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ABERGO

"TURN ON THE TEACHER FAN ..."

A POST-OCCUPATION ANALYSIS ON THERMAL COMFORT IN A UNIVERSITY LABORATORY

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ABSTRACT

Throughout the history of work, the human body has been adapting to different working environments and the changes that occurred in it, creating its own mechanisms that provide a better feeling of thermal comfort to these environments. Currently, several activities are performed in closed environments that, in turn, being poorly designed, generate ergonomic problems, poor lighting and poor use of natural and artificial ventilation. Nowadays, there is already a concern to make changes in the workplaces so that they adapt to their users. Therefore, it became necessary to invest in research on thermal comfort. Therefore, this article aims to analyze thermal comfort in a laboratory at the facilities of a university located in the Midwest region of Minas Gerais, seeking to identify how the design of a space can influence the thermal sensation. The results found showed that modifications without prior analysis in the environment in question, increased the points of thermal non-conformity by 20%, remaining outside the comfort range (-0.82 <VME <0.82).

KEYWORDS: Thermal comfort; Workplace; Laboratory

1. INTRODUCTION

Throughout the history of work, the human body has adapted to various work environments and the changes that occurred within them, creating its own mechanisms to provide a better sense of thermal comfort in these settings. Nowadays, many activities are carried out in enclosed spaces which, when poorly designed, lead to ergonomic problems, inadequate lighting, and inefficient utilization of both natural and artificial ventilation (Sevegnani; Filho; Silva, 1994).

Some work activities are subject to using spaces with artificially constructed or mechanized climate control, providing a relative "comfort" so that they can carry out their tasks with optimal performance, adapting and correlating thermal sensation with well-being at work, as expressed by satisfaction with the organizational environment (Leite, 2003).

Due to the significant number of activities carried out in enclosed environments, studies on thermal comfort become crucial, aiming to provide guidelines that satisfy individuals in all settings (Andreasi, 2009), which, according to Batiz et al., (2009), align with mankind's intuitive pursuit of feeling naturally well.

According to Frota and Schiffer (2001), it is known that individuals have better health and peak performance when their bodies function without experiencing thermal stress or fatigue, highlighting the need for studies addressing this matter. They further assert that it is a part of the architectural objective to provide thermal conditions that are compatible with thermal comfort, allowing heat exchange between the human body and the environment to occur without significant effort from individuals.

Therefore, research endeavors aim to analyze and establish the necessary conditions to evaluate and design an environment suitable for human activities and occupations. They also seek to establish methods for conducting more detailed thermal analysis. These studies are based on human satisfaction in being in a thermally comfortable environment, human performance, and energy conservation, given the mechanization and industrialization of the current population (Lamberts, 2011).

Therefore, the following study aims to analyze thermal comfort in a laboratory within the facilities of a university located in the Central West region of Minas Gerais, after the space has been occupied. It seeks to identify how the design can influence thermal sensation, taking into account both natural and artificial ventilation.

According to the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), thermal comfort is the state of mind that expresses human satisfaction with the thermal environment surrounding them, resulting from a satisfactory combination of surrounding temperatures (Lamberts, 2014).

According to Ruas (1999), the initial considerations for establishing criteria for thermal comfort were made in the early 20th century. Since then, efforts have been made to understand the factors that influence thermal sensation and how they are interconnected. Studies indicate that comfort is associated with the thermal balance of the human body and that it encompasses both personal and environmental factors.

According to Frota and Schiffer (2001), the well-being of individuals in the environments they inhabit also depends on heat generated by machines and equipment used during work activities, the presence of other people, artificial lighting, and solar heat.

Existing studies are not sufficient to adopt values as suitable for the general population, as it must be considered that people have different perceptions, and sensations are subjective. Perception plays an important role in allowing individuals to attribute meanings to things, actions, and events (BATIZ et al., 2009).

According to ISO 7730/94, the combination of various factors is the primary determinant of the sensation of thermal comfort or discomfort (Oliveira et al., 2010). Therefore, well-being depends on factors that affect the functioning of the thermoregulatory system; causing discomfort and inefficiency at work, which can increase the likelihood of accidents (Ruas, 1999; 2001).

From an educational perspective, it's important to emphasize that attention plays a significant role in comprehension and learning. It becomes crucial to analyze factors that can interfere with attention, such as heat, noise, poor lighting, and so on. "Attention is a mental process that allows people to focus on a specific stimulus or relevant information" (Batiz et al., 2009). It also serves as a prerequisite for the functioning of complex cognitive processes since it's not possible to assess perception or any other mental activity without considering attention processes (Batiz et al., 2009).

According to Wargocki et al. (2005), an increase in temperature and air quality reduction impairs performance in education, negatively impacting learning capacity. It's also noted that many studies do not consider all thermal variables, as many only assess air temperature, which can influence their results (Batiz et al., 2009). According to Lorsch and Abdou (1994, as cited in Andreasi, 2009), better thermal conditions enhance productivity and human performance.

As mentioned earlier, several variables associated with the performed activity influence our thermal comfort, determining whether there is comfort or discomfort. These variables can be divided into two groups, as presented below: environmental variables and human variables.

Environmental variables: Air temperature (ta) or Dry-bulb temperature (Tbs): When the temperature is lower than that of the skin, heat is removed by convection. If the air temperature is higher than that of the skin, it will transfer heat to the body; Mean radiant temperature (trm): It is uniform in an imaginary environment where heat exchange by radiation is equal to the non-uniform real environment; Relative humidity (UR): Provides the amount of water vapor in the air relative to the maximum amount it can hold at a given temperature; and Relative air velocity (vr): Air velocity affects heat exchange by convection and evaporation (Lamberts, 2014; Ruas, 1999).

Human variables: Metabolic rate: Metabolism is how the body acquires the necessary energy. The release of this energy varies according to muscular activity; Clothing worn: It imposes thermal resistance, acting as a barrier to heat exchange between the body and the environment (Lamberts, 2014).

With the established connection between thermal discomfort, decreased worker productivity, and dissatisfaction with the work environment, it became necessary to conduct studies to establish corrective and/or preventive measures in workspace designs, aiming to adapt them to the users' needs. The initial studies emerged in Post-Occupancy Evaluation in the 1970s (Nogueira et al., 2005) and demonstrate that:

> Modern conceptions of organization and production, driven by globalization, have introduced new concerns that have become new research topics related to environmental comfort, such as energy efficiency, occupational health, and productivity (Lamberts et al., 1997, as cited in Nogueira; Duarte & Nogueira, 2005, p. 39).

Post-Occupancy Evaluation (POE) is a systematic and rigorous process for quality control in environments after some time of their construction and occupation. Its main characteristic is the participation of users in the analysis process (Rheingantz et al., 2006). The results of the analysis are based on the intersection of user feedback with technical reports when interpreting responses (Filho, 2008).

It is a methodology already applied in developed countries that focuses on the occupants of the environment and their needs. From this, ideas are developed about the consequences of the design on the building (Rheingantz; Cosenza & Lima, 2006).

POE is an effective practice for controlling the quality of the environment, providing feedback to projects with new information. It can be used to identify ergonomic, construction, aesthetic, and comfort problems in a space in use. This allows for finding solutions that can minimize issues and provide greater comfort to users (Ferraz, 2010). According to Rocha (2007), POE research prioritizes the use, maintenance, and operation of space from the user's perspective and is commonly used to assess the performance of built environments.

> The general principles of Post-Occupancy Evaluation encompass two spheres: intervention in the built environment, minimizing or eliminating the issues raised and enhancing the positive aspects highlighted by users, contributing to the maintenance and improvement of the quality of life in a given built space; the informative sphere, through the creation of databases, result systematization, based on the surveys conducted (charts, tables) (Rocha, 2007, p.9).

In this way, Post-Occupancy Evaluation (POE) can be an efficient method for the development and process of an environment, based on prior knowledge of user needs and the early identification of satisfaction levels (Rheingantz; Cosenza & Lima, 2006).

2. METHODS

The Fanger model (cited in Ruas, 1999) was followed, in which he created a Comfort Diagram, aided by computers, to determine various combinations of variables that provide comfort. To complete the evaluation, a criterion called Estimated Mean Vote (EMV) was also created to assess the discomfort of the population under analysis. This method classifies the environment into seven different sensation perceptions: -3 (very cold), -2 (cold), -1 (slightly cold), 0 (comfort), +1 (slightly warm), +2 (warm), and +3 (very warm) (Ruas, 2001).

Due to the complexity involved in calculating EMV, ISO 7730 (1994) provides, in addition to the formula, a set of tables that facilitate its determination. This is possible by combining various environmental and personal factors, enabling the determination of thermal sensation for a specific group (Ruas, 2001).

The standard also explains how to calculate the Predicted Percentage of Dissatisfied (PPD) people with the environment and presents a graph that can be used to determine it. The application of the method adopted by the international standard allows verifying if the environment meets acceptable conditions of thermal comfort, establishing higher limits of acceptability in environments where this is possible, and providing variable combinations that enable a sense of thermal neutrality (Lamberts, 2011).

Studies have shown that there were differences in the application of existing methods for thermal comfort evaluation, requiring a correction factor. A new model proposed by Humphreys and Nicol (2002) and Fanger and Toftum (2002) called the "adaptive method" emerged (Andreasi, 2009).

Considering that people have different thermal perceptions, that sensations are subjective, and that it is not possible to please 100% of the population under study, the final EMV value should be between -0.82 and 0.82 to consider the environment thermally comfortable for at least 80% of the people present in the space (Ruas, 1999).

Therefore, these standards aim to provide information, guidance, and recommendations on how to consider people's adaptation to the environment when assessing and designing buildings, systems, and work environments (Lamberts, 2011).

To apply the method and estimate the thermal sensation of people who use the space under analysis, we need (based on ISO 7730/1994): Define the study location; Gather the characteristics of the study location; Know the type of clothing worn; Know the type of activity performed in the study location; Divide the occupied area into equal squares; and Define the measurement points at the center of these squares.

With this information at hand, we will proceed to measure air temperatures and relative air velocities. Measurements should be taken at 0.60 meters above the floor for seated individuals and at 1.10 meters above the floor for standing individuals. Air temperature can be measured using mercury thermometers, resistance thermometers, or thermocouples. Average radiant temperature is measured using a globe thermometer (tg) (which can also be used to measure air temperature). Air velocity is measured using a thermal anemometer capable of measuring velocities on the order of 0.05 m/s.

After the measurements, we need to organize the values found into a table (Table 1) where the first three columns contain the values found during the measurements. After filling the first columns, we calculate the VME for trm=ta using values from the table of physical activity levels according to the activity performed. For some VME values, it is necessary to perform double linear interpolation, while for others, you can simply use the values established in the tables. Below are the formulas for double linear interpolation (iii) used and a sample table format to be used for organizing the calculations (Ruas, 1999): Initially, interpolate in $z = \underline{f}(x_{j-1}, y_c)$, obtaining equation (i).

$$\underline{f}(x_{j-1}, y_c) = f(x_{j-1}, y_{i-1}) + \frac{y_c - y_{i-1}}{y_i - y_{i-1}}[f(x_{j-1}, y_i) - f(x_{j-1}, y_{i-1})] \quad \text{(i)}$$

Subsequently, you should interpolate in $z = \underline{f}(x_j, y_c)$, obtaining equation (ii).

$$\underline{f}(x_j, y_c) = f(x_j, y_{i-1}) + \frac{y_c - y_{i-1}}{y_i - y_{i-1}}[f(x_j, y_i) - f(x_j, y_{i-1})] \quad \text{(ii)}$$

Finally, by combining equations (i) and (ii), we obtain double linear interpolation in $z = \underline{f}(x_c, y_c)$.

$$\underline{f}(x_c, y_c) = \underline{f}(x_{j-1}, y_c) + \frac{x_c - x_{j-1}}{x_i - x_{i-1}}[\underline{f}(x_j, y_c) - \underline{f}(x_{j-1}, y_c)] \quad \text{(iii)}$$

As the VME values correspond to the condition where trm=ta, it is necessary to perform corrections on them. For this correction, we require the values obtained from the ΔVME/°C trm graphs established by the standard for the type of activity under study, as a function of clothing thermal insulation and air velocity (m/s). With these values, we fill column 5 of the table, and thus, we perform the calculations for the first correction by multiplying column 2 by column 5, and the result is in column 6. To complete the correction and find the real VME, we add the values from column 4 (initially obtained values) to the values in column 6 and fill column 7 with the results.

As defined by FUNDACENTRO, the values obtained in column 7 are analyzed to check if they fall within the range of -0.82 to 0.82, which are considered ideal values for thermal comfort for at least 80% of the people in the environment. Based on the results, we will assess whether the environment provides conditions for thermal comfort or if modifications are needed to achieve comfort.

3. Results And Discussion

The first step was to determine the location where the measurements would be conducted. In informal discussions with some professors, it was suggested to carry them out in a Hydraulic and Pneumatic laboratory. The study space was constructed with masonry, lacks windows, has only one door, and houses machines and equipment that emit heat and noise during operation. Through analysis, it was established that the employee's activity is characterized as sedentary (58 $\frac{W}{m^2} - 1met$) and light clothing thermal insulation (0.5 clo) (Lamberts, 2011; Ruas, 1999, p. 16-30).

The space was then divided into 10 distinct uniform points for temperature and air velocity measurements, during the afternoon period between 2:00 PM and 5:00 PM, using a digital thermal anemometer Model TAFR-180 and a globe thermometer Model TGD-400. The procedure was carried out twice, once with the door open and once with the door open and the fan turned on (frequent conditions of use according to the occupants of the area).

Below is a sketch of the laboratory with marked points and two tables (**Table 2 and 3**) with the data collected during the measurement.

After data collection, calculations were performed to determine the necessary parameters for which control measures should be adopted in the workplace (**Tables 4 and 5**). The calculations were done with the help of the Excel program, and the table below presents the final results obtained for both situations.

According to the values found, we noticed that two out of the ten points evaluated in the initial analysis (environment without a fan) have values outside the appropriate limit (-0.82 < VME < 0.82) for thermal comfort, representing 20% of the total.

In the second analyzed situation, despite the presence of a fan in the environment, it is noticeable that four out of ten points show non-compliance with the specified limit (-0.82 < VME < 0.82), representing 40% of the total.

The seemingly contradictory result demonstrates the ineffectiveness of applying a thermal comfort control methodology without prior in-depth analysis because the adopted modification can worsen the situation instead of improving it. This is evidenced by the deterioration of the environment with the fan turned on, corresponding to a 20% increase in non-compliance points from the first to the second situation.

It's worth noting that the measurements were taken during the Autumn, a period when temperatures are milder in some locations. Additionally, discomfort can occur due to low temperatures, as evidenced by the surpassing of the lower comfort limit (VME < -0.82).

The results obtained indicate that the existing ventilation system is not effective in maintaining thermal comfort at all points in the environment. It is necessary to adopt control measures to address the data that does not meet the requirements. The adoption of these measures should be based on future studies that define a ventilation system capable of providing thermal comfort at these points without causing any disturbance in areas that already meet the criteria for thermal satisfaction.

The need for improvements is also justified based on legal requirements outlined in NR 17, which stipulates that working environmental conditions should be adapted to the psychophysiological characteristics of workers and the nature of the work to be performed, thereby preventing both discomfort and productivity loss.

In the pursuit of alternatives to address the non-compliance issues, we can suggest some possible solutions. For instance, installing windows in the environment to take advantage of natural ventilation. Since we have observed that the current fan is not entirely effective, another option is to install ceiling fans with adjustable speed to ensure uniform ventilation throughout the space and provide options for both warmer and cooler days.

It's important to remember that any modifications to be made should undergo validation studies to assess their efficiency, always aiming to provide the best environmental conditions for employees and all users of the space.

4. CONCLUSIONS

The present study focused on fulfilling the initial objective of evaluating the thermal comfort of a space, aiming to identify how the design of the environment can influence thermal sensation and potential measures to be considered for creating a better environment for its users.

We found that, despite the measurements not taking place during the hottest time of the year, we obtained a significant number of non-compliance values. This occurred because non-compliance also happens when temperatures are low. In the first situation, we had two non-compliant points, and in the second situation, there were four non-compliant points. This demonstrates that the modification made (adding a fan) is not effective in controlling non-compliance. One of the initially non-compliant points (point 5) became compliant, but others became non-compliant.

The data also indicate that the situation could be more critical due to the design of the environment, and if the study had been conducted during hotter or colder periods, it might have been even more challenging, especially in extreme conditions. We can conclude that the location requires adjustments, and we have proposed some modifications to be carried out, but these need validation in future studies to assess the feasibility of such adjustments.

To complement the study and for comparison purposes, it would have been valuable to conduct measurements during different seasons of the year. This would include summer, characterized by intense heat in the region, autumn as performed (a transitional period), and also during winter, with low temperatures. It would be important to investigate how the environment behaves under different temperatures and situations, even to assess whether the suggested modifications would be effective throughout the year.

As we've seen earlier, the comfort or discomfort of users in an environment can significantly influence their productivity and job satisfaction, either negatively or positively. When satisfaction increases, we can consequently boost productivity, reduce production costs, absenteeism, and turnover, and enhance product quality. In the context of education, providing thermal comfort means improving the ability to concentrate for the majority of students, thereby increasing their performance and interest in classroom subjects. All these factors underscore the importance and justification for investments in thermal comfort.

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TABLES

Table 1 - Table used for field data recording

	1	2	3	4	5	6	7
Measurement Points	t_a (°C)	Δt $trm - t_a$ (°C)	v_r **(m/s)**	**VME** $trm = t_a$	$\Delta VME/°C$ **trm** $(°C^{-1})$	ΔVME **(2x5)**	VME_{real} **(4+6)**

Model table for data collection and storage according to Fundacentro, developed by Ruas in 1999. Air temperature (ta) or Dry Bulb Temperature (Tbs): When the temperature is lower than that of the skin, heat is removed by convection. If the air temperature is higher than that of the skin, it will transfer heat to the body; Mean Radiant Temperature (trm): It is uniform in an imaginary environment where heat exchange by radiation is equal to the non-uniform real environment; Relative Humidity (UR): Provides the amount of water vapor in the air relative to the maximum amount it can hold at a given temperature; and Relative Air Velocity (vr): Air velocity affects heat exchange by convection and evaporation. Source: Ruas, 1999.

Table 2 - Data collection with the door open

Points of collection	Globe Temperature (°C)	Ambient Air Temperature (°C)	Air Velocity (m/s)
1	21,80	26,90	0,00
2	21,60	26,70	0,00
3	21,60	26,90	0,00
4	21,50	26,50	0,00
5	21,10	25,70	0,00
6	21,60	26,80	0,10
7	21,50	26,60	0,10
8	21,60	26,80	0,40
9	21,20	26,00	0,00
10	21,30	26,10	0,00

Results obtained in the initial measurements.
Source: Author.

Table 3 - Data collection with the door open and fan turned on.

Points of collection	Globe Temperature (°C)	Ambient Air Temperature (°C)	Air Velocity (m/s)
1	22,00	26,90	0,30

2	21,90	26,80	0,10
3	21,90	26,90	0,20
4	21,90	26,80	0,20
5	21,90	26,90	0,10
6	21,90	26,90	0,40
7	22,10	26,80	0,10
8	22,30	26,90	0,50
9	22,00	26,80	0,40
10	21,90	27,00	0,10

Results obtained from the second measurements.
Source: Author

Table 4 - Final results with the door open.

	1	2	3	4	5	6	7
Measurement Points	t_a (°C)	Δt $trm - t_a$ (°C)	v_r **(m/s)**	**VME** $trm = t_a$	$\Delta VME/°C$ **trm** $(°C^{-1})$	ΔVME **(2x5)**	VME_{real} **(4+6)**
1	26,90	-5,10	0,00	0,38	0,17	-0,87	-0,48
2	26,70	-5,10	0,00	0,31	0,17	-0,87	-0,56
3	26,90	-5,30	0,00	0,38	0,17	-0,90	-0,52
4	26,50	-5,00	0,00	0,23	0,17	-0,85	-0,62
5	25,70	-4,60	0,00	-0,07	0,17	-0,78	**-0,86**
6	26,80	-5,20	0,10	0,28	0,16	-0,83	-0,55
7	26,60	-5,10	0,10	0,21	0,16	-0,82	-0,61
8	26,80	-5,20	0,40	-0,31	0,14	-0,73	**-1,04**
9	26,00	-4,80	0,00	0,04	0,17	-0,82	-0,78
10	26,10	-4,80	0,00	0,08	0,17	-0,82	-0,73

Air temperature (ta) or Dry Bulb Temperature (Tbs): When the temperature is lower than that of the skin, heat is removed by convection. If the air temperature is higher than that of the skin, it will transfer heat to the body; Mean Radiant Temperature (trm): It is uniform in an imaginary environment where heat exchange by radiation is equal to the non-uniform real environment; Relative Humidity (UR): Provides the amount of water vapor in the air relative to the maximum amount it can hold at a given temperature; and Relative Air Velocity (vr): Air velocity affects heat exchange by convection and evaporation.

Table 5 - Final results with the door open and fan turned on.

	1	2	3	4	5	6	7
Measurement Points	t_a (℃)	Δt $trm - t_a$ (℃)	v_r **(m/s)**	**VME** $trm = t_a$	$\Delta VME/℃$ **trm** ($℃^{-1}$)	ΔVME **(2x5)**	VME_{real} **(4+6)**
1	26,90	-4,90	0,30	-0,12	0,15	-0,73	**-0,85**
2	26,80	-4,90	0,10	0,28	0,16	-0,78	-0,51
3	26,90	-5,00	0,20	0,05	0,15	-0,76	-0,71
4	26,80	-4,90	0,20	0,01	0,15	-0,74	-0,73
5	26,90	-5,00	0,10	0,31	0,16	-0,80	-0,49
6	26,90	-5,00	0,40	-0,26	0,14	-0,70	**-0,96**
7	26,80	-4,70	0,10	0,28	0,16	-0,75	-0,47
8	26,90	-4,60	0,50	-0,37	0,14	-0,62	**-1,00**
9	26,80	-4,80	0,40	-0,31	0,14	-0,67	**-0,98**
10	27,00	-5,10	0,10	0,36	0,16	-0,82	-0,47

Air temperature (ta) or Dry Bulb Temperature (Tbs): When the temperature is lower than that of the skin, heat is removed by convection. If the air temperature is higher than that of the skin, it will transfer heat to the body; Mean Radiant Temperature (trm): It is uniform in an imaginary environment where heat exchange by radiation is equal to the non-uniform real environment; Relative Humidity (UR): Provides the amount of water vapor in the air relative to the maximum amount it can hold at a given temperature; and Relative Air Velocity (vr): Air velocity affects heat exchange by convection and evaporation.