

# A Field Study on Thermal Comfort of Occupants at a Library Using Natural Ventilation and Air-Conditioning System in Brazil

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**Abstract**-A field of study was conducted to investigate the thermal environment and occupants' comfort in a central Library of a public university in Brazil, using the A/C (air-conditioning) system and natural ventilation. The occupants' thermal perceptions in the library were measured and characterized. The response of the occupants has indicated that the thermal conditions at the library are better with the use of Natural Ventilation than with the use of A/C system. Besides, both of the cases are satisfactorily in accordance with the ASHRAE Standard 55. However, the temperature and the relative humidity (RH) were too high compared to the optimal range of 18-22°C and 55±5% respectively. Findings of this study are very useful for designing heating, ventilating and air-conditioning (HVAC) systems with energy-saving methodology for library buildings in hot humid regions.

**Keywords**- *Thermal Sensation, Natural Ventilation, Energy Saving Strategy, Field Study*

## I. INTRODUCTION

Library buildings are significant in their representation of cultural heritage and knowledge. It's necessary to provide thermal comfort to the occupants as well as to guarantee an indoor climatic condition for protecting the collection. The HVAC (heating, ventilating and air-conditioning) system that prevails in this type of construction is the A/C (air conditioning) system, in reason of minimizing the temperature fluctuation and relative humidity (RH). Higher temperature levels accelerate the degradation process and high relative humidity provides the ideal environment to promote chemical reactions and proliferation of fungi and bacteria [1]. For general libraries, the American Society of Heating, Refrigerating and Air Conditioning Engineering (ASHRAE) Handbook 2007 recommends a temperature range of 15-25°C and a RH of less than 60% [2].

Brazil being a tropical large country, its area bears a variety of climate and macroclimates. Referring to Campo Grande, the city is located in a tropical wet and dry climate where people live in a wet summer with temperatures ranging from 31.4 – 20.5°C and a dry winter with temperatures ranging from 15.4 – 26°C “Fig. 1” [3]. The bioclimatic chart “Fig. 2” indicates that

in 45.23% of the hours during a year the city is in thermal comfort, during the hot months the chart points as main strategy the use of natural ventilation, it's also observed that the use of A/C (air-conditioning) system is not necessary for thermal comfort. Throughout most of Brazil's territory this building design strategy has been the most effective to achieve thermal comfort. Despite that, the use of A/C systems as a main cooling system has been drastically increasing [4].

As a result of the recent energy crises [5], Brazilian Government has been promoting energy saving initiatives including a Federal Regulation for Voluntary Labeling of Energy Efficiency Levels in Commercial, Public and Service Buildings [6] These regulations summarize an immense effort in order to provide guidelines based on Brazil's climate requirements for designer in general with specific items related to lighting system, HAVC systems and building envelope. However naturally ventilated indoor environments still appear as an open category and the references into the proposed regulations refer direct to current standards such as ASHRAE Standard 55[7].

In this scenario a public library cannot ignore the energy-saving strategies. The use of air movement in hot humid climate in Brazil as buildings thermal comfort strategy is very efficient [8-12] but also underestimated by ASHRAE Standard 55 and ISO 7730:05 [13].

Subjects' conditions in climate chambers differ into real buildings and therefore experiments into indoor environments could provide complementary results [12].

This research aims to provide:

- Measurement and characterization of occupants' thermal perceptions in a library in Brazil.
- Measurement of the indoor thermal environmental parameters by sensors.
- Determination of the acceptable neutral temperature in the library.
- Determination of strategies in designing HVAC systems with low energy consumption for a thermally comfortable environment.

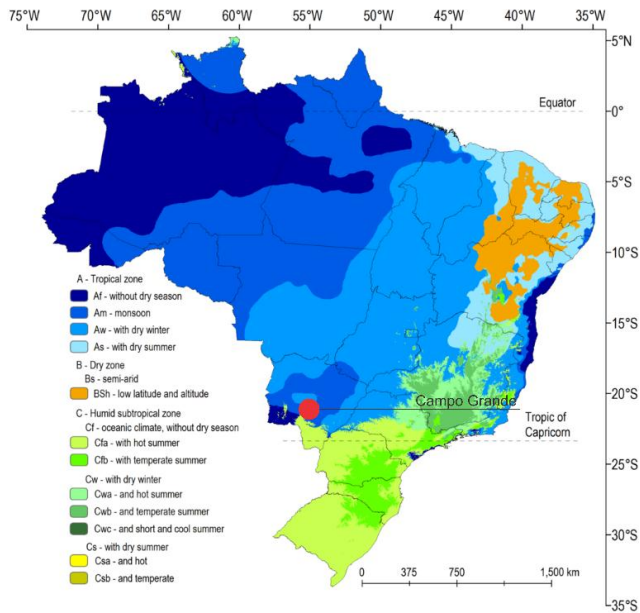


Figure 1. Climatic classification of South America (Campo Grande highlighted). Adapted from Peel et al. (2007).

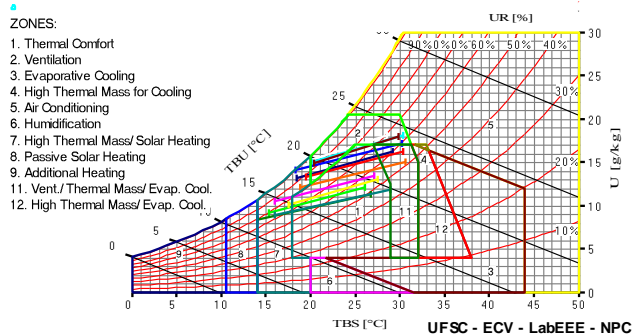


Figure 2. Psychrometric Chart of Campo Grande city. Adapted from AnalysisBio

## II. METHODOLOGY

With a view to measuring and characterizing occupants' thermal perception at the library, a field of study was conducted using subjective questionnaires survey and also thermal-environmental parameter monitoring, following ISO 7726:98 [14] criteria. The aim of the subjective measurement was to analyze the relationship between the use of natural ventilation and the HVAC system. The statistical analysis led to the implementation of a practical thermal comfort temperature and also determination of strategies in designing HVAC systems with low energy consumption for libraries in hot humid climate.

The measurement was conducted during the hottest months in Campo Grande at the top floor of the library, because it is the one with the highest concentration of thermal loads. Other studies have been developed over the years, such as those

performed in offices [15], open spaces [16], food courts [17] and schools [18]; none in libraries.

### A. Subjective Measurement

Only the subjects that have been inside the building for at least 20 minutes and were seated were considered in the research. They were not informed if the A/C system was turned on or off. The questionnaire included Physiological Information, Thermal Sensation and Thermal Preference.

Among the physiological information the subjects answered questions about gender, age, weight, height. They also informed what they were wearing as well as their activity in the past 20 minutes in order to find out the thermal clothing isolation and their metabolic rate.

The questions in the section of thermal sensation and thermal preference concerned how the thermal environment was felt. For thermal sensation there was a seven-point scale (Fanger 7-point scale, ranging from -3 to +3, corresponding to very cold and very hot and 0 being the thermal neutral condition) to mark. For thermal preference there was a three point-scale (warmer, neutral and colder) to mark.

### B. Measurement of Indoor Environment

Air temperature, relative humidity, mean radiant temperature and air velocity were used as thermal comfort parameters to evaluate the library indoor air conditions. These variables were measured by three types of instruments: a data logger HOBO RH/Temp. model H08-003-02, a globe thermometer model TGM-100 and a hot wire anemometer "Table I".

In order to calculate some variables, such as the average radiant temperature and the operating temperature, the library tables were divided into 5 areas according to their proximity of the windows and the incidence of solar radiation "Fig. 03".

The environment was measured with the A/C system turned on and with only natural ventilation. With natural ventilation, the experiment was divided in 4 phases: with all windows closed (phase 01), with all windows open (phase 02), with only north windows open (phase 03) and with only south windows open (phase 04). The aim was to identify the potential and differences between the apertures for thermal comfort.

## III. RESULTS

In the library 544 subjects answered the questionnaire. The participants were 372 females (68%) and 172 males (32%). Their mean age was of 22.15 years with a range of 17-65 years. Table II shows a descriptive summary of the subject occupants who participated in the questionnaire.

### A. Indoor Environment

Table III shows statistical summaries of the indoor measurements for the use of A/C system and the use of natural ventilation. They include air temperature, mean radiant temperature, operative temperature, RH, air velocity, PMV and PPD.

TABLE I. MONITORED PARAMETERS

Sensor	Monitored Parameter	Precision	Measurement interval
Hobo RH/Temp.	Relative Humidity	+/-3%	5 min
Hobo RH/Temp.	Air Temperature	+/-2%	5 min
Globe Thermometer	Radiant Temperature	0.1%	5 min
Hot wire Anemometer	Air Velocity	+/-1%	5 min

TABLE II. A DESCRIPTIVE SUMMARY OF THE SUBJECT OCCUPANTS PARTICIPATED IN THE QUESTIONNAIRE

		A/C system	Natural Ventilation
Sample size		233	310
Gender	Male	65	112
	Female	168	198
Age	Mean	23.39	21.23
	Maximum	65	37.00
	Minimum	17	17.00
	Standard deviation	5.67	4.20
Clothing insulation (clo)	Mean	0.84	0.87
	Maximum	1.42	1.06
	Minimum	0.66	0.67
	Standard deviation	0.15	0.06

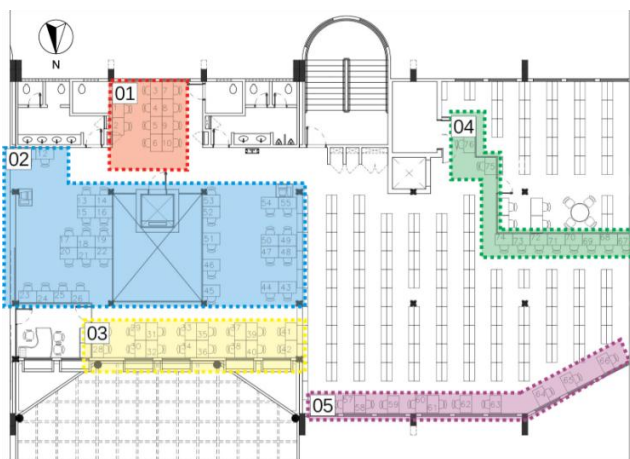


Figure 3. Map of 2th floor of library separated in areas (middle part)

The mean air temperature of the library using the A/C system and Natural Ventilation in the four phases were: 23.95, 25.2, 24.45, 24.36 and 24.3°C respectively. The minimum and the maximum air temperature in °C with A/C and at the four phases were: (19.81, 26.34), (24.01, 26.34), (22.48, 25.95), (22.09, 26.34) and (22.09, 26.34) respectively. In certain few points using the A/C system, the air temperature was suitable for the temperature limit recommended by ASHRAE.

The mean MRT (mean radiant temperature) with the A/C system and with natural ventilation at the four phases were:

24.22, 25.96, 25.23, 25.53 and 25.28. The lowest MRT was 19.81 with A/C system and the highest MRT was 30.44 with natural ventilation at the phase 01 when all windows were closed. The minimum and the maximum RH measured with the A/C system and with natural ventilation at the four phases were (49.75%, 72.50%), (65.70%, 81.90%), (66.80%, 85.50%), (63.20%, 89.90%), (63.20%, 96.20%); the mean RH were 60.65%, 74.67%, 76.12%, 73.96% and 76.68% respectively. In none of the cases the RH was compatible with the ASHRAE limit of <60%, with the A/C system turned on at certain points, the RH reached the ASHRAE recommendation, but still not enough to guarantee the dehumidification properly. With a temperature >20°C, RH >65% intensifies the development of mycete colonies and prompts the life cycle of harmful insects [1].

In none of the cases the air temperature and the RH were satisfactory to conservation of the collection. It is clear that the A/C system of the library is not functioning properly.

The mean air velocities measured in the study were: 0.05, 0.00, 0.05, 0.00 and 0.01m/s. These are within the acceptable range of 0.10-0.25 m/s for a library as recommended by ASHRAE [2]. For naturally ventilated places in hot humid climates, higher air speed values may be desirable to remove sensible and latent heat from the body [9].

Comparing the air speed between the phases with natural ventilation, the ones with the north windows opened (phase 02 and 04) get the higher values and also the lower temperatures, which indicates that the north aperture has more impact in the library air flow.

### B. Thermal Sensation

Fig. 4 is the comparative distribution of frequency for thermal sensation scale responses, in all Naturally Ventilated phases. and Fig. 5 is the A/C system frequency distribution of thermal sensation scale. The conditions described as slightly cool (-1), neutral (0) and slightly warm (+1) were considered acceptable, all other votes indicated discomfort [19].

Comparing the occupants' responses in all phases with natural ventilation, variations in their thermal sensation are visible. At phase 02 and 04, 11% of them were felling cold while at phase 01 and 03, 8% and 2% respectively were felling hot. These results met that the aperture of north windows get more impact in refrigerated their bodies and even over cooler.

The acceptable range of naturally ventilated at the four phases were: 92% - phase 01, 88% phase 02, 98% phase 03 and 89% phase 04.

With the A/C system 16.75% of the occupants felt that the thermal environment was not acceptable. and the acceptability was 83,26% the lowest value between all phases. The discomfort with the A/C system is not polarized, there was discomfort caused by warm and cool temperatures, which suggests that the library's A/C system has not an equal distribution of air flow and that the building has hot and cold areas.

TABLE III. STATISTICAL SUMMARIES OF INDOOR MEASUREMENTS

		A/C system	Natural Ventilation			
			Phase 01	Phase 02	Phase 03	Phase 04
Mean Air Temp. (°C)	Mean	23.95	25.20	24.45	24.36	24.32
	Maximum	26.34	26.34	25.95	26.34	26.34
	Minimum	19.81	24.01	22.48	22.09	22.09
	Standart deviation	1.99	0.80	0.94	1.17	1.24
Mean radiant temp.(°C)	Mean	24.22	25.96	25.23	25.33	25.28
	Maximum	28.60	30.44	26.34	25.95	26.34
	Minimum	19.81	25.17	24.40	24.40	24.40
	Standart deviation	1.79	0.86	0.44	0.39	0.57
Mean operative temp. (°C)	Mean	24.08	25.82	25.23	25.33	25.24
	Maximum	26.30	26.75	26.34	25.95	26.34
	Minimum	19.81	25.17	24.40	24.40	24.40
	Standart deviation	1.95	0.40	0.44	0.39	0.57
Mean relative humidity (%)	Mean	60.65	74.67	76.12	73.96	76.68
	Maximum	72.50	81.90	85.50	89.90	96.20
	Minimum	49.75	65.70	66.80	63.20	63.20
	Standart deviation	5.05	4.22	4.65	7.35	8.41
Mean air velocity (m/s)	Mean	0.05	0.00	0.05	0.00	0.01
	Maximum	0.69	0.00	1.60	0.00	0.20
	Minimum	0.00	0.00	0.00	0.00	0.00
	Standart deviation	0.08	0.00	0.27	0.00	0.04
PMV	Mean	0.32	0.65	0.35	0.45	0.36
	Maximum	1.35	0.76	0.49	0.52	0.59
	Minimum	-1.15	0.49	-0.84	0.39	-0.49
	Standart deviation	0.49	0.07	0.24	0.06	0.21
PPD (%)	Mean	12.16	13.96	8.73	9.38	8.66
	Maximum	43	17.33	19.91	10.66	12.46
	Minimum	5	10	5.41	8.21	5.30
	Standart deviation	8.65	1.93	1.97	1.08	1.72

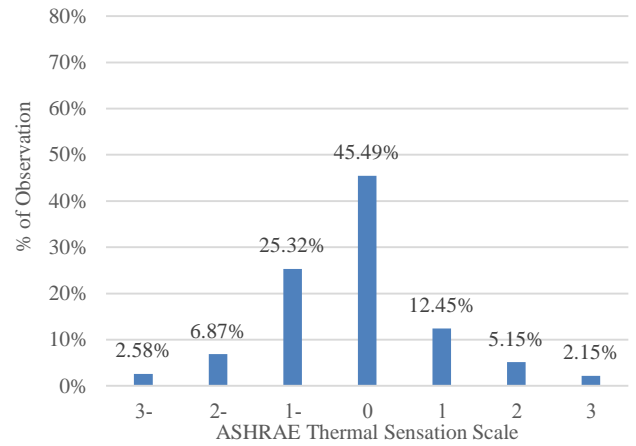


Figure 5. Frequency of thermal sensation responses with A/C system

### C. Thermal Preference

The evaluation of preferred temperature was done by answering the question: “thermally, how would you rather be feeling right now?” The subjects rated their preference in a tree-point scale: warmer (+1), no change (0) and cooler (-1). Fig. 6 shows the overall thermal preference in each naturally ventilate phases and with the A/C system. With natural ventilation in phase 01, the portion of occupants who would rather be cooler was 57%, with the aperture of the windows this number decreased to 11%, 15% and 13% in phase 02, 03 and 04 respectively. Showing that a simple window opening can change their thermal preferences.

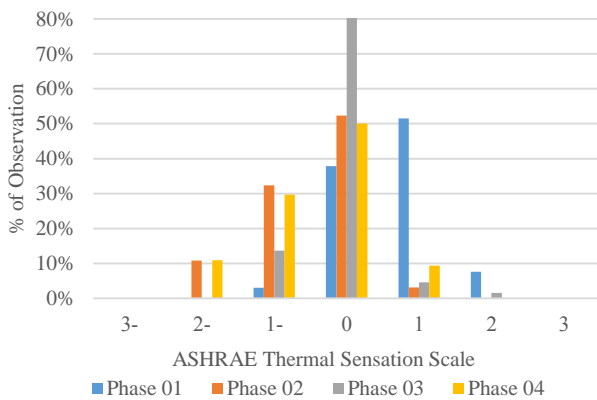


Figure 4. Frequency of thermal sensation response with Natural Ventilation in all phases

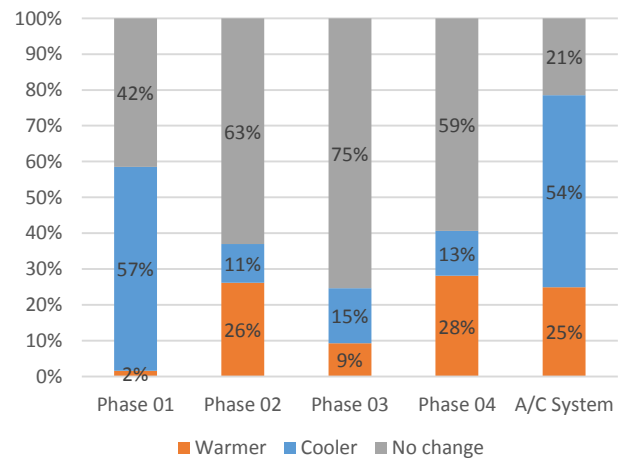


Figure 6. Overall thermal preference range

Using the A/C system 54% of occupants would rather be cooler and 25% warmer. Simple linear regression models were developed incorporating temperature levels with “prefer warmer” or “prefer cooler” conditions. Figure 7 and 8 shows that the intersection of the lines points the preferred temperature to be 25.2°C with A/C system and 25.7°C with natural ventilation. Note that the ASHRAE Handbook 2007 suggests a temperature range of 15-25°C and a RH less than 60% for libraries conservation, so in both cases the neutral operative temperature is above the recommendation, but still inside the comfort zone (between -1 to +1).

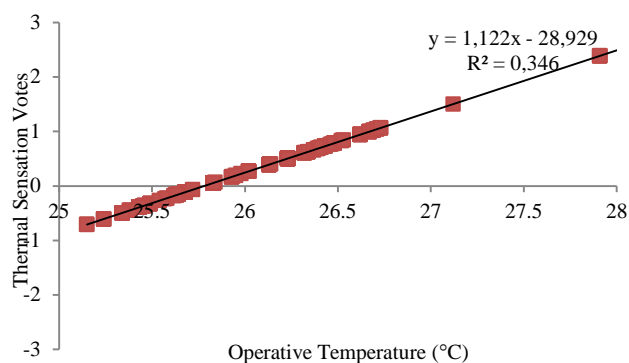


Figure 7. Simple linear regression to calculate the neutral operative temperature with natural ventilation

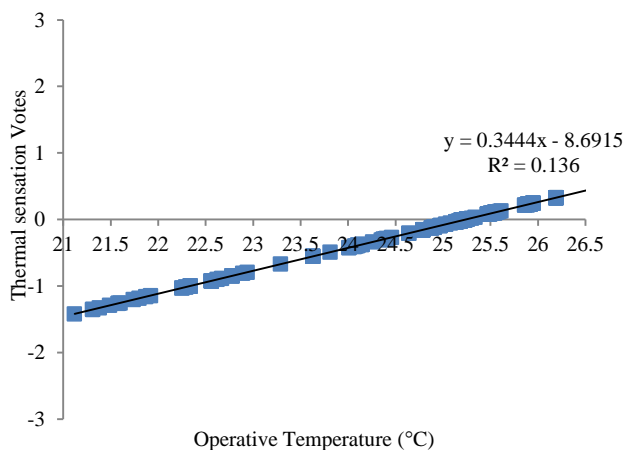


Figure 8. Simple linear regression to calculate the neutral operative temperature with A/C system.

According to the ASRAE Standard 55, a thermal environment is considered comfortable if it is accepted by 80% of the occupants [2] this study shows that in all cases the acceptability reached the standard. However, even at the best scenario (using natural ventilation) if we separate the library thermal sensation responses by areas “Fig. 3”, some points were impaired and need attention as shown in Table IV.

This division might be useful to determine the desk placement throughout the library, since the natural ventilation proved to be efficient for the occupants’ thermal comfort. The same way the bookshelves can be confined in a smaller and artificially conditioned environment.

TABLE IV. THERMAL SENSATION RESPONSE BY AREA WITH NATURAL VENTILATION

Phase		01	02	03	04
Area A	Comfortable	100%	100%	100%	100%
	Cold	-	-	-	-
	Hot	-	-	-	-
Area B	Comfortable	100%	96,3%	100%	92,6%
	Cold	-	3,7%	-	7,4%
	Hot	-	-	-	-
Area C	Comfortable	92,3%	77%	100%	77%
	Cold	-	23%	-	23%
	Hot	7,7%	-	-	-
Area D	Comfortable	56%	100%	89%	100%
	Cold	-	-	-	-
	Hot	44%	-	11%	-
Area E	Comfortable	100%	67%	100%	78%
	Cold	-	33%	-	22%
	Hot	-	-	-	-

#### IV. DISCUSSION

The library has two types of collection, the loan books and the especial collection. The loan books can be borrowed and taken away from the library and the especial collection is kept in a restrict room with a controlled environment. This research is focused on the common area of the library, where the loan books are stored, although these books are regularly exposed to a variety of environments, a great portion of them remain stocked for a long time and need an ideal environment away from humidity, dust, high temperatures, insects and microorganisms. A controlled environment can extend their lives and also avoid any biological proliferation.

In relation to the air velocity with natural ventilation, the relation could not be calculated because the wind has a very anarchic compartment and more accurate equipment would be needed to register.

#### V. CONCLUSIONS

The following conclusions are drawn concerning the conservation of the collection and thermal satisfaction of the occupants in the Public Library of Federal University of Mato Grosso do Sul:

The occupant’s responses indicated that the thermal conditions with natural ventilation are better for thermal comfort.

The actual A/C system was not suitable for the library space, requiring re-adjustment of the set-point temperature and the humidity control.

The Neutral operative temperature calculated by the subject's responses was 25.2°C with the A/C system and 25.7°C with natural ventilation, both with temperatures too high for the collection conservation.

The RH measured in both cases was above 60%, which can cause serious damage to the materials in display.

The separation of collection store area from study area is an energy-saving option, since the temperature and ideal RH can be considered to cool for the user's thermal sensation.

The use of fans can improve the thermal comfort on non-windy days, it's also important that the occupants have the fan control.

The findings of this research with the consideration of occupants' thermal comfort are useful in designing a low energy consumption HAVC system for libraries in hot humid climates.

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