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Influence of Gender on Thermal, Air-Movement, Humidity and Air-Quality Perception in Mixed-Mode and Fully Air-Conditioned Offices

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Abstract: As gender may influence thermal and air quality perception in indoor environments, the aim of this study was to analyse gender influence on air movement, air humidity, air quality and thermal perception in office buildings in Southern Brazil. Statistical descriptions, regression analyses and hypothesis tests were performed using data collected from field studies conducted in a fully air-conditioned building and in three mixed-mode buildings. In addition, comfort temperatures were estimated through the Griffiths method. Results showed that females tend to feel colder compared to males. Men and women tended to present higher thermal acceptability and thermal comfort in mixed-mode buildings and in fully air-conditioned buildings, respectively. Weak but significant correlations were obtained between some environmental and subjective variables. In general, comfort temperatures were statistically higher for females (24.2 °C) than for males (23.5 °C). Significant gender differences for thermal perceptions of indoor environments were detected.

Keywords: thermal comfort; gender; thermal perception; office buildings; mixed-mode buildings; comfort temperature; air quality; air movement; air humidity; personalised environmental control systems

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Citation: Maykot, J.K.; Oliveira, C.C.d.; Ghisi, E.; Rupp, R.F. Influence of Gender on Thermal, Air-Movement, Humidity and Air-Quality Perception in Mixed-Mode and Fully Air-Conditioned Offices. *Sustainability* **2022**, *14*, 9722. https://doi.org/10.3390/su14159722

Academic Editor: Vincenzo Costanzo

Received: 23 June 2022
Accepted: 4 August 2022
Published: 7 August 2022

1. Introduction

Some research studies have assessed comfort in office buildings [1–5] since, depending on environmental conditions and considering that working hours in these environments may be extended, human health and behaviour may be harmed. Both quantitative aspects and more subjective, qualitative and psychological aspects may affect the user's perception of the environment [6]. Shahzad et al. [7] evaluated thermal preference patterns of office building occupants in the UK, Sweden and Japan using a qualitative methodology that includes the spatial context of the user's workspace. According to the study, when individual differences are ignored, more energy is consumed while occupants feel uncomfortable. Therefore, studying thermal comfort in offices is essential to reduce energy consumption in such buildings. According to Pérez-Lombard et al. [8], office buildings are those with the highest energy consumption and the highest CO_2 emissions among commercial buildings.

Concerns regarding the health and performance of occupants not only justifies thermal comfort studies but also air quality assessments in office buildings [9–11]. Some studies have reported effects on concentration and learning capacities associated with users' satisfaction with indoor air quality [12–14]. Vimalanathan and Babu [15], for example, showed that environmental temperature may affect office workers' performance. On the other hand, Liu et al. [16] found that relative humidity exerts a more significant influence on learning performance than the air temperature. It is also noteworthy that there are studies associating exposure to air pollution with increased risk of death from cardiovascular diseases [17].

Carbon dioxide is considered an indoor air quality indicator [18]. Promoting indoor air circulation, even for a short period, might be a strategy to reduce high concentrations of this gas [19–23]. Experiments carried out in office rooms in Slovakia showed that CO_2 concentrations higher than 1000 ppm may trigger fatigue, reducing the workers' performance [24].According to a study conducted in the USA [25], most measurements of carbon dioxide concentration taken in offices were within the range recommended by ASHRAE. Such research also concluded that users' satisfaction with indoor environments is influenced by gender, age and workstation position. In Germany, a survey found associations between air quality of offices and temperature dissatisfaction and perception of air humidity [26].

Besides the association of air quality with environmental variables, which affect thermal comfort sensation, differences between thermal perceptions of men and women have been reported in the literature [27]. Studies have found that females are more thermally dissatisfied than males [28–30]. A survey conducted in China showed that women tend to tolerate thermal discomfort more than men [31]. Another study did not detect significant gender differences in thermal sensation [32]. When comparing comfort temperatures between genders, some research indicates that females prefer higher temperatures than males [33,34]. Other studies, however, either did not find differences in neutral temperatures of men and women [32,35] or obtained a higher neutral temperature for men when compared to that found for women [36]. Such contrasts further highlight the importance of conducting more thorough investigations to assess the influence of gender on thermal comfort.

It is noticeable that air quality may be associated with variables that affect thermal comfort, and gender may influence the occupants' thermal perception. Thus, the aim of this study was to quantify the difference in thermal, air-movement and humidity sensation, as well as air-quality satisfaction, for males and females in offices located in Southern Brazil. The influence of gender on subjective responses to indoor thermal perception was also investigated separately for mixed-mode and fully air-conditioned offices. In addition, the thermal comfort temperatures for each gender in office buildings were estimated.

2. Materials and Methods

This research analysed 7564 data from field studies conducted between 2014 and 2016 in four office buildings. Three could operate under air-conditioning or natural ventilation (mixed-mode buildings), while the fourth was fully air-conditioned. The study counted on the voluntary participation of office workers, among whom the majority (>90%) agreed to participate. All the buildings are open plan with lightweight partitions. The mixed-mode ones were built in the 1990s, have operable windows controlled by the users and have window or split air-conditioners. The fully air-conditioned building was built in the 1980s, has a central air-conditioning system with strict temperature control (around 24 °C) and has sealed windows.

All buildings are located in Florianópolis, a city with a humid subtropical climate, in the southern region of Brazil. According to data from the Brazilian National Meteorology Institute, the mean annual temperature and the mean annual relative humidity between 2010 and 2020 in Florianópolis were 21.3 °C and 79.2%, respectively. When analysing mean monthly temperatures during this period, it is noteworthy that the lowest mean value was recorded in July (16.7 °C), while the highest mean values were registered in January and February (25.5 °C). Figure 1 shows the monthly mean temperature and humidity from 2010 to 2020, in addition to the maximum and minimum monthly mean temperature values.

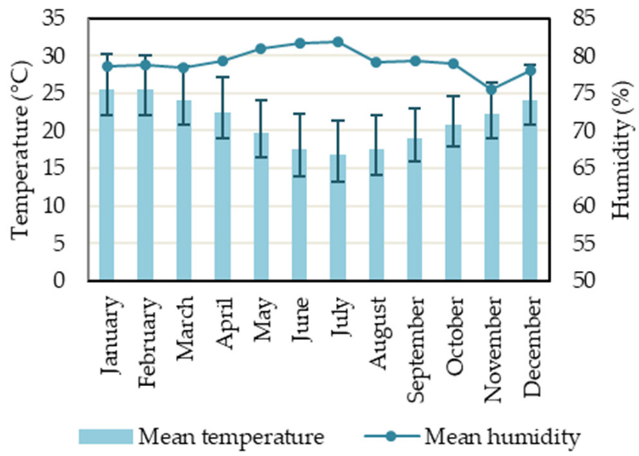

Figure 1. Minimum, mean and maximum temperatures and mean humidity per month, from 2010 to 2020.

2.1. Field Studies

Field studies were conducted during mornings and afternoons, covering all year seasons. Before beginning the experiment, microclimate stations were installed and placed in the geometric centre of the spaces, according to ASHRAE 55 [37] guidelines, to measure environmental variables of indoor environments: air temperature, globe temperature, air velocity and relative humidity. Using a portable thermo-anemometer, it was also possible to measure air temperature and air velocity in sites close to windows, portable fans or air-conditioners. Carbon dioxide concentrations were measured following ISO 16000-1 [38] and ISO 16000-26 [39] recommendations using CO_2 analysers. Technical information about the thermo-anemometer and CO_2 analyser is shown in Table 1.

Table 1. Technical specifications for portable thermo-anemometer and CO_2 analyser.

Equipment	Model (Brand)	Parameters	Accuracy
Portable thermo-anemometer	AirFlow TA 35 (TSI Inc. Shoreview, MN, USA)	Air temperature (°C) Air speed (m/s)	±1.0 ±3%
CO_2 analyser	435-2 (Testo)	CO_2 (PPM)	±75

A questionnaire was also applied to register the occupants' characteristics and their perceptions related to the environment. The occupants provided their anthropometric and clothing characteristics and their perceptions of the thermal environment using personal computers. Metabolic rates and clothing insulation were obtained through the data collected, as indicated in ASHRAE 55 [37]. Regarding thermal, humidity and air-movement acceptability, occupants could classify their environment as acceptable (0) or unacceptable (+1). Considering thermal comfort, users classified their environment as comfortable (0) or uncomfortable (+1). Occupants also showed their air quality perceptions. Figure 2 shows the scales used to assess air quality, as well as the other subjective variables on which users showed their opinions.

Initially, questionnaires were explained to occupants, and they were instructed to behave as if it were a typical working day. Thus, the thermal environment and clothing insulation could be adjusted according to the occupants' preferences. After explanations, questionnaires were applied, with repetition of rounds every 20 min in order to register possible changes in the users' perception of the environment. When conducted in the morning, the experiments started around 8:45 a.m., and in the afternoon they started at 1:50 p.m.

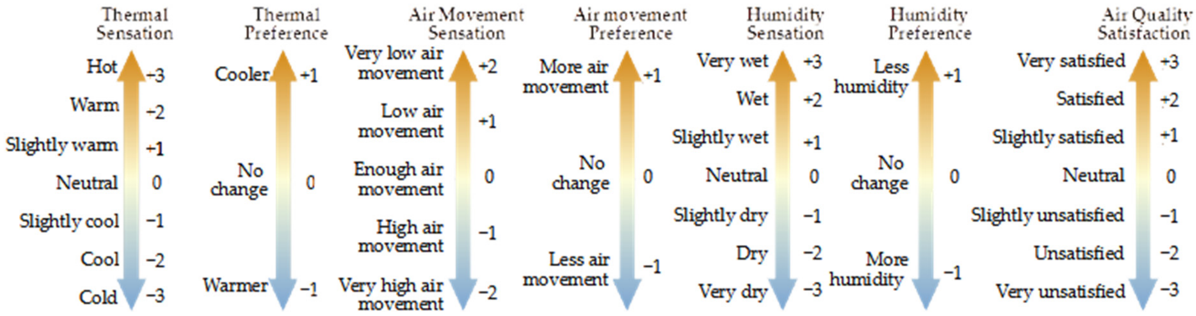

Figure 2. Scales regarding subjective variables which show the occupants' perceptions in offices.

2.2. Comfort Temperature and Air Humidity

As found in the research of Rupp et al. [40], the linear regression method failed to estimate the occupants' thermal comfort temperature in mixed-mode buildings. Thus, thermal comfort temperatures for each gender were calculated using Griffiths' method (Equation (1)) [41], considering 0.5 °C^{-1} for Griffiths' slope [42].

$$T_{comf} = T_{op} - {}^{TSV}/_{G} \tag{1}$$

where T_{comf} is the thermal comfort temperature (°C); T_{op} is the indoor operative temperature (°C); TSV is the thermal sensation vote and G is the Griffiths constant (°C^{-1}).

Analyses associated with air humidity were performed using absolute humidity, as suggested by Nicol et al. [43]. Absolute air humidity was taken as the humidity ratio, calculated according to ISO 7726 [44] (Equation (2)). Total atmospheric pressure was assumed as 101.325 kPa.

$$Wa = 622.0\frac{Pa}{P - Pa} \tag{2}$$

where Wa is the humidity ratio (g/kg); Pa is the partial pressure of water vapour (kPa) and P is the total atmospheric pressure (kPa).

2.3. Data Analysis

Firstly, anthropometric data such as age, weight and height as well as data on variables which influence the occupants' thermal comfort were summarised as means, maximums and minimums. Statistical descriptions were also performed separating data according to gender and type of building.

Subjective data related to users' perceptions were combined with environmental data obtained from each participant's response. Then, statistical measures for data description were extracted (means, maximums, minimums and frequency charts). Correlation and regression analyses were also performed. In addition, users' perceptions were assessed, separating data by type of building, operation mode and gender.

The influence of gender on thermal comfort sensation was assessed using data with similar environmental characteristics, metabolic rates and clothing insulation for men and women. Thus, hypothesis tests were conducted for males and females for the variables thermal sensation, thermal preference, thermal acceptability and thermal comfort.

The possibility of existing significant gender differences in thermal perception and thermal comfort temperatures was assessed through the Mann–Whitney test as the Gaussian curve did not characterise data distribution. For the analyses, a significance level of 0.05 was assumed. Thus, probabilities of significance (p-values) lower than 0.05 indicated statistically significant differences between data, and p-values higher than 0.05 indicated no evidence of significant differences between data.

3. Results

Field studies provided 7564 data from both environmental variables and votes associated with participants' perception of the environments occupied. In the fully air-conditioned building, 2094 votes were recorded, while in the mixed-mode buildings, 5970 votes were recorded. Means, maximums and minimums for subjective and environmental variables related to the thermal environment for each type of building are shown in Table 2. Remarkably, females presented a slightly higher mean clothing insulation than males in both building types, although these differences were not statistically significant.

Table 2. Data summary separated by type of building and gender.

Type of Building	Central Air-Conditioned					Mixed-Mode				
	Female (n = 796)		Male (n = 1298)		Total Mean	Female (n = 2610)		Male (n = 2860)		Total Mean
	Mean	Range	Mean	Range		Mean	Range	Mean	Range	
Age (years)	36	17–58	41	16–74	39	37	16–68	39	15–81	38
Clothing insulation (clo)	0.68	0.41–1.40	0.65	0.41–1.33	0.66	0.70	0.41–1.73	0.67	0.41–1.49	0.69
Height (m)	1.64	1.50–1.79	1.77	1.55–1.97	1.72	1.63	1.48–1.80	1.76	1.52–1.97	1.70
Metabolic Activity (W/m^2)	1.10	1.00–1.40	1.10	1.00–1.40	1.10	1.15	1.00–1.40	1.14	1.00–1.40	1.15
Weight (kg)	62	40–98	83	50–135	75	65	45–170	82	43–130	74
Air velocity (m/s)	0.12	0.10–0.30	0.12	0.10–1.00	0.12	0.12	0.10–0.56	0.13	0.10–1.10	0.12
Operative temperature (°C)	23.4	21.8–25.9	23.3	21.7–26.2	23.3	24.0	17.6–28.5	23.7	16.9–28.5	23.8
Relative humidity (%)	62.7	43.0–77.0	61.6	23.0–78.0	62.0	63.2	33.0–85.0	61.8	34.0–87.0	62.5
Thermal sensation	−0.40	−3–2	−0.05	−3–3	−0.19	−0.09	−3–3	0.11	−3–3	0.01
Thermal preference	−0.21	−1–1	0.09	−1–1	−0.02	−0.05	−1–1	0.12	−1–1	0.04
Thermal acceptability	0.09	0–1	0.04	0–1	0.06	0.05	0–1	0.06	0–1	0.06
Thermal comfort	0.15	0–1	0.10	0–1	0.12	0.12	0–1	0.14	0–1	0.13

3.1. Gender and Vote Distributions for Thermal, Air-Movement and Humidity Sensations

For each ventilation type, Figure 3 shows the distribution of votes of thermal, air-movement and humidity sensation according to gender. Males and females felt mostly neutral or slightly warm/cool in all buildings, and they preferred no changes to the ambient conditions. The thermal sensation frequency between −1 and −3 varied from 23.4% to 38.8% for women and from 15.1% to 21.7% for men, with the highest percentages in the fully air-conditioned building. Thus, females felt colder than males in all ventilation types. The same was observed in some studies developed in climate chambers [34,45], in office buildings operating under air-conditioning in Qatar and India [30] and in universities in Scotland and England [46]. In contrast, research conducted on a climate chamber in the USA [47] did not identify a significant difference between genders in terms of thermal sensation and thermal acceptability.

In buildings operating with air-conditioning devices turned on, there was a higher frequency of women with high air-movement sensation (around 8%) compared to men (around 3%). Other research has reported that women tend to have less satisfaction and acceptability with air movement [30], preferring lower air speed than men, especially at high temperatures [47]. An analysis of studies carried out in a climate chamber with air currents produced by fans showed that women generally feel less warm and more uncomfortable when there are air currents, preferring higher temperatures than men [45].

Furthermore, in these buildings, the percentage of votes indicating a dry sensation was slightly higher among females (25% on mean) than males (23% on mean). There was a remarkable percentage of responses "I don't know how to answer" for men (between 5.5% and 10.1%) and especially for women (between 6.8% and 15.5%).

The percentage of women's thermal acceptability and thermal comfort was slightly higher compared to men in mixed-mode buildings, while the opposite was observed in the fully air-conditioned building. In the natural ventilation mode, the air-movement and humidity acceptability were slightly higher for women than for men, and the contrary occurred in the air-conditioning mode.

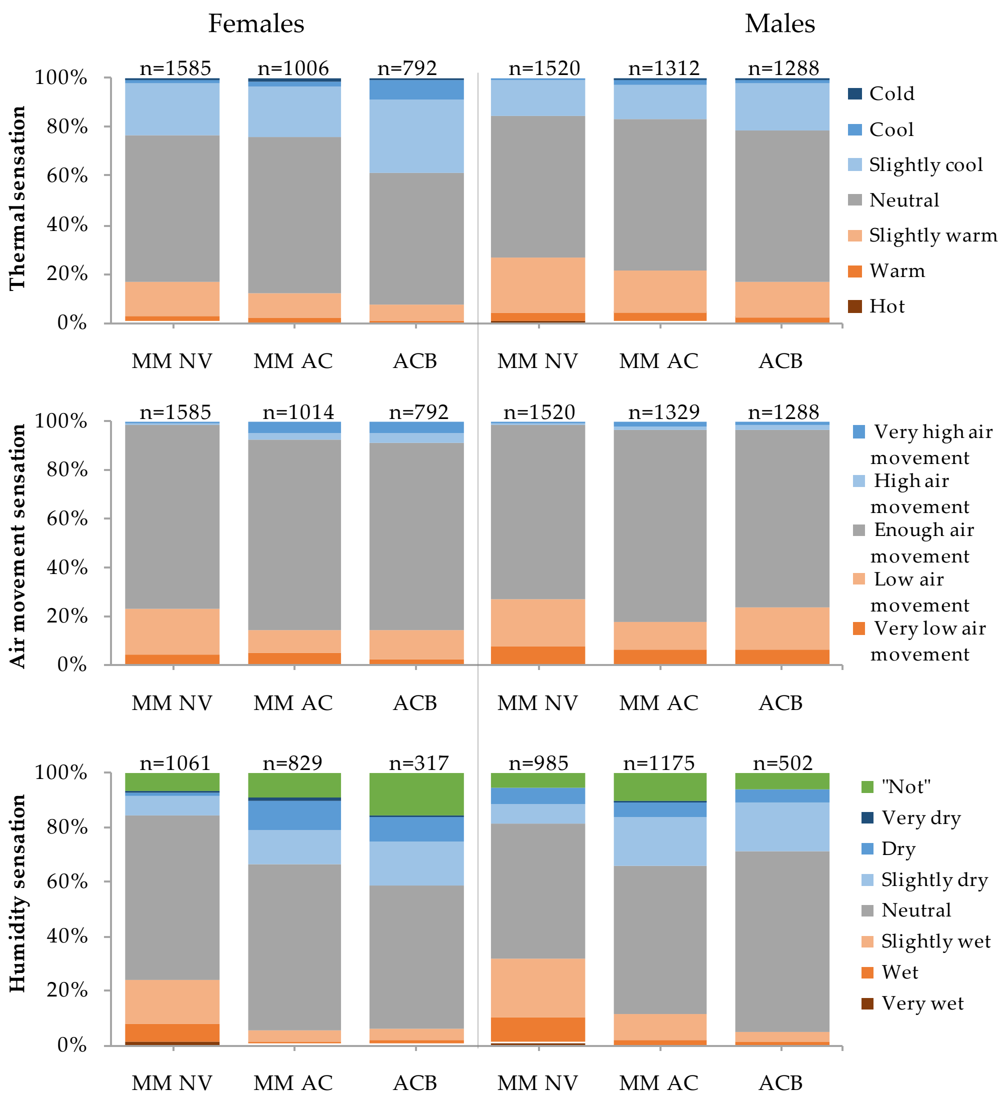

Figure 3. Distribution of votes of thermal, air-movement and humidity sensation for each ventilation type according to gender. Note: MM NV stands for mixed-mode buildings in natural ventilation mode, MM AC stands for mixed-mode buildings in air-conditioning mode and ACB stands for fully air-conditioned building.

Remarkably, females in mixed-mode buildings operating in natural ventilation mode were more likely to accept the thermal environment than under circumstances in which the air-conditioning devices operated. Moreover, males had the opposite perception. A study in naturally ventilated houses in India also pointed out that women showed greater comfort and acceptability of environmental conditions, being more tolerant of the thermal environment [48].

3.2. *Environmental and Subjective Variable Correlations Considering Gender*

Correlations between environmental and subjective variables were analysed using the coefficient of determination and linear regression equations for females (Table 3) and males (Table 4). The response "I do not know how to answer" was excluded from the humidity perception analyses. For both genders, the thermal sensation and preference tended to rise as air temperature increased (statistical significance of $p < 0.001$). In other words, users felt warm and preferred a cooler environment, as predicted. These relationships were more evident for women in mixed-mode buildings under natural ventilation mode and for men in mixed-mode buildings under both operation modes. However, the correlations between air temperature and subjective thermal variables were weak ($R^2 \leq 0.15$ for males and $R^2 \leq 0.10$ for females).

Table 3. Females' linear regressions between environmental and subjective variables.

Variables	Mixed-Mode NV		Mixed-Mode AC		Fully Air-Conditioned	
	Equation	R^2	Equation	R^2	Equation	R^2
Ta × TS	TS = 0.15Ta − 3.62 [a]	0.10	TS = 0.14Ta − 3.62 [a]	0.04	TS = 0.09Ta − 2.54 [b]	0.01
Ta × TP	TP = 0.09Ta − 2.16 [a]	0.08	TP = 0.10Ta − 2.38 [a]	0.04	TP = 0.10Ta − 2.63 [a]	0.03
Va × AMS	$p > 0.05$ [d]	0.00	$p > 0.05$ [d]	0.00	AMS = −1.73Va + 0.24 [b]	0.01
Va × AMP	$p > 0.05$ [d]	0.00	$p > 0.05$ [d]	0.00	AMP = −1.35Va + 0.11 [b]	0.01
Wa × AHS	$p > 0.05$ [d]	0.00	$p > 0.05$ [d]	0.00	AHS = 0.19Wa − 2.26 [b]	0.03
Wa × AHP	AHP = −0.03Wa + 0.45 [b]	0.01	$p > 0.05$ [d]	0.00	$p > 0.05$ [d]	0.00
CO_2 × AQS	$p > 0.05$ [d]	0.02	$p > 0.05$ [d]	0.00	$p > 0.05$ [d]	0.01

Note: [a] Statistically significant with $p < 0.001$. [b] Statistically significant with $p < 0.01$. [c] Statistically significant with $p < 0.05$. [d] Statistically non-significant with $p > 0.05$.

Table 4. Males' linear regressions between environmental and subjective variables.

Variables	Mixed-Mode NV		Mixed-Mode AC		Fully Air-Conditioned	
	Equation	R^2	Equation	R^2	Equation	R^2
Ta × TS	TS = 0.17Ta − 3.82 [a]	0.15	TS = 0.17Ta − 4.12 [a]	0.09	TS = 0.16Ta − 3.86 [a]	0.03
Ta × TP	TP = 0.09Ta − 2.03 [a]	0.09	TP = 0.12Ta − 2.72 [a]	0.09	TP = 0.13Ta − 3.01 [a]	0.04
Va × AMS	$p > 0.05$ [d]	0.00	AMS = −0.90Va + 0.28 [b]	0.01	AMS = 1.51Va + 0.07 [a]	0.02
Va × AMP	$p > 0.05$ [d]	0.00	AMP = −0.47Va + 0.17 [c]	0.00	AMP = 0.62Va + 0.06 [b]	0.01
Wa × AHS	AHS = 0.11Wa − 0.87 [a]	0.02	$p > 0.05$ [d]	0.00	$p > 0.05$ [d]	0.00
Wa × AHP	AHP = 0.06Wa − 0.54 [a]	0.02	$p > 0.05$ [d]	0.00	$p > 0.05$ [d]	0.00
CO_2 × AQS	$p > 0.05$ [d]	0.01	AQS = $0.002CO_2 - 0.32$ [b]	0.07	$p > 0.05$ [d]	0.00

Note: [a] Statistically significant with $p < 0.001$. [b] Statistically significant with $p < 0.01$. [c] Statistically significant with $p < 0.05$. [d] Statistically non-significant with $p > 0.05$.

Regressions between air velocity and air-movement sensation and preference were non-significant for women in mixed-mode buildings and for men in natural ventilation mode ($p > 0.05$). Weak but significant correlations ($R^2 \leq 0.02$) were found for the fully air-conditioned building. In this building, women experienced the sensation of high air movement and preferred lower air movement as air velocity increased, as expected. It is interesting to observe the opposite effect in men, i.e., the sensation of low air movement and the preference for high air movement by an increase in air velocity.

Additionally, regressions between the humidity ratio and humidity sensation and preference were non-significant in most cases ($p > 0.05$). There was a small direct correlation in the mixed-mode buildings operating under natural ventilation for both genders. Other studies also found no correlation between absolute humidity and humidity subjective votes [26]. These results may be related to the fact that users are probably acclimatised to the region's high humidity, which reduces occupant sensitivity [34,49].

There were no significant regressions between carbon dioxide and air quality satisfaction ($p > 0.05$), except for a weak correlation for men in mixed-mode buildings under air-conditioning mode ($R^2 = 0.07$).

3.3. Influence of Gender on Thermal Perception

The possible existence of significant gender differences for the subjective variables associated with the occupants' thermal perception was investigated for each type of building. For each type, votes with similar environmental, metabolic and clothing characteristics were selected. Table 5 shows mean, maximum and minimum operative temperature, relative humidity, air velocity, clothing insulation and metabolic activity.

Table 5. Description of data used to assess a possible gender effect on users' thermal perceptions.

Type of Building and Operation Mode	N	Operative Temperature (°C)		Relative Humidity (%)		Air Velocity (m/s)		Clothing Insulation (clo)		Metabolism (W/m^2)	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Fully air-conditioned	517	23.5	21.8–25.8	64.9	60.0–70.0	0.11	0.10–0.20	0.58	0.56–0.60	1.09	1.00–1.40
Mixed-mode	1232	24.1	23.0–25.5	64.6	60.0–70.0	0.10	0.10–0.12	0.65	0.41–1.41	1.16	1.00–1.40
Mixed-mode (air-conditioned)	637	24.0	23.1–24.7	60.8	50.0–75.0	0.10	0.10–0.12	0.60	0.52–0.74	1.15	1.00–1.40
Mixed-mode (naturally ventilated)	878	24.3	23.0–25.5	61.9	46–72	0.10	0.10–0.12	0.62	0.50–0.73	1.16	1.00–1.40

The assessment of the possibility of a gender effect in the fully air-conditioned building was carried out with 195 votes from females and 122 votes from males. For this type of building, significant differences between males' and females' thermal sensations (p-value < 0.001) and between males' and females' thermal preferences (p-value = 0.001) were found. No significant gender differences were detected in terms of thermal acceptability (p-value = 0.20) and thermal comfort (p-value = 0.36).

The analysis for the mixed-mode building considered 665 votes from males and 567 votes from females. The Mann–Whitney test indicated the existence of significant differences between thermal sensations shown by men and women (p-value < 0.001). These differences were also detected for thermal preference (p-value < 0.001) and thermal comfort (p-value < 0.01) for men and women. Statistical differences between the thermal acceptability for each gender were not evidenced (p-value = 0.80).

Regarding data collected from mixed-mode buildings operating under air-conditioning, 171 and 466 responses of females and males, respectively, were considered. Hypothesis tests showed significant differences between men's and women's thermal sensations (p-value < 0.01), thermal preferences (p-value < 0.001) and thermal acceptability (p-value < 0.05). No significant differences were found between female and male thermal comfort mean (p-value = 0.26).

For data analysis from mixed-mode buildings operating under natural ventilation, 368 and 510 votes from women and men, respectively, were included. Under these conditions, significant differences were found in thermal sensations, preferences and comfort (p-values < 0.001) for each gender. No statistically significant gender differences were found for thermal acceptability (p-value = 0.44). Table 6 shows mean results for variables associated with thermal perception, separated by gender for each type of building and operation mode.

Table 6. Means of thermal perception variables organised for each type of building, operation mode and gender.

Type of Building (Operation Mode)	Thermal Sensation		Thermal Preference		Thermal Acceptability		Thermal Comfort	
	Women	Men	Women	Men	Women	Men	Women	Men
Fully air-conditioned	−0.32	−0.07	−0.16	0.15	0.01	0.03	0.08	0.11
Mixed-mode	−0.10	0.14	−0.06	0.12	0.05	0.05	0.12	0.17
Mixed-mode (air-conditioned)	−0.12	0.07	−0.05	0.13	0.08	0.04	0.17	0.14
Mixed-mode (naturally ventilated)	0.02	0.25	0.02	0.17	0.04	0.05	0.06	0.16

Significant differences between male and female thermal sensations were detected for all types of buildings and modes of operation studied. Such differences were also found in studies conducted in Doha, Qatar and Chennai, India, but not in data from studies performed in Tokyo, Japan and Hyderabad, India [30]. Another research from India also found a significant gender effect for subjective responses regarding the thermal environment of offices [2], corroborating the results of this study.

3.4. Gender and Thermal Comfort Temperatures

According to the Griffiths method and through a general data analysis, comfort temperatures were estimated as 24.2 and 23.5 °C for women and men, respectively. It is noted that the thermal comfort temperature for females is 0.7 °C higher than for males, and this difference is statistically significant.

Assessing data from the fully air-conditioned building, the comfort temperature estimated for females was significantly higher (24.2 °C) than that for males (23.4 °C). Statistical differences between comfort temperatures for males and females were also found when analysing data from mixed-mode buildings. For these buildings, the women's thermal comfort temperature was 24.1 °C, while the men's one was 23.5 °C.

Regarding data from mixed-mode buildings operating under air-conditioning, significant differences were also detected between the thermal comfort temperatures for each gender. Temperatures were estimated as 24.7 °C for females and 23.9 °C for males.

Data analysis from mixed-mode buildings operating under natural ventilation resulted in comfort temperatures of 23.6 °C for women and 22.5 °C for men. The Mann–Whitney test indicates that this difference is statistically significant. Table 7 shows the thermal comfort temperatures estimated for each type of buildings and mode of operation analysed.

Table 7. Thermal comfort temperatures according to gender and Mann–Whitney test statistics.

Type of Building (Operation Mode)	Thermal Comfort Temperature (°C)		Test Statistics (U)	*p*-Value
	Female	Male		
General analysis	24.2	23.5	8,685,061	<0.001
Central air-conditioned	24.2	23.4	644,480	<0.001
Mixed-mode	24.1	23.5	4,534,209	<0.001
Mixed-mode (air-conditioned)	24.7	23.9	879,809	<0.001
Mixed-mode (naturally ventilated)	23.8	23.1	1,459,018	<0.001

The thermal comfort temperatures estimated in this study were lower than those found by research studies performed in China and India [33,50], countries where comfort temperatures exceeded 25 °C. As found in this paper, statistically significant gender differences in thermal comfort temperatures were detected in India [30,50]. Furthermore, in China [33,34] and India [30,50], the female thermal comfort temperatures were higher than the male ones. In Doha, Qatar, significantly different thermal comfort temperatures for each gender and more similar to this study were obtained [30]. However, in Qatar, the male thermal comfort temperature was higher than the female one, diverging from the results presented in this study. In Tokyo, however, no statistical differences were detected between male and female thermal comfort temperatures [30].

3.5. Gender and Air Quality

As shown in Figure 4, the percentage of votes considering a satisfactory air quality was higher for males than for females in all buildings. Especially in the fully air-conditioned building, 34.1% of women and 65.3% of men were satisfied with the air quality. In mixed-mode buildings, there was a similar distribution of votes for air quality problems between females and males. However, in the fully air-conditioned building, the frequency of votes indicating "Air is not clean" and "Air is odorous" as a problem was more significant for women (between 6.8% and 50.0%) than for men (between 3.3% and 21.2%). On the other hand, in mixed-mode buildings there was a similar distribution of votes for air quality problems between females and males.

A study in an office building mainly operating under air-conditioning also observed that women were predominantly dissatisfied with air quality compared to men [51]. On the other hand, research that evaluated air-conditioned offices in Qatar, India and Japan identified a non-significant difference between genders in air quality satisfaction assessment [30].

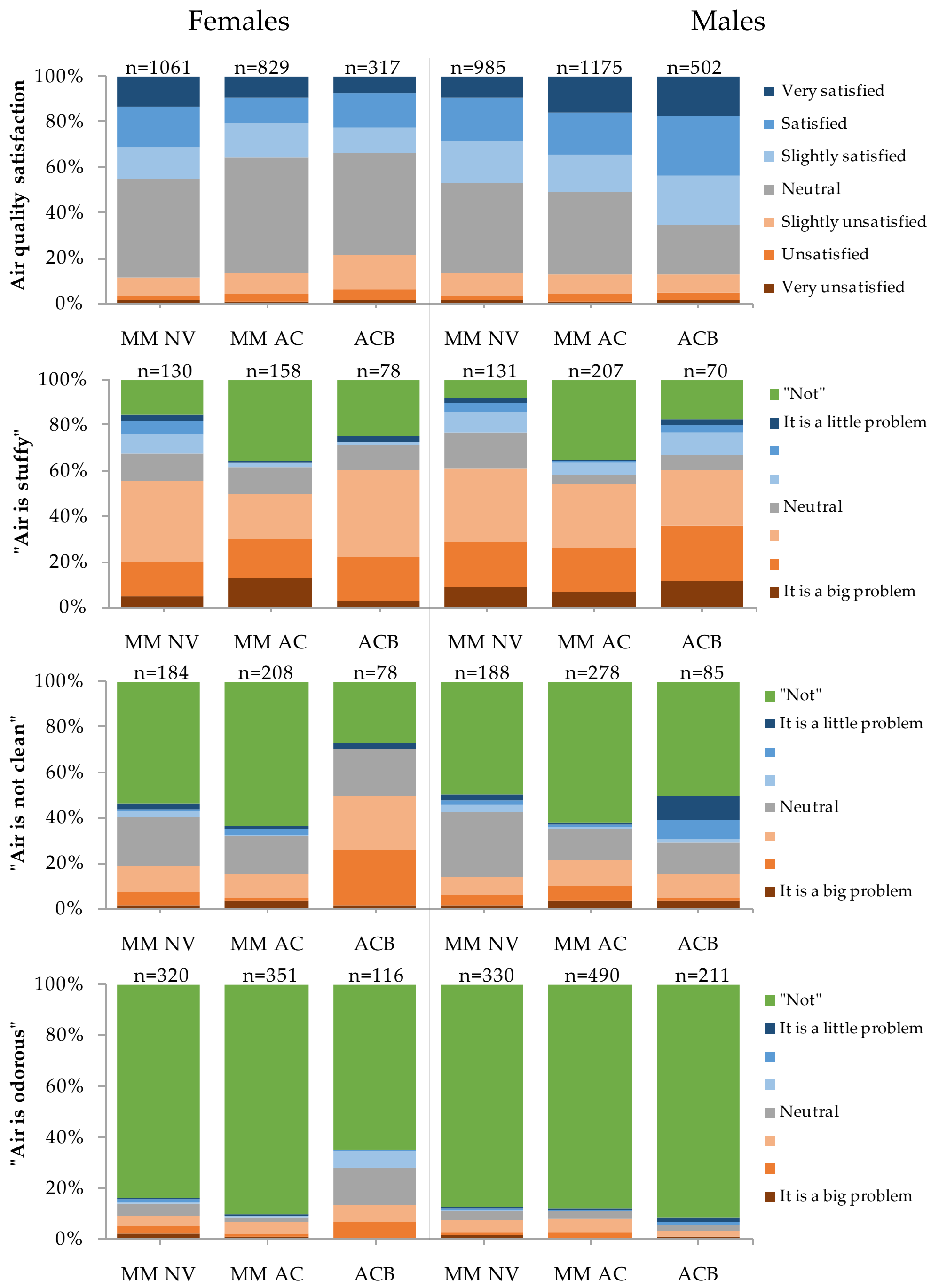

Figure 4. Distribution of air quality satisfaction and air quality problems votes for each building ventilation type according to gender. Note: MM NV stands for mixed-mode buildings operating under natural ventilation, MM AC stands for mixed-mode buildings operating under air-conditioning and ACB stands for fully air-conditioned building.

4. Conclusions

This paper reports results from field research carried out between 2014 and 2016 in three office buildings in Southern Brazil. More than 7500 votes on occupants' environmental perception were collected, including 3406 female votes (45%) and 4158 male votes (55%). Statistical descriptions were performed to compare perceptions on the thermal environment and air quality for each gender. After separating data by gender, regression analyses were conducted to investigate possible correlations between subjective and environmental variables. Hypothesis tests were carried out to assess a possible gender effect on thermal perception and thermal comfort in office rooms. Finally, females' and males' thermal comfort temperatures were estimated. Through this study, it was possible to conclude that:

1. Most men and women were in thermal neutrality or felt slightly warm/cool, preferring no changes in the environmental conditions;
2. Women felt colder compared to men in all building types and operating modes;
3. Women tended to present higher thermal comfort and acceptability in mixed-mode buildings;
4. There was a tendency for men to present higher thermal acceptability and comfort in fully air-conditioned buildings;
5. Increasing air temperature tended to increase not only thermal sensation but also thermal preference of men and women;
6. Women tended to feel the air slightly drier than men when air-conditioners were turned on;
7. When the rooms were naturally ventilated, humidity acceptability was higher for women than for men;
8. Weak but significant correlations were obtained between air velocity and air-movement sensation for the fully air-conditioned building. Positive and negative correlations were found for females and males, respectively;
9. Under similar environmental, metabolic and clothing conditions, statistically significant gender differences were observed for thermal sensation and thermal preference variables in the fully air-conditioned building;
10. For mixed-mode buildings operating under air-conditioning, there were significant gender differences in thermal sensation, preference and acceptability. In these buildings, females tended to feel slightly cooler (preferring a warmer environment), and men felt slightly warmer (preferring a cooler environment);
11. For mixed-mode buildings operating under natural ventilation, statistical gender differences were observed for thermal sensation, thermal preference and thermal comfort. In this mode of operation, women presented a mean thermal sensation closer to neutral and men, a mean thermal sensation more distant from neutrality compared to results obtained in other buildings operating under air-conditioning;
12. Statistical gender differences were detected for thermal comfort temperatures calculated for all assessed buildings and operation modes. Female thermal comfort temperatures were significantly higher than male ones;
13. For all building types considered, the percentage of males' votes considering satisfactory air quality was higher than the females' percentage. This finding suggests that women tend to be more sensitive regarding air quality.

Due to the possible existence of a gender effect on users' thermal and air quality perception in office rooms, engineers and architects should seek to design buildings that reduce this effect. For mixed-mode buildings operating under natural ventilation, the difference between thermal comfort temperatures for each gender was lower than the temperature differences found in the other cases. Using natural ventilation may be a strategy to reduce differences between females' and males' thermal comfort temperatures, as well as the energy consumption of the building. Another interesting strategy to enhance users' individual comfort, including both males and females, is the use of personalised environmental control systems (PECS) that allow individual control of people's surroundings, e.g., the use of small portable fans or heaters, and the use of blinds or shutters on windows for local airflow regulation.

Author Contributions: Conceptualisation, J.K.M., C.C.d.O. and R.F.R.; data curation, J.K.M., C.C.d.O. and R.F.R.; formal analysis, J.K.M., C.C.d.O. and R.F.R.; investigation, J.K.M.; methodology, J.K.M., C.C.d.O. and R.F.R.; project administration, R.F.R.; supervision, E.G. and R.F.R.; visualisation, J.K.M.; writing—original draft, J.K.M. and C.C.d.O.; writing—review and editing, J.K.M., C.C.d.O., E.G. and R.F.R. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financed in part by the *Coordenação de Aperfeiçoamento de Pessoal de NívelSuperior*—Brazil (CAPES)—Finance Code 001. The authors would like to thank the Brazilian National Council for Scientific and Technological Development (CNPq) for the financial support.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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