Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1806-2563
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v28i2.28308

Human thermal comfort and architectural volume

Etianne Alves Souza de Oliveira[1*], Antonio Augusto de Paula Xavier[2], Ariel Orlei Michaloski[2] and Elisandra Montes Pizybski[2]

[1]Instituto Federal de Educação, Ciência e Tecnologia, Rua Aloísio Stofel, 1261, 89885-000, Jardim Alvorada, São Carlos, Santa Catarina, Brazil.
[2]Departamento de Pós-graduação em Engenharia de Produção, Universidade Tecnológica Federal do Paraná, Ponta Grossa, Paraná, Brazil.
**Author for correspondence. E-mail: etianne_oliveira@hotmail.com*

ABSTRACT. It has been questioned what influence the architectural variables have on the workers' thermal comfort since the building is a barrier between both the external and internal environments. This article presents the findings of an applied research that correlated the analytical thermal comfort of workers with the architectural volume of the workspace. We used the *Confortímetro Sensu*® equipment and the *software Analysis* CST 2.1® for measuring thermal variables and calculating the analytical comfort of workers. The research was applied in different thermal conditions and different space volumes. The statistical results of this sample did not provide evidence to support the assertion of a correlation between architectural volume of spaces and thermal comfort of workers.

Keywords: environmental ergonomics, worker, PMV (Predict Mean Vote).

Conforto térmico humano e volume arquitetônico

RESUMO. Questiona-se qual a influência que as variáveis arquitetônicas têm sobre o conforto térmico dos trabalhadores visto que a edificação é a barreira entre o ambiente externo e o interno. Este artigo apresenta os resultados de uma pesquisa aplicada que correlacionou o conforto térmico analítico dos trabalhadores e o volume arquitetônico do espaço de trabalho. Foi utilizado o equipamento *Confortímetro Sensu*® e o *software Analysis* CST 2.1® para medir variáveis térmicas e calcular o conforto analítico dos trabalhadores. A pesquisa foi aplicada em diferentes condições térmicas e diferentes volumes de espaço. Nos resultados estatísticos desta amostra, não há evidência para apoiar a afirmação de uma correlação entre volume arquitetônico dos espaços e conforto térmico dos trabalhadores.

Palavras-chave: ergonomia ambiental, trabalhador, PMV (Predict Mean Vote).

Introduction

This article presents the findings of the correlation between data of the architectural space volume and the level of thermal comfort of workers who use offices to perform their tasks.

Human beings do not respond to the environment in the same way, there are human characteristics that determine sensitivities and different responses to the same environmental conditions. Environmental Ergonomics is presented as an integral part of ergonomics which leads to a better understanding of the relationship between space and occupants. It is seen and practiced from the viewpoint that the environmental characteristics of spaces have no effect on the occupants (Parsons, 2000).

Most work activities are carried out inside buildings which are designed to meet functional, environmental, economic and human demands. Therefore, the balance among these demands is important, since the lack of human comfort can have a direct effect on worker's productivity and an indirect effect on production, economy and environment (Castilla et al., 2011).

In Brazil, the labor regulatory standard establishes that Ergonomics approaches agents resulting from working conditions involving biomechanical factors, psycho-physical demands of the job, deficiencies in the production process and the environmental conditions of architectural spaces such as ventilation, lighting and noise which may cause discomfort or occupational stress (Norma Regulamentadora [NR 17], 2007).

Parsons (2000) states that the three factors considered as priorities in the studies of Environmental Ergonomics are related to health, comfort and human performance, with the attempt to integrate these effects. However, according to the researcher, there is not enough objective knowledge which enables accurate conclusions. Corroborating with this premise, Chen and Chang (2012) claim that there is a need to consider carefully the search criteria, especially those related to the location and selection of the sampling group. That happens because of the sensitivity in human responses and the variability of intervening variables concerning the research which can skew the findings, especially in certain subjective aspects as it is with the level of thermal comfort.

Considering the state of the art produced by similar research, this article presents the results of a statistical analysis based on Environmental Ergonomics evaluating the psychophysical factors of workers. In this case, the thermal comfort of office workers; and also factors of the physical workspace, that is, the architectural volume of the space.

This article presents the description of the tools, the location of the research, the sample and research criteria. Thereafter, the findings are presented with characterization of the sample, sampling groups, normality of the samples, and correlation between groups. The findings presented are discussed in view of similar research; and it ends up presenting the conclusions reached, the limitations of the study and suggestions for further research.

Material and methods

Tools

The three tools used were an analytical measurement of the thermal comfort (PMV) with the use of a sensor device, a self-applied questionnaire and an architectural survey of the workspaces.

The *Confortímetro Sensu*® equipment, a tool used in measuring the thermal comfort, was installed in the workspace and it measured the four environmental thermal variables of the space where the workers were performing their tasks. These variables were used to calculate the analytical thermal comfort (PMV) using the *software Analysis* CST 2.1®. Data were collected every five minutes during the work shifts as scheduled in Table 1. Collection procedures followed ISO 7726 (International Organization for Standard [ISO], 1998) and 7730 (International Organization for Standard [ISO], 2005a).

The insulation level of the workers' clothing, measured in clo (1 clo = 0.155 m^2 °C W^{-1}), was obtained by a self-applied questionnaire, using the *clo* measurement table in relation to the garment, according to ISO 9920 (International Organization for Standard [ISO], 2005b). By applying the questionnaire, it was also possible to check the level of the subjective thermal comfort of the workers, using the Seven-Point Scale, according to ISO 7730 (ISO, 2005a). From the data collected, 93% of the subjective thermal comfort responses were equal to the analytical thermal comfort and none was discrepant, this confirms the analytical measurement as a good tool for measuring the thermal comfort in this sample.

Table 1. Daily schedule of data collection.

Search Duration			
1st office shift		lunch	2nd office shift
Subjective thermal comfort analysis			Subjective thermal comfort analysis
Measurement of analytical thermal comfort variables.			Measurement of analytical thermal comfort variables.
8 am	12am	2pm	6 pm

The volume measurement (m^3) of the architectural spaces was taken after the physical survey of the measures of each workspace, obtained by multiplying the floor area by the height of the space.

The sample

The sample consists of 45 evaluations made with 25 office workers from four different companies, in 10 workplaces with different volume (m^3). On the second day of the survey application, some workers missed work and a replication was not possible, Table 2.

Table 2. Population sample of the companies, workers and rooms.

Companies	Workers	Workers surveyed		Rooms surveyed
		Collection 1	Collection 2	
Co. 01	10	10	8	4
Co. 02	4	4	3	1
Co. 03	7	7	5	1
Co. 04	4	4	4	4
Total	25	25	20	10

Data collection took place from February to November 2014 allowing the data to be obtained under different thermal conditions. Two data collections were carried out observing the typical thermal conditions of summer and winter and according to the companies' permition so as not to disrupt the tasks.

Location

Companies 1 and 2 are specific educational service providers, Figure 1a and b. Company 3 provides service to the community, Figure 1c. Company 4 is an administrative company linked to the agro-industrial sector, Figure 1d. Each one has different numbers of workspaces. Table 2.

Figure 1. a) Company 1, b) Company 2, c) Company 3, and d) Company 4.

Search criteria

All companies develop their activities in naturally ventilated environments, thus their workers are subject to the conditions and thermal variation of the region. The geographic region where the research was applied has an average annual temperature of 18°C with an average minimum of 13 and a maximum of 25°C, and four well-defined seasons. These thermal characteristics favor the use of naturally ventilated buildings and they are within the ideal average for human comfort in sedentary activities (Lan, Lian, & Pan, 2010).

The main task performed by the workers of the companies is classified as a sedentary activity with the metabolic rate of 70 W m^{-2}, typical of an office environment (ISO, 2005). The workers have performed their functions for at least twelve months, ensuring familiarity with the task performed. The workers' mental workload is greater than the physical load, criteria confirmed by the questionnaire.

Both the companies and the subjects agreed to participate in the research and all the protocols of the Research Ethics Committee were met according to Resolution 466/12 of the National Council of Health - BR.

This research has the Committee's approval - CAAE n. 24498514.4.0000.5547.

Results and discussion

Sample characteristics

It is an independent simple random sample, consisting of healthy workers with a body mass of 70 kg (+/- 12.72), 56 men and 44% women. Their average age is 34 years (+/- 12.79). Seventy-six percent of them possess college education and have worked in the same function for more than twelve months.

Sampling groups

The sample data were pooled and analyzed in two ways.

First set: individual data of analytical thermal comfort (PMV), as variable 1, and the corresponding space volume (m^3), as variable 2, amounting to 45 pairs of data, Table 3.

Second set: the volume of each room (m^3), as variable 1, and the average comfort of the workers who use them, as variable 2, Table 4.

By analyzing the data of the 2nd set graphically, it was noticed that the workers in spaces smaller than 50 m^3 were, on average, more uncomfortable than those in larger ones. Therefore, questions were raised about the existence of a correlation between the means of sample with thermal comfort and the space volume, Figure 2.

In each of the ten spaces, with different volumes (m^3), different amounts of analytical thermal comfort assessments (PMV) were collected. Each space presented an average of analytical thermal comfort ranging from slightly cold (-1.03) to slightly warm (+0.55), Table 4 and Figure 2.

Table 3. 1st Set – Individual analytical thermal comfort (PMV) and space volume 2014.

Sample N.	Thermal comfort PMV	Space volume m³	Sample N.	Thermal comfort PMV	Space volume m³	Sample N.	Thermal comfort PMV	Space volume m³
1	0.06	116.95	16	-0.50	68.93	31	1.43	64.82
2	-0.46	67.96	17	0.99	68.93	32	-0.97	64.82
3	-0.65	68.93	18	0.78	68.93	33	-1.16	64.82
4	-0.70	68.93	19	-0.71	178.93	34	0.75	64.82
5	-0.17	51.5	20	-0.99	178.93	35	-0.25	64.82
6	0.34	67.96	21	-1.39	178.93	36	0.45	64.82
7	0.27	67.96	22	-1.39	178.93	37	0.89	64.82
8	0.48	67.96	23	-0.83	178.93	38	-0.53	29.48
9	0.34	116.95	24	-0.42	178.93	39	-0.79	47.57
10	0.27	116.95	25	0.45	178.93	40	-0.30	26.62
11	0.06	116.95	26	0.15	178.93	41	-0.88	43.81
12	0.69	116.95	27	0.51	178.93	42	-1.52	29.48
13	0.75	51.50	28	0.31	178.93	43	-1.14	47.57
14	1.06	51.50	29	0.21	178.93	44	-0.52	26.62
15	-0.13	68.93	30	0.51	178.93	45	-0.52	43.81

Table 4. 2nd Set - Space volume and PMV averages.

Room N.	1	2	3	4	5	6	7	8	9	10
Sample N.	12	5	6	4	7	3	2	2	2	2
Average (PMV)	-0.30	0.28	-0.03	0.16	0.16	0.55	-0.97	-0.70	-1.03	-0.41
Volume (m³)	178.93	116.95	68.93	67.96	64.82	51.5	47.57	43.81	29.48	26.62

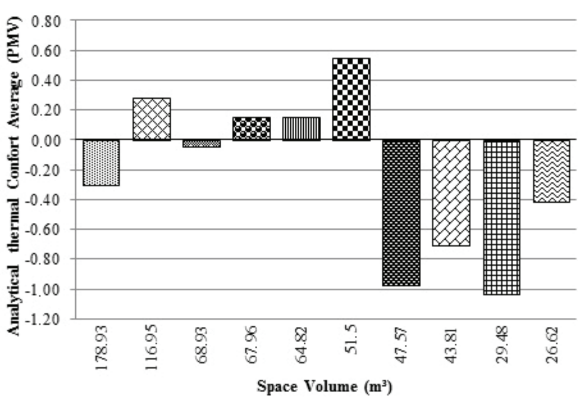

Figure 2. Thermal comfort by space volume.

Data normality

The normal distribution analysis of analytical thermal comfort data (PMV) presented.

P > 0.05; thus data is derived from a normal distribution. Kolmogorov-Smirnov sample = 0.102 < Kolmogorov-Smirnov reference = 0.205, and Shapiro-Wilk sample = 0.977 > Shapiro-Wilk reference 0.944; Figure 3a. In the data set there are no spurious values, Figure 3b. The analytical thermal comfort (PMV) accounted for 93% of the subjective thermal comfort evaluations, proving to be a good measurement tool of thermal comfort for this sample.

In the data set of workspace architectural volume, the normal distribution was p < 0.05; therefore, data do not derive from a normal distribution. Kolmogorov-Smirnov sample = 0.308 > Kolmogorov-Smirnov reference = 0.205 and Shapiro-Wilk sample = 0.793 < Shapiro-Wilk reference = 0.944, Figure 4a. In the data set there are no spurious values, Figure 4b.

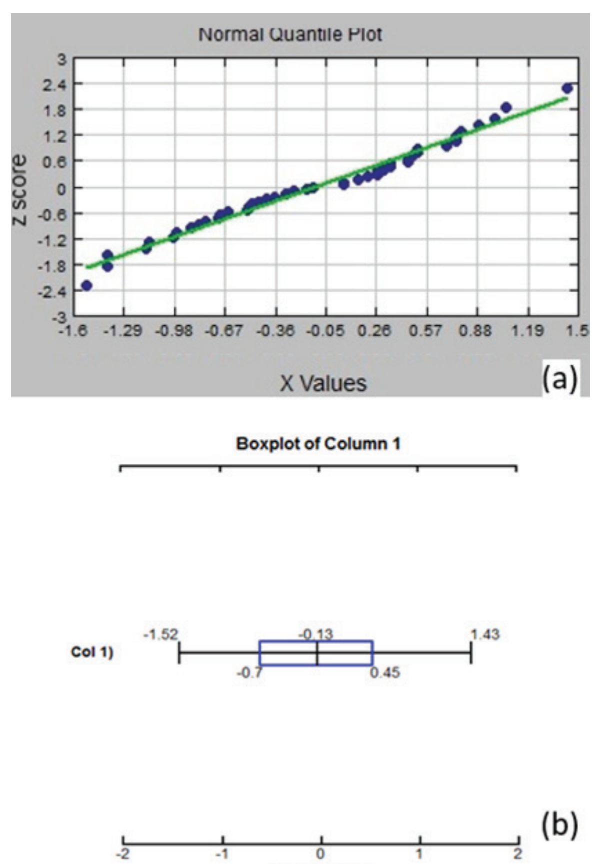

Figure 3. a) Quartis normal PMV; and b) Boxplot PMV.

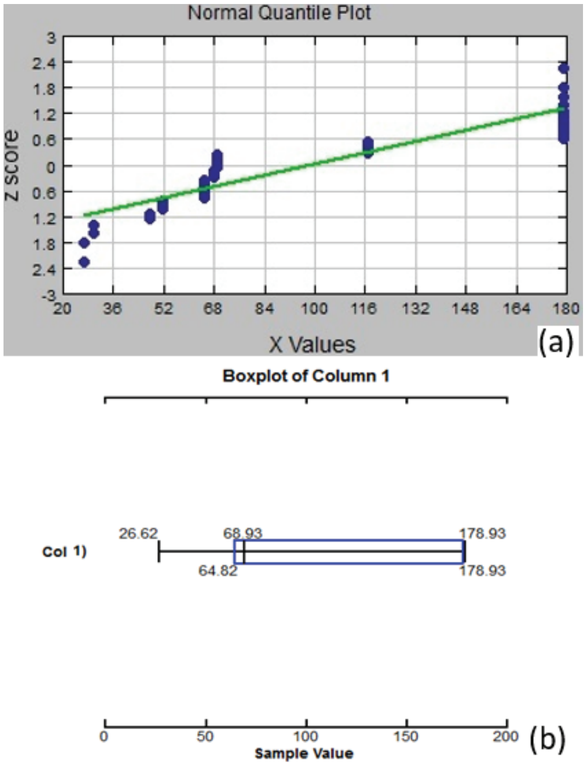

Figure 4. a) Quartis normal architectural volume of the workspaces; and b) Boxplot architectural volume of the workspaces.

Correlations

The analysis seeks to identify the association relationship between the data sets. As one of the data sets did not present normality, Spearman correlation test was used.

The hypothesis analyzed in the correlation between the sampling groups is: H0 $p=0$, i.e., there is no correlation. H1 $p\neq 0$, i.e., there is correlation.

1st Set Correlation - The 45 pairs of individual data of the analytical thermal comfort (PMV) and their respective space volumes were correlated by Spearman. The correlation found was + 0.0816; below the critical correlation parameter ± 0.295; (n = 45). This finding supports H0, that is, there is no correlation.

2nd Set Correlation - The result of the Spearman correlation among the 10 data sets of cubic footage of the spaces (m^3) and their respective means of analytical thermal comfort (PMV) was + 0.575; below the critical correlation parameter ± 0.648 (n = 10). This finding supports H0, that is, there is no correlation.

Research indicates that the most relevant indoor environmental parameters for the occupants' comfort are associated with thermal, visual, acoustic environments and air quality (Frontczak, Andersen, & Wargocki, 2012).

A similar survey which assessed the relationship between well-being and working conditions suggests that there is a correlation between negative affect and working conditions (-0.365), i.e., the better the working condition, the lower the negative affect. This finding suggests that working conditions have an effect on the worker's psychological health changing his/her well-being (Souza, Bertolini, & Ribeiro, 2014).

The relationship between internal and external spaces has been presented as a component in the design of spaces with focus on environmental issues. The use of sealed spaces and the need for integration between the internal and external environments of buildings are questioned. This discussion is based on the maintenance of comfort and well-being of occupants and on the need of environmental adjustment for the occupant (Prieto, 2012).

Another research that investigated the hypothesis that the office type has an influence on the workers' health, suggests that smaller office sizes promote loss in health. Better health and greater job satisfaction are related to cell and flex offices. Researchers attribute the difference to the variation of architectural and functional elements present in different offices (Danielsson & Bodin, 2008).

A study on thermal performance of buildings with air-conditioning in which the potential of natural ventilation in workspaces was assessed, suggests that up to 30% of the hours of occupancy can be used in mixed form, ensuring comfort to the occupants. However there is a preference for fully air-conditioned workspaces due to conventional office environment culture (Brandão, 2008).

Nogueira, Siqueira, Souza, Niedzialkoski, and Prado (2012) found minimal differences when analyzing the thermal comfort in buildings with different architectural variables and that were subject to the same external thermal conditions. According to the authors, the results are justified due to the type of covering structures and ventilation adopted in the buildings. The researchers point out that the architectural solutions of a building can influence the levels of thermal comfort of the occupants, and also reduce the use of mechanical climatization. Nevertheless, depending on the solutions adopted, these improvements may be insignificant.

Souza and Rodrigues (2012) investigated the effectiveness of natural ventilation in naturally ventilated spaces and observed that cross ventilation efficiency is on average 3.5 times larger than the single-sided one. They suggest that it helps in the thermal gradient, in the air renewal, and contributes to the temperature distribution within the environment promoting health and comfort to the occupants. The researchers note that ventilation is influenced by many factors, thus undergoing variations according to weather conditions, architectural and urban solutions of its surroundings.

Al-Obaidin, Ismail, and Rahman (2014) state that the roof is responsible for about 70% of the total heat gain in a building and there are significant differences in its performance as to color use and properties of the material in use. They point out that the passive cooling technique provides technology that allows the use of buildings with comfortable conditions through natural means.

Based on the reported findings, it is possible to infer the following:

In both correlation analyses data support the null hypothesis and the findings are not statistically significant.

It is observed that in both cases the space volume was not able to change the workers' analytical thermal comfort (PMV) in a statistically significant way. The findings are only valid for this sample; it is not possible to extend this inference to other samples or population.

These results can be explained by the variety of intervening architectural features of each building surveyed, for example the coatings, building system, the geographical position of architectural spaces. These architectural features, jointly, may have contributed more to the workers' thermal comfort than the space volume variable (m^3) itself.

Conclusion

The findings of this research applied in real work environments show that in this specific sample the variable volume of architectural space (m^3) was associated with 8.16% to the level of the occupants' analytical comfort and with 57.14%, considering the comfort averages, for each space. These data is considered insignificant by the statistics and suggest that there is no evidence to support the assertion of a correlation between volume of architectural spaces and workers' thermal comfort, since the data support the null hypothesis. A larger sample is necessary as well as its application in other segments of the productive sector, and also the extension of this inference to other samples or populations.

Acknowledgements

The authors are deeply thankful to the Federal Institute of Maranhão (IF-MA), Federal Technological University of Paraná (UTFPR) and to the companies named 2nd Registry Office, Apae, Rural Union and Ponta Grossa Conservatory for the funding, technical support and availability, respectively.

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Received on June 25, 2015.
Accepted on October 16, 2015.