*Work 41 (2012) 1606-1611*
*DOI: 10.3233/WOR-2012-0359-1606*
*IOS Press*

# Analysis of the thermal comfort model in an environment of metal mechanical branch

Pinto, N. M.*[1], Xavier, A.A.P.[2] and Regiane T. do Amaral[3]

[1]*Instituto Federal do Espírito Santo, Coordenadoria de Segurança do Trabalho - Vitória, Brasil*
[2]*Universidade Tecnológica Federal do Paraná, Depart. Engª de Produção -Ponta Grossa, Brasil*
[3]*Instituto Federal do Espírito Santo, Subgerência de Administração Geral - Cariacica, Brasil*

**Abstract**: This study aims to identify the correlation between the Predicted Mean Vote (PMV) with the thermal sensation (S) of 55 employees, establishing a linear multiple regression equation. The measurement of environmental variables followed established standards. The survey was conducted in a metal industry located in Ponta Grossa of the State of Parana in Brazil. It was applied the physical model of thermal comfort to the environmental variables and also to the subjective data on the thermal sensations of employees. The survey was conducted from May to November, 2010, with 48 measurements. This study will serve as the basis for a dissertation consisting of 72 measurements.

Keywords: predicted mean vote, thermal sensation, employees, environmental variables, thermal comfort.

## 1. Introduction

### *1.1 Thermal comfort*

Thermal comfort according to a response of one of the participants "is a pleasant sensation of temperature that makes you want to work". The air temperature is one of the environmental variables to be measured. There are four personal and two environmental variables that are measured and tabulated in studies of thermal comfort environment.

But what exactly is Thermal Comfort? It is defined in [11] as "That condition of mind which expresses satisfaction with thermal environment". ISO has a definition that expresses one's imagination as to their contentment in hot, cold or pleasant place. However, when speaking about thermal comfort, there is need for measurements that are standardized with parameters that can be compared and analyzed. *

Thermal comfort is the individual's satisfaction with the thermal conditions of the environment.

According to [7] early study on comfort assessed how the hygrometric thermal conditions affected labor performance. These studies have proposed the creation of thermal comfort indexes, which sought to encompass in a single parameter, several variables as the activity exerted by the person, the type of clothing and environmental parameters that provided the heat exchanges between the body and the environment. In the group classified as theoretical indexes, the one proposed by [6], and also those proposed by [8, 15, 16] are highlighted.

According to [18] the basis of the studies on thermal comfort is found in the thermal balance between man and the environment around him. These studies were impelled by Fanger´s studies on climate chambers (1970), in Denmark and they are standardized in [11].

*Corresponding author e-mail*normapintodemelo@gmail.com*

The equation of heat balance, according to the heat exchange between body and environment is given by equation [1]:
Thermal comfort is given by:

$$M - W = Q_{SK} + Q_{RES} \quad \text{Eq. (1)}$$

where:
M = metabolic rate of heat production (W/m²);
W = rate of mechanical efficiency (W/m²);
$Q_{SK}$ = total rate of heat loss through the skin (W/m²);
$Q_{RES}$ = total rate of heat loss through breathing, (W/m²);

Men have a very effective thermal control system of the temperature that ensures that the body temperature is about 37°C. When body temperature increases, there is a peripheral vascular expansion, the blood flows increases to the skin causing the person starts to sweat.

The evaporation of sweat takes the heat off the body, keeping it at about 37°C. When the body begins to cool, the blood vessels constrict, reducing blood flow to the skin, and increasing internal heat production by stimulating the muscles to tremble. The sensors of heat and cold are on the skin and hypothalamus. The sensors support the body when skin cools below 34°C.

The studies of thermal comfort aim to analyze and establish conditions to assess whether a thermal environment is or is not suitable for human activities and occupations and also to establish methods and principles for a detailed thermal analysis of the environment.

*1.2 Environmental and personal variables*

According to [5] the group of environmental variables measured in the environment is composed of Air Temperature (airT), mean radiant temperature (MRT); Relative Air Speed (RAS) and Relative Air Humidity (RHA). This group measures the heat exchange between human body and environment. By the same author, the group of personal variables consists of the Metabolic Rate (M), obtained from the table at [12] and the clothing insulation (clo), obtained according to [13].

*1.3 Personal variables*

*1.3.1 The metabolic rate (M):*

Furthermore, [12] clarifies that the metabolic rate (M) measures the energetic value of muscular load and gives a numerical index of activity, being an important factor in studies of thermal comfort. In warm climates the levels of metabolic heat production associated with muscular work increase body heat and its dissipation occurs by evaporating sweat.
The activity resulting metabolism is measured in units "met". One met, which corresponds to 58.2 W/m², equals the energy produced per a surface area unit of a body of a person sitting at rest.

The tables in this International Standard regarding to the average individual:
- 30 years old man, weighing 70 kg and being 1.75 m tall has body surface area of 1.8 m².
- 30 years old woman weighing 60 kg and being 1.70 m tall has body surface area of 1.6 m².

Users should make appropriate corrections when they are dealing with special populations including children, elderly, people with physical disabilities, etc...

In studies of thermal comfort and stress calculations that require calculation of the skin area that limits the maximum amount of sweat per day for humans, the following DuBois equation [2] is used.

$$A_{Du} = 0.202\, m^{0.425}\, l^{0.725} \quad \text{Eq. (2)}$$

where:
$A_{Du}$ = surface area of the nude body, or the DuBois area (m²);
$m$ = body mass (kg);
$l$ = body height (m).

*1.3.2 The thermal insulation of clothing (clo)*

Thermal insulation is the resistance to sensible heat exchange through a set of clothes. Thermal insulation of clothing is measured by the unit “clo”. The “clo” is expressed in m².K/W or "clo", where 1 clo equals 0.155 m².K/W. The determination of these values was made using heated manikins [5], and the results of these determinations are duly tabulated in ASHRAE standards and manuals [1, 2, 11, 13].

According to the teachings of the researcher [6], "Neutrality is the thermal condition in which a person does not prefer either more heat or cold over the environment around them". For [17], however: “Thermal neutrality is the condition of

mind which expresses satisfaction with body temperature as a whole".

### 1.4. Determination of indexes PMV and PPD

According to [11], the index PMV (Predicted Mean Vote) Predictive Mean Vote, indicates the thermal sensation of people, represented by Figure 1 in the scale of [11].

#### 1.4.1 The PMV index

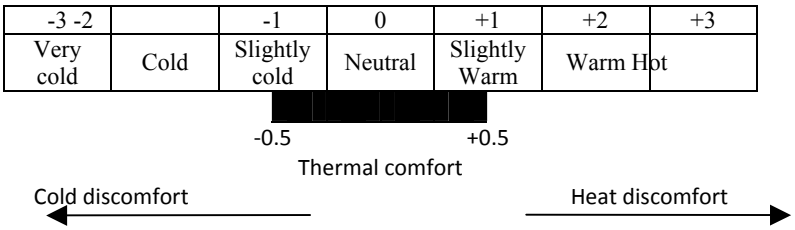



Figure 1: Thermal Sensation Scale
Source: ISO 7730/2005

The model PMV does not deal directly the influence of the climate in the open air. According to [3], in general, persons in the environment of hot climate tend to report that feel more heat in the neutral temperatures ( - 0.5 < neutral > + 0.5).

$$PMV = [0.303.\exp(-0.036M) + 0.028]L \quad \text{Eq. (3)}$$

where:
PMV = predicted mean vote PMV, or analytical sense of thermal comfort, dimensionless;
M = metabolic rate of heat production due to the activity, (W/m²);
L = heat load acting on the body (W/m²).

#### 1.4.2 PPD index

Equation [3] is used to calculate the index PMV and the Predictive Mean Vote Estimate.

The PPD index (Predicted Percentage of Dissatisfied), which indicates the percentage of people dissatisfied with thermal conditions of an environment, is directly related to the PMV and it can be obtained from the same data and software used in the calculation of PMV, or by means of Figure 2 of the scheme that is highlighted.

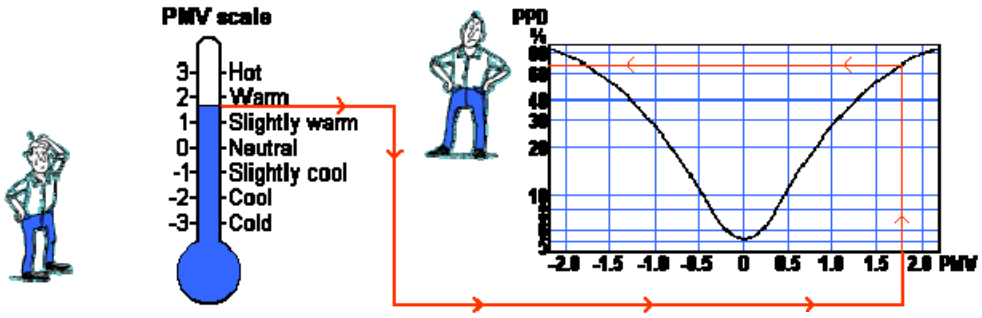



Figure 2: Percentage of People Dissatisfied according to the Predicted Mean Vote (PMV)
Source: Innova

Equation [4] is used to calculate the PPD using the values of PMV.

$$PPD = 100 - 95.\exp[-(0.03353.PMV^4 + 0.2179.PMV^2)]$$ Eq. (4)

## 2. Objective

The aim of this paper is to identify the correlation between the Predicted Mean Vote (PMV) called the thermal comfort model studied by [5] and standardized by [11] with the thermal sensation (S).

Report the results declared by 55 employees in 48 measurements of six environmental variables and two personal variables, called real sensations through a regression analysis seeking to establish an equation between S and the six variables in the model, identifying the variables that exert the greatest influence on the majority of the employees.

## 3. Methodological procedures

The analyzed variables are composed of two groups: environmental variables and personal variables. For the collection of environmental variables the Confortímetro Sensu apparatus was used, in accordance to [10], recording measurements every 30 minutes in the workday. Results for the group composed by the personal characteristics of the clothing insulation (clo), were obtained according to [13] and the Metabolic Rate (M), were obtained from the table of [12].

Questionnaire with five items was applied in a metal industry located in Ponta Grossa of the State of Parana in Brazil. The first sought information about the workplace, age, weight and height of each respondent. The second item noted the activity at four different times during the workday. The third item noted the respondent's thermal sensation across a perception scale of seven points. The fourth item, on the same scale of the previous item, investigated the thermal preference of the respondent. Finally, the fifth item identified the clothing used by the respondent during the interview. The use of Fanger's model and the questionnaire, allowed to create an equation whose variables identified environmental and personal factors of greatest influence in the real sensations reported by employees.

To calculate the indexes PMV and PPD the web tool Human Heat Balance [4] was used. It was fed with the Environmental variables measured with the Confortímetro Sensu apparatus, according to the standards [10], and with data from the Metabolic Rate (M), obtained from the table of [12] and the clothing insulation (clo), obtained according to [13].

Sensations and preferences were collected through the questionnaire according to the model that will be part of the Annexes of the dissertation. Measurements followed the precepts of [10].

For data analysis, the software Statistica 6.1 was used with 90% confidence.

## 4. Correlation between the PMV index and true sensations

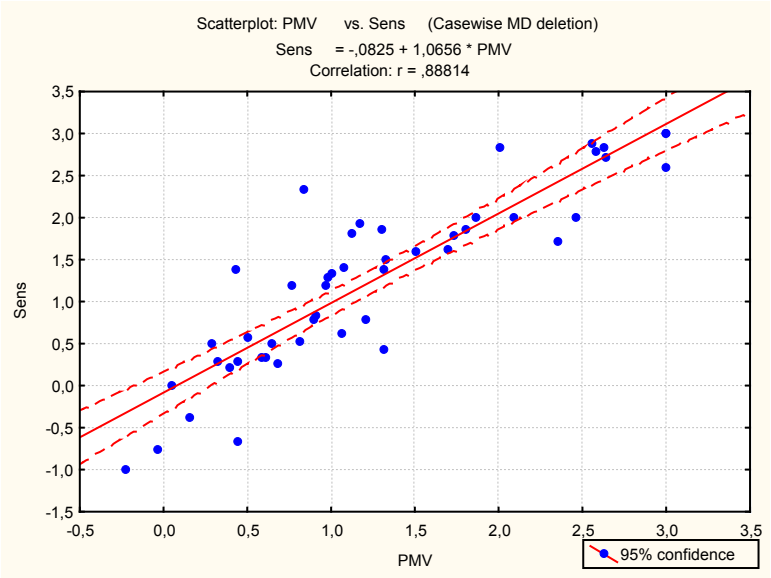
The relationship between PMV and sensations showed a determination coefficient of $R^2 = 0.58$. A set of values with the regression line between the real sensation and the 6 variables of [6] model with a coefficient of determination of $R^2 = 0.84$ is shown in Figure 1. The study sought to establish the equation between the thermal sensation and the 6 variables of the model to achieve the equation:

SENS = 0.005M + 0.05Tar + 0.17Trm - 0.01RH - 2.08 Var - 1.21clo - 2.18.

Eq. (5) where:

SENS = sensation;
M = metabolic rate of heat production (W/m²);
Tar = air temperature (° C);
Trm = mean radiant temperature (° C);
RH = Relative humidity (%);
Var = relative air velocity (m/s);
clo = thermal insulation of clothing (m². K/W) or "clo", where 1 equals 0.155 clo m².K/W.

Graph 1 – PMV vs Real sensation




Source: Research data

As a result, it was noted that the mean radiant temperature (ART), air tem perature, and metabolic rate v ariables co uld im pact thermal sensation of com fort for em ployees i n t he workplace researched. High tem peratures can cause irritab ility, im paired co ncentration and may be causes of industrial accidents.

The evaporation of sweat can bring the employee present ing i nternal body heat ing in low relativ e h umidity an d high temperature, to feel colder temperature than the one measured in a thermometer. This sensation of coolness on the skin o f th e em ployee m ay lead to intensify his/her activ ities an d th is can resu lt in physical harm.

## 5. Conclusions

For better understanding the employees´ sensations regardi ng t he thermal environment around them, i t was devel oped t he equat ion: SENS = 0.005M + 0.05Tar + 0.17Tmr - 0.01RH - 2.08Var - 1.21clo - 2.18.

The correlation that identified the variable that exerts the greates t in fluence o n th ermal sensation was the m ean radiant tem perature, MRT group of t he envi ronmental vari ables was tested.

This p aper will b e p art o f th e basis of the studies of a master's degree di ssertation and i n the set of al l m easurements; discussions and suggestions will be made.

## Acknowledgements

The authors thank Fundação Araucaria - Agency to prom ote the re search of the State of Parana, B razil, for fi nancial support to present this paper at the IEA 2012 - 18th World Congress on Ergonom ics i n R ecife – February 2012.

## References

[1] AMERICAN SOCIETY OF HEATING, REFRIGERATING A ND A IR CONDITIONING ENGINEERS, INC. *Thermal Environmental Conditions for Human Occupancy*, ASHRAE Standard 55-1992. Atlanta, 2005.

[2] *ASHRAE Fundamentals.* Atlanta, 2005 Cap.8: Thermal Comfort.

[3] de Dear, R. J. & Brager, G. S. (1998). Developing an adaptive model of thermal co mfort and preference. *ASHRAE Transactions, 104*(1), 1-18.

[4] de Dear, R. Hum an Heat Balance. University of Australia, Sydney. Access in 10/02/2011< http://web.arch.usyd.edu.au/~rdedear>

[5] Fanger, P.O., 1970, " *Thermal Comfort – Analysis and Applications in Environmental Engineering*", United States, McGraw-Hill Book Company.

[6] Fanger, P. O . *Thermal Confort, Analysis and Applications in Environmental Engineering*. New York, McGraw-Hill Book Company, 1972.

[7] Fontanella M.S; Souza H.A . Avaliação de índices de conforto térmico entr e os univer sitários na cidade de Ouro Preto.In:X ENCAC, Natal,outubro,2009.

[8] Givoni, B. Com fort Clim ate Analysis and Building Design Guidelines. *Rev. Energy and Buildings.* Lausanne: v. 18, n. 1, p. 11-23, 1992.

[9] Innova, Air Tech I nstruments. T hermal C omfort. Access in 17/10/2010 <file://K:\Marketing\Homepage\Gammel%20Homepa ge\Website\books\thermal\therm...>

[10] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. *Ergonomics of the thermal environment — Instruments for measuring physical quantities***,** ISO 7726. Genebra, 1996, 39p.

[11] _____. *Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort,* I SO 7730, Genebra, 2005.

[12] _____. *Ergonomics of the thermal environment — Determination of metabolic rate,* ISO 8996, Genebr a, 2004.

[13] _____. *Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble,* ISO 9920, Genebr a, 2007. Second edition 2007/06/01.

[14] Oliveira,S.J.F. Conforto tér mico no am biente de trabalho: avaliação das variáveis subjetivas da percepção do calor. Available in: http://www.aedb.br/seget/artigos10/201_ARTIGO%2 0-%20SEGET.pdf.: 24/11/ 2010.

[15] Olgyay, V. *Design with climate*. New Jersey: Princeton University, 1963.

[16] Szokolay, S. V. *Thermal Design of Buildings*. Australia: Raia Education Division, 1987.

[17] T anabe**, S.** *Thermal Comfort Requirements in Japan*. Waseda, 1984. T ese de Doutorado – Waseda University.

[18] Xavier, A.A P. Condições de Confor to T érmico para Estudantes de 2º. Gr au na Região de Florianópolis. 198f. Dissertação (Mestrado em Engenharia Civil) – Departamento de Construção Civil da Univer sidade Federal de Santa Catarina, Florianópolis, 1999.