Exploring the Brazilian Thermal Comfort Database: an overview on the main contributions

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Abstract: Significant data from thermal comfort studies conducted in indoor built environment have been included in databases worldwide, e.g. the ASHRAE Global Thermal Comfort Database II, where Brazil holds a relevant position. The records include a total of 10,925 thermal comfort votes, coming from field studies mainly conducted in offices and schools. Thus, this paper aims to present the database, describing its characteristics and main results from a preliminary analysis. The method was based on the standardization and treatment of raw data from field studies, and some analysis of thermal perception responses and environmental variables were performed. The results highlighted some important variations in thermal perception among people from different climates in Brazilian territory, which is also influenced by the current ventilation system mode. People from Brazilian tropical climates showed a neutral thermal sensation balance close to 27.4 °C of mean operative temperature; meanwhile, those from subtropical climates were close to 24.4 °C. The overall thermal preference tended to cooler than neutral, particularly in naturally ventilated environments. The contributions of this investigation are mainly related to the gaps identified in the database, such as limited climate types and building typologies. Thus, the database expansion would provide valuable information to be analysed and further incorporated in the Brazilian Standard.

Keywords: Indoor thermal comfort, Brazilian thermal comfort database, Field studies.

1. Introduction

In thermal comfort studies, significant data from field investigations conducted in indoor built environment have been included in databases worldwide. In countries with large territorial extension, diverse climatic characteristics and various cultural aspects, there is a concern about how those parameters would influence people's thermal perception in occupied spaces. Thus, increasing the number of representative thermal comfort data from different regions has become a key point to the discussion and comparison of the results about occupants' thermal perception and related behaviours.

The main initiatives of documenting human thermal perception through "right-here-right-now" subjective evaluation and the related thermal environmental variables by means of field measurements are the ASHRAE Global Thermal Comfort Databases (De Dear, Brager and Cooper, 1997; De Dear *et al.*, 2016; Földváry Ličina *et al.*, 2018). The ASHRAE II Database added approximately 82,000 new sets of data collected until 2015 (Földváry Ličina *et al.*, 2018), expanding the global database to a number close to 108,000 votes (Databases I and II together). The countries with the biggest amount of thermal comfort data in current ASHRAE II Database are India (n = 16,110), USA (n = 8,546) and China (n = 8,235).

Brazil holds a relevant position in the ASHRAE II Database, as it is the fourth country in terms of data amount (n = 7,390). It is also the only representing South America in the global database so far. The need to document and explore the results set of this Brazilian data has motivated the creation of project focused in a national database in 2014, entitled "Brazilian Thermal Comfort Database". The Brazilian Database is still under construction and has added new data from field studies performed after 2015, which are not included in ASHRAE Database II.

The discussion of the main results, gaps and contribution of the current Brazilian database is the main subject of the present work. The raw data from field investigations were treated and standardized and some analysis related to thermal perception responses and indoor environmental variables were performed. It is expected that the future efforts regarding thermal comfort field evidence in Brazil may be pointed out based on the characterisation and the preliminary results from Brazilian database.

2. Methods

The Brazilian thermal comfort database[1] is a set of information related to the indoor thermal environment (physical variables measured) and the occupants' characterization and thermal perception. The data collected came from field studies conducted in indoor environments during their daily occupation – "real" environments with occupants performing their habitual activities.

For the time being, the documented data was obtained through field studies in universities classrooms and offices. This kind of environment usually guarantees that a considerable number of subjects have a similar profile and were using the same space at the same metabolic rate. According to the international measurement protocols recurrent in base surveys (De Dear, Brager and Cooper, 1997; De Dear and Brager, 1998; ASHRAE, 2010), the physical variables related to the indoor thermal environment (air temperature, mean radiant temperature, relative humidity and air velocity) should be recorded by appropriated and previously calibrated instruments, while the subjective responses from the occupants should be documented through questionnaires. The methods adopted in the field investigations must be in accordance with proposed standards by the project (which can be accessed in the project link[1] below). The thermal comfort field investigations whose data were included in the database are classified as Class II from De Dear, Brager and Cooper (De Dear, Brager and Cooper, 1997), since the measurements of indoor environmental variables were performed at a single measurement height. Regarding the subjective information, personal anthropometric characteristics such as gender, age, weight and height were filled in by the buildings' occupants.

Thus, the metabolic rate and the clothing insulation were estimated according to the auxiliary tables of ASHRAE 55 (2017) standard. The occupants were requested to address their sensation, preference and acceptability related to the current thermal environment and air movement (right-here-right-now questionnaires). The researchers were aware of possible changes in activity and/or clothing from the occupants during the field investigations, as well as the monitoring of environmental controls (air-conditioning, fans, windows, doors etc.) available for thermal adaptation. Particularities of methodological procedures adopted in each field study can be found in detail by assessing the references in Table 1.

[1] Access link: http://www.labeee.ufsc.br/projetos/base-brasileira-de-dados-em-conforto-termico (Accessed: 12 December 2019)

Table 1. Brazilian thermal comfort field studies in added in the national database

Title / Portuguese (English) – available link	**Reference Author (year)**	**n data**
Análise dos níveis de conforto térmico em um edifício de escritórios na cidade de Maringá (Analysis of thermal comfort levels in an office building in the city of Maringá) - http://www.labeee.ufsc.br/node/211	**Gomes** (2003)	**567**
Aceitabilidade do movimento do ar e conforto térmico em climas quentes e úmidos (Indoor air movement acceptability and thermal confort in hot-humid climates) - http://www.labeee.ufsc.br/node/156	**Cândido** (2010)	**2,075**
Condições de conforto térmico e aceitabilidade da velocidade do ar em salas de aula com ventiladores de teto para o clima de Florianópolis/SC (Thermal comfort conditions and acceptability of air speed in classrooms with ceiling fans in the climate of Florianópolis/SC) - http://www.labeee.ufsc.br/node/290	**De Vecchi** (2011)	**2,507**
Avaliação de conforto térmico em edificações comerciais que operam sob sistemas mistos de condicionamento ambiental em clima temperado e úmido (Thermal comfort evaluation in commercial buildings operating under mixed-mode conditioning systems in temperate and humid climate) - http://www.labeee.ufsc.br/node/657	**De Vecchi** (2015)	**2,688**
Conforto térmico em ambientes de escritórios naturalmente ventilados: pesquisa de campo na cidade de Florianópolis por meio da abordagem adaptativa (Thermal comfort in naturally ventilated office environments: field research in the city of Florianopolis through the adaptive approach) - https://repositorio.ufsc.br/xmlui/handle/123456789/156885	**Pires** (2015)	**455**
Análise das condições de conforto térmico no clima quente e úmido de São Luís (MA): estudos de campo em salas de aula naturalmente ventiladas e climatizadas (Analysis of thermal comfort conditions in the hot and humid climate of São Luís (MA): field studies in naturally ventilated and air-conditioned classrooms) - http://www.labeee.ufsc.br/node/734	**Buonocore** (2018)	**2,680**
Potencial de incremento do conforto térmico dos usuários em escritórios com o uso de ventiladores de mesa durante o verão (Potential for increasing users' thermal comfort in offices through the use of table fans during the summer) - http://www.labeee.ufsc.br/node/739	**André** (2019)	**383**

2.1. Standardization and treatment of raw data

In the preparation of the unified database, raw data from field studies conducted in Brazil were grouped and coded. An electronic spreadsheet model for data standardization and other field surveys' guidelines can be found on the project's website. The climate characteristics, occupants' information and thermal assessment, indoor and outdoor environmental variables should be registered by the researchers and submitted in a spreadsheet.

In this standardized spreadsheet, each row must correspond to a user's point-in-time perception response and the total number of rows is the total of data records (n). The indoor operative temperature was calculated for the entire sample based on the recommendations of ASHRAE 55 (2017). The outdoor variables (air temperature and relative humidity) were obtained through the meteorological station closest to the survey site. Finally, a procedure for excluding discrepant data was adopted in the full spreadsheet, according to the criteria as follows:

- Simultaneous "unacceptable" and "comfortable" votes for the thermal environment;

- Simultaneous “unacceptable” vote for the thermal environment and “no change” vote for the thermal preference;
- Simultaneous “uncomfortable” vote for the thermal environment and “no change” vote for the thermal preference;
- Simultaneous “unacceptable” and “no change” votes for the current air movement.

A total of 175 votes (1.6% of the total 11100 raw data) fell into at least one of the conditions mentioned above. Thus, those votes were excluded, and the resulting sample is composed of 10,925 votes. The Welch's T-Test (Spearman's method for non-normal distribution samples and categorical variables) and the Mann-Whitney Test were adopted in the comparison of unpaired samples’ means and medians. The hypothesis tests were performed in R programming language through RStudio interface. The significance level adopted in the tests was 5% (p-value < 0.05).

3. Results

3.1. Brazilian database characteristics

The database currently has 10,925 valid votes, which are distributed in the cities as illustrated in Figure 1. Most of the data was collected in the city of Florianopolis (Southern region of Brazil), with 5,704 votes added. In the Northeast region – São Luis and Maceio cities – more than 4,000 votes were computed. According to the Koppën-Geiger climate classification (Kottek *et al.*, 2006), the group of data correspond to three existing climate types in Brazil: Aw, Am and Cfa (Figure 1).

Among the data from the Cfa climate in Brazilian database, there is a predominance of winter and autumn seasons, which corresponded to 71% of the data. In tropical climates, there was a balanced amount of data in the two seasons: 45% of the votes were collected during the rainy (or wet) season, and 55% were reunited during the dry season.

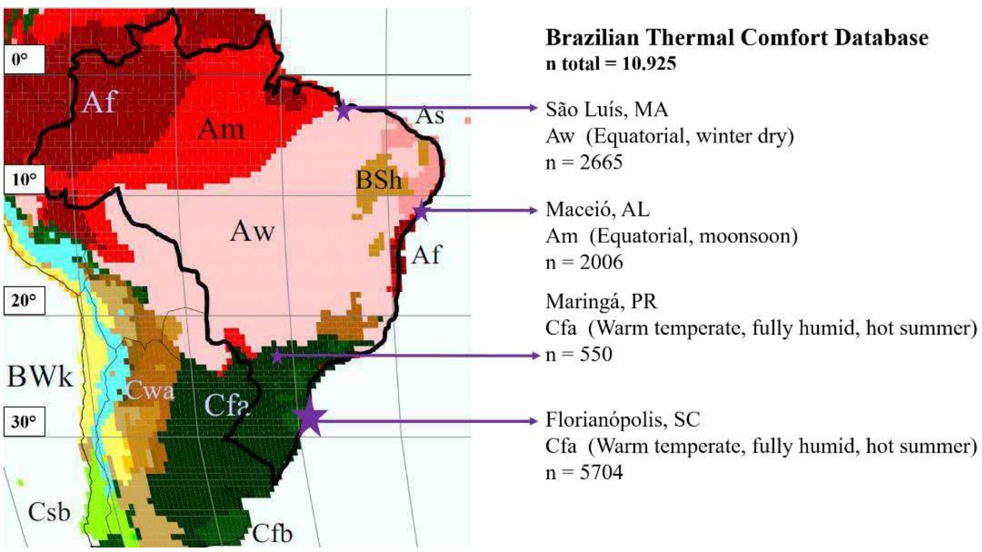

Figure 1. Characterization of Brazilian Database and Koppën-Geiger climate classification. Source: adapted from Kottek et al (Kottek *et al.*, 2006)

From Figure 1 it is possible to identify all Brazilian climate types and the recorded data from each city. There are three main climates, divided into nine specific climate types as follows: equatorial/tropical (Af, Am, As and Aw), arid (BSh) and warm temperate (Cfa, Cfb, Cwa, Cwb). The database is composed of numerous sets of data from tropical (A) and temperate (C) climates, which are predominant in Brazilian territory. Some of the specific Koppen climate types remained out of the thermal comfort field campaigns so far, particularly the drier climates (BSh, Cwa and Cwb).

The room cooling systems and the operation modes are shown in Figure 2. The spaces assessed in the field campaigns were mainly based on naturally ventilated (NV – 37%) or mixed-mode (MM – 40%); MM buildings could be operated with air conditioning and/or natural ventilation. The other 23% of the data were collected in constantly air conditioned (AC) environments. The operation modes verified throughout the field investigations were air conditioning (AC), natural ventilation (NV), natural ventilation with fans simultaneously (NV with fans), only fans operating (fans only), and air conditioning with fans simultaneously (AC with fans). During the occupancy time, natural ventilation (NV) was the predominant operation mode in MM environments (≅32%). There was a significant number of responses occurring with fans on, particularly AC with fans (≅28%). The "Fans only" group in MM (≅24%) represent the moments of only fans operating while windows were closed – see De Vecchi (De Vecchi, 2011) for more details.

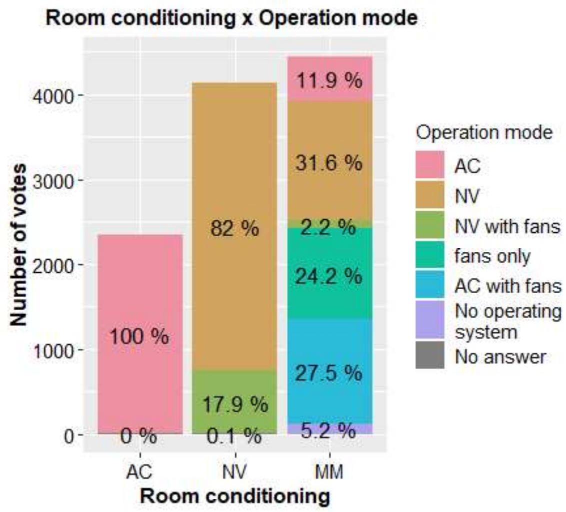

Figure 2. Number of votes obtained in each room conditioning type and percentages of each operation mode

Regarding the use of the spaces in which field studies were carried out, 62% corresponded to educational buildings (undergraduate classrooms – CR – and design rooms – DR), while 38% of the votes were collected in offices (OF). In Figure 3, the groups with ages under 20 years and between 21-30 years were predominant, noticeably in educational rooms. Regarding the occupants' gender, 60% are females and 40%, males. Females' participations predominated in educational spaces, while in offices the percentages of males and females were very similar.

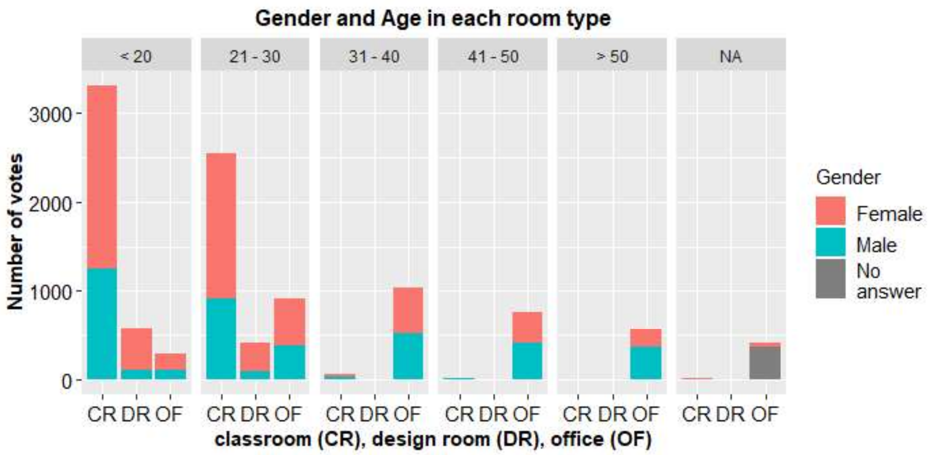

Figure 3. Occupants' gender and age in each room type

The maximum, median and minimum recorded values of body mass index (BMI), metabolic rate and clothing insulation, as well as 1st and 3rd interquartile intervals, are represented per room type in Figure 4. BMI's distribution was similar in educational spaces and presented a higher median value in the office rooms' sample (Figure 4a). In general, the occupants presented a normal nutrition level – between 18.5 and 25.0 kg/m² (*Body Mass Index - BMI*, 2019). The metabolic rate distribution (Figure 4b) presented small variation among the room type samples due to the predominant sedentary activities performed (overall mean value = 1.1 met and overall standard deviation of 0.1 met); in the design rooms (DR), occupants average metabolic rate was 1.2 met.

Regarding the total clothing insulation, variations among seasons and room types were identified. In general, there was a predominance of users with light clothing, such as trousers and short-sleeved shirt (0.5 clo). The clothing insulation values were mainly higher than 0.5 clo in winter, while in the other seasons, they usually remained below 0.5 clo. According to Figure 4c, clothing insulation values varied the most in offices (from 0.2 to 1.5 clo). The median value was the lowest in classrooms and highest in offices, probably because of the dress code usually adopted in each room type.

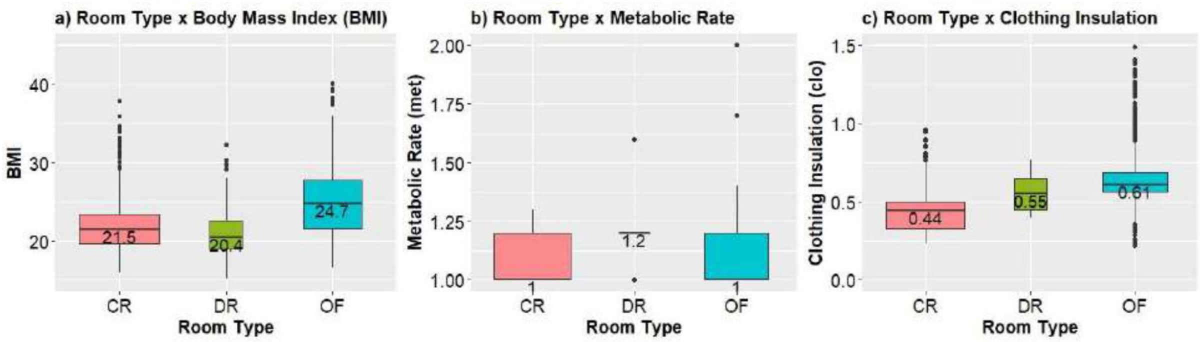

Figure 4. Occupants' BMI (a), metabolic rate (b) and clothing insulation (c) in each room type

Regarding the indoor environmental variables (Table 2), there was a large variation between minimum and maximum values from the whole database sample. However, the mean and the median values were close, and the standard deviation values were little. The air velocity values registered were predominantly low (mean value = 0.26 m/s) although some higher values were measured (standard deviation = 0.29 and maximum value above 4 m/s). Air velocity values above 2 m/s were verified in 37% of the overall sample, mainly in spaces with fans on.

Table 2. Summary of indoor environmental variables for the whole database sample

Values	Ta (°C)	RH (%)	Va (m/s)	To (°C)
Maximum	32.9	89	4.17	32.9
Median	25.8	64	0.18	25.7
Mean	25.9	64	0.26	25.9
SD (+/-)	2.9	11	0.29	2.8
Minimum	15.4	23	0.00	16.6

The indoor environmental conditions analysed are strongly related to the climates in which field surveys were carried out, as shown in Figure 5. A smaller variation in the operative temperature from tropical climates (Am and Aw in Figure 5a) was observed, while the temperature amplitude recorded in the subtropical climate (Cfa in Figure 5a) was higher. However, 50% of the recorded operative temperature values were between 25-30 °C in Am/Aw climates and between 23-26.5 °C in Cfa. The average operative temperature in tropical climates was 27.6 °C, and in the subtropical climate was 24.6 °C.

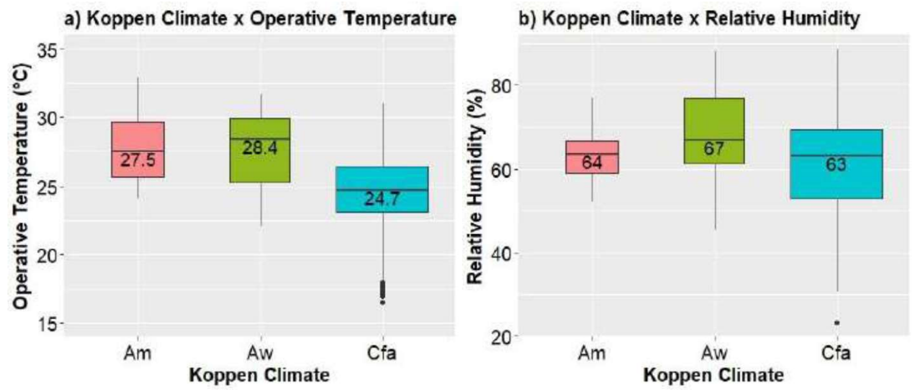

Figure 5. Indoor operative temperature (a) and relative humidity (b) registered in each Koppen climate type

Although the Aw climate typically presents an annual rainfall index lower than that from Am climate, the relative humidity mean, median and interquartile values from the Aw sample were higher than those from the Am sample (Figure 5b). As expected, larger variations in indoor relative humidity were verified in the Cfa climate, while in tropical climates at least 50% of the recorded values were above 60%. The differences between the median values of operative temperature and relative humidity in each Koppen climate sample (Am, Aw and Cfa) were statistically significant (p-value < 0.05).

3.2. Brazilian thermal perception

The occupants' thermal sensation vote (TSV) as a function of indoor operative temperature and in different Koppen climates is illustrated in Figure 6. The values in red represent the mean operative temperatures in each TSV sample. The average temperatures that corresponded to each thermal sensation in Cfa climate were lower than the average temperatures in tropical climates. Neutral votes (0) were achieved when mean operative temperature was around 24 °C in Cfa and 27 °C in Am/w. For instance, a mean operative temperature around 27° C resulted in a neutral thermal sensation (0) in tropical climates and a warm thermal sensation (+2) in the subtropical climate.

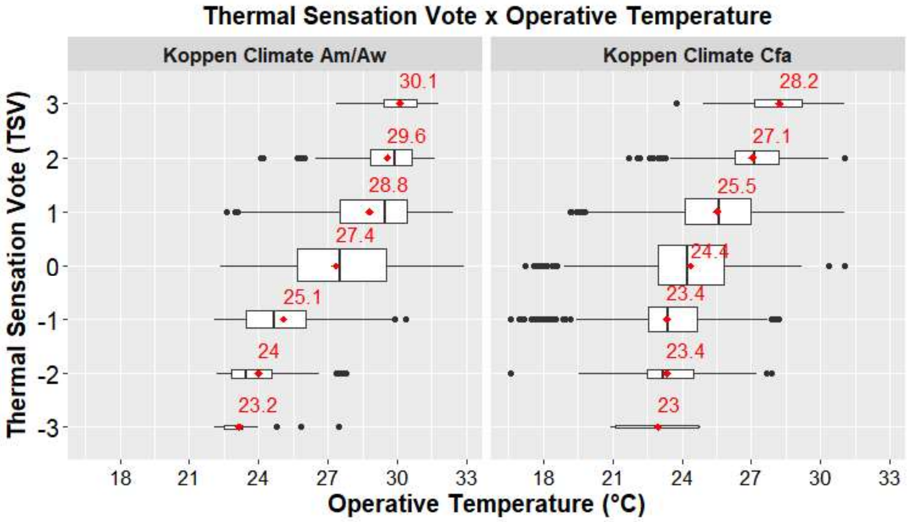

Figure 6. Thermal Sensation Vote's distribution in each Koppen climate

Different thermal responses regarding warmer and cooler sensations were observed among the analysed climates. In the cold side of the scale, a smaller operative temperature variation between the slightly cool (-1), cool (-2) and cold (-3) votes was observed in Cfa sample, if compared to the tropical (Am/w) samples. For instance, there was a difference of 1 °C between the average neutral (0) and slightly cold (-1) samples' operative temperature in Cfa climate, while in tropical climates it was equal to 2.3 °C. In the warm side of the scale, the opposite situation has occurred. The mean operative temperature required to feel warmer in tropical climates was higher than the one required in the subtropical climate.

Occupants' thermal acceptability was also different among the addressed climates, as depicted in Figure 7. In general, people from tropical climates (Am/w) expressed less dissatisfaction regarding the coldest thermal sensations, if compared to people from subtropical climate (Cfa). Thermal acceptability in the "warm" TSV (+2) was surprisingly high among the occupants in Am/w climates. Those results suggest distinct aspirations from people living in different Brazilian regions. The inhabitants of tropical climates expressed different acceptability levels to warm and cool thermal sensations, positively to the cooler and negatively to the warmer ones. In subtropical climate, the dissatisfaction levels with warm and cool TSV's were similar.

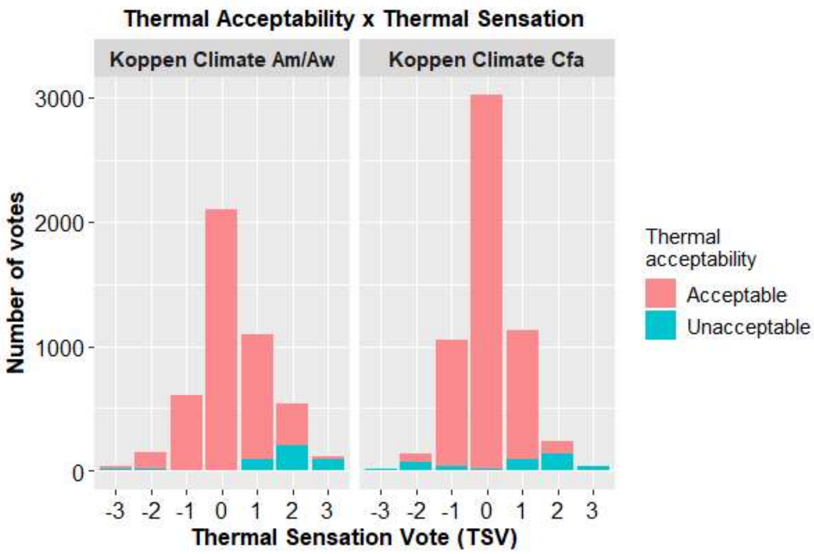

Figure 7. TAV x TSV in each Koppen climate

The “probit” percentage of dissatisfied people was addressed in a comparison between two sets of samples from the ASHRAE II Database, as shown in Figure 8. The data was filtered and limited to the humid subtropical climate (Cfa), as it is the only Brazilian climate type appearing in the interface so far. Thus, the sample in blue is composed of Brazilian data, and the sample in pink represents the World data (including Brazil). When evaluating the dissatisfaction with warm (+2) and cool (-2) TSVs, there is a noticeable difference between the samples. The probability of dissatisfaction in the Brazilian sample was higher for warmer thermal sensations (more than 50%), while it was higher for cooler thermal sensations in the World sample. The addition of tropical climate data from Brazil in the global database might accentuate that difference, since high unacceptability with the warmer thermal sensations was detected in the “A” climate sample.

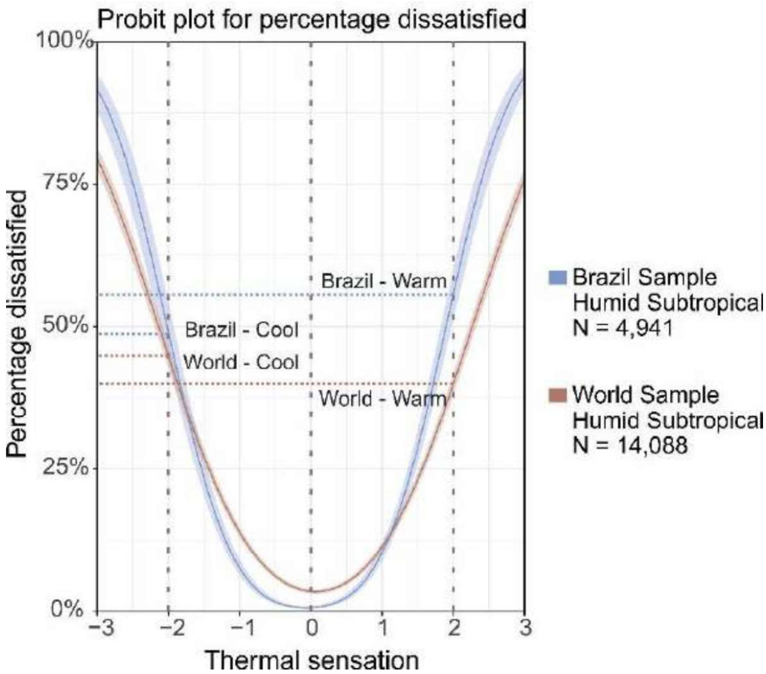

Figure 8. Comparison between Brazil and World samples in the ASHRAE II Database. Source: adapted from *ASHRAE Global Thermal Comfort Database II Visualization* (2018)

Occupants’ thermal preference was assessed in Figure 9. The thermal preference vote was collected in 83% of the data from Brazilian database (n=9095). By analysing these data, it was noticed that the relation between thermal sensation and thermal preference was significantly influenced by the conditioning mode of the environment. In general, there was a higher number of users feeling uncomfortable by cold in air-conditioned environments (AC), when compared to naturally ventilated environments (NV) – the percentage of users who preferred the environment to be warmer in AC was higher than in NV.

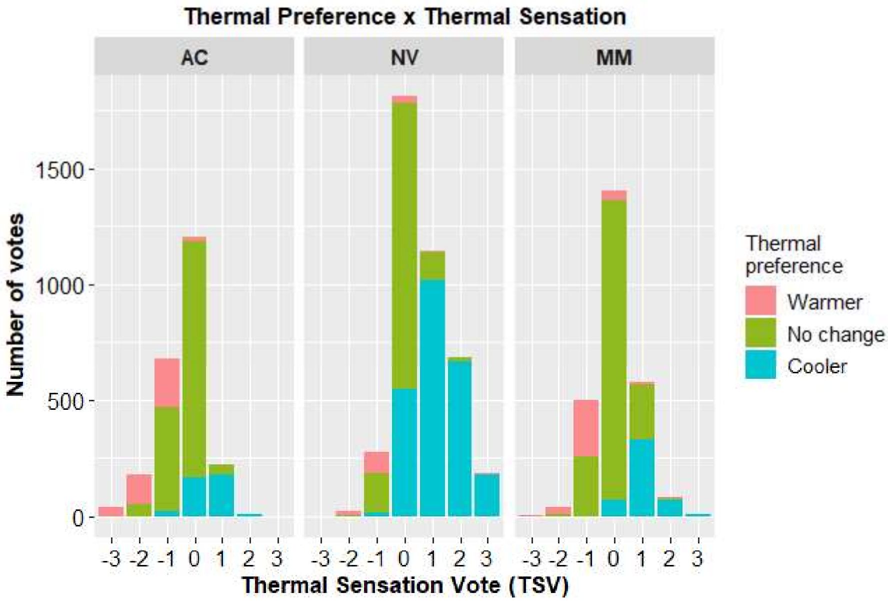

Figure 9. TPV x TSV in each room conditioning available

The thermal preference votes of subjects who declared to be neutral presented variations among the cooling operation modes. The overall preference under the neutral votes was “no change”, followed by “cooler”. This was verified particularly in NV environments – the preference to be cooler was more evident if compared to MM or AC environments. However, among the “slightly warm” TSV sample (+1), the predominant preference was to be cooler in all operation modes.

4. Discussion

The preliminary analysis from thermal perceptions in Brazilian database highlighted an overall preference for cooler environments and overall high acceptability levels in climates characterized by elevated air temperature and humidity. However, significant influence of climate particularities and cooling conditioning modes on thermal perception votes was also verified. Therefore, it can be assumed that thermal comfort requirements are different between people from tropical and subtropical climates (Figure 6 and Figure 7), and between occupants from air-conditioned and naturally ventilated spaces (Figure 9). Additionally, a preliminary comparison between Brazil and World samples in the ASHRAE Database II (Figure 8) highlighted a particularity of perception from the Brazilian sample available in the global database so far. The database has joined up a significant number of votes to corroborate this point. Nevertheless, to which extent the added data properly represents (or no) the diverse climatic and cultural contexts existing in Brazil is a question that must be considered when new efforts of thermal comfort field studies are idealised.

The explored data was collected in three Koppen-Geiger climate classifications that cover a significant extent of the national territory and represent the main climate types – equatorial/tropical and temperate/subtropical. As shown in Table 2 and Figure 5, the conditions of indoor temperature presented some variations within the database, but the mean and median values of relative humidity were close among the studied climates (between 60-70%). Some areas of the Brazilian territory are characterised by drier and colder climate conditions, which are still underexplored. Moreover, the preliminary analysis presented must advance into a more detailed assessment between the environmental variables measured and the perception votes collected, as the developed model in the ASHRAE Global Database II (Földváry Ličina *et al.*, 2018). Relative humidity and air velocity values may be assessed in conjunction with an indoor temperature parameter in future investigations with the whole Brazilian database as matter.

The room types currently addressed are restricted to undergraduate rooms (educational use) and offices. Thus, some occupant characteristics such as activity level and predominant age may present little variation among the samples, as shown in Figure 4b. Thermal comfort studies in the Brazilian residential sector were recently conducted, focusing on occupant behaviour related to adaptive resources such as the air-conditioning usage. The future data to be added in the national database may be applied in thermal preference and comfort assessments within the full amount of data. Additionally, assessing the thermal comfort issue in diverse building types would contribute to reunite variated occupant characteristics regarding social and economic profiles found in the national territory. No questions about personal income have been included in the questionnaires so far.

The consolidation of the Brazilian thermal comfort database and its related analysis are important requirements to the National Standard, which must be continuously revised and improved as already verified by previous studies such as Candido *et al.* (2010), and the findings of De Vecchi *et al.* (2015). The last cited publication suggested a clothing adjustment zone to be incorporated in the adaptive zone of the proposed Brazilian Standard NBR 16401-2. From the preliminary results, thermal comfort evaluation methods in buildings with diverse conditioning modes must be distinguished since occupants' thermal perception in AC, NV and MM buildings has varied. The applicability of the methods for determining acceptable thermal environments should be extended to the personal and physical conditions found in the database sample; particularly the clothing insulation values – a great amount of them was below 0.5 clo in classrooms.

5. Conclusion

The present work aimed to depict the Brazilian thermal comfort database by describing its characteristics and the main thermal perception results from a preliminary analysis. The database is being built up based on the standardization and treatment of raw data from field studies conducted in real occupancy spaces. The analysis performed so far has associated the main thermal perception responses and the respective measured environmental variables.

Based on the results of this paper, it can be concluded that the occupants' thermal perceptions within Brazil's territory presented relevant variations due to the influence of climate particularities and cooling conditioning modes. Brazil is a large and varied country in its geographical, climatic, social and economic dimensions, which must be considered in environmental assessments performed in occupied spaces. The main highlights from the preliminary results are as follows.

- People from tropical climates (Koppen's A classification) presented a neutral thermal sensation balance close to 27.4 °C of mean operative temperature, meanwhile those from subtropical climate (Koppen's C classification) were close to 24.4 °C. Occupants from tropical climates seems to be more tolerant to the warmest thermal sensations, once the mean operative temperature required to feel warmer in tropical climates was higher than the one required in the subtropical climate;
- Overall thermal acceptability was high, especially under warm and cool conditions in tropical climates. The former represented an undesired but acceptable situation, while the latter was generally acceptable in the occupants' assessment. Instead, people from subtropical climate expressed almost the same dissatisfaction with warm and cool conditions indoors, if compared to people from tropical climates;
- People from Brazilian humid subtropical climate (Cfa) tend to be more dissatisfied with the warmer thermal sensations, whilst the World sample from humid subtropical climate tend to be more dissatisfied with the cooler thermal sensations;
- Thermal Preference Vote's distribution has varied among the available conditioning mode (AC, NV and MM). The overall thermal preference tended to cooler than neutral, particularly in naturally ventilated environments, where occupants were more susceptible to hot discomfort. Conversely, some cold discomfort was detected noticeably in air-conditioned spaces.

Although the results gave an overview of the thermal perception in Brazilian buildings, some gaps were pointed out in the database characterisation. Therefore, to reunite representative evidence from field investigations, expanding the database is a current priority. The future studies on the subject can be classified in two: field survey campaigns considering the variability of climates and building typologies, which would enable the access to diverse occupants' profiles and characteristics; and comparisons between the sets of data corresponding to Brazilian and World databases, highlighting Brazil's particularities regarding the preferred environmental conditions, preferred cooling conditioning modes, air movement evaluation and overall acceptability/comfort perceptions.

6. References

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