Thermal comfort in buildings located in regions of hot and humid climate of Brazil.

Wagner Augusto Andreasi [1] and Roberto Lamberts [2]
[1] Laboratory of Analysis and Development of Buildings, Universidade Federal de Mato Grosso do Sul, Brasil.
[2] Laboratory of Energy Efficiency in Buildings, Universidade Federal de Santa Catarina, Brasil.

Abstract

The present work was developed in 2005 in a Brazilian region of hot and humid climate with volunteers performing sedentary activity. The predicted mean votes (PMV) , the thermal sensation votes (TSV) and the thermal preference votes (TPV) were acquired and calculated according to the standards ISO7726 (1996), ISO7730 (1994) and ISO10551 (1995). PMV and TSV did not show good correlation in naturally ventilated buildings. Differences were also found in those environments with the application of the methodologies proposed by Humphreys and Nicol (2002) and Fanger and Toftum (2002). It was also researched an adjustment equation to the PMV based in TSV that also resulted inadequate. The research also showed that approximately 79% of the volunteers who took part in the experiment in naturally ventilated buildings preferred that the thermal environment changed while in the air-conditioned environment the percentage was of about 55%.

Key words: Thermal comfort; Thermal Sensation; Predicted Mean Vote; Hot and humid Climate; Field Research.

1. Introduction

Many indices have already been proposed to the definition of thermal comfort in indoor environments. However, Fanger (1970) proposed an equation which made it possible to many levels of activities and clothing isolation as well as to an extensive combination of radiant average temperature, temperature, humidity and relative velocity of air the indication of the PMV. This model, adopted as an international standard ISO7730 (1994) recommends for a condition of thermal comfort both in naturally ventilated buildings and air-conditioned ones that the PMV should be between –0.5 and +0.5 in the seven point scale of ASHRAE. But the application of this model has caused controversy in the scientific field because there are field researches which indicate bias between the PMV and the TSV. Besides the discussion which involves the use of values listed to the metabolic rate and the index of clothing insulation because of the difficulties of their correct estimates, Dear and Brager (2002) among other indicate subjective factors such as “acceptability” and “thermal satisfaction” among the factors for those differences. Before that, Fountain et al. (1996) had already examined how people’s sensations and thermal preferences could be influenced by the culture and climate associated with the expectation and thermal adaptation. Höpe (2002) stated that before discussing the thermal comfort it is necessary to define it clearly once in his opinion three approaches must be taken into account: the psychological, the thermophysiological and the one based in the thermal balance of the body.

Up till now, the intervention of adaptative factors in the PMV was not considered by Fanger's model.
However, at present there is a discussion about it and in the search of reducing the differences found between the normalized model and the field research, adaptive models to the evaluation of thermal comfort mainly in naturally ventilated buildings are produced. Humphreys and Nicol (2002), Fanger and Toftum (2002) and the ACS – Adaptive Comfort Standard of the ASHAE (2004).
Actually this discussion is fed by the predominant quantity of work carried out in the North Hemisphere besides the important contribution by the ones realized in Australia and more recently here in South America although in a smaller quantity. One should not disregard the innumerable researches carried out in regions of tropical climate Nicol (2004), Mallick (1996), Cheong et al (2006); hot climate Fanger and Toftum (2002), Zhao et al. (2004) and hot and humid Shama and Ali (1986), Wong and Khoo (2003), Feriadi and Wong (2004), Yamtraipat et al.(2005), Hwang et al. (2006).
In this way, the present field research was carried out in a region of hot and humid climate, next to the latitude of 20° S with volunteers developing a sedentary activity aiming not only to contribute to the discussion above mentioned but also:

- Evaluate from the TSV and TPV and from the methodologies proposed by Fanger (1970), Humphreys and Nicol (2002) and Fanger and Toftum (2002) the condition of thermal comfort in those environments;
- Define equations of adjustment to the PMV obtained by the application of ISO 7730 (1994) to the evaluation of the thermal comfort in those environments;
- Identify the event of thermal memory in the participant volunteers;
- Define the importance of the air velocity in the TSV and in the TPV in the prediction of thermal comfort in naturally ventilated buildings;
- Define which is the most significant between the TSV and the TPV obtained through the application of the ISO10551 (1995) to the evaluation of the thermal comfort in naturally ventilated buildings and,
- Indicate the predicted percentage of dissatisfied people (PPD) in the researched environments.

2. The main characteristics of the cities, environments and participant volunteers.

2.1 Cities

The research was carried out in Coimbra ($57^0$46'W / $19^0$55'S and 93m of altitude), Corumbá ($57^0$38'W / $19^0$01'S and 158m of altitude) and Campo Grande ($54^0$37'W / $20^0$28'S and 564m of altitude), cities from the State of Mato Grosso do Sul/Brazil. According to the Brazilian Institute of Geography and Statistics (IBGE), those places are inserted in regions of hot and humid climate with up to three dry months and average temperatures above 24° C; absolute maximum of 42° C and absolute minimum of 0° C.

2.2 Environments

The experiments were carried out in four environments being three of them naturally ventilated and one air-conditioned. While the three first belong to the Brazilian Army's headquarters, the air-conditioned one is occupied by the GIDUR – Administration of the Urban Development Supporting Branch/MS – from Caixa Econômica Federal (Federal Bank) in the city of Campo Grande.

2.3 Volunteers.

All the volunteers who took part in the experiment in the naturally ventilated environments developed sedentary activity (1.2 met) while those from the air-conditioned environment kept an activity which indicated, on average, 1.3 met.

Regarding the clothing insulating index, it was observed the values indicated in the following table, obtained through the application of the ISO7730 (1994).

Table 1 – Indices of clothing isolation (clo) observed in the experiments.

	Experiment		
	Local	Abril	November
NV Building	Coimbra	0,34	0,50
	Corumbá	0,34	0,59
	Campo Grande	1,09	0,59
AC Building	Campo Grande	0,48	0,50

While in the naturally ventilated buildings participated as volunteers recruits and veteran soldiers, in the air-conditioned one the volunteers were males and females workers.

3 Applied methodology

3.1 The indoor and outdoor climatic variables

The acquisition of the indoor and outdoor climatic variables corresponded to that prescribed by the ISO7726 (1996), being the indoor ones recorded at 1 minute intervals with a microclimatic station BABUC produced by the Italian company LSI - *Laboratori di Strumentazione Industriali*.

Table 2 – Technical characteristics of the BABUC sensors.

Probe		Resolution	Accuracy	Range
Psychometric portable probe with forced ventilation	tw / ta	0,03 ^{0}C	±0,13 ^{0}C	-20,0 ^{0}C to +60,0 ^{0}C
	RH	0,001	±0,5% (70 to 90%)	0 to 100%
			± 1% (40 to 70%)	
			± 2% (15 to 40%)	
Globe thermometric probe		0,3 ^{0}C	±0,15 ^{0}C	-10,0^{0}C to 100,0^{0}C
Hot wire anemometric probe		0,01 m/s	±0,04 m/s to 0 < va < 1m/s	0 to 50m/s
			± 4% va to va > 1m/s	

The outdoor variables were obtained each 15' with HOBO® from the North-American company Onset Corporation.

Table 3 – Technical characteristics of the Onset sensors

	Probe Hobo H8 Pro Series	
	Accuracy	Range
ta	±0,2^{0}C	-30^{0}C to 50^{0}C
RH	±0,3%	0% to 100%

3.2 Personal Variables of the Volunteers

The sensations and thermal preferences of the volunteers were obtained according to ISO10551 (1995).

3.2.1 Naturally ventilated buildings

Two questionnaires were applied in the naturally ventilated buildings and in the first one, the volunteers related approximately 30 minutes after waking up their age, height, weight ,date of arrival at the headquarter, previous city and state residence. Besides that, they answered the questions: “was your night thermally comfortable?” and “how do you think the day is going to be thermally?”. While the first question had the answers “yes, it was comfortable”, “it was not comfortable” and “I do not remember” the second presented: “cold”, “cool”, “slightly cool” , “neutral”,” slightly warm”, “warm” and “hot”. The aim of those questions was to evaluate in percentage the capacity of *memory and thermal expectancy* of the volunteers.

In the second questionnaire, filled in the second phase of the experiment and 30 minutes after the entrance in the environment, the volunteers answered a question identical to the one described above, what intended to check the *capacity of memory* of the volunteer in relation to the thermal sensation in the recent night. For this, the answers were compared among them and among the thermal sensation votes.

In the sequence, answering “do you think that the fan which is turned on here, makes you feel thermally more comfortable?” with the options: “yes, much more”, “yes, a little more”, Indifferent”, “no, a little less”, and “no, much less”. We intended to verify the influence of the fan in the sensation and thermal preference of the volunteers.

Finally they answered the questions related to the ISO10551 (1995). Those questions were repeated every 20’ , three times more.

Considering that the volunteers in those environments were wearing military uniform, it was not necessary the individual identification of the clothing adopting a constant value of each environment.

3.2.2 Air-conditioned environment

In the air-conditioned environment, it was applied just one questionnaire and always at the beginning of the afternoon and the first answers were given 30 minutes after entering the place of the experiment and they were about: age, height, weight, sex, month and year of the beginning of their activities in that environment, pervious city and state residence, educational level and which clothes they were wearing according to the ISO7730 (1994) options. In the sequence the volunteers answered the questions registered in the ISO10551 (1995) what was repeated three times more after consecutive intervals of 20 minutes.

3.3 Data samples

3.3.1 Naturally ventilated buildings

In those environments we totaled 1,150 votes.

Table 4. - Sample of votes in each naturally ventilated environment.

	Stage 1		Stage 2		
Local	Abril	November	Abril	November	
Recruits	252	0	318	92	
Veteran	134	121	114	119	1.150

The development of an outdoors nocturnal activity in the headquarter justifies the absence of recruits in the experiment carried out in Coimbra during the month of November.

3.3.2 Air-conditioned environment

In this environment 78 volunteers participated, 41 in April and 37 in November.

In this way, the total of votes obtained in the project was 1,228.

4. **Results and discussion**

4.1 Volunteers involved

The statistics of the anthropometric data of the recruit and veterans volunteers are represented in Table 5 as follows:

Table 5 – Statistic data from the resulting sample of the volunteers – NV Env

	Subjects (recruits) - NV Buildings			Subjects (veterans) - NV Buildings		
Statistics	Age (years)	Height (m)	Weight (kg)	Age (years)	Height (m)	Weight (kg)
Means	19	1,73	66	26	1,73	73
Std. err.	0,038	0,003	0,456	0,692	0,005	0,967
Median	19	1,73	65	23	1,725	70
Mode	19	1,70	64	21	1,7	64
Standard Deviation	0,677	0,061	8,009	7,294	0,057	10,278
Variance	0,458	0,004	64,143	53,201	0,003	105,645
Kurtosis	1,234	-0,341	0,280	-0,221	-0,501	-0,105
Minimum	18	1,57	52	19	1,58	55
Maximum	21	1,9	91	44	1,85	100
Sum	5796	537,5	20447	2928	197,14	8193
Quantity	311	311	309	111	114	113
Confidence interval (95,0%)	0,075	0,007	0,897	1,372	0,011	1,916

The test of normality of the distribution of the frequency of the samples carried out by *the Adherence Test of Kolmogorov and Smirnov* with a 95% level of confidence indicated that only the variable "height" has a normal distribution.

The sample of the volunteers that took part into the experiments in the air conditioned environment are indicated on Table 6, with the appliance of *the Adherence Test of Kolmogorov and Smirnov* with a 95% level of confidence that indicated that all variables have normal distribution.

Table 6 – Statistic data from the resulting sample of the volunteers on the air conditioned environment

	Subjects (veterans) - NV Buildings		
Statistics	Age (years)	Height (m)	Weight (kg)
Means	26	1,73	73
Std. err.	0,692	0,005	0,967
Median	23	1,725	70
Mode	21	1,7	64
Standard Deviation	7,294	0,057	10,278
Variance	53,201	0,003	105,645
Kurtosis	-0,221	-0,501	-0,105
Minimum	19	1,58	55
Maximum	44	1,85	100
Sum	2928	197,14	8193
Quantity	111	114	113
Confidence interval (95,0%)	1,372	0,011	1,916

4.2 Climatic variables

4.2.1 Naturally ventilated buildings

The temperatures and relative humidity of the air (indoors and outdoors) and the operative temperatures during the two phases of the experiments are shown in Table 7 below.

Table 7 – Climatic variables observed in the experiments – NV Buildings

Local	Month	Mean	t_a (^{0}C)		RH (%)		t_o (^{0}C)
			Indoor	Outdoor	Indoor	Outdoor	
Coimbra (NV Building)	Abr	Min	33,9	35,3	47	38	34,5
		Max	34,7	36,1	53	44	
	Nov	Min	29,9	-	65	-	30,6
		Max	30,3		71		
Corumbá (NV Building)	Abr	Min	33,6	34,0	54	51	33,3
		Max			56	54	
	Nov	Min	28,3	27,5	56	58	27,4
		Max	30,7	28,7	62	62	
Campo Grande (NV Building)	Abr	Min	22,1	16,0	58	83	24,0
		Max	23,2	16,4	59	88	
	Nov	Min	28,3	30,3	73	56	28,7
		Max	28,7	31,1	75	61	

The intervals obtained were:

$$22.1^0C < t_{a\ IND} < 34.7^0C$$
$$16.0^0C < t_{a\ OUT} < 36.1^0C$$
$$47\% < RH_{IND} < 75\%$$
$$38\% < RH_{OUT} < 88\%$$

During the experiments, the indoor climatic variables obtained with the BABUC were.

Table 8 - Data observed in the naturally ventilated buildings in April.

	Observed data in April - NV Buildings											
	Coimbra				Corumbá				Campo Grande			
	1^0.	2^0.	3^0.	4^0.	1^0.	2^0.	3^0.	4^0.	1^0.	2^0.	3^0.	4^0.
tg (*C)	34,5	34,6	34,6	34,4	33,3	33,4	33,4	33,4	23,5	23,8	24,6	24,8
ta (*C)	34,4	34,5	34,5	34,2	32,9	33,1	33,2	33,2	22,7	23,2	24,0	24,0
RH (%)	49	49	50	52	59	69	75	76	60	59	57	58
va (m/s)	0,20	0,21	0,22	0,24	0,06	0,15	0,19	0,19	0,09	0,08	0,09	0,09

Table 9 – Data observed in the naturally ventilated buildings in November

	Observed data in November - NV Buildings											
	Coimbra				Corumbá				Campo Grande			
	1^0.	2^0.	3^0.	4^0.	1^0.	2^0.	3^0.	4^0.	1^0.	2^0.	3^0.	4^0.
tg (*C)	30,1	31,0	31,1	31,0	26,2	27,3	28,2	28,7	28,3	28,7	28,8	28,9
ta (*C)	29,6	30,2	30,1	30,0	25,9	26,8	27,5	27,9	28,2	28,4	28,7	28,8
RH (%)	71	69	67	66	71	69	66	65	73	74	74	73
va (m/s)	0,07	0,17	0,25	0,22	0,21	0,15	0,08	0,09	0,03	0,15	0,29	0,27

The tests of normality of the distribution of the frequencies of these variables were carried out by the *Adherence Test of Kolmogorov and Smirnov* with a level of confidence of 95% resulting that all of them have a normal distribution.

4.2.2 Air-conditioned environments

In an identical way to the monitoring carried out in the naturally ventilated buildings, the values obtained in the air-conditioned environment were:

Table 10 – Climatic variables observed in the experiments – AC building

Campo Grande (AC Building)	Abr	Min	25,5	32,8	44	31	23,3
		Max		33,6		34	
	Nov	Min	24,6	29,9	53	57	24,3
		Max				60	

The internal variables are indicated on table 11 that is in the sequence.

Table 11 – Data observed in the environment with air-conditioning in April and in November

	Campo Grande - AC Building							
	Abril				November			
	1º.	2º.	3º.	4º.	1º.	2º.	3º.	4º.
tg (°C)	23,6	23,5	23,5	23,5	24,6	24,5	24,4	24,5
ta (°C)	22,6	22,5	22,6	22,6	23,8	23,7	23,7	23,7
RH (%)	53	53	53	53	56	56	55	55
va (m/s)	0,16	0,18	0,18	0,17	0,09	0,10	0,08	0,08

The tests of the normality of the distribution of frequencies were carried out by the *Test of Adherence of Kolmogorov and Smirnov with* a confidence level of 95% indicated that all of them have a normal distribution.

4.3 Analysis of the PMV, PPD, TSV and TPV obtained on the experiments

The PMV and PPD were calculated through the software *InfoGAP – v.2.0.6* – developed by the Italian company LSI-Lastem which considers the ISO7730 (1994) and the TSV and TPV were obtained according to the ISO10551 (1995).

In the application of the methodology proposed by Fanger and Toftum (2002) the factors 0.5 to Coimbra, 0.7 to Corumbá and 0.8 to Campo Grande were considered justifying respectively by the predominance of a hot period in all seasons of the year as well as the existence of few buildings with air-conditioners in Coimbra and a period of hot summer and the different quantities of buildings with air-conditioners in Corumbá and Campo Grande. The results obtained are in Tables 12, 13 and 14 and in Table 12 specifically, we should consider that during the first period of the experiment in Corumbá the environment remained with the fans deliberately turned off. We have to take the same consideration in Table 13 in the first periods of the experiments in Coimbra and in Campo Grande. On these tables the mean values obtained in each of the 4 periods of the experiment are shown.

On the other hand, we should consider that in Campo Grande, on April's experiment, on the day before the experiment, a cold mass of air passed through the city provoking a decrease of 8ºC into the external temperature, decreasing from 19ºC to 11ºC, what is a very low value to the standards of the region, on this part of the year.

We observe on table 12 bellow that even not taking into account the TSV pointed in the first period of Corumbá's experiment thanks to the fact that the fans were off what did not represent the subject's routine, in none of the periods the PMV follow the TSV showing the existence of the discrepancies already mentioned on similar researches in other regions of the world. The methodologies proposed to correct the PMV indicated values that were very close to the TSV, with a maximum nominal difference (ΔV) of 0.4 what has no significance, demonstrating in principle that they are adequate to the finality deserved. The minors mean (ΔV) in Coimbra, Corumbá and Campo Grande were respectively 0,1; 0,2 (ΔV[TSV x PMV_{HN}]) and 0,1 (ΔV[TSV x PMV_{HN}]).

Table 12 – Average values of the TSV and PMV found in April – NV Buildings.

	Observed data in abril - NV Buildings											
	Coimbra				Corumbá				Campo Grande			
	1^{0}.	2^{0}.	3^{0}.	4^{0}.	1^{0}.	2^{0}.	3^{0}.	4^{0}.	1^{0}.	2^{0}.	3^{0}.	4^{0}.
TSV	1,6	1,5	1,3	1,3	2,4	1,8	1,7	1,6	-0,9	-0,5	-0,2	-0,2
PMV (ISO 7730)	3,0	3,0	3,0	3,0	2,7	2,8	2,9	2,9	0,4	0,5	0,7	0,7
PMV (H,N)*	1,5	1,5	1,5	1,5	1,4	1,4	1,5	1,5	0,1	0,1	0,2	0,2
PMV (F,T)**	1,5	1,5	1,5	1,5	1,9	2,0	2,0	2,0	0,3	0,4	0,6	0,6
ΔV [TVS x PMV(HN*)]	0,1	0,1	0,2	0,2	1,0	0,4	0,2	0,1	0,9	0,4	0,0	0,0
ΔV [TVS x PMV(FT**)]	0,1	0,1	0,2	0,2	0,5	0,2	0,3	0,4	0,6	0,1	0,4	0,4
* Humphreys, M. A.; Nicol, J. F. (2002)					** Fanger, P.O; Toftum, J. (2002)							

The table 13 below, that represents the votes obtained on the November's experiment and where were not taken into account Coimbra's first period votes because the fans were purposely turned off, we could observe that discrepancies between the PMV and the TSV were also found. However, we observe that the correction methodology proposed by Humphreys e Nicol (2002) returned values that were very close in Coimbra and Campo Grande while Fanger and Toftum's (2002) one returned the same approach only in Coimbra. This fact can be attributed to the adoption of an inapropriate index (0.8), that can certainly be better analyzed in another experiment. The discrepancies observed in Corumbá can be attributed to the sort of activity realized by the soldiers which are out of this work control, not forgetting the fact that the soldiers entered to the monitored environment 30 minutes before they first answered the questions.

Table 13 – Average values of the TSV and PMV found in November – NV Buildings

	Observed data in novembro - NV Buildings											
	Coimbra				Corumbá				Campo Grande			
	1^{0}.	2^{0}.	3^{0}.	4^{0}.	1^{0}.	2^{0}.	3^{0}.	4^{0}.	1^{0}.	2^{0}.	3^{0}.	4^{0}.
TSV	1,8	0,9	0,9	0,8	0,9	1,4	1,5	1,5	1,7	0,5	0,2	0,1
PMV (ISO 7730)	1,7	1,9	1,9	1,8	0,4	0,8	1,1	1,3	1,4	1,3	1,3	1,3
PMV (H,N)*	0,7	0,8	0,8	0,8	0,1	0,3	0,5	0,6	0,6	0,6	0,5	0,5
PMV (F,T)**	0,9	1,0	1,0	0,9	0,3	0,6	0,8	0,9	1,1	1,0	1,0	1,0
ΔV [TVS x PMV(HN*)]	1,1	0,1	0,1	0,0	0,8	1,1	1,0	0,9	1,1	0,1	0,3	0,4
ΔV [TVS x PMV(FT**)]	0,9	0,1	0,1	0,1	0,6	0,8	0,7	0,6	0,6	0,5	0,8	0,9
* Humphreys, M. A.; Nicol, J. F. (2002)					** Fanger, P.O; Toftum, J. (2002)							

In the air-conditioned environment both the ISO7730 (1994) and the methodology of Humphreys and Nicol (20002) showed values very close to those of the TSV. In Table 14 below, the values of the nominal differences (ΔV) found are related.

Table 14 – Average values of the TSV and PMV found in April and November – AC Buildings.

	Campo Grande - AC Building							
	Abril				November			
	1^{0}.	2^{0}.	3^{0}.	4^{0}.	1^{0}.	2^{0}.	3^{0}.	4^{0}.
TSV	0,1	0,1	-0,1	-0,1	0,4	0,3	0,3	0,2
PMV (ISO 7730)	-0,6	-0,7	-0,7	-0,7	-0,1	-0,2	-0,1	-0,1
PMV (H,N)*	-0,6	-0,8	-0,6	-0,6	-0,2	-0,2	-0,2	-0,2
ΔV [TVS x PMV(HN*)]	0,7	0,9	0,5	0,5	0,6	0,5	0,5	0,4
* Humphreys, M. A.; Nicol, J. F. (2002)								

4.3.1 Observed correlations

4.3.1.1 Naturally ventilated buildings

In the following figures the correlations with 95% of confidence are shown as well as the ones made with the mean votes of each period and according to each one of the classes of volunteers. The votes of the periods which the fans were off were not take into account on the correlations.

We observe on Figure 1 bellow that in the correlation of the TSV with the PMV the coefficient of determination obtained ($r^2 = 0.4032$) indicates that approximately only 40% of the variation of the TSV was explained by the regression line , confirming that the application of the ISO7730 (1994) in the researched environments and under the climatic conditions verified is not adequate to the thermal evaluation that we want.

We can also observe that there is a huge quantity of volunteers out of the comfort range of TSV = +-0.5 admitted by the standard recently mentioned. The majority of them manifested discomfort by hot while a small parcel by cold.

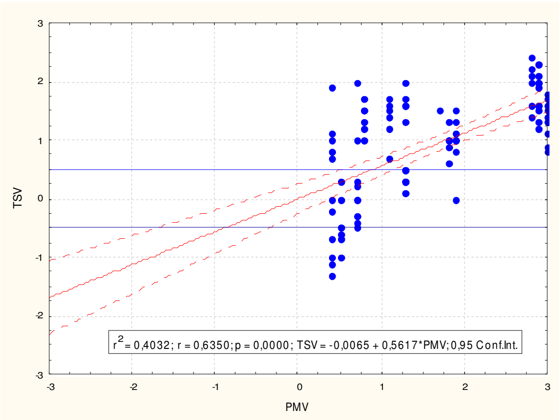


Figure 1- Correlation between the TSV by class and the PMV in the naturally ventilated buildings

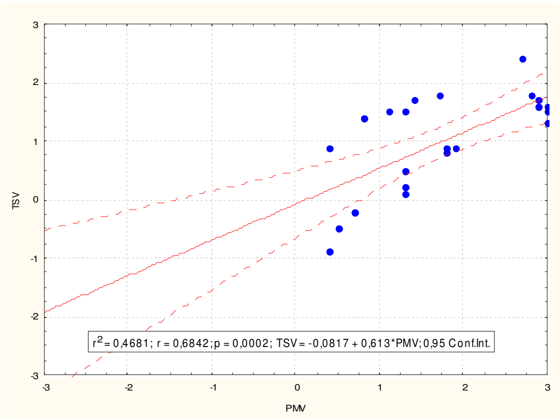


Figure 2 - Correlation between the mean TSV and the PMV in the naturally ventilated buildings

We observe on Figure 1 and 2, that shows the mean TSV of the volunteers by class and period and the mean TSV by period both correlated with the PMV respectively, that the best coefficient of determination is obtained on the correlation of the mean TSV thanks to the smaller dispersion existent when we work with mean values.

This variety of thermal sensation votes between the volunteers can be demonstrated on Table 15, where the coefficients of determination obtained on the correlations between this variable (in each volunteer class) and the PMV obtained on the experiments realized on naturally ventilated buildings. We observe that the minor coefficient of determination was revealed with the TSV indicated by the recruits that are not fan or air conditioner users and higher one, that was also statistically low, was the one indicated by the recruits that are air conditioner users. However, approximately 70% of the volunteers only use fans what turns this fact as a decidable factor on the analysis study realized on the item 4.5 that talks about the influence of the air velocity on the TSV and the TPV to the prediction of the thermal comfort on naturally ventilated buildings.

Table 15 – Correlation TSV and PMV found in April and November in NV Buildings.

Correlation TSV x PMV		r^2 =
Vet	that had AC	0,3953
	that had fan	0,3419
	Without AC and an	0,4201
Rec	that had AC	0,5405
	that had fan	0,5249
	Without AC and an	0,2539

Figure 3, listed bellow, indicates the correlation between the TSV and the TPV with a line with an angular coefficient inverse from the one obtained on the correlation illustrated on figure 1. This inversion results from the thermal sensation votes varying from 0 (neutral) to +3 (hot) regrets to the thermal sensation votes that varies from 0 (neither warmer or cooler) to –3(much cooler). The determination coefficient (r^2 = 0.5917) obtained on the correlation shows that approximately 60% of the TSV are related to the TPV. We observe that there is also a huge quantity of volunteers located above the superior limit of comfort proposed by ISO7730 (1994) indicating, coherently, the discomfort by hot and the preference of fresher environments.

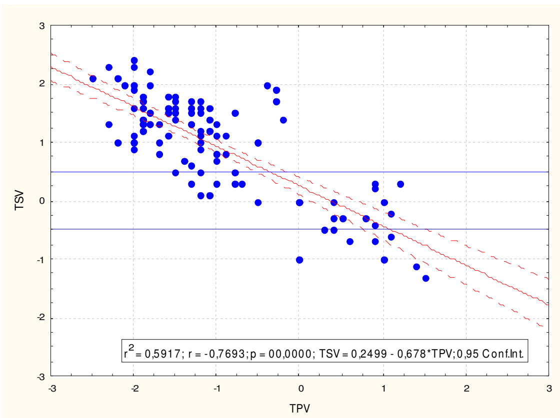


Figure 3 – Correlation between TSV and the TPV in the naturally ventilated buildings

Figure 4 demonstrates that, by the same way, the correlation between the TPV and the PMV according to ISO7730 (1994) didn't produce a nice coefficient of determination (r^2 = 0.4402). This fact reaffirmed positionings about the application of ISO7730 (1994) into naturally ventilated buildings of this particular region under the climatic conditions verified did not represent the thermal reality experienced by the volunteers. However, in addition to the dispersion of the votes, we visualized that there was coherence between the TSV and the PMV what indicates discomfort by hot and a preference for fresher environments.

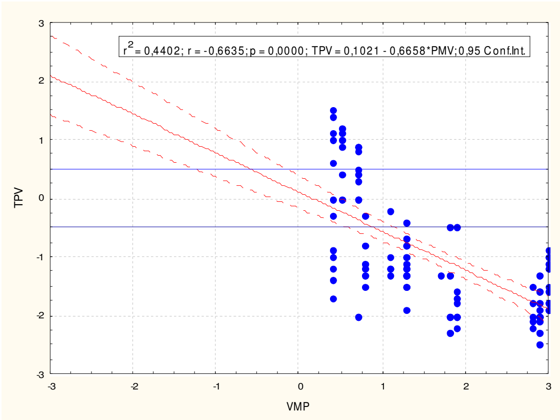


Figure 4 – Correlation between the TPV and the PMV in the naturally ventilated buildings

The correlations between the TSV and the PMV obtained from the correction methodologies proposed by Humphreys and Nicol (2002) and Fanger and Toftum (2002) are represented on Figures 5 and 6. On them we can observe that the coefficients of determination were, respectively, $r^2 = 0.4239$ and $r^2 = 0.4421$ indicating that researches has to be done to adequate these proposals to the naturally ventilated buildings experimented on this work.

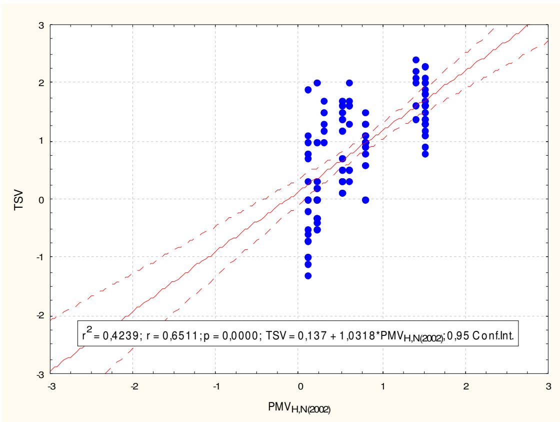


Figure 5 – Correlation between the TSV and the $PMV_{H,N(2002)}$ in the naturally ventilated buildings

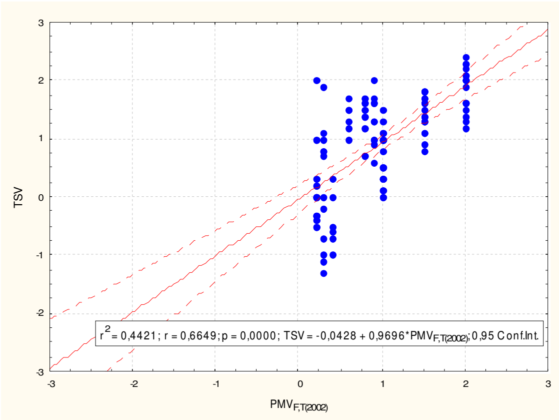


Figure 6 – Correlation between the TSV and the $PMV_{F,T(2002)}$ in the naturally ventilated buildings

4.3.1.2

4.3.1.3 Air-conditioned environment

Considering that the discrepancies found between the VST and the VMP were insignificant in the AC building, it has become unnecessary the graphic representation of the correlation found.

4.3.2 *Adjustment Equations* to the PMV calculated by the ISO7730 (1994).

4.3.2.1 Naturally ventilated buildings

The previous item showed us that there are discrepancies between the TSV and the PMV calculated according to the ISO7730 (1994) and to the correction methodologies proposed by Humphreys and Nicol (2002) and Fanger and Toftum (2002). This fact turned possible the proposition of an *adjustment equation* from the PMV(iso) to the TSV indicated on the researched region. However, as we will observe on Figure 6 bellow, the correlation between the TSV and the PMV(iso) resulted in a low coefficient of determination (r^2 = 0,4004) indicating that the *adjustment equation* searched is not applicable to the pretended region.

On Figure 7 we can visualize the correlation between the TSV and the PMV(iso):

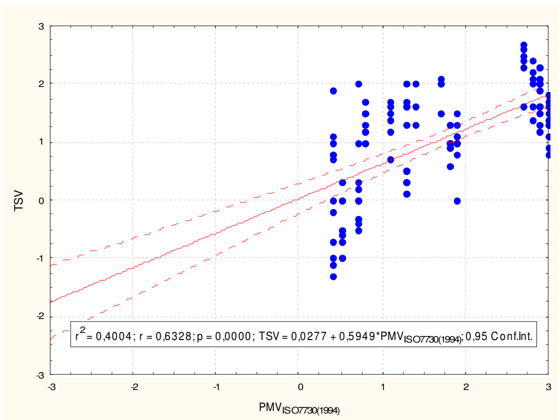


Figure 7 – Correlation between the TSV and the $PMV_{(ISO)}$ – NV Buildings

Thanks to this, besides already demonstrated by the poor determination coefficients obtained by the correlations between the TSV and the $PMV_{ISO7730\ (1994)}$; TSV and $PMV_{H,N(2002)}$; TSV and $PMV_{F,T(2002)}$ as well as on the adjustment equation proposed, we can affirm that to have better conclusions, new experiments must be done on the region to evaluate naturally ventilated buildings occupied by people developing sedentary activities in hot humid climates in Brazil.

4.3.2.2 Air-conditioned environment

Considering the small discrepancies found between TSV and the PMV it has become unnecessary the proposition of the adjustment equation for this environment. Nevertheless, in order to obtain a rigorous approximation to the TSV indicated by the volunteers, the methodology of correction proposed by Humphreys and Nicol (2002) shall be applied as it has presented the smallest nominal differences.

4.4 *Capacity of thermal memory* of the volunteers.

The capacity of thermal memory was analyzed through the answers given to the question "was your night thermally comfortable?" in which 60.00% of the volunteers answered "yes, it was comfortable"; 39.47% "it was not comfortable" and just 0.53% " I do not remember". In the air-conditioned environment, 86.00% answered "yes, it was comfortable" and 14.00% "it was not comfortable". The percentage obtained considering all the environments were 63.00% answered "yes, it was comfortable"; 36.50% "it was not comfortable" and just 0.47% "I do not remember".

Those results reinforce the hypothesis that there is a strong indication that the *thermal memory* of the nocturnal thermal environment can be useful in the study of thermal comfort in built environments.

4.5 The influence of the *air velocity* in the TSV and in the TPV in the prediction of thermal comfort in naturally ventilated buildings.

The analysis of the answers given in question 5 "Do you think that the fan that is here, turned on, makes you feel thermally more comfortable?" revealed uncertainty just in the experiment carried out in Campo Grande in the month of April, certainly due to the fact that the average air temperature in that environment 23.5°C being very close to the inferior limit of the operative temperature verified on the item 4.6. In Coimbra and Corumbá, according to what can be observed on table 16 bellow, the majority of the volunteers reported that with the fans on, they felt a little bit more comfortable. We can observe that the votes manifested on the morning were reaffirmed on the afternoon and with this meaning they were stronger in Corumbá.

Table 16 – Percentage obtained in the answers given to question 5, in the NV Buildings.

	Coimbra		Corumbá	
	In the morning	The afternoon	In the morning	The afternoon
Yes, much more.	24%	31%	35%	22%
Yes, a little more.	67%	62%	47%	64%
Indifferent.	4,5%	3,5%	10%	7%
No, a little less.	4,5%	0%	6%	6%
No, mucj more.	0%	3,5%	2%	1%
No. of subjects	84	26	163	102

.

On tables 17 and 18, respectively, the TSV related in April (Corumbá) and in November (Coimbra) trying to evaluate the influence of the air velocity into the TSV and TPV indicated by the volunteers that commonly used the fans are shown.
In Corumbá, where the fans were off into the first period of the experiment, we observe thanks to the small amount of equipment installed on the ceiling of the environment, the ventilation produced by them was not uniform and almost zero near both sides of the room. Thanks to this, the seats and the questionnaires filled were identified from 1 to 6, generating the data reproduced on table 17 bellow.
On these tables only the volunteers that were fan users were considered as they represent 70.00% of the data obtained.

Table 17 – TSV as function of the location of the seats in Corumbá, in April

Corumbá (abril)	Subjects that had fan							
	Seat 1 (v_a = 0,06 m/s)				Seat 6 (va = 0,18 m/s)			
	1º.	2º.	3º.	4º.	1º.	2º.	3º.	4º.
TSV	2,7	2,5	2,4	2,1	2,0	1,7	1,6	0,9
TPV	-2,1	-2,4	-2,2	-1,8	-1,4	-1,3	-1,4	-1,0

We observe that on the referred table the indication that the air velocity on seat 1 had a mean value of 0.06 m/s while on the seat number 6 it was 0.18 m/s. This mean values refers to the 2º, 3º and 4º period as in the 1º one the fans were off as already mentioned. Table 16 reveals that with a higher average of the air velocity, the TSV on the seat number 6 were smaller than on the seat 1 and thet the values decreased with time.

On table 18 the values of TSV and TPV indicated on the experiments realized in Coimbra in November are shown. On these occasion, due to the fact that on that environment there were no fans installed on the ceiling, the experiment was realized with natural ventilation, maintaining on the first period the windows closed and on the 2º, 3º and 4º permanently open. The medium air velocities were, respectively, 0.07 m/s and 0.21 m/s. Table 18 bellow indicates the TSV and the TPV obtained on the experiment.

Table 18 – TSV and TPV in Coimbra, in November

Coimbra November	Subjects that had fan			
	1º.	2º.	3º.	4º.
TSV	2,1	1,0	1,1	1,0
TPV	-2,0	-1,9	-2,1	-1,7

We observe that only in the first period the TSV and the TPV maintained reasonable correlation. On the other periods of the experiment the TPV didn't follow the TSV indicated by the volunteers.
By this way, we can conclude that the intensity of the air velocity verified on the present research was sufficient only to provoke a small change on the thermal sensation, being, however, insufficient to influence the thermal preference of the volunteers, this fact might have occurred thanks to the difficulty to understand correctly what's the difference in the scale of "thermal preference" values.

4.6 Analysis of the most significant vote between the TSV and TPV to evaluate the Thermal comfort in indoor environments.

The initial hypothesis took into account that the best correlation between the TSV or the TPV in relation to the operative temperature was the indicative searched. However, as we could observe on Figure 8 and 9, none of the 2 correlations did not produced a good determination coefficient. On the correlation with the VST we obtained $r^2 = 0.4690$ and with the TPV, $r^2 = 0.5314$. So, we opted to analyze the TSV with the TPV in the range admitted by ISO7730 (1994) as of comfort with the TSV varying from +0.5 to –0.5.

We observe on Figure 8 that the operative temperature for the comfort limits one inside the limit of the ISO7730 (1994) varies approximately from 23ºC to 31ºC. On this interval we can visualize some points that represent the volunteers in the comfort zone.

However, we observe that the higher contingent of volunteers are found above the line that limit the TSV = +0.5, indicating that they are with discomfort by heat.

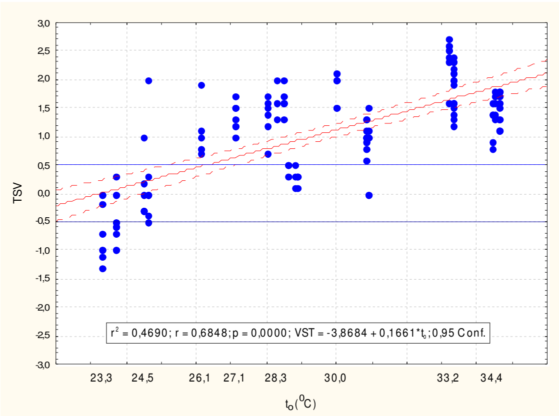


Figure 8 – TSV x to correlation for naturally ventilated buildings

On Figure 9 we verified that the TPV located under the line that indicates the inferior limit of ISO7730 (1994) reinforce the recently found; it means that in the experiment realized few volunteers stayed on the comfort zone while the majority preferred a fresher environment.

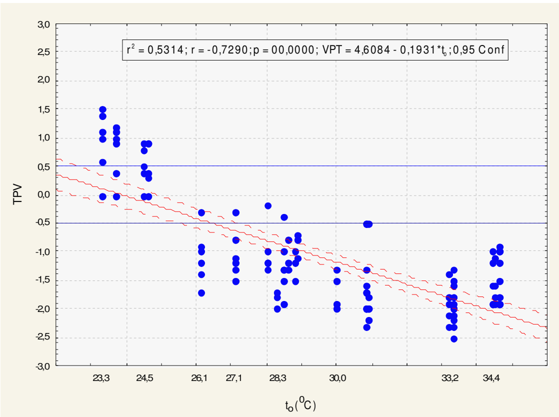


Figure 9 – TPV x to correlation for naturally ventilated buildings

4.7. Analysis of the PPD on the experimented environments

The analyses were realized from 4 hypotheses. For that, the medium values of the TSV and PPD obtained in each experimented period were taken into account.

4.7.1. Hypothesis 1: People who indicated ± 2 and ± 3 in the scale of thermal sensation according to item 4 of ISO 7730 (1994).

The votes which had this indication are represented in Table 19 as follows.

Table 19 – TSV and PPD obtained following the hypothesis 1

TSV x PPD (Hypothesis 1)																
TSV	-0,4	-1,7	-1,2	-0,7	2,3	2,2	2,1	2,1	2,5	2,3	2,3	2,4	2,0	1,0	2,3	1,3
PPD	34	10	8	15	55	45	35	37	63	60	62	58	5	5	6	4

The graphic representation of the correlation between these variables did not produce a curve that seems like Fanger's (1970) model. However, the best coefficient of determination ($r^2 = 0.4911$) was obtained with an exponential curve ($y = a*exp^{b*x}$) as we can see on Figure 10 bellow:

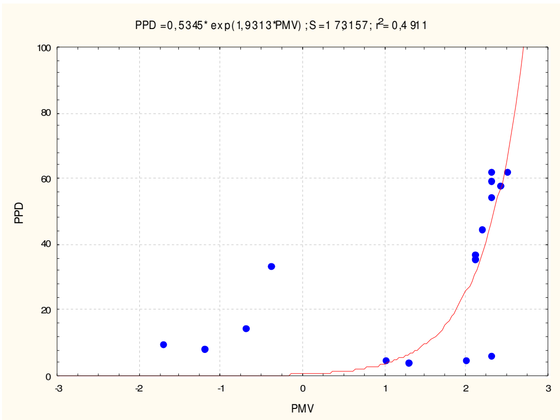


Figure 10 - PPD x TSV (±2 and ±3)

The resultant equation was:

$$PPD = 0.5345*exp^{1.9313*TSV} \quad \text{with } r^2 \cong 0.49 \text{ and standard error} = 17.31$$

We observed that the coefficient of determination ($r^2 \cong 0.49$) indicates a low correlation between the variables what makes unnecessary further analysis to this option as it has to be rejected.

4.7.2 Hypothesis 2: Considering the votes out the band from +0.5 to –0.5 of the scale of thermal sensation as predicted in Appendix D of ISO7730 (1994).

It was considered in this hypothesis that the volunteer who votes +1 could have voted between +0.1 and +1 and those who voted –1 between –0.1 and –1. In this way, the votes between +0.5 and –0.5 were considered as comfort and those from +0.6 to +1.0 and from

-0.6 to -1.0 votes of discomfort as it is indicated in Table 20 below.

Table 20 – Thermal sensation votes in the present hypothesis

TSV		
+3		uncomfortable
+2		uncomfortable
+1	from +0,6 to +1,0	uncomfortable
	from 0 to <+0,6	comfortable
0		comfortable
-1	from 0 to <-0,6	comfortable
	from -0,6 to -1,0	uncomfortable
-2		uncomfortable
-3		uncomfortable

The TSV and PPD obtained are indicated on Table 21. The correlation PPD and TSV resultant is represented on Figure 11 on the sequence.

Table 21 - TSV and PPD obtained following the hypothesis 2

TSV x PPD (Hypothesis 2)																
TSV	-0,4	-0,6	-0,4	-0,4	2,2	2,1	2,0	1,9	2,2	2,0	2,1	2,1	0,4	0,2	0,2	0,0
PPD	58	36	29	33	75	67	60	60	75	74	74	72	26	26	29	27

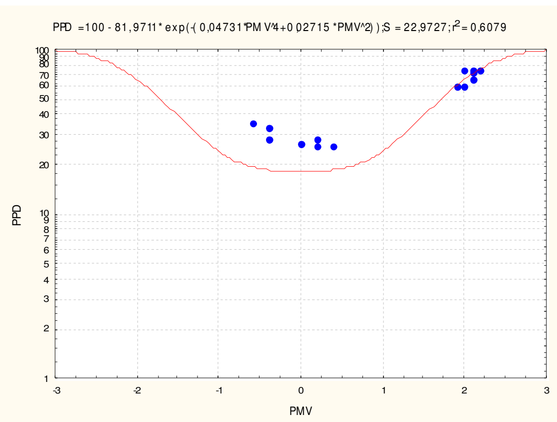


Figure 11 – PPD x TSV (- 50% of those who voted +1 or –1 in thermal sensation scale)

Resulting equation: $PPD = 100 - 81.9711 * e^{-(0.04731*TSV^4+0.02715*TSV^2)}$

$r^2 \cong 0.61$ standard error = 22.97

The coefficient of determination indicating mean correlation added to the standard error founded does not allow this option to be used on the region studied.

4.7.3 Hypothesis 3: All the people who indicated the option “comfortable” in the question “how are you feeling now?” are comfortable.

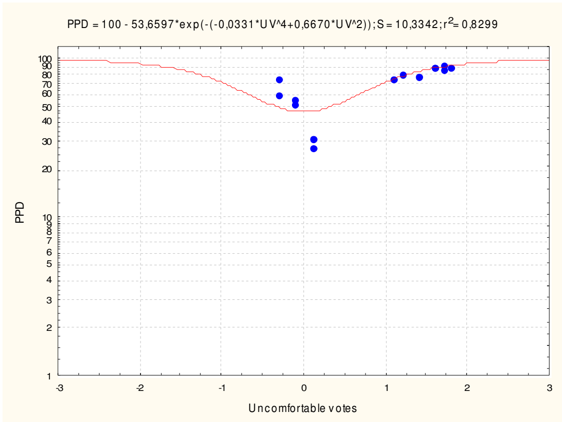
This hypothesis considers that the answer given to question 7 “How are you now?” should be understood as unquestionable and that in this way, the other votes indicate the people dissatisfied with the thermal environment. However, the good coefficient of determination could indicate that this option should be accepted, but the dispersion of the data around the TSV = 0, that indicates that 46% of the people are dissatisfied with the thermal environment, did not allow its application.

Table 22 - TSV and PPD obtained following the hypothesis 3

TSV x PPD (Hypothesis 3)																
TSV	0,4	0,2	0,2	0,0	2,5	2,2	2,2	2,2	2,2	1,9	1,6	1,4	1,9	0,9	0,8	0,8
PPD	25	26	29	27	96	78	76	71	88	52	56	50	77	30	19	15

Figure 12 below represents the correlation obtained.

Figure 12 – PPD x TSV (± 1 and with a comfortable vote)



Resulting equation: $PPD = 100 - 53.6597 * e^{-(-0.0331*TSV^4 + 0.6670*TSV^2)}$

$r^2 \cong 0.83$ standard error= 10.33

5. Conclusions

This work has the objective of discussing and presenting proposals about the following subjects:

5.1 The analysis of the PMV in relation to the TSV and the proposition, if necessary, of *adjustment equations.*

On the analysis of the naturally ventilated buildings it was proved the existence of discrepancies between the PMV and the TSV_{ISO} as well as in relation to the correction methodologies proposed by Humphreys and Nicol (2002) and Fanger and Toftum (2002). These findings allowed us to propose an *adjustment equation* that produced a coefficient of determination that indicated a little correlation between the variables, turning it unusable for the application on the environments researched. By this way, the evaluation of naturally ventilated buildings occupied by people developing sedentary activities and located on the region researched still needs to be solved. The discrepancies found on the correction methodologies, like the *adjustment equation,* might have occurred on the composition of the original model of calculus that besides being already questioned about the application of the tables concerning the clothes insulation and the metabolic rate, the region researched has climatic factors that extrapolate the limits imposed by the normalized model. Frequently the air temperatures are higher than 30ºC as well as the PMV calculated analytically are also higher than +2.0, as it has been demonstrated. These factors certainly shall have contributed to the discrepancies observed on this work.

On the air conditioned environment, we verified little discrepancies what made unnecessary the proposal of *adjustment equations.* However, the Humphreys and Nicol's (2002) methodology produced nominal differences inferior to the ones verified between the VST and the PMV calculated using ISO7730 (1994), what makes it usable with no restrictions.

5.2 *Thermal memory*

In the analysis of the capacity of thermal memory of the volunteers, 63.00% of the volunteers reaffirmed in the evening period what they stated early in the morning, that is, the fact that their night had been thermally comfortable. Only 0.47% did not remember about the nocturnal thermal condition. These results reinforce the hypothesis that there is a strong indicative that the thermal memory of the nocturnal thermal environment can help thermal comfort researches on the built environment.

5.3 The importance of the air velocity in the indication of the TSV and TPV.

It has been shown that there is a large variety of TSV indicated by the different classes of volunteers (Table 15) and that approximately 70.00% of the volunteers are fan users. This percentile was determinant to choice the class analyzed on this item. Then, we could observe that in the morning statement of the majority of the volunteers relating that they felt a little bit more comfortable with the fans turned on was reaffirmed in the TSV and TPV indicated in the afternoon experiment. This verification was valid for both Coimbra and Corumbá. However, the answers indicated by the volunteers from Campo Grande in April's experiment revealed uncertainties justified by the fact that the average temperature of the air in the environment (23.5° C) is very close to the inferior limit of the operative temperature verified in this work for naturally ventilated buildings. On the other hand, we also verified that the air velocity was sufficient to let the thermal sensation a little better but insufficient to influence the thermal preference of the volunteers.

5.4 Definition of the most significant between the TSV and the TPV to the indication of the human thermal state.

As already affirmed before, in the initial hypothesis considered that the best correlation between the TSV and the TPV in relation to the operative temperature was the searched indicative. However, as we could observe on figures 7 and 8, none of the 2 correlations produced a good coefficient of determination. On the correlation with the TSV, we obtained r^2= 0.4690 and with the TPV r^2 = 0.5314. So, we opted to analyze the TSV and

the TPV on the range admitted by ISO7730 (1994) as the comfort one, with the TSV varying from –0.5 to +0.5.
The correlations realized it has been demonstrate that inside the ISO7730's(1994) limit the operative temperature varies approximately from 23ºC to 31ºC. On this interval we visualize some points that represents the volunteers that are comfortable. However, in the correlation of the TSV with the operative temperature we observed that there was a higher number of volunteers above the limit line that had TSV = +0.5 indicating that they are uncomfortable by hot, as well as in the correlation with the TPV that reveals that a little amount of the volunteers stayed on the comfort zone while the great majority preferred the thermal environment to be fresher.
By this way, on the analysis of the naturally ventilated buildings occupied by people developing sedentary activities and located on the region experimented and that takes into account the operative temperature, we shall consider the sensation and the thermal preferences of the volunteers, as we already expected.

5.5 Analysis of Percentage of thermally dissatisfied people (PPD)
From the admitted hypothesis, only the one that considered that were thermally dissatisfied the votes that indicated an option different from "comfortable" in the question "how are you felling at the present moment?" with $r^2 \cong 0.83$ and standard error = 10.33 can be accepted but with restrictions, because the indication that 46% of the volunteers were thermally dissatisfied.

5.6 About ISO 7730 (2005)
We observed that in the experiments realized on the naturally ventilated buildings only a few number of thermal sensation votes between 0 and –3 and thermal preference votes between 0 and +3 occurred, certainly because of the climatic characteristics of the region that frequently has the air temperature higher than the limit adopted by ISO 7730 (1994) and by the actual ISO 7730 (2005). It has also been demonstrated that discrepancies were verified between PMV and TSV, what clearly shows that ISO 7730 (1994) is not adequate for this region, what probably happened thanks to the climatic occurrences recently considerated. However, this fact could have been round by ISO 7730 (2005) recently approved. We should also warn about our regional climatic characteristic, that is the reason why we constantly have PMV > +2 and $t_a > 30^0C$, is also decidable for turning impossible to fit our environments on the 3 categories proposed on the TableA.1 of the Appendix A, as we will always have PPD >> 15% and PMV >> +0.7. The use of the Figure A.1 is impossible because the relative humidity on the region is commonly higher than 50%.
Thanks to it, we understand that ISO 7730(2005) will contribute with nothing for the evaluation of the thermal comfort in naturally ventilated buildings and in regions of hot humid climates like the environments where this work took place. This finding can be solved adding climatic data of regions like the ones evaluated on this work do the field work database and produce futher analysis to be considered by the standards.

According to what is written above, we can affirm that the results obtained on this research, the evaluation of thermal comfort of people developing sedentary activities in naturally ventilated buildings located in a hot-humid region of Brazil still needs a lot of

study. For this, we must extend the research not only adding new locations but also using more volunteers, turning more representative the results obtained.
The experiment realized on the air conditioned environment demonstrates that the ISO7730(1994) and the Humphreys and Nicol's (2002) methodology are adequate to the evaluation of people developing sedentary activities having this last one the preference as the differences between the TSV and the PMV obtained using it have little nominal values.

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