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Research article

Strategies for thermal comfort in university buildings - The case of the faculty of architecture at the Federal University of Bahia, Brazil

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ABSTRACT

Buildings constructed according to bioclimatic architectural principles in amenable climates have often experienced posterior interventions that have closed ventilation openings for the installation of air conditioning units.

The present work sought to investigate the reasons for installing air conditioning equipment in buildings even under adverse economic conditions and with the awareness of their negative environmental implications. The Faculty of Architecture building at the Federal University of Bahia, located in the city of Salvador, Bahia State, Brazil, was the focus of the present investigation. It was determined that the lack of maintenance of the windows and window frames, and the closing of projected openings compromised natural ventilation.

The study confirmed the adequacy of the architectural project in relation to the local climate, and *in loco* measurements likewise confirmed the efficiency of natural ventilation through the windows and other openings in the faculty room and classrooms examined. The results of the interviews concerning thermal comfort indicated that 53% of the users felt comfortable. Nonetheless, it was found that the building's windows and window frames were poorly maintained, compromising their ability to facilitate efficient natural ventilation and significantly diminishing the capacity for thermal regulation in the building.

This study calls attention to the necessity of refining and improving the maintenance of university buildings to reduce the intensive use of artificial air conditioning in detriment to investments in projects that could lend priority to natural ventilation and the maintenance of good window operating conditions.

1. Introduction

Public teaching institutions in developing countries, such as Brazil, have shown a tendency to promote thermal comfort by installing air conditioning units, leaving aside the possibility of focusing on natural ventilation that would be both more economically sound and healthy. A number of factors converge to favor the installation of air conditioning, including a lack of knowledge about the concepts and techniques of bioclimatic architecture, and the difficulty of encountering appropriate hardware and professionals competent to propose more natural solutions.

In spite of the frequent increases in electrical energy tariffs in Brazil that have serious impacts on the operational costs of teaching institutions, the individuals that frequents those institutions are not directly impacted by (or even sometimes aware of) the costs involved. The intensive installation of air-conditioning units has contributed significantly to energy consumption, as the administrators of public institutions tend only to seek lower initial investment costs (as opposed to maintenance costs).

Schulze and Eicker (2013) studied the potential use of natural ventilation to promote electrical energy economy. Their findings demonstrated that there was very little information available concerning thermal comfort and air quality inside buildings without artificial air-conditioning. Architectural projects do not often emphasize natural ventilation due to the lack of information concerning comfort levels in buildings that depend only on natural ventilation. The NatVent Project reported that the lack of experience and background knowledge of architects and engineers represented the principal barriers to wider uses of natural ventilation (Schulze and Eicker, 2013).

Projects that consider strategies of natural ventilation can result in significant reductions in energy consumption. Manzano-Agugliaro et al. (2015), for example, concluded that the use of bioclimatic architectural principles should be much more widely adopted as they result in very significant reductions of energy consumption. Souza and Rodrigues (2012) demonstrated that cross ventilation is 3.5 times more efficient than unilateral ventilation, and that building plans that consider the

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principles of natural ventilation, local climatic conditions, and wind direction can generate optimal results of thermal comfort. Architectural projects of school buildings that incorporate principles of natural ventilation can demonstrate considerable reductions in energy consumption.

There are three basic objectives of natural ventilation: i) the cooling of interior air; ii) the cooling of the build structure itself; and, iii) direct cooling of the human body through convection and evaporation. Natural ventilation during the night takes advantage of the thermal mass of the building as a cooling element (Taleb, 2015).

Lamberts et al. (2014) observed that the directives of bioclimatic architecture focus on: i) projects that consider the physical orientation of the building in terms of wind and solar radiation directions; ii) the shading of building openings; and, iii) construction techniques adapted to the regional climate that can guarantee greater thermal comfort for the users and a more energetically efficient structure.

Ricciardi and Burratti (2018) investigated the environmental quality of university classrooms and determined that evaluations of environmental comfort do not depend only on objective parameters, making a combination of physical measurements, questionnaires, and personal interviews necessary to provide a more comprehensive evaluation. Nematchoua et al. (2014) examined the perceived thermal comfort in 28 buildings and schools in a region with a humid tropical climate. Those researchers used an adaptive approach to study naturally ventilated buildings (according to ASHRAE 55/2004, ISO 7730, and ISO 10551) during both the dry and rainy seasons. Fully 74.6% of the interviewees stated that they experienced thermal comfort, while 25.3% were neutral.

Zomorodian et al. (2016) reported that thermal comfort was directly related to well-being and productivity, and noted that concerns about energy conservation among school administrators had acquired significant importance in recent years. Their study provided an overview of field research concerning thermal comfort in school buildings in the last five decades, and concluded the thermal preferences of the students were largely not within the traditional established comfort zone – and that natural ventilation was essential to internal air quality and thermal comfort.

An important point to be stressed is that environmental thermal comfort conditions are directly related to human productivity – making it essential that academic environments are conducive to physical well-being. Haddad et al. (2016) noted that school buildings are among the most important types of structures for investigating sustainability, an area that involves environmental quality, energy efficiency, and the need for a healthy and productive environment for educational purposes.

Studies by Soares et al. (2015) and Nandarani and Harold (2016) likewise demonstrated the concern of several countries and universities with establishing actions aimed at reducing energy consumption through technological innovations and user awareness – as user behavior has a decisive influence on the implementation and success of sustainability practices and energy consumption reductions. Paço and Lavrador (2017) investigated the existence of relationships between knowledge and attitudes and between knowledge and environmental behavior, and concluded that there was no direct relationship between knowledge, attitude, and behavior. People can be aware, but still not change their behaviors or attitudes in relation to energy usage.

More recent studies by researchers at Michigan State University demonstrated the concerns of other academic communities in that regard. Summer and Marquart-Pyatt (2018) examined the factors influencing energy conservation behaviors, and concluded that the interviewees they worked with would support policies to rationalize energy use in buildings.

From a public health standpoint, natural ventilation reduces the permanence time of infectious diseases in the air, and so decreases the number of working days lost due to health problems. According to INMETRO (2017), air-conditioning systems can actually increase the frequency of infectious diseases when strict and systematic cleaning schedules are not enforced. The “sick building syndrome” is known to be more common in air-conditioned buildings than in naturally ventilated buildings. Seppänen and Fisk (2004) and Kembel et al. (2012) likewise reported significant positive impacts of natural building ventilation, including reductions in respiratory allergies and other communicable diseases.

Despite the points mentioned above, there has been a growing tendency to adopt artificial air-conditioning to improve thermal comfort in public university buildings. This can be exemplified by the recent acquisition of numerous air-conditioning units by the Federal University of Bahia (UFBA), which was confirmed through visits to other buildings and conversations with the University administration. New buildings are currently being designed to operate solely with air-conditioning, that is, they will not have window frames that open (such as the Classroom Pavilion at the Institute of Public Health).

Considering the importance of energy efficiency in meeting the future demands of Brazil, the Brazilian Ministry of Mines and Energy launched a National Energy Plan (PNE) projecting forward to the year 2030 (EPE, 2014). That country recently adopted the National Program for the Conservation of Electric Energy (PROCEL) to contribute to rational energy use. Within that concept, the Brazilian Program of Building Evaluation (PBE Edifica) was established in partnership with National Institute of Metrology, Quality and Technology (INMETRO) and Eletrobras (two agencies empowered to evaluate energy performance in residential, commercial, and public buildings).

Among those regulations, Normative Instruction No. 2 (published in June/2014) established rules for contracting federal public building projects with National Energy Conservation Labels (ENCE). Within that effort, public universities, especially in areas related to Engineering and Architecture, are viewed as having fundamental roles in consolidating practical applications and stimulating the development of energy-efficient projects that will meet thermal comfort standards through passive solutions and achieve desired environmental performance goals wherever possible using renewable energy.

The following studies can be highlighted within an international scenario: the World Energy Outlook and the Energy Efficiency Market Report, both produced by the International Energy Agency (IEA); the (Annual Energy Outlook, prepared by the Energy Information Administration/U.S. DOE); and Energy Efficiency. The IEA Program has published strategies promoting the use of natural ventilation in buildings as well as alternative energy technologies (such as wind energy).

According to the Energy Technology Perspectives Report (ETP, 2015), the growing energy and infrastructure demands of emerging economies stress the importance of implementing technological solutions that can reduce CO_2 emissions. As a consequence of such discussions, projects incorporating low energy consumption strategies, including passive air-conditioning, are now priority considerations in many countries.

The Ecocampus project, an environmental management system directed towards educational institutions, has been active in Europe since the beginning of the current century (Tauchen and Brandli, 2006). The United Kingdom led the university movement at that time, but educational institutions in several other countries have since become increasingly committed to pursuing teaching practices focusing on the sustainable operation of their campuses.

The culture of artificial air conditioning is increasingly being adopted at UFBA, and not only in administrative buildings, but also in classrooms. According to data presented by the Energy Consumption Diagnosis Report (elaborated by the working group for water and electric power management at UFBA), there has been a marked increase in spending on energy consumption by the University (UFBA, 2015). Additionally, due to the growing use of air conditioners in UFBA buildings, the institution has hired a specialized company to execute continuous installation services and provide technical assistance and preventive maintenance for those acclimatization systems (UFBA,

Table 1
Energy expenditure and consumption at the faculty of architecture.
Own elaboration, based on UFBA/SUMAI.

YEAR	VALUE	kWh
2015	R$ 80,825.00 (US$20,521.49)	121,655.68
2016	R$ 135,665.00 (US$34,445.38)	201,731.11
2017 (Jan to June)	R$ 87,713.00 (US$22,270.36)	137,408.80

2017).

According to data provided by the Superintendence of the Environment and Infrastructure (SUMAI) and presented in Table 1, there was a 59.57% increase in electric energy costs in the Faculty of Architecture – with the energy bills in the first half of 2017 being greater than the entire year of 2015. The installation of 24 air-conditioning units during that period surely contributed to that difference (UFBA, 2017).

According to the Final Report of the Work Group for Administrating Water and Electrical Energy at UFBA (UFBA, 2015), which collected data between April/2013 and April/2015, UFBA accrued expenses of approximately $22 Million Reais (approximately US$5,500,000) with electrical energy in that time period. Fig. 11 shows that increasing trend of expenses (with reductions in expenditures during holiday months).

Even buildings that had been designed and built according to bioclimatic architectural principles, such as the UFBA Faculty of Architecture, have seen an increasing adherence to artificial air-conditioning. Their installation has so far been limited to administrative offices – but without any attempts to adopt simple measures to improve their thermal performance by passive means. It is therefore necessary to question the necessity of installing air-conditioners in buildings designed according to bioclimatic principles and to investigate if: those buildings are performing well; are there design flaws? What would those flaws be? Or does that situation reflect other priorities, such as the growing culture of using artificial air-conditioning?

In order to encounter answer to those questions, the present work developed a case study of on-site evaluations of four rooms in the UFBA Faculty of Architecture (three classrooms and one faculty room) – all of them currently without artificial air-conditioning, to gauge user satisfaction with regard to thermal comfort and to examine the possibility of increasing their thermal performances through passive measures. The present work therefore focused on aspects related to user opinions, their clothes, the internal climatic conditions of the rooms examined, their operating conditions, and the lack of maintenance.

2. Contextualization

2.1. The local climate

The city of Salvador is located at sea level in northeastern Brazil (12° 58′16″S and 38° 30′39″W). The region is characterized by a warm and humid Atlantic tropical climate (Bioclimatic Zone 8), according to the NBR 15220 classification of Brazilian Association of Technical Standards (known as ABNT) (ABNT, 2005), with relatively constant temperatures throughout the year. According to NBR 15575 (ABNT, 2013), a typical Austral summer day in the city of Salvador has an air temperature range of 6.1 °C, with a maximum of 31.6 °C; the Austral winter season has a daily amplitude of 5 °C, and a minimum temperature of 20 °C. The average annual temperature is 25.2 °C, with 76.97% relative humidity, and a wind speed of 3.1 m/s (Labeee, 2016; INMET, 2016).

The mesoclimatic conditions of Salvador can be described as having a general tendency for positive thermal stress during the day throughout the year (even during the winter season), although there are perceptible seasonal climatic variations (Moura et al., 2006).

Natural ventilation is essential for obtaining year-round thermal comfort, even in periods of low thermal stress. The wind regime in Salvador is relatively constant throughout the year, with low percentages of calm. The winds predominate from the southeastern quadrant, with average annual velocities ranging from 2.9 m/s to 3.4 m/s. The highest winds occur during the summer months, blowing predominantly from the east. Those easterly winds continue throughout the summer months until March, then shifting to a more southerly direction during the winter (INMET, 2016).

Moura et al. (2006) concluded that buildings constructed in elevated areas (above 60 m) in the city of Salvador show good thermal comfort conditions.

2.2. Climate-related thermal comfort strategies

Several studies have pointed out natural ventilation and shading as the principal strategies for thermal comfort in buildings in regions with hot and humid climates, such as the city of Salvador. Fanger et al. (1998), Frota and Schiffer (2001), Corbella and Yannas (2009), Bittencourt and Candido (2010), Marcondes (2010), Fong et al. (2011), Lamberts et al. (2014), and Haddad et al. (2016) all proposed strategies to promote natural ventilation in buildings.

Natural ventilation strategies involve passively cooling building environments by replacing warmer internal air with cooler external air.

2.3. Qualitative analysis of the building

The architectural design of the UFBA Faculty of Architecture was originally elaborated by a commission composed of the architects/professors Diógenes Rebouças, Américo Simas, and Oscar Caetano Silva, and is considered a good example of modern Bahian (and Brazilian) architecture. Its construction took place in stages during the 1960s and 1970s, with the east wing being built between 1963 and 1967, and the portico and auditorium being completed in 1973 (Andrade, 1989).

In the 1980s, the mezzanine was designed by the architect and professor Heliodório Sampaio and built where the administration currently operates. In 2010, construction of a new pavilion was begun (a project authored by the architect and professor Pasqualino Magnavita) to house laboratories and faculty offices, although it has not yet been concluded.

The Faculty of Architecture buildings are located in the Federation neighborhood, on a ridge approximately 50 m above sea level (a.s.l.), with good natural ventilation. The buildings were designed to take advantage of the near-constant wind using bioclimatic architectural principles, with the sectors oriented perpendicular to the prevailing winds to allow interior cross-ventilation through the entire building.

Surrounding the buildings are large areas of vegetation (Fig. 1a) that provide shade and create microclimates with milder temperatures. The central patio is largely open, and takes advantage of the direction of the wind for cross ventilation (Fig. 1b). The building was constructed at 56 m a.s.l. and is open to the landscape and to facilitate ventilation, presenting, according to Andrade (1989), transparency, amplitude, and integration with environment.

In addition to having an ideal location and the correct orientation to take advantage of Salvador's predominant winds, the sector that houses the classrooms (east wing) was provided with openings in its opposite walls to facilitate cross ventilation as well as other construction details that facilitate air circulation, as shown in Fig. 2.

Additionally, ceramic ventilation block walls (Fig. 2) were built in the public circulation areas that provide access to classrooms to protect against the direct incidence of sunlight while allowing free air flow. Such shading strategies, including a thick vegetation cover, provide thermal comfort and contribute to the reduction of global warming (Nery et al., 2006).

a) b)

Fig. 1. (a) Aerial photograph of the UFBA Faculty of Architecture, (b) the Main Entrance. Source: (a) ® Google Maps, and (b) M. Costa.

3. Methodology

A quantitative case study methodology was adopted, investigating the natural environment, analyzing documents, collecting data through physical measurements, and holding interviews with building users.

This work therefore represents an exploratory research project designed to call attention to the growing, but undesirable, trend of using mechanical air-conditioning devices instead of investing in passive solutions to the thermal regulation of internal environments.

According to Denzin and Lincoln (2006), in that type of research model the interdisciplinarity of subjects is taken into consideration. Field research itself is an investigation. In light of its objectives, it is possible to categorize such research as exploratory, a technique widely used by researchers for rapid and efficient data collection from a study population, which could be a case-study, an interview, participatory research, or other.

Gil (2008) contributed to that theoretical approach by considering that the principal objective of exploratory research is to increase familiarity with a problem, make it more explicit, and sharpen the ideas involved. That same author noted that exploratory research is flexible and can incorporate bibliographic research, interviews with individuals familiar with the problem, and analyses of similar situations.

Additionally, according to Severino (2007), exploratory research seeks only distinct information about a certain object, thus delimiting a finite research area and mapping its manifestations.

Within that methodological process, evaluations were made of the thermal conditions of environments at the Faculty of Architecture in a faculty room and four classrooms by measuring environmental variables and interviewing their users to assess their degrees of thermal comfort satisfaction. In parallel, a quantitative evaluation was undertaken of the physical and architectural aspects of each room and their degrees of conservation, to identify possible faults that would negatively impact those thermal environments.

That methodological process will be described below.

3.1. Field survey period

Field surveys were conducted once a week (at 10:00, 13:00, and 16:00) for eight consecutive weeks during the Austral summer months (February, March, and April/2017).

3.2. Environmental parameters measured

As the environmental variables that most influence the sensation of thermal comfort are air temperature, relative humidity, surface temperature, and wind velocity, measurements were made of:

- The average wind velocity (m/s) in the plane of the window openings using a Minipa MDA-11 digital thermo-anemometer (for 16 s).
- Air temperature, measured by the same thermo-anemometer.
- The surface temperatures of the walls, ceilings, and floors, using a Raytec.
- Raygner ST6 surface temperature gauge.

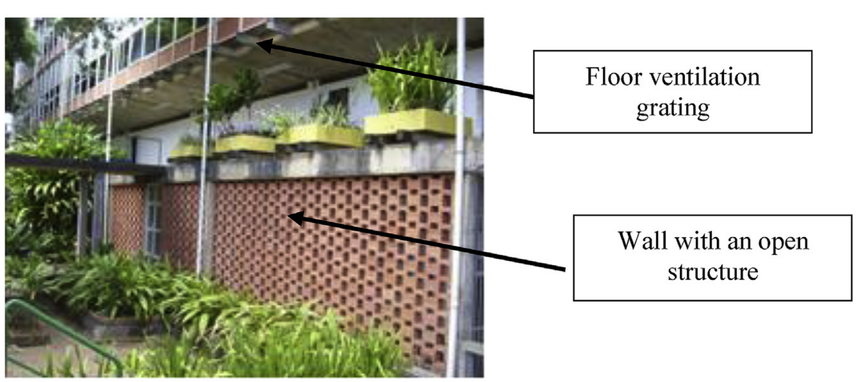


Figure 2. Circulation Area

Fig. 2. Circulation area.

We also acquired wind speed, air temperature, and relative humidity data for the city of Salvador during the same survey period, as published on the www.climatempo.com.br website.

3.3. Interviewing the occupants

Whenever measurements were made of environmental parameters, up to five occupants of each room were interviewed. The classrooms can hold more than 30 students, although only approximately 20 were present most of the time. The faculty room holds only six people. The choice of which five people in the classrooms were interviewed was essentially random, although to obtain greater sampling uniformity, four were chosen from near the corners of the room and one from the center whenever possible. If, at the time of measurement, the rooms were occupied by less than five people, all of them were interviewed. As such, the sampling represented approximately 20% of each group.

To determine the degree of user satisfaction in terms of thermal comfort, the questionnaires were based on the ISO 7730 (2005) that quantifies their sensations as: very cold (−3), cold (−2), slightly cold (−1), neutral (0), slightly warm (1), warm (2), and very warm (3).

To account for possible inconsistencies in interviewee responses, the clothing they were using at the time was also taken into consideration, in terms of their degrees of thermal insulation (according to ISO 7730 parameters that establish the thermal resistance indices of clothing; using the "clo" unit). The positions of the interviewees in the rooms were recorded, as well as their ages, gender, and their time of permanence in that space.

Before the definitive application of the questionnaires, pre-tests were performed to validate them and verify that the questions could be easily understood. A total of 178 people (both students and faculty) were interviewed. Of those, 37% were men and 63% women; the youngest was 18 and the oldest 67.

3.4. Descriptions and qualitative evaluations of the classrooms analyzed

3.4.1. Classroom A

Classroom A (Fig. 3a) is located on a slope at 52.5 m a.s.l. It has an internal area of 72.15 m^2, a ceiling height of 2.97 m, and the capacity to accommodate 30 students. The external wall of the room is oriented at 75° NE toward a silent, outside vegetated environment. The windows on that wall (3 mm thick clear glass) were held in maxim-ar frames (opening up to 45°) with dimensions of 6.80 × 1.80 m, with Venetian slats above them (Fig. 3b), comprising a total area of 24 m^2, with the lower sill at 1.16 m.

The wall with the entrance door (opposite from the main windows) is open near the ceiling (0.60 × 6.85 m), and the total open area of the room represents 7% of its floor space. The side of the room with the entrance door faces an internal corridor with a "honey-combed" brick wall that allows cross ventilation.

The conservation status of the windows is precarious, however, with broken panes and accessories that make opening and closing them more difficult, thus diminishing their ability to allow natural ventilation and improve thermal comfort levels.

3.4.2. Classroom B

Classroom B (Fig. 4a, e, b) is situated at 56.0 m a.s.l. It has a floor area of 75.74 m^2, a ceiling height of 2.88 m, and the capacity to accommodate 34 students. The outside wall is oriented at 75° NE, has six maximum-air window modules with wooden frames and clear glass (3 mm). Each module is 1.0 × 1.0 m, with a sill height of 50 cm. Just two of those six modules can currently be opened up to 90°, while the others are fixed. Above.those windows there are 50 cm openings, which are currently sealed with plastic sheets. The effective opening area of this room represents 3% of its floor area.

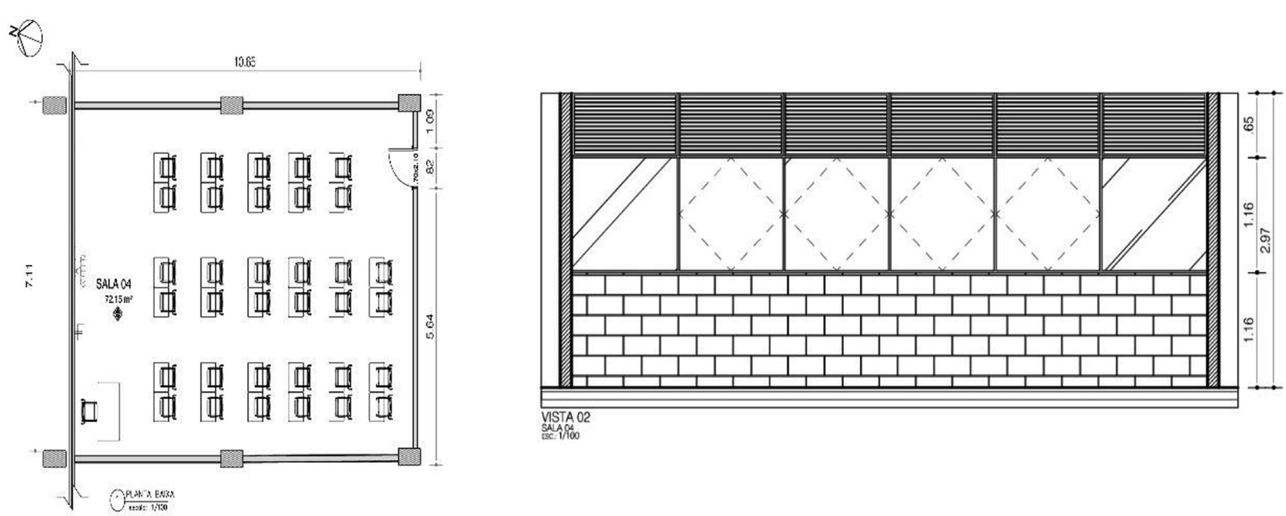
Due to maintenance problems, only two of the windows could be opened and, even then, only by adjusting the improvised cords that held them. The lateral panes of glass were broken and had been substituted by PVC panels. The above-window openings are covered with plastic sheets. See Fig. 5a and b.

There is a 20 cm opening just below the ceiling above the entrance door wall that opens to an outdoor corridor adjacent to a garden. That opening is just slightly below the ceiling and allows cross ventilation; the vegetation and the roof over the external circulation area favors its shading (Fig. 6).

3.4.3. Classroom C

Classroom C, a drawing board room (Fig. 7), is located on the upper floor (62.50 m a.s.l.); it has a floor area of 240 m^2 and a 3.60 m ceiling, with the capacity to accommodate 40 students. The ceiling is a precast concrete slab covered with asbestos cement tiles.

The room has two sets of windows with 12 maximum-air opening modules each, on opposite walls (75° NE and 75° SW) with dimensions of 15 m × 2.38 m, and a sill height of 0.62 m. The frames are made of aluminum with clear glass (3 mm) and can be opened up to 90°; above the windows are openings with shutters (also aluminum). The total open air circulation space of that room represents 14% of its floor area.



a) b)

Fig. 3. a) Floor plan of classroom A, b) Frontal view of the windows.

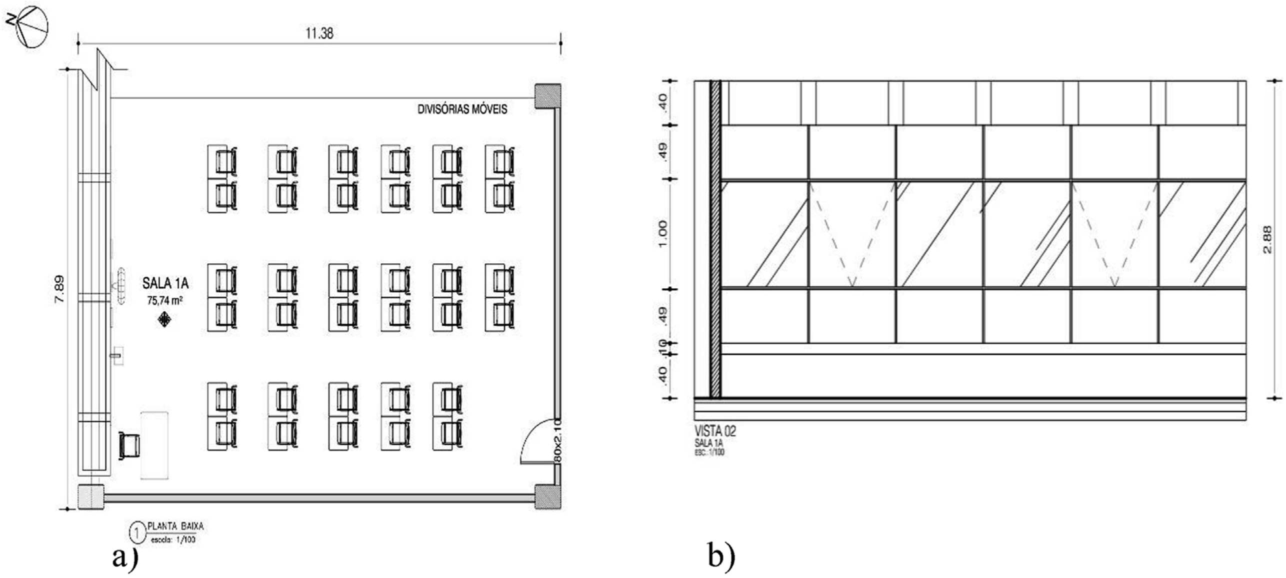


Fig. 4. (a) Floor plan of classroom B, and (b) Frontal view of the windows.

It should be noted that the exterior wall extends beyond the floor slab, favoring air circulation. Additionally, there is an external roof overhang that helps protect the room from direct sunlight. On the third outer wall, oriented at 15° SE, there are two doors, as well as fixed-glass windows.

The conditions of the windows in this room are currently precarious, with broken hardware, and many of them secured only with cord. A construction detail between the window frame and the wall, which was originally designed to facilitate ventilation, is currently sealed with a PVC sheet (Fig. 8).

3.4.4. Room D

The faculty office (Fig. 9 a and b) has a floor area of 21.79 m^2 and a ceiling height of 2.97 m. The outer wall is oriented at 15° SE and has a clear glass window set subdivided into 1.26 × 1.26 m modules, with the sill 50 cm above the floor (with an area of 5.91 m^2); one of the modules can be opened up to 90°; two can be opened only up to 30° due to blockage by pillars at the corners of the room.

Above those openings are three more fixed glass modules (Fig. 9b). There were originally construction details in this room that increased natural ventilation and circulation, such as openings on the floor near the facade. The room has a meeting table that can accommodate approximately six people. The outside environment is quiet and faces an inner garden, with a leafy mango tree in the background.

Fig. 6. Circulation area outside classroom B.

There is an entrance door on the opposite wall (facing 15° NO), plus a glass window (1.40 × 2.37 m) with guillotine-type opening (Fig. 10) that provides cross-ventilation. Those openings face an open external circulation area (Fig. 1b). The total open space available for air

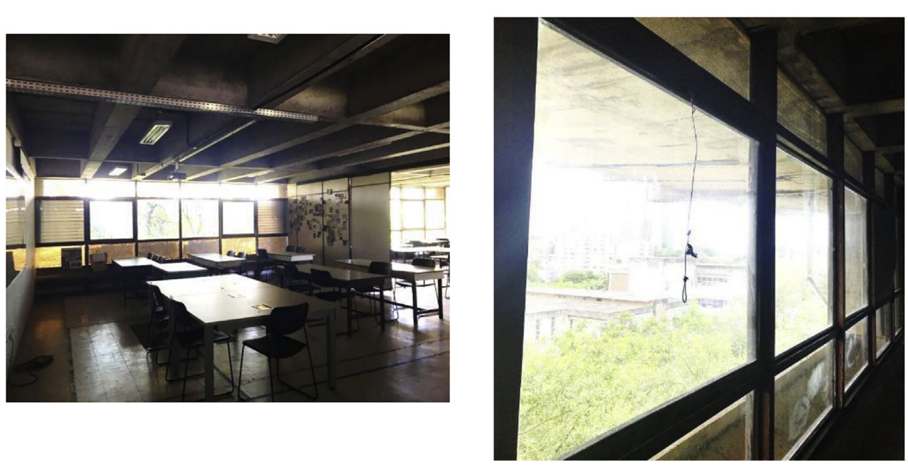


Fig. 5. (a) Classroom B, and (b) Detail of the wooden windows.

Fig. 7. Overview of the classroom.

Fig. 8. Windows open to 90°, with floor ventilation grating below.

circulation of this room represents 28% of its floor area.

At the time of the present research, the administrative rooms were being adapted to accommodate split-type artificial air-conditioners, and all of the openings originally designed to provide permanent natural ventilation were being sealed.

4. Results of the measurements and surveys of the rooms examined

During the survey period, meteorological data for the city of Salvador indicated air temperatures between 23 °C and 32.5 °C, averaging 28.4 °C; the relative humidity varied between 52% and 92% (average 72%), and wind speeds ranged from 0.5 m/s to 3.8 m/s (average 1.6 m/s).

The average air temperatures recorded in the surveyed rooms was 27 °C, with the highest recorded temperature being 30 °C in classroom C (March/03/2017, at 10:00), while the lowest was 22.8 °C in room D (March/30/2017, at 10:00) The mean surface temperatures were slightly higher than the mean air temperatures.

Wind speeds recorded during the measurements ranged from 0 to 3.5 m/s, with a weighted average of 0.84 m/s. Wind velocities were recorded in the planes of the outer walls in all of the rooms studied, and consistently had values exceeding 2.0 m/s; values above 3.0 m/s were recorded in three of the four rooms examined. Those results indicated that, despite occasional calm moments, the facades of the building have access to good natural ventilation.

Of the individuals questioned about their respective thermal sensations, 1% reported feeling slightly cold, 53% said they felt thermally comfortable (neutral thermal stress), 28% reported mild warmth sensations, 14% felt quite warm, while 4% said they felt uncomfortably warm. Overall, the respondents wore light clothing, although some were more heavily dressed. The average *clo* recorded in the research was 0.39, a result that could be expected as, according to Ricciardi and Buratti (2018), values below 0.5 are typical for the summer.

Classroom A showed the greatest user satisfaction (79% experiencing neutral thermal comfort) as well as the greatest weighted average wind velocity (1,27 m/s)The wind velocity in that classroom varied from 0 to 3.5 m/s. Interestingly, the classroom had ventilation openings equivalent to only 7% of its floor area.

Classroom C demonstrated the second greatest user satisfaction (56% experiencing neutral thermal comfort) as well as the second greatest weighted average wind velocity (1.18 m/s). That classroom, however, demonstrated the highest air temperature (30.2 °C), and the highest ceiling surface temperature (30 °C). The ventilation openings were equivalent to 14% of the floor area.

Classroom B demonstrated the lowest user satisfaction (only 38% of the users were satisfied, while 40% experienced slight warmth); that classroom also demonstrated the lowest maximum wind velocity (2.25 m/s). The ventilation openings in that classroom corresponded to only 3% of its floor area.

Classroom D likewise demonstrated low user satisfaction (44% satisfied while 22% experienced slight warmth); that classroom also demonstrated the lowest weighted average wind velocity (0,74 m/s).

Table 2 presents a synthesis of the results of the minimum, mean, and maximum values of air temperature, surface temperature, wind velocity, and *clo*.

5. Discussion

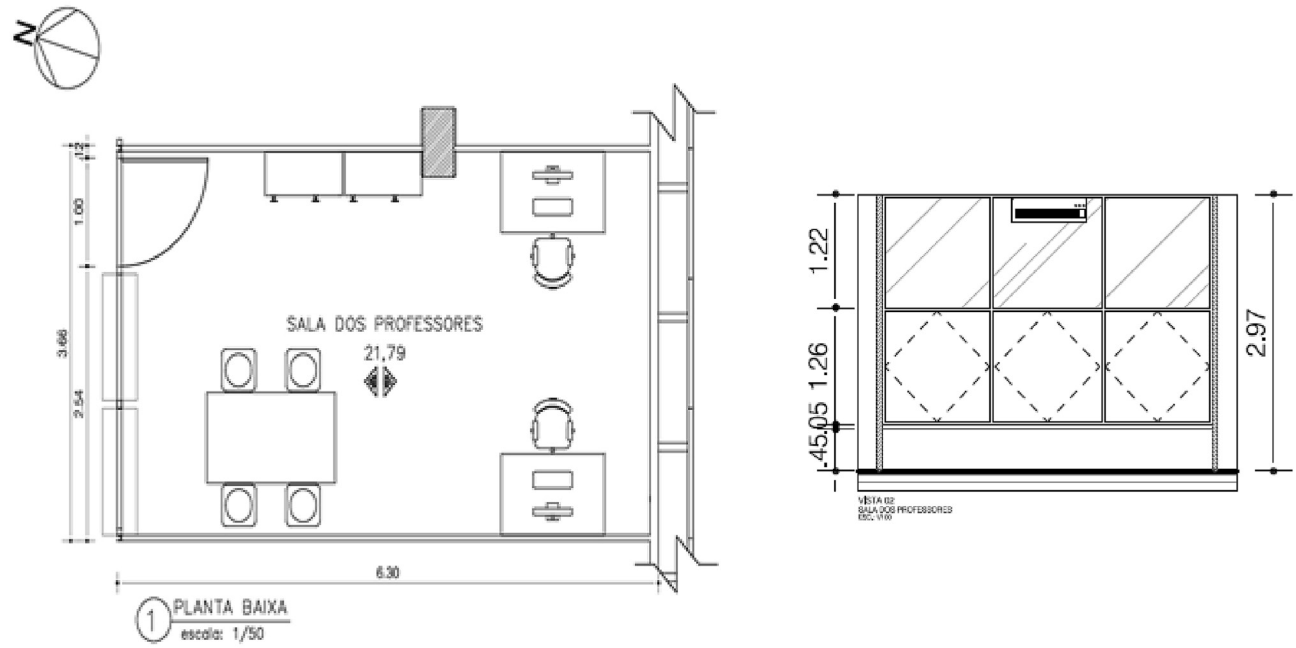
5.1. Regarding the thermal performances of the rooms under current conditions

The Faculty of Architecture building was designed in accordance with bioclimatic architectural principles, with its component sections elongated perpendicular to the dominant winds, which then can reach the entire structure – allowing cross ventilation in the building interior and protection against direct sunlight and providing high levels of both shade and natural ventilation. The area surrounding the building is well-shaded, with a distinct microclimate with amenable temperatures. As was noted above, that high degree of shading is quite strategic, and according to Nery et al. (2006), it provides thermal comfort conditions and contributes to reductions in energy consumption.

All of the rooms studied had adequate numbers of windows, and always had ventilation openings on the opposing walls to allow cross-ventilation. The windows installed in the rooms were the maximum-air type, which can be moved on their horizontal axis. That window design is considered suitable for promoting natural ventilation, as it allows up to 100% air passage (depending on the opening angle). Additionally, the windows are positioned at heights that favor the users, promoting a sensation of thermal comfort by facilitating heat loss by convection and evaporation, through increased air velocity.

During the data collection surveys, however, not all of the windows could be fully opened due to their poor state of conservation (or due to design flaws). Fixed windows were found that should have been capable of movement; others had broken fittings and cords were used to hold them open; broken glass panes were replaced with wood or PVC panels. Other problems, such as pillars positioned near the windows that prevented their complete opening, were also noted.

Additionally, the window modules positioned above the movable windows had shutters with just a few openings, or were completely closed off with fixed glass. Ventilation in the upper layers of rooms is



a) b)

Fig. 9. (a) Floor Plan of classroom D, and (b) Frontal view of the window.

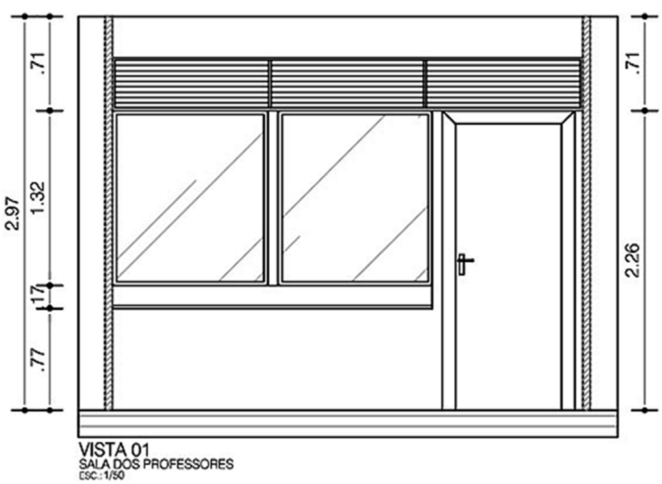


Fig. 10. Frontal view of the guillotine window.

also known to be necessary to facilitate the extraction of the warm air that rises to the ceiling and to replace it with fresh outside air.

In that sense, the window frames like those installed in the FAUFBA rooms studied here have lost a significant part of their thermal regulation potential due to design flaws or maintenance issues. Due to the dynamic character of natural ventilation, it is important to allow the adjustment of window openings by users to control the quantity and direction of the airflow in the indoor environment and thus respond to changing external climatic conditions.

Additional situations were noted that detracted from the thermal performance of the building, such as excess areas of glass in proportion to the volumes of the rooms in the mezzanine (which is oriented 15° SE and exposed to direct solar radiation during the summer, although at low angles of incidence) and high levels of diffuse sunlight. Another issue identified was the poor thermal insulation of the roof, which is composed of concrete slabs and fiber-cement tiles.

5.2. Regarding the possibility of improving the thermal performances of the rooms through passive measures

The principal functions of windows are room ventilation and illumination, so that adequate window opening areas, the positions in which they are installed, and the manners in which they can be opened represent the main factors determining air circulation quality. Therefore, having adequate openings and well-dimensioned and well-regulated fittings are important for allowing users to regulate the opening angles and ensure appropriate ventilation under changing conditions.

Other factors also contribute to improving the thermal performance of a building, such as greater shading of glass areas (as in the case of the windows in the mezzanine rooms that are oriented 15° SE) either by architectural elements or through the use of glass with higher Solar Factors (that minimize thermal gains from both direct and diffuse solar radiation). The thermal insulation of the building's roof should also be improved.

5.3. Regarding the current trend of adopting artificial air-conditioning systems to achieve thermal comfort in university buildings

According to Monteiro et al. (2015), people living in hot climates become accustomed to higher environmental temperatures (near 30 °C) so that being able to manipulate the conditions in the building to suit their activities and preferences becomes more important than the narrow limits of theoretical comfort zones.

Due to the growing popularity of artificial air-conditioning systems and the general lack of concern about energy consumption, little attention has been paid to the importance of window designs and their fundamental roles as promoters of thermal comfort (Santo et al., 2016). The use of air-conditioning to improve user comfort produces an unwanted side effect of reinforcing a preference for that artificial technique (and also considerably increases electric bills and maintenance expenses). That situation is even more troublesome when considering public buildings, particularly those designed for educational activities.

Current projects being designed and built for the Federal University of Bahia have not given priority to the use of natural ventilation. The

Environments	Air temp. (ºC)	Surface temp. (ºC)	Wind velocities at the openings (m/s)	Clo
Classroom A	Mín.: 25.20 Mean: 26.76 Max.: 28.35	Ceiling: 27.87 Floor: 27.91 Wall: 27.83	Mín.: 0 Mean: 1.27 Max.: 3.37	Mín.: 0.18 Mean: 0.41 Max.: 0.81
Classroom B	Mín.: 24.40 Mean: 26.90 Max.: 29.95	Wall: 29 Floor: 28 Ceiling: 28	Mín.: 0 Mean: 0.72 Max.: 2.25	Mín.: 0.23 Mean: 0.38 Max.: 0.78
Classroom C	Mín.: 25.05 Mean: 27.37 Max.: 30.25	Wall: 28.57 Floor: 28.57 Ceiling: 30	Mín.: 0 Mean: 1.18 Max.: 3.59	Mín.: 0.18 Max.: 0.59 Mean: 0.36
Classroom D	Mín.: 22.85 Mean: 26.70 Max.: 29.40	Wall: 27.70 Ceiling: 28.63 Floor:28.46	Mín.: 0 Mean: 0.74 Max.: 3.01	Mín.: 0.24 Mean:0.42 Max.: 0.58

Fig. 11. History of monthly expenditures for electrical energy at UFBA.

Table 2
Synthesis of the results.
Own elaboration.

Environments	Air temp. (°C)	Surface temp. (°C)	Wind velocities at the openings (m/s)	Clo
Classroom A	Mín.: 25.20	Ceiling: 27.87	Mín.: 0	Mín.: 0.18
	Mean: 26.76	Floor: 27.91	Mean: 1.27	Mean: 0.41
	Max.: 28.35	Wall: 27.83	Max.: 3.37	Max.: 0.81
Classroom B	Mín.: 24.40	Wall: 29	Mín.: 0	Mín.: 0.23
	Mean: 26.90	Floor: 28	Mean: 0.72	Mean: 0.38
	Max.: 29.95	Ceiling: 28	Max.: 2.25	Max.: 0.78
Classroom C	Mín.: 25.05	Wall: 28.57	Mín.: 0	Mín.: 0.18
	Mean: 27.37	Floor: 28.57	Mean: 1.18	Max.: 0.59
	Max.: 30.25	Ceiling: 30	Max.: 3.59	Mean: 0.36
Classroom D	Mín.: 22.85	Wall: 27.70	Mín.: 0	Mín.: 0.24
	Mean: 26.70	Ceiling: 28.63	Mean: 0.74	Mean:0.42
	Max.: 29.40	Floor:28.46	Max.: 3.01	Max.: 0.58

advanced training center of the Institute of Collective Health (ISC) is an example of an innovative perspective in the field of collective health – but that new building is being designed to use air-conditioning in most of its rooms.

A study by Camille and Siiri (2018) demonstrated that the most successful and lasting conservationist innovations in universities were those implanted in institutions where a culture of sustainability was already widespread. Therefore, encouraging the use of air-conditioning demonstrates to the academic community that the administration is not committed to reducing energy consumption or to adopting other actions aimed at sustainability.

In the case of the Faculty of Architecture, although most of its rooms still do not have air-conditioners, air-conditioning units have been regularly installed in administrative rooms without first exploring simple measures that could improve their thermal performances through passive routes. Such measures are likewise not being adopted in other environments (such as classrooms) – thus compromising the thermal comfort of their users.

6. Conclusion

Architecture projects should strive to provide thermal comfort to their users and at the same time seek energy efficiency. In the case of the Faculty of Architecture, the original design of the building incorporated architectural strategies based on bioclimatic principles that favored the use of natural ventilation, including taking advantage of the site topography, solar orientation, cross ventilation, and the sizes and types of openings.

We found, however, that the window frames in the Faculty of Architecture buildings were not in good repair, which hampers control of their opening angles, which, in turn, significantly compromises natural ventilation – the main strategy of passive temperature regulation in hot and humid climates.

It was also observed that even during the most critical periods of thermal discomfort in Salvador, and even with the building not fully realizing its potential for cooling its internal spaces by passive routes, more than half of the people interviewed said they experienced thermal comfort. These results confirm the need to maintain the building windows in good working order so that users can control ventilation flows.

Natural ventilation could be taken advantage of in other institutions located in tropical climates, with the perspective of reducing energy consumption and promoting sustainable development.

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