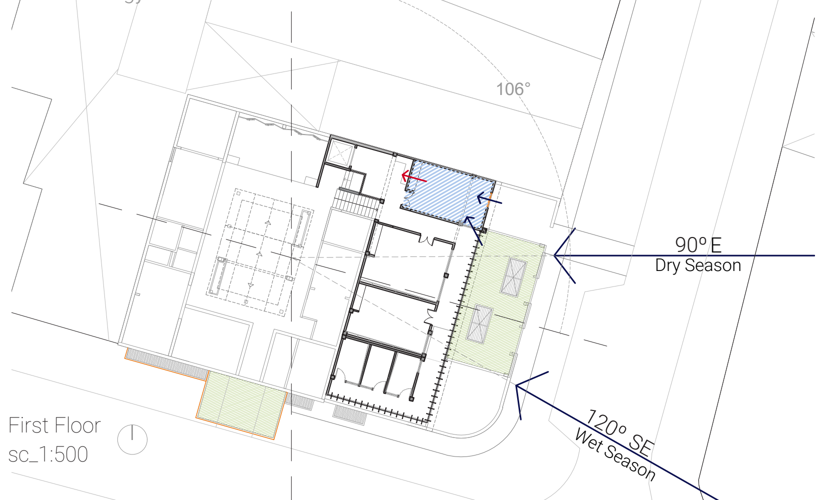
Fig 7.27:Illuminance Comparison Current and Proposal
Source: EnergyVer simulation

On the other hand, the Useful Daylight illuminance (UDI) has been improved with the proposal. The amount of mean glared area of the room decreased considerably from 14.1% to 2.7%. However, there is a high percentage, up to 70%, in the morning and afternoon in wet season that not meets the minimum required for daylight illuminance.

7.4 AIRFLOW ANALYSIS PROPOSAL

"Corocora" Room

Fig 7.28: wind direction plan
Source: EnergyVer simulation



Area Room: 25.3 m²

- Minimum Area Windows per room (A room/8): **3.16m²**
- Area total Windows (Proposal): **3.63 m²**

STACK VENTILATION CALCULATION

Calculation Proposal: January

$$q_s\,[m^3/s] = C_d * A * \sqrt{2 * g * H * \frac{abs(T_z - T_e)}{T}}$$

$$q_s\,[m^3/s] = 0,6 * 1,15 * \sqrt{2 * 9,8 * 2,9 * \frac{abs(29,55 - 28,73)}{29,14}}$$

$$q_s\,[m^3/s] = 0,87$$

$$q_s\,[m^3/s] = 0,87 * 3600$$

$$q_{s,h}\,[m^3/h] = \mathbf{3141,53}$$

REQUIREMENTS

Table 7.0 AIRFLOW RATE FOR IAQ (Indoor Air Quality)

$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}IAQ(p)*}$ [m³/	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
157,5	28	15	0,375	9

vol [m³]	$ACH_{r\text{-}IAQ}$ [1/h]
75,90	2,08

Table 7.1 AIRFLOW RATE FOR COOLING

airflow rate for cooling

	$q_{r\text{-}cool}$ [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]
JAN	**682,97**	185,04	0,28	1,18	**29,6**	28,7
FEB	**986,38**	185,76	0,28	1,18	**29,6**	29,0
MAR	**483,22**	178,82	0,28	1,18	**29,1**	27,9
APR	**922,96**	173,82	0,28	1,18	**27,4**	26,9
MAY	**572,12**	170,13	0,28	1,18	**28,1**	27,2
JUN	**726,83**	168,10	0,28	1,18	**27,4**	26,7
JUL	**5107,61**	168,76	0,28	1,18	**26,8**	26,7
AUG	**918,40**	172,96	0,28	1,18	**27,8**	27,2
SEPT	**1086,44**	179,48	0,28	1,18	**28,1**	27,6
OCT	**621,07**	184,68	0,28	1,18	**28,7**	27,8
NOV	**583,01**	183,00	0,28	1,18	**28,5**	27,5
DEC	**859,74**	181,80	0,28	1,18	**28,9**	28,3

vol [m³]	$ACH_{r\text{-}cool}$ [1/h]
75,90	9,00
75,90	13,00
75,90	6,37
75,90	12,16
75,90	7,54
75,90	9,58
75,90	67,29
75,90	12,10
75,90	14,31
75,90	8,18
75,90	7,68
75,90	11,33

Table 7.2 PROPOSAL AIRFLOW VS REQUIRED

	Proposal	Requirements	
	q_s,h [m3/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	**2458,59**	157,5	682,97
FEB	**2044,39**	157,5	986,38
MAR	**2905,94**	157,5	483,22
APR	**2123,81**	157,5	922,96
MAY	**2646,13**	157,5	572,12
JUN	**2356,39**	157,5	726,83
JUL	895,78	157,5	5107,61
AUG	**2110,63**	157,5	918,4
SEPT	**1963,79**	157,5	1086,44
OCT	**2615,99**	157,5	621,07
NOV	**2700,85**	157,5	583,01
DEC	**2191,69**	157,5	859,74

$q_{r\text{-}IAQ(p)}$ [m³/h]: min. required airflow rate per person
ACH_{IAQ} : Air change per hour
$q_{r\text{-}cool}$ [m³/h]: min. required airflow rate for cooling
$\rho_{a;ref}$ [kg/m³]: Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ [kg/m³]: Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} [1 m/s]: Coefficient of wind speed
C_t [m/s]: Coefficient of wind turbulence
C_{st} [m/s]: Coefficient of stack effect
$u_{10;site}$ [m/s]: Wind at the zone level, at 10 m height
$h_{w;st}$ [m]: Useful height for stack effect for airing
$h_{w;fa}$ [m]: Free area height of the window "i"
$h_{w;path}$ [m]: Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i [°C]: day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air
H [W]: day-averaged hourly heat gain in a space
g [m/s]: Acceleration of gravity

According to the Italian decree DM 05-07-75,, the minimum area of windows of this room should be 3.16 m² (1/8th floor area). The new proposed windows are meeting the minimum area required with 3.63m².
The ventilation system has changed from single-sided ventilation to stack ventilation. With the new proposal the airflow entering through the windows meets the minimum Day average IAQ requirements for the room that is 157.5m3/h, as well as for cooling requirements. But it is insufficient for cooling in July due to low temperature differences in that month.

7.4.1 COMPARISON AIRFLOW PERFORMANCE

Current vs Proposal

When comparing the analysis of the proposal with the existing room, the change generated by the type of ventilation system used is evident. while the figure 7.29 of the current state shows that with the single-sided ventilation design the airflow does not reach the required airflow in most months, both airflow rate for Indoor Air Quality ($q_{r\text{-}IAQ}$) and airflow rate for cooling ($q_{r\text{-}cool}$), the one of the proposal (figure 7.30) with stack ventilation shows a clear improvement.
The large increase in the amount of airflow in the proposal is due to adjustments in the architectural design in which the addition of a new window, the reduction of the current window on the east façade, and the addition of louvers on the upper west side are proposed, as well as the increase of the ceiling and roof height. It is important to clarify that the results show an airflow rate considering the windows always opened.
While the stack ventilation depends on the temperature difference, rather than air pressures, in the proposal the airflow rates tend to be high in all months except July. This is the coldest month, therefore, its temperature difference is short. In this case, the ventilation should be provided by using other mechanical methods to help the air to increase its speed to improve the comfort.

Table 7.3 CURRENT
Single-sided Ventilation

	Current state	Requirements	
	q_v-IAQ [m³/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	216,43	157,5	473,43
FEB	134,53	157,5	598,47
MAR	188,00	157,5	294,16
APR	139,96	157,5	514,83
MAY	179,90	157,5	304,48
JUN	167,01	157,5	348,75
JUL	116,73	157,5	716,85
AUG	148,81	157,5	453,01
SEPT	125,52	157,5	662,51
OCT	172,65	157,5	361,09
NOV	168,28	157,5	376,37
DEC	132,94	157,5	598,87

Table 7.4 PROPOSAL
Stack Ventilation

	Proposal	Requirements	
	q_s,h [m3/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	**2458,59**	157,5	682,97
FEB	**2044,39**	157,5	986,38
MAR	**2905,94**	157,5	483,22
APR	**2123,81**	157,5	922,96
MAY	**2646,13**	157,5	572,12
JUN	**2356,39**	157,5	726,83
JUL	895,78	157,5	5107,61
AUG	**2110,63**	157,5	918,4
SEPT	**1963,79**	157,5	1086,44
OCT	**2615,99**	157,5	621,07
NOV	**2700,85**	157,5	583,01
DEC	**2191,69**	157,5	859,74

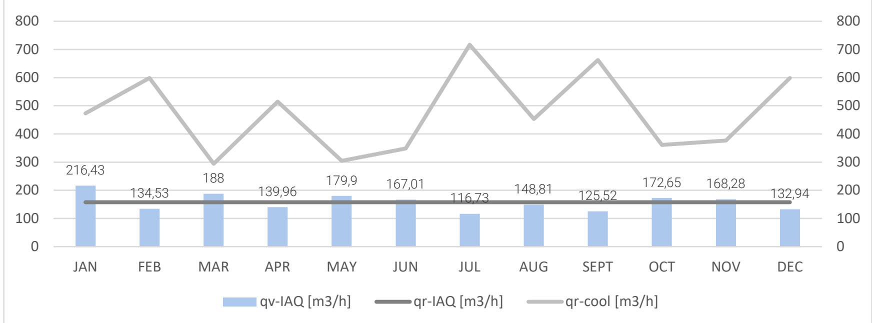


Fig 7.29 Comparison Airflow Current state vs requirements
Source: Author´s elaboration

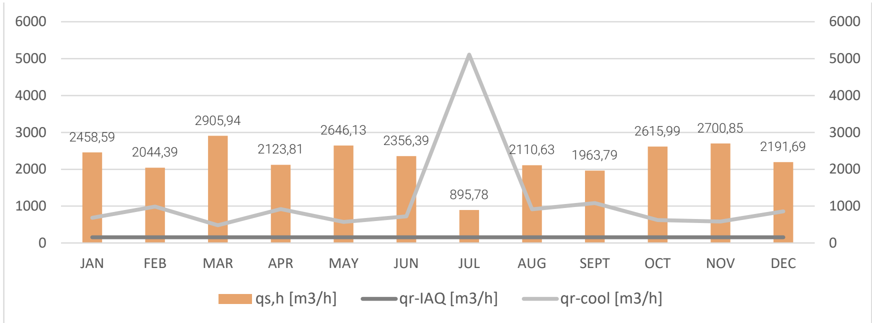


Fig 7.30 Comparison Airflow proposal vs requirements
Source: Author´s elaboration

7.5 ACOUSTIC ANALYSIS PROPOSAL

"Corocora" Room

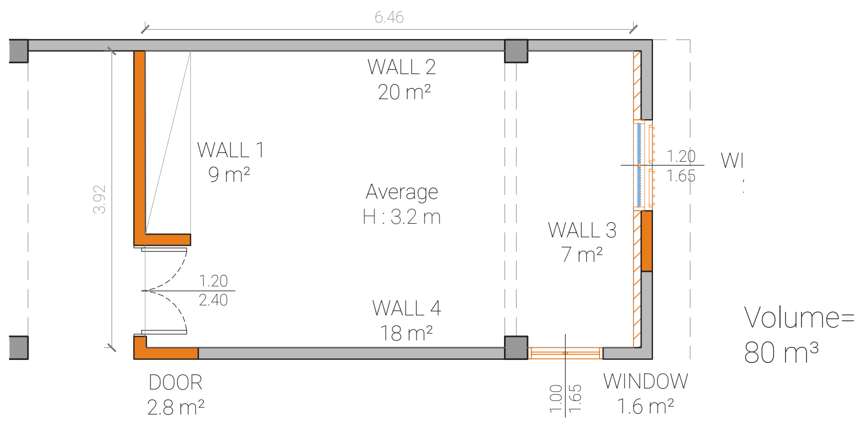
For the acoustic analysis of the proposal, it has been used the same methodology as the current analysis to calculate the reverberation time of the room. Since the dimensions of the room have changed, all the data of the calculation have been replaced. The room volume has been considered as an average taking into account the new ceiling has different heights. The new volume is 80 m³. As well as the new windows or walls have been added.

The proposal has been calculated and divided into 3 options that differ between them in some materials for the ceiling and/or floor.
-Proposal Option A: This proposal has kept the floor and walls materials from the current proposal, but it has a new ceiling divided into 2 areas with different materials. One part is composed of wooden slats with an air gap behind it (for ventilation proposal), and the other is with fabric glass wool insulated panels.
-Proposal Option B: The second one remains as the current proposal with the same floor and walls, but the ceiling is composed of wooden slats with an air gap behind (as Option A) and glazed painted plasterboard.
-Proposal Option C: The last one uses the same ceiling as option B, but it has a wood parquet over concrete for flooring.

REVERBERATION TIME: PROPOSAL Option C	Empty Room	Occupied Room
T60 (125Hz): $\frac{0.16 x 80\ m^3}{11.05}$	**1.16 s**	**0.83 s**
T60 (500Hz): $\frac{0.16 x 80 m^3}{7.67}$	**1.67 s**	**0.71 s**
T60 (1000Hz): $\frac{0.16 x 80\ m^3}{5.77}$	**2.22 s**	**0.79 s**

OPTIMAL T60: 0.8s - 0.9 s

Fig 7.31 Acoustic proom plan/Source: Author´s elaboration



For the following calculation formula and table, it has been chosen option C. Additionally, it has been added a calculation for a half occupied room with the option of using removable insulated fabric panels that can be put on and taken off.

Table 7.5 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS OPTION C**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+4)	46	Painted plaster on Clay block	0,02	0,02	0,02
Wall (3)	7	Gypsum board + Glass wool	0,3	0,15	0,05
Ceiling 1	18	Glazed paint Plaster board	0,29	0,05	0,03
Ceiling 2	7	Wooden Slats+ Air gap	0,14	0,4	0,32
Floor	25	Wood parquet on concrete	0,04	0,07	0,06
Door	2,9	Solid wood	0,1	0,05	0,04
Window	3,6	Double glass	0,15	0,03	0,03
Musicians playing(15)			0,29	0,69	0,7
Movable wall panels	3	Fabric +Glass wool panel	0,06	0,6	0,91
Total Empty room			11,05	7,674	5,7752
Total Half Occupied			13,55	14,994	14,105
Total Occupied			15,4	18,024	16,275

7.5.1 COMPARISON ACOUSTIC PERFORMANCE

Current vs Proposal

According to the following results for each of the proposed options, it is possible to see that most of the options have an improvement of the reverberation time of the room, which was very short when occupied according to the data of the first analysis (chapter 4). However it varies from on option to another according to the materials and just 2 options could meet the requirement of the optimal T_{60} that should be between 0.8 and 0.9s fo music classroom. All the new proposal options, unlike the existing one, have a wall with an addition of gypsum board and thermal insulation on one facade, as well as a part of the ceiling with wooden slats and air cavities as a ventilation system.

The graph of the empty room shows always a long reverberation time on each proposal option. While the time at the frequency decreases with each proposal, at higher frequencies it increases. However, the reference point fo the study of the proposal will be the occupied or half-occupied

Table 7.6 **COMPARISON REVERBERATION TIME CURRENT VS PROPOSALS**

	CURRENT	125Hz	500Hz	1000Hz
T_{60}	Total Empty room	2,67	0,94	1,06
	Total Half Occupied	1,65	0,62	0,66
	Total Occupied	1,24	0,48	0,50

	PROPOSAL A	125Hz	500Hz	1000Hz
T_{60}	Total Empty room	1,73	0,96	0,66
	Total Half Occupied	1,31	0,68	0,51
	Total Occupied	1,09	0,54	0,43

	PROPOSAL B	125Hz	500Hz	1000Hz
T_{60}	Total Empty room	1,24	2,12	2,92
	Total Half Occupied	1,00	0,96	1,01
	Total Occupied	0,87	0,78	0,86

	PROPOSAL C	125Hz	500Hz	1000Hz
T_{60}	Total Empty room	1,16	1,67	2,22
	Total Half Occupied	0,94	0,85	0,91
	Total Occupied	0,83	0,71	0,79

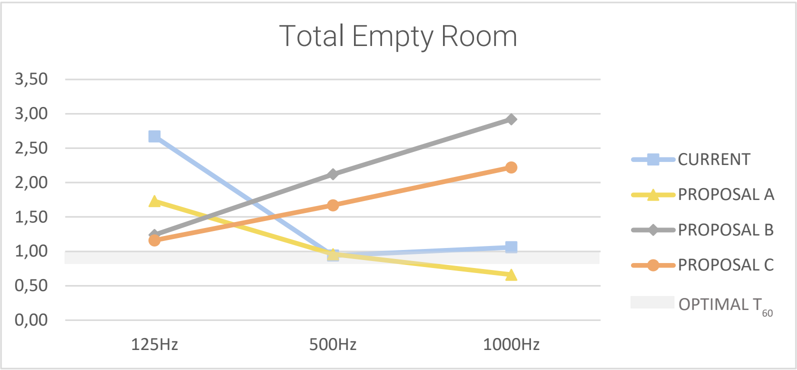


Fig 7.32:Comparison Empty room Reverberation time between current and proposals
Source: Author´s elaboration

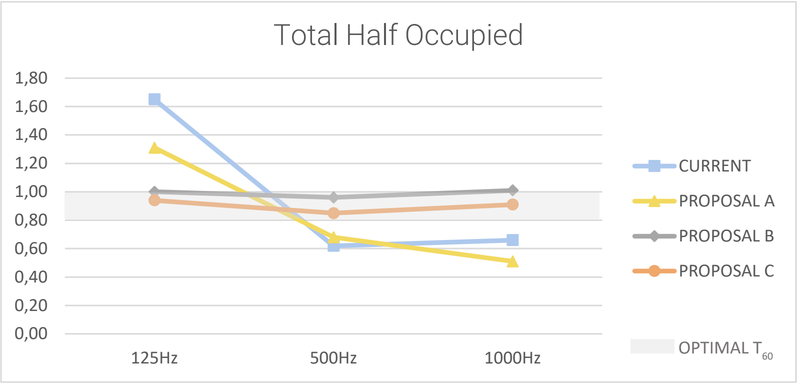


Fig 7.33:Comparison Half occupied room Reverberation time between current and proposals. Source: Author´s elaboration

room In proposal option A, the replacement of one part of the ceiling with a common acoustic material, as it is the fabric insulated panel with glass wool, does not improve considerably the reverberation time and does not reach the optimal T_{60} . This is due to the existence of great absorptive areas.

In proposal option B, the replacement of the ceiling with glazed painted plasterboard allows for meeting the requirements of optimal T_{60} when occupied in the lower and higher frequencies. When it is half of its occupancy (8 out of 15 students), the reverberation tends to be longer than the optimal value. However, it is proposed the addition of removable fabric insulated panels that can be manipulated depending on the number of students in class.

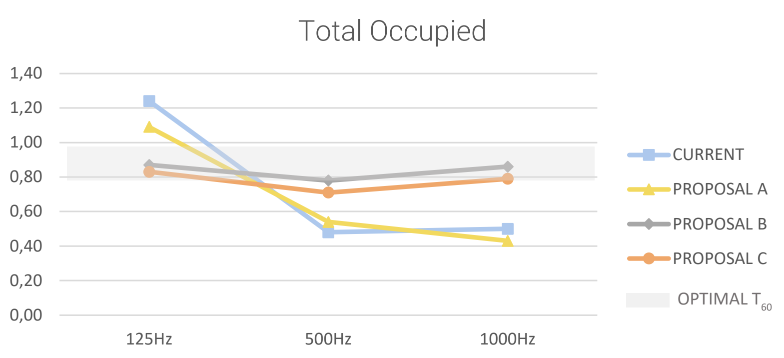
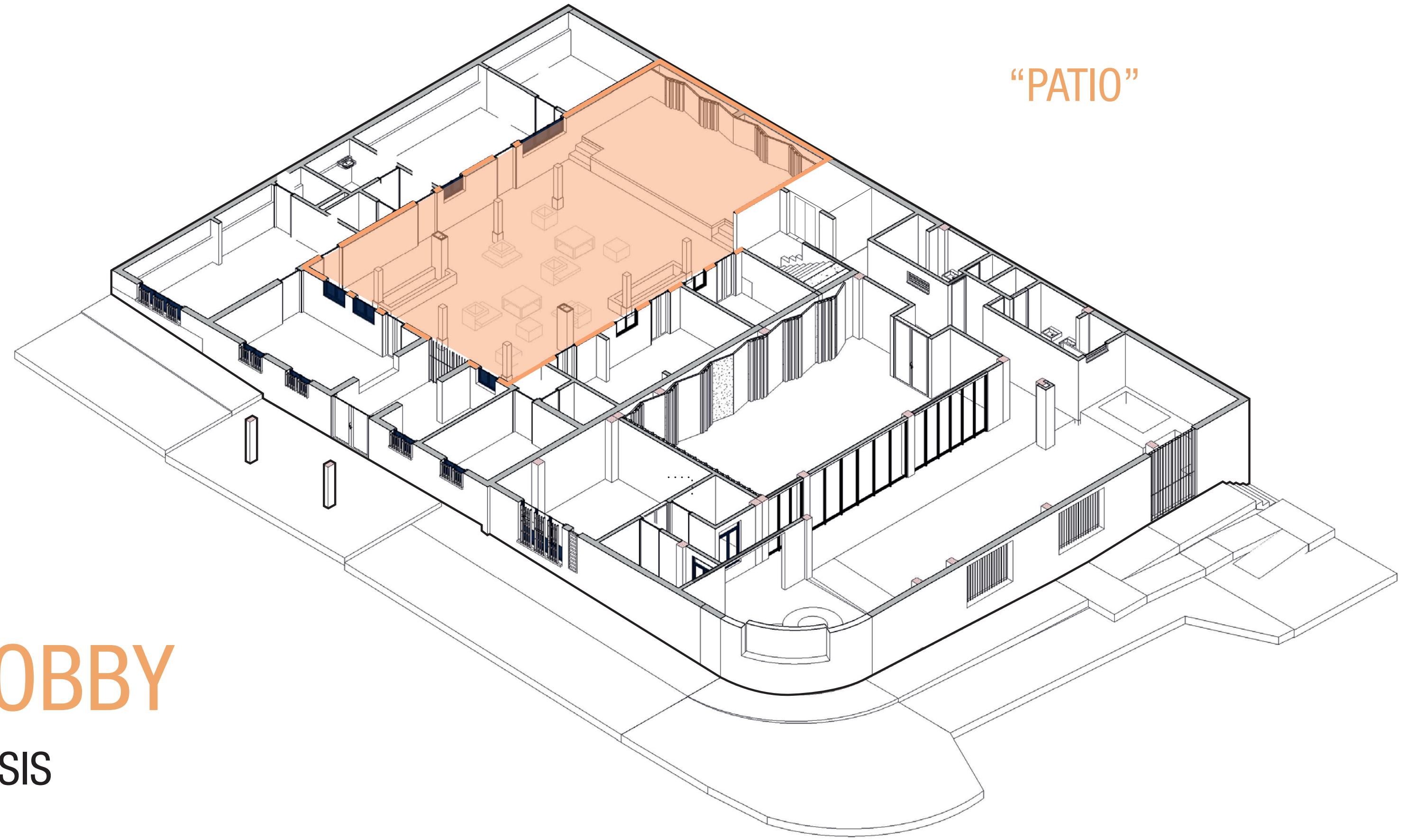


Fig 7.34:Comparison total Occupied room Reverberation time between current and proposals. Source: Author´s elaboration

In proposal option C, one part of the ceiling remains as proposal B glazed painted plasterboard but replacing the material of the floor with Wooden parquet. For medium and high frequencies, the T_{60} almost reaches the value required. And when it is with half occupancy the value is in the range of optimal T_{60} when using some removable fabric insulated panels that help to increase the reflection of the sound. The appliance of some diffusor to amplify the sound is a great strategy, but it is recommended mostly for big rehearsal rooms or concert halls.

To conclude, the results show the option B or C could develop a better acoustic performance.



SCENARIO/LOBBY

ROOM PROPOSAL ANALYSIS

Fig 7.35 Axonometry Scenario/Lobby (“Patio”) proposal location/ Source: Author´s elaboration

7.6 ROOM PROPOSAL ANALYSIS: “Patio”

Scenario/Lobby

Music Concert/ Lobby

_Pre-Orchestra and orchestra concerts
_Main Lobby

70 people (Average capacity)

Area=139 m²
Volume= 538m³

Level 0.00
Ground Floor

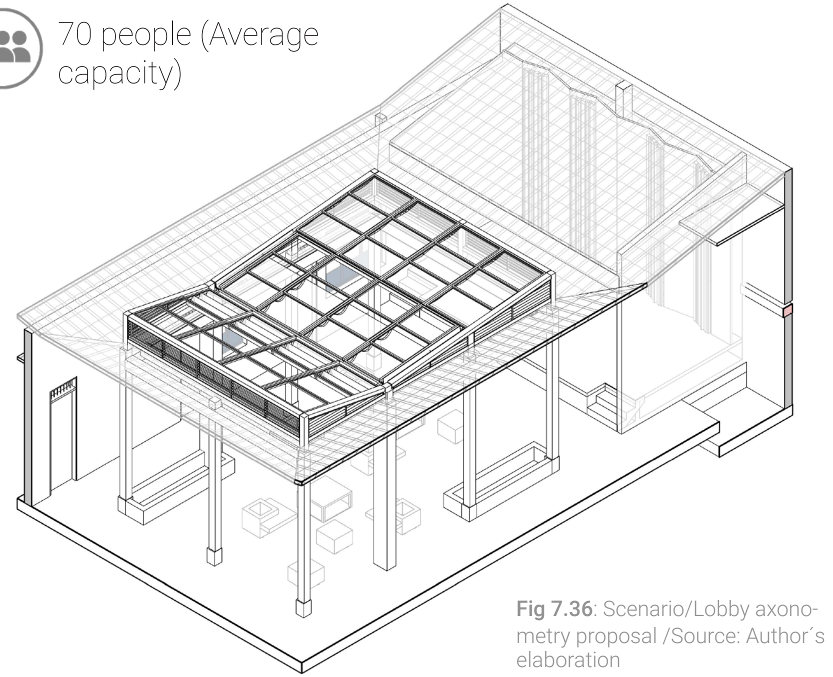


Fig 7.36: Scenario/Lobby axonometry proposal /Source: Author´s elaboration

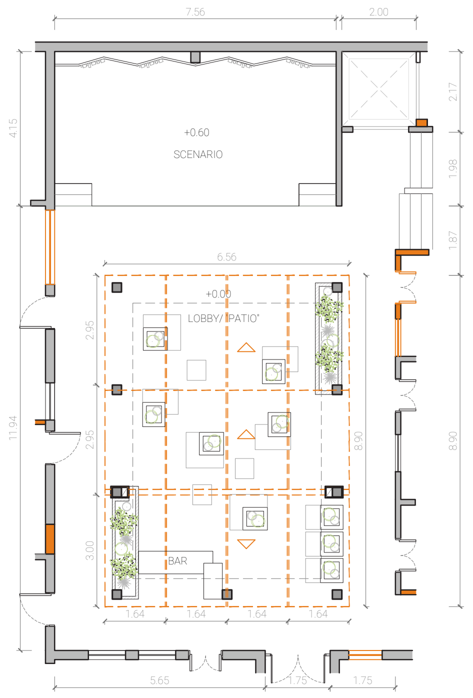


Fig 7.37: Floor plan proposal Scenario-Lobby. Scale 1:200 /Source: Author´s elaboration

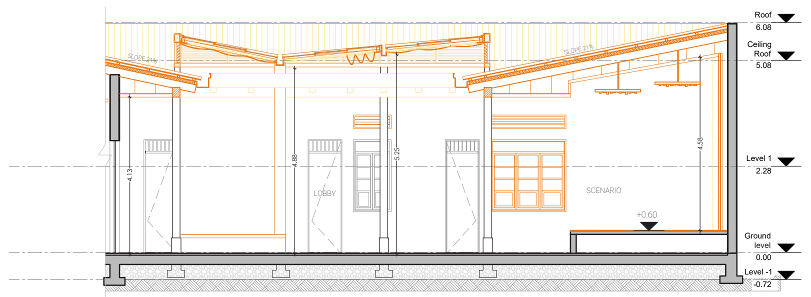


Fig 7.38: Section proposal "Scenario-lobby. Scale 1:200 /Source: Author´s elaboration

7.7 IMPUT DATA PROPOSAL

Scenario/Lobby

Thermal and Daylighting Analysis SIMULATION

To carry out the evaluation, both for Thermal and Daylighting, the software used was EnergyVer. The imput data has been change from the current design according to the new dimensions and characteristics of the proposal. The form and characteristics of this room have been simplified for this simulation.

The room has been simulated with 3 options with different materials. The data shown below corresponds to the option 3, that shows better performance results.

EnergyVer Imput Data

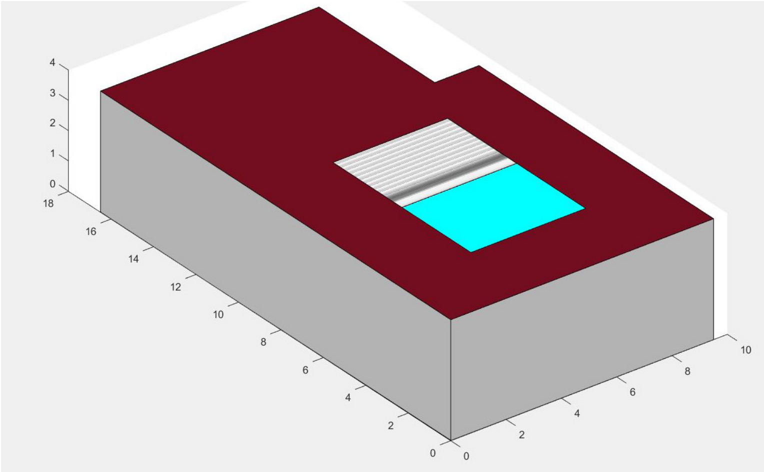


Fig7.39: Axonometry of the room simulated/Source: EnergyVer simulation

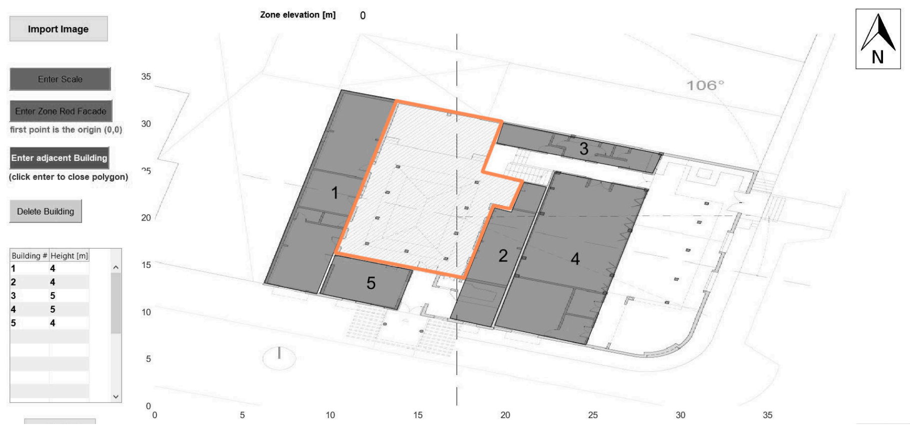


Fig 7.40: Site context/Source: EnergyVer simulation

To calculate the context for shadowing mainly, it has been included all the rooms next to the Patio. The blocks 3 and 4 represent a higher building with one more storey.

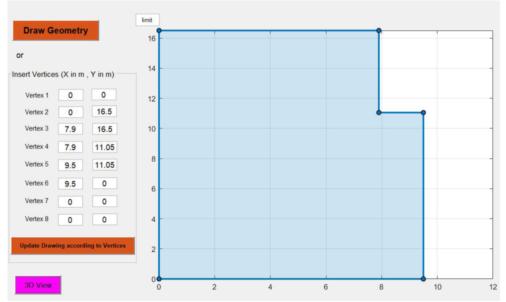


Fig 7.41: Draw geometry/Source: EnergyVer simulation

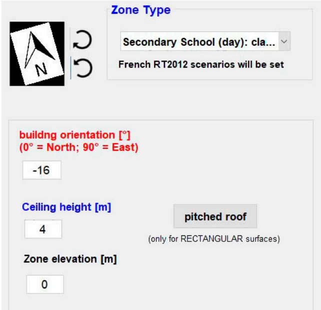


Fig 7.6: Geometry. Zone type
Source: EnergyVer simulation

Drawing Geometry and Function

The form and dimensions have change from the current building. The room is comformed by less vertices. For the ceiling the height remains as 4m although for some calculation it has bee taken into account 3.7 m as an average between the lobby and scenario height.

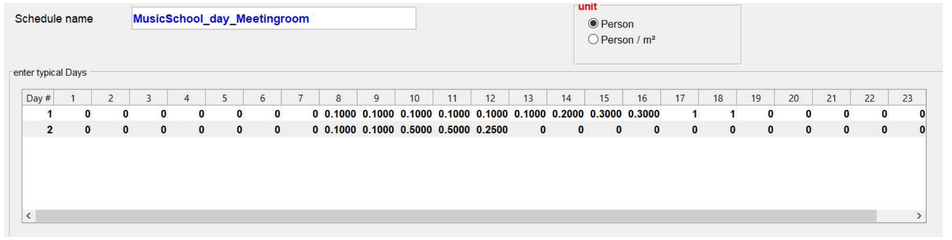


Fig 7.42: Schedule/Source: EnergyVer simulation

Meeting room schedule

The schedule created responds to meeting function where there is constantly an occupation from the beggining of the day at 8:00 until the evening with a higher occupancy. It assumes the possibility of music presentations mainly in the afternoon.

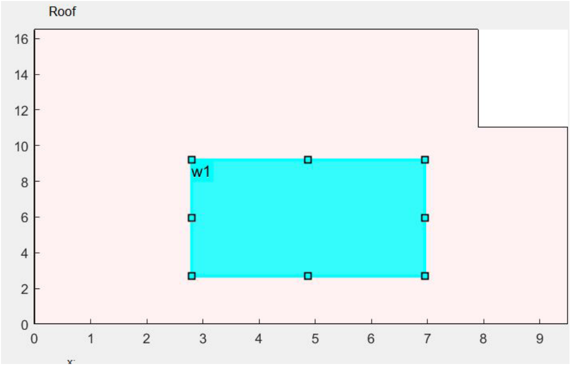


Fig 7.43: Roof data/ Source: EnergyVer simulation

Skylight dimensions

The new skylight is placed in the middle with the same position of the existing one, but it changes its form and height. Vertical windows have not been considered for this room.

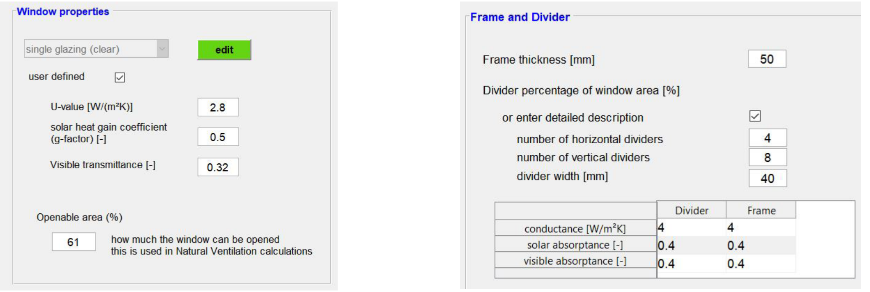


Fig 7.44: Windows properties. Glass and frame
Source: EnergyVer simulation

Skylight properties

The U-value of the new skylight is now 2.80 with a multiwall polycarbonate material. The solar factor and visible transmitance have decreased due to the selection of a white colored panels. The openable area is 61%, and it has been taken into account with an opened rectratable roof.

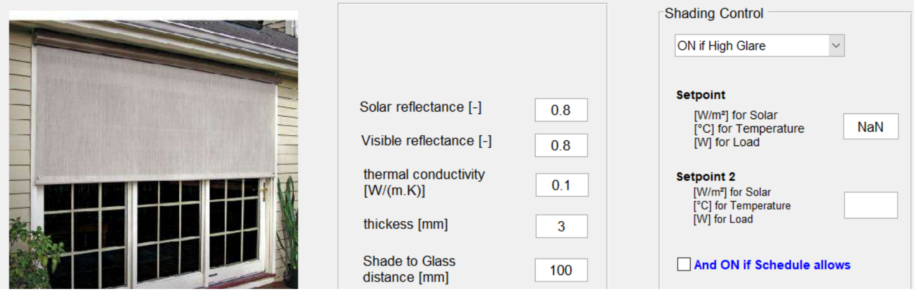


Fig 7.45: Velums /blinds /Source: EnergyVer simulation

Shading devices

For the skylight, it has been considered the use of horizontal movable fabric velums. For the simulation, the data has been introduced as a screen opaque shading to be open if there is high glare.

Construction materials:
The room proposal chosen has been simulated with the following materials. Existing material walls with single and double clay blocks(**Type 1 -Type 4**), New metal roof (Steel) + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + timber board (**Type 2**) and existing floor type with clay tiles(**Type 3**).

Facade type and Boundary conditions
The number on the colored facades corresponds to the material type described before. The boundary conditions have been change. For this evaluation it is just considered as an external wall the cian facade that corresponds to the neighbor courtyard. The rest are all internal walls.

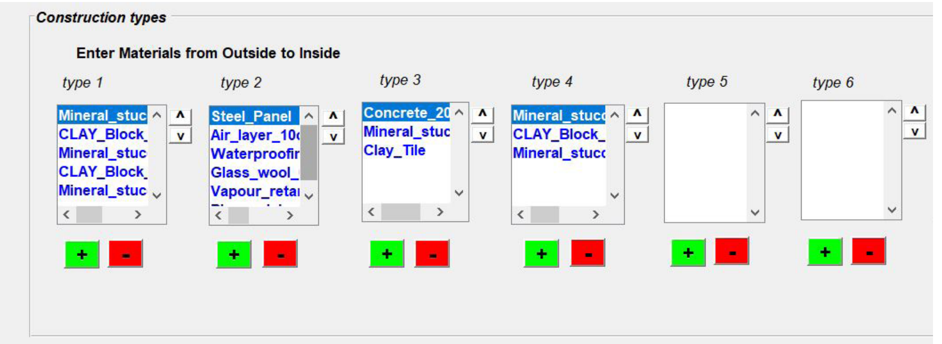


Fig 7.46: Construction types and materials
Source: EnergyVer simulation

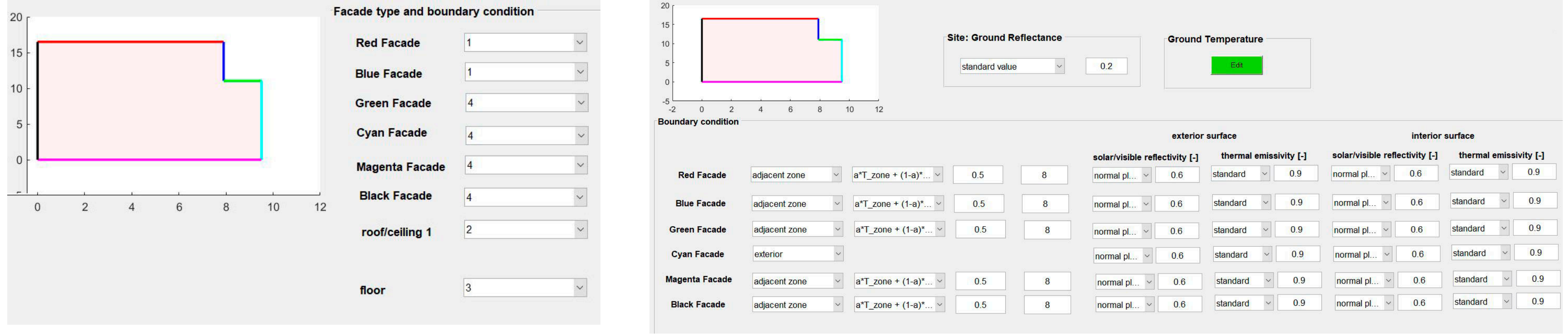


Fig 7.47:Boundary conditions of facades/
Source: EnergyVer simulation

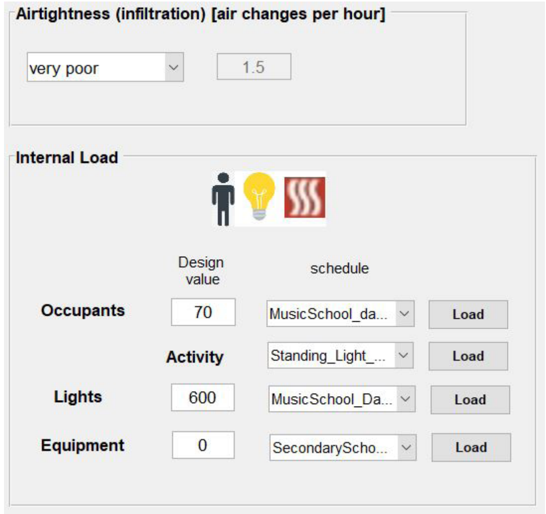


Fig 7.48Airtightness and occupancy/
Source: EnergyVer simulation

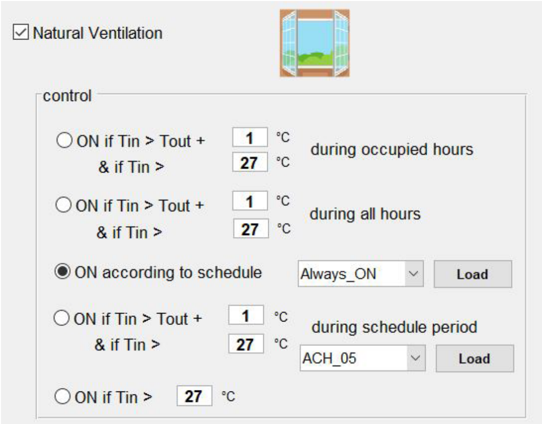


Fig 7.49:Natural ventilation /Source: EnergyVer simulation

Systems and loads:
For the simulation of this room it has been considered always ON the natural ventilation.
The airtightness is still considered as very poor since the case study has a constant warm and humid climate. The simulation increasing the value has been negative
The values of occupants and lighting remain equal to the proposal imput data, with 70 students in average, and standing light activity.

7.8 THERMAL COMFORT ANALYSIS PROPOSAL

Scenario/Lobby

- **Total** Occupation Hours/Year: **3375**
- Average Indoor Relative Humidity (Occupation Hours): **67%**

- Occupied hours where Relative Humidity > 70%: **2003 (59% year)**

- Occupied hours where Operative Temperature > T limit (28°C): **699(20% year)**
  Occupied hours where Operative Temperature > T limit (30°C): **249(7% year)**
  Occupied hours where Operative Temperature <T limit (21°C): **161 (4% year)**

- Overheating hours (EN class 2): **272 (8% year)**

- **Optimal Operative Temperature** (Adaptive EN class 2)

T_c : 0.33 * T_{rm} + 18.8
T_c : 0.33 * **24.51 °C** + 18.8
T_c : **26.88 °C**

Upper Limit (+3): **29.88 °C**
Lower Limit (-4): **22.88 °C**

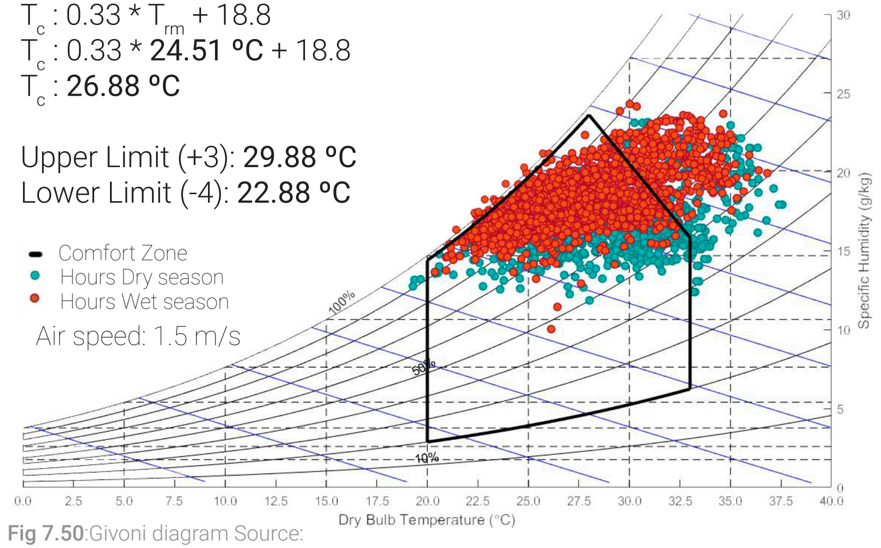
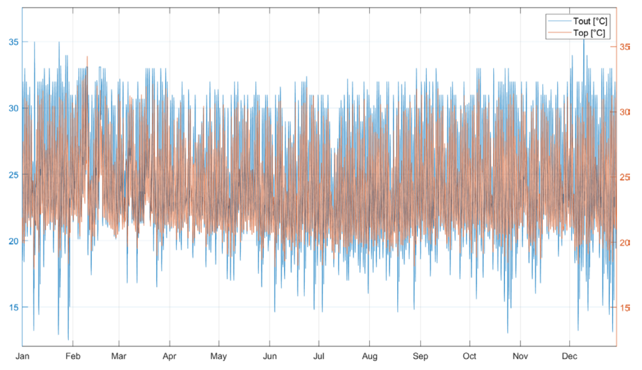


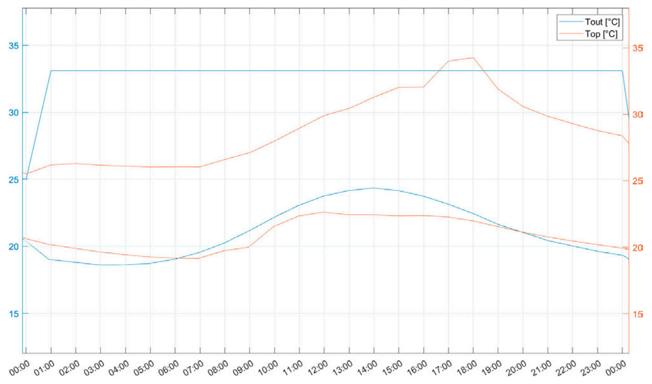
Fig 7.50:Givoni diagram Source: EnergyVer simulation



T Outdoor Air Average: **24.55 °C**

T operative Average: **23.91°C**

Fig 7.51 Operative Temperature vs Outdoor Air Temperature Year



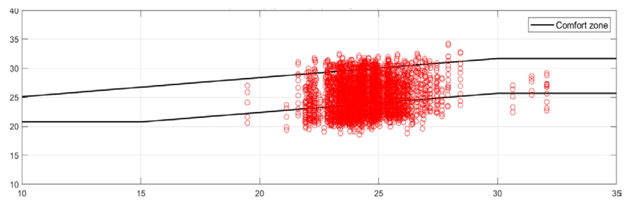
WARMEST DAY
09 February

T Out Average: **33.1 °C**
T op Average: **30.54 °C**

COLDEST DAY
09 Jul

T Out Average: **21.65 °C**
T op Average: **21.95 °C**

Fig 7.52 Operative Temperature vs Outdoor Air Temperature Warmest /Coldest day



Average (°C) of hours occupied Year

Running mean Outside T: **24.51 °C**
T Operative **25.27°C**

Fig 7.53 Operative Temperature Vs Running Mean Temperature during occupied hours

According to the new simulation of internal thermal comfort, the room has lower Operative temperatures than the Outdoor temperature: 23.91C°/24.51C° of occupied hours. The Standard EN 16798 (EN Class 2) indicates a 5% limit of discomfort hours of adaptive comfort temperature, therefore the proposal value is still out of this limit with 8%year. The warmest day shows a maximum temperature of 30.54°C which is lower than the Outdoor value 33.1°C on 9 February. The minimum temperature is 21.95 °C which is almost the same of the outdoor temperature of 21.65 C°in 9 June 8wet season). With the lowest value of higher temperature, the Relative humidity has increased up to 59% of the total occupied hours with a value over 70%(RH). 20% of the occupied hours there is an operative temperature over 28°C and 7% over 30°c, which still creates thermal discomfort in the room.

7.8.1 COMPARISON THERMAL PERFORMANCE

Current vs Proposal

To find the best solution for thermal comfort improvement, the analysis has been carried out with the simulation of 3 proposal options taking into consideration mainly the characteristics of the roof and the skylight due to the complexity of the room. Each option varies in the number of new materials and architectural adjustments. The following chart shows the thermal comfort performance of all the options including the base case (current room). For the simulation has been selected a normal level of expectations of Adaptive comfort (EN class 2). In this chart, it is possible to see the more strategies and material layers are, the more decreases the hours of discomfort due to overheating hours.
The first option (Op1) has the same materials as the base case on walls with white-painted clay blocks, and clay tiles on the floor. But it differs from the existing one with a roof replacement for cooling the building. As for the "Corocora" simulation, it has been taken into consideration a metal roof. using the properties of steel and with a high Solar Reflectance Index (SRI) color.

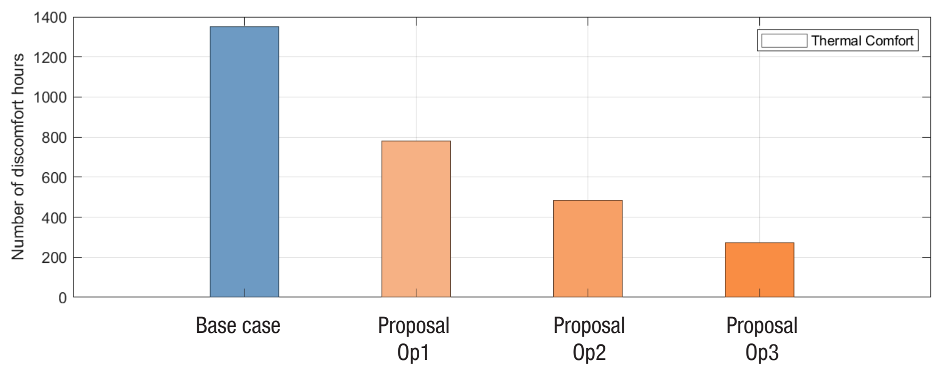


Fig 7.54:Thermal comparison chart-
Source: EnergyVer simulation

BASE CASE (Current state)
Fibercement-Roof + Clay tiles floor + Polystyrene foam ceiling+ Simple clear Polycarbonate sheet.

PROPOSAL Op 1
Roof Replacement: Metal roof (Steel) + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + slated timber ceiling + Clay tiles floor + Polystyrene foam ceiling+ Simple clear Polycarbonate sheet (same form as the existing one)

PROPOSAL Op 2
Roof Replacement: Metal roof (Steel) + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + slated timber ceiling + **Clay tiles floor + skylight replacement: Shape and height, with new louvers and retractable Double glass panels with fabric white retractable velums.**

PROPOSAL Op 3
Roof Replacement: Metal roof (Steel) + Air layer + Polyethylene waterproof + Glass wool insulation + Polypropylene vapor retarder + slated timber ceiling + **Clay tiles floor + skylight replacement: Shape and height, with new louvers and retractable Multiwall white polycarbonate panels with fabric white retractable velums.**

It has been assumed a SRI of 0.75, is an average between white, almond, and light gray color panels. The roof has different layers composed by Air layer between timber purlins, a Polyethylene waterproof membrane, 6 cm of Glass wool insulation, a Polypropylene vapor retarder membrane and a base of timber board. For the ceiling it has been proposed a slated timber, however, for the simulation it has not been considered.

The graph, mentioned before, has shown a great decrease in discomfort hours just by replacing the roof.
The second option (op2) starts from the roof replacement and simulates the performance of a new skylight proposed. The new skylight is a retractable roof made with double glass panels. The inverted shape of the skylight has been designed with vertical louvers and horizontal movable panels shaded with fabric white retractable velums. The simulation also has shown a thermal comfort improvement decreasing more than 300 discomfort hours

The third option (Op 3) has almost the same material characteristics as option 2 described before. But differs from the skylight material. For this simulation, it has been selected a multiwall polycarbonate sheet (10 mm). It has shown a better solar control performance due to the properties of a white-colored sheet with high SRI. The visible transmittance and solar factor are reduced allowing to keep the room cooled from the outside environment. Additionally, the fabric white retractable velums helped to control the sun when the roof is opened blocking the direct sun rays. With this proposal, the discomfort due to overheating hours has been decreased from 1300 hours to 272, which is a great thermal improvement.

The new room has been designed with fixed and movable vegetation pots that could improve even more the results, but they have not been considered for this simulation.

After all the simulations were done, the third option with the best thermal performance has been considered as a great solution for this meeting room.
The following graph shows the new operative temperature of the proposal chosen against the operative temperatures of the current design room. According to it, it is possible to see a great decrease in higher temperatures with the proposal. The new operative temperatures in the new room have an average of 25.27ºC when occupied, while the current room has an average of 28.31ºC. Which it means a decrease of almost 3 degrees.

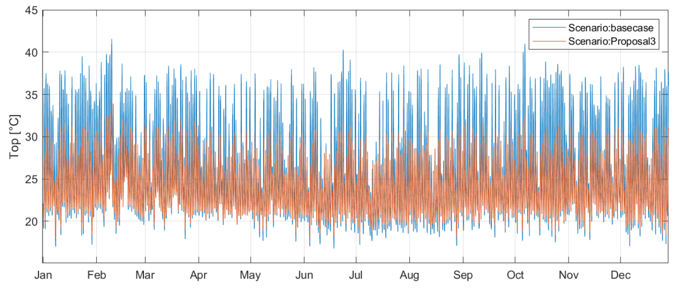


Fig 7.55:Thermal comparison chart Operative temperature current vs proposal. Source: EnergyVer simulation

The following chart shows the number of discomfort hours when the operative temperature is over 28ºC in occupied hours.
Even with the renewal proposal, the number of discomfort hours at this temperature is almost 700 hours, which represents 20% of the total occupancy hours. However, a great difference in the reduction of discomfort hours over 28ºC concerning the original design is demonstrated.

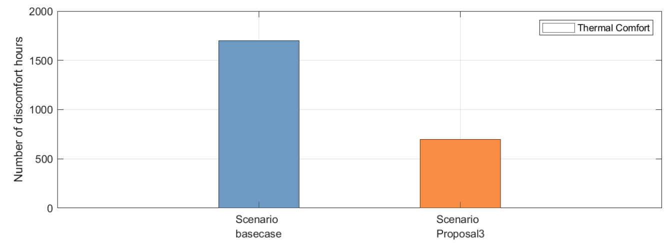


Fig 7.56:Thermal comparison char. Operative temperature. Source: EnergyVer simulation

7.9 DAYLIGHT ANALYSIS PROPOSAL

Scenario/Lobby

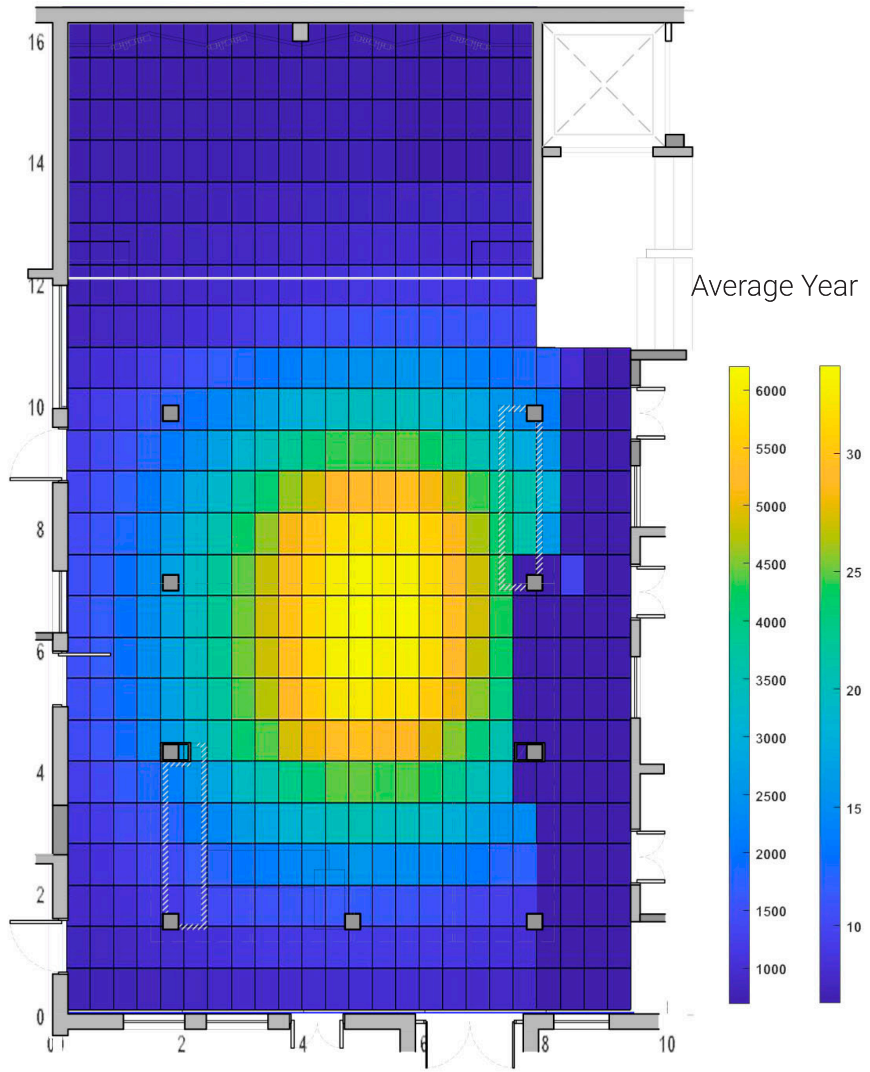


Fig 7.57 Illuminance plan/ Source: EnergyVER

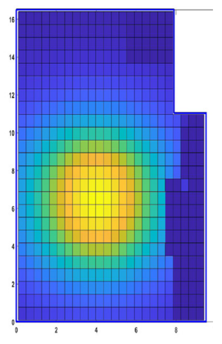
- Mean DAYLIGHT FACTOR (DF): **18.62%**
  DF threshold level for Meeting spaces : 2%
  Room Area DF > 2%: **100%**
- Mean DAYLIGHT AUTONOMY (DA): **85.56%**
  Room Area DA > 50%: **100%**

Fig 7.58 Illuminance Hours plan Dry season / Source: EnergyVER

Fig 7.59 Illuminance Hours plan Wet season / Source: EnergyVER

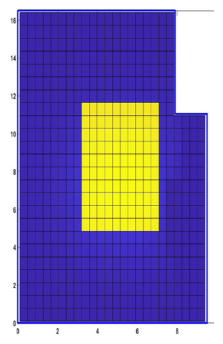
DRY SEASON

21- December 08:00



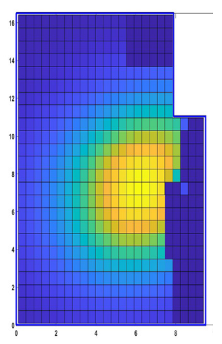
Area DI < 300 lx:**0%**
Area DI > 3000 lx: **0%**

21- December 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **23.1%**

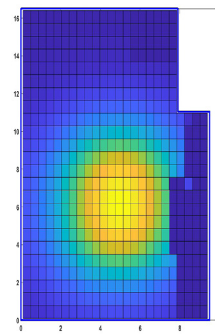
21- December 17:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **0%**

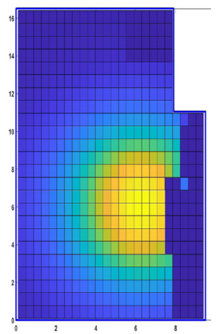
WET SEASON

21-June 08:00



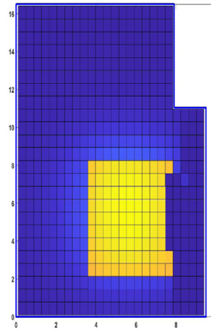
Area DI < 300 lx: **21%**
Area DI > 3000 lx: **8.3%**

21-June 13:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx: **30.4%**

21-June 17:00



Area DI < 300 lx: **0%**
Area DI > 3000 lx:**0%**

- USEFUL DAYLIGHT ILLUMINANCE (uDI): **300 - 3000 Lux**
  Room Area UDI: **82.1% / 80%** (Minimum)
  Room Area DI < 300 lx: **0%**
  Room Area DI > 3000 lx: **23.3%** Glared area

Based on a minimum daylight factor of 2% for meeting room daylighting, 100% of the room area achieves the threshold with a DF of 18.62%. Also, 100% of the room has a Daylight Autonomy over 50%. And for Useful daylight Illuminance (300 to 3000 lx), the room has reached the room area requirement with 82% over 80%. The glared area of the room has been greatly reduced with mean value 23.3%, but it is still a high value for a room with a high occupancy and constante use. Both in Wet and Dry season, the glared area it is produced mostly at midday with a percentage between 20 and 30%.

7.9.1 COMPARISON DAYLIGHT PERFORMANCE

Current vs Proposal

According to the daylight simulations results, despite all the new proposals of a skylight that have shown 100% covered area with daylight factor (DF) accomplished, there are some positive but also negative illuminance performances depending on the chosen materials. The following chart shows the Useful daylight Illuminance performance of some of the proposed options against the current design in terms of the percentage of an area over the threshold value. Taking into account a threshold value between 300 and 3000 luxes. Although, the simulation has been carried out with 3 proposals, for the comparison it has been taking into account just the Op2 and Op3 due to the replacement of the skylight.
The chart shows how the second proposal option increases the visual discomfort with 100% of the area out of the threshold values. This is due to the change from clear plastic material to a glass one. Despite the proposal is designed with a double- glazing panels and with fabric retractable velums, the properties of the materials are not enough to block the amount of solar radiation the rooms receive almost all the occupied hours in this latitude 0 where the building is located.
On the contrary, the third option (Proposal 3), which is designed with the same retractable skylight system but with multiwall white polycarbonate panels, the discomfort area drops considerably to 23%. That is why option 3 is the most recommended to be applied in terms of daylighting.
.

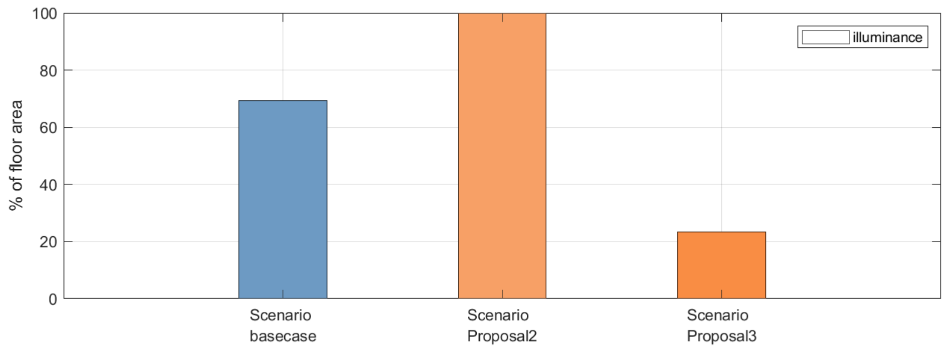


Fig 7.60: Area room of Daylight factor.
Source: EnergyVer simulation

BASE CASE (Current state) _SKYLIGHT
Simple and ondulated clear Polycarbonate sheet.

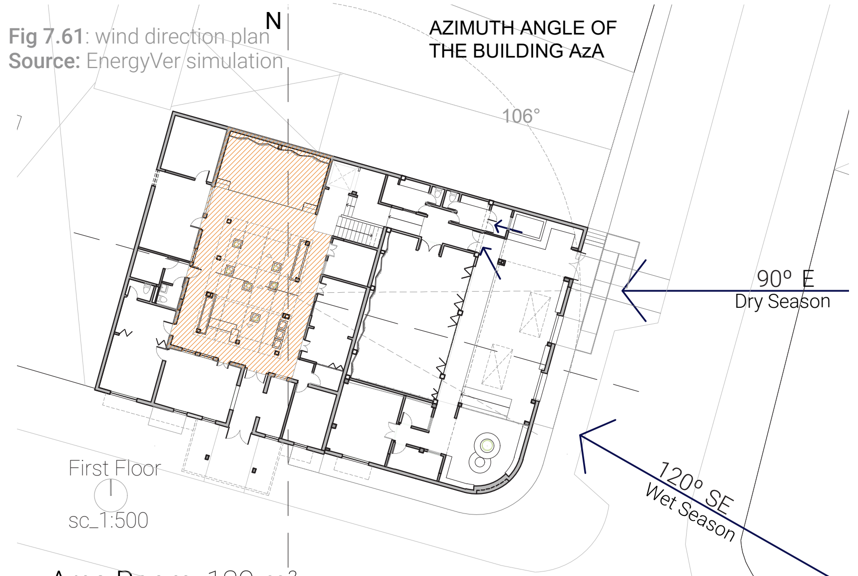
PROPOSAL Op 2- SKYLIGHT
New Shape and height, with new louvers and retractable **DOUBLE GLASS PANELS** with fabric white retractable velums.

PROPOSAL Op 3 - SKYLIGHT
New Shape and height, with new louvers and retractable **MULTIWALL WHITE POLYCARBONATE SHEET** with fabric white retractable velums.

7.10 AIRFLOW ANALYSIS PROPOSAL

Scenario/Lobby

Fig 7.61: wind direction plan
Source: EnergyVer simulation



Area Room: 139 m²

- Minimum Area Windows per room (A room/8): **17.3m²**
- Area total Windows Open skylight(Proposal): **42.05 m²**
- Area total Windows Closed skylight(Proposal): **26.06 m²**

STACK VENTILATION CALCULATION

Calculation Proposal: January

$$q_s\,[m^3/s] = C_d * A * \sqrt{2 * g * H * abs\frac{(T_z - T_e)}{T}}$$

$$q_s\,[m^3/s] = 0{,}6 * 4{,}1 * \sqrt{2 * 9.8 * 2{,}75 * abs\frac{(25{,}99 - 28{,}73)}{27{,}36}}$$

$$q_s\,[m^3/s] = 5{,}715$$

$$q_s\,[m^3/s] = 5{,}715 * 3600$$

$$q_{s,h}\,[m^3/h] = \mathbf{20575}$$

REQUIREMENTS

Table 7.7 AIRFLOW RATE FOR IAQ (Indoor Air Quality)

$q_{r\text{-}IAQ}$ [m³/h]	$q_{r\text{-}IAQ(p)*}$ [m³/	N_{occ} [-]	F_{occ} [-]	h_{occ} [-]
787,5	30	70	0,375	9

vol [m³]	$ACH_{r\text{-}IAQ}$ [1/h]
537,93	1,46

Table 7.8 AIRFLOW RATE FOR COOLING

	$q_{r\text{-}cool}$ [m³/h]	H [W]	C_a [W/kg°C]	ρ [m³/kg]	t_i [°C]	t_e [°C]
JAN	2949,35	2670,03	0,28	1,18	25,99	28,73
FEB	3017,58	2582,25	0,28	1,18	26,42	29,01
MAR	3603,74	2476,60	0,28	1,18	25,85	27,93
APR	4978,38	2664,67	0,28	1,18	25,24	26,86
MAY	3898,96	2731,02	0,28	1,18	25,04	27,16
JUN	3728,96	2328,57	0,28	1,18	24,84	26,73
JUL	3493,19	2700,71	0,28	1,18	24,38	26,72
AUG	3676,71	2684,67	0,28	1,18	24,99	27,20
SEPT	5025,85	3022,19	0,28	1,18	25,78	27,60
OCT	4867,89	3007,62	0,28	1,18	25,93	27,80
NOV	4184,71	2654,64	0,28	1,18	25,58	27,50
DEC	3046,93	2758,37	0,28	1,18	25,56	28,30

vol [m³]	$ACH_{r\text{-}cool}$ [1/h]
537,93	5,48
537,93	5,61
537,93	6,70
537,93	9,25
537,93	7,25
537,93	6,93
537,93	6,49
537,93	6,83
537,93	9,34
537,93	9,05
537,93	7,78
537,93	5,66

Table 7.9 PROPOSAL AIRFLOW VS REQUIRED

	Proposal	Requirements	
	q_s,h [m3/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	20575,4	787,5	2949,3
FEB	19875,7	787,5	3040,4
MAR	18082,9	787,5	3603,74
APR	16213,8	787,5	4978,96
MAY	18530,1	787,5	3898,96
JUN	17602,7	787,5	3728,96
JUL	19676,3	787,5	3493,19
AUG	18921,2	787,5	3676,71
SEPT	16978,2	787,5	5025,85
OCT	17153,7	787,5	4867,89
NOV	17487,6	787,5	4184,71
DEC	20739	787,5	3046,93

$q_{r\text{-}IAQ(p)}$ **[m³/h]:** min. required airflow rate per person
ACH_{IAQ} : Air change per hour
$q_{r\text{-}cool}$ **[m³/h]:** min. required airflow rate for cooling
$\rho_{a;ref}$ **[kg/m³]:** Air density at 283 K (9.85 Cº)
$\rho_{a;e}$ **[kg/m³]:** Air density at temperature exterior
$A_{w;tot}$: Area total of windows openings
C_{wind} **[1 m/s]:** Coefficient of wind speed
C_t **[m/s]:** Coefficient of wind turbulence
C_{st} **[m/s]:** Coefficient of stack effect
$u_{10;site}$ **[m/s]:** Wind at the zone level, at 10 m height
$h_{w;st}$ **[m]:** Useful height for stack effect for airing
$h_{w;fa}$ **[m]:** Free area height of the window "i"
$h_{w;path}$ **[m]:** Mid-height of the window "i" relative to ventilation zone floor level
T_z / t_i **[°C]:** day-averaged indoor air temperature
T_e / t_e [°C]: day-averaged outdoor air temperature
N_{occ} [-]: hocc / 24
F_{occ} [-]: number of occupants
h_{occ} [-]: hours of occupation during the day
C_a [W/Kg°C]:: thermal heat capacity of air
H **[W]:** day-averaged hourly heat gain in a space
g [m/s]: Acceleration of gravity

According to the Italian decree DM 05-07-75, the minimum area of windows of this room should be 17.3 m² (1/8th floor area). The new proposed Skylight, which counts as the only window of this room, is meeting the minimum area required with 26.06m² when it is closed on the operable roof, and 42.05 m², when it is opened.

The ventilation system remains as stack ventilation, but the skylight design of the new proposal has been changed adding some vertical louvers and retractable operable horizontal skylight. With the new proposal, both, closed or completely opened, the airflow meets the minimum Day average IAQ requirements for the room which is 787.5m3/h, as well as for cooling requirements. But it is insufficient for cooling in July due to low-temperature differences in that month.

7.10.1 COMPARISON AIRFLOW PERFORMANCE

Current vs Proposal

When comparing the analysis of the proposal with the existing room, the new proposal improves notably the airflow performance with the strategies taken into account. The proposal reaches the required airflow in all months, both airflow rate for Indoor Air Quality ($q_{r\text{-}IAQ}$) and airflow rate for cooling ($q_{r\text{-}cool}$), even in July that was not full-filled with the current design. The following comparison figure 7.62-7.63 shows the great difference and improvement with this new proposal.
The large increase in the amount of airflow in the proposal is due to adjustments in the architectural design such as the incremental of the height , addition of louvers and the opening option of the skylight. Even if the retractable roof is not open, the vertical louvers that surround it and the high difference of height between the inlets (next to the stairs and entrances) and outlet, allow to extract easily the warm temperature producing the stack effect.

Table 7.10 CURRENT
Stack Ventilation

	Current state	Requirements	
	q_v-IAQ [m³/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	113811,8	787,5	6898,7
FEB	10288,8	787,5	8118,4
MAR	13307,2	787,5	4781,7
APR	11908,4	787,5	6714,3
MAY	10409,8	787,5	8951,74
JUN	13340,9	787,5	4675,6
JUL	8242,6	787,5	14444,5
AUG	9894,2	787,5	9743,8
SEPT	12965,3	787,5	6220,5
OCT	15823,6	787,5	4072,1
NOV	12238	787,5	6178,5
DEC	10878,8	787,5	7931,9

Table 7.11 PROPOSAL
Stack Ventilation

	Proposal	Requirements	
	q_s,h [m3/h]	q_r-IAQ [m³/h]	$q_{r\text{-}cool}$ [m³/h]
JAN	20575,4	787,5	2949,3
FEB	19875,7	787,5	3040,4
MAR	18082,9	787,5	3603,74
APR	16213,8	787,5	4978,96
MAY	18530,1	787,5	3898,96
JUN	17602,7	787,5	3728,96
JUL	19676,3	787,5	3493,19
AUG	18921,2	787,5	3676,71
SEPT	16978,2	787,5	5025,85
OCT	17153,7	787,5	4867,89
NOV	17487,6	787,5	4184,71
DEC	20739	787,5	3046,93

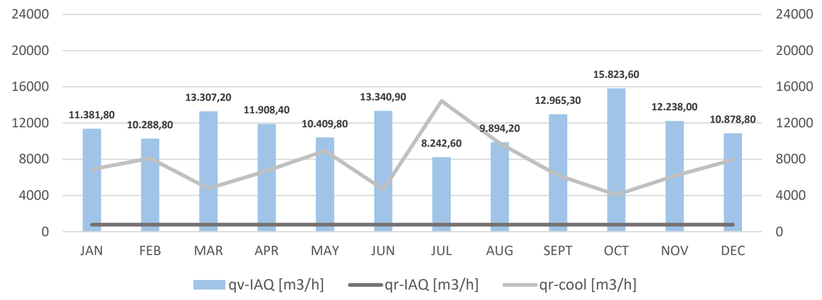


Fig 7.62:Comparison Airflow Current state vs requirements
Source: Author´s elaboration

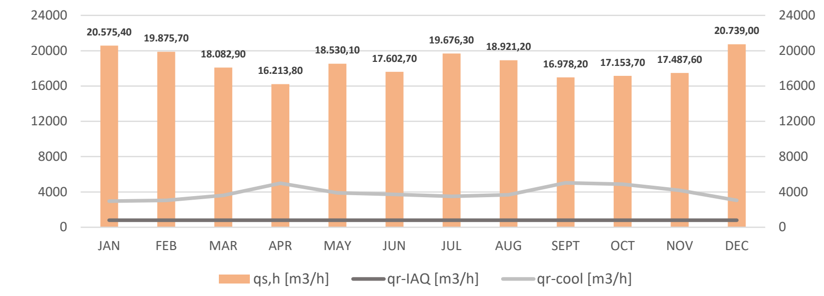


Fig 7.63:Comparison Airflow proposal vs requirements
Source: Author´s elaboration

7.11 ACOUSTIC ANALYSIS PROPOSAL

Scenario/Lobby

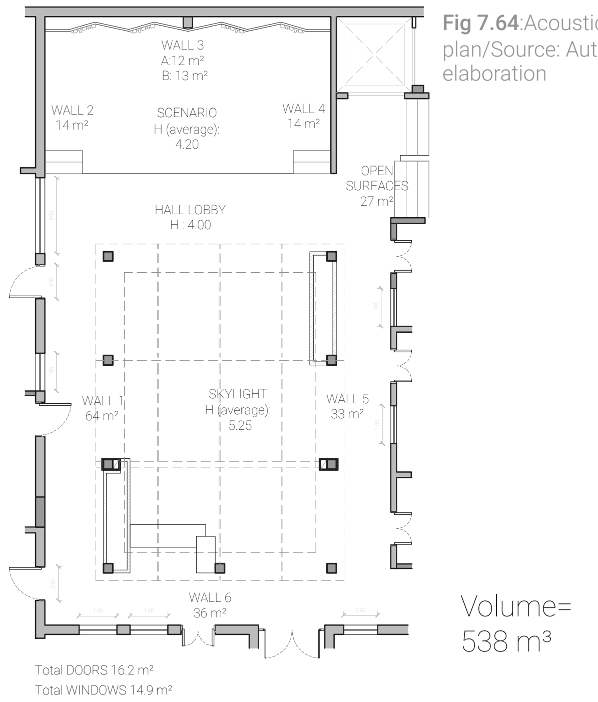


Fig 7.64:Acoustic proom plan/Source: Author´s elaboration

For the acoustic analysis of the Scenario/Lobby proposal, it has used the same methodology as the current analysis to calculate the reverberation time of the room. For it all the dimension data has been added separated by zones and type of surface. The room volume has been considered average taking into account the scenario and lobby have different heights. The new volume is 538m³. The proposal has been calculated with 2 options that differ between them in some materials for the ceiling and/or floor.
Both proposals, A and B have been designed to replace the expanded polystyrene by different ceiling materials. Also for the scenario, it has been added a wood parquet floor and alternating wood slats and gypsum board for the main wall (Wall 3A). To treat possible echoes in the room for music performances, diffuser suspended wooden clouds have been proposed.
-Proposal Option A: This proposal has been calculated with Varnished Plywood panels for the scenario ceiling, Polycarbonate sheets for the retractable skylight, and a Velour Fabric velum for solar control under the skylight
-Proposal Option B: For this proposal, it has been considered Gypsum board for the scenario ceiling, and double-glazing with Fiberglass fabric velums for the skylight.
The following table shows the input data of the sound absorption characteristics of the materials and then there is an example of the calculation formula for proposal A.

Table 7.12 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS OPTION A**

SURFACE	m²	MATERIAL	125Hz	500Hz	1000Hz
Wall (1+2+4+5+6)	160	Concrete block painted	0,1	0,06	0,07
Wall (3A)	12	Wooden Slats	0,28	0,15	0,12
Wall (3B)	13	Gypsum board	0,29	0,05	0,04
Ceiling Hall lobby	70	Wooden Slats+ Gypsum	0,2	0,16	0,2
Ceiling Scenario	30	Varnished Plywood panels	0,15	0,06	0,07
Skylight	37	Polycarbonate	0,35	0,18	0,12
Skylight Blinds	37	Velour Fabric velum	0,03	0,11	0,17
Floor lobby	107	Ceramic Clay Tile	0,01	0,01	0,01
Floor Scenario	30	Wood parquet on concrete	0,04	0,07	0,06
Door	16,2	Solid wood	0,1	0,05	0,04
Window	14,9	Double glass	0,15	0,03	0,03
Open surfaces	27	Air	0	0	0
Musicians playing(20)			0,29	0,69	0,7
People seated(50)		Plastic chairs	0,28	0,35	0,1
Movable wall panels	6	Fabric +Glass wool panel	0,06	0,6	0,91
Total Empty room			62,18	43,81	49,42
Total Half Occupied			72,08	59,46	58,92
Total Occupied			81,62	71,51	62,96

REVERBERATION TIME:
PROPOSAL Option A

	Empty Room	Occupied Room
T60 (125Hz): $\frac{0.16 \times 538 m^3}{62.18}$	**1.38s**	**1.05 s**
T60 (500Hz): $\frac{0.16 \times 538 m^3}{43.81}$	**1.96 s**	**1.20 s**
T60 (1000Hz): $\frac{0.16 \times 538\ m^3}{49.42}$	**1.74 s**	**1.37 s**

OPTIMAL T60: 1.2s - 1.4s

According to the results, with the materials proposed for each area of the scenario/lobby room in proposal A, it is possible to reach, when occupied, the Optimal reverberation time (T_{60}) defined for this meeting room dedicated mainly to small concerts.

7.5.1 COMPARISON ACOUSTIC PERFORMANCE

Current vs Proposal

According to the following charts for each of proposed options, it is possible to see that both options (A+B) have an improvement of the reverberation time of the room, which was short when occupied according to the data of the first analysis (chapter 4). Being this a space for the development of small concerts, but at the same time the main lobby of the house, the Optimal T_{60} has been calculated between 1.2s and 1.4s. The current design analysis of this room showed a short reverberation with the existing materials.

The following table 7.13 shows the performance of the materials of the current design and proposal A and B divided into 3 categories of occupancy: Empty, half-occupied and occupied in the different low and high frequencies.

Table 7.13 **MATERIALS AND SOUND ABSORPTION COEFFICIENTS OPTION C**

		125Hz	500Hz	1000Hz
	CURRENT	125Hz	500Hz	1000Hz
T_{60}	Total Empty room	2,46	1,38	1,51
	Total Half Occupied	1,65	0,62	0,66
	Total Occupied	1,51	0,83	0,88
	PROPOSAL A	125Hz	500Hz	1000Hz
T_{60}	Total Empty room	1,38	1,96	1,74
	Total Half Occupied	1,19	1,45	1,46
	Total Occupied	1,05	1,20	1,37
	PROPOSAL B	125Hz	500Hz	1000Hz
T_{60}	Total Empty room	1,40	1,46	1,34
	Total Half Occupied	1,20	1,15	1,17
	Total Occupied	1,06	0,95	1,04

For the evaluation of the empty room, the calculation has included some movable acoustic panels with fabric and glass wool to increase the reverberation time that was too long. However, the chart (Fig.7.65) below shows a long reverberation except for proposal B, which is almost within the optimal range. Nevertheless, the evaluation will be more focus on the results when the room is half-occupied or occupied.

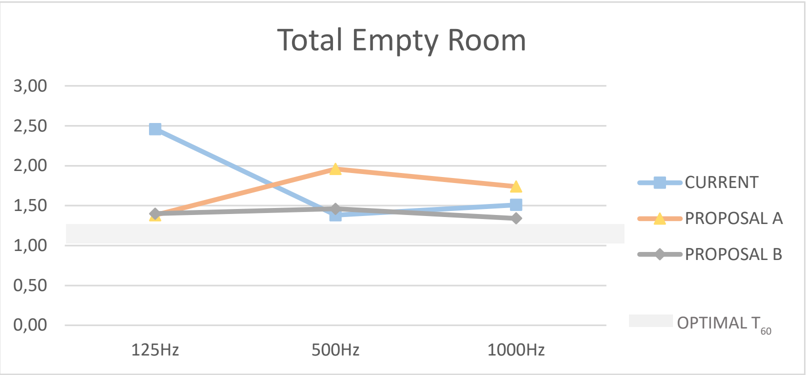


Fig 7.65:Comparison Empty room Reverberation time between current and proposals
Source: Author´s elaboration

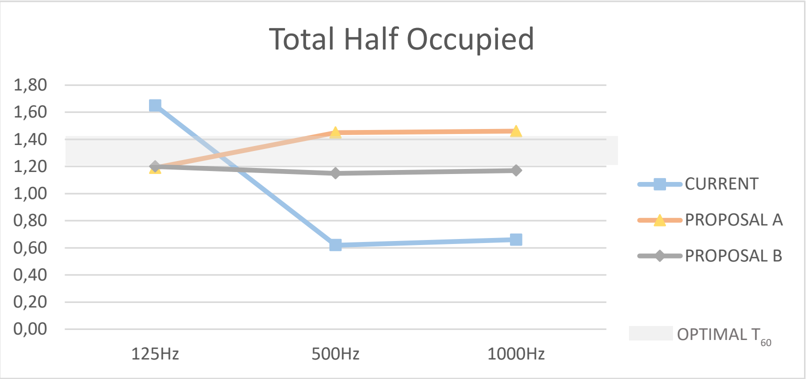


Fig 7.66:Comparison Half occupied room Reverberation time between current and proposals. Source: Author´s elaboration

When the room is half-occupied, taking into account 10 musicians and 25 spectators, there are diverse results according to the Fig 7.66. As for the empty room case, for this calculation has been considered some movable acoustic panels with fabric and glass wool to correct the reverberation time that was long with the chosen materials. While in the current design the T_{60} was short in medium and high frequencies (500 Hz and 1000 Hz), in the proposals A and B is near to the Optimal range . On the contrary, for low frequencies (125Hz) the T_{60} was long in the current case, and both proposals meet the requirement reaching 1.20s.

Finally, the occupied room graph (fig 7.67) shows an improvement of the reverberation time, that was too short for the function of the room. To increase the reverberation time it has been necessary to add more reflective materials than absorptive ones. The better acoustic performance shown according to the results is the proposal A, mainly in medium and high frequencies (500-1000 Hz) reaching 1.20s and 1.37s of T_{60}, but not for low frequencies (125Hz).

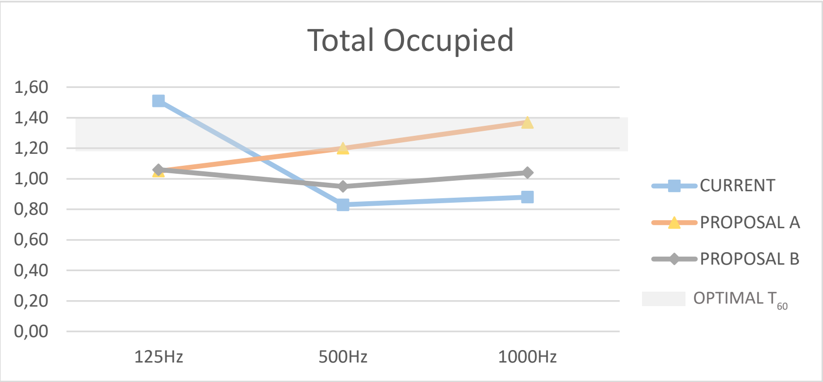


Fig 7.67:Comparison total Occupied room Reverberation time between current and proposals. Source: Author´s elaboration

According to the results, the suggested option to improve the acoustic performance of the scenario and lobby room would be the Option A, which uses more reflective materials. However, it is essential to use panels with absorbent materials that can be removed and put on according to the occupancy of the room since the total occupancy is for occasional events.

7.12 CONCLUSIONS

With the results of the simulations carried out with simplified methods of calculations throughout the chapter, it can be concluded that the application of the different design strategies analyzed above show improvement of interior comfort in the different categories evaluated. However, not all strategies are appropriate for all cases. Therefore, it has been important to evaluate some of the rooms with different material options in order to determine the best performance in all environmental categories.
The following graphs show the performance of the current design compared to the proposal one. For proposal case, it has been chosen the best design option for each evaluated room (See chapter 7.2.1 and 7.8.1)

Graph 1: Current vs Proposal Thermal Performance conclusions
The graph shows a better performance of the selected proposal (Option 4-see materials in chapters 7.2.1 and 7.8.1) with a significant decrease of the discomfort hours both for “Corocora” classroom and Scenario/lobby room. However, following Standard EN 16798 (EN Class 2) which indicates a 5% limit of discomfort hours of adaptive comfort temperature, the proposals are still over the limit with 25% for “Corocora” and 8% the Scenario.

Graph 2: Current vs Proposal Daylighting Performance conclusions
According to the graph, the percentage of glared area decreases with the selected proposal (Option 4-see materials in chapters 7.2.1 and 7.8.1) more than the half to the current state. The most significant improvement is in Scenario case which was more than 70% of the glared area because of its skylight current design.

Graphs 3 and 4: Current vs Proposal Airflow Performance conclusions
The graphs show the performance of each room separately by month. Although in “Corocora” room, both the current and proposal design have

THERMAL COMFORT PERFORMANCE

Graph 1

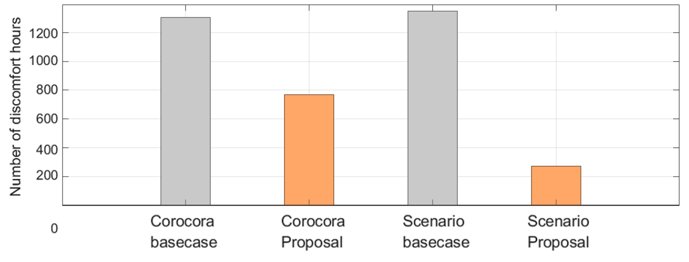


Fig 7.68:Current vs Proposal Thermal comfort Performance conclusions

DAYLIGHTING PERFORMANCE

Graph 2

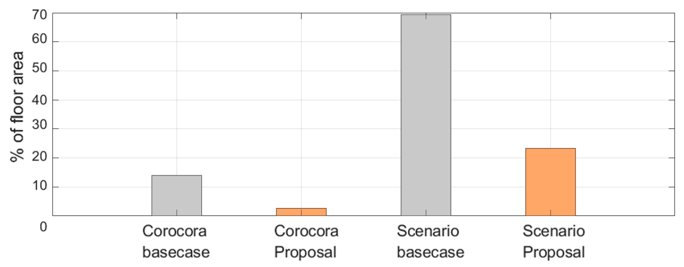


Fig 7.69:Current vs Proposal Daylighting Performance conclusions

AIRFLOW PERFORMANCE

Graph 3

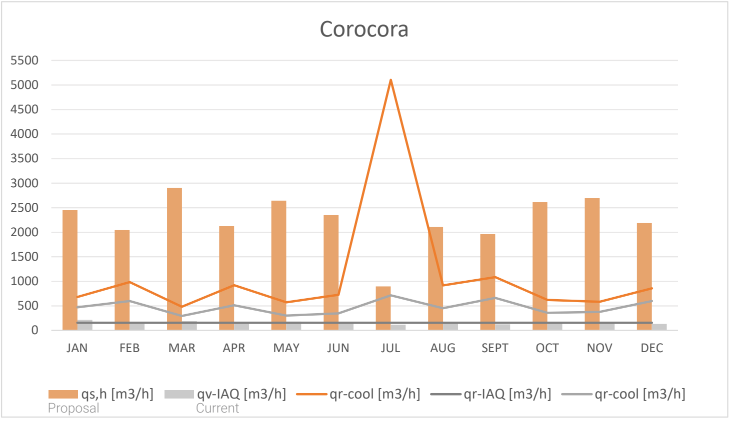


Fig 7.70:Current vs Proposal Airflow Performance conclusions: “Corocora”

Graph 4

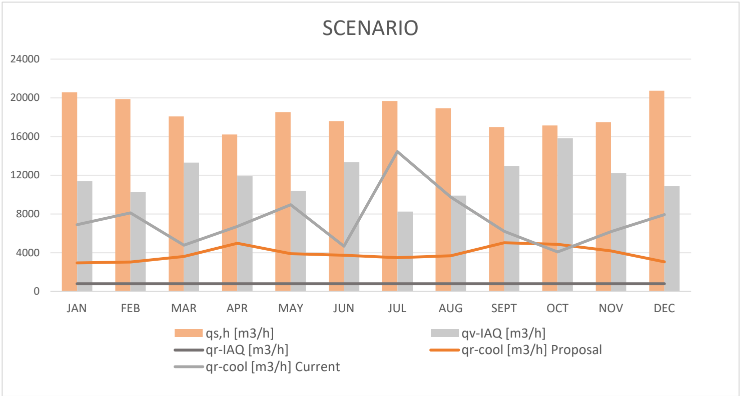


Fig 7.71:Current vs Proposal Airflow Performance conclusions: Scenario

ACOUSTIC PERFORMANCE

Graph 5

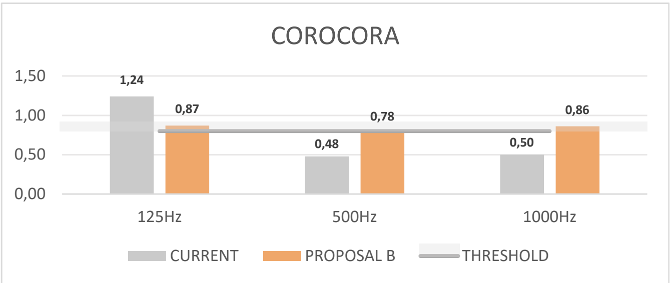


Fig 7.72:Current vs Proposal Acoustic Performance conclusions: “Corocora”

Graph 6

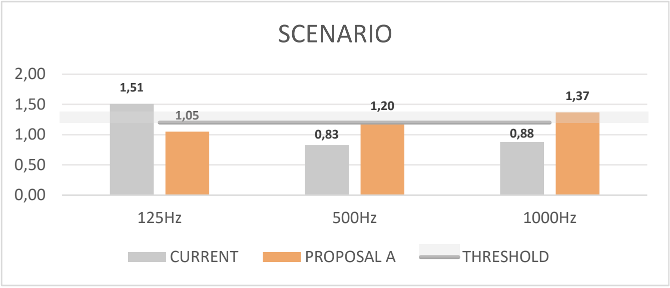


Fig 7.73:Current vs Proposal Acoustic Performance conclusions: Scenario

different ventilation systems, the graph shows each performance against its required value for minimum airflow quality and minimum airflow for Cooling. While the current room has not met the requirements for cooling in all months, the proposal meets the requirements because of the change, from single-sided ventilation to stack ventilation. July is the only month that does not meet the threshold value due to the small difference between interior and exterior temperatures.
In the case of the Scenario graph, which works with stack ventilation is it possible to see that the design proposal increases the amount of airflow and meets the requirements without problem, while the current one does not accomplish it for July.

Graph 5 and 6: Current vs Proposal Acoustic Performance conclusions: Since the threshold value of Optimal reverberation time differs from the function of the 2 evaluated rooms, the graphs shows the performance of each room separately and are divided into 3 frequencies, 125 Hz, 500 and 1000Hz. The results show the selected proposal, Option B for Corocora and A for the scenario (see materials in chapters 7.2.1 and 7.8.1) improves the reverberation time mainly for medium and high frequencies reaching the requirement. Both cases required the addition of reflective materials for medium and high materials and some absorptive taking into account the current conditions showing a short reverberation time.

After performing the evaluation using different materials in each of the design options (a, b, c..), not just the one explained before, It has been possible to conclude that not all strategies are appropriate for all categories.
An example of this is the decision to reduce the window dimensions on the east facade and enlarge the room area for the simulation of the “Corocora”

classroom. This adjustment showed a noticeable improvement in thermal comfort by reducing solar gains from radiation, however, it reduced the amount of illumination required mainly in the morning and evening hours. Another example in this room, is the use of insulating materials such as fiberglass or mineral wool to prevent overheating in the exterior facade or as noise insulation. At the thermal level it shows improvement, only if used in the external facade, however at the acoustic level the extreme use of such panels is inappropriate because it increases the absorption level of the room, shortening the reverberation time even more. It also happens to the Scenario/Lobby room. In the current case the reverberation time was short for its function, so the addition of too much absorptive materials could worsen the acoustic performance when doing music shows. For this case the solutions have included some absorptive and reflective fixed materials, as well as movable and temporally elements that create an acoustic balance for different types of occupancy.

On the other hand, the strategy of increasing the slope of the roof, changing its materials and adding louvers on the west facade, generates a positive impact in terms of ventilation and thermal comfort. The high temperature difference between the interior and exterior and the height between the inlet and outlet windows allow a greater air flow and thus reduce the overheating that generates discomfort. It also was a good strategy to be applied in the main internal "Patio" where it is placed the lobby and small scenario. While the current skylight has small open area, the incremental of its height with vertical louvers and retractable roof allows to improve the effect of stack ventilation with the proposal. At the same time, the new roof for the skylight allows to have an inlet airflow which improves the thermal comfort in the rooms next to the "Patio".

The simulations carried out allow to visualize several materiality options that can generate a good performance and improve in some measure the current conditions, not only of the evaluated rooms, but also to be applied to other rooms. Although this work has focused on the suggestion of one proposal, most of the proposed materials and design strategies of all options for each category have shown a better performance than the current building design. Therefore, the suggested option or a combination of the options could be taken into account to seek to improve performance.

CONCLUSIONS

knowing in detail the main characteristics of the hot-humid climate of the tropical zone, and understanding the conditioning elements of the microclimate has been fundamental for the development of an integral proposal for the improvement of a building in the development of this work.
The simple method used, of qualitative and quantitative evaluation from 5 environmental categories such as building construction, thermal comfort, daylight, natural ventilation, and acoustics, has allowed highlighting the most common and also specific problems of a building, mainly in its interior.
From the building design, poor accessibility to all spaces for disabled people and reduced room areas for storage and services, as well as for some classrooms are some of the main problems.

From thermal evaluation, discomfort occurs due to high operative temperatures according to the adaptive range limit with 50% of the rooms overheated more than 5% of their occupied hours. Also the excess moisture and condensation, all caused by high levels of humidity and long raining periods, in turn affected the infrastructure and furniture of the building.
From daylighting, glare is the most common problem of rooms. 62.5% of the rooms are over the maximum value accepted for daylight illuminance. Rooms located on the East facade have a high percentage of glared area in the morning, while rooms in the southwest facade have it in the evenings. The main interior "Patio" of the house has the highest glared area because it is exposed to direct horizontal sunlight all day.

From natural ventilation, the quantity of airflow of half of the rooms is not enough to meet the minimum requirements of quality of air and to cool the space. This happens due to the ventilation system of the current design, where 62.5% of the rooms work with singled-sided ventilation, which results in an inaccurate strategy for this type of climate.

Finally, from acoustic simplified evaluation, inadequate acoustic treatment is the main problem due to the properties of existing materials. As well as problems of background noise from outdoor context and in between the classrooms affecting acoustic comfort.
All those main problems mentioned before have been a challenge and the starting point to develop an improvement proposal.

Finding the balance between thermal, visual, and acoustic comfort has been possible by developing some of the tropical architecture design criteria studied throughout the work. However, the definition of the numerous strategies must be carefully studied and prioritized to achieve the best environmental performance. After making a detailed, but simple, evaluation of the design strategies applied for one of the chosen building spaces, it has been found that not all the decisions made provide an absolute improvement in each of the environmental aspects.
However, taking into account the environmental conditions of the site studied, avoiding overheating that produces thermal stress and cooling the building mainly through natural ventilation has been the main design strategies for the renovation of the music house.
The renovation proposal carried out not only seeks the internal improvement of spaces by adapting to microclimate conditions but also helps reduce energy consumption increased by the need for mechanical cooling in areas with this particular climate.

Through simple passive strategies with a low economic impact in the construction, a renovation proposal has been achieved with a design that provides more comfortable spaces for those who inhabit the building, and also adds an environmental and aesthetic value, turning the building into a benchmark of sustainability.

The development of this work from the theoretical study of the climate, its design criteria, the interior qualitative and quantitative evaluation, and subsequent proposal for architectural renovation, become a guideline for the recovery of existing buildings, as well as for the development of new buildings with this hot-humid climate in the Tropics.

BIBLIOGRAPHY

BOOKS AND ARTICLES

Bay, Jooh-Hwa ., On Boon-Lay g, Tropical sustainable architecture, Social an environmental dimensions.

Beck, H., Zimmermann, N., McVicar, T. et al. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 5, 180214 (2018).

Beranek, Leo.L. Music, acoustics & architecture. 1992, pag 31

Carrión, A . 1998. Diseño acústico de espacios arquitectónicos. Barcelona:Edicions UPC . P. 71

deDear RJ, Brager GS. ASHRAE RP-884 Final Report: developing an adaptive model of thermal comfort and preference. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers; 1997.

Gelfand, L. (2010) Sustainable School architecture. Design for primary and secondary schools. pag 288

Giordano, Roberto 2013, I prodotti per l`edilizia sostenibile.

Grosso, Mario.2017. Il raffrescamento passivo degli edifici in zone a clima temperato

Haq Gilania, Khan, Paoc. 2015.Thermal comfort analysis of PMV model Prediction in Air conditioned and Naturally Ventilated Buildings.

Humphreys, M (1997) An adaptive approach to thermal comfort criteria, in clements.Croome.Naturally Ventilaed buildingsfor the senses.

IUPS Thermal Commission.2001. Glossary of terms for thermal physiology Nicol JF, Humphreys MA. Adaptive thermal comfort and sustainable thermal standards for buildings.

Lam, William M. C. 1977. Perception and lighting as formgivers for architecture. New York: McGraw-Hill.

Lechner Norbert, 2008.Heating, Cooling, Lighting. Sustainable methods for architects, Third edition

Lopez, C & Sierra, D (2018) Condicionantes bioclimáticos en la arquitectura colonial de Colombia: la casa-patio en Cartagena de Indias y Bogotá. Revista ESTOA Nº12

McCue, E., Rehearsal Room Acoustics, Acoustical Design of Music Education Facilities, E.McCue & R.H.Talaske Editors, Acoustical Society of America, New York, (1990) 36 - 41.

Olgyay, V., Olgyay, A., Lyndon, D., Olgyay, V. W., Reynolds, J., & Yeang, K. (2015). Design with climate: Bioclimatic approach to architectural regionalism

Rausch, J. M. (2011). De pueblo de frontera a ciudad capital: la historia de Villavicencio, Colombia, desde 1842 (M. V. Mejía Duque, Trd.). Universidad de Los Llanos.

Salamanca Uribe, J. (2009). Villavicencio, la ciudad de las dos caras. Revista Credencial Historia, (231)

Tay, Kheng Soon.Mega-cities in the tropics.Singapore 1989 : Institute of Southeast Asian Studies

Yeang, Ken. Green design in the hot humid Tropical zone. Bay, Jooh-Hwa ., On Boon-Lay g, Tropical sustainable architecture, Social an environmental dimensions.

STANDARDS

ANSI-ASA_2010_part_1_acoustic standard

Acoustical Society of America, 20120. Acoustical Performance Criteria, Design-Requirements, and Guidelines for Schools, Part 1: Permanent Schools. ANSI/ASA S12Part 1

ASHRAE, 2004. Standard 55 thermal environmental conditions for human occupancy.Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASHRAE Standard 55 e thermal environmental conditions for human occupancy. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2004.

ISO 7730, 2005.Thermal comfort using calculation of the PMV and PPD indices and local thermal consideration,International Organization Standardization

Consejo Colombiano de Construcción Sostenible CCCS. 2021. "Estado de la construcción sostenible en Colombia".P. 6, 48

BSI, 2015. Draft BS EN 16798-7 Energy performance of buildings. Part 7: Ventilation for buildings

EN 17037:2018 Daylighting in buildings

DM 5 luglio 1975, DECRETO MINISTERIALE 5 LUGLIO. Requisiti igienico sanitari dei locali d'abitazione. art 5.

LEED, 2019. LEED v4 for building design and construction

SOFTWARE

EnergyPlus™. Computer software.https://energyplus.net/
EnergyVer. Computer software. https://www.energyver.com/

WEBSITES

Acoustic Suplies
-https://www.acoustic-supplies.com/absorption-coefficient-chart/

Archdaily
-https://www.archdaily.com/470704/desa-mahkota-school-eleena-jamil-architect?ad_source=search&ad_medium=search_result_projects

Archdaily
-https://www.archdaily.com/171336/distort-house-tws-partners

Archdaily
-https://www.archdaily.com/873780/house-of-music-mario-cucinella-architects

Arquitectura en acero
-http://www.arquitecturaenacero.org/proyectos/edificios-comerciales/holcim-costa-rica-sa

Arquitectura Panamericana
-http://www.arquitecturapanamericana.com/british-american-tobacco/

Brill Hart Architecture
-https://brillhartarchitecture.com/gallery/brillhart-house-3/

Bruno Stango
-http://www.brunostagno.info/proyectosHTML/bat2.htm#

Bunker Audio
-https://www.bunker-audio.com/bunker-audio-portal-sonido-documentos

Climate.OneBuilding.Org
-https://climate.onebuilding.org/WMO_Region_3_South_America/COL_Colombia/index.html

Consejo Colombiano de Construcción Sostenible
-https://www.cccs.org.co/wp/haga-parte-del-cccs/comparativo-sistemas-de-certificacion-en-construccion-sostenible-en-colombia/

Consejo Colombiano de Construcción Sostenible
-https://www.cccs.org.co/wp/download/estado-de-la-construccion-sostenible

Consejo Colombiano de Construcción Sostenible https://casa.cccs.org.co/proyectos-casa/

Corrosionpedia
https://www.corrosionpedia.com/definition/5226/solar-reflective-index

Curaduría Segunda de Villavicencio
-https://www.curaduriasegundavillavicencio.com.co/cartografia/

Design Buildongs.co.uk
-https://www.designingbuildings.co.uk/wiki/Interstitial_condensation

Electropedia
https://www.electropedia.org/

Floodmap.com
-https://www.floodmap.net

Fundación Batuta
-https://www.fundacionbatuta.org/organizaciones.php

GloH20
-http://www.gloh2o.org/koppen/

Heat Island.gov
-https://heatisland.lbl.gov/resources/roofing-tile

Instituto de Hidrología, Meteorología y Estudios Ambientales
-http://atlas.ideam.gov.co/visorAtlasClimatologico.html

Mass Design Group
-https://massdesigngroup.org/work/design/gheskio-tuberculosis-hospital

MC Architects
-https://www.mcarchitects.it/project/casa-della-musica-pieve-di-cento
Meteoblue
-https://www.meteoblue.com/es/tiempo/archive/windrose/villavicencio_colombia_3665900

Muziekenz Org
-http://www.muziekenzorg.nl/userfiles/files/KENNISBANK/Houding/EnergyExpenditureBrass-Woodwind_EffectBodyPosture.pdf

National Geographic
-https://education.nationalgeographic.org/resource/tropics

Plataforma Arquitectura
-https://www.plataformaarquitectura.cl/cl/763478/casa-brillhart-brillhart-architecture

Revista Axxis
-https://www.revistaaxxis.com.co/arquitectura/la-sostenibilidad-como-necesidad

Sound Assured.com
-https://www.soundassured.com/blogs/blog/reverberation-time-calculator-and-definition

Sustainable Development,org
-https://sustainabledevelopment.un.org/memberstates/colombia

Villavicencio official Page
-https://www.villavicencio.gov.co/

Weather Atlas.com
-https://www.weather-atlas.com/es/colombia/villavicencio-clima

Wind Finder.com
-https://www.windfinder.com/windstatistics/villavicencio_la_vanguardia_aeropuerto

World Maps of koeppen-geiger
-http://koeppen-geiger.vu-wien.ac.at/present.htm