International Journal of
Science and Engineering Investigations vol. 6, issue 65, June 2017
ISSN: 2251-8843

Evaluation of Thermal Comfort of Men and Women in Food Courts

Rejane MartinsViegas[1], Wagner Augusto Andreasi[2]
[1]Postgraduation Program in Energy Efficiency and Sustainability, Federal University of Mato Grosso do Sul, Brazil
[2]Ph.D., Prof. in the Postgraduation Program in Energy Efficiency and Sustainability, Federal Univ. of Mato Grosso do Sul, Brazil
[2]Coordinator of the Laboratory of Analysis and Development of Buildings (LADE)
([1]rejaneviegas@hotmail.com, [2]wagner.andreasi@ufms.br)

Abstract- The objective of this study was to evaluate the thermal comfort in both genders in food courts of commercial buildings located at tropical humid climate, by surveying environmental variables (air temperature, mean radiant temperature, relative humidity and air speed) and personal variables (thermal clothing insulation and metabolic rate) along with subjective variables, according to ASHRAE Standard 55/2013, ISO / FDIS 7730: 2005 (E) and ISO 10551: 1995. It was found that both genders were dissatisfied with the temperatures at issue, males more dissatisfied than females. Regarding thermal sensation, no significant difference was seen in the two areas studied both in the spring and summer time. Variations were identified between the comfort analytical results PMV (Predicted Means Vote)/ PPD (Predicted Percentage of Dissatisfied) and the users´ actual thermal sensations, thus, the ISO / FDIS 7730: 2005 (E) and ASHRAE 55 (2013) standardized models showed no applicability for this type of environment, inserted in this climate.

Keywords*- Thermal Comfort, VMP/PPD, Human Genders*

I. INTRODUCTION

The thermal comfort and the differences between human genders under the effect of heat have been studied since 1967 [1]. Some factors must be considered, such as the building and local climate, have been evaluated by researchers in different climatic regions of the world. The current experiment takes place in a region of tropical humid climate.

As it can vary from one person to another [2], thermal comfort is a very subjective issue, determined by psychological and physiological differences [3]. Although discrepancies still appear between males and females, they are not considered significant [2].

The ISO 7730 [8], created in 1984 and named "Moderate thermal environments - Determination of PMV (Predicted Means Vote) and PPD (Predicted Percentage of Dissatisfied) indices and specification of thermal comfort conditions", has been revised every 10 years, incorporating the latest advances in related techniques. The first update took place in 1994 and the last version was presented in 2005, entitled "Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort with calculation of the PMV and PPD indices and local thermal comfort criteria". That is the standard third edition and provides information on local thermal discomfort and indication of thermal comfort categories. It was developed in parallel with the revision of the ASHRAE 55 standard [9], based on the Fanger method [1], and specifies the methods of measurement and evaluation of moderate thermal environments. The standard describes thermal discomfort or thermal dissatisfaction by the PPD index, predicting the percentage of people likely to feel cold or hot in a given environment. The PPD is obtained from the PMV.

The objective of this article was to analyze and determine the thermal comfort by gender in food courts of commercial buildings with mixed mode of ventilation, considering that the region of humid tropical climate presents high temperatures over most of the year, which can cause thermal discomfort.

II. REVIEW OF LITERATURE

Numerous studies have been developed addressing gender and thermal comfort. Fanger [2] conducted several experiments of thermal comfort, therefore providing subsidies for the equation and analytical calculations of thermal comfort: the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD). He concluded that no significant difference is seen between genders in thermal preferences.

Karjalainen [4] conducted a scientific review on men´s and women´s evaluation of internal thermal comfort. Gender differences were generally considered poor and insignificant, but women expressed more dissatisfaction than men, especially in conditions where the environment was colder (northern Finland), where the winter is very cold and temperatures range from - 4 ° C to -15 ° C.

Zhai [5] developed a study with 30 female and 30 male students in a hot and humid Chinese city in which the participants were exposed to seven combinations of temperature and humidity in climate chambers. They were monitored all year round in their classrooms and dormitories. All students presented clothing insulation value 0.5 clo. During the experiment, subjective and physiological responses were also collected while the participants were inside the chambers. The results were analyzed by the Fisher exact test, used to compare the percentage of dissatisfied people for both genders. The findings showed no significant differences in the thermal sensation felt after the participants were exposed to the seven temperatures provided (F = 0.38 p = 0.54), although women tended to be more dissatisfied with cold temperatures and men more dissatisfied with hotter temperatures.

Another study involving men and women [6] was carried out with the aim of comparing the subjective effect of the thermal sensation under the effect of heat on. The volunteers were exposed to temperatures between 23.3 °C and 43.3 °C. For the analysis of results, linear regression equations related to the thermal sensation and air temperature were made, showing that the desired temperature for men has a lower significance than for women (1%).

In the US, researchers investigated the influence of gender and age on thermal satisfaction in office environments. Field measurements included data collection of the four environmental variables and questionnaires about thermal satisfaction were distributed to each occupant at their workstations. The analysis of the environmental and subjective variables reinforces the correlation between the quality of environment available and the user´s satisfaction. The statistical analysis of data such as age and gender revealed that there is a significant difference, more frequent in cold thermal environments, of women in relation to men, unlike in warm environments, where the thermal satisfaction of both genders is almost the same [7].

III. MATERIALS AND METHODS

The method adopted consists of a quantitative and comparative analysis of the thermal sensation values from data collected by the PMV/PPD model, which served as a basis for international standards of thermal comfort, such as ISO 7730 [8] and ASHRAE 55 [9].]. In addition, the users were given questionnaires based on ISO 10551 [10].

The areas chosen for experiment are food courts of two hypermarkets located in the city of Campo Grande, capital of the State of Mato Grosso do Sul, Brazil, defined by geographic coordinates (latitude 20º28'13.40 "S and longitude 54º37'25.87" W), tropical climate with dry winters and wet summers [11]. Measurements were made in the spring of 2016 and summer of 2017.

A. Environment Characterization

The buildings consist of a ground floor, and the roofs of the food courts are partially composed of glass skylights, providing a mix of natural and artificial lighting. Despite the possibility of natural light entering the room, the studied areas do not have any opening at hand that could allow natural air to enter the environment. The internal space - mall, checkout and food court – is interconnected without delimitation made by walls or partitions. The buildings operate with artificial air conditioning system for most of the day, alternating with natural ventilation mode, and users have no control over the thermal condition of the environment.

The internal space of Supermarket 1´s food court is presented in Fig. 1. The environment has a square-shaped architectural typology, totaling approximately 190.00 m² in the area of food tables, with capacity for 169 people in a sitting position. The environment distribution of the food court of Supermarket 2 is presented in Fig. 2. It is a triangle-shaped facility with about 435.87m² in the table area, seating 338 people.

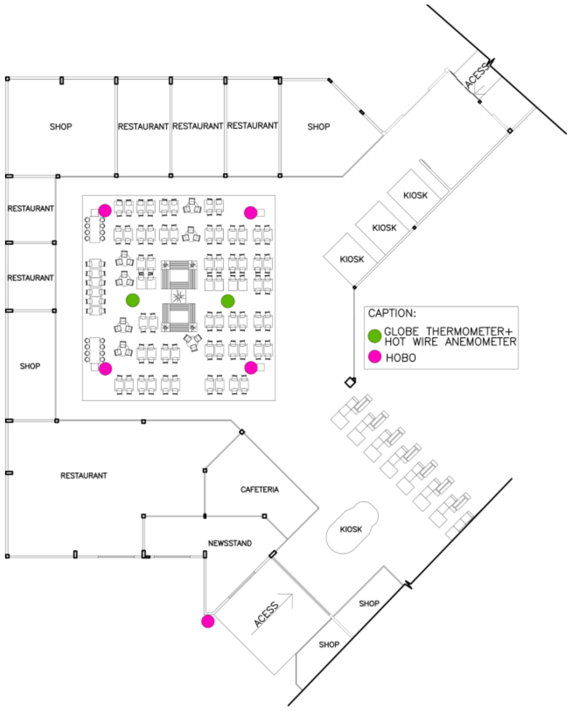


Figure 1. Food Court 1

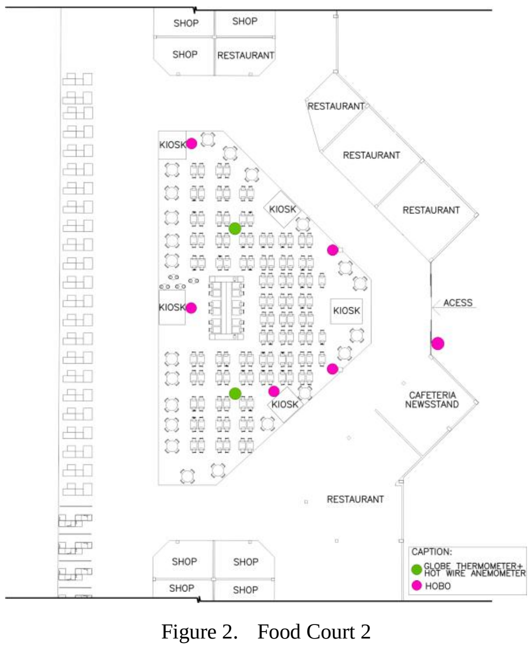


Figure 2. Food Court 2

B. *Measuring equipment (environmental variables)*

The positioning of the air temperature measurement equipment is specified by ISO 7726 [12]. The dry-bulb temperature sensor - TGM100 was used on a tripod to measure the air (ºC) and globe (ºC) temperatures that define the mean radiant temperature (1). The digital hot-wire anemometer allows measuring the air speed (m/s), and the HOBO® RH TEMP sensor was used for collecting the relative humidity (%) and air temperature (°C), all represented in Fig. 3 with specifications in Table 1.

$$t_r = [(t_g + 273)^4 + 2,5 \,.\, 10^8 .\, v_a^{0,6} \,.\, (t_g - t_a)]^{1/4} - 273 \quad (1)$$

Where:

tr = Radiant temperature
ta = Air temperature (ºC)
tg = Globe temperature (ºC)
va = Air speed (m/s)

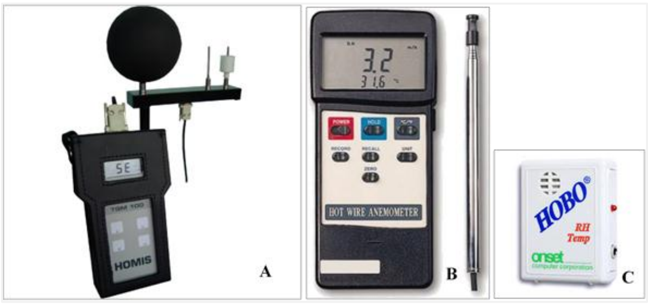


Figure 3. Sensor-like equipment for measuring the environmental variables A) The dry-bulb temperature sensor - TGM100; B) Hot wire anemometer; C) Hobo

TABLE I. TECHNICAL SPECIFICATIONS OF SENSORS

Characteristics	Globe Thermometer	Hot wire anemometer	Hobo
Tar accuracy	0,1%	± 2%	± 2%
Mrt accuracy	0,1%	-	-
Har accuracy	0,1%	-	± 3%
Var accuracy	-	± 1%	-
Tar reach	-10 a 70°C	0 a 80ºC	-20ºC até 70ºC
Trm reach	-50 a 100°C		
Har reach	15 a 85%	-	0% até 95%
Var reach	-	0 a 20 m/s	-

C. *Questionnaires (subjective variables)*

In the same period when the climate variables were obtained, the users were given questionnaires divided into two parts. The first addressed anthropometric characteristics such as gender and clothing, and the second referred to thermal sensation according to ISO 10551 [10]. The question was, "How are you feeling now in terms of temperature?" The following options wereprovided: Comfortable; Slightly Uncomfortable; Uncomfortable; Very Uncomfortable. As a parameter for the evaluation, adults of both sexes were chosen.

D. *Procedures and analyses*

Data were collected in the spring of 2016 and summer of 2017, morning and afternoon, starting at 12:00 and finishing at 14:00. In the experiments, the users had no control over the thermal conditions of the premises, such as opening or closing doors (the rooms do not have windows) and turning the air conditioning system on or off.

For the analysis of personal variables, it is essential to determine the individuals´ metabolic rate, which is the amount of heat produced by the body. The metabolic rate was thus estimated at 1.2 met, defined by ASHRAE 55 [9] with the individuals performing the same activity in a sitting position. Another variable is clothing, for which the following options were selected: sleeved T-shirt, singlet, long-sleeved shirt, short-sleeved shirt, shorts, jeans, trousers, skirt, dress, socks/pantyhose, sneakers, slippers, shoes and boots. In addition to these options, the values +0.04 clo were added to each individual for underwear.

The records of the environmental variables were kept every five minutes, after which the mean values were determined. Before collecting the variables, the equipment was assembled and installed one hour in advance for stabilization. The measurements were undertaken on a sector basis, so that each equipment could cover the divided area for better evaluation of results.

In Area 1, seven points were established, one in the external area and six in the internal space (Fig. 1). In Area 2, nine points were settled, one and eight in the external and internal zones, respectively (Fig. 2)

For data analysis, PMV and PPD values were obtained from the averages of air temperature (ºC), air velocity (m/s), air humidity (%), mean radiant temperature (ºC), metabolic rate (met) and clothing insulation (clo). The PMV is known as the thermal comfort equation and is contained in ISO 7730 [8], the first thermal comfort standard to be used on a global scale.

The results were evaluated by the Ladesys 1.0 software developed by the Laboratory of Analysis and Development of Buildings (LADE) – UFMS, in which the input data of environmental and personal variables were inserted. A table was then generated that calculates all the data and the information output, such as PMV and PPD. For the data to be considered valid, the Pearson´s coefficient of variation was used, which is a relative measure of dispersion used to estimate the accuracy of experiments and that represents the standard deviation expressed in percentage.

IV. RESULT AND DISCUSSION

The users who participated in the survey were classified by gender (Fig. 4). Among the respondents, the female was the majority, both in the spring and in summer for the two areas.

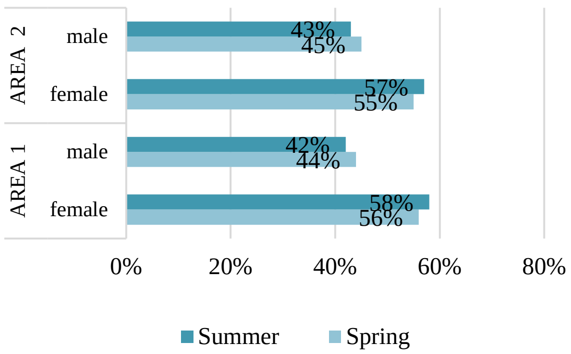


Figure 4. Gender of interviewees

Tables II show the means of the personal and environmental variables of the four measurements and their averages with statistical analyses. The abbreviations used in the tables are represented as follows:

Clo = Mean thermal insulation of clothing

Ta = Air temperature (ºC)

Trm = Mean Radiant temperature

Va = Air speed (m/s)

Ha = Air humidity (%)

The environmental parameter that presented the highest coefficient of variation was air velocity, with high dispersion of 65% in the spring and 287% in the summer, therefore considered heterogeneous data. The subjective parameter, such as Clo, presented data with intermediate dispersion in both genders, since it did not exceed the considered limit of 30%. The remaining variables were evaluated with low dispersion and were considered homogeneous data for not exceeding the variation of 15%. The results of the degrees of thermal sensation are seen through charts of absolute frequency and relative frequency

In Food Court 01 (Fig. 5), in the spring season, most individuals (regardless of gender) expressed that they were feeling "comfortable", resulting in a coefficient of variation of 15% of the Thermal Sensation Vote (TSV). In the summer season, while the females felt "comfortable", most males felt "slightly uncomfortable", resulting in a coefficient of variation of 26%, with an intermediate difference between genders.

As to Food Court 02 (Fig. 6), in the spring season, while females felt "uncomfortable", most males felt "very uncomfortable", resulting in a high coefficient of variation of 13% between the genders. In the summer season, the majority in both genders felt "slightly uncomfortable", producing a coefficient of variation of 19%, with intermediate difference between genders.

TABLE II. VARIABLES OF SEASONS

Spring							
Data			*Clo*	*Ta*	*Trm*	*Va*	*Uar*
AREA 1	FEM	mean	0,42	27,3	30,5	0,12	54,3
		standard deviation	0,13	0,19	0,47	0,06	0,69
		coef. var. (%)	30,0	0,7	1,5	49,6	1,2
	MALE	mean	0,47	27,3	30,5	0,12	54,3
		standard deviation	0,11	0,19	0,47	0,06	0,69
		coef. var. (%)	22,6	0,7	1,5	49,6	1,2
AREA 2	FEM	mean	0,46	31,8	33,1	0,08	40,9
		standard deviation	0,10	0,45	0,39	0,05	2,81
		coef. var.(%)	21,9	1,4	1,2	65,0	6,9
	MALE	mean	0,48	31,8	33,1	0,08	40,9
		standard deviation	0,08	0,45	0,39	0,05	2,81
		coef. var.(%)	17	1,4	1,2	65,0	6,9
Summer							
Data			*Clo*	*Ta*	*Trm*	*Va*	*Uar*
AREA 1	FEM	mean	0,43	29,0	28,9	0,01	52,5
		standard deviation	0,10	0,36	0,61	0,04	1,45
		coef. var. (%)	23,3	1,3	2,11	287	2,8
	MALE	mean	0,48	29,0	28,9	0,01	52,5
		standard deviation	0,09	0,36	0,61	0,04	1,45
		coef. var. (%)	19,3	1,3	2,11	287	2,8
AREA 2	FEM	mean	0,41	29,0	28,6	0,2	42,0
		standard deviation	0,11	0,58	0,6	0,09	1,82
		coef. var.(%)	27,3	2,00	2,3	34,3	4,3
	MALE	mean	0,45	29,0	28,6	0,2	42,0
		standard deviation	0,11	0,58	0,6	0,09	1,82
		coef. var.(%)	24,8	2,00	2,3	34,3	4,3

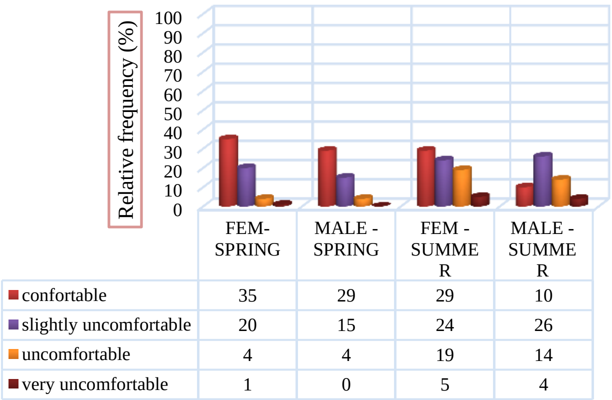
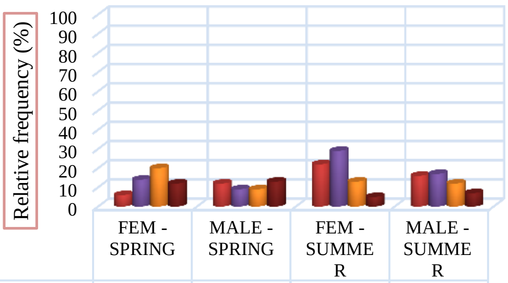


Figure 5. Thermal sensation Results - Area 01



	FEM - SPRING	MALE - SPRING	FEM - SUMMER	MALE - SUMMER
confortable	6	12	22	16
slightly uncomfortable	14	9	29	17
uncomfortable	20	9	13	12
very uncomfortable	12	13	5	7

Figure 6. Thermal sensation Results - Area 02

In applying the PMV method (Tables III), users lie in the "discomfort" range, since ISO 7730 [8] admits acceptable environments between - 0.5 <PMV <+ 0.5. The PPD should not exceed 10% and the results of males and females in both seasons exceeded the admitted value. The statistical analysis revealed no significant differences between genders in relation to PMV or PPD, with all variations below 10%.

TABLE III. RESULTS OF THE VMP/PPD METHOD

Spring					
Data		*VMP*	*PPD*	*Analysis ISO 7730*	*Analysis ASHRAE 55*
AREA 1	fem	0,99	25,7	Slightly heat	Slightly heat
	male	1,06	28,6		
	mean	1,03	27,1		
	sd	0,05	2,05		
	cv (%)	4,83	7,55		
AREA 2	fem	2,23	85,8	Heat	Heat
	male	2,23	86,0		
	mean	2,23	85,9		
	sd	0,00	0,14		
	cv (%)	0,00	0,16		
Summer					
Data		*VMP*	*PPD*	*Analysis ISO 7730*	*Analysis ASHRAE 55*
AREA 1	fem	1,30	40,1	Slightly heat	Slightly heat
	male	1,34	42,5		
	mean	1,32	41,3		
	sd	0,03	1,7		
	cv (%)	2,14	4,11		
AREA 2	fem	0,75	16,8	Slightly heat	Slightly heat
	male	0,82	19,1		
	mean	0,79	17,9		
	sd	0,05	1,63		
	cv (%)	6,31	9,06		

V. CONCLUSION

This study reported field experiments that included measurements of environmental and subjective variables undertaken in the city of Campo Grande, MS, Brazil, in the food courts of two commercial buildings, where the artificial mode of air conditioning prevails in the spring and summer seasons. The collected data were submitted to statistical analysis in order to check possible differences between genders as to the thermal sensation variable. Based on the obtained results, it is concluded that:

- No significant differences were seen between genders as to the thermal insulation of clothing (Clo);
- Regarding the users´ thermal sensation even though there was a difference of low to intermediate dispersion, no significant difference was observed in the two studied areas, for both spring and summer seasons;
- In this type of environment, males were more dissatisfied with the heat than females;
- Variations were observed between the actual thermal sensations of the users and those recommended by the PMV analytical model, with exception for Area 2 in the summer season, where VST and PMV were also "slightly uncomfortable" for both genders;
- The interpretation of thermal comfort using the calculation of PMV/PPD indices of ISO 7730/2005 [8] does not adequately assess the percentage of thermally unsatisfied people;
- Considering the variables found, the air conditioning system should control the temperatures (Table IV) to achieve thermal comfort, since the offered internal air temperature is high, causing heat discomfort to men and women.

TABLE IV. TEMPERATURE BANDS FOR COMFORT

Season	Area 1	Area 2
Spring	22,9 °C - 23,3 °C	21,2 °C - 21,4 °C
Summer	24,1 °C - 24,5 °C	27,0 °C - 27,4 °C

Therefore, this study corroborates the findings of other researchers who evaluated the same aspect in different climatic regions in the world. Also, it is important to perform field studies to obtain actual thermal sensations, since the findings of this research show that the users' sensations and the PMV/PPD analytical method are discrepant. This study did not address menopausal women, a condition that can lead to differences in thermal sensation when compared with women not undergoing such process. In further studies about the thermal comfort assessment, statistical analyses can be applied to other variables, such as the users´ weight, age and height.

REFERENCES

[1] Morimoto, T., Slabochova, Z., Naman R.K., argent 2nd F. Sex differences in physiological reactions to thermal stress. Journal of Applied Physiology, Vol. 22.3, 526-532, 1967.

[2] Fanger P.O. Thermal comfort: analysis and applications in environmental engineering. Copenhagen: Danish Technical Press; 1970.

[3] Schellen, L. The influence of local effects on thermal sensation under non-uniform environmental conditions-Gender differences in thermophysiology, thermal comfort and productivity during convective and radiant cooling. Physiology & Behavior, Vol. 107 (2012) 252–261, 2012.

[4] Karjalainen S. Thermal comfort and gender: a literature review. Indoor Air, Singapore, Vol. 22: 96–109, 2012;

[5] Zhai, Y., Zhang, Y., Meng, Q., Chen, H., Wang, J. Gender differences in thermal comfort in a hot-humid climate. Proceedings of the 13th International Conference Indoor Air, Hong Kong. July. 2014.

[6] Beshir, M. Y.; Ramsey J.D. Comparison between male and female subjective estimates of thermal effects and sensations. Applied Ergonomics, Vol.12.1, 29-33, 1981.

[7] Choi, J.; Aziz A.; Loftness V. Investigation on the impacts of different genders and ages on satisfaction with thermal environments in office buildings. Building and Environment, Vol. 45, 1529–1535, 2010.

[8] ISO 7730 - International Organization for Standardization. "Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort", 2005.

[9] ANSI/ASHRAE Standard 55. "Thermal Environmental Conditions for Human Occupancy. American Society of Heating Refrigerating and Air Conditioning Engineers" Inc. Atlanta, USA, 2013.

[10] ISO 10551 - International Organization for Standardization. "Ergonomics of the thermal environment - Assessment of the influence of the thermal environment using subjective judgment scales". Genebra. 1995.

[11] Kottek, M., Grieser, J., Beck, C., Rudolf B., Rubel F. World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrif, Vol. 15, n.3, pp. 259–263, 2006.

[12] ISO 7726 - International Organization for Standardization. "Ergonomics of the thermal environment - Instruments for measuring physical quantities". 1998.

Rejane Martins Viegas is an architect and urbanist postgraduated in construction management, currently taking her master degree in Energy Efficiency and Sustainability, and a researcher at the Laboratory of Analysis and Development of Buildings (LADE) in the School of Civil Engineering, of the Federal University of Mato Grosso do Sul , Brazil.

Wagner Augusto Andreasi (B.Eng., M.Sc., Ph.D.) is professor in the Postgraduation program in Energy Efficiency and Sustainability, Federal University of Mato Grosso do Sul, Brazil , and is the coordinator of the Laboratory of Analysis and Development of Buildings (LADE).