CHAPTER 125

The recent microapartments in São Paulo: A case study of thermal and luminous performance

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Carolina Carvalho Leme
Doctor; Department of Architecture Technology – FAUUSP

Leonardo M. Monteiro
Associate professor; Department of Architecture Technology – FAUUSP

Joana C. S. Gonçalves
Associate professor; Department of Architecture Technology – FAUUSP

ABSTRACT
The compact apartments in the city of São Paulo have been growing significantly since 2013, driven by the economic, social, urban and demographic transformations of the recent decades. In 2021, the micro-apartments with less than 45m² accounted for 76% of the total residential launches in the city of São Paulo, with 58% between 45m² and 30m². The high representation of micro-apartments in the current real estate situation in São Paulo emphasizes the importance of studies focused on these new housing models. The objective of the article is to verify the thermal and luminous performance of open-plan micro-apartments produced between 2011 and 2017 in the city of São Paulo. The method is experimental based on empirical surveys of thermal and light variables from five case studies. The measurement results were comparatively analyzed from design and environmental assessments, allowing to investigate issues related to the thermal and luminous comfort of the user of the case studies. The results indicated the low environmental quality of the evaluated micro-apartments, with at least 45% of the time in cold discomfort during the winter and only 60% of IDU in the year (useful daylight illuminances: 300lux – 3000lux).

Keywords: Minimum dwelling, Residential, Thermal performance, Daylight, Adaptive comfort.

1 INTRODUCTION

In recent decades, the increase in the value of land and the structural changes of the family nucleus are influencing residential spaces and fostering the production of minimal housing in large urban centers. The 2022 Continuous National Household Sample Survey (Pnad Continua), prepared by the Brazilian Institute of Geography and Statistics (IBGE), attested that in ten years there was an increase of 43.7% of single-person households, from 7.5 million in 2020 to 10.8 million in 2021. In response to this growing demand for housing, innovative concepts for a smaller dwelling have appeared in multiple cities (COHEN, 2021) as more viable alternatives in central regions.

The city of São Paulo has also seen a significant growth in compact real estate since 2013. In 2021, properties with less than 45m² represented 76% of the total residential launches, with 58% between 45m² and 30m² (SECOVI, 2021). According to SECOVI yearbook, this typology is concentrated in the infrastructure axes where there are legal incentives for population densification, especially in the South and West zones. The main incentive instrument was the 2016 decree related to the Zoning Law that allows microapartments to be classified as "non-residential", stimulating the creation of mixed-use buildings by increasing the constructive power around the established infrastructure axes, such as subway stations and large avenues.

Contemporary microapartments minimize space through optimized floor plans to make them as efficient as possible for their size, providing affordable living in urban areas (GABBE, 2015). According to Leme and Monteiro, the solutions currently offered are mostly free plan, in which a single reduced space should respond to the different levels of comfort depending on the activity to be performed. In addition, compact housing contributes significantly to urban densification, increased diversity of homes and energy efficiency, combined with the reduction of carbon emissions by minimizing dependence on vehicles and stimulating walking (COHEN, 2021).

Therefore, the high representativeness of microapartments in the current real estate situation in São Paulo accentuates the importance of studies focused on these new housing models. Despite the relevance of the theme, there are few studies, nationally and internationally, that address issues of thermo-luminous comfort in minimum living spaces with free plan, especially in relation to contemporary production. The field surveys addressed are an integral part of the doctoral research [1] and contemplate the inductive stage of the research, in addition to serving for the adherence of the simulations performed in the deductive stage. To this end, the surveys were carried out in units of free plan, with an internal area of approximately 20m², without occupation and with more usual architectural solutions currently offered by the market. The research cited aims to investigate the correlation between the constructive premises of design (surroundings, template, depth of plant, ceiling height and orientation) and passive strategies (percentage of glass in the façade, thermal mass, shading and ventilation) in promoting the thermo-luminous comfort of the current microapartments through combinatorial analyses.

2 THEORETICAL FRAMEWORK

According to World Bank indicators, it is estimated that about 70% of the world's population will be concentrated in urban centers and 85% in underdeveloped countries by 2030. This growth is leading to an increase in the urban density of buildings, especially in the city center, thus influencing the characteristics of indoor environments that increasingly depend on artificial systems to operate satisfactorily (Lamberts, 2015). According to the author, it is imperative that architects and engineers when thinking of joint ways to improve the environmental comfort of the user and the performance of buildings consider that people spend between 80% to 90% of their days indoors.

[1] Direct doctoral research, in development (2017-2023) in the graduate program of Architecture and Urbanism of the University of São Paulo, FAUUSP.

In the literature review conducted by Frontczak and Wargocki (2011), seven of the nine studies raised by the authors indicated that users classify thermal comfort as the most important parameter to improve satisfaction with the internal environment. The authors also pointed out that thermal comfort is influenced by the type of building (residential, commercial, naturally ventilated, conditioned) and seasonal climate change and, therefore, the controls of internal environmental conditions require a case-by-case approach, making it difficult to adopt universal solutions that respond satisfactorily to all.

In environments where the same space must respond to different levels of comfort, such as in microapartments, the object of study of this research, the complexity of promoting internal comfort is intensified. For Gabbe (2015), a microapartment is a developed version of a studio that minimizes space and maximizes efficiency. However, there is no consensus in the academic literature regarding its terminology and definition, varying in size and nomenclature according to country and city. In São Paulo, microapartments, popularized as kitchenettes and studios, originated in the 50s as residential units ranging from 14 m2 (the size of a hotel room) to 28 m2, in which kitchen appliances were compacted in an area attached to the living room (Gonçalves, 2018). For the Union of Real Estate Purchase, Sale and Administration Companies (SECOVI) the total area to be considered is composed of internal and external area of the unit (balconies and balconies), the institution categorizes the residential units by area and by number of bedrooms, with the smallest range being 45m² of total area.

3 METHODOLOGY/ METHOD

The theme was investigated through case studies using experimental inductive methods, with the objective of investigating the thermo-luminous performance of the envelope of the recent microapartments in the city of São Paulo. The applied methodology was conducted in 4 stages: stage 1, sample design of case studies; stage 2, field survey; step 3, data processing; Step 4, analysis and discussion of the results. The design analyses and the primary data obtained in the measurements will have as theoretical basis the secondary data collected in the bibliographic review and in the current norms and legislations explained throughout each stage.

3.1 STAGE 1: DESIGN OF THE SAMPLE OF CASE STUDIES

Five architectural solutions representative of microapartments were listed as case studies based on the survey of Leme and Monteiro (2016) about the recent production of microapartments in the city of São Paulo between 2011 and 2017. According to a survey by the authors, the current offer of compact apartments is characterized by housing for the middle and upper class, with an area between 20 and 45m², free plan and balcony, concentrated along the infrastructure axes of the capital of São

Paulo. The five units studied have approximately 45m² of total area, free plan, ceiling height of about 2.65m, balcony and are distributed in three buildings, two in the south zone and one in the west zone of the city of São Paulo. Each unit is an example of the typologies of microapartment most commonly offered in the city, being: (a) studio with ventilated façade and brises on the balcony; (b) studio with balcony glazing; (c) studio with uncovered extended balcony; (d) duplex - unit with two floors; (e) loft – unit with double height (5.64m).

The constructive solutions of the case studies are quite similar, following the market construction standard: reinforced concrete slab, aluminum frames and ceramic block sealing. Only the envelope of the unit (a) that presents a solution of better thermal performance, with ventilated façade by means of shading of ceramic plates and air layer, in addition to brises on the balcony. As for the openings, with the exception of the duplex and the loft, the other case studies have only one opening characterized by sliding doors in aluminum frame and colorless float glass, which are the access to the balconies and do not have shading or ventilation elements, such as shutters.

Finally, it was sought to maintain the same units for all stages of measurements (summer and winter), however, unit (a) was measured on different floors between summer and winter, but remaining the same façade for both. In winter, the surveys of the variables took place in the extremity unit, on the 5th floor. In the summer, the research was conducted in the unit in the middle of the 2nd floor.

3.2 STEP 2: FIELD SURVEY

The experimental descriptive methodology was adopted for the elaboration of the field surveys. The measurements were performed according to the guidelines described in ISO 7726 (2001), for thermal variables (air temperature; black globe temperature; air velocity and relative humidity) and the guidelines of the Natural Lighting standard ABNT 15215-2003 part 4 - *Measurement method for the luminous variables* (illuminance).

3.2.1 Description of procedures

The field surveys were conducted in three stages: 1. Test, in order to validate and improve the procedures for measurement; 2. Winter; 3. Summer. In each case study unit, a tripod composed of a black globe, a hot wire sensor and a data logger (HOBOware) was arranged for the collection of primary data on thermal (air temperature, air velocity, relative humidity and globe temperature) and luminous (illuminance) variables. The sensors were located 1.10m high in the center of the units, oriented to the openings and with data records every 15 minutes.

The surveys of the variables were carried out in stages lasting 20 days each, in typical periods of winter and summer according to the climatic conditions predicted by INMET, interspersing moments with the open and closed frame. The variation of the state of the miter allowed understanding the behavior of the buildings in relation to air intake, collecting data in situations with and without natural ventilation. Table 01 presents the characterization of the measurement periods. As for the test stage, it occurred during 10 days, only in unit (c), in the month of July.

Table 01 | Characterization of the measurement period

Unit	*Measurement duration*	*Measurement period*	*Period temperature**		
			Average**	Maxim	Minim
Test Stage (2017)	10 days	02 – 12 / July	23.8°C	32.5°C	19.3°C
Winter Stage (2017)	22 days	08 – 31 / August	17°C	30°C	11°C
Summer Stage (2018)	22 days	05 – 26 / March	23.8°C	32.5°C	19.3°C

* Outdoor air temperature, data referring to the INMET station, Mirante de Santana in São Paulo.
** Average of the calculated outdoor air temperature for the measurement period.

3.3 STEP 3: DATA PROCESSING

Because these are residential spaces, the adaptive model was chosen as an index of thermal comfort, since it considers naturally ventilated environments and the user as an active agent in the formatting of comfort. For the treatment of the primary data, parameters and evaluation criteria were adopted to validate the results, which were:

(1) External climatic data: the automatic station of the Santana viewpoint in São Paulo-SP was adopted as a source of climate data from the external environment.

(2) Discrepancies in the data collected: With the care to impress reliability to the research, some procedures were established regarding the discrepancies found. Data were collected every 15 minutes, when the discrepancy of values between the intervals was greater than 2°C, those were replaced by the mean of the adjacent values. In the rare situations in which there were discrepancies above four consecutive time intervals, such values were disregarded for the calculations of secondary variables and comfort indices.

(3) Data interval used for evaluations: As the primary data measured were recorded every 15 minutes, and the data from the automatic station every hour, the simple average of the intervals that made up each hour of the measured records was stipulated. This mean was used to calculate the secondary variables and the indices adopted.

(4) Calculated variables: In addition to the variables from the measurements and the automatic station, it was also necessary to use calculated variables for the composition of the analyses, which are:

- Average radiant temperature is calculated from air temperature, globe temperature and air velocity and according to Nicol, Humphreys and Roaf (2012), expressed by

$$Trm = [(Tg+273)^4 + (1.2* 10^8*d-0.4)Var0.6(Tg-Tar)]0.25-273$$

Trm = Radiant temperature, in °C;

Tar = Air temperature, in °C;

d = Diameter of the globe, in m;

Tg = Globe temperature, in °C;

Var = Air velocity, in m/s;

- Operating temperature (To), an index that combines air temperature and average radiant temperature into a single value, expressing their married effect (Nicol, Humphreys, and Roaf; 2012) The evaluation of comfort in the adaptive approach will be expressed as a function of the operating temperature established by ASHRAE 55 (2013), considering a metabolic rate of 1 met. As in some moments there was variation of air velocity greater than 0.1 m/s, it was decided to use the calculation of the CIBSE (2006) for operative temperature that considers such variation in the expression of the To.

$$To = [Ta \times \sqrt{(10\ Var)} + Trm] / [1 + \sqrt{(10\ Var)}]$$

Trm = Radiant temperature, in °C ;

Var = Air velocity, in m/s;

Tar = Air temperature, in °C;

To = Operating temperature °C;

- External illuminance (E), the data obtained from INMET, in relation to the amount of light available, refer to solar radiation and it is necessary to transform them into illuminance. According to Alucci (2001), IPT research (report 13.257 – 1980) indicates the following correlation between solar radiation and the level of illuminance:

$$E\ (lux) = (94 \times R)\ W/m^2$$

where:

R = incident solar radiation, in W/m²;

E = Illuminance, in lux

3.4 STEP 4: CRITERIA FOR ANALYSIS OF THE RESULTS

The adaptive model was adopted as the thermal comfort index and the UDI – index of useful illuminances of natural light for luminous comfort.

- Adaptive model considers naturally ventilated environments, in which the thermal conditions of the spaces are mainly regulated by the occupants (ASHRAE 55, 2013). It will present acceptability ranges (80% and 90%) in relation to the thermal comfort of the user correlating the measured operating temperatures and the monthly average of the outdoor air temperature.

- Useful illuminances of Natural Light (UDI) considers useful values of illuminance and what percentage of occurrence of these during the year. The useful illuminance ranges used for evaluation of luminous comfort were between 300 and 3000lux, which is considered desirable or at least tolerable by the occupants (Mardaljevic et al, 2012). Still, the UDI is subdivided into two categories: supplementary and autonomous. In the supplementary, it is understood that when the evaluation of natural illuminance is between 100 and 300lux, depending on the task to be performed there is a need for complementation with artificial lighting. Less than 100lux is considered non-useful, higher than 3000 lux excessive and between 300 and 3000lux autonomous.

It is noteworthy that the research on the determination of the UDI range refers to non-residential spaces, and that uncertainties are observed between the preferred or tolerated limits for commercial and residential buildings (MARDALJEVIC et Al; 2012). The authors emphasize that the scales presented should be taken as illustrative and subject to further revision, rather than preserving it in perpetuity.

3.4.1 Step 4: Analysis of the results

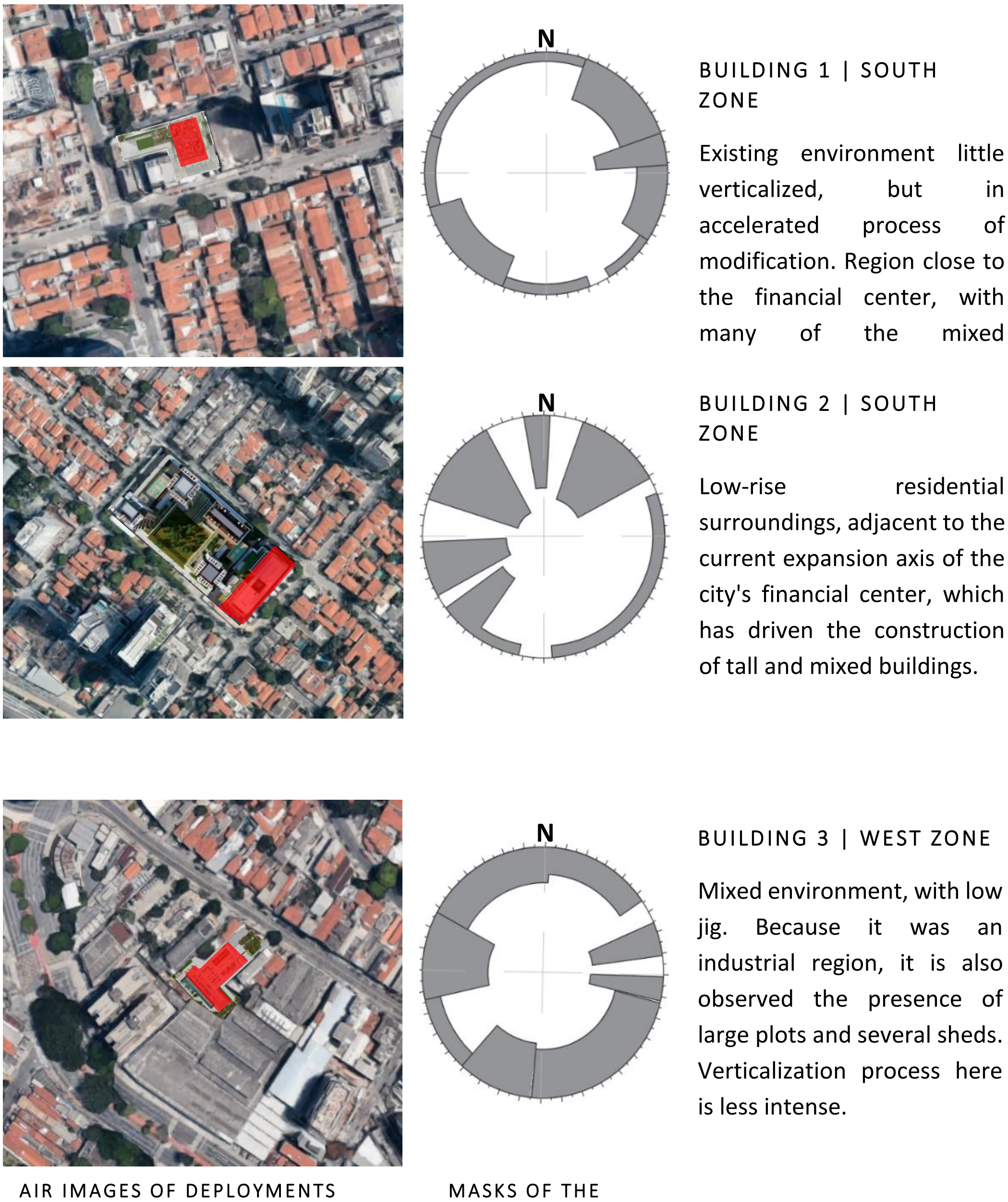
The analyses and evaluations of the data collected and treated in the field surveys were constructed from the correlation of two approaches: design and environmental. The first, by understanding the imperative relationship of the project in the formatting of comfort, will focus on the impacts of the architectural and constructive solutions adopted for thermo-luminous comfort. The second focuses on the evaluation of thermoluminous performance from environmental variables through comfort indices and natural lighting assessments.

3.4.2 Analysis of the results: Design

After the treatment of the empirically obtained data, it was possible to generate a series of evaluations and analyses that supported the discussion of thermo-luminous comfort with a focus on the space-user relationship. As the spatial relationship is more operative in the formatting of thermo-luminous comfort, the design evaluations in relation to the architectural and constructive solutions adopted are also predominant in the analysis of the results. Thus, the surveys not only contributed to the quantification of environmental variables, but also to the qualitative analysis of the spaces presented.

The design analyses are organized in two blocks: implantation and formatting of the internal space. As for the implantation, the five units surveyed are distributed in three buildings, two in the south zone and one in the east zone. Building 1 contains unit (a), located on the sixteenth floor of the southeast façade. Building 2, unit (b), on the sixteenth floor of the south façade. Finally, building 3, in which all three units are on the southwest façade, with unit (c) on the second floor, unit (d) on the fifteenth and unit (e) on the third.

Figure 01 | Images areas of google maps of October 2017 and masks of the surroundings produced by the author based on an archive of the urban fabric of São Paulo obtained from CESAD – Source: author.



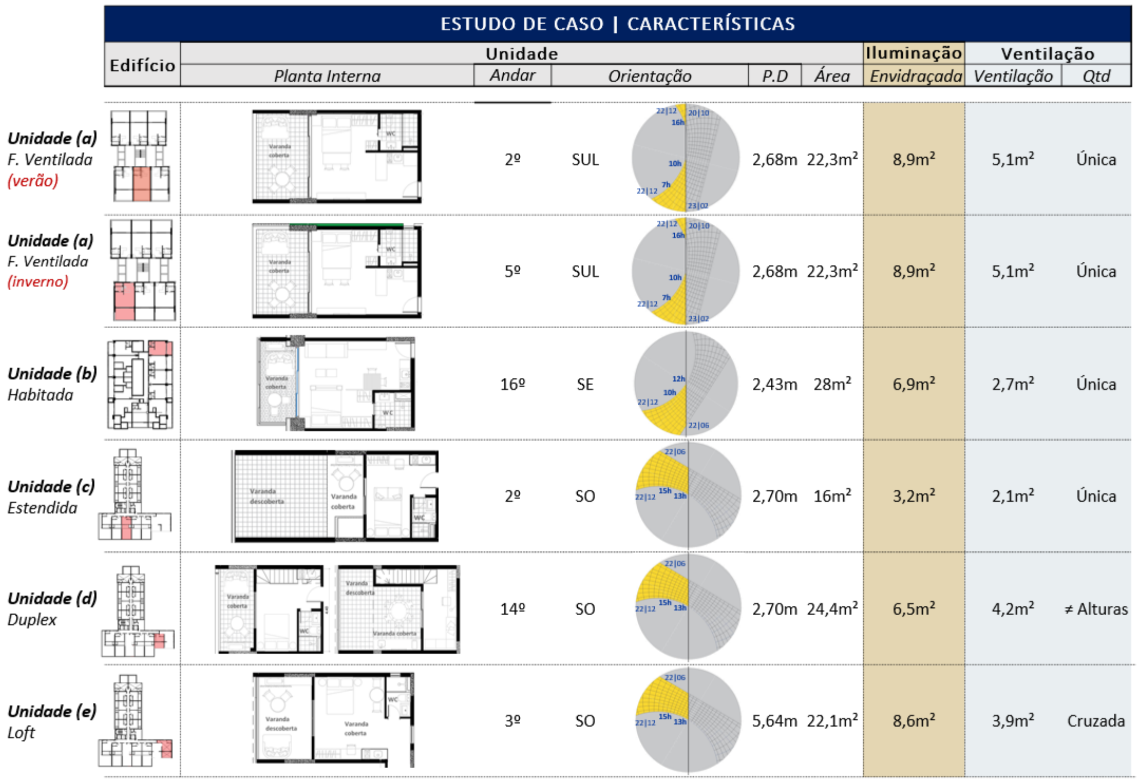
They are buildings with many units per floor, in which mostly, a single opening is responsible for ventilation and lighting, intensifying the impacts of the implantation and obstruction of the towers in the formatting of comfort. In the 3 projects studied, it is observed the conditioning of the design of the building to the constructive coefficients and the geometry of the lot, being the comfort and habitability of the units resulting from these premises. Such logic in microapartment developments tends to penalize the passive performance of the units and the quality of the built environment, whether internal or external, since it does not incorporate specificities of the terrain and bioclimatic issues in its design premises.

The mask of building 1 has the largest portion of visible sky, but its immediate surroundings indicate significant changes in land use and occupation. In building 2, the signs of verticalization of the surroundings are also evident, however, most of the obstruction measured comes from the towers of his own enterprise. As the units are distributed in two facades, in the northwest-southeast axis, such obstruction becomes quite impactful in the formatting of comfort. Instead of minimizing the effects of the change of the surroundings, the units in the façade oriented to the interior of the development present strong obstruction of the adjacent towers of the enterprise. The façade oriented to the buildings external to the enterprise, despite presenting little obstruction, is more susceptible to the changes of densification and verticalization present in the region.

Building 3 has the most horizontal surroundings, with little obstruction. While buildings 1 and 2 are deployed in relatively flat areas. Finally, building 3 is located in a relief region and because it is at a higher level than the immediate vicinity has the effects of verticalization attenuated.

As for the formatting of the internal space, the five case studies listed are representative examples of the diversity of microapartment solutions currently offered. Figure 2 illustrates a summary table categorizing each case study in relation to its architectural features. It is observed the standardization of the projects, regardless of the area, the specificities of each enterprise and the orientation. All presented very similar space solutions and occupancy proposals, encouraging the integration of the balcony with the internal space through balcony glazing[2].

[2] The balcony glazing is characterized by colorless glass movable panels, from floor to ceiling, fixed together to the sill. As they cannot interfere with the façade to maintain its uniformity, these end up facilitating exposure to direct radiation and limiting ventilation and lighting controls.



ESTUDO DE CASO | CARACTERÍSTICAS						Iluminação	Ventilação	
Edifício	Unidade							
	Planta Interna	Andar	Orientação	P.D	Área	Envidraçada	Ventilação	Qtd
Unidade (a) *F. Ventilada* *(verão)*		2º	SUL	2,68m	22,3m²	8,9m²	5,1m²	Única
Unidade (a) *F. Ventilada* *(inverno)*		5º	SUL	2,68m	22,3m²	8,9m²	5,1m²	Única
Unidade (b) *Habitada*		16º	SE	2,43m	28m²	6,9m²	2,7m²	Única
Unidade (c) *Estendida*		2º	SO	2,70m	16m²	3,2m²	2,1m²	Única
Unidade (d) *Duplex*		14º	SO	2,70m	24,4m²	6,5m²	4,2m²	≠ Alturas
Unidade (e) *Loft*		3º	SO	5,64m	22,1m²	8,6m²	3,9m²	Cruzada

Still, the artifice of the balcony glazing encourages the increase of ambient area, representing a significant portion of the useful area, according to figure 2, and being marketed as an environment of permanent use, when integrating the internal area. This situation results from rules of the Code of Works of São Paulo (1992) that allow the use of balconies and terraces as instruments to increase the constructive potential. The combination of these environments allowed in most of the cases studied, makes the balcony a space of permanent use, nullifying the gains from the shading and cooling of the air of this element. According to Gonçalves (2015), adequate shading is one of the most important passive strategies for the adequate performance of buildings in Brazilian bioclimatic zones.

It is important to emphasize that the question raised so far is related to the change in the use of the environment and not to the existence of the balcony, since in the explicit context its function as a space of transition and shading is suppressed. The use of transitional environments is a very interesting strategy in the formatting of comfort in places with a subtropical climate, especially in compact spaces such as those studied. These elements can serve as protection against direct radiation and weather, without generating major interference in access to ventilation and natural lighting.

As well as shading, openings are also key components to building performance. In the buildings evaluated, both the design and the quality of the frames in relation to the openings presented a very deficient performance. Because they are compact spaces, where a single environment is responsible for developing different activities, the openings accumulate several functions and, therefore, there is a need for greater diversity of the solutions adopted. In all the units analyzed, the frame between the balcony and the interior, if it is not the only one, is the main responsible for the renewal of the air and the penetration of natural light, in addition to functioning as the only element of access to the external environment.

As they are developments with many apartments per floor, the possibility of several openings in different facades is difficult. However, there is no differentiation of architectural and constructive solutions according to the orientation and immediate surroundings. In addition, the way the frames are developed, from design to installation, fosters a series of interferences that induce conflicts between their various functions and penalize their performance. In the case studies, all the openings were composed of colorless, fixed or sliding glass cloths, without shutters and often of low quality allowing a high rate of air infiltration and noise. In fact, what was found was the absence of frames with more elaborate controls of ventilation and lighting that would provide adaptations to the diversity of use inherent to the occupation of the microapartments.

In buildings 1 and 2, the frames were of iron frames and prefabricated, presenting less infiltration and better performance. In building 1, the suppression of the balcony door is not allowed and because it is located in a region under air routes, the frames have double glazing and sound insulation with rubber seals in the fittings between the leaves. In building 3, the frames are aluminum mounted on the construction site, with 4mm glass, which makes them more fragile and with less sealing power, allowing greater infiltration of air, water and solid particles.

As for the quantity and distribution of openings in the case studies, only the units located at the ends of the buildings have more than one opening (units (a) and (e)). However, only unit (e) has openings on opposite sides and heights, allowing cross-ventilation to occur. In the others, when there are two frames, these are on the balcony and in the bathroom, not allowing adequate cross ventilation.

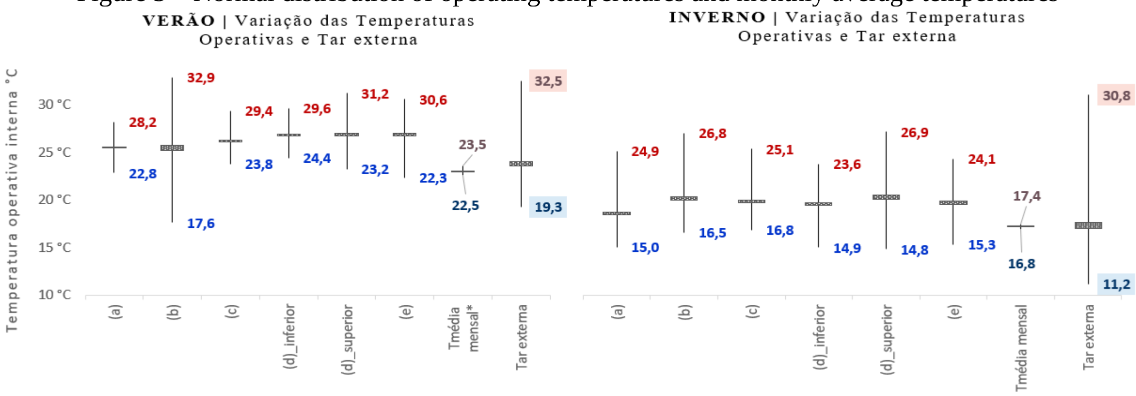
4 ANALYSIS OF THE RESULTS: ENVIRONMENTAL

In residential and multifunctional environments, such as those studied, the search for environmental quality through passive strategies is essential for energy efficiency and the reduction of carbon emissions, especially in mild climates such as the city of São Paulo. Relying exclusively on active air conditioning solutions from individualized active equipment, as is foreseen in all the units studied, can cause damage to the well-being and health of the occupants. These systems can affect indoor air quality by confining the environment, making it difficult to renew air and remove CO2 from human respiration. As the field surveys took place in empty units (with the exception of the summer period of unit (b)), the mechanized lighting and conditioning system was not in operation and, therefore, the results are compatible with those of naturally ventilated environments.

In residential buildings the occupancy rate is predominantly nocturnal and, therefore, the strategies to be adopted should prioritize such a period of permanence. In the microapartments, the versatility of the compact space implies greater complexity in the formatting of comfort and the maintenance of environmental quality. Thus, the evaluation of comfort in its entirety must consider such dynamics and the interaction between the various spheres of environmental comfort, especially thermal and luminous.

As for thermal comfort in climates such as São Paulo, where there is a high daily thermal amplitude, hot and humid summer and cold winter, it is important to consider shading, ventilation and thermal mass as the main passive strategies. The thermal mass plays a fundamental role in the formatting of comfort in residential spaces, since it contributes to the retention of daytime heat during cold nights, a frequent condition in the climate of São Paulo (GONÇALVEZ, 2015). In microapartments the effect of thermal mass is amplified due to the volume of air being small in relation to the total area of the envelope. It is possible to verify this effect in Figure 3, in which the thermal amplitude of the internal operating temperature is considerably lower than the amplitude of the external air temperature.

Figure 3 – Normal distribution of operating temperatures and monthly average temperatures



*average monthly temperatures (average of the previous 30 days outdoor air temperature)

However, the constructive quality and architectural solutions of the units evaluated for the effect of thermal mass is relatively low, which results in a thermal amplitude of approximately 4ºC, in environments without thermal load gains. In addition, the internal highs in the summer are very close, in some cases higher than the maximum of the external temperature. Another factor that influences the results obtained is the percentage of glass area. The high glass areas of the units studied reduce the effect of the mass and contribute to the rapid exchange of heat between the external and internal environment.

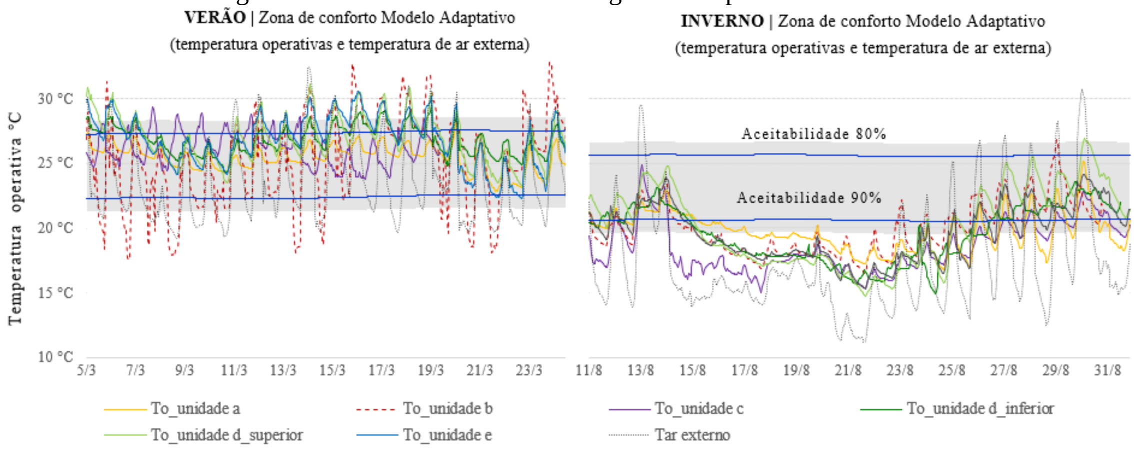
In cases of similar spaces, but with more appropriate solutions to bioclimatic issues, the results obtained demonstrated a significantly better performance. In a study on kitchenettes of the Copan building, Gonçalves et al (2018) obtained an internal temperature variation between 0.5 and 1°C, both in summer and winter.

According to the authors (GONÇALVES et al, 2018), the thermal mass, by contributing to an internal surface temperature lower than the air temperature in summer, plays a fundamental role in reduced spaces, especially in subtropical climates such as the city of São Paulo. Thus, the effect of radiant heat from surfaces in these environments can result in both discomfort due to asymmetry and overheating. Because they are compact spaces, the proximity of the user to the envelope is frequent, intensifying the action of these surfaces in the sensation of comfort.

As for the variation of the architectural solutions, it is perceived the influence between the different floors of the unit (d), duplex, which resulted in a low thermal amplitude of the lower floor and a high variation of the internal operating temperature in the upper floor. The upper floor has a smaller area and volume of air, is on the top floor, receiving horizontal radiation through the roof, which amplifies the heating capacity of this environment. Thus, the opening between these two floors in unit (d) allows and intensifies thermal exchanges by pressure difference, creating a pocket of hot air on the upper floor. Thus, the upper floor is warmer than the lower floor presenting higher internal temperatures in both measurement periods.

When evaluating the operating temperatures in relation to the comfort zone resulting from the adaptive model, it is observed the high inefficiency of these units in staying within the range of 80% of acceptability (figure 4). Even oriented to faces with less solar insolation, there is a trend in the summer of overheating, outside the comfort zone due to excess heat. Already in winter the high inefficiency of the construction in conserving the solar gain, resulted in long periods below the comfort zone. In winter, the glazed area of the relatively extensive façade enables the penetration of solar radiation, but does not allow the conservation of this inside the environments, especially during the night periods. This dynamic is evidenced by the high daily thermal amplitudes, including moments of discomfort due to heat during the winter period.

Figure 4 – Comfort assessment through the Adaptive Model Index



In table 02 it is possible to verify the percentage of hours in which each unit remained in the comfort zone during the field surveys. In the winter period, the units no longer reach 50%, demonstrating the inefficiency of the envelope in keeping in the comfort zone. Still, it is important to note that although the summer period presents better results, the units were empty and, therefore, without internal heat gains, with the exception of unit (b).

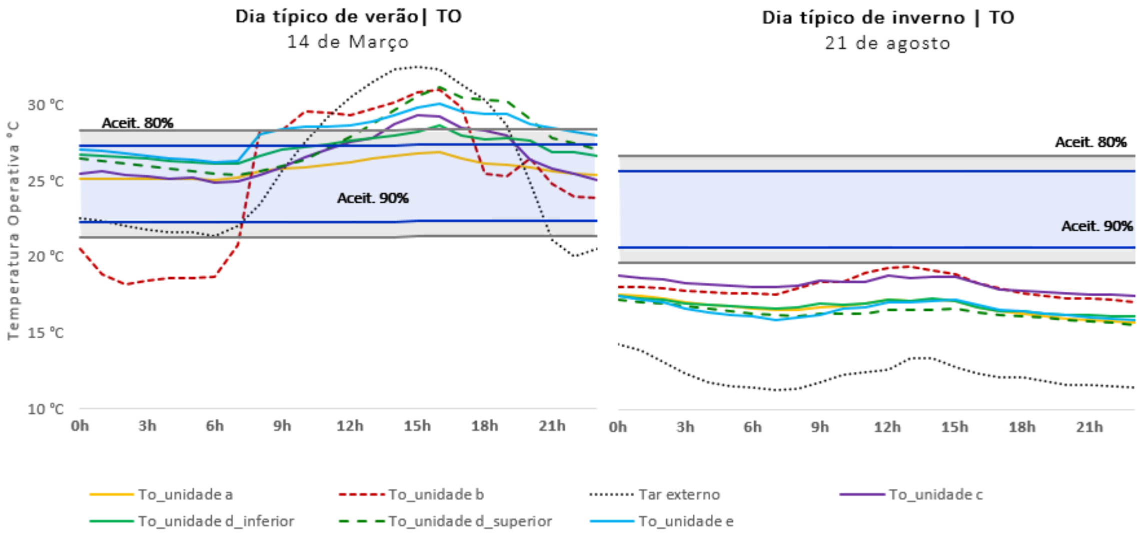
Table 02 – Percentage of hours in discomfort due to cold, heat and comfort by the index of the adaptive model (ASHRAE -55, 2013)

Units	SUMMER – Range of 80% acceptability			WINTER – Range of 80% acceptability		
	heat	comfort	cold	heat	comfort	cold
Unit (a)	-	100,0%	-	-	29,3%	70,7%
Unit (b)*	29,6%	58,5%	11,9%	0,8%	53,3%	46,5%
Unit (c)	2,7%	97,3%	-	-	49,1%	50,9%
Unit (d)	29%	71,0%	-	2,4%	49,5%	47,1%
Unit (e)	26,3%	73,7%	-	-	49,5%	50,5%

*Unit (B) There was activation of the air conditioning during the summer measurement period.

For a more assertive analysis of the dynamics of the units evaluated, it was decided to examine two representative days, one characteristic of winter and the other of summer, with all openings closed. Thus, it is guaranteed the evaluation of the performance of the envelope on days with climatic characteristics typical of the winter and summer periods, since during the surveys there were climatic fluctuations. In the comparison between the typical days (figure 5) the observed performance is well below that stipulated by the acceptability ranges, with the exception of unit (a) in the summer. All units in the winter fell below the comfort zone limit of 80% acceptability. In the summer there is a warming during the day, with a peak in the afternoon and that is preserved during the night. In addition, it was found a greater difficulty of nocturnal dissipation of the heat accumulated during the day in the summer.

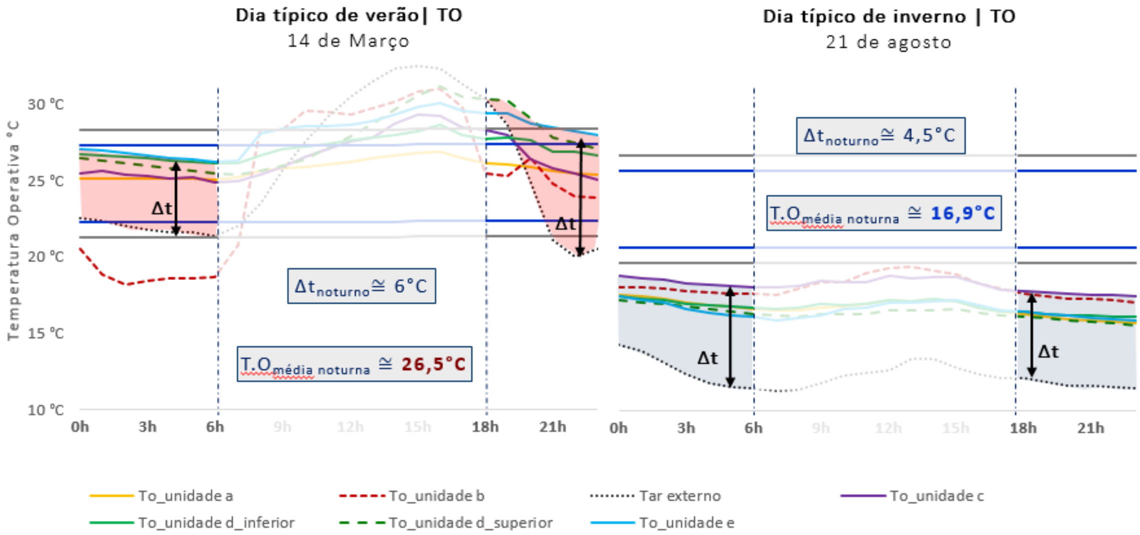
Figure 5 – Comfort assessment through the Adaptive Model Index – typical summer and winter days



Reaching the comfort zone at night in homes is of paramount importance mainly so as not to affect the quality of sleep. As the surveys, in the majority, occurred in empty spaces, some weightings should be considered regarding the results found. The alternatives of adaptation of the users to achieve comfort in situations such as those shown in figures 5 and 6 are more efficient in winter than in summer. For heating, one should consider the capacity of radiant exchange between the upholstery and the human being, the increase in the resistance of the garments, and the production of internal heat. According to Lin and Deng (2008), the effect of the thermal insulation of the bed system on the operating temperature is approximately 5.3ºC per clo, which significantly affects the neutral temperature during sleep. Still, during sleep the user's ability to adapt is limited (DE DEAR et al, 2009) and, therefore, the space should act more preponderantly in the formatting of comfort.

Analyzing figure 6, the temperature delta between the external and internal environment is smaller and more constant in winter. By the adaptive model of ASHRAE 55 none of the units studied would be within the range of 80% acceptability on the typical winter day, however, the average internal operating temperature was 16.9°C, not so far below that of the range of 80% acceptability. Achieving comfort in such a situation requires more feasible adaptation strategies on the part of users, such as the increase of clothing and layers of covers in bed.

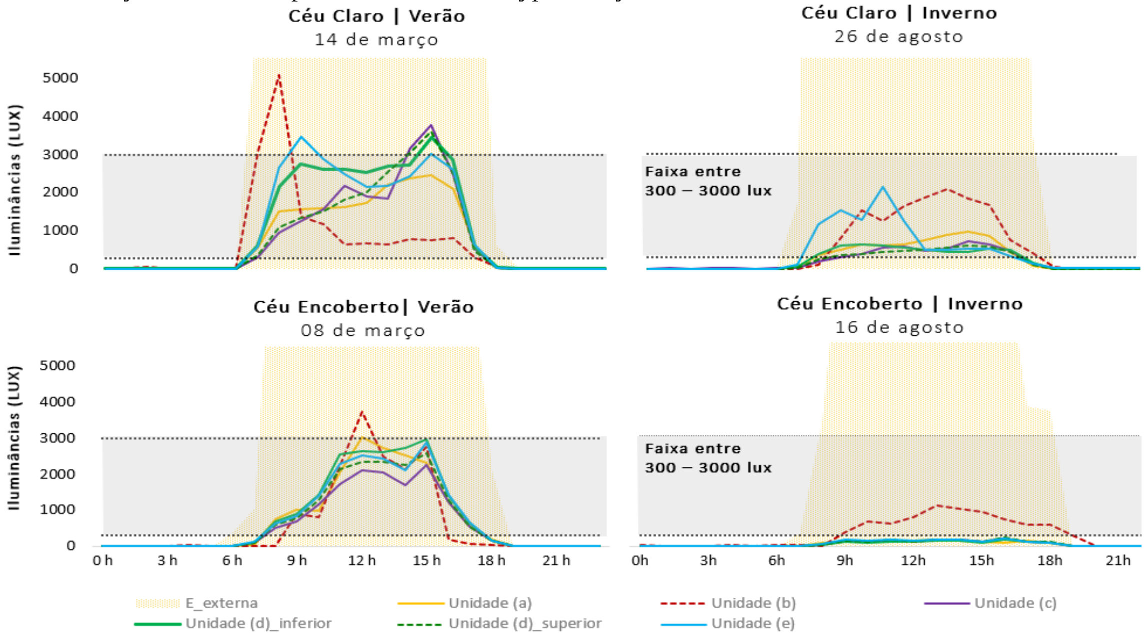
Figure 6 – Comparison between typical summer and winter days



When considering the internal load, the little capacity of the user to adapt to the heat during sleep, on summer days such units tend to leave the comfort zone which can induce the use of air conditioning, as observed in the inhabited unit (b). This situation is reinforced by the high average internal operating temperature observed, 26.5°C. Thus, in standard situations of occupation, the results showed a greater tendency to discomfort due to heat, highlighting the low capacity of the envelope to promote the comfort of users, without the use of active strategies.

In relation to luminous comfort, the penetration of natural light in the case studies occurs almost exclusively through the doors of the balconies. These elements tend to provide a heterogeneous distribution of natural light inside the environment, since they are located only in one orientation, on the wall and without differences in height. Figure 7, a comparative table of illuminances between winter and summer, shows a very low availability during winter in relation to summer. However, in summer the possibility of glare from excess illuminance is relatively high.

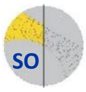
Figure 7 – Analysis of the Comparison between the typical days of winter and summer with overcast and clear skies



The evaluation of the illuminances of daylight working (UDI) of the measurement period indicated a satisfactory attendance of the illumination in the summer. However, in winter the results showed a short period with autonomy of natural light, especially if considering the potential of illuminance of the external environment. These values reinforce the deficiency of the solutions adopted in taking advantage of the bioclimatic potentials of the region in which the units are inserted, promoting dark environments despite the large glass areas. On the typical winter day, when there is a predominance of cloudy skies, as shown in Figure 8, the results indicated the need to use artificial lighting throughout the day, whether this complements natural or total lighting. This situation can lead to a significant increase in energy consumption and damage to visual acuity and the health of the user.

Figure 8 – Summary table of Useful Illuminances (UDI)

Construction Features						**Total Period**		**Typical Days**	
Unit	*Orientation*	*Walk*	*P.D*	*Floor area*	*Glazed Area*	**Summer**	**Winter**	**Summer**	**Winter**
Unit (a) *F. Ventilated*	S	2nd	2,68m	22,3m²	8,9m²	**83,4%**	**58,5%**	**95,8%**	**0%**
Unit (b) *Inhabited*	HE	16th	2,54m	28m²	6,9m²	**73,6%***	**87,5% ***	**83,3%***	**100,0%***
Unit (c) *Extended*	SO	2nd	2,70m	16m²	3,2m²	**81,1%**	**50,8%**	**87,5%**	**0%**
Unit (d) *Duplex*	SO	14th	2,70m	24,4m²	6,5m²	**64,9%**	**58,5%**	**91,7%**	**0%**

Unit (e) *Loft*		Third	5,64m	22,1m²	8,6m²	**83,4%**	**59,0%**	**87,5%**	**0%**

5 CONCLUSIONS

The evaluation of five case studies during representative periods of summer and winter by means of on-site measurements made it possible to ascertain the thermo-luminous performance of the recent production of microapartments. The results demonstrate the low environmental quality of the case studies evaluated, since most of them presented inadequate thermal performance for the period analyzed. The evaluations allow to induce that the climatic aspects, the specificities of the implantation and the environmental quality of the spaces were neglected in the process of conception and development of the project.

In residential and multifunctional environments, such as those studied, the search for environmental quality through passive strategies is essential for energy efficiency and the reduction of carbon emissions, especially in mild climates such as the city of São Paulo. The incentive to depend on active air conditioning solutions from individualized equipment, as is foreseen in all the units studied, can cause damage to the well-being and health of the occupants. These systems can affect indoor air quality by confining the environment, making it difficult to renew air and remove CO_2 from human respiration.

Although the occupation is predominantly nocturnal, it is also important to consider the influence of natural lighting in the morning and on weekends, in addition to its relationship with thermal comfort and its gains in visual quality and perception of space. Natural lighting is an important issue in architecture by affecting the functional arrangement of spaces, the comfort of the occupants (visual and thermal) and the energy consumption of the building. The Brazilian territory is abundant in natural light and as a sustainable source of excellent quality, absorbing it in architectural projects becomes imperative. In addition, the pandemic has significantly increased remote work, which requires better performance of residential spaces to ensure adequate environmental quality and comfort of users, especially during the day. Such behavioral, social and environmental changes should be considered in the evaluation of environmental comfort and in the design of spaces.

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