

Occupant behavior and energy consumption in residential buildings in a humid subtropical climate

Comportamento do usuário e consumo de energia em edificações residenciais localizadas em clima subtropical úmido

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Abstract

Buildings consume large amounts of electricity and occupant behavior is a key factor influencing this; mainly through interactions with the building and personal habits. This article investigates occupant behavior in multifamily housing in Brazil, a developing country with a humid, subtropical climate, focusing on thermal comfort and energy consumption. A survey was applied to residents of 155 homes located in Santa Maria, in southern Brazil, obtaining their perceptions of thermal comfort and adaptive behavior. Monthly energy consumption data were obtained for 51 homes. Results showed a relationship between occupant behavior, demographics, and energy consumption. The main actions investigated were opening and closing windows and wearing clothes according to thermal comfort. Occupant income influenced air-conditioning use for heating, and ages affected strategies to achieve thermal comfort. Occupation criteria and air-conditioning setpoints were also influenced by family characteristics. This study reinforces the importance of understanding building occupant profiles to achieve greater energy efficiency.

Keywords: Occupant behavior. Residential building. Energy consumption. Subtropical climate.

Resumo

Edificações consomem grande quantidade de energia e o usuário é um dos fatores que influenciam esse consumo, principalmente através de sua interação com a edificação e hábitos pessoais. Este artigo busca entender o comportamento do usuário em edifícios residenciais localizados em clima subtropical úmido, focando no conforto térmico e consumo de energia. Um questionário foi aplicado em 155 residências localizadas no sul do Brasil, obtendo-se as percepções dos usuários para conforto térmico e hábitos relacionados ao comportamento adaptativo. Adicionalmente, dados de consumo de energia mensal foram obtidos para 51 residências. Os resultados mostraram uma relação entre o comportamento do usuário, dados demográficos e consumo de energia. As principais ações levantadas foram abrir e fechar janelas e o uso de roupas conforme o conforto térmico. A renda familiar influenciou o uso de ar-condicionado artificial para aquecimento e a idade afetou as ações que os ocupantes assumem para atingirem o conforto térmico. Os padrões de ocupação e setpoints do ar-condicionado também foram influenciados pelo perfil das famílias. Este estudo reforça a importância de conhecer os perfis de ocupação das edificações para atingir sua maior eficiência energética.

Palavras-chave: Comportamento do usuário. Edificações residenciais. Consumo de energia. Clima subtropical.

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Introduction

Building use and construction account for approximately 30% of global energy consumption (GABC; IEA; UNEP, 2019). In Brazil, the residential sector alone represents 10.7% of national energy use (EPE, 2023). Although several studies have explored the influence of building characteristics on energy performance and simulation, discrepancies remain between predicted and actual consumption (Rinaldi; Schweiker; Iannone, 2018; Gao; Koch; Wu, 2019). In this context, occupant behavior emerges as a key factor in bridging this gap (Branco *et al.*, 2004; Tam; Almeida, 2018; Parker, 2012; Liu *et al.*, 2022; Xu *et al.*, 2023).

Occupant behavior refers to the ways individuals adjust indoor environmental conditions to achieve thermal comfort (Chen, 2015), including actions such as opening and closing windows, using air conditioning (AC), adjusting clothing, or consuming hot and cold drinks, along with physical and physiological responses (Nicol; Humphreys, 2002; Wagner; O'Brien; Dong, 2018). These adaptive behaviors are a central focus of studies seeking to improve the accuracy of building performance simulations (Balvedi *et al.*, 2018; Ahmed *et al.*, 2023; Mylonas; Tsangrassoulis; Pascual, 2024).

Schweiker (2017) categorized prior research on occupant behavior into four areas:

- (a) identifying influencing factors;
- (b) reducing the gap between predicted and actual performance;
- (c) understanding the effect of occupant behavior on energy consumption; and
- (d) enhancing building performance simulation inputs.

In order to address the first area, studies employ three complementary methods: data collection (e.g., in situ monitoring, laboratory experiments, questionnaires, and virtual reality); occupant behavior modeling based on collected data; and simulations integrating both collected data and modeling (O'Brien *et al.*, 2017; Liu *et al.*, 2022). Although occupancy is not classified as occupant behavior, it is often included on account of its relevance (Carpino *et al.*, 2017; Santin; Itard; Visscher, 2009; Mitra *et al.*, 2020; Muroi *et al.*, 2019). For instance, Gill *et al.* (2011) and Yohanis *et al.* (2008) found that increased occupancy tends to reduce per capita energy consumption. Fabi *et al.* (2012) identified four key influencing factors: contextual (e.g., environment, building characteristics, weather, and AC access); psychological (e.g., preferences, routines, and habits); social (e.g., income and education); and physiological (e.g., age, gender, and health).

Since occupants interact directly with building systems, their actions significantly influence indoor environmental conditions and energy use (Hong *et al.*, 2017). Consequently, many studies, which examine energy-behavior, narrow the gap between predicted and actual consumption. Ouyang and Hokao (2009) demonstrated that lifestyle matters: in a survey of 124 Chinese households, smaller dwellings with fewer appliances used less energy. In Brazil, Ramos *et al.* (2020) surveyed residents in 281 cities and found that 89% preferred natural ventilation - even during the summer - impacting their energy use. Balvedi *et al.* (2018) confirmed that income and climate strongly influence occupant behavior, as observed in a southern Brazilian City.

Given that occupant behavior is influenced by climate, economic, cultural, and social issues, local and regional studies are essential for a deeper understanding of this phenomenon. Expanding behavioral datasets may enhance simulation processes and improve modeling accuracy. In this context, this study investigates occupant behavior in multifamily housing in Brazil, a developing country with a humid, subtropical climate, with an emphasis on thermal comfort and energy consumption.

Method

Characterization of the area studied

The research was conducted in Santa Maria, in southern Brazil, a city located at 29°41'02" S, 53°48'25" W, with approximately 270,000 inhabitants, 95% of whom live in urban areas (IBGE, 2023). The local economy is based on commerce and services (ADESM, 2020). The climate is classified as Cfa, subtropical, with hot, humid summers, and no dry season (Kuinchtner; Buriol, 2001). Table 1 presents the monthly temperature (minimum and maximum) and rainfall (IRGA, 2022) averages.

Weather conditions in the city are variable, with winter temperatures occasionally exceeding 30 °C due to strong northerly winds. Relative humidity remains high year-round (60% to 83%), with peaks during autumn and winter (Hedwin; Buriol; Streck, 2009; Costa; Sartori; Fantini, 2007; Sartori, 2003).

Table 1 - Monthly mean, maximum, and minimum temperatures, and rainfall in Santa Maria, Brazil

Month	Min. temp. (°C)	Max. temp. (°C)	Rainfall (mm)
January	19.8	30.9	166.3
February	19.4	29.9	139.6
March	18.5	29.1	127.7
April	15.0	25.7	170.1
May	12.0	22.0	154.4
June	10.3	19.7	149.1
July	9.4	19.0	159.0
August	10.5	21.4	111.2
September	11.9	22.1	158.5
October	14.8	25.2	173.3
November	16.4	27.8	132.7
December	18.6	30.3	154.3

Source: IRGA (2022).

Study procedures and tools

The method was based on an occupant survey, which was structured in two steps, based on Ramos *et al.* (2020), Ghisi and Balvedi (2017), and Gill *et al.* (2011): 1) qualitative and 2) quantitative. This research was submitted and approved by the Human Research Ethics Committee (CAAE: 29790820.4.0000.5346). Figure 1 summarizes this method.

Qualitative survey

This step aims to understand habits and motivation behind adaptive behavior in multifamily housing, while considering social and economic contexts. Structured interviews were conducted collecting data on:

- (a) household composition (number of residents, gender, age, education, and income);
- (b) housing characteristics (number of rooms, solar exposure, and shade in the living room and bedrooms);
- (c) occupancy patterns throughout the day and week;
- (d) thermal comfort perceptions in the summer and winter;
- (e) adaptive thermal comfort strategies; and
- (f) monthly energy consumption (kWh) for 2019.

Data were analyzed using ATLAS.ti (2020), to identify common behaviors for thermal comfort and energy use.

Between March and April 2020, 9 apartments in three buildings were surveyed (one respondent per unit), selected based on building characteristics, urban context, and respondent availability (Figure 2). Seasonal consumption variations were attributed mainly to heating or cooling, while assuming that other uses (e.g., TV, radio, and shower) remained relatively consistent.

Quantitative survey

This phase investigated adaptive behaviors through a structured, multiple-choice questionnaire, adapted from Ramos *et al.* (2020) and Ghisi and Balvedi (2017). Collected data included:

- (a) respondent's daily occupancy;
- (b) habits, motivation, and frequency of adaptive behavior for heat and cold discomfort;
- (c) demographic data;
- (d) housing characteristics; and
- (e) optional data on energy use, appliance operation, and lighting.

Figure 1 - Method diagram

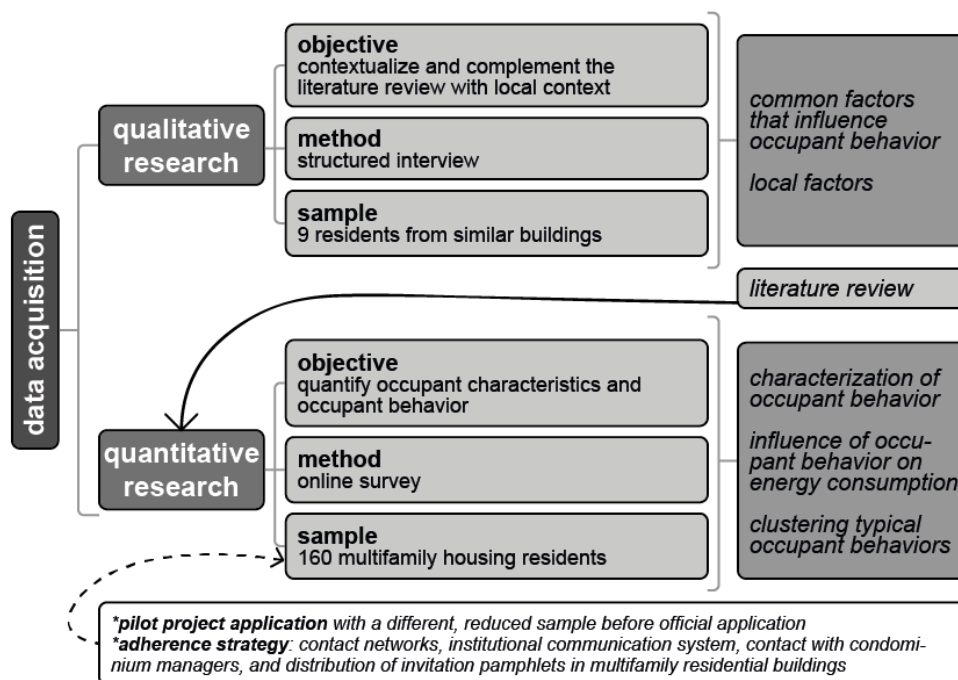


Figure 2 - Locations and features of selected buildings participating in the qualitative survey



Source: adapted from Google Maps (2021).

The participants were adults (≥ 18 years old), living in multifamily buildings. A non-probabilistic proportional sample was adopted, due to recruitment constraints. This procedure allows for comparisons across the strata considered, however, it does not permit statistical inferences beyond the surveyed group. The sample was based on 11,413 qualifying housing units (multifamily housing units with up to three bedrooms), from a total of 23,467 (IBGE, 2010c), and $\pi = 0.49$. A sample size of 96 was calculated using Equation 1 (Malhotra, 2012), assuming a 95% confidence level and 10% margin of error. Questionnaires were distributed via email and social media between September 2020 and January 2021, yielding 155 valid responses, which were retained to strengthen the robustness of the analysis. Participants were asked to answer questions related to 2019.

$$n = \frac{\pi(1-\pi)z^2}{D^2}$$

Eq. 1

Where:

n is the sample size (number of respondents, one per apartment);

π is the proportion of homes in the study sample, given the total number of homes (0 to 1);

z is the confidence level (1.96 for 95%); and

D is the margin of error (0.10 for 10%).

Data were analyzed using descriptive statistics and frequency distribution to characterize respondents, housing, thermal comfort perceptions, occupancy, and adaptive behavior. The responses were compared to Brazilian Institute of Geography and Statistics data (IBGE, 2010d). Thermal perception was assessed for the entire house for summer and winter and rated on a 7-point scale (−3 cold to +3 hot) (ISO, 2005). Occupancy was recorded using time slots. Adaptive behavior options included predefined and open-ended responses. Social (age, income, and education), physical (floor level and solar exposure) and perceptual (thermal comfort) factors were tested for association with occupant behaviors (e.g., clothing adjustments, window use, fan, heating, use of air-conditioning, and setpoints), using non-parametric association, due to the categorical nature of most variables (Giolo, 2017). Chi-square tests were applied for multi-category factors and binomial for binary comparisons. The null hypothesis assumed no association between behavior and contextual factors. The associations were considered significant at a p -value below 0.05.

Hierarchical cluster analysis identified occupancy profiles (Manly, 2019), based on schedules, window, and use of air-conditioning. In order to calculate the distance matrix of the observations, Euclidean distance was used as the standard. The number of groups was optimized between 2 and 6 by evaluating approximately 30 different statistical indices. Different methods for calculating cluster distance were assessed using their respective cophenetic correlation coefficients, with the average linkage method proving to be the most appropriate. Once defined, the clusters were characterized by demographic and behavioral characteristics, including energy consumption.

Multiple linear regression analysis quantified the impact of occupant behavior on energy consumption (Charnet *et al.*, 2008), with predictors including number of residents, device ownership, AC use patterns, setpoints, and months of use. To estimate the linear regression model, discrete quantitative variables (representing counts) were used without transformation of their original values. In contrast, nominal categorical variables (representing a choice among response options) were converted into dummy variables. To select the variables included in the adjusted regression model, a stepwise regression was applied, with the Akaike Information Criterion (AIC) used as the criterion for removing predictors that did not contribute significantly to the model. The final model was statistically evaluated with regarding residual distribution and the influential observations (outliers).

All statistical analyses were performed using Excel® 2019 and R software (R Core Team, 2021), with following packages: car, cluster, dendextend, factoextra, hnp, knitr, lmtest, NbClust, tseries and vegan.

Findings and discussion

Qualitative survey

The qualitative survey identified the most common adaptive behaviors reported in literature, including window use, AC, fan and heating use, and personal strategies, such as adapting clothing and consuming hot or cold drinks (Figures 3 and 4), from 9 respondents labeled R1 to R9. These behaviors were frequently mentioned by respondents as part of their daily routines, in order to deal with thermal discomfort. Participants reported more diverse and detailed strategies for heat discomfort, which explains the higher frequency of mentions, compared to cold discomfort.

However, the interviews also revealed the reasons for certain behaviors that diverged from those typically discussed in literature. Actions such as closing windows, adjusting blinds, or using fans and AC were often driven by non-thermal factors, including protection against insects, privacy, humidity control, or drying clothes (Figure 5). These findings reinforced the importance of including both predefined options and open-ended responses in the quantitative survey, in order to capture a broader range of local behaviors and reasons.

Figure 3 - Adaptive behavior for heat discomfort and respondents' illustrative comments

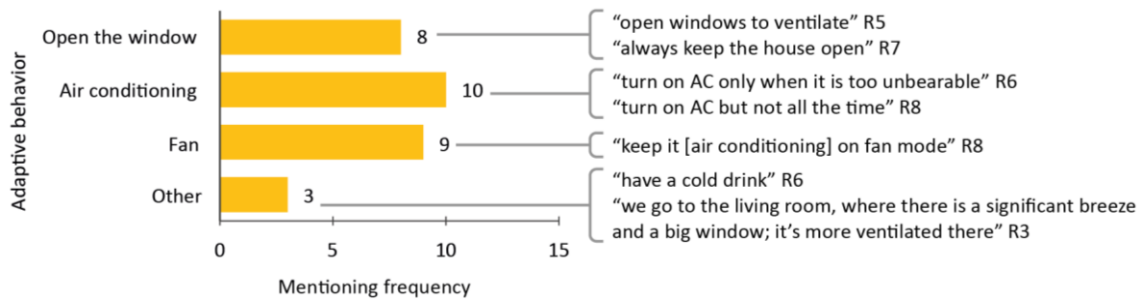


Figure 4 - Adaptive behavior for cold discomfort and respondents' illustrative comments

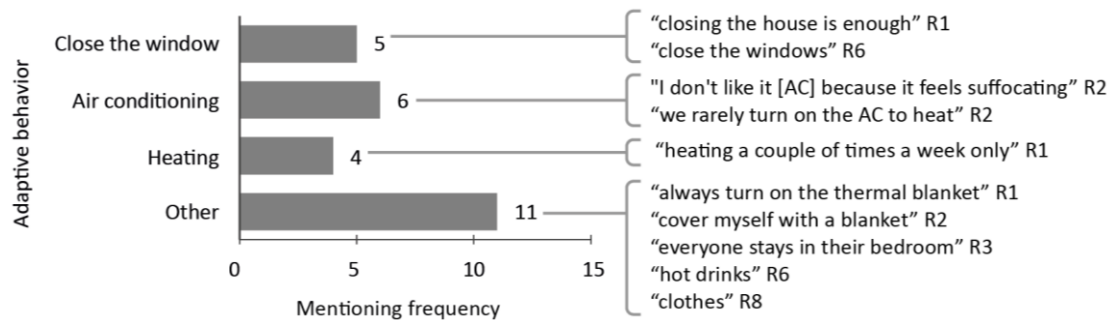
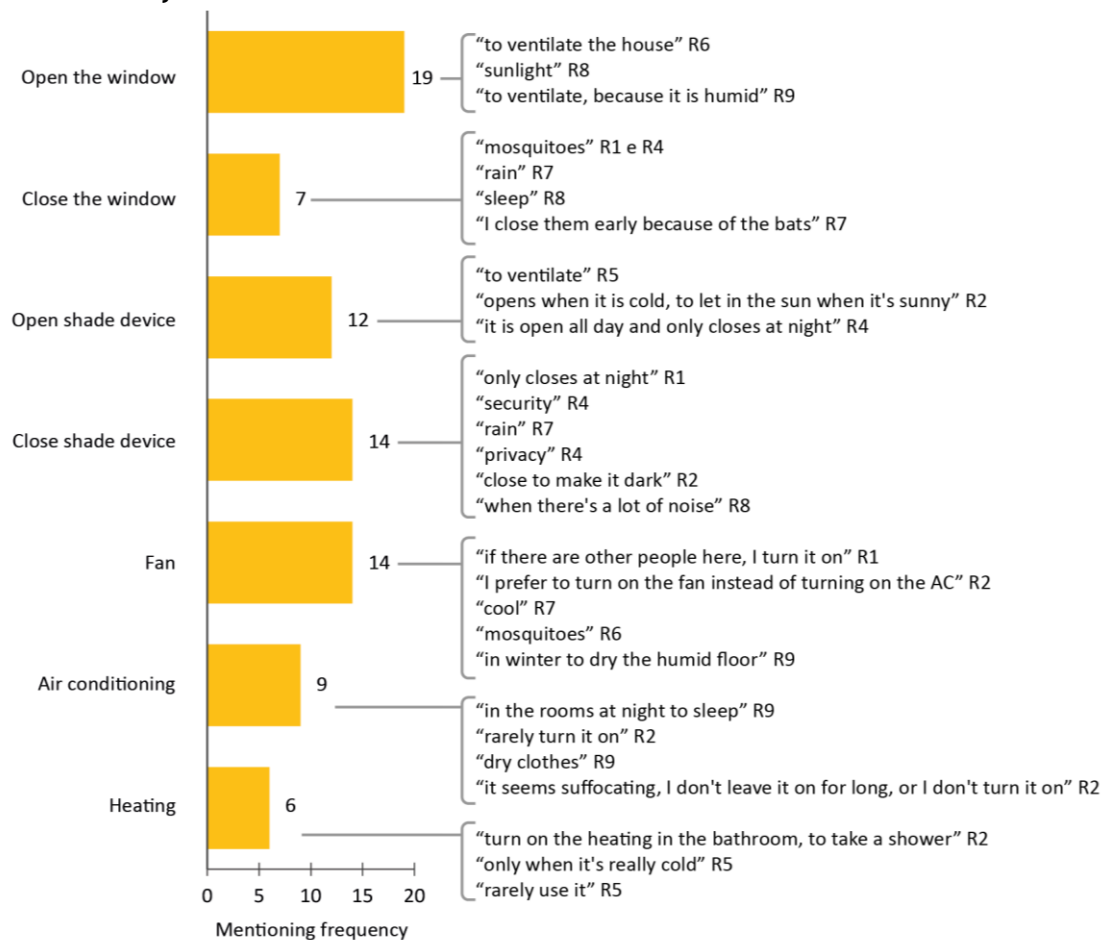


Figure 5 - Reasons for opening windows, adjusting shade devices and using fans, AC, and heating in the qualitative survey



In addition, energy consumption data provided insights into seasonal trends and household practices (Figures 6 and 7). Figure 6 shows that energy consumption increases during months with higher temperatures and relative humidity for 2019 (INMET, 2020). Figure 7 demonstrates a general rise in energy consumption with the number of residents (Huebner; Cooper; Jones, 2013; Ouyang; Hokao, 2009), but also considerable variation among respondents with the same number of residents, suggesting the influence of additional factors which should be explored. This step tested the feasibility of data collection. While informative, it demanded a greater effort from participants and was therefore included as an optional section in the quantitative survey. The findings also highlighted the need for more detailed data on appliance use, which may strongly affect energy consumption patterns.

Quantitative survey

Sample characteristics

The final sample included 155 valid responses. Figures 8 to 10 illustrate the sample's education levels, income, and number of residents per home. Most respondents held postgraduate degrees (59%), while the most common national education level is high school to undergraduate (11 to 14 years of education) (IBGE, 2010d). In relation to income, 34% reported earning 10 or more minimum wages, while national and regional data indicates between 2 and 5 as the most frequent range (IBGE, 2010c). This disparity is possibly linked to the participants' higher educational levels.

Figure 6 - Monthly temperature (maximum, average, minimum), relative humidity, and monthly energy consumption (average, maximum, minimum) for 2019

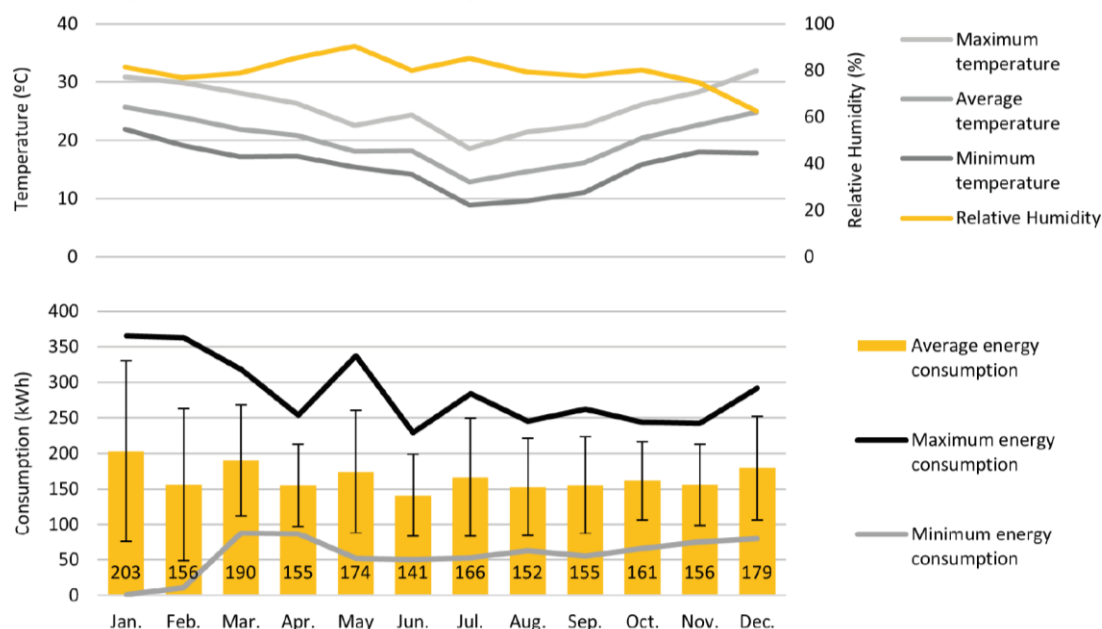


Figure 7 - Monthly energy consumption by residence in the qualitative survey sample

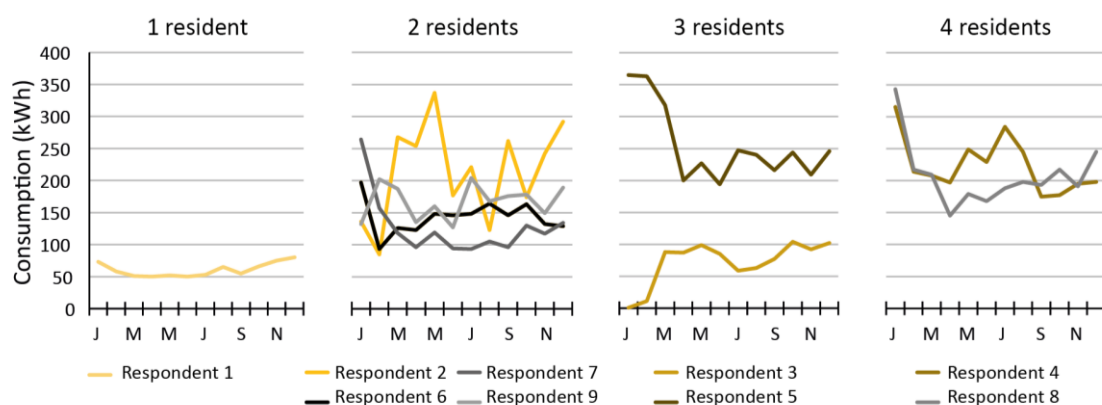
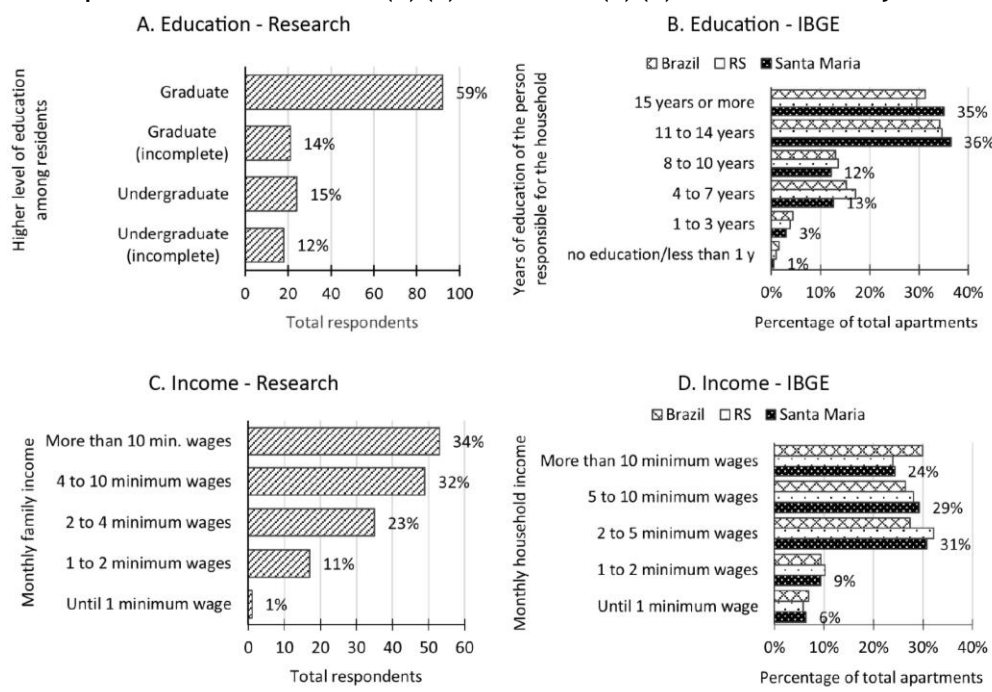
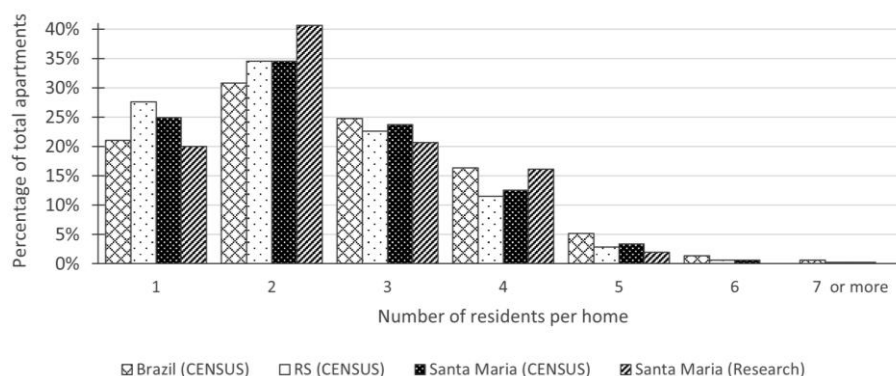


Figure 8 - Comparison of education level (A) (B) and income (C) (D) between this study and IBGE data



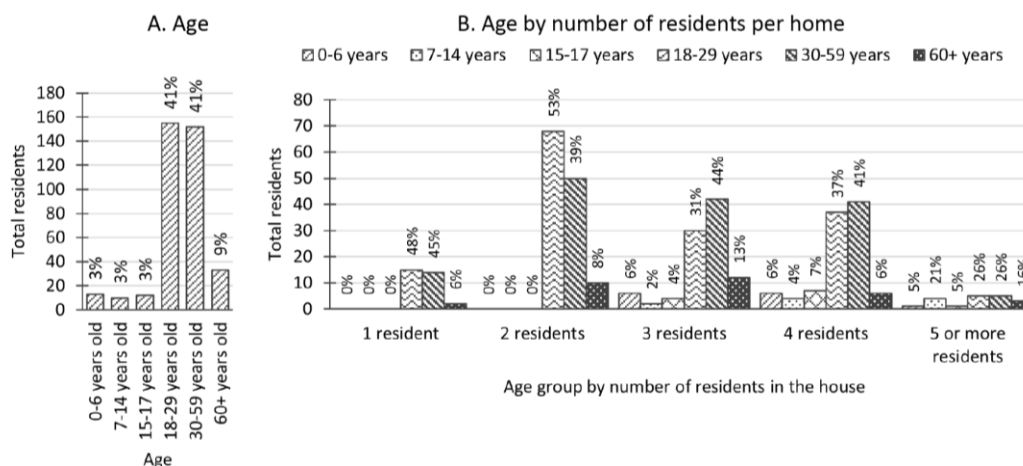
Source: adapted from IBGE (2010a, 2010b, 2010c).

Figure 9 - Number of residents per home



Source: adapted from IBGE (2010a, 2010b).

Figure 10 - Age distribution by number of residents per home

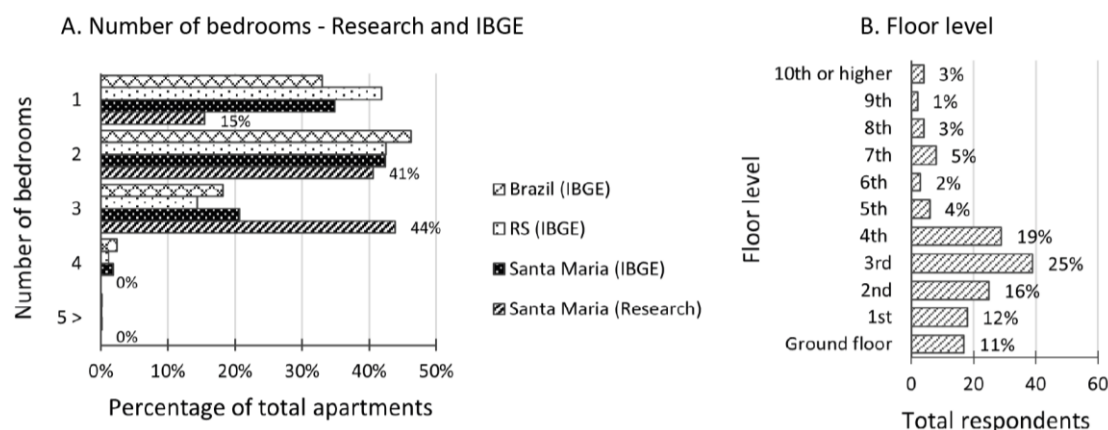


The number of residents per home averaged 2.4 residents (range: 1 to 6), which is below the national average of 3.5 for residential building regardless of typology (Eletrobras, 2019), reflecting the studied housing typology - apartments with up to three bedrooms. Additionally, this variation may reflect income and social context, since the regional number of residents per home average (2.7) is lower than the national average (3.0) (IBGE, 2018).

To characterize the age distribution of residents, respondents reported the number of household members within each age group in the surveyed homes (Figure 10). The age distribution demonstrated that 41% of respondents were aged between 18 and 29, and 41% were between 30 and 59. Smaller household sizes typically comprised adults from the same age group, while larger household sizes tended to include multiple ages. These demographic characteristics influenced energy consumption and behavior and will be discussed later on in this article.

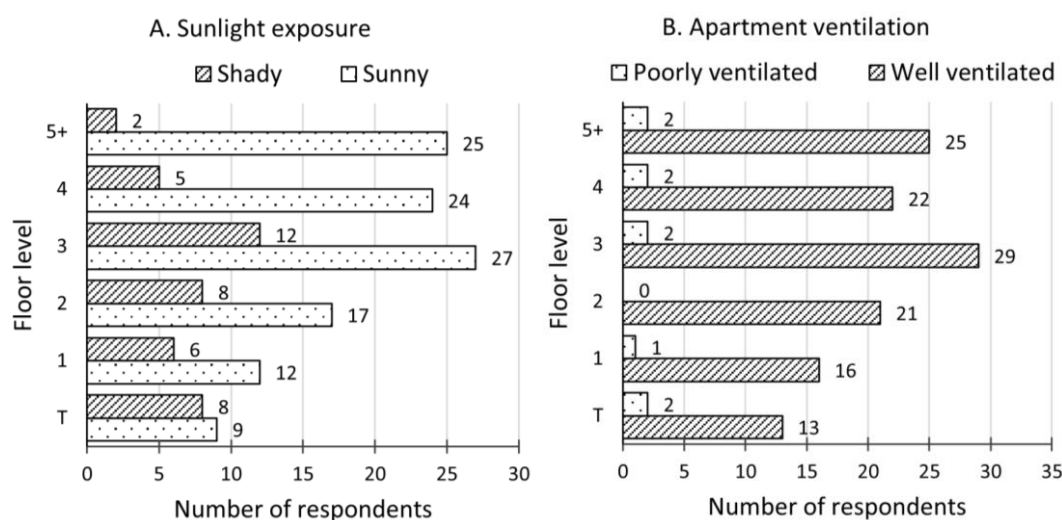
Most homes had two (41%) or three (44%) bedrooms, and were located up to the fourth floor, reflecting typical local building characteristics (Zambonato *et al.*, 2021) (Figure 11). In relation to environmental conditions (Figure 12), 74% reported sufficient sunlight exposure and 93% described their homes as well-ventilated. Poor sunlight and ventilation were more frequent on the lower floors – up to 47% and 13%, respectively – due to shade and obstructions. As in India (Indraganti, 2010a), residents on lower floors often kept the windows closed due to privacy or noise, limiting natural ventilation.

Figure 11 - Distribution of apartments by number of bedrooms and floor level



Source: adapted from IBGE (2010d).

Figure 12 - Occupant perception of sunlight exposure and apartment ventilation



Perception of thermal comfort

The perception of thermal comfort was assessed for the entire home (Figure 13). Although most respondents perceived their homes as well-lit and well-ventilated, only 3% reported feeling comfortable in summer, and 14% in winter. Discomfort during the summer was predominantly heat-related (63%), while winter discomfort stemmed from feeling cold ('Cool' to 'Cold' - 86%).

The qualitative data presented a link between discomfort and solar orientation: hotter in northwest-facing units, and colder in the southeast-facing ones. However, these patterns were not statistically significant in the quantitative phase, possibly due to rooms with varying orientations in the same unit, and the assessment of thermal comfort for the whole apartment.

Occupancy pattern

Figure 14 summarizes weekday occupancy. Figure 14A presents the average occupancy. However, different occupancy patterns were identified. According to Figures 14B to 14E, while 26% stayed home all day (Figure 14B), 29% were absent between 8 am and 6 pm, and 25% returned home for lunch (Figures 14C and 14D, respectively). A further 20% followed varying schedules (Figure 14E). These results mirror the patterns identified in Chinese studies (Chen *et al.*, 2015), reinforcing the need to incorporate diverse occupancy profiles in energy simulations. Unlike national regulation assumptions (ABNT, 2021; INMETRO, 2012), which simplify occupancy behavior, many respondents returned home at midday – a common practice in medium-sized Brazilian cities due to shorter commutes and lower costs (ABRASEL, 2023).

Only 2% reported identical weekday/weekend routines; 48% stayed home most weekends. Seasonally, 54% took their vacations in the summer, 23% in winter, while 47% maintained consistent annual routines (respondents could select more than one annual occupancy option). These variations critically influence energy use patterns and should be represented in simulations in order to avoid underestimations (Hong *et al.*, 2017; Yan; Hong, 2018).

Adaptive behavior

Figure 15 demonstrates the frequency of adaptive behaviors (respondents could select more than one option). Individual adjustments were more frequent than environmental ones. Changing clothes was the primary response to both heat (84%) and cold discomfort (92%), consistent with findings from India (Indraganti, 2010a), Nepal (Rijal, 2018), and Germany (Meinke *et al.*, 2017). At home, these strategies are more flexible and influenced by individual perception, environmental awareness, and attitudes (Von Grabe, 2016; Yang; Yan; Lam, 2014; De Vecchi; Lamberts; Cândido, 2017). This behavioral aspect is relevant for thermal simulations, since it affects AC setpoints.

Use of air-conditioning ranked second for heat discomfort (82%), which is higher than the national averages (Ramos *et al.*, 2020), possibly due to wider AC access (88% ownership), leading to lower tolerance to indoor temperature variations, as noted by Yan *et al.* (2017). Fan use (59%) and opening windows (47%) were also common and aligned with highly reported natural ventilation. Individual adjustments such as drinking cold beverages (81%) and showering (55%) were also frequent, echoing behaviors in Nepal and India (Rijal, 2018; Indraganti, 2010b).

Figure 13 - Thermal comfort perception for summer and winter

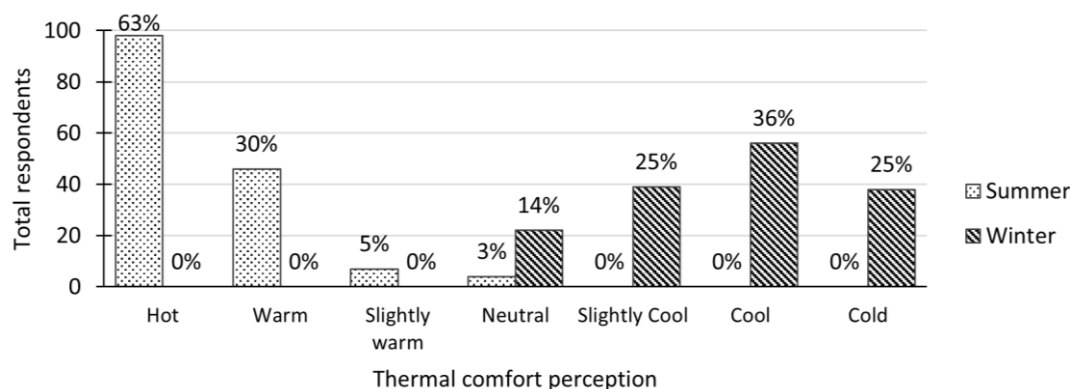


Figure 14 - Occupancy patterns: average (A) average, and occupancy 1 (B), occupancy 2 (C), occupancy 3 (D), and occupancy 4 (E)

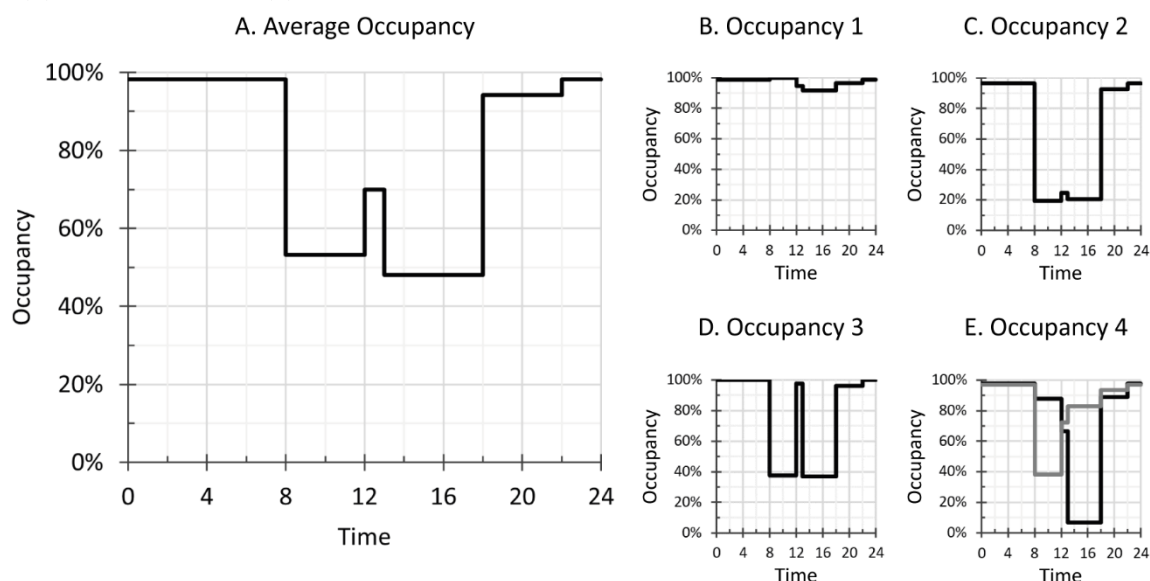
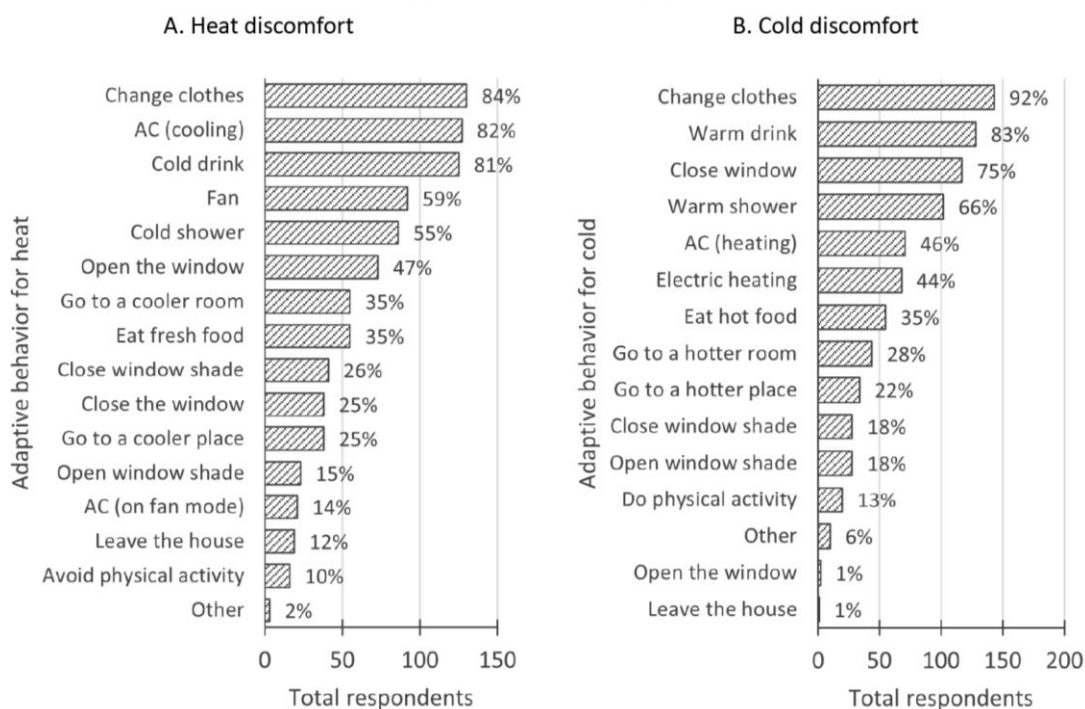


Figure 15 - Adaptive behavior for heat (A) and cold thermal (B) discomfort



For cold weather, respondents preferred adjusting their clothing (92%), hot drinks (83%), and closing windows (75%). Less frequent use of heating and AC may reflect local mild winters and recurring heatwaves, which may increase tolerance of colder weather.

Relationship between adaptive behavior and context

Table 2 summarizes the associations between the frequency of adaptative behavior (for cold and heat discomfort) and contextual factors, such as income, age, floor level, direct solar exposure, and perception of thermal comfort. Only AC, when used for heating, showed significant associations (p -value < 0.05) particularly with income and the perception of comfort.

Table 2 - Comparison between adaptive behavior and contextual factors

Contextual factors		N	Heat discomfort			Cold discomfort		
Factor	Group		Freq.	χ^2	p-value	Freq.	χ^2	p-value
AC			(cooling)			(heating)		
income χ^2 (gl = 2)	up to 4	53	33	3.80	0.15	16	6.81	0.03
	5 a 10	49	45			21		
	>10	53	49			34		
age range χ^2 (gl = 3)	young people	50	36	1.16	0.76	20	3.00	0.39
	adults	57	47			23		
	elderly people	22	20			11		
	children	26	24			17		
floor level χ^2 (gl = 3)	T+1 st	35	31	0.47	0.92	15	1.28	0.73
	2 nd	25	21			11		
	3 rd	39	29			15		
	>4 th	56	46			30		
solar radiation (Binomial)	Sunny	114	97		0.55	56		0.35
	Shaded	41	30			15		
comfort perception χ^2 (gl = 2) v χ^2 (gl = 3) i	comfort	4 22	2	0.49	0.78	2	8.12	0.04
	slightly warm/cold	7 39	5			18		
	warm/cool	46 56	38			29		
	heat/cold	98 38	82			22		

AC heating use increased with income: 30% of respondents earning up to 4 minimum wages used AC for heating, compared to 43% in the 5-10 wage group, and 64% among those earning over 10 minimum wages. This effect was stronger for heating than cooling, likely because, as mentioned earlier, milder winter temperatures allow greater tolerance, while prolonged high summer temperatures lead to more consistent use of air-conditioning.

Although not statistically significant associations were found, the results suggested patterns linking adaptive behavior to contextual factors. The perception of comfort followed a similar trend in relation to AC heating use: only 9% of those who reported feeling comfortable in winter used AC for heating, compared to 46%, 52% and 58% among those who felt slightly cold, cool, and cold, respectively. This reinforces the potential of passive environmental design to reduce energy demands.

Age also shaped behavioral patterns: younger adults more often adopted passive strategies, while families with children and the elderly relied more on AC, reflecting differences in thermal tolerance. Young adults reported greater heat discomfort in summer, whereas elderly individuals were more affected by cold, possibly due to metabolic and thermoregulatory changes. Since perception drives behavior, these differences directly influence energy-related practices.

The floor level also impacted behavior. Lower-floor residents used fans more frequently to cool rooms, while upper-floor occupants relied on windows – possibly due to better ventilation. For cold discomfort, lower-floor residents used heaters more frequently, whereas upper-floor residents adjusted window use to maximize solar heat gains.

Use of windows and shade devices

Window use was primarily linked to occupancy and ventilation. Blinds were closed at night for privacy and opened during the day for ventilation. Shutters followed similar patterns (Figure 16). Windows were opened mainly for ventilation and sunlight, and closed to control ventilation and the indoor temperature. Blinds and shutters were adjusted primarily for glare control and privacy (Figure 17).

The use of windows and shade devices followed habitual routines rather than being strictly comfort driven. Windows were often opened briefly when residents were home, while shutters were routinely closed at night. Windows were also closed to block the wind (preventing unwanted heat or cold) and to maintain the indoor temperature – often complementing use of air-conditioning, rather than promoting passive ventilation. Shade devices were opened for daylight and closed for sleep or privacy.

Figure 16 - Window (A), blind (B), and shutter (C) operations

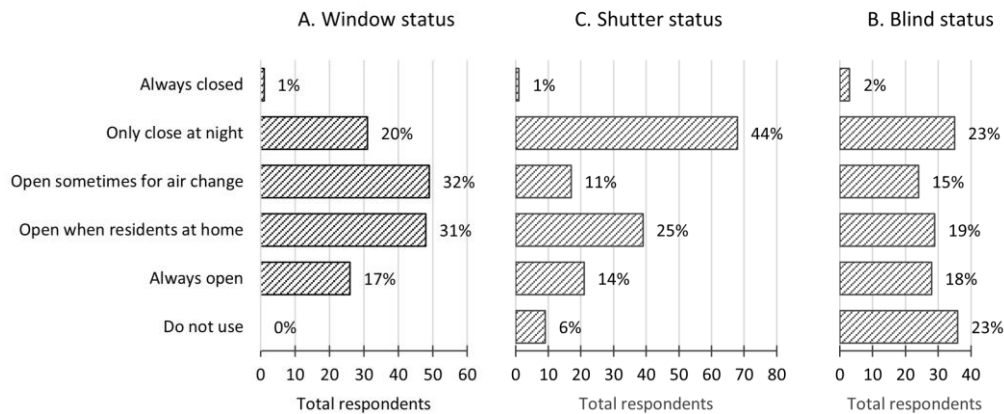
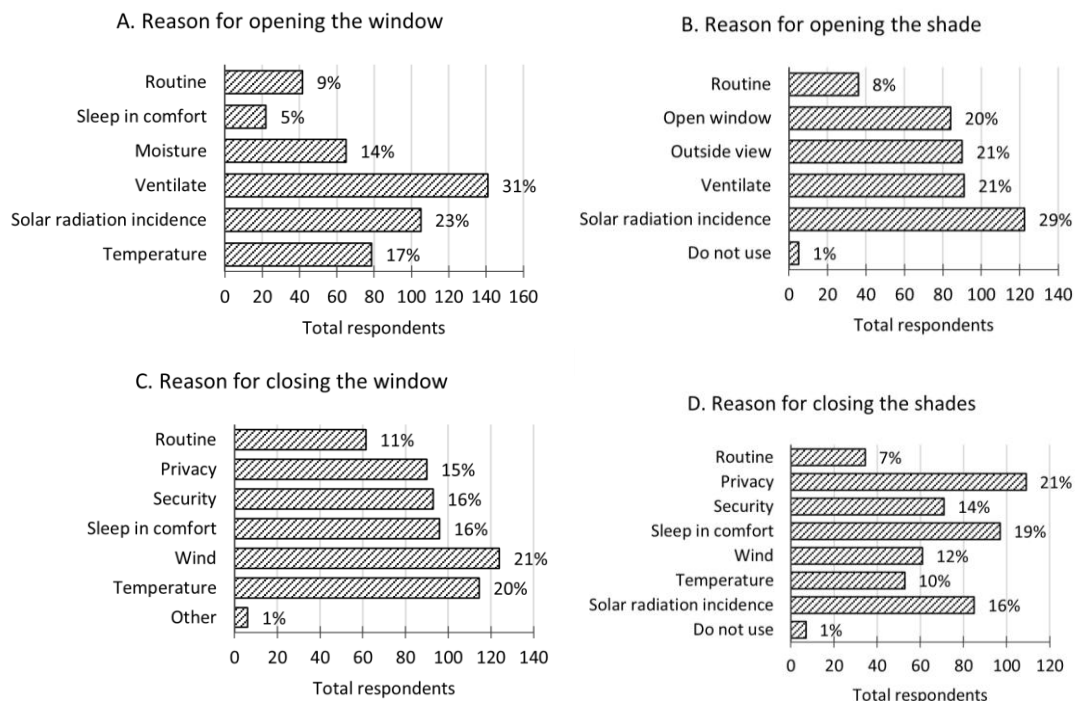


Figure 17 - Reason for opening windows (A) and shutters (B) and for closing windows (c) and shutters (D)



Use of AC, fans, and heaters

Cooling practices varied by device: fans operated for longer periods; AC in ventilation mode was often unavailable, or off, and AC cooling was typically used for short intervals (Figure 18). The lower energy cost of fans possibly made them preferable for continuous use. AC and fan usage were strongly linked to sleep comfort (often associated with closing windows for privacy or glare), and thermal regulation. Thermal comfort was the main driver for using fans and AC in both modes (Figure 19).

For heating, 34% of respondents used AC or heaters briefly, and only 10% used them for extended periods (Figure 20). The AC heating mode was less common than cooling, reflecting both climatic conditions and appliance availability. Heating use showed similar trends. Most respondents used heaters or AC briefly in order to achieve comfort. Individual and passive adaptive behaviors remained prevalent: 35% did not have a heater, 23% lacked AC with a heating function, and 4% and 14%, respectively, reported never using them. As with cooling devices, thermal comfort was the primary motivation for using heating devices (Figure 21).

Figure 18 - Fan (A) and AC (B) and (C) use for cooling

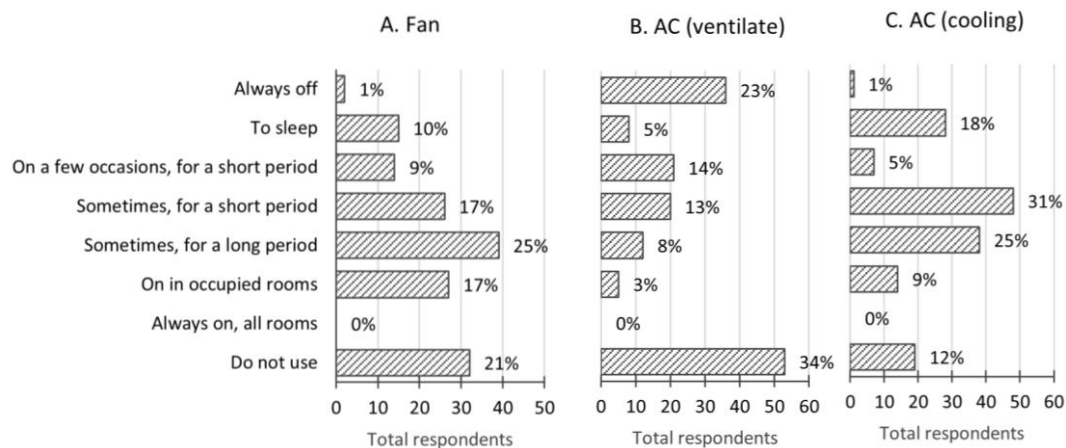


Figure 19 - Reason for using a fan (A) and AC (B) (C) for cooling

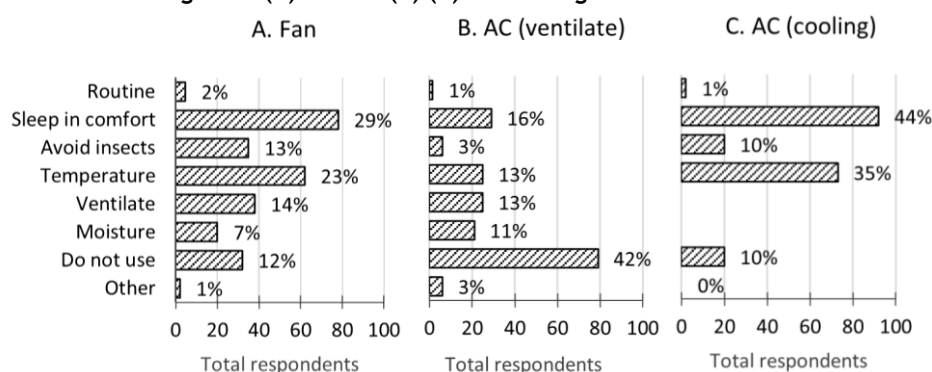


Figure 20 - Use of heater (A) and AC (B) for heating

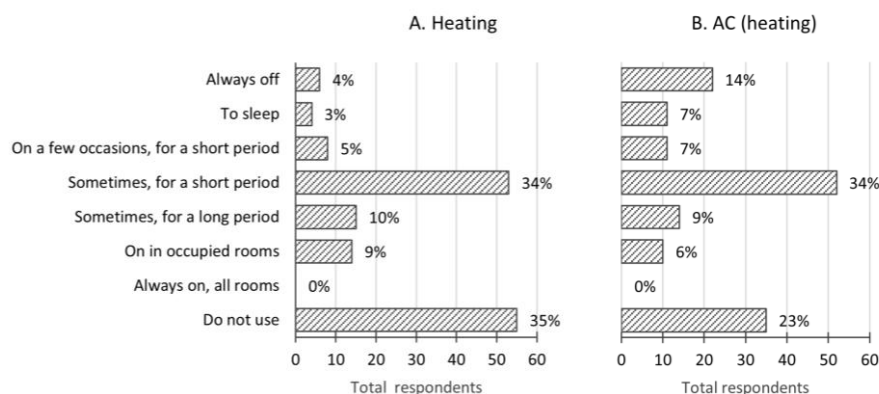
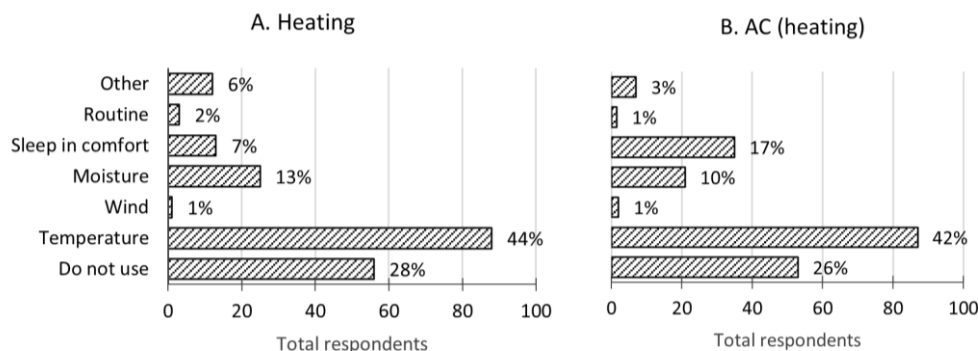


Figure 21 - Reason for using heating (A) and AC (A) for heating



According to Eletrobras (2019), only 23% of Southern Brazilian homes have AC, which is mainly used for cooling and heating (67%) and sometimes only for cooling (3%). In southern Brazil, use of air-conditioning is concentrated in extreme seasons and typically limited to short periods. Income strongly influences AC adoption (Ramos *et al.*, 2020; Indraganti, 2010b): families earning up to 4 minimum wages reported little or no use, while higher-income household sizes used it more frequently, underscoring the weight of energy costs in household decisions (Table 3).

Months of air-conditioning use and temperature setpoint

Figure 22 illustrates the months of AC operation for cooling and heating, alongside monthly average temperatures for 2019 and the comfort zone (PROJETEE, 2021). Use of air-conditioning followed seasonal extremes, with cooling used more frequently than heating. On average, AC cooling was used for 4 months annually, although some respondents reported occasional year-round use. The heating mode was used for an average of 2 months and was only mentioned for 6 months of the year. These usage patterns are critical for accurate building simulations (Rinaldi; Schweiker; Iannone, 2018; Yan *et al.*, 2021).

Income showed a significant correlation with the number of months of air-conditioning use for both modes (Tables 4 and 5), with additional associations for age and the perception of comfort in the heating mode. The strongest associations are highlighted in bold in the tables. Houses with a higher income, children, or elderly residents, and those reporting greater discomfort during cold weather, tended to use heating for more months during the year.

For cooling, usage varied a little with income beyond a threshold: those earning below 4 minimum wages used AC less, while those earning 5 or more used it for 3 to 6 months. Similarly, for heating, prolonged use was more frequent among respondents earning over 10 minimum wages. It is important to highlight that AC cooling usage for 4 to 5 months was consistent across income groups. Other variables showed no significant statistical correlation. The difference in use of air-conditioning for cooling and heating by income suggests a greater tolerance of the cold, where occupants initially resorted to passive strategies, such as changing their clothing and window adjustments before using the AC.

AC setpoint temperatures

Figure 23 presents setpoint preferences. When multiple values were reported (e.g., 22 °C and 25 °C), the average (23.5 °C) was used. If respondents initially selected extreme settings for rapid conditioning, only the final stabilized setpoint was considered. The average cooling setpoint was 21.7 °C (range: 16-27 °C), with over half the responses being between 21 °C and 23 °C – similar to national trends (Ramos *et al.*, 2020). The average heating setpoint was 26.3 °C (range: 17-32°C), which is slightly higher than the Brazilian average of 25.5 °C (Ramos *et al.*, 2020).

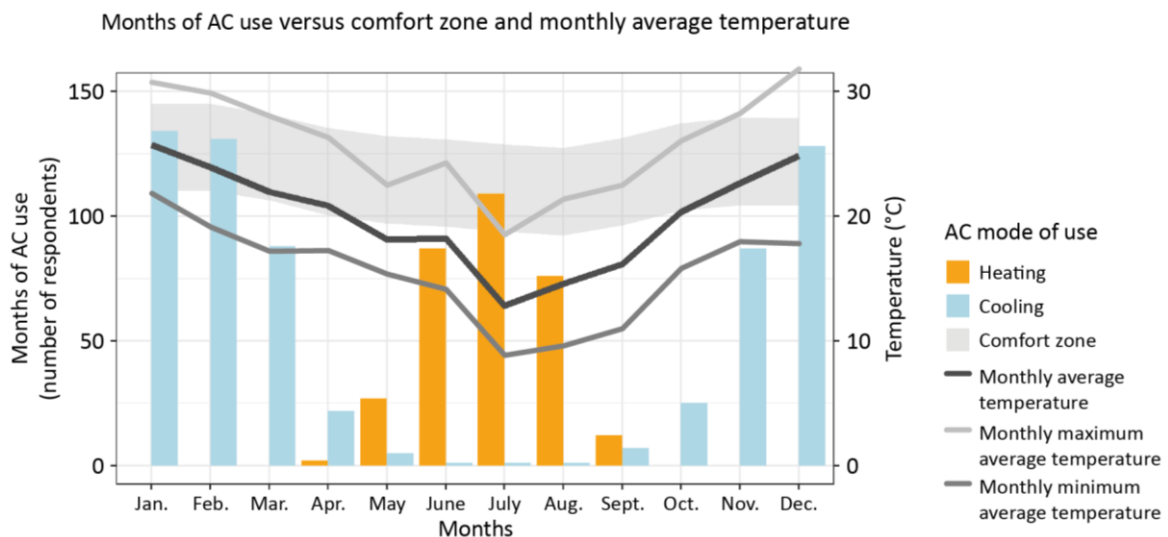
Both average setpoints diverged from seasonal comfort zones: cooling was set below the comfort zone (22-29 °C) during peak summer use, and heating was set above the comfort zone (18-25 °C) in winter.

Table 3 - Comparison of equipment use patterns and contextual factors

Contextual factors		Fisher	Equipment use pattern															
			Absolute result								Result in %							
Factor	Grupo	p-value	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Fan																		
Income	≤ 4	<0.01	6	0	10	10	14	3	10	0	11	0	19	19	26	6	19	0
	5 to 10		11	0	7	19	4	3	3	2	22	0	14	39	8	6	6	4
	>10		15	0	10	10	8	8	2	0	28	0	19	19	15	15	4	0
Floor	T+1 st	0.04	4	0	9	15	3	1	2	1	11	0	26	43	9	3	6	3
	2 nd		5	0	4	6	4	3	3	0	20	0	16	24	16	12	12	0
	3 rd		4	0	10	9	7	5	4	0	10	0	26	23	18	13	10	0
	>4 th		19	0	4	9	12	5	6	1	34	0	7	16	21	9	11	2
AC (ventilation mode)																		
Age range	Young	<0.01	21	0	0	1	4	3	3	18	42	0	0	2	8	6	6	36
	Adult		18	0	2	7	11	7	1	11	32	0	4	12	19	12	2	19
	Elderly		4	0	1	1	4	5	1	6	18	0	5	5	18	23	5	27
	Children		10	0	2	3	1	6	3	1	38	0	8	12	4	23	12	4
AC (cooling mode)																		
Income	≤ 4	0.03	15	0	4	7	15	2	9	1	28	0	8	13	28	4	17	2
	5 to 10		2	0	2	17	14	2	12	0	4	0	4	35	29	4	24	0
	>10		2	0	8	14	19	3	7	0	4	0	15	26	36	6	13	0
Heater																		
Perception of thermal comfort (cold or hot)	comfort	0.02	12	0	1	0	4	1	3	1	55	0	5	0	18	5	14	5
	slight discomfort		17	0	2	1	15	2	0	2	44	0	5	3	38	5	0	5
	discomfort		18	0	6	11	17	2	0	2	32	0	11	20	30	4	0	4
	Significant discomfort		8	0	5	3	17	3	1	1	21	0	13	8	45	8	3	3
AC (heating mode)																		
Income	≤ 4	<0.01	19	0	1	3	11	3	5	11	36	0	2	6	21	6	9	21
	5 to 10		10	0	2	5	21	1	3	7	20	0	4	10	43	2	6	14
	>10		6	0	7	6	20	7	3	4	11	0	13	11	38	13	6	8
Sunlight through windows	sunny	0.01	21	0	10	13	37	11	7	15	18	0	9	11	32	10	6	13
	shady		14	0	0	1	15	0	4	7	34	0	0	2	37	0	10	17

Note: Key: equipment use pattern: (1) do not have or use, (2) always on in all rooms, (3) on in occupied rooms, (4) sometimes for a long period, (5) sometimes for short periods of time, (6) occasionally, for a short period, (7) to sleep, (8) always off.

Figure 22 - Months of air-conditioning use for cooling and heating, average monthly dry bulb temperature for 2019, and comfort zone



Source: temperatures for 2019 obtained from INMET (2020) and comfort zone obtained from PROJETEE (2021).

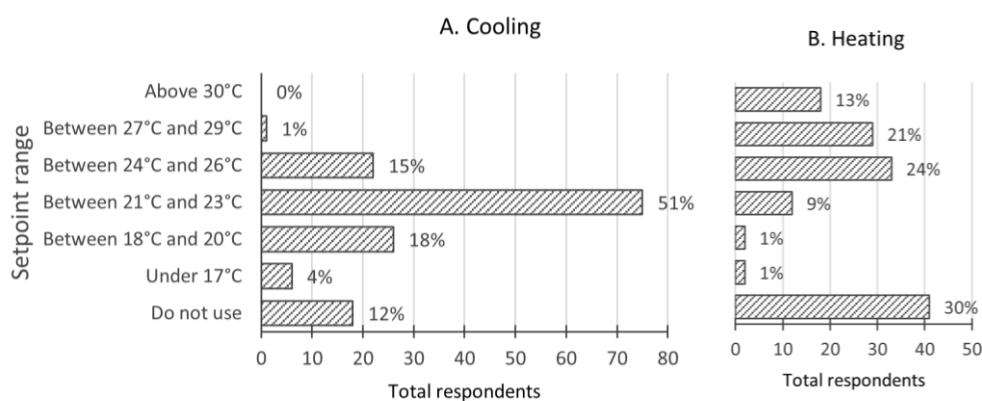
Table 4 - Number of months of air-conditioning use (cooling) and contextual factors

Contextual factors		Fisher	Number of months of AC use (cooling)												
			Absolute result/Result in %												
Factor	Group	p-value	0	1	2	3	4	5	6	7	8	9	10	11	12
AC (cooling)															
Income	≤ 4	<0.01	14	0	3	5	13	15	2	0	0	1	0	0	0
	5 to 10		3	0	2	10	10	12	7	4	0	0	0	0	1
	>10		1	0	2	11	13	12	7	3	3	1	0	0	0
Income (%)	≤ 4		26	0	6	9	25	28	4	0	0	2	0	0	0
	5 to 10		6	0	4	20	20	24	14	8	0	0	0	0	2
	>10		2	0	4	21	25	23	13	6	6	2	0	0	0

Table 5 - Number of months of air-conditioning use (heating) and contextual factors

Contextual factors		Fisher	Number of months of AC use (heating)													
			Absolute result							Result in %						
Factor	Group	p-value	0	1	2	3	4	5	6	0	1	2	3	4	5	6
<i>AC (heating)</i>																
Income	≤ 4	<0.01	25	1	12	12	3	0	0	47	2	23	23	6	0	0
	5 to 10		14	3	11	12	5	2	2	29	6	22	24	10	4	4
	>10		6	5	10	18	12	2	0	11	9	19	34	23	4	0
Age range	Young	0.04	20	3	12	9	4	0	2	40	6	24	18	8	0	4
	Adults		19	3	10	18	4	3	0	33	5	18	32	7	5	0
	Elderly		3	2	3	8	6	0	0	14	9	14	36	27	0	0
	Children		3	1	8	7	6	1	0	12	4	31	27	23	4	0
Perception of comfort	comfort	0,03	11	1	4	3	1	2	0	50	5	18	14	5	9	0
	little cold		12	3	10	10	4	0	0	31	8	26	26	10	0	0
	cold		14	4	15	17	4	0	2	25	7	27	30	7	0	4
	very cold		8	1	4	12	11	2	0	21	3	11	32	29	5	0

Figure 23 - Cooling (A) and heating (B) setpoint ranges



The setpoint preferences were also related to income (cooling and heating) and age group (cooling) (Table 6). While the 21-23 °C range was most common across all income groups, lower-income respondents more frequently selected 18-20 °C for cooling, whereas higher-income respondents opted for 24-26 °C. These variations suggest that income influences not only AC ownership and duration of use, but also thermal expectations and comfort standards.

Influence of occupant behavior on energy consumption

Energy consumption data were collected from 51 of the 155 respondents who agreed to participate in the detailed survey. These participants provided their monthly energy consumption from January 2019 to December 2019, together with information on appliance ownership and usage frequency for high-energy

consumption devices. The majority of respondents lived in houses with 1 or 2 occupants, had an income exceeding 10 minimum wages, were adults, resided in homes receiving direct sunlight, and lived on the third floor, or higher. Table 7 summarizes their characteristics.

Figure 24 demonstrates respondents' ownership of electrical appliances. All participants owned a refrigerator, while an electric shower, TV, and computer were present in 96% of the homes. Only 2 respondents (4%) did not have an electric shower. Split AC and washing machines were found among 90% of the respondents. More than half the homes had an electric iron, washing machine, electric oven, microwave, toaster, electric kettle, and fan.

According to the Brazilian government (Eletrobras, 2019), artificial lighting accounts for 9.67% of residential energy consumption. In order to assess its impact, data were collected on daytime artificial lighting use in the living room and master bedroom (Figure 25). Most homes did not require artificial lighting either in the living room (67%) or bedroom (86%) during the day.

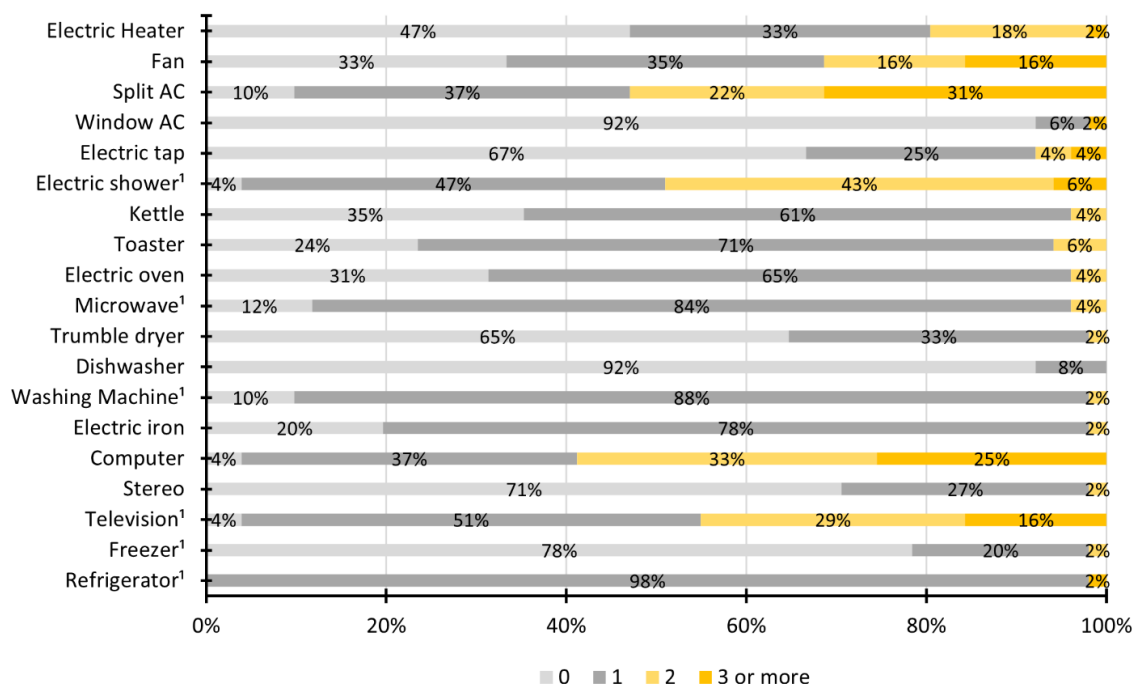
Table 6 - Setpoint and contextual factors

Contextual factors		Fisher	AC setpoint															
			Absolute results									Results in %						
Factor	Group	p-value	N	<17	18-20	21-23	24-26	27-29	>30	C	N	<17	18-20	21-23	24-26	27-29	>30	C
AC (cooling)																		
Income	≤ 4	<0.01	15	1	9	20	4	0	15	1	28	2	17	38	8	0	0	2
	5 to 10		2	4	9	30	3	0	2	4	4	8	18	61	6	0	0	0
	>10		1	1	8	25	15	1	1	1	2	2	15	47	28	2	0	0
Age range	Young	<0.01	13	1	6	25	3	0	13	1	26	2	12	50	6	0	0	0
	Adults		4	5	9	27	10	0	4	5	7	9	16	47	18	0	0	2
	Elderly		0	0	9	8	2	0	0	0	0	0	41	36	9	0	0	0
	Children		1	0	2	15	7	1	1	0	4	0	8	58	27	4	0	0
AC (heating)																		
Income	≤ 4	0.02	23	0	0	2	7	6	8	0	43	0	0	4	13	11	15	0
	5 to 10		11	1	1	3	13	10	4	0	22	2	2	6	27	20	8	0
	>10		7	1	1	7	13	13	6	0	13	2	2	13	25	25	11	0

Table 7 - Detailed survey: Respondent characteristics

Parameter	Group	Number	%
Number of residents	1	16	31%
	2	17	33%
	3	9	18%
	4	7	14%
	5	2	4%
Minimum wage range	≤ 4	14	27%
	5 to 10	13	25%
	< 10	24	47%
Age range	Young	10	20%
	Adults	25	45%
	Elderly	8	16%
	Children	10	20%
Floor level	Ground and first floor	10	20%
	2 nd	7	14%
	3 rd	18	35%
	≥ 4 th	16	31%
Direct sunlight	Sunny	41	80%
	Shady	10	20%

Figure 24 - Equipment ownership among respondents



Note: ¹appliances that consume the most energy according to Eletrobras (2019).

Figure 25 - Daytime use of artificial lighting in rooms (A), during the day (B) and the night (C)

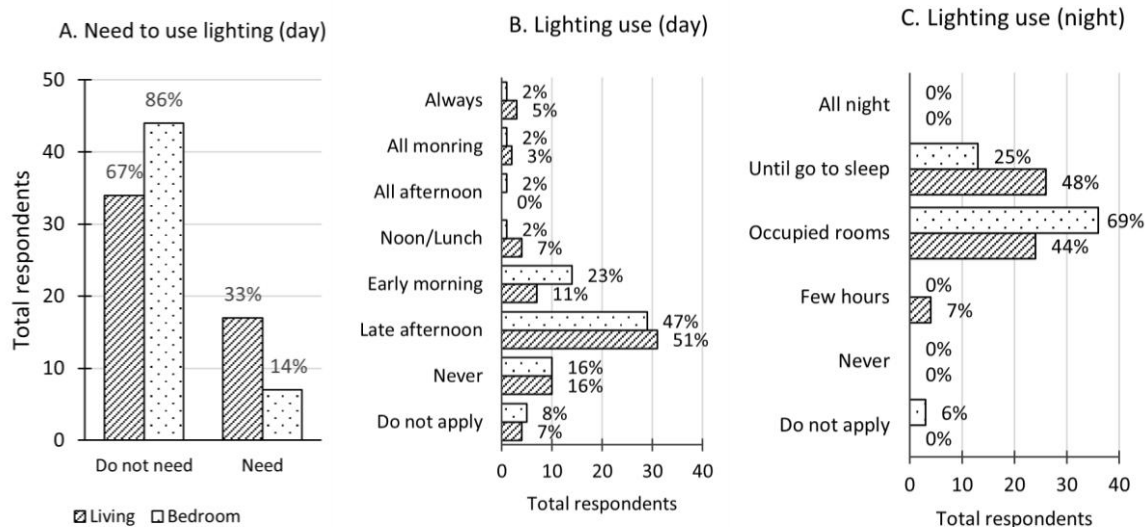


Figure 26 presents the monthly energy consumption. The highest consumption occurred during temperature extremes: January (225 kWh), which is the hottest month, and July (209 kWh) which is one of the coldest months, and both fall outside the comfort zone.

This increased consumption is possibly due to use of air-conditioning. As noted in the previous section, the months with the highest energy consumption align with those of greater air-conditioning use. During extreme temperatures, passive adjustments such as adjusting clothing and opening or closing windows may not be sufficient to maintain thermal comfort.

The mid-season months presented lower, more stable energy consumption, shown by reduced variability in Figure 26. Energy use decreased during transitional months with milder temperatures, reducing the need for artificial conditioning. This suggests the influence of adaptive behavior, since consumption peaked in the

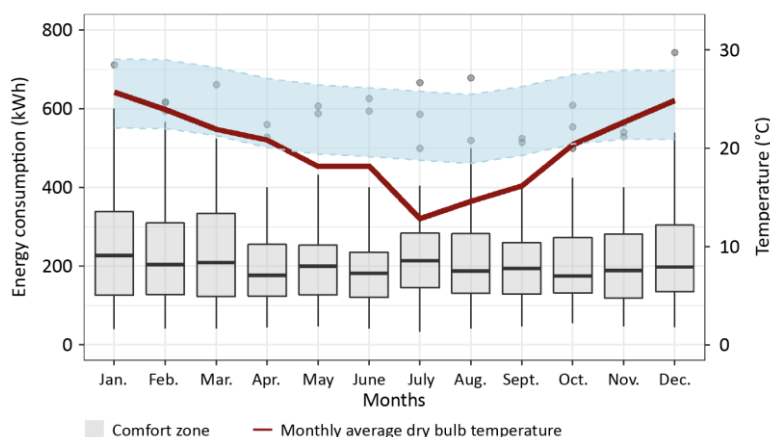
months with extreme temperatures, when occupants relied more on artificial conditioning, resulting in a higher standard deviation.

Outliers were identified in all months, with some exceeding 500 kWh. Two homes, with 2 and 4 occupants and high incomes, consistently had above-average consumption (525 kWh to 715 kWh) for at least 8 months, possibly due to the residents' habits and lifestyles, as well as appliance use. One 4-member home reported owning multiple freezers, an electric faucet, AC, fan, and a heater. Other outliers had high energy use (541 kWh to 743 kWh) during extreme heat, but with significantly lower consumption in the preceding and following months (257 to 429 kWh), coinciding with Brazil's vacation period, when residents spend more time at home.

Per capita energy consumption followed a similar pattern to total consumption (Figure 27), with the highest average in February (117 kWh), and with July ranking fifth (106 kWh). However, per capita consumption showed more consistent variation across the months (standard deviation: 47 to 87 kWh) compared to total consumption (109 kWh to 225 kWh), with the greatest fluctuations occurring during the summer. This indicates that differences in the number of residents per home balanced out energy use variations.

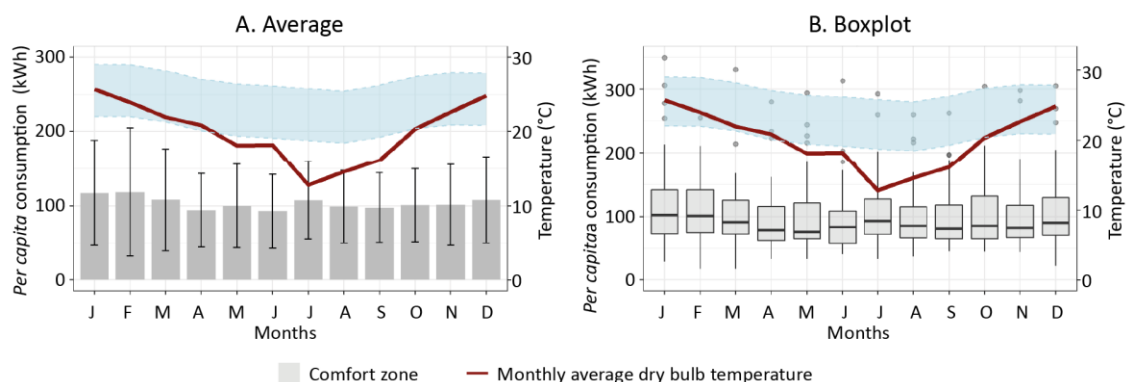
Table 8 demonstrates the relationship between energy consumption and household size. In line with Gill *et al.* (2011) and Yohanis *et al.* (2008), per capita energy consumption decreases as the number of residents increases, since certain energy uses (e.g., refrigerator, washing machine, and dishwasher) are independent of occupancy and are shared more efficiently. This effect is more pronounced in larger households. However, total consumption rises for up to 4 residents but declines in 5-person households, suggesting additional influencing factors.

Figure 26 - Total energy consumption versus temperature



Source: temperatures for 2019 obtained from INMET (2020) and comfort zone obtained from PROJETEE (2021).

Figure 27 - Average (A) and boxplot (B) of energy consumption per capita versus temperature



Source: temperatures for 2019 obtained from INMET (2020) and comfort zone obtained from PROJETEE (2021).

Table 8 - Energy consumption and number of residents

Number of residents	1	2	3	4	5	Total
Total energy consumption (kWh)	1,351	2,628	3,476	3,850	3,740	2,588
Per capita consumption (kWh/person)	1,351	1,314	1,159	962	748	1,148
Sample	16	17	9	7	2	51

Linear regression analysis was used to assess the influence of occupant behavior on energy consumption. The explanatory variables included the number of residents per home, equipment ownership, use of AC use patterns (cooling and heating), setpoints, and months of AC use. A stepwise regression excluded low significance variables, such as common appliances (e.g., refrigerator, TV, computer, microwave, electric oven, and shower), and rarely owned devices (e.g., stereo, dishwasher, and electric faucet). The final model retained significant factors, including the number of residents per home, high-energy appliances with varied ownership (e.g., freezer, dryer, AC, fan, and heater), AC use patterns, setpoints, and operational AC months.

The model demonstrated statistical significance ($p\text{-value} \ll 0.01$) and explained 89.8% energy consumption. Table 9 presents the regression coefficients and their significance. Figure 28 illustrates the correlation between reported and predicted annual energy consumption, highlighting the proximity between observed and estimated values.

The model indicates a positive intercept of 244.1 kWh, representing a fixed annual energy consumption common to all respondents. As expected, the number of residents contributes to increased energy consumption. Notably, heater use showed a negative increment (-273.9 kWh), which does not imply that heaters reduce consumption but suggests that their use may replace other energy-intensive equipment, leading to an overall reduction.

AC use patterns and setpoints had a positive impact on annual energy consumption, since the reference category represents non-ownership or non-use of AC. Longer AC usage periods (cooling) resulted in higher consumption increases. The smallest increment was associated with turning on AC to cool occupied rooms, whereas the highest was linked to prolonged use to maintain thermal comfort. The pattern of AC use (cooling) for a long period presented the highest estimated increase among all variables considered by the model. On the other hand, AC use (cooling) for sleep represented a negative increment, indicating that considering the expected consumption due to the number of residents, possession, and pattern of other equipment usage, AC energy consumption (cooling) at night may be lower than energy consumption during the day.

As expected, the greater period of AC use to heat or cool, the greater the energy consumption increase. The setpoint had an inverse ratio of increase consumption: milder setpoints such as 24 °C to 26 °C for cooling, and 18 °C to 20 °C for heating tend to reduce energy consumption more significantly than extreme setpoints. Similar to the AC analysis (cooling), in the face of expected consumption (due to the number of residents and use of AC, for example) depending on the setpoint used, this consumption may be reduced. The difference between the most extreme and moderate use setpoints may lead to an annual saving of up to 777 kWh for cooling, and 618 kWh for heating. Rinaldi, Schweiker and Iannone (2018) and Csoknyai *et al.* (2019) observed a similar influence for the heating setpoint and resulting energy consumption, indicating that moderate setpoints consume less energy than extreme ones.

Typical behavior profiles

Occupancy patterns, windows, and AC (cooling and heating) use, obtained from 51 respondents, were considered for cluster analysis, identifying four typical behavior profiles (Figure 29).

The occupation pattern presented a significant variation between behavior profiles, as shown in Figure 30. Group 1 has the shortest house occupancy time, which would correspond to users who work or study outside the home all day. Group 2 presents an intermediate occupation pattern, which would correspond to a user who works or studies part-time. Group 3 has the longest occupancy period, with almost all residents at home all day. Finally, Group 4 presents behavior similar to the mean behavior observed for the entire sample, in which some of the residents leave home in the mornings and afternoons, and most of them have lunch at home.

Table 9 - Linear regression model for energy consumption

Coefficients	Estimate	Standard error	T-statistic	p-value	Significance
(Intercept)	244.1	472.1	0.52	0.61	
Number of residents per home	391.0	131.9	2.97	<0.01	**
Freezer	844.2	279.3	3.02	<0.01	**
Tumble dryer	464.4	282.0	1.65	0.11	
AC window	423.3	245.7	1.72	0.10	.
AC split	444.0	129.3	3.44	<0.01	**
Fan	315.4	143.2	2.20	0.04	*
Heater	-273.9	172.3	-1.59	0.12	
AC (cool) use – On in occupied rooms	2,854.7	1,050.2	2.72	0.01	*
AC (cool) use – Sometimes for long periods	4,462.0	1,269.8	3.51	<0.01	**
AC (cool) use – Sometimes for short periods	3,260.0	1,218.5	2.68	0.01	*
AC (cool) use – Occasionally, for short periods	3,699.4	1,283.0	2.88	<0.01	**
AC (cool) use – To sleep	3,610.7	1,193.3	3.03	<0.01	**
AC setpoint (cool) – 18°C to 20°C	-4,724.5	1,374.7	-3.44	<0.01	**
AC setpoint (cool) – 21°C to 23°C	-5,070.8	1,382.0	-3.67	<0.01	**
AC setpoint AC (cool) – 24°C to 26°C	-5,501.9	1,415.5	-3.89	0.00	***
AC (cool) months of use	279.0	103.2	2.70	0.01	*
AC (heat) use – On in rooms with occupants	3,318.0	973.8	3.41	<0.01	**
AC (heat) use – To sleep	-1,202.3	546.6	-2.20	0.04	*
AC setpoint (heat) – 18°C to 20°C	-1,597.7	803.6	-1.99	0.06	.
AC setpoint (heat) – 24°C to 26°C	-1,358.8	295.4	-4.60	0.00	***
AC setpoint (heat) – over 30°C	-979.3	386.5	-2.53	0.02	*
AC (heat) months of use	373.9	120.7	3.10	<0.01	**

Note: Significance: 0 *** 0.001 ** 0.01 * 0.05 - 0.1.

Figure 28 - Correlation between observed and predicted annual energy consumption

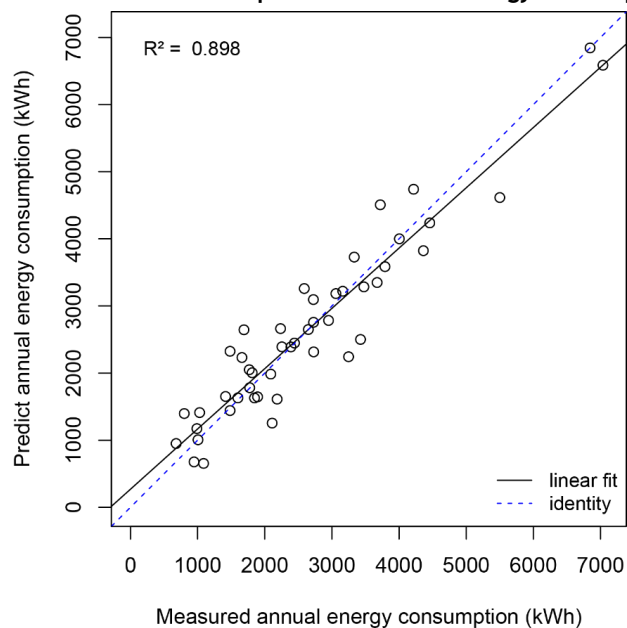
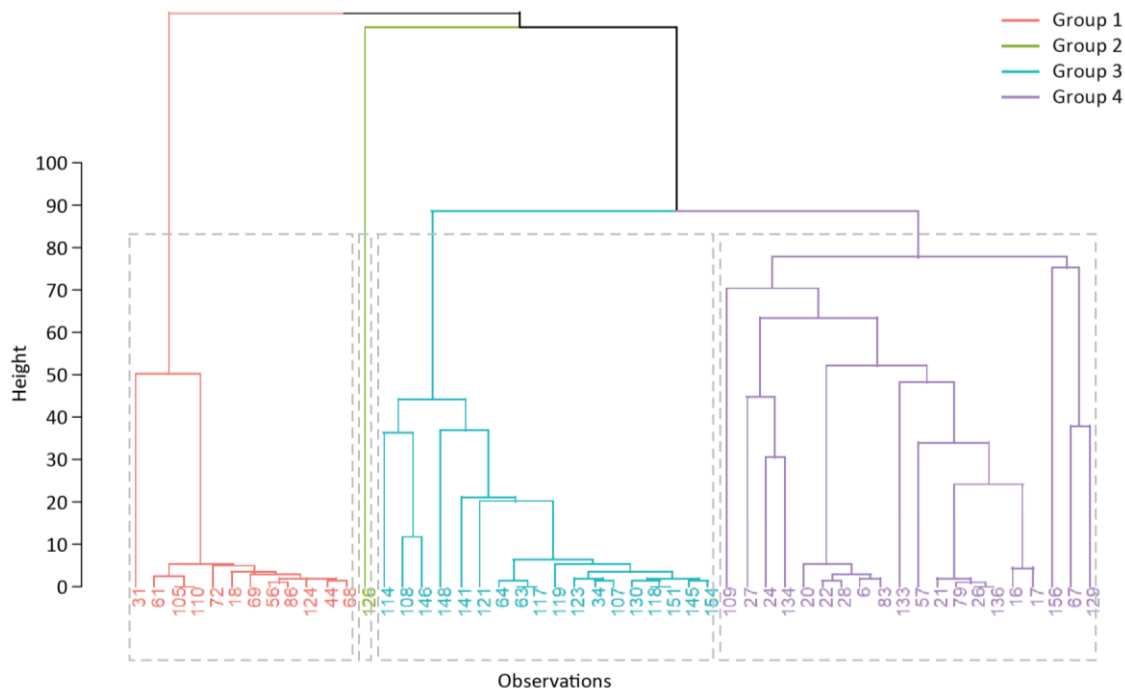


Figure 29 - Grouping dendrogram - Average



Note: Profile 1 (red) - 2 individuals, young people, adults, and the elderly, and incomes of up to 4 minimum wages. Profile 2 (green) - one adult, and income of above 10 minimum wages. Profiles 3 (cyan) - 18 individuals, families mainly comprised adults and adults with children, and high incomes. Profile 4 (lilac) - 20 adults with middle- and high-income ranges.

Figure 30 - Typical behavior profiles

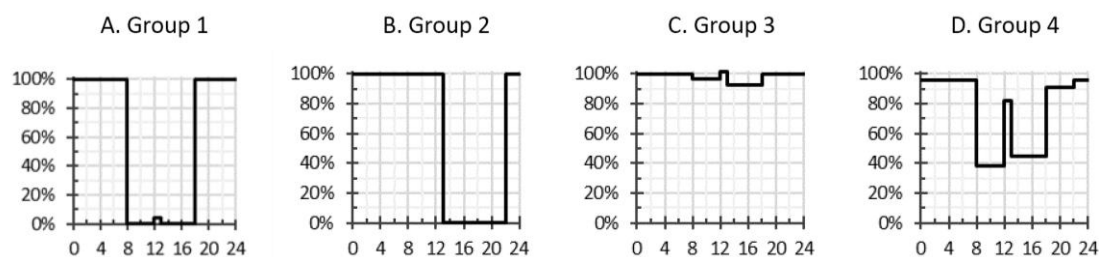


Table 10 presents a summary of the typical profile characteristics. With regards to window use, Profile 1 uses the windows the least, only utilizing them a few times for air circulation. Profile 2 presents an intermediate window use pattern, opening them when the residents are at home. Profiles 3 and 4 use open windows for a longer period, being closed only at night. With regards to AC use on cooling mode, Profiles 1 and 3 use it for a shorter time, a few times per day, until reaching thermal comfort. Profile 2 makes longer AC use to cool the room for sleeping. Profile 4 has AC use for cooling, characterized both by use a few times a day for a short time, and sleeping, since these adjustments were of the same frequency among individuals belonging to this group.

AC use to heat was similar for the four groups, being used a few times per day for a short time, solely to maintain thermal comfort. Heating mode AC is used for a shorter time interval, when compared to AC use for cooling. Balvedi *et al.* (2018) defined three user profiles in Florianópolis and their behavior profiles were tested in energy simulations of a multifamily dwelling, resulting in oscillations higher than 130% in the results of degree cooling and heating time between the behavior profiles. Furthermore, Balvedi *et al.* (2018) indicate that the profile behaviors result in a varied thermal home behavior, which may also occur in this study.

Figure 31 presents the average energy consumption of the profiles identified. There is a difference in energy consumption between typical behavior profiles, indicating that they may influence energy consumption. Profile 1, which spends more time outside the home, and has a lower window and AC use, had a lower annual

energy consumption, of 1,253 kWh on average. Profiles 2, 3, and 4, with higher occupation during the day, presented a higher energy consumption, which gradually increases from Profile 2 to Profile 4: 2,110 kWh, 2,422 kWh, 2,725 kWh, indicating an association between the occupancy pattern and energy consumption.

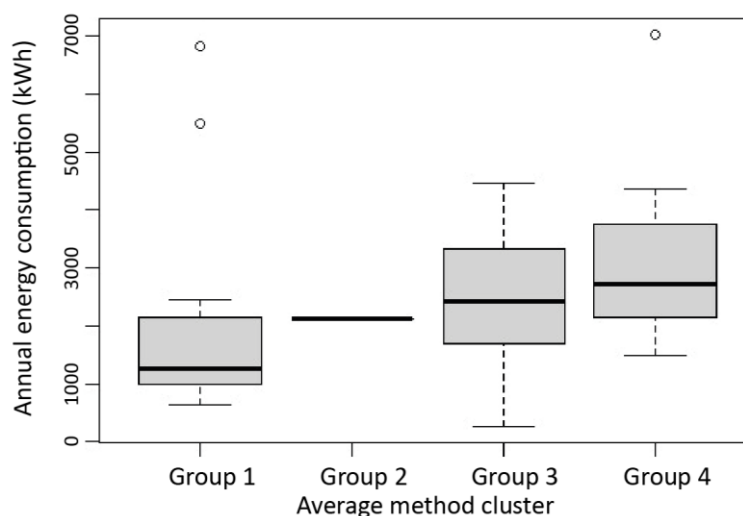
The identified profiles may contribute to more realistic, representative simulations of the occupancy profile of residents in multifamily dwellings of up to 3 bedrooms. However, use is restricted to simulations developed for the same public and region, since occupant behavior is influenced by contexts such as climate, local culture, and building characteristics.

A better understanding of occupant interactions with residential buildings may contribute to the design and construction of buildings that enable and enhance the use of varied adaptive behaviors, with an emphasis on individual adjustments and passive conditioning. For the use of these buildings to be as efficient as possible, it is also important for educational strategies to raise occupant awareness of the use of passive conditioning strategies, as well as the effects of certain use patterns and artificial conditioning setpoints on energy consumption. Furthermore, it is important to adapt buildings to the climate in which they are located, in order to achieve better levels of the perception of comfort, and less use of artificial conditioning strategies.

Table 10 - Typical profile behavior according to the studied groups

Profile		Profile 1	Profile 2	Profile 3	Profile 4
Occupant characterization	Age range	18 to > 60	30 to 59	>18 + <18	18 to > 60
	Income (minimum wage)	< 4	>10	> 10	5 to 10
Occupant data (schedule, window use, AC use in cooling and heating mode)	Occupancy	out of the home all day	Part-time	all day at home	lunch time at home
	Window use	opened sometimes to refresh the air	opened when occupants are at home	closed at night	closed at night
	AC use - cooling	A few times per day, for a short time	to sleep	A few times per day, for a short time	A few times per day, for a short time, to sleep
	AC use - heating	A few times per day, for a short time	A few times per day, for a short time	A few times per day, for a short time	A few times per day, for a short time

Figure 31 - Annual energy consumption for typical profiles



Conclusions

The research characterized occupant behavior, the influence of contextual factors, and their impact on energy consumption in a sample of multifamily homes with up to 3 bedrooms located in a city in southern Brazil, in a Cfa, humid subtropical climate.

The results showed that occupant adjustments to achieve thermal comfort are more individual than environmental or spatial. They are mainly passive, such as individual adjustments, and use of windows in winter. AC use is higher during the summer. This difference was observed for different age and income groups. Young and lower-income occupants make greater use of passive adjustments, while adults, the elderly, and higher-income users make greater use of AC. However, when available, AC use in the cooling mode is similar for the different income ranges studied.

The order and frequency of the adjustments observed were different to what was expected. For cold discomfort, closing windows is the 3rd most mentioned adjustment, while AC and heaters are 5th and 6th. For heat discomfort, AC appears in 2nd position, while opening windows is the 6th adjustment. Future studies may investigate the reasons for window use being rarely reported as adaptive behavior for heat, although most respondents consider their homes to be well ventilated.

As expected, energy consumption was higher for homes with a higher number of users and tended to decrease considering per capita consumption. Energy consumption had a greater influence on the pattern of use and air conditioning setpoint, and greater impact for cooling than heating. For cooling, when AC is used at night, energy consumption is comparatively lower than other patterns of use.

The use of lower AC setpoints in cooling mode resulted in lower energy consumption, reduced by up to 777 kWh a year by changing the cooling setpoint from between 18 °C and 20 °C to between 24 °C and 26 °C, and up to 618 kWh when changing the heating range setpoint above 30 °C to between 18 °C and 20 °C.

The research identified more than one occupancy profile, similar to other studies, presenting diverse characteristics and behaviors. Further studies may contribute towards understanding whether typical profiles occur in other contexts, since this variation may affect computational energy simulations and thermal building performance.

The study has a number of limitations related to the survey application. Despite efforts to disseminate the survey invitation by social media, email, and distributing flyers to various buildings, the first and second target audience was mainly the academic community, and the latter resulted in a low response rate, and limited sample diversity. Conducting the survey at a single time point, while requesting respondents to report on behaviors over the entire year, may have introduced a recall bias, and led to generalizations or distortions, since responses relied on participant memories. Furthermore, application during spring and summer may have yielded a disproportionate response for the warm season, while responses related to winter behaviors may have been underrepresented due to the temporal distance from the survey period. In addition, the sample size may have affected non-parametric association analyses, since certain category intersections yielded no responses. Future research should consider investigating occupant behavior in other housing typologies, across varying income and educational levels, and through incorporation of environmental and behavioral monitoring.

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