MODELING OF URBAN BUS DRIVERS' THERMAL SENSATION AS A FUNCTION OF THE THERMAL COMFORT PARAMETERS

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Abstract

Research into thermal comfort in vehicle environments has been gaining prominence among researchers due to the impacts generated, which range from maintaining the thermal sensation of the occupants, to ensuring the satisfactory performance of drivers in terms of safety in traffic and in energy sustainability. With this background, this study aimed to evaluate the thermal comfort parameters that influence the thermal sensation of urban bus drivers. To this mean, the four environmental parameters in the cabins of urban buses were measured and the two personal parameters of three drivers of the same bus line were estimated, and the influences of these six parameters on the subjective thermal sensation were analyzed using the Ordinal Logistic Regression Models of the Generalized Linear Models methodology. The field survey was performed from September to December 2021 and over three daily trips, totaling 180 measurements of thermal conditions. As a result, both the Predicted Mean Vote index and the thermal sensation votes indicate that the environments of the bus drivers' cabins analyzed are, in general, within the scale of thermal discomfort by heat, with a predominance of the "Warm" class. Furthermore, the model adjustments converged on only three distinct models and they demonstrated that the thermal sensation was influenced by the environmental parameters, and not by the personal parameters. Finally, we concluded that the model that best fit to the sensation was that as a function of the air temperature, with a moderate explanatory ability due to the value of Pseudo $R^2 = 0.669$. In addition, the proportional chance curves of this model indicated the following air temperature ranges for the respective heat thermal discomfort classes: when ta < 28°C, the greater chances are in the choice of thermal neutrality and the other classes of thermal discomfort by cold that were not reached by this research, which were not achieved by this research; for 28°C ≤ ta ≤ 30°C the tendency is higher for a slightly warm sensation; for values in the range 30.5°C ≤ ta ≤ 32.5°C it is more natural that they opine on the heat scale; and for values of ta > 33°C the tendency is for conductors to feel extremely hot.

Keywords: thermal comfort, thermal sensation vote; bus drivers, public transport.

1. Introduction

The growth and expansion of cities have resulted in a large portion of people making use of public transport to commute. Among the existing means of public transportation, the buses are considered to be the most popular and most often used by people (NGUYEN-PHUOC et al., 2018a, 2018b; PRAKASH et al., 2014). Usually, the occupants of the vehicle, as in the case of passengers and workers of the bus itself, travel long distances spending a significant portion of their time within these environments (ALAHMER et al., 2011; CROITORU et al., 2015) and, in many cases, this time tends to increase due to intense traffic in large urban centers. Added to this fact, people and companies have sought ways to find better comfortable mobility, fuel reduction, safety of those involved, among other factors that have had an impact on the increased interest in thermal comfort research aimed at the vehicular environment (ALAHMER et al., 2011; CROITORU et al., 2015; DANCA; VARTIRES; DOGEANU, 2016).

According to Almeida, Xavier and Michaloski (2020), few studies aimed to access thermal comfort in urban buses cabins have been published and these studies (ASSUNCAO; JARDIM; DE MEDEIROS, 2014; ISMAIL et al., 2015b, 2015a) did not sufficiently represent all six relevant parameters used in the normalized thermal comfort model. In addition, these cited papers did not measure the thermal comfort parameters in the range of the Predicted Mean Vote – Predicted Percentage Dissatisfied (PMV – PPD) model, nor did they correlate them with the thermal sensation opinion of the drivers (ALMEIDA; XAVIER; MICHALOSKI, 2020).

The classic PMV – PPD model was developed by Fanger in 1970 in laboratory experiments (YAO; LI; LIU, 2009). With this model, it is possible to predict the mean response of the thermal sensation opinion of a large group of people exposed to the same environment (ALAHMER et al., 2011; PEETERS et al., 2009; RUPP; VÁSQUEZ; LAMBERTS, 2015), as well as the percentage of dissatisfied people with this environment (DJONGYANG; TCHINDA; NJOMO, 2010). According to Yao, Li and Liu (2009), Fanger's model was incorporated into ISO standards in the 1980s, and it is still the basis of ISO 7730 and ASHRAE 55 standards (RUPP; VÁSQUEZ; LAMBERTS, 2015).

The Fanger model is based on the determination of two indices in the assessment of thermal compliance of a given environment: the Predicted Mean Vote (PMV) index is the result of the combination of six parameters that are divided into four environmental and two personal parameters (ALMEIDA et al., 2020; PALA; OZ, 2015; SIMION; SOCACIU; UNGURESAN, 2016) and results in objective values, which can be related to the subjective scale of seven points of the thermal sensation votes listed in the ASHRAE - 55 and ISO 7730 standards (ASHRAE - 55, 2017; ISO 7730, 2005).

The environmental parameters are composed of the air temperature (AT), mean radiant temperature (MRT), air velocity (AV) and air relative humidity (RH), and the personal parameters relate to the clothing thermal insulation (Iclo) and the metabolic rate (M) (ALMEIDA et al., 2020; ENESCU, 2017; RUPP; VÁSQUEZ; LAMBERTS, 2015). The thermal sensation vote can be within a 7-point scale, (a single option can be chosen between -3, -2, -1, 0, +1, +2 and +3 and which corresponds respectively to the sensation classes “cold”, “cool”, “slightly cool”, “neutral”, “slightly warm”, “warm” and “hot” respectively (ASHRAE - 55, 2017; ISO 7730, 2005).

Given this context, this research aimed to relate the thermal sensation votes of the bus drivers with the thermal comfort parameters in their cabins. Thus, the following sections are intended to explain the methodology adopted by the field research, the results and the final considerations.

2. Methodology

This study is the result of a field research conducted in urban bus cabins in Brazil. The following subsections detail the studied environment, the data collection procedure and tools, and the data analysis methods.

2.1 Studied Environment

The field research employed as a sampling method the non-probabilistic technique. In this type of technique, the elements are included in the study without knowing their probabilities, because the sample is not previously statistically determined (SWEENEY; WILLIAMS; ANDERSON, 2013).

Therefore, the research was conducted for a 60-day period, from September to December 2021, in a transportation company that serves the public in the metropolitan region of João Pessoa, in Paraíba State, Brazil. The company provided a public transportation line with a population of four male drivers, and three other drivers who volunteered to participate in the research were included as samples. In addition, the available line was composed of 60 mandatory stops, distributed over 24 kilometers and with an average trip duration of 80 minutes.

Each driver was observed for 20 days and, during three daily trips; the environmental parameters (air temperature, mean radiant temperature, air velocity and air relative humidity) were measured and personal parameters (metabolic rate and clothing thermal insulation) were estimated and used as inputs for Fanger's Predicted Mean Vote index according to (ISO 7730, 2005). In addition, at the end of each trip, the subjective vote of the drivers' thermal sensation was questioned and their anthropometric characteristics (weight, age and height) were recorded.

2.2 Data Collection Procedure and Tools

The collection of data referring to the parameters, the subjective vote and the anthropometric characteristics was made by using two different equipment: a Comfortmeter Sensu® as shown in Figure 1, and an adapted research survey.

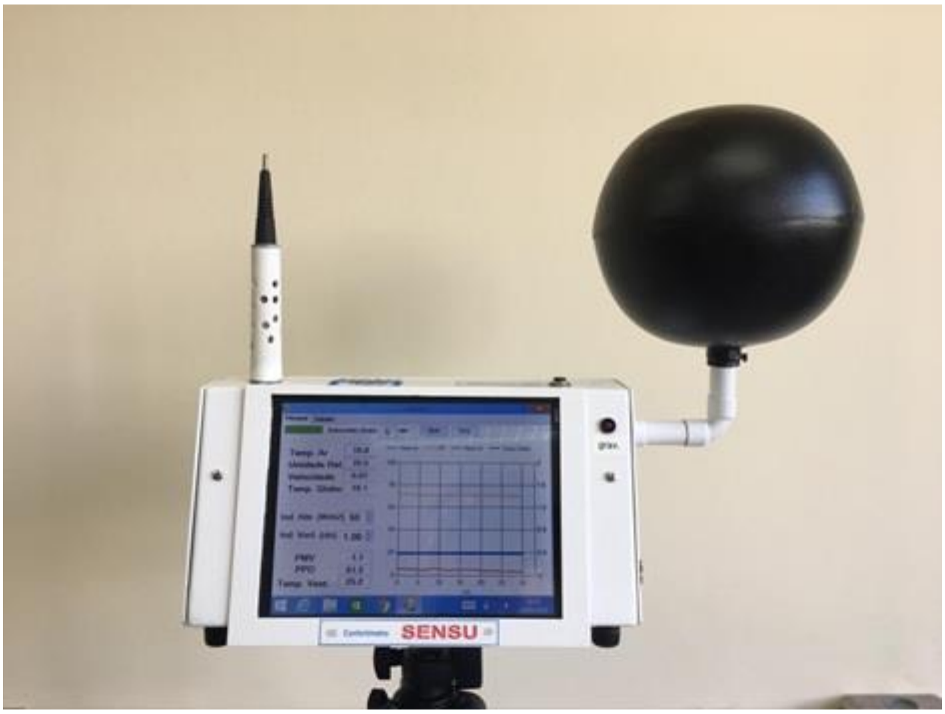
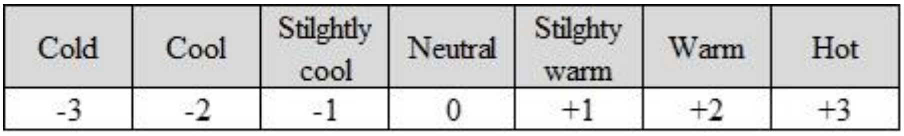


Figure 1. Comfortimeter Sensu® Equipment.

The equipment in Figure 1 is capable of measuring and storing values of air temperature, globe temperature, air velocity and air relative humidity. It was positioned in the drivers' cabins with the globe positioned at a height of 60 cm above the bus floor and recorded the variables with 1-minute intervals, for a total duration of 50 min, following the procedures of ISO 7726 (ISO 7726, 1998).

The survey, in addition to collecting information about the drivers' anthropometric data, was adapted from the ISO 9920, ISO 10551 and ASHRAE 55 standards (ASHRAE - 55, 2017; ISO 7730, 2005; ISO 9920, 2007) in order to assess the thermal sensation votes of the drivers at the end of the trips and describe what kind of clothing was used by them during the workday.

The classes and scale used to encode the thermal sensation vote can be seen in Figure 2.



Cold	Cool	Stilghtly cool	Neutral	Stilghty warm	Warm	Hot
-3	-2	-1	0	+1	+2	+3

Figure 2. Thermal sensation classes and scale.

At the end of each trip, the drivers were asked to mark a single option within the scale as shown in Figure 2. In addition, they were asked about what kind of clothing they were wearing and, with this data, the thermal insulation of the clothing was estimated according to ISO 9920 tables (ISO 9920, 2007).

Drivers' metabolic rates were estimated based on Equation 1.

$$M = Mt * \left(\frac{Adu.p}{Adu.a}\right) \qquad \text{(Eq. 1)}$$

Where:

M = metabolic rate (W/m2);

Mt = tabulated metabolic rate extracted from ISO 8996 (1990) (W/m2);

$A_{du.p}$ = Dubois area of a standard individual (height of 1.70 m and weight of 70 kg);

$A_{du.a}$ = Dubois area of the sample.

In general, the survey procedure in the buses' cabins was carried out during the 80 minutes of each trip and consisted of three stages: the initial stage had a duration of 20 minutes and consisted of positioning and acclimatizing the comfortmeter equipment; the second stage had a duration of 50 minutes and referred to the measurement of air temperature, globe temperature, air velocity and air relative humidity; the last step lasted for 10 minutes and was intended to answer the survey.

2.3 Data Analysis

Data analysis began with the tabulation of the data collected, which were organized in Microsoft Excel® student version spreadsheets. Subsequently, using the software itself, the mean radiant temperature was calculated and with the aid of the Thermal Comfort Tool, Fanger's Predicted Mean Vote index was calculated. Finally, a statistical analysis was performed.

The mean radiant temperature was calculated for each trip by using Equation 2.

$$t_{rm} = \left[\left(t_g + 273\right)^4 + 2.5 \times 10^8 \times {v_a}^{0.6} \times \left(t_g - t_a\right)\right]^{1/4} - 273 \qquad \text{(Eq. 2)}$$

where:

t_{rm} = mean radiant temperature (°C);

t_a = air temperature (°C);

t_g = globe temperature (ºC);

v_a = air velocity (m/s).

Equation 2 is present in ISO 7726 (ISO 7726, 1998) and it is used when the heat exchange coefficient by forced convection of the globe (HCG) is greater than natural convection, as was reported in all this research.

The PMV index was calculated individually by the Thermal Comfort Tool from the Center for the Built Environment (CBE) at the Berkeley University of California, which is available online and free of cost. With this tool it is possible to calculate different thermal comfort indices according to ASHRAE 55, ISO 7730 and EN 16798–1 standards (TARTARINI et al., 2020).

Statistical analysis was performed in two stages: descriptive and inferential. The description generated summarized information through tables and the plotting of illustrative graphs via Exploratory Data Analysis (COOPER; SCHINDLER, 2014).

Regarding the inferential analysis, conclusions were made about the population based on the investigated conditions of the sample (KING; ROSOPA; MINIUM, 2018). Therefore, this research used the Generalized Linear Models according to Hosmer JR, Lemeshow and Sturdivant (2013) and through Ordinal Logistic Regression models, based on Abreu, Siqueira and Caiaffa (2009), Harrell (2015) and Williams (2006), the drivers' thermal sensation vote was related to environmental and personal parameters.

3. Results

As previously reported in the methodological section, the field research took place for over 60 days, equally divided by the sample of three urban bus drivers. In addition, the environmental parameters of the bus drivers' cabins were measured over three daily trips, the drivers' personal parameters were estimated and, at the end of each trip, they were asked about the sample's thermal sensation of the sample. However, the total number of observations in this research was 180.

Given this, the following subsections are intended to expose the results of the analysis of environmental and personal parameters and the modeling of the thermal sensation vote as a function of these parameters.

3.1 Analysis of Environmental and Personal Parameters

The results of this subsection are involved in the descriptive statistical analysis of the environmental parameters air temperature (ta), mean radiant temperature (trm), air speed (va) and relative humidity (rh) of the urban bus cabins, and in the estimation of personal parameters clothing thermal insulation (Iclo) and metabolic rate (M) of urban bus drivers.

The values of the descriptive statistics of the environmental parameters cited per trip are in Table 1.

Table 1. Descriptive statistics of environmental parameters per trip

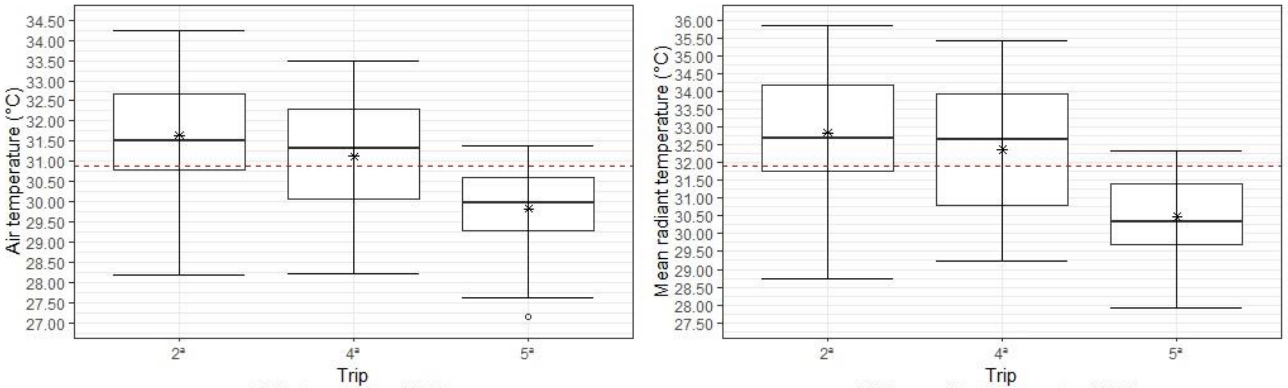
Trips	Statistics	ta (°C)	trm (°C)	va (m/s)	rh (%)
2nd trip	Mean	31.65	32.87	0.45	57.54
	Median	31.51	32.69	0.45	58.02
	Minimum value	28.18	28.72	0.31	42.77
	Maximum value	34.23	35.95	0.68	77.90
	Standard deviation	1.44	1.79	0.06	7.08
4th trip	Mean	31.12	32.37	0.47	58.50
	Median	31.33	32.66	0.47	57.06
	Minimum value	28.22	29.22	0.29	46.79
	Maximum value	33.48	35.41	0.91	76.44
	Standard deviation	1.30	1.79	0.10	5.67
5th trip	Mean	29.83	30.47	0.50	63.81
	Median	29.98	30.34	0.48	63.29
	Minimum value	27.16	27.90	0.37	54.94
	Maximum value	31.37	32.34	0.93	75.44
	Standard deviation	0.97	1.11	0.09	4.51

The mean values of the parameters “ta”, “trm”, and “rh”, shown in Table 1, for the 5th trip are quite different from the values for the 2nd and 4th trips. However, “va” has practically homogeneous means among the three observed trips.

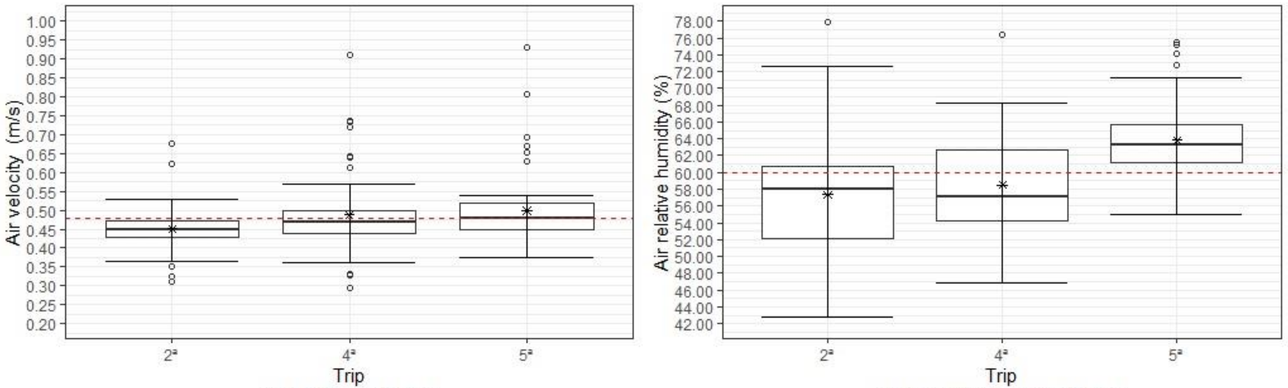
Also in Table 1, we can observe that the lowest means and the lowest values of “ta” and “trm” were recorded on the 5th trip and the opposite effect can be found on trip number 2 for the same parameters. The most discrepant maximum and minimum values can be seen in “rh” on the 2nd trip in comparison to the other trips, due to the higher value of the standard deviation of this parameter.

In general, and relating to the mean values of the parameters, we can infer that the 5th trip can be considered the most thermally comfortable trip.

In order to visually expose the information mentioned in Table 1, we plotted the graphs present in Figure 3, comparing each environmental parameter in each of the observed trips.



(a) Air temperature X Trips (b) Mean radiant temperature X Trips



(c) Air velocity X Trips (d) Air relative humidity X Trips

Figure 3. Graphs of environmental parameters per trip.

Figure 3 displays the graphs of “ta”, “trm”, “va” and “rh” considering the trips selected for the measurement, as well as the overall means of these parameters represented by the red dashed horizontal lines, and the means measured for each trip shown in Table 1, represented by *. The overall means of these parameters were 30.87 °C, 31.89 °C, 0.48 m/s and 59.89% respectively.

Graphs (a) and (b) of Figure 3 clearly show that the 5th trip was the mildest considering parameters “ta” and “trm”, if compared to the other trips, and thus, confirming the inferences shown in Table 1. On the other hand, this trip, in general, had highest values of “rh” as shown in graph (d), and in graph (c) we can find similar behavior of the air speed between trips, with some distant points.

In general, the graphs in Figure 5 indicate that the means of “ta”, “trm” and “rh” cannot be considered equal among the observed trips and, in contrast, there are indications that the means of the parameter “va” of the trips are homogeneous. The evidence of discrepancies values is important for modeling of the thermal sensation vote as a function of the parameters, because it is possible to verify if these discrepancies influence when selecting the different classes of the cited vote.

Knowing the four environmental parameters of urban bus cabins, our research tried to estimate the two personal parameters for the bus drivers. These personal parameters are described as clothing thermal insulation (Iclo) and metabolic rate (M) and, usually, their estimated values are extracted from tables of ISO 9920 (ISO 9920, 2007), for the "Iclo", and the ISO 8996 or ASHRAE -55 (ASHRAE - 55, 2017; ISO 8996, 2004), for the "M".

The value of the "Iclo" depends on the kind of clothing that were worn at the time of the survey and, thus, we observed that the drivers were wearing the required uniform provided by the public transportation company as shown in Table 2.

Table 2. Typical clothing of bus drivers

Clothing	**Value (clo)**
Underpants	0.03
Socks	0.02
Undershirt	0.09
Short-sleeves shirt	0.15
Lightweight trousers	0.20
Shoes (thin-soled)	0.02
Seat	0.25
Total	**0.76**

The total "Iclo" value in Table 2 refers to the pieces of clothing observed and questioned by the drivers, in addition to the bus seat. This total value was estimated for drivers 2 and 3, since driver 1 did not use the undershirt and, therefore, the value of "Iclo" for the latter was estimated at 0.67 clo.

Adding the seat to the overall value is essential to avoid errors in the calculation of Fanger's PMV index due to this parameter. The addition of 0.25 clo for the bus drivers' seat is recommended in ISO 9920 (ISO 9920, 2007) and is due to the fact that the seat is not ventilated.

The metabolic rate of bus drivers in this research was estimated by Equation 1 present in subsection 2.2 of the methodology. However, to validate this equation, we made use of data from Table 3.

Table 3. Data used to validate the metabolic rate model of drivers

Sample	**Age**	**Weight**	**Height**	**Adu**	**M_ISO**	**M_x**	**M**
1	36	86.6	168	1.96	72.28	75.15	73.05
2	42	73	170	1.84	65.92	73.60	68.52
3	19	81	180	2.01	80.73	65.24	74.65
4	22	71	174	1.85	56.77	63.43	68.87
5	20	78	178	1.96	62.56	64.75	72.87
6	23	67	180	1.85	60.94	62.61	68.87
7	48	60	170	1.69	77.85	72.24	63.04
8	22	73	185	1.96	70.4	64.08	72.85
9	29	61	165	1.67	45.02	63.52	62.13

10	20	78	178	1.96	60.49	64.75	72.87
11	32	71	175	1.86	75.97	68.19	69.16
12	33	46	151	1.39	67.59	60.57	51.67
13	42	56	177	1.69	65.3	68.09	63.04
14	19	62	168	1.70	62.87	59.09	63.38
15	25	61	163	1.66	61.73	61.62	61.58
16	24	70	185	1.92	65.8	64.06	71.57
17	39	64	159	1.66	64.94	69.25	61.73
18	24	50	152	1.45	58.61	57.58	53.80
19	27	50	163	1.52	62.12	59.01	56.59
20	40	90	180	2.10	77	78.15	78.07
21	45	91	177	2.08	83.87	80.86	77.49
22	32	70	174	1.84	61.61	67.87	68.46
23	23	52	159	1.52	50.69	57.75	56.51
24	29	60	165	1.66	60.4	63.20	61.69
25	30	58	170	1.67	70.16	63.03	62.14
26	28	69	153	1.67	70.8	65.64	61.98
27	26	51	165	1.55	54.15	58.85	57.58
28	42	57	158	1.57	74.19	68.41	58.49
29	18	62	176	1.76	52.98	58.61	65.56
30	20	54	157	1.53	59.7	56.97	56.90

The data in Table 3 were extracted from the sample available in Xavier's research (XAVIER, 2000), except for column "M", where the values were calculated by Equation 1 and considered the data from Xavier's sample.

To select the model to estimate the metabolic rate of bus drivers, the data generated by the proposed models (M_x and M) were considered and compared by the methodology of ISO 8996 present in Table 3 as "M_ISO", through of the statistical tests F–Snedecora and T–Student. However, to perform these two tests, we checked if the data generated by "M_x" and "M" came from a normal distribution and if the variances were homogeneous, using normality and homoscedasticity tests.

The Lilliefors, Cramér-von Mises, Shapiro-Wilk, Shapiro-Francia, and Kolmogorov Smirnov statistical tests were used to verify the normality of the data from the proposed models. In addition, the Bartlett test was used to check if the variances are constant between "M_ISO" and the other models, and also the F-Snedecora and T-Student tests. The results of the statistical tests cited are shown in Table 4.

Table 4. Results of statistical tests applied in M_x and M

Models	**Normality test**					**Bartlett**	**Teste F**	**Teste T**
	Lilliefors	**Cramér V. M.**	**Shapiro Wilk**	**Shapiro Francia**	**Kolmogorov Smirnov**			
M_x	0.15	0.10	0.05	0.06	0.61	0.04	0.04	0.96
M	0.19	0.20	0.41	0.54	0.67	0.20	0.20	0.98

The p_values from the normality tests for the “M_x” and “M” models in Table 4 were greater than or equal to the significance level α=0.05, indicating that the data from these models are normally distributed.

Also in Table 4, it is shown that the p_value of “M_x” does not satisfy the F and Bartlett tests, because they were lower than the significance level α=0.05, indicating that this model does not present homogeneous variance to the data calculated by ISO 8996. Therefore, the “M” model, from Equation 1 proposed in the methodological section, was considered the best fit, since it was the only to pass all the tests in Table 4.

Once defined which model would be used to estimate the values of the drivers' metabolic rates, Table 5 shows the estimated values of this parameter and used by this research.

Table 5. Values of metabolic rates of urban bus drivers

Driver	**Metabolic rate (W/m2)**
Standard driver*	75**
Driver 1	87.28
Driver 2	79.31
Driver 3	69.55

* Male driver, 1.70 m, 70 kg and 35 years old

** Reference value of the metabolic rate (Mt) extracted from table B.1 of ISO 8996 (1990)

Table 5 shows the values of “M” for each driver sampled for this research, as well as the values of a standard driver as described in table B.1 of ISO 8996 (1990). This value, extracted from the aforementioned standard, served as the input for Equation 1, which resulted in the estimated metabolism values for each driver.

Based on the measured values of the environmental parameters and estimated values of the personal parameters, the thermal sensation vote was modeled as a function of these parameters.

3.2 Thermal Sensation Vote Modeling

This subsection is intended to address the analysis of the thermal sensation vote of bus drivers, surveyed by direct interview at the end of each trip, after each of the 180 observed trips.

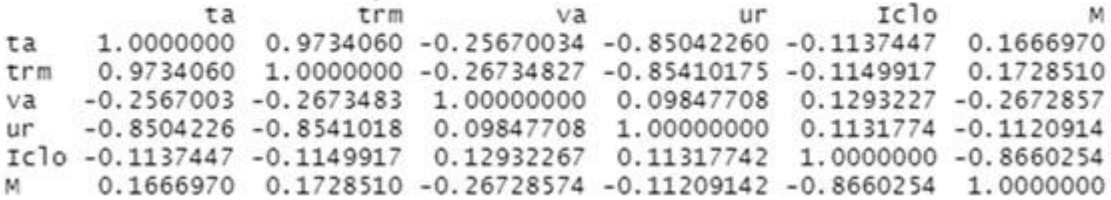
Thus, the thermal sensation vote (tsv) was modeled as a function of the six parameters, which are air temperature (ta), mean radiant temperature (trm), air velocity (va), air relative humidity (rh), thermal insulation of the clothing (Iclo) and metabolic rate (M), from the thermal comfort methodology.

However, the votes from Figure 1 in subsection 2.2 of the methodology, is a dependent variable of the ordinal categorical type and, in the analysis of this type of variable, the Ordinal Logistic Regression model is commonly used (HARRELL, 2015). In the construction of this type of model, by using the Generalized Linear Models methodology and with the aid of the R Studio software, it can be adjusted by the "lrm" function.

According to Harrell (2015), this type of model requires complying with four assumptions for the data set of the modeling variables and, according to Williams (2006), the key problem of OLR models is the violation of their assumptions, which must be tested.

The required assumptions, according to Harrell (2015), are (a) that the dependent variable is categorical and ordinal, assumption already satisfied since the vote is of this nature; (b) that the observations are independent, also already satisfied since the measurements were made under particular conditions and on different days; (c) that there is no correlation between the independent variables and (d) that the odds are proportional.

We used the Spearman correlation test against the assumption of absence of correlation of the independent variables and the result is shown in Figure 4.



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              ta        trm          va          ur       Iclo          M
ta     1.0000000  0.9734060 -0.25670034 -0.85042260 -0.1137447  0.1666970
trm    0.9734060  1.0000000 -0.26734827 -0.85410175 -0.1149917  0.1728510
va    -0.2567003 -0.2673483  1.00000000  0.09847708  0.1293227 -0.2672857
ur    -0.8504226 -0.8541018  0.09847708  1.00000000  0.1131774 -0.1120914
Iclo  -0.1137447 -0.1149917  0.12932267  0.11317742  1.0000000 -0.8660254
M      0.1666970  0.1728510 -0.26728574 -0.11209142 -0.8660254  1.0000000
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Figure 4. Correlation matrix of thermal comfort parameters.

In Figure 4, there are two groups of variables that are strongly correlated with each other.

The first group is formed by the environmental parameters (ta, trm and rh) and the second by the personnel (Iclo and M). Due to this strong correlation between the variables that compose the groups, it is not convenient to generate a single model with all the variables together.

Therefore, Equation 3 displays the generic model of the thermal sensation vote as a function of thermal comfort parameters for further adjustments purposes.

$$mlo_i = lrm(vst \sim A_1X_1 + A_2X_2 + \cdots + A_NX_N, data = x) \qquad \text{(Eq. 3)}$$

where:

mloi = are the OLR models, ∀ i=1, 2, … and 6;

lrm = function of the OLR models of the Generalized Linear Models methodology

tsv = thermal sensation vote;

X_N = thermal comfort parameters, ∀ N=1, 2 3;

A_N = parameter coefficients, ∀=1, 2 and 3

Note, in Equation 3, that the drivers' thermal sensation vote was modeled as a function of the combination of at most three thermal comfort parameters. This happened because we considered that the models must respect the correlation assumptions found in Figure 4. In this case, six models were generated for each highlighted subjective vote in which the variables with strong correlation between them did not remain in the same model.

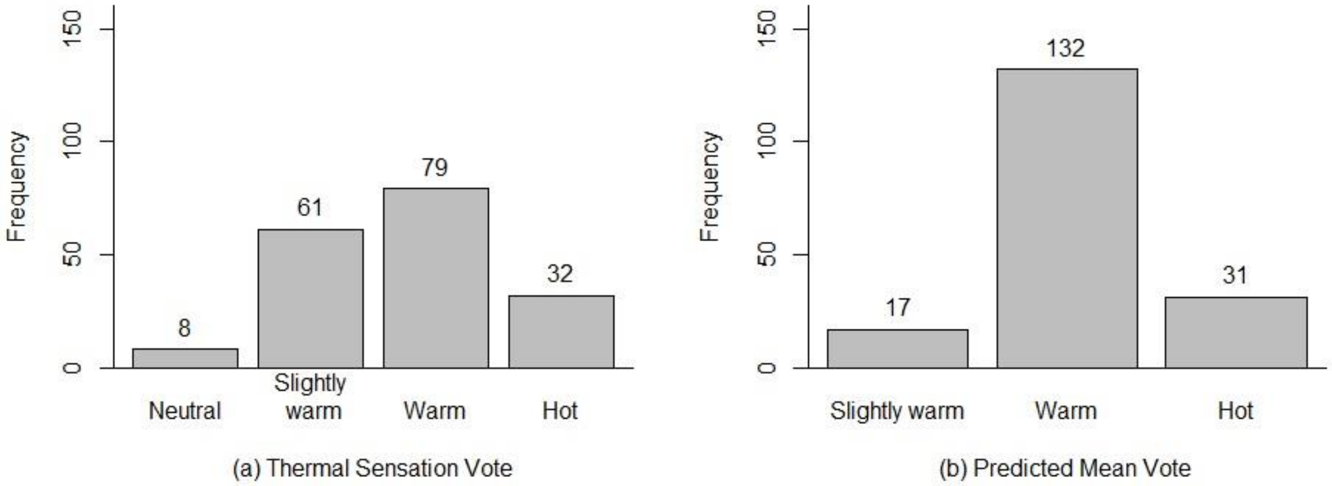
The six models initially generated were fitted following the Backward method and then the quality of the adjustments will be verified.

According to Abreu, Siqueira and Caiaffa (2009), any regression model must be checked for the quality of its fit, because a poorly fitted model can lead to biased estimation of the effects. In the case of OLR models, it is no different, however, there are few methods for ordinal response and these methods are usually Pearson or deviance tests, in addition to graphical analysis of scores and partial residuals

In the residual score graph, the proportional hypothesis is tested and, if it is true, a horizontal and constant trend of the classes' behavior is expected for each significant independent variable of the model. Furthermore, the means of each class must be close to zero for each significant independent variable (ABREU; SIQUEIRA; CAIAFFA, 2009). In the case of graphical analysis of the partial residuals, the linear and parallel behavior of the classes is frequently verified due to each significant independent variable of the fitted models (ABREU; SIQUEIRA; CAIAFFA, 2009).

The subjective vote for thermal sensation and the Fanger's PMV index are usually associated with a 7-point scale. For a subjective vote, the person can choose a single option among the values -3, -2, -1, 0, +1, +2 and +3 and which corresponds to the thermal sensation classes of "Cold", "Cool", "Slightly cool", "neutral", "Slightly warm", "Warm" and "Hot" respectively. The PMV index is calculated individually by combining the 6 parameters, widely cited, and according to equation 1 present in ISO 7730 (ISO 7730, 2005).

Thus, to verify the thermal sensation classes pointed out by the drivers of this research, as well as the calculated PMV values, a frequency graph was generated and is shown in Figure 5.



(a) Thermal Sensation Vote

(b) Predicted Mean Vote

Figure 5. Frequency of the thermal sensation votes and PMV index.

In Figure 5, the thermal sensation votes, as well as the calculated PMV index, indicate that the environments of the analyzed bus drivers' cabins are, in general, within the scale of thermal discomfort by heat, with a predominance of the "Warm" class, due to the higher frequency of occurrence. The similar profile between the results of both terms in the figure, may be strong evidence that the PMV index is a good predictor of the thermal sensation vote of people present in the vehicular environment, in the case of buses, and that this index can be used for this purpose.

Table 6 shows the adjusted models of the wind chill votes, with their respective significant independent variables and classes, the coefficients of variables and classes, and the results of the statistical tests performed.

Table 6. Results of adjustments in the thermal sensation vote models

Model	Variable	Coefficient	Pr(>|Z|)	Pr(> chi^2)	Pseudo R^2
mlo1	ta	1.8679	0.0001	0.0001	0.669
	y≥1	-52.2284	0.0001		
	y≥2	-56.5965	0.0001		
	y≥3	-60.7520	0.0001		
mlo3	trm	1.2044	0.0001	0.0001	0.584
	y≥1	-33.7401	0.0001		
	y≥2	-37.4293	0.0001		
	y≥3	-41.1563	0.0001		
mlo5	rh	-0.2486	0.0001	0.0001	0.466
	va	-6.2686	0.0004		
	y≥1	22.1833	0.0001		
	y≥2	18.6116	0.0001		
	y≥3	15.6581	0.0001		

Table 6 shows the three fitted models of the six possible initially generated according to Equation 3 and respecting the result of Figure 4. This reduction in the number of models was due to the fact that the six possible models, when fitted, resulted in three models with equal variables.

Paying attention to the values Pr(>|Z|) of the Wald test of the classes and independent variables, it is shown that they were lower than the significance level $\alpha=0.05$, indicating that the classes and environmental parameters represented by “ta”, “trm”, “rh” and “va” of their respective models were the only considered to be significant. Moreover, according to the coefficients of “ta” and “trm”, there is a tendency for the drivers' thermal sensation vote to increase in the class as these mentioned temperatures also increase, and the class of “tsv” to reduce as relative humidity and air velocity increase.

Also, according to Table 6 and examining the column of Pseudo R^2 values, it is observed that the mlo1 model with Pseudo R$^2\approx0.7$ was the best fitted and that the air temperature moderately explains part of the variability of the thermal sensation perceived by drivers and the others models have a low explanatory power. However, they cannot be discarded, since the results of Pearson's likelihood ratio tests [Pr(> chi^2)], when compared to the significance level $\alpha=0.05$, indicate that there is a possibility that these models represent part of the variability of the thermal sensation vote, through the variables that were considered significant.

In general, the drivers' thermal sensation vote can be explained by environmental parameters, and not by personal ones, in view of the aforementioned particular conditions of this research. However, the parameters “ta”, “trm” and “rh” can only be modeled in separate models and the “va” can be grouped with “rh” in the same model, according to Equations 4, 5 and 6.

$$mlo1 = lrm(vst{\sim}ta, data = x, x = TRUE, y = TRUE) \quad \text{(Eq. 4)}$$

$$mlo3 = lrm(vst{\sim}trm, data = x, x = TRUE, y = TRUE) \quad \text{(Eq. 5)}$$

$$mlo5 = lrm(vst \sim ru + va, data = x, x = TRUE, y = TRUE) \qquad \text{(Eq. 6)}$$

Note that in Equations 4, 5 and 6 only the significant independent variables from their respective models discussed in Table 6 are present, and the other variables (Iclo and M) were suppressed due to the insignificance of their coefficients.

Using R Studio software, sequences of 1000 data were simulated for air temperature, mean radiant temperature, relative air humidity and air velocity, and it was verified through the fitted models that the probabilities of these simulated datasets being in the "Neutral", "Slightly warm", "Warm" and "Hot" classes of the thermal sensation vote.

With this, we plotted graphs of the curves of probabilities related to the possible response of drivers regarding the perceived thermal sensation, in the cited classes as a function of the significant variables "ta", "trm", "rh" and "va" and according to each fitted model.

The graph shown in Figure 6 allows us to verify the probability curves generated by the Ordinal Logistic Regression model "mlo1".

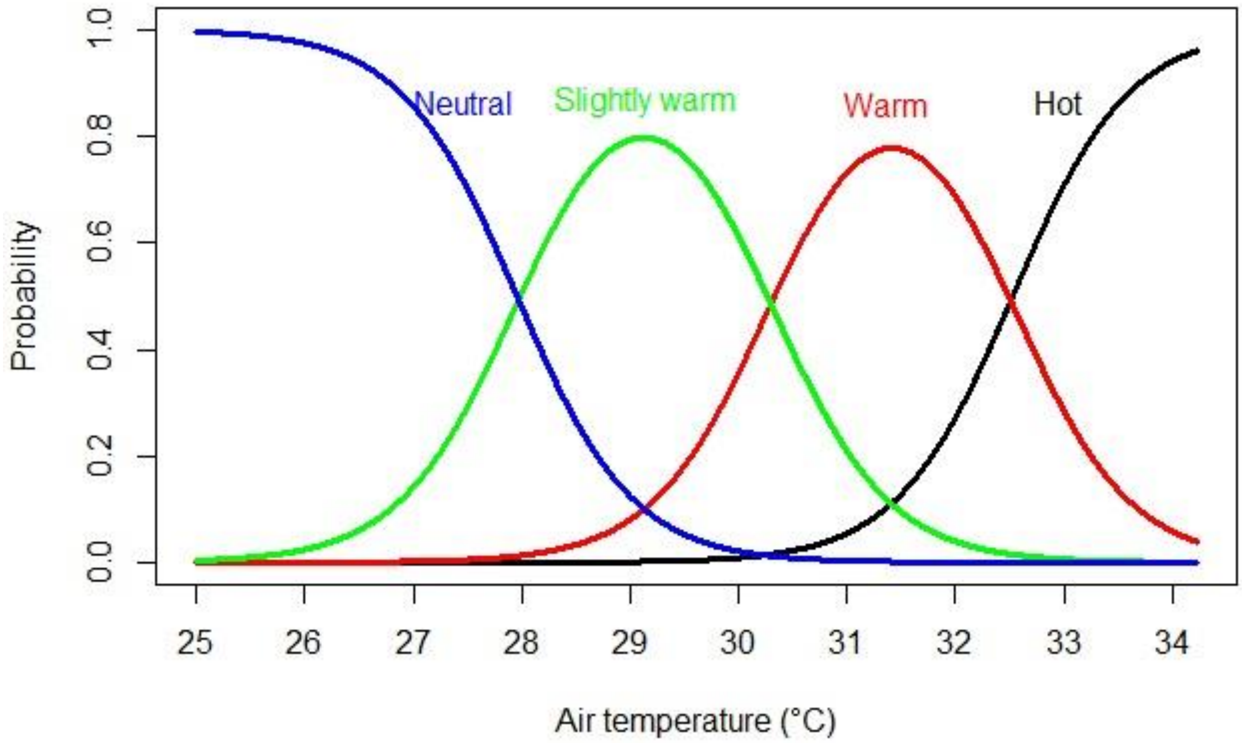


Figure 6. Proportional chance curves of thermal sensations for mlo1.

The graph in Figure 6 demonstrates the proportional odds curves of the "mlo1" model for the thermal sensation "Neutral" (0), "Slightly warm" (+1), "Warm" (+2) and "Hot" (+3). Based on this graph, it is possible to verify the thermal sensations most likely to occur for different values of air temperature.

Figure 6 shows that for values of ta<28°C, the probability of drivers responding that they are with a sensation of thermal neutrality and the other classes not observed by this research. In the range of values of 28°C ≤ ta ≤ 30°C, there is a high probability of choosing the class "Slightly warm" and when the interval is 30.5°C ≤ ta ≤ 32.5°C, the chances are great to choose the “Warm” class. Finally, for values of ta>32.5°C, the chances of drivers saying that they are “Hot” increase.

In the graph of Figure 7, it is possible to examine the probability curves generated by the “mlo3” Ordinal Logistic Regression model.

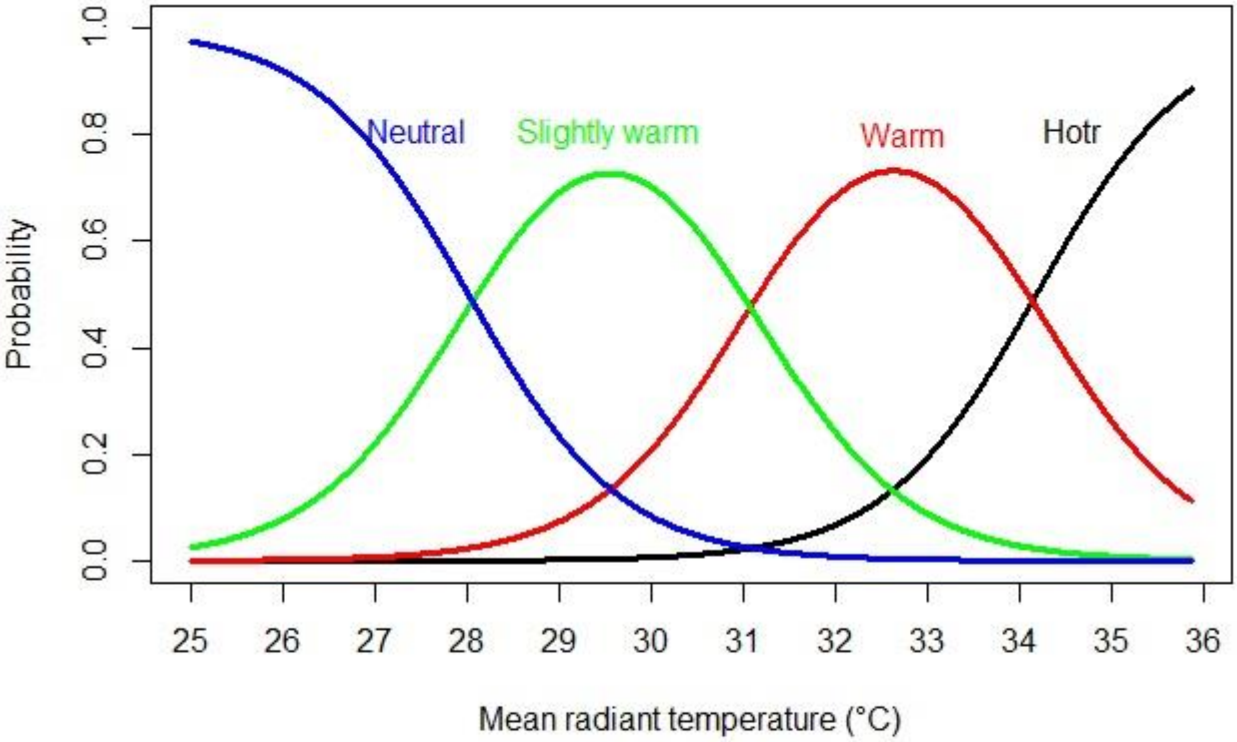


Figure 7. Proportional chance curves of thermal sensations for mlo3.

Figure 7 describes the proportional odds curves of “mlo3” for the “Neutral”, “Slightly warm”, “Warm” and “Hot” thermal sensation classes. Based on it, it is possible to verify the most acceptable thermal sensations to be chosen by drivers for different values of the mean radiant temperature.

When trm>28°C, the probability of drivers choosing the “Neutral” class and the others, which were not observed by this research, is high. The curve representing the “Slight warm” class indicates that in the range of 28°C ≤ trm ≤ 31°C there is a high probability of conductors reporting this thermal sensation. while in the range of 31°C ≤ trm ≤ 34°C, the chances are higher in the “Warm” class choice. Finally, for values of trm>34°C, the chances of drivers saying that they are feeling “Hot” increases.

In the graph of Figure 8, it is possible to verify the probability curves generated by the “mlo5” Ordinal Logistic Regression model.

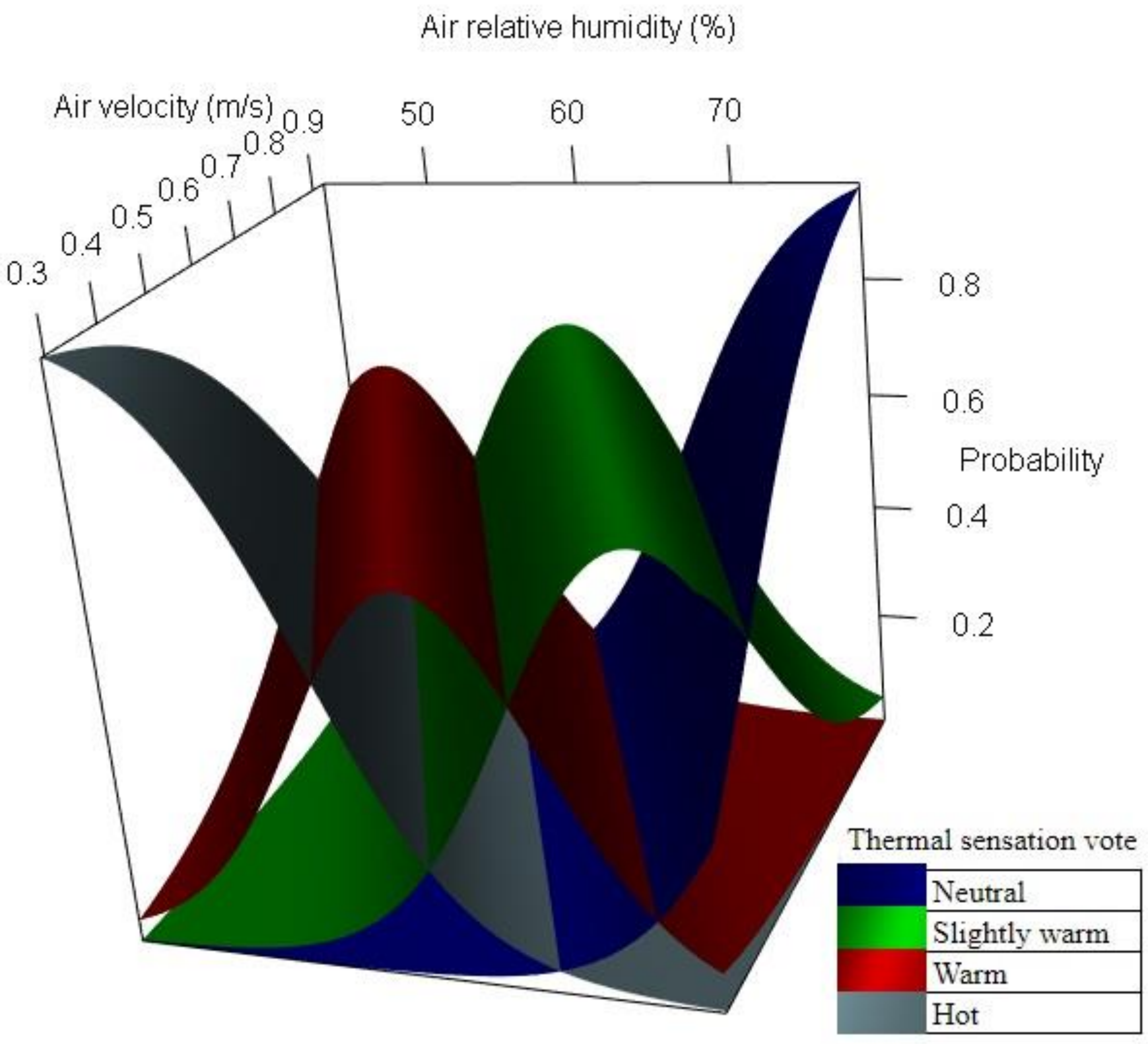


Figure 8. Proportional chance curves of thermal sensations for mlo5.

The proportional odds curves of the “mlo5” model for the classes of thermal sensations mentioned above can be seen in Figure 8. Looking at the graph, the most plausible thermal sensations to be chosen by drivers for different values of relative humidity together with the air velocity.

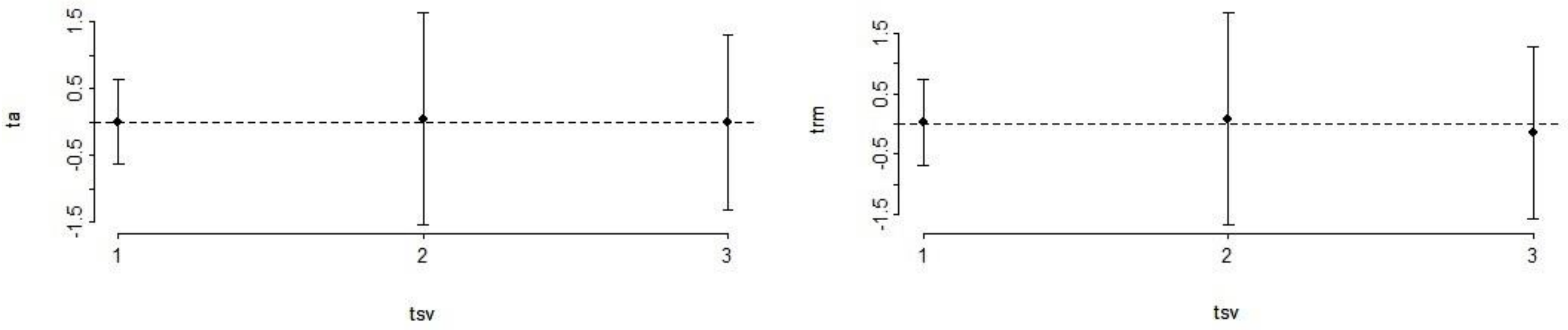
Still observing Figure 8, it is noted that for the combination of values rh>70% and va>0.8m/s, there is a greater tendency for drivers to respond who have the thermal sensation of neutrality and the other classes, which were not observed by this research. At the opposite end of the graph, for values of rh<50% and va<0.4 m/s, there is a high probability of the “Hot” class being chosen.

For the combination of the intervals 50% ≤ rh ≤ 60% and 0.4m/s ≤ va ≤ 0.6m/s, the chances are higher that the conductors will point out that they are “Warm”, and the “Slight warm” class has a high probability of being chosen when the combination of intervals is 60% ≤ rh ≤ 70% and 0.6 m/s ≤ va ≤ 0.8 m/s.

The statements made about the probabilities or odds ratios on top of the fitted models “mlo1”, “mlo3” and “mlo5”, which were modeled by the “lrm” function based on Ordinal Logistic Regression, will only be valid if the qualities of the fits are verified.

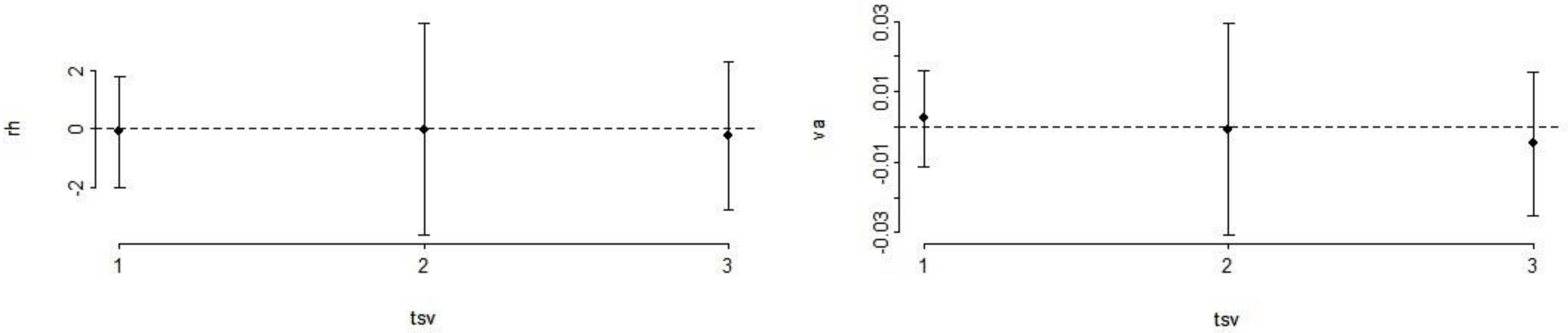
The results of the Pearson and deviance tests for the fitted models “mlo1”, “mlo3” and “mlo5” are presented in Table 6 and demonstrate that there is a possibility that these models represent part of the variability of the thermal sensation vote as a function of their respective significant independents variables.

However, this research deepened the validation of its fitted models by the observations of scores and partial residuals that are present in Figures 9 and 10, respectively.



(a) Residual score graph for the air temperature of the mlo1 model

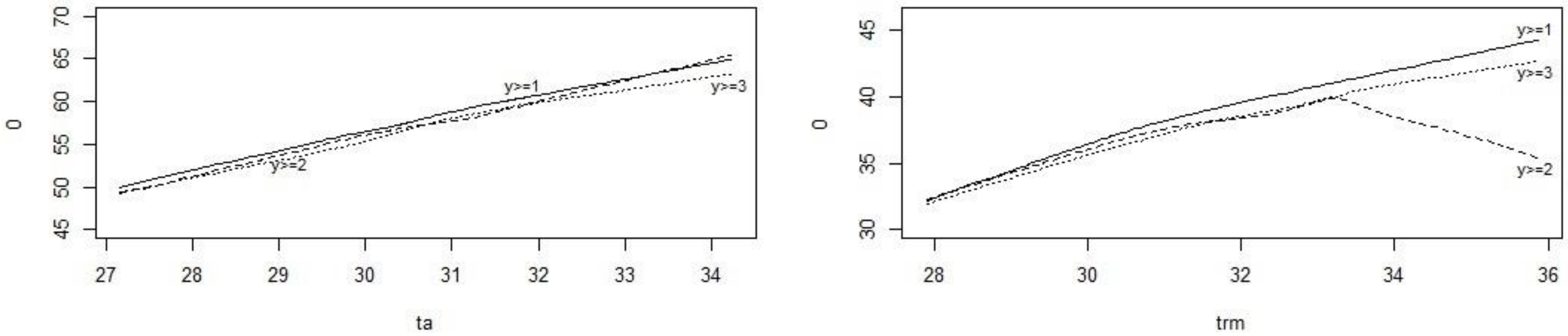
(b) Residual score graph for the mean radiant temperature of the mlo3 model



(c) Residual score graph for the air relative humidity of the mlo5 model

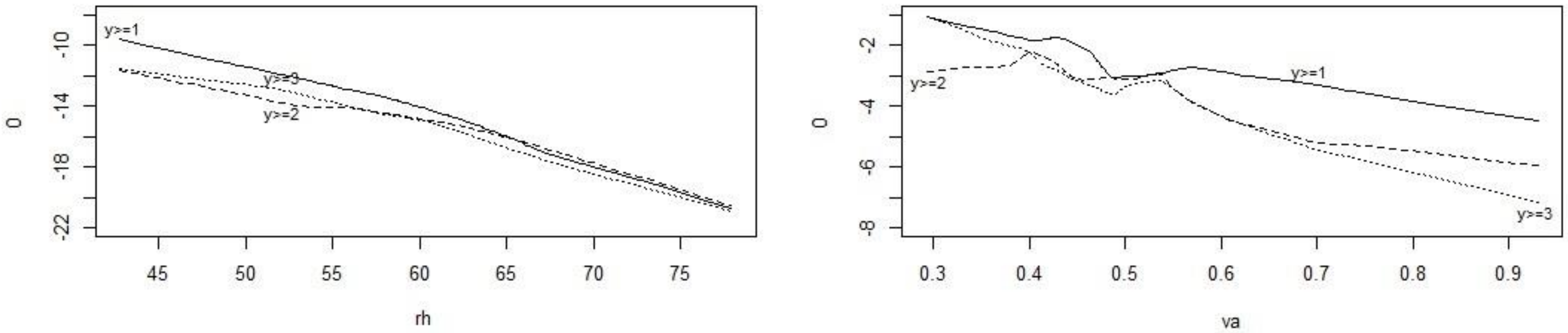
(d) Residual score graph for the air velocity of the mlo5 model

Figure 9. Residual scores graphs of the variables included in the models



(a) Partial residual graph for the air temperature of the mlo1 model

(b) Partial residual graph for the mean radiant temperature of the mlo3 model



(c) Partial residual graph for the air relative humidity of the mlo5 model

(d) Partial residual graph for the air velocity of the mlo5 model

Figure 10. Partial residual graphs of the variables included in the models

Figure 9 presents four graphs of the residual scores for each significant independent variable from their respective fitted models. According to graphs (a), (b), (c) and (d), it is possible to observe the expected behavior of the classes to be constant, horizontal and with the means close to zero.

Figure 10 displays four graphs of partial residuals for each significant independent variable from their respective fitted models. Therefore, checking the graphs (b) and (d) of, it is clear that the assumption of linearity can be discarded for the independent variables: mean radiant temperature and air velocity. However, it can be inferred that for values lower than 33°C of "trm", a linear behavior is observed between the categories, the same cannot be concluded for "va", because, in all its graphic extension, the behavior linear can be discarded. For air temperature and relative humidity, graphs (a) and (c), a well-defined linear behavior is verified, demonstrating that they are good predictors of the thermal sensation vote.

Overall, the graphs in Figures 9 and 10, allow us to infer that the fitted model "mlo1", whose variable "ta" proved to be significant, can be considered the best predictor for the thermal sensation vote of bus drivers, therefore, the assumption of parallelisms can be considered reasonable for the classes, while the other models did not present this behavior. With this, it reinforces the inference made in the results of the Wald tests and the moderate value of Pseudo R^2 in Table 6, and validates the statements made in the probability curves in Figure 6.

4. Conclusion

Among the various types of comfort investigated in urban buses, which may reflect on the quality of the service perceived by passengers and even when choosing whether to use this means of transportation, we find thermal comfort. Research of this nature has been gaining prominence due to the impacts generated by these results, which range from maintaining the thermal sensation and thermal well-being of the occupants, to ensuring the satisfactory performance of drivers in terms of traffic safety and energy sustainability.

From the perspective of thermal sensation, the subjective votes of thermal sensation by urban bus drivers were evaluated through the methodology of Generalized Linear Models. The votes were modeled by Ordinal Logistic Regression, as a function of the six parameters considered as inputs of the PMV index, which is the best known and publicized index of thermal comfort. Therefore, the results of the adjustments in the generated models converged to only three different models and they demonstrated that the thermal sensation vote can be modeled only as a function of environmental parameters, and not by personal parameters.

The three thermal sensation models were a function of different parameters, one with air temperature only, another with mean radiant temperature only and the third with air velocity combined to air relative humidity. Of these three models, the best fit for sensation was as a function of air temperature, with moderate explanatory power due to the value of Pseudo $R^2 = 0.669$. However, the likelihood ratio test indicated that it can be used to evaluate the effects caused by air temperature on drivers' thermal sensation.

The proportional chance curves of the best model indicated that there is a high probability of drivers choosing thermal sensations as a function of air temperature as follows: when ta<28°C, the greater chances are in the choice of thermal neutrality and the other classes of thermal discomfort by cold that were not reached by this research; for 28°C ≤ ta ≤ 30°C the tendency is greater to feel slightly warm; for values in the range 30°C ≤ ta ≤ 33°C it is more natural that they opine on the warm scale; and for values of ta>33°C the tendency is that the conductors feel very hot.

As an indication of future research, it will be interesting to expand the state of the thermal comfort methodology beyond the heat discomfort observed by this research, in order to discover the important parameters for the thermal sensation vote when drivers are subject to cold, as well as the ranges of the possible parameters significant to this vote for the thermal sensation classes "Very cold", "Cold" and "Cool".

Also, as an indication for future research, we recommend: comparing the thermal sensation of passengers to those of bus drivers; to find out which thermal comfort indexes can serve as a predictor of the thermal sensation of bus occupants, among others.

5. References

Abreu, M. N. S., Siqueira, A. L., & Caiaffa, W. T. (2009). Regresión logística ordinal en estudios epidemiológicos. *Revista de Saúde Pública*, *43*(1), 183–194.

Alahmer, A., Mayyas, A. A. A., Mayyas, A. A. A., Omar, M. A., & Shan, D. (2011). Vehicular thermal comfort models; a comprehensive review. *Applied Thermal Engineering*, *31*(6–7), 995–1002. https://doi.org/10.1016/j.applthermaleng.2010.12.004

Almeida, M. das N., Xavier, A. A. de P., & Michaloski, A. O. (2020). A Review of Thermal Comfort Applied in Bus Cabin Environments. In *Applied Sciences* (Vol. 10, Issue 23). https://doi.org/10.3390/app10238648

Almeida, M. das N., Xavier, A. A. de P., Michaloski, A. O., & Soares, A. L. (2020). Thermal Comfort in Bus Cabins: A Review of Parameters and Numerical Investigation. In *Occupational and Environmental Safety and Health II* (pp. 499–506). Springer.

ASHRAE - 55. (2017). Thermal Environmental Conditions for Human Occupancy, 2017. In *American Society of Heating, Refrigerating and Air-conditioning Engineers*. American Society of Heating, Refrigerating and Air-conditioning Engineers.

Assuncao, A., Jardim, R., & De Medeiros, A. (2014). Voice complaints among public transport workers in the metropolitan region of belo horizonte, Brazil. *Folia Phoniatrica et Logopaedica*, *65*(5), 266–271. https://doi.org/10.1159/000357301

Cooper, D. R., & Schindler, P. S. (2014). *Business Research Methods.© The McGraw− Hill Companies*.

Croitoru, C., Nastase, I., Bode, F., Meslem, A., & Dogeanu, A. (2015). Thermal comfort models for indoor spaces and vehicles - Current capabilities and future perspectives. *Renewable and Sustainable Energy Reviews*, *44*, 304–318. https://doi.org/10.1016/j.rser.2014.10.105

Danca, P., Vartires, A., & Dogeanu, A. (2016). An Overview of Current Methods for Thermal Comfort Assessment in Vehicle Cabin. *Energy Procedia*, *85*(November 2015), 162–169. https://doi.org/10.1016/j.egypro.2015.12.322

Djongyang, N., Tchinda, R., & Njomo, D. (2010). Thermal comfort: A review paper. *Renewable and Sustainable Energy Reviews*, *14*(9), 2626–2640.

https://doi.org/https://doi.org/10.1016/j.rser.2010.07.040

Enescu, D. (2017). A review of thermal comfort models and indicators for indoor environments. *Renewable and Sustainable Energy Reviews*, *79*, 1353–1379. https://doi.org/https://doi.org/10.1016/j.rser.2017.05.175

Harrell, F. E. (2015). *Regression modeling strategies: with applications to linear models, logistic and ordinal regression, and survival analysis* (Vol. 3). Springer.

Hosmer Jr, D. W., Lemeshow, S., & Sturdivant, R. X. (2013). *Applied logistic regression* (Vol. 398). John Wiley & Sons.

Ismail, A. R., Abdullah, S. N. A., Abdullah, A. A., & Deros, B. M. (2015). A descriptive analysis of factors contributing to bus drivers' performances while driving: A case study in Malaysia. *International Journal of Automotive and Mechanical Engineering*, *11*(1), 2430–2437. https://doi.org/10.15282/ijame.11.2015.23.0204

Ismail, A. R., Atikah Abdullah, S. N., Abdullah, A. A., Ab Hamid, M. R., & Md. Deros, B. (2015). Relationship between thermal comfort and driving performance among Malaysian bus driver. *ARPN Journal of Engineering and Applied Sciences*, *10*(17), 7406–7411.

ISO 7726. (1998). Ergonomics of the Thermal Environment: Instruments for Measuring Physical Quantities. In *International Standard for Organization* (Vol. 7726). International Organization for Standardization.

ISO 7730. (2005). Ergonomics of the thermal environment, analytical determination and interpretation of thermal comfort using calculations of the PMV and PPD indices and local thermal comfort criteria. In *International Standard for Organization*. International Organization for Standardization.

ISO 9920. (2007). Ergonomics of the thermal environment–Estimation of thermal insulation and water vapour resistance of a clothing ensemble. In *International Standard for Organization*. International Organization for Standardization.

King, B. M., Rosopa, P. J., & Minium, E. W. (2018). *Statistical reasoning in the behavioral sciences*. John Wiley & Sons.

Nguyen-Phuoc, D. Q., Currie, G., De Gruyter, C., Kim, I., & Young, W. (2018). Modelling the net traffic congestion impact of bus operations in Melbourne. *Transportation Research Part A: Policy and Practice*, *117*, 1–12. https://doi.org/10.1016/j.tra.2018.08.005

Nguyen-Phuoc, D. Q., Currie, G., De Gruyter, C., & Young, W. (2018). Congestion relief and public transport: An enhanced method using disaggregate mode shift evidence. *Case Studies on Transport Policy*, *6*(4), 518–528. https://doi.org/10.1016/j.cstp.2018.06.012

Pala, U., & Oz, H. R. (2015). An investigation of thermal comfort inside a bus during heating period within a climatic chamber. *Applied Ergonomics*, *48*, 164–176. https://doi.org/https://doi.org/10.1016/j.apergo.2014.11.014

Peeters, L., De Dear, R., Hensen, J., & D'haeseleer, W. (2009). Thermal comfort in residential buildings: Comfort values and scales for building energy simulation. *Applied Energy*, *86*(5), 772–780.

Prakash, N. K. U., Bhuvaneswari, S., Kumar, M. R., Lankesh, S., & Rupesh, K. (2014). A study on the prevalence of indoor mycoflora in air conditioned buses. *Microbiology Research Journal International*, 282–292.

Rupp, R. F., Vásquez, N. G., & Lamberts, R. (2015). A review of human thermal comfort in the built environment. *Energy and Buildings*, *105*, 178–205. https://doi.org/https://doi.org/10.1016/j.enbuild.2015.07.047

Simion, M., Socaciu, L., & Unguresan, P. (2016). Factors which Influence the Thermal Comfort Inside of Vehicles. *Energy Procedia*, *85*, 472–480. https://doi.org/https://doi.org/10.1016/j.egypro.2015.12.229

Sweeney, D. J., Williams, T. A., & Anderson, D. R. (2013). Estatística aplicada à administração e economia. *São Paulo: CENGAGE Learning*.

Tartarini, F., Schiavon, S., Cheung, T., & Hoyt, T. (2020). CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX*, *12*, 100563.

Williams, R. (2006). Generalized ordered logit/partial proportional odds models for ordinal dependent variables. *The Stata Journal*, *6*(1), 58–82.

Xavier, A. A. de P. (2000). Predição de conforto térmico em ambientes internos com atividades sedentárias-Teoria física aliada a estudos de campo. *Florianópolis: Universidade Federal de Santa Catarina*.

Yao, R., Li, B., & Liu, J. (2009). A theoretical adaptive model of thermal comfort – Adaptive Predicted Mean Vote (aPMV). *Building and Environment*, *44*(10), 2089–2096. https://doi.org/https://doi.org/10.1016/j.buildenv.2009.02.014