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Bioclimatic analysis of three buildings by Gilberto Gatto Sobral. Study case Universidad Central del Ecuador Análisis bioclimático de tres edificios diseñados por Gilberto Gatto Sobral. Caso de estudio Universidad Central del Ecuador

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ABSTRACT The bioclimatic quality of three buildings by architect Gilberto Gatto Sobral at Universidad Central del Ecuador was evaluated with two objectives: to find problems that might affect users' health and productivity, and to establish if climate had a significant role in the design of these buildings The buildings included two faculties: Law and Economics, and the General Administration. Bioclimatic quality was established by comparing existing levels of temperature, relative humidity, and natural light against comfort standards and the local climate. Data were measured over two years in space samples using data loggers. It was concluded that all buildings have spaces outside of comfort being too cold and dark; and climate played a minor role because despite attempts to control natural light, the thermal behavior of materials and the sun's apparent movement were ignored.

RESUMEN Se hizo una evaluación de la calidad bioclimática de tres edificios del arquitecto Gilberto Gatto Sobral en la Universidad Central del Ecuador con dos objetivos: encontrar evidencia sobre posibles problemas en los espacios que podrían afectar la salud y productividad de sus usuarios, y determinar si el clima tuvo un papel significativo en el diseño de estos edificios. Los edificios eran dos facultades: Jurisprudencia y Economía, y la Administración General. La calidad bioclimática se estableció a través de la comparación de los niveles existentes de temperatura, humedad relativa y luz natural contra estándares de confort y el clima local. Los datos fueron medidos en muestras de espacios usando *data-loggers*. Se concluyó que todos los edificios tienen espacios fuera del confort siendo demasiado fríos y oscuros; y el clima tuvo un rol menor debido a que se ignoró el comportamiento térmico de los materiales y el movimiento aparente del sol, pero se intentó controlar la luz natural.

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PALABRAS CLAVE arquitectura moderna, educación, *data-loggers*, frío, clima.

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1. Introduction

Buildings influence people's health and well-being in various ways. Firstly, through their indoor environment, being cold, hot, humid, dark, bright, noisy, or quiet. Secondly, through the quality of their air, which can be fresh, stale, or contaminated with fungi, molds, or harmful products. Next, through their materials, whether natural or artificial. They also influence well-being through the positive or negative experiences they generate, which can be pleasant or inhumane, depending on their form, scale, privacy, beautiful views, or the presence of gardens. Nowadays, the effects of buildings on health are considered by specialized sub-disciplines of architecture, such as bioclimatic architecture, which focuses on the indoor environment and starts with the study of a place's climatic elements and how to moderate their impacts on people.

The effect of buildings on health is a serious issue for any type of building due to the high amount of time people spend indoors. However, it is particularly important in educational buildings that demand attention and concentration. The greatest physical and mental efforts of teachers and students occur in classrooms (Gonzalo, et al., 2010). Therefore, when an educational building creates uncomfortable indoor environments for its users, it affects their productivity and ability to learn.

In 2019, the Central University of Ecuador (UCE) approved a study on its main campus with two objectives: first, to find evidence of potential problems concerning its bioclimatic quality; and second, to understand the role that climate played in the campus design process. To achieve the first objective, measurements of temperature, relative humidity, and natural light were taken in a sample of six buildings. These buildings were chosen because informal complaints about bioclimatic issues, such as having too cold environments during the day, were common among their users. Additionally, the frequent use of artificial conditioning devices, such as electric heaters, was observed. The fact that Quito's climate, the equatorial city where the UCE campus is located (0º12´S latitude, 78º30´W longitude, 2850 meters above sea level), is generally comfortable during the day throughout the year, with cold nights and early mornings, suggested that the campus buildings might be performing inadequately, lowering temperatures below comfort levels during the day. To achieve the second objective, buildings from three different architectural periods (modern, postmodern, and eclectic) were selected to be studied through a comparative analysis.

In the region, particularly in Argentina, there is a significant amount of qualitative and quantitative research on the bioclimatic quality of existing school buildings. For instance, the University of Tucumán conducted an environmental assessment of the buildings on its campus, focusing on standard classrooms to propose renovations or changes in use to address detected problems. In its Faculty of Architecture, parameters such as temperature, sunlight exposure, and natural light were measured in standard theoretical classrooms (Gonzalo et al., 2010), while natural and artificial light were measured in standard workshop classrooms (Márquez Vega et al., 2021). The verification of improvement proposals was done through calculations and both physical and computer simulations. Similarly, the University of La Plata carried out studies in its Faculty of Architecture, measuring natural and artificial lighting, temperature, and relative humidity in standard workshop classrooms, focusing on developing a methodology for evaluating the bioclimatic quality of large classrooms (San Juan et al., 2003). In all three cases, data loggers and lux meters were used to take measurements, which were then compared against the standards of the Argentine Institute of Standardization and Certification (IRAM) and/or the Basic Standards for School Architecture. In Ecuador, although limited, there are already studies on the bioclimatic quality of existing buildings. Some manually take temperature measurements on-site at certain hours to compare them against surveys on perceived comfort by users (Fernández Mendoza et al., 2023), while others evaluate a building's bioclimatic quality through computer simulations, simulating ventilation with Computational Fluid Dynamics (CFD) or thermal comfort with Energy Plus (Cepeda and Morales, 2018). The present research contributes methodologically by using precision data loggers to automatically collect real on-site data without the presence of people, comparing it against comfort standards to determine bioclimatic quality without proposing renovations or corrections. Instead of focusing solely on classrooms, it selected representative spaces in each building to achieve a preliminary general diagnosis.

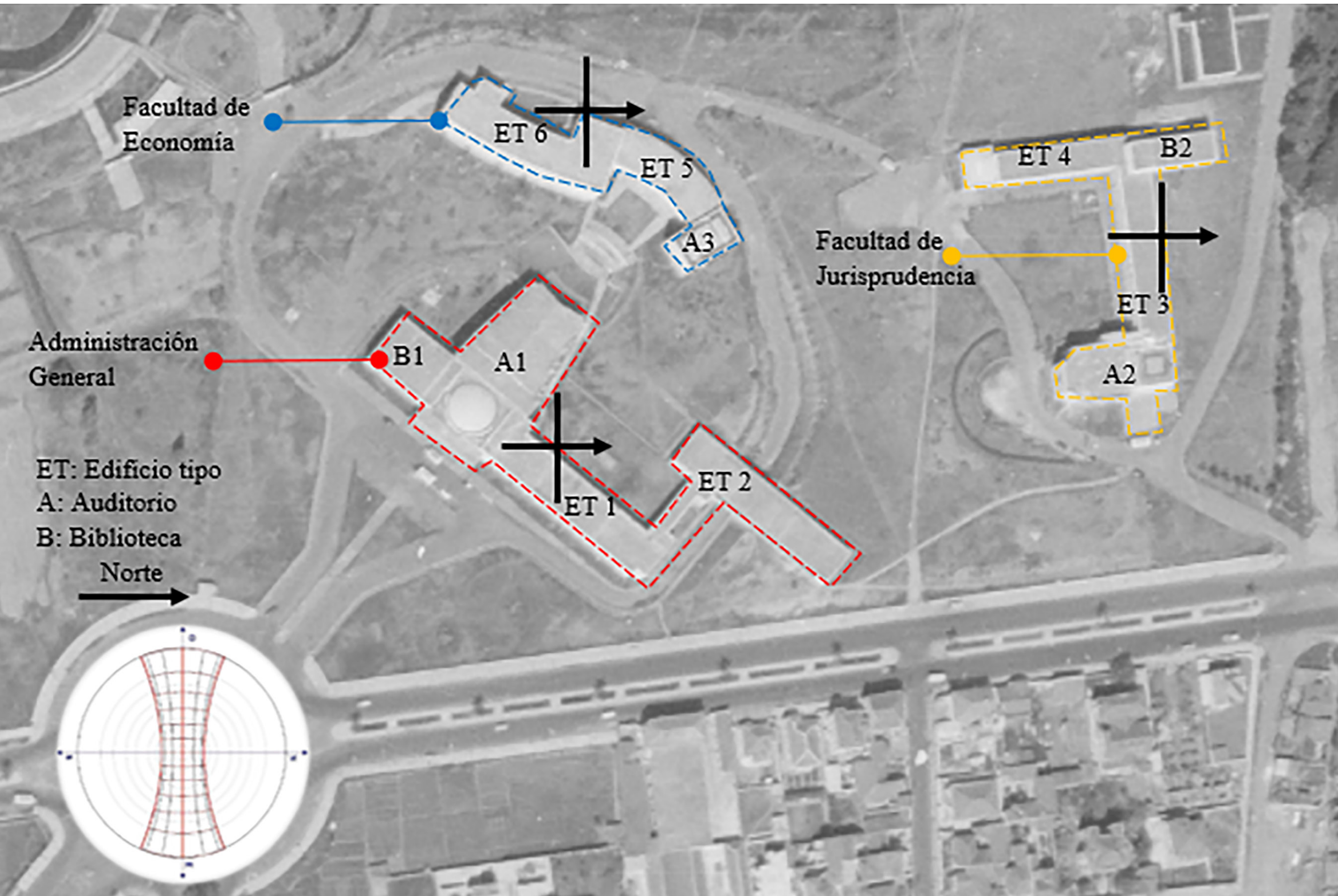
The three buildings from the modern architectural period studied in this research—General Administration, and the Faculties of Economics and Jurisprudence—were designed by the Uruguayan architect Gilberto Gatto Sobral. In Ecuador, there is a growing interest in studying the modern architecture produced in the country during the 20th century, with many historical, archival, or documentary investigations, as well as studies of typologies, architects, or specific works. Gilberto Gatto Sobral is studied for his influence on the development of modern cities in Ecuadorian cities such as Quito (Villagomez et al., 2020) and Cuenca (Rivera Muñoz, 2020), for his influence on other modern Ecuadorian architects (Vallejo Guayasamín, 2020), for his works, specifically his educational buildings (Villagomez et al., 2020), and for his use of concrete (Bonilla et al., 2020).

These studies speak positively of Gatto Sobral, praising the adaptation of his buildings to the landscape and topography of Quito (Villagomez et al., 2020), recognizing his efforts to enrich the international modern language of his buildings with the introduction of local artisanal details (Vallejo Guayasamín, 2020), and highlighting his educational buildings as the first to apply modern architectural principles in education in Ecuador (Villagomez et al., 2020). His buildings are described as "articulated, light, flexible, functional, and luminous" due to the use of "linear, extensive, and open forms" based on "hygienist and functionalist principles" (Villagomez et al., 2020, p. 55).

This research contributes to the study of modern architecture from a new perspective because Gilberto Gatto Sobral is not well understood in terms of the bioclimatic quality of his projects. This, in turn, will lead to a better understanding of the bioclimatic behaviour of educational buildings designed under modern architectural principles in Ecuador. The study begins with one of Gatto Sobral's major educational works, the UCE campus, for which he created the master plan around 1945. The campus was designed to include 24 buildings on a hill located between the old Colonial Centre and the new modern neighbourhoods in northern Quito. This campus was a significant part of the Urban Development Plan initially conceived to guide the expansion of modern Quito. By 1959, Gatto Sobral had already constructed the General Administration building and the Faculties of Jurisprudence and Economics, opting for modern architecture instead of the traditional architecture that predominated in Quito at the beginning of the 20th century (Villagómez et al., 2020). This decision meant that:

- Instead of using buildings that faced an internal courtyard, he used elongated and slender buildings that faced the external landscape.
- Instead of using load-bearing brick walls with sloping wooden roofs and tiles, he used reinforced concrete structures, glass, and flat roofs.
- Instead of small windows with or without balconies, he used large horizontal windows with sunshades or brise-soleil.
- Instead of ornate facades with neoclassical principles and symmetry, he used facades based on functionalist principles.

Figure 1: Aerial photograph of the Central University of Ecuador Campus, Quito, Ecuador. Military Geographic Institute (1959)



With these parameters, Gatto Sobral essentially created the same type of building but used them in different combinations. The typical building featured concrete, brick, and glass, with an elongated and slender shape, two or three stories high. Offices and/or classrooms were linearly distributed along one side, with an open but covered corridor on the other side. For the combinations (Figure 1):

- In Economics, two typical buildings were linearly connected by linking them with an open hall supported by pillars and sculptural spiral staircases.
- In General Administration, two typical buildings were linearly connected by linking them with an arcade/covered corridor.
- In Jurisprudence, an L-shape was formed with two typical buildings.

The combinations in all three cases were topped off with an auditorium and/or a library at one of the ends or vertices.

2. Methods

The bioclimatic quality was established through a comparative analysis of existing levels of temperature, relative humidity, and natural light measured in the buildings, compared to accepted comfort standards or indices, local climate data from official meteorological stations, and the apparent solar movement in Quito. Representative spaces in each building were measured using data loggers over representative periods of time. Measurements and comparative analysis focused on the buildings as a whole.

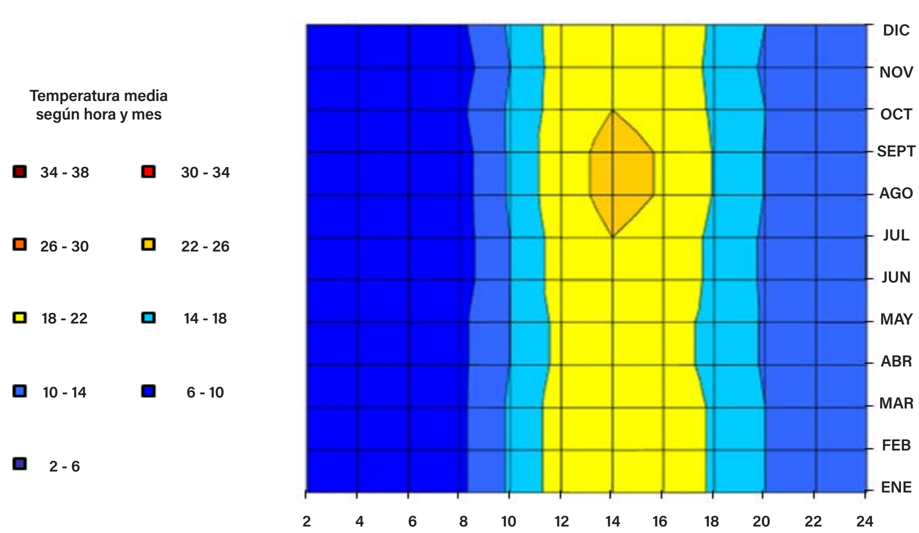
All buildings were measured without the presence of people to obtain values that reflect the "pure" behaviour of the buildings in response to Quito's climate. A total of twelve data loggers were used: ten HOBO® U12-012 units to measure temperature in degrees Celsius (°C), relative humidity in percentage, and natural light in Lux, and two HOBO® MX1102 units to measure temperature in degrees Celsius (°C) and relative humidity in percentage.

When measuring a building, twelve representative spaces were selected to place the twelve data loggers and collect information. After the measurement period, the data loggers were retrieved, the information was downloaded, and they were then placed in another set of twelve new spaces. This process was repeated as needed.

The sets of spaces formed a representative sample of the building, as they were chosen based on similar characteristics for a comparative analysis among them, which would then be applied to the rest of the building. These spaces could have similar functions such as classrooms or offices, or they could be located in similar positions within the building but on different floors (top, middle, and ground floor), or they could be on the same floor but in different positions (ends, centre).

The measurement periods were defined as seven days. It's unnecessary to take measurements throughout the entire year in these types of studies because samples can be taken for short periods and applied to the rest of the year. For instance, the University of La Plata, located at 35 degrees South latitude, determined a measurement period of seven days in July, during its coldest season (San Juan et al., 2003). In Quito's case,

Figure 2: Isopleth created using e-Clim software using data from the M0024 QUITO INAMHI-INNAQUITO weather station
Evans and Delbene (2004); INAMHI (1990-2012)



samples can be taken at any time of the year due to its equatorial latitude with daily rather than seasonal climate variations. Quito experiences essentially the same climate throughout the year, with cold nights and early mornings, comfortable mornings, warmer mid-days, and comfortable to cool evenings, as observed in Figure 2. Analysis of the seven-day measurements from the data loggers could be applied to the rest of the year considering two aspects: first, the angle of the sun during solstices and equinoxes (the sun travels at a 66,5-degree angle from the ground to the north in June and to the south in December, and approximately 90 degrees from the ground at noon near March and September); and second, the varying amount of rainfall in certain months.

The measurement weeks for the Faculties of Economics and Jurisprudence took place in November, while for General Administration, they occurred in October due to logistical and timing reasons. These measurements occurred between the December solstice and the September equinox.

The temperature in Quito varies from 7 to 23 °C, relative humidity from 40% to 94%, and rainfall from 20 to 160 mm according to a 13-year average of meteorological data taken at the station closest to UCE (Quito-Inamhi-Quito at 00º13´S latitude, 78º32´W longitude, 2879 meters above sea level) (National Institute of Meteorology and Hydrology - INAMHI, 1990-2012). These data indicate that a building in Quito:

- Needs to increase temperature through solar radiation input in the mornings from 6:00 AM to 11:00 AM when temperatures only reach 13 to 17 °C, and in the evenings from 5:00 PM to 8:00 PM when temperatures drop to 8 to 14 °C.
- Needs to create shade and/or prevent overexposure and overheating from 12:00 PM to 4:00 PM when temperatures reach 22 to 23 °C.
- Needs to prevent the loss of accumulatedheat during nights when temperatures drop to 7 to 11 °C between 10:00 PM and 4:00 AM.
- Requires shade for outdoor spaces between 10:00 AM and 4:00 PM not only to avoid overexposure and overheating but also to protect people from UV radiation in a city with high solar altitude and altitude above sea level.

The data loggers were placed as follows:

- One in the centre of each enclosed space up to 100m². If the enclosed space was larger, it was divided into zones and a data logger was placed in the centre of each zone. The University of La Plata did something similar by placing three data loggers to measure temperature in a space of approximately 405m² (San Juan et al., 2003). Certain ventilation and artificial heating companies recommend measuring temperature every 100m² (Siber Ventilación Inteligente, 2024). This central distribution is suitable for measuring temperature and relative humidity because it reflects the overall reality of the enclosed space. However, it has limitations for measuring natural light since measuring only the central point of the room does not capture variations at peripheral points, which can sometimes be significant. When a space or spaces exhibited interesting lighting behaviour, additional measurements were taken using a grid of nine points across the work plane.
- Placed on a table or desk at a height of seventy centimetres, as the primary activity in the spaces was sedentary, either office work or studying. This location prevented floor or ceiling temperatures from affecting temperature and relative humidity measurements. For natural light measurements, it provided an ideal reading on the work plane. If placing them on a table was not possible due to safety or logistical reasons, they were placed on a high beam, window frame, lintel, or overhang, but never exceeding two meters in height. Temperature and relative humidity stratification within the same enclosed space was considered acceptable.
- Positioned away from direct sunlight; however, some spaces with skylights or glass-covered courtyards unavoidably experienced sun exposure, which was taken into account during the analysis.

The data loggers were programmed to record information every hour.

The data measured with the data loggers were compared against comfort standards (Table 1), considering individual measurements, averages of all temperatures, averages of temperatures by types and/or positions of

Table 1: Comfort Standards Defined with Values from the bioclimatic method of Silvia de Schiller and John Martin Evans, the Home Coach Smart Indoor Air Quality Monitor, and studies from the University of La Plata. Evans (1988); NETATMO (2023); San Juan, et al., (2003)

Temperature		RH		Natural light
Too cold <15 °C	Fatigue, sleepiness, loss of attention, lethargy, colds, bone pain	Insane moist >80%	Nasal congestion, encourages mold and fungus growth, increases	Technical drawing and special classrooms, ideal 1000 lux, minimum 750 lux
Cool 15-17°C		poor 70-80%		Office work and common classrooms ideal 500 lux, minimum 300 lux
Healthy 18 a 26 °C	Minimum for classrooms according to Argentine Standard 20 °C	Healthy 30%-40% and 50-60%.		Circulation and reading 50 lux
Hot 26-29°C	Headache, sleepiness, loss of attention, irritability, dehydration.	Poor 30-20%	Causes dry skin and mucous membranes	
Too hot >29 °C		Dry insane <15%		

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spaces (maximum and minimum), absolute individual measurements (maximum and minimum), and ranges (differences between maximum and minimum values).

The comfort standards were defined using recommended values from Silvia de Schiller and John Martin Evans based on their seminal research in bioclimatic architecture (Evans, 1988), the Home Coach Smart Indoor Air Quality Monitor (NETATMO, 2023), and Argentine regulations for school buildings (San Juan, Viegas, & Melchior, 2003).

3. Results

3.1. General administration

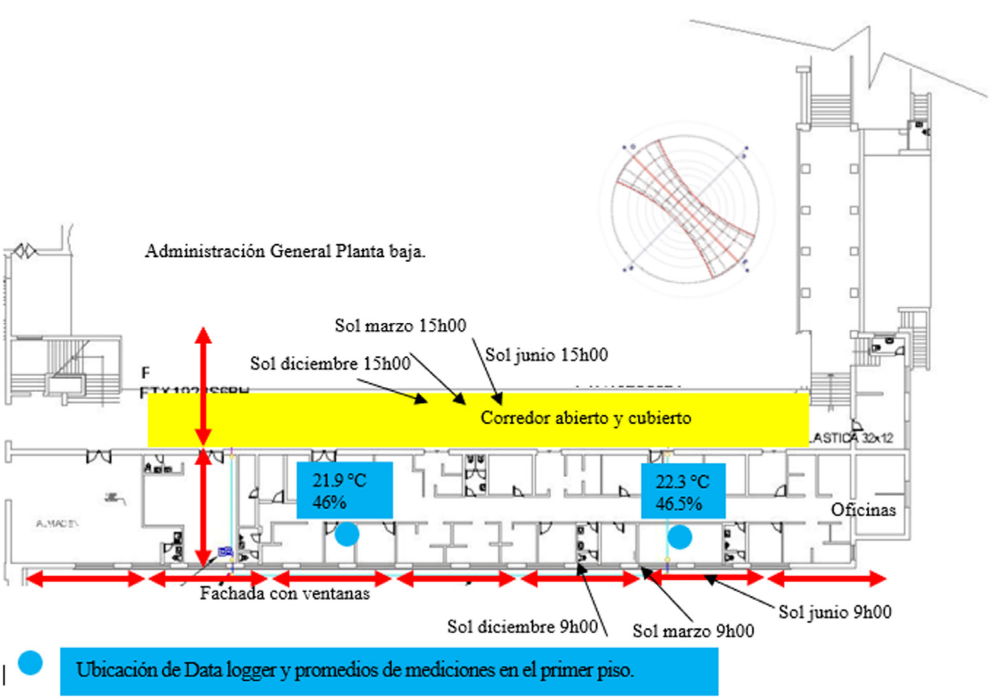
General Administration consists of two identical two-story buildings, ET1 and ET2. This building type has proportions where its length is five times its width, and its width is three times the height of one floor (Figure 3). One third of the length of the floor is used for the corridor, and two thirds for the offices. Building type ET1 has two floors, while ET2 has one; ET1 mirrors ET2 along its long side. Eleven offices on the first floor of building ET1 were measured in October 2021; these spaces had an orthogonal configuration with windows facing outward on a single facade and interior finishes of natural materials such as wood or leather.

When averaging all recorded measurements across all spaces, an average temperature of 20,81°C, with a relative humidity of 52,7%, and natural illumination of 45,3 lux, was obtained. When averaging by zones, the offices of the rectorate and vice-rectorate on the 2nd floor had a temperature of 21,7°C, humidity of 47%, and less than 50 lux of natural light. The highest and lowest individual values recorded were 23,35°C and 18.83°C for temperature, 66% and 48% for humidity, and 681,9 lux and 3,9 lux for natural light. Cooler temperatures generally occurred during the nights, early mornings, and mornings, while warmer temperatures were observed around midday. The combination of temperature and humidity falls within comfort ranges.

ET1 receives direct solar gain through office windows only in the morning, whereas ET2 receives it only in the afternoon. It can be inferred that around the December solstice, ET1 could reach its highest temperatures due to greater morning solar exposure on the windowed facade, while in June it would experience lower temperatures due to less solar exposure (Figure 4 real orientation). Conversely, ET2 would exhibit the opposite behaviour, possibly recording its highest temperatures in June due to greater afternoon solar exposure on the windowed facade, while in December it would have lower temperatures due to reduced solar exposure.

By 1975, ET2 underwent an expansion that maintained its corridor intact but doubled the width of the offices, resulting in a much deeper, almost square-shaped floor plan to accommodate a printing press. The analysis indicates that despite receiving only about three to four hours of effective sunlight through its windows each day (from 8:00 am to 12:00 pm), ET1 manages to maintain internal temperatures within comfort standards in the month of October. This suggests that direct solar gain through windows is not the only source of heat for the building and is likely supplemented by heat transmission through brick walls and concrete roofs, as well as by internal coverings of wood and leather.

Figure 3: Ground floor plan of the General Administration of the Campus of the Universidad Central del Ecuador, Quito, Ecuador
Universidad Central del Ecuador (2020)



The analysis also indicates that ET1 would have had a more balanced annual solar exposure if its long facade had been oriented perpendicular to the east-west axis as seen in Figure 4 (ideal orientation). This would have avoided the reduced sunlight in June due to the current 45-degree rotation where the sun angle tends to be too parallel to the facade. Similarly, ET2 would benefit from this opposite orientation, avoiding reduced solar exposure in December.

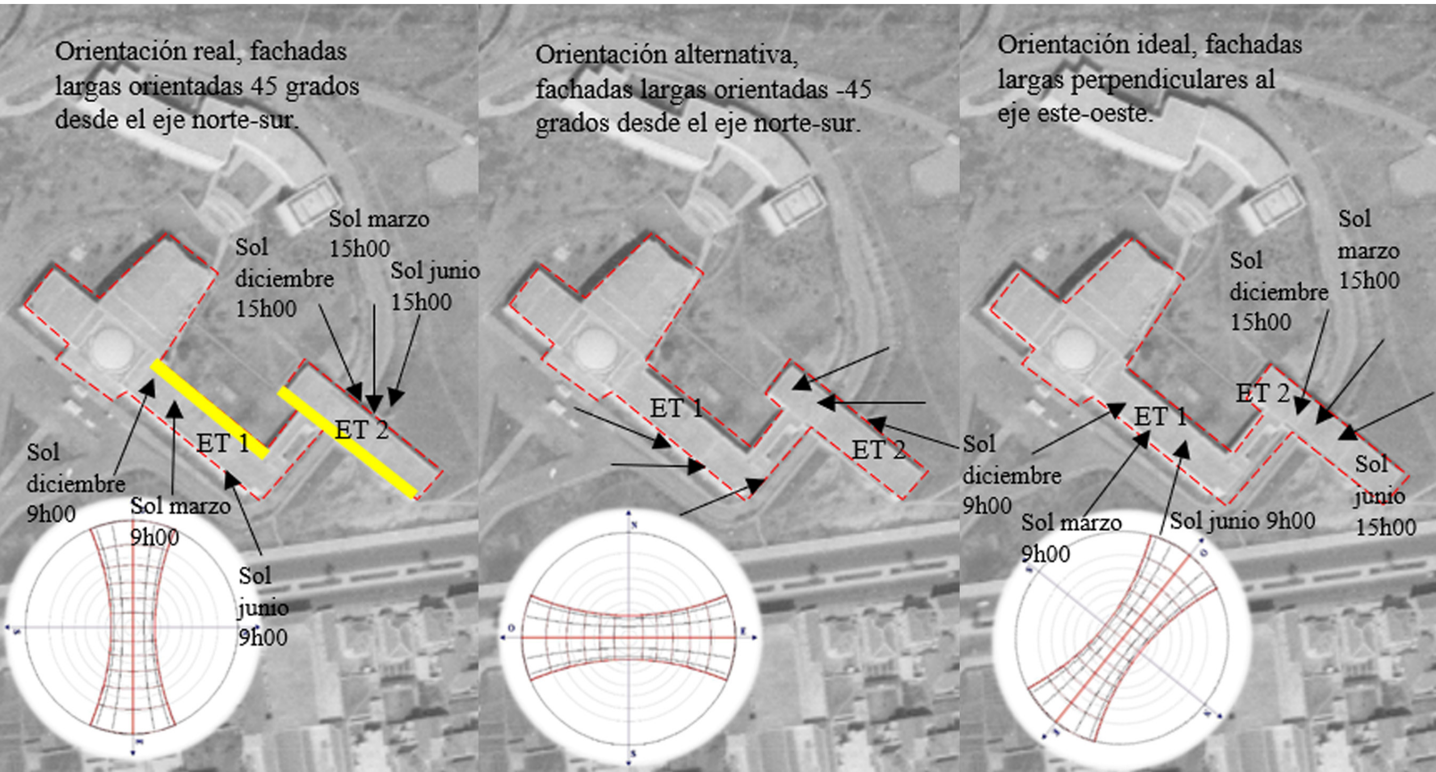
3.2. Faculty of economics

Economics consists of two standard buildings of two floors each, ET5 and ET6. The building type of the Economics faculty is similar in proportion to the General Administration building, but with the difference that its floor plan is not a perfect rectangle, but curves outward, giving the corridor that connects the building types ET5 and ET6 a slightly sinuous shape. The ratio is characterized by the total width of the floor plan being three times its height; the width of the floor plan is divided lengthwise so that the corridor occupies one-third and the classrooms, the remaining two-thirds; the total length of the building is five times the total width of the floor plan (Figure 5); ET6 is three stories high, and ET5 is two; ET6 is a mirror of ET5 on its long side. Twenty-four spaces (classrooms and offices) were measured in November 2020. Classrooms were selected at the ends and centre of the three floors (basement, first floor and second floor) of ET6 and the centre of the second floor of ET5.

These classrooms have a slightly trapezoidal floor plan with a single facade featuring windows, and a wooden floor covering. The facade consists of a solid parapet of one meter high. Above this, there is a 1,5-meter window that can be opened at the ends, with a 20cm high sunshade or brise-soleil. Above this, there is another window about 70cm high, occupying the entire length of the classroom (Figures 7 and 8).

When averaging all the measurements recorded across all spaces in the Faculty of Economics, an average temperature of 18,92 °C, relative humidity of 47%, and 26 lux of natural light were registered. Averaging by zones, the basement recorded 18,12 °C, the ground floor 18,98 °C, and the upper floor 20,16 °C. The basement had 53.47% humidity, the ground floor 47,34%, and the upper floor 44,71%. The combination of temperatures and humidity across all measured floors falls within comfort standards. Temperatures increase by around 1 °C on each higher floor; thus, higher floors are warmer than lower floors." Humidity is inversely proportional, decreasing an average of 4% on each higher floor. Light levels are below the

Figure 4: Aerial photograph of the General Administration of the Campus of the Central University of Ecuador, Quito, Ecuador. Military Geographic Institute (1959)



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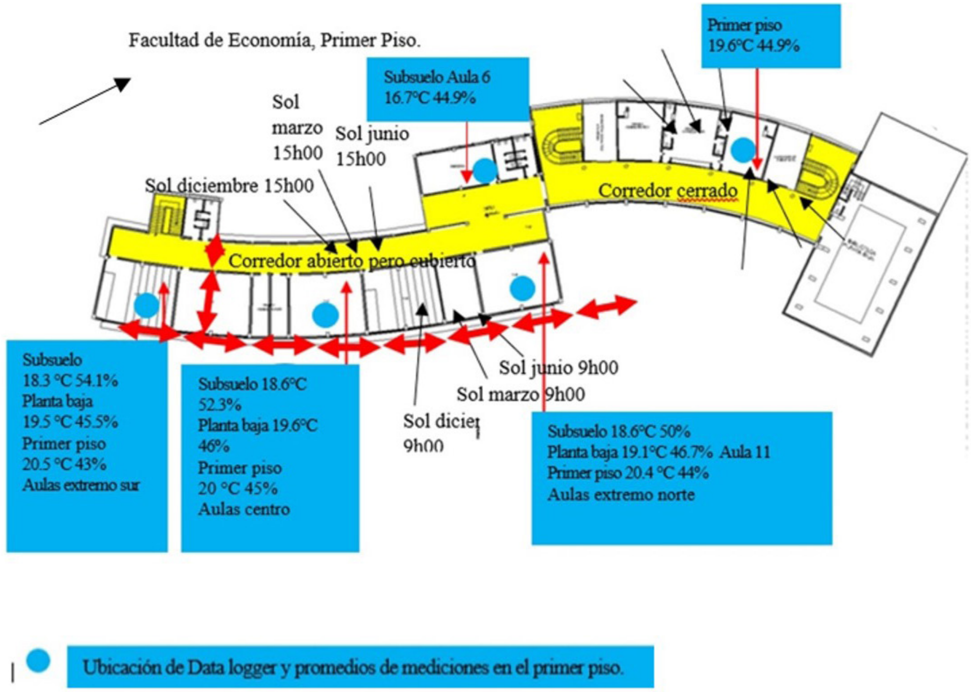

Figure 5: First floor plan of the Faculty of Economics of the Campus of the Universidad Central del Ecuador, Quito, Ecuador
Universidad Central del Ecuador (2020)

minimum range of 50 lux. The average temperatures of all classrooms fall within acceptable comfort ranges, with an increase of 1°C on each floor: 18,3 to 18,6°C in the basement classrooms, 19,1 to 19,6°C on the ground floor, and 20 to 20,5°C on the first-floor classrooms.

The highest and lowest individual values recorded were 23 and 16,3 °C, 61 and 34% humidity, 145,8 and 3,9 lux. The coldest temperatures generally occurred at night, early morning, and morning, while the hottest ones were near noon.

It is inferred that ET6 would record higher temperatures in December due to the greater solar exposure of its façade with windows in the morning, while in June it would have lower temperatures due to the lesser solar exposure. ET5 would have an opposite behaviour, that is, it would record higher temperatures in June and lower ones in December (Figure 6 real orientation). Additionally, ET6 gains direct solar radiation through its windows only in the morning, while ET5 gains it only in the afternoon due to the linear configuration with spaces on one side and a corridor on the other. ET6 would have had a more balanced annual solar exposure if its long façade had been oriented perpendicular to the east-west axis (Figure 6 ideal orientation), thus avoiding the lower solar exposure in June in the current orientation because the sun's angle tends to be too parallel to the long façade; the same would occur in ET2 but in an opposite manner, that is, the lower solar exposure in the month.

The curvature of ET6 and ET5, although very slight, causes different solar behaviour in the classrooms at the centre and at the south and north ends. The windows are protected by two concrete brise-soleil that prevent sunlight from entering after ten in the morning near March, September, and December; the classrooms do not receive sunlight through their windows near June. The coldest place on average was classroom six, with a temperature of 16,7°C, which is below the minimum range and 2°C below the temperature of the neighbouring classrooms. This occurs because it is semi-underground and has only one high and elongated window. The empty auditorium has temperatures below the minimum comfort range throughout the day due to the lack of windows and being semi-underground.

All the spaces had natural lighting levels below the minimum required for office and classroom activities. An interesting lighting behaviour was detected in classroom eleven when it was modified by placing a false ceiling of gypsum or drywall at the height of the brise-soleil, suppressing the high window of 0,7m (Figure 7). Measurements were taken in classrooms eleven, seven, and nine additionally, following the nine-point grid on the work plane. This revealed that classroom eleven had lower natural light levels in areas further from the window compared to classrooms seven and nine, indicating that the high window allowed light to penetrate more deeply. This suggests that there was an intentional design consideration regarding the climate, specifically natural light, by Gatto Sobral.

3.3. Faculty of law

The Faculty of Law consists of buildings of the ET3 and ET4 types. The typical building of the Faculty of Law has proportions where the length of the building is six times the total width of the floor, the width of the floor is three times the height of one floor, and on the floor plan, the classrooms occupy a width twice that of the corridor (Figure 8). The ET3 and ET4 buildings are two stories high and perpendicular to each other. Later, an additional three-story building was constructed parallel to ET3 and perpendicular to ET4, forming a new U-shaped composition. It is suspected that this addition was not made by Gatto Sobral. Nineteen spaces were measured (classrooms, offices, and auditorium on the ground floor; classrooms on the first floor, and classrooms on the second floor) in November 2020. These spaces had an orthogonal configuration with windows on only one façade and wooden coverings on the floors.

By averaging all the measurements recorded in all the spaces of the Faculty of Law, a temperature of 17,91°C, a relative humidity of 57%, and 22,6 lux were obtained.

By averaging the measurements by zones, the ground floor has a temperature of 17,6°C, the second floor 17,32°C, the third floor 18,83°C, and the library 17,8°C. The ground floor has a relative humidity of 59%, the second floor 56,04%, the third floor 51,21%, and the library 61,31%. The third floor, being the highest, is approximately 1°C warmer than the lower floors with 18,8°C. Humidity tends to be inversely proportional across the floors; that is, lower temperatures correspond with higher humidity levels. The combination of temperature and humidity on all the measured floors is below the comfort range, with low temperatures and high humidity levels. The light levels are also below the comfort range.

The highest and lowest individual temperatures recorded were 25,50°C and 14,26°C, showing a thermal amplitude of 11°C, with humidity levels of 73% and 42%, and light levels of 1787 and 3,9 lux. The coldest temperatures generally occurred at night, early morning, and morning, while the hottest ones were near midday. Almost all spaces recorded values below the comfort zone, except for two spaces: the auditorium and classroom 27 on the third floor, which reached temperatures within the comfort range (23°C and 20°C).

ET3 receives direct solar gain through the classroom windows throughout the day only near the June solstice, while ET4 gains solar exposure in the classroom

Figure 6: Aerial photograph of the Faculty of Economics of the Campus of the Universidad Central del Ecuador, Quito, Ecuador. Military Geographic Institute (1959)

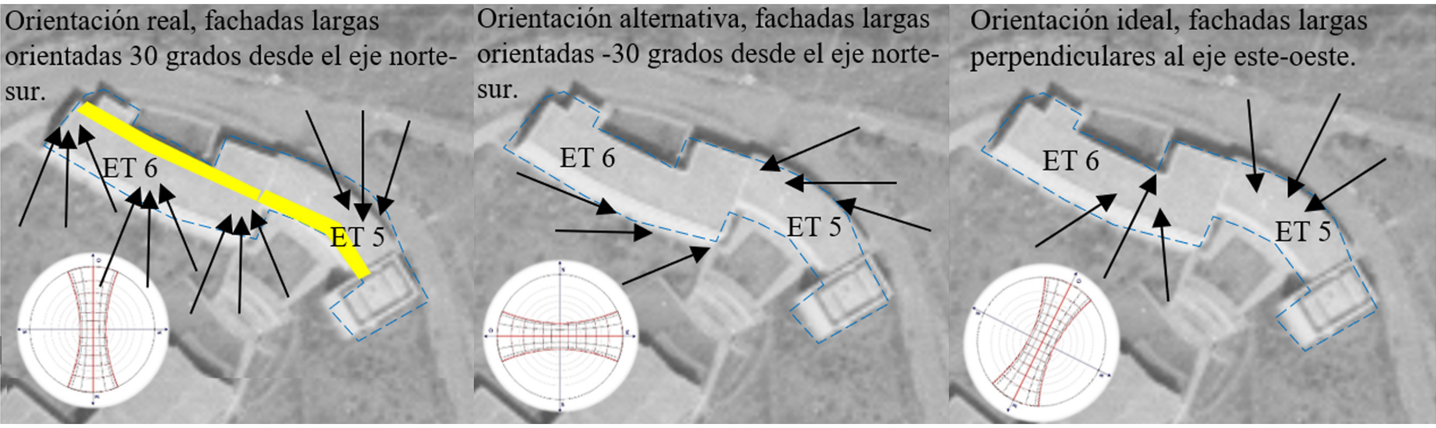

Figure 7: Classrooms of the Faculty of Economics of the Campus of the Universidad Central del Ecuador, Quito, Ecuador.

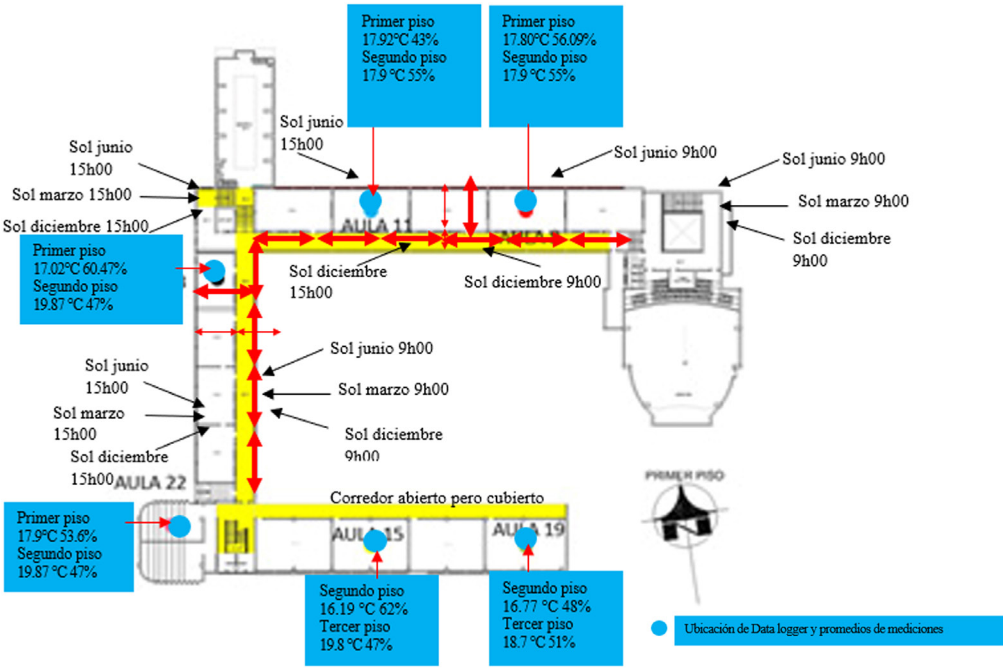

Figure 8: First floor plan of the Faculty of Law, Universidad Central del Ecuador Campus, Quito, Ecuador. Universidad Central del Ecuador (2020)

windows only in the afternoons throughout the year. It can be inferred that near the December solstice, ET3 could reach its lowest temperatures due to the lack of solar exposure on the façade with windows (Figure 9 real orientation).

The perpendicular arrangement of ET4 and ET3 does not allow for a more balanced solar exposure in either alternative one or two (Figure 9), as one of the buildings will always have a period of the year without receiving solar radiation through its windows. Among General Administration, Economics, and Law, the latter exhibits the worst climatic performance, being the coldest and most humid. The library maintains an average temperature below the comfort range at 17,8°C. The empty auditorium has an average temperature below the comfort range at 17,3°C. Regarding natural lighting, the classrooms have levels below the range for offices as they receive light only on the side opposite the corridor.

4. Discussion

The analysis of bioclimatic quality measurements of the buildings on the UCE campus (Tables 2 and 3) allowed for an evaluation of Gatto Sobral's educational buildings from a new perspective.

The buildings designed by Gatto Sobral on the campus are described as luminous (Villagomez et al., 2020). However, when considering the averages of natural light at central points across all measured spaces and averages by zones, none fall within the minimum range for office or educational activities. The causes primarily lie in the form and proportion of the typical building, which despite appearing from a distance as elongated, slim, linear, and open (Villagomez et al., 2020), is actually a massive structure with a depth that is too great relative to the height of its windows. Offices and classrooms typically have only one window, effectively illuminating only a third of the interior of the floors with natural light. Paradoxically, this also reflects Gatto Sobral's adaptation of buildings to the landscape and topography (Villagomez et al., 2020), creating massive structures that appear slim and elongated from a distance, prioritizing the visual aesthetics of the buildings over their liveability.

It must be acknowledged that Gatto Sobral did incorporate functional and aesthetic manipulations of diffuse light, such as the use of glass blocks in the facades of the library or the skylight made of glass blocks in the auditorium of the Faculty of Law, as well as the design of windows and over-windows in the Economics classrooms. However, the overall result of their buildings did not achieve adequate levels of natural lighting, leading to health issues such as visual fatigue or low mood among students and faculty, especially, and impairing the performance of activities in classrooms and offices. This has necessitated the use of artificial light throughout the day to compensate for this deficiency.

The second major issue with Gatto Sobral's buildings is that they are cold. Although some spaces recorded temperatures within the comfort range, particularly

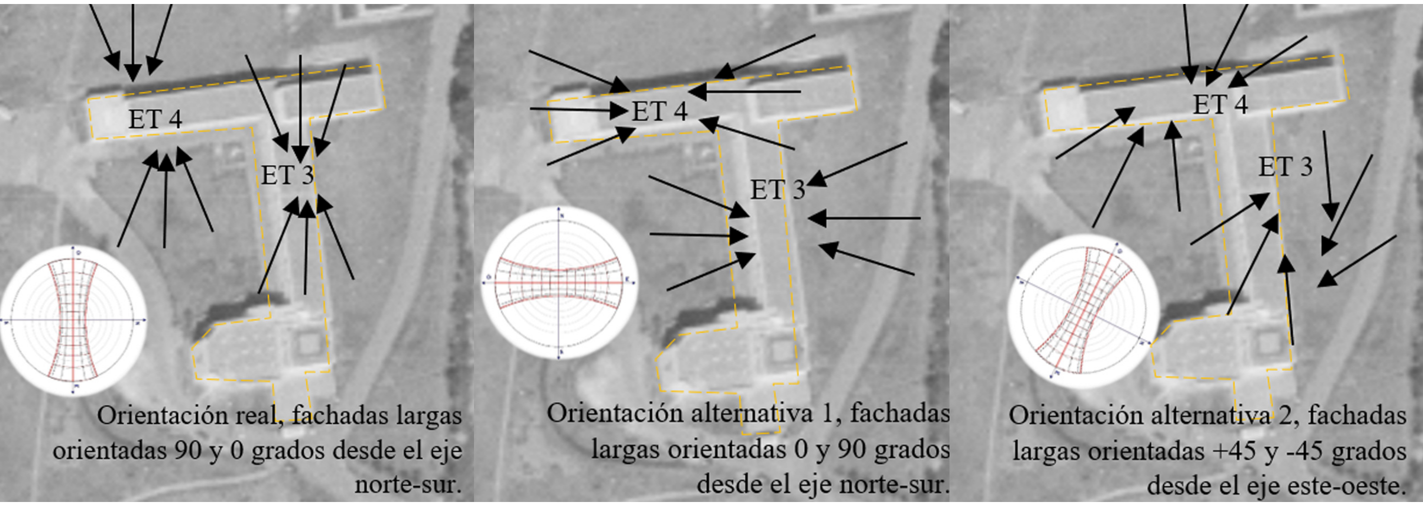

Figure 9: Aerial photograph of the Faculty of Jurisprudence of the Campus of the Central University of Ecuador, Quito, Ecuador. Military Geographic Institute (1959)

Building	Temperature °C	RH %	Natural light lux
General administration	20,81	52,71	45,31
Economy	18,9	47,59	26,03
Jurisprudence	17,91	57,07	22,62

Table 2: Total averages

<table>
<tr><th>Building</th><th colspan="2">Temperature °C</th><th colspan="2">RH %</th><th colspan="2">Natural light lux</th></tr>
<tr><td rowspan="2">General administration</td><td>23,35</td><td>20,37</td><td rowspan="2">66,23</td><td rowspan="2">48,39</td><td rowspan="2">681,9</td><td rowspan="2">3,9</td></tr>
<tr><td colspan="2">Thermal amplitude: 2,98</td></tr>
<tr><td rowspan="2">Economy</td><td>23</td><td>16,3</td><td rowspan="2">61</td><td rowspan="2">34</td><td rowspan="2">145,8</td><td rowspan="2">3,9</td></tr>
<tr><td colspan="2">Thermal amplitude: 6,4</td></tr>
<tr><td rowspan="2">Jurisprudence</td><td>25,50</td><td>14,26</td><td rowspan="2">73,46</td><td rowspan="2">42,97</td><td rowspan="2">1787</td><td rowspan="2">3,9</td></tr>
<tr><td colspan="2">Thermal amplitude: 11,24</td></tr>
</table>

Table 3: Absolute maximums and minimums

in General Administration, they were close to the minimum range of 18°C. This can still feel cold for some people, especially when performing sedentary work for three or more consecutive hours, as in classes, and it is two degrees below the Argentine standard of 20°C for educational spaces. General Administration had the best thermal performance, and the Faculty of Law had the worst, as seen in Table 2. When comparing Victor Olgyay's comfort diagrams for Quito's climate with the measurements of the three buildings, it is observed that only General Administration has average, maximum, and minimum values within the comfort range. The values for Economics (Figure 16) and Law fall below the comfort range, within the zone indicating that temperatures need to be raised. The low temperatures recorded can cause problems such as fatigue, drowsiness, loss of attention, lethargy, colds, and even bone pain in teachers, students, workers, and administrative staff. This is particularly detrimental to UCE as it can reduce the learning and concentration capacity of students and teachers.

There is no easy architectural solution to passively and long-term fix these problems due to the shape (large spaces, deep floor plans, incorrect orientation) and the materials (concrete, brick, and glass) used. However, in the short term, conditions could be actively improved with electric heaters. When comparing the three buildings, it becomes apparent that Gatto Sobral did not consider solar orientation or subordinated it to the adaptation to the landscape and topography of the terrain. Additionally, the symmetrical or perpendicular layouts of the typical buildings are inadequate for Quito's latitude as they cause imbalanced sunlight exposure throughout the year. The concrete slabs and floors, along with the width of the brick walls, also contribute to the low temperatures in the buildings.

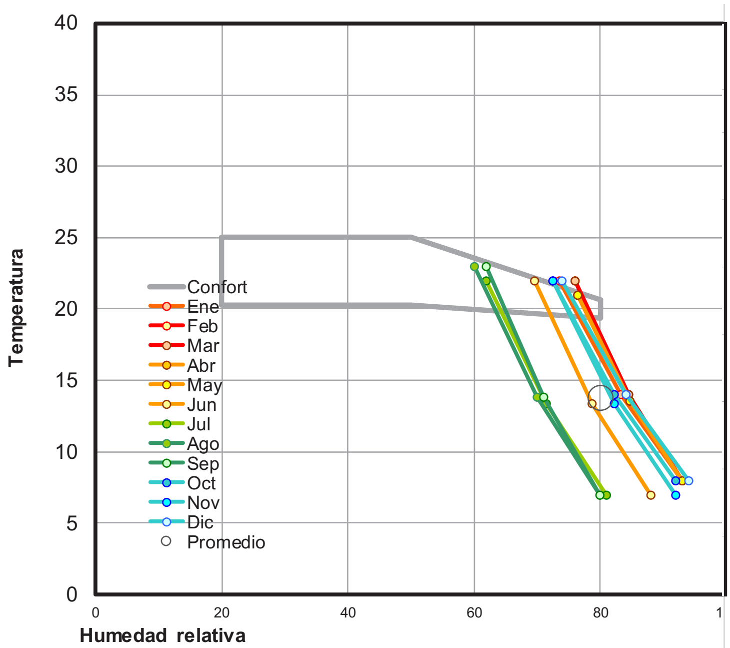

Figure 10: Victor Olgyay comfort diagram made with e-Clim software using data taken from the M0024 QUITO INAMHI-INNAQUITO meteorological station. Evans and Delbene (2004), (2024)

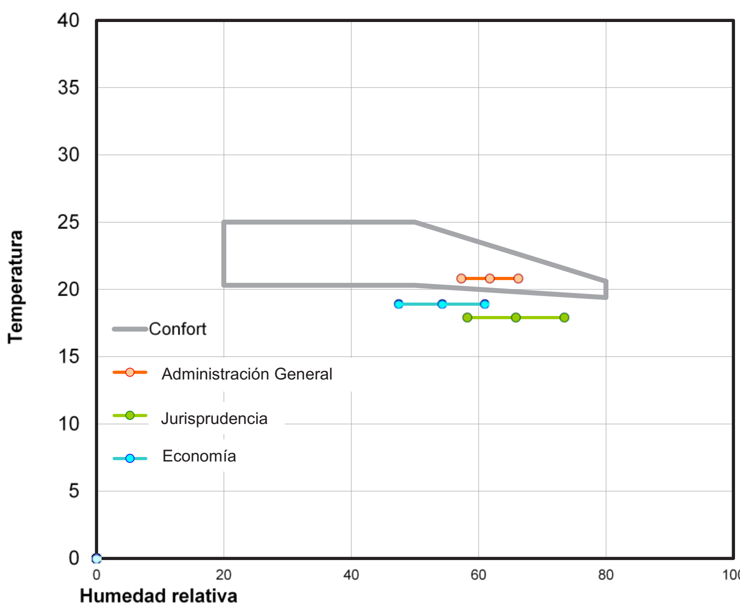

Figure 11: Victor Olgyay's comfort diagram made with e-Clim software using total average and absolute maximum and minimum data from the General Administration, the Faculty of Jurisprudence and the Faculty of Economics. Evans y Delbene (2004) (2024)

The fact that the UCE campus has constructed buildings with bioclimatic issues despite being planned from scratch within an Urban Master Plan, on a free and spacious plot of land, with government funding, and with professional architects, is not unusual. There have been other modern large-scale projects that failed in their climatic adaptation. For example, the Brazilians Oscar Niemeyer and Lucio Costa designed the new city of Brasília from scratch along with several of its most important buildings, and they had problems with the heat and the latitude of Brazil. The iconic architect Le Corbusier designed the Master Plan for the city of Chandigarh in India, but the brise-soleil he projected did not control the sun as expected, an error likely due to the architect relying more on his "instinct" than on his knowledge when facing a different hot climate and latitude compared to Europe (Szokolay, 1998).

It is true that, since its origins, the modern movement has shown an interest in hygiene and health, materialized mainly in studies on ventilation and sunlight exposure. However, despite this, it made significant climatic adaptation errors that can be attributed to three causes: a lack of knowledge on how to work with the climate; the desire to distance themselves from the materials and forms used in traditional architecture and/or that recalled an inappropriate, bourgeois, historicist, or primitive image—load-bearing walls, sloped roofs, overhangs, brick, wood, tile, small windows with wooden frames, and decorations—and instead experiment with new forms and materials, such as concrete, large glass windows, plastics, beam-column structures independent of the walls, brise-soleil, and flat roofs. Moving away from tradition meant moving away from vernacular architecture, or "archetypal regional" architecture (Grosso, 2021, p. 119), which developed forms and techniques that work in the local climate after processes of trial and error that took generations. The third cause is related to an attitude that permeated modern architecture and could be summarized by the motto "starting from scratch" or "recreating the world" (Wolfe, 2010, p. 156), which gave certain places the status of "experimental laboratories" or "testing grounds" (McGuirk, 2014) and endowed their designers with a certain heroic aura.

Brian Goldstein differentiates between the two types of stories that can be told about a building: one is the story of its design, and the other is the story of its experience (Goldstein, 2023). The first story celebrates the designer and the creative risks they took, omitting the second, which tells how the building is inhabited. Photographs of buildings usually show them as beautiful but do not convey the bioclimatic problems they have inside because these are invisible. These buildings are photogenic but uncomfortable. Something similar happened with the Gatto Sobral case; the UCE campus was a new world, and the narrative that predominates in the studies mentioned in the introduction is the design of the buildings, celebrating their formal beauty and integration with the landscape but omitting the experience, according to which all generations of students and teachers have suffered from cold and darkness. The bioclimatic quality problems of the UCE case were made visible by data loggers. The UCE campus and the Urban Plan of Quito also emerged in an era when Ecuador desired modernization, thinking about the future rather than old living standards. Therefore, the departure from the traditional can also be seen as a departure from what was considered primitive, not realizing that this would produce buildings that did not passively adapt to the climate and would affect the health of their users.

5. Conclusions

This study, which covered the diagnosis of bioclimatic quality through the measurement of quantitative conditions of temperature, relative humidity, and natural lighting of three modern buildings on the UCE campus designed by the architect Gilberto Gatto Sobral, led to two conclusions:

Firstly, the bioclimatic quality of these buildings is inadequate. Most of the studied spaces in the sample suffer from cold and dimness, requiring significant architectural intervention to passively address these issues, or the use of electric heaters and artificial lighting. It is recommended to continue with a series of investigations to expand on the results obtained in this study. On one hand, this involves focusing on measuring the typical classroom or representative classroom of each building in greater depth, including occupancy considerations. On the other hand, these investigations should aim to propose design solutions that surpass the current conditions. Additionally, planning research that correlates the health and satisfaction of teachers and students with the quantitative measures taken in classrooms could also be beneficial.

Secondly, climate did not play a significant role during the design of the buildings. Gatto Sobral exhibited behaviours similar to other architects of the modern movement of his time, using new forms and materials without considering the local climate. Despite having certain design intentions aimed at manipulating natural light, he did not take into account solar geometry or the thermal behaviour of materials, resulting in buildings with deficient thermal and lighting performance.

Conflict of Interests. The author declare no conflict of interests.

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