Work Safety: Fuzzy Inference Model Specification for Evaluation of Heat Agent

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Abstract

This research proposes an inference model fuzzy to analyses hazardous environmental work conditions, specifically insalubrious work conditions relevant for heat risk to support the safety engineers for making decisions. *The article presents a study that consists of a fuzzy inference model specification for the evaluation of heat agents. The structure of model fuzzy used are inputs temperature and metabolic rate, while the output is work environment condition that could be salubrious or insalubrious. Through, the inference method Mamdani and rules established according to Brazil legislation about heat, Occupational Hygiene Standard 06, the proposed model can determine the work conditions about the heat. The validation process is done in an industry from the Industrial Pole of Manaus, therefor all the process necessary for preparations to use the proposed model is described to obtain all the variables necessary in the field. As a result, the proposed model got the correct classification of work environment conditions with pertinent results according to current legislation and technical expertise.*

Keywords: fuzzy; heat; metabolic rate; legislation; salubrious; insalubrious.

1. Introduction

The safe work once more represents a challenge in Brazil. According to [1] in between 2016 to 2018 is registered 1.409.293 accidents at work and beyond this, a lot of cases it hasn't been registered. Workers get injured and become ill for the five types of risk, they are physical, chemical, biological, ergonomic and accidents, the physical risk are passives to generate unhealthy conditions on organization. Such factor, take into account the worker spends more than 1/3 of his day on the job, healthy conditions of this environment is fundamental to good development of the worker just as influence productivity [1]. Among all these risks, heat is one of the most dangerous because of a lot of reasons, likewise the difficulty to reduce in a work environment. It's necessary high investment to reduce the heat to a few degrees centigrade.

Certainly, in Brazil, many regions suffer from high temperature and as consequence the heat, but the Amazonia regions beyond this have a great potential for heat risks because high humidity of the region increases temperature, thus its daily saboteur of workers health conditions [2]. For that, this research opted to develops an inference model based on fuzzy logic to analyses the hazard conditions (insalubrious) of the heat risk, therefore it's possible obtain indicator to such assessment [3]. Such technique allows to separate salubrious and insalubrious environmental work conditions, besides identify limits of these conditions, indeed the conception of fuzzy logic allow incorporate subjective standards and judgments to provide the classification of the type of work activity [4].

In other words, increase more reliability on analyses of heat to reduce cost and time associate with this process that determine environmental work conditions engaged by safety engineers and the fuzzy model proposed fundamental results according to current legislation.

2. Literature Review

2.1 Occupational Health and Safety in Brazil

From World War II, Brazil starts the process of industrial development, through Consolidation of Labor Laws (*Consolidação das Leis de Trabalho* - CLT) [5] coming by Decree – Law N.5.452/1943, the first laws of protection to worker, in Getúlio Vargas government. This, on Chapter V treats the security and medicine of labors, later altered by Law 6.514/1977.

Only in 1972, against increase the accidents of work environment, starts regulate create of Occupational Safety and Medicine Services (*Serviços de Segurança e Medicina do Trabalho* - SESMT), through Ordinance 3.237/1972 in base with recommendation of International Labor Organization (*Organização Internacional do Trabalho* - OIT) 112. Although, only with Ordinance 3.214/1978 that published the first 28 Regulatory Standards (Normas Regulamentadoras - NR).

2.2 Analyze of heat risk on working environmental based on NHO6

NHO6 [6] and NR15 [7] are the legislation that regulates the environmental working conditions and activities effect by heat. The assessment of heat must follow the methodology describes on NHO6 on following aspects: Determination of metabolic rate; Determination of thermal overload by index Wet Bulb Index Globe Thermometer (*Índice de Bulbo Úmido Termômetro de Globo* – IBUTG); Determination of occupational heat exposure limit; Measure equipment according to the mounting, position, and procedure

on the place of use; Correct procedure of user; Measure and calculation.

The IBUTG the indicator of occupational temperature that wraps measurements of parameters. This has influence by thermal overload and considering this process has temperature and humidity [8]. Equation 1 represents the calculation of IBUTG.

$$\text{IBUTG} = 0{,}7\ \text{tbn} + 0{,}3\ \text{tg} \quad (1)$$

Where tbn is the temperature wet bulb temperature and globe temperature.

The metabolic rate represents the metabolic heat production by the organism. According to NHO6, the metabolic rate must be estimated by worker activity introduced on the NHO6, give in Watts (W). It´s necessary to identify the worker activity and consult NHO06 chapter 5.2 to determine the metabolic rate.

In brief, the metabolic rate and IBUTG features required conditions to determine heat hazard working environments, this how NHO6 describe. In this process, it´s necessary get metabolic rate by worker activity from NHO06 chapter 5.2 and occupational heat exposure limit on NHO06 chapter 5.3. After that, if the IBUTG measured and calculated get over the occupational heat exposure limit find from metabolic heat, the worker environmental conditions are insalubrious, otherwise salubrious. This reference tables are only to climatized workers, but this analysis is possible to not a climatized worker if consult other tables from NH06.

2.3 Insalubrious

Insalubrious means hazard conditions, but it´s no a danger that happens immediately, there is associate a work unhealthy conditions that cause illness on daily worker [9]. Therefore, the current legislation on Brazil, CLT art. 189 defines insalubrious as activities or operations that put the worker to unhealthy conditions or methods, as a result, exposes the worker above the tolerance limits of the risk according to intensity and time allowed by legislation [5].

2.4 Fuzzy Logic

The Fuzzy Logic have a large use to elaborate computational models, from human perception with subject's information is possible to suit subjective variables on the computational model. This interconnection must be done by intuitive mathematics models and rules instead of complex models, it´s one advantage to use fuzzy logic. The logic fuzzy use subject variables as hot, cold, and very high to create models.

The fundamental of logic is an application of membership function to describes events that were not possible to happen from series of inference for various degrees of certainty about the event [10]. Besides membership function represents the limits of a fuzzy set by a range of two values to map an event. Although, fuzzy sets differ from classic sets because do not establish a binary logic, therefore associate a determinate range to the degree of membership of the fuzzy set. In the same ways, a fuzzy set can operate in between them sets likewise classic set as operation of sum, subtraction, multiplication, and division.

Equation 2 presents algebraically a fuzzy set [10].

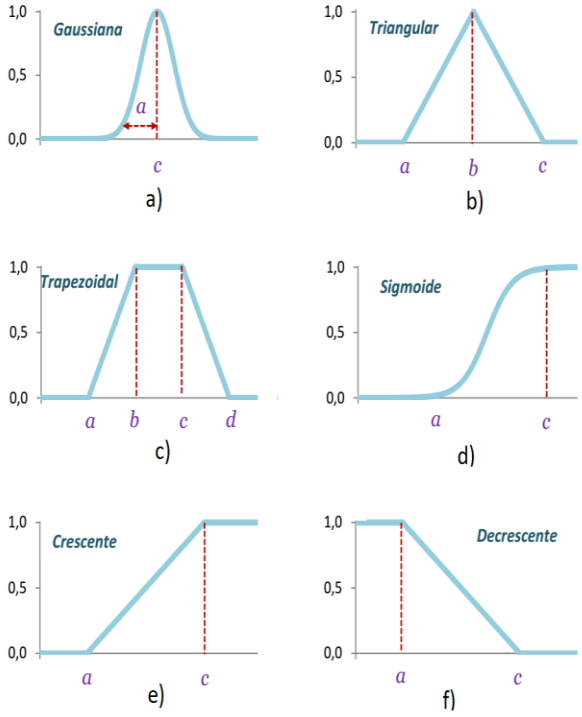
$$\mu: U \longrightarrow [0,1] \quad (2)$$

Where this function is a membership function represents by μ, it is a fuzzy set F of universe U that associate $x \in U$ a number (x) on the range [0,1]. This definition informs that fuzzy sets are a specific case or extension from classic sets [11].

2.6 Membership Function

The membership function could be different mathematics functions according to the necessity of a fuzzy project. The principal functions of literature could be seen in the
Figure *1* that consists of his representations on the cartesian plane.

Figure 1:Membership function.



Source: [12].

According to
Figure *1*, the membership function are representations of geometric forms to maps dataset by logic fuzzy. Certainly, they are triangular (
Figure *1* b.), trapezoidal (
Figure *1* c.), r-function (
Figure *1* e.), l-function (
Figure *1* f.), gaussian (
Figure *1* a.) and sigmoid (
Figure *1* d.).
The equation of this function is represented according to Table 1. Use max () and min () to facilitate computational implementation of this equation on fuzzy set on script language by matlab, octave and scilab [12].
Table 1 shows equation of membership function.

Table 1: Equations of membership function.

Membership	Equation	Where

Function		
Triangular	$f_{mtr}(x,a,b,c) = \min(\max(0,\frac{x-a}{b-a}), \max(0,(\frac{c-x}{c-b})))$	-
R-Function	$f_{mc}(x,a,c) = \min(1, \max(0,(\frac{x-a}{c-a})))$	-
L-Function	$f_{md}(x,a,c) = \min(1, \max(0,(\frac{c-x}{c-a})))$	-
Trapezoidal	$f_{mtra}(x,a,b,c,d) = \min(tra1,tra2)$	Tr1a= $\min(0,\max(0,(\frac{x-a}{b-a})))$ e Tra2 = $\min(0,\max(0,(\frac{d-x}{d-c})))$
Sigmoid	$f_{sig} = \frac{1}{1+e^{-\alpha(x-\beta)}}$	$\alpha = \frac{2}{a-c} ln\left(\frac{1-\gamma}{\gamma}\right)$ e $\beta = \frac{a+c}{2}$
Gaussian	$f_{mgau}(x,c,a) = \exp\left(-\frac{(x-c)^2}{a}\right)$	-

Source: [12].

2.7 Fuzzy Inference

The fuzzy inference maps input data to output data through logic fuzzy. This is done in a base of rules defined mathematically on a model with a relation of a fuzzy set to a fuzzy subset. The membership function happens to be given according to the equation 3 [13].

$$\mu_R(x,y) = \max_{1\leq i\leq r}(\mu_{Ri}(x,u)) \ \forall \ x \in U \quad (3)$$

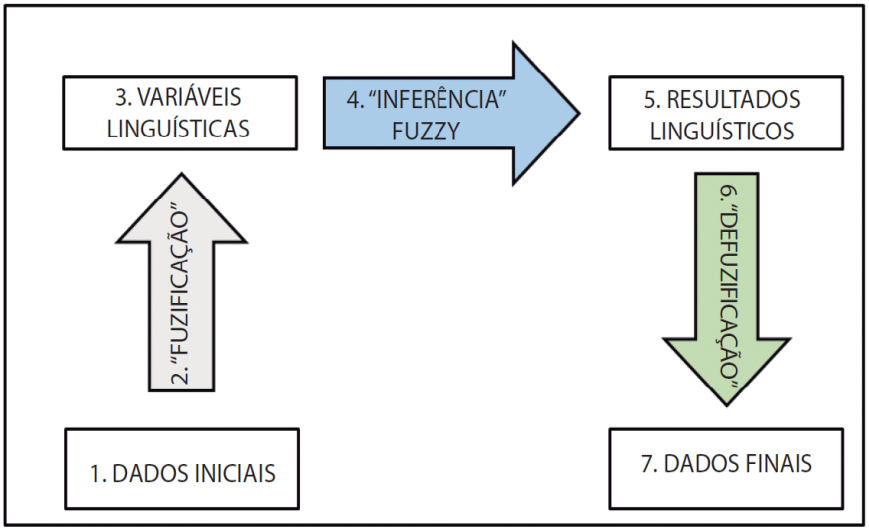
Where Ri é a relation fuzzy of rule i, being the membership function is obtained by values x (input criterion) and u (output criterion). This inference method is Mamdami, most used in literature.

2.8 Fuzzification and Defuzzification

The Fuzzification is the process with a membership function to maps input and obtains linguistic variables similar to a pre-processing process, but defuzzification is the reverse process, to obtain value from linguistic variables, it´s the objective of defuzzification, thus must application specific methods to do this.

Fuzzification and defuzzification can be represented on a fuzzy system as Figure 2. So, fuzzification happened on input data and fuzzification on output data.

Figure 2: Logic Fuzzy System.



Source: [3].

To realize the defuzzification is necessary use the centroid method according to Equation 4 [13].

$$w^0 = \frac{\sum_i \mu_c(w_i).w_i}{\sum_i \mu_c(w_i)} \quad (4)$$

Where w^0 is estimated element, μ_c is membership function and w_i is input data i of element.

3. Methodology

The studies of safety work and occupational health make possible propose a fuzzy inference model for classification of work environmental condition. Therefore, the propose of methodology is to elaborate a model fuzzy to determine salubrious and insalubrious conditions effects by heat.

The specifications of model fuzzy are approach on software MATLAB via toolbox logic fuzzy and established the membership function with inputs and output of the proposed mode, inference method and parametrization.

3.1 Method

It has been analyzed all the possibilities of the implication of fuzzy model through the membership function, responsible for an associate degree of a variable to input/output concerning his membership on fuzzy set, and the inference method what is modeled by mathematic rules for fuzzy relation from a fuzzy set and logic fuzzy adopted.

It has been studied from literature about inference methods as Mamdani and Takagi-Sugeno. Although, Mamdani because the less computational complex has more application in the context of this research.

Based on studies of Regulatory Standards, more deeply NR15, it is defined the variables of proposed modeling of the heat, it has been necessary to obtain inputs and outputs with ranges of a universe of discourse from an interpretation of current legislation.

It´s necessary to specify the universe of discourse, according to the NR15 the range of temperature is 24.7°C and 33.7°C, by the conception of fuzzy projects proposes the division of this range to satisfy limits of temperature to contemplate all possible ranges of metabolic range according NR15.

The validation process of the proposed model was realized on one medium-size industry from the Industrial Pole of Manaus. This industry works on the production of expanded polyethylene, the process has environments non-climatized as sectors of pre-expansion, production, and logistic. In brief, the environments have high temperature and activities developed by operators has high caloric expenditure.

3.1 Material

It´s necessary to use a thermometer certified according to NHO06 to obtain values of temperature and calculate the IBUTG, it is the input "measured temperature" of the proposed model. The Figure 3 represents the instrument used in research to measure.

Figure 3: Thermometer.

Source: Author.

4. Results

4.1 Model Specification and Overview

It was used the following membership functions to maps input and output for necessary research scope, in brief triangular, r-function, l-function, and gaussian.

The triangular function allows maps variable fuzzy set either small or large range, as a result, this function gets adjustable space for a variable (input/output). Besides, different from the triangular function, the trapezoidal function can be interpreted for its geometric characteristic rectangular that offers a plateau that proposes constants or a fixed set of degree membership. As a matter of fact, this function makes it possible to obtain a constant threshold for classification. Therefore, the gaussian function becomes appropriate to be a nonlinear function that can map a large number of points on your curve.

While about the inference fuzzy method chose was Mandanni because is largely used in literature by theoretical simplicity and facility of implementation for diverse problems to modeling. Consequently, it would be the necessary inference according to the variables on NR15 that will be measured temperature and metabolic rate. Although the other inference method on literature is Takagi-Sugeno, that method has computational complexity and theoretical to implementation, empirically it would not have great relevance

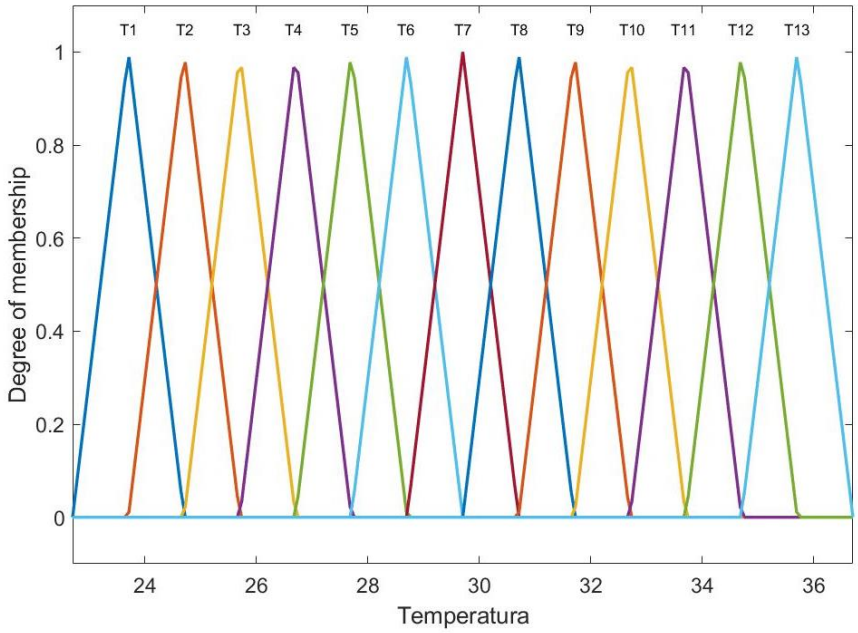
for this research.

The inputs are the measured temperature of environmental working and metabolic rate of worker, while the output is salubrious/insalubrious (hazardous environmental work).

So, the inputs more relevant for this research, indeed, it was the measured temperature of indoor environmental working and metabolic rate of the climatized worker. While salubrious and insalubrious are expected results of occupational health that reflect the conditions of environment working. All these variables are according to the classification of occupational heat exposure limit availed on NHO6.

It has been used a triangular function with the variation of two degrees from incrementation of 22.7°C until 36.7°C to represent the measured temperature and named each function as the linguistic variable "T" with the triangular function, could be seen in Figure 4 all linguistic variables that ranges. So, obtain 13 membership functions to represent measured temperature, the sets from to 34.7°C-36.7°C contemplate above the value established from NR15 (Maximum 33,7 – NR15) because this value can be finding easily in industries.

Figure 4: Fuzzy temperature T4.



Source: Author.

The Table 2 represents the relation between linguistic variables and values of input temperature established for the proposed model.

Table 2: Linguistic Variable of Temperature.

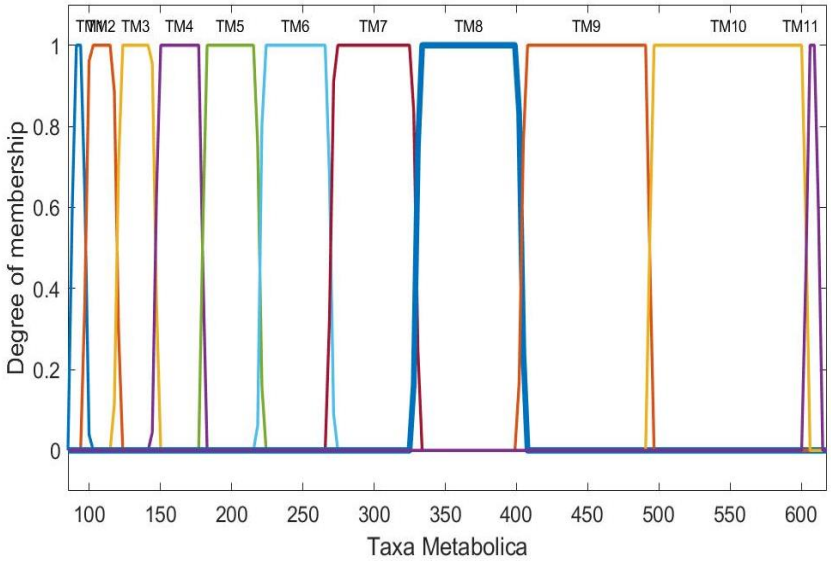
LINGUISTIC VARIABLE	NUMERIC RANGE
T1 [22,7 23,7 24,7]	[22,7 36,7]
T2 [23,7 24,7 25,7]	
T3 [24,7 25,7 26,7]	
T4 [25,7 26,7 27,7]	
T5 [26,7 27,7 28,7]	
T6 [27,7 28,7 29,7]	
T7 [29,7 30,7 31,7]	

T8 [30,7 31,7 32,7]	
T9 [30,7 31,7 32,7]	
T10 [31,7 32,7 33,7]	
T11 [32,7 33,7 34,7]	
T12 [33,7 34,7 35,7]	
T13 [34,7 35,7 36,7]	

Source: Author.

In the same way, the universe of discourse of metabolic rate according to N15 is 100W to 603W. For this set, instead of using the triangular function, it has opted trapezoidal functions to the respective threshold temperature. The Figure 5 shows all linguistic variables of metabolic rate, each one it is named by "TM", all these ranges have been chosen through necessity from temperatures sets, thus is obtained 11 membership functions.

Figure 5: Fuzzy metabolic rate set.



Source: Author.

The Table 3 represents the relation between linguistic variables and values of input metabolic rate established for the proposed model.

Table 3: Linguistic Variable of Metabolic Rate.

LINGUISTIC VARIABLE	NUMERIC RANGE
TM1 [85 90 95 100]	[85 615]
TM2 [95 100 117 122]	
TM3 [117 122 144 149]	
TM4 [144 149 177 182]	
TM5 [177 182 217 222]	
TM6 [217 222 267 272]	
TM7 [267 272 327 332]	

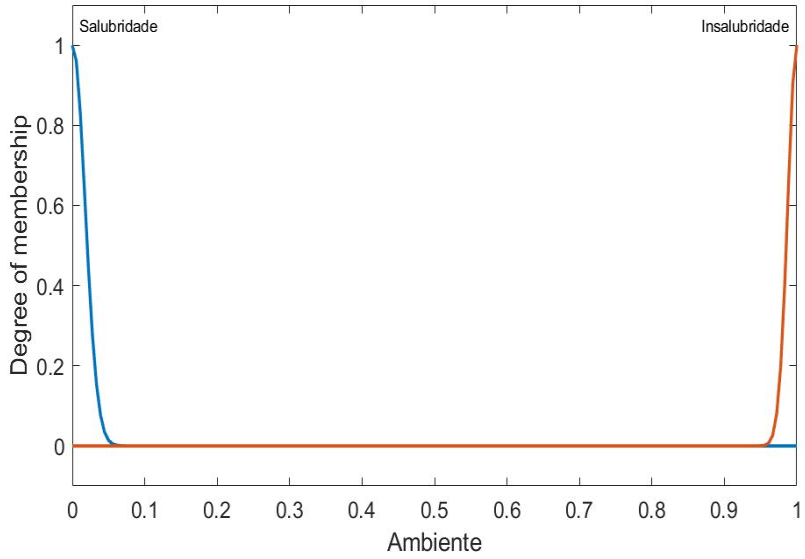
TM8 [327 332 401 406]	
TM9 [401 406 491 496]	
TM10 [491 496 601 606]	
TM11 [601 606 610 615]	

Source: Author.

All these specifications and parameterization have the objective to have options of classification and pertinent to the observation of specialists in occupation safety engineering.

The salubrious and insalubrious are defined from a range of 0 to 1. According to Figure 6, on extreme of this range is used gaussian function near to 0 to represent the salubrious environment of work and another gaussian function near to 1 that is insalubrious.

Figure 6: Fuzzy environment set.



Source: Author.

From observations of study, empirically, the threshold value is 0.1 to classification the environment of work. If the value of output is less than 0.1, the environment of work is salubrious, otherwise, it is insalubrious. Established all necessary sets to decision making about conditions environment of work influenced by heat, which is measured temperature, metabolic rate, and environment of work, the next step is to define inference rules to associate each variable to the condition of effect and cause and consolidate the proposed model, the inputs are measured temperature and metabolic rate and output its environment of work. How already explain previously, a threshold of temperature will be using with trapezoidal membership functions to obtain conditions of work environment which will be salubrious or insalubrious. Thus, were obtained 143 inference rules and the main rules that explain transitions sets from salubrious to insalubrious have been represented according to Table 4, the other rules are the combinatorial of all sets.

Table 4: Main Fuzzy rules.

Rules	Measured Temperature	Logic Operator	Metabolic Rate	Work Environment
21	T2	and	TM10	Salubrious
22	T2	and	TM11	Insalubrious
31	T3	and	TM9	Salubrious
32	T3	and	TM10	Insalubrious
41	T4	and	TM8	Salubrious
42	T4	and	TM9	Insalubrious
51	T5	and	TM7	Salubrious
52	T5	and	TM8	Insalubrious
61	T6	and	TM6	Salubrious
62	T6	and	TM7	Insalubrious
71	T7	and	TM5	Salubrious
72	T7	and	TM6	Insalubrious
81	T8	and	TM4	Salubrious
82	T8	and	TM5	Insalubrious
91	T9	and	TM3	Salubrious
92	T9	and	TM4	Insalubrious
101	T10	and	TM2	Salubrious
102	T10	and	TM3	Insalubrious
111	T11	and	TM1	Salubrious
112	T11	and	TM2	Insalubrious

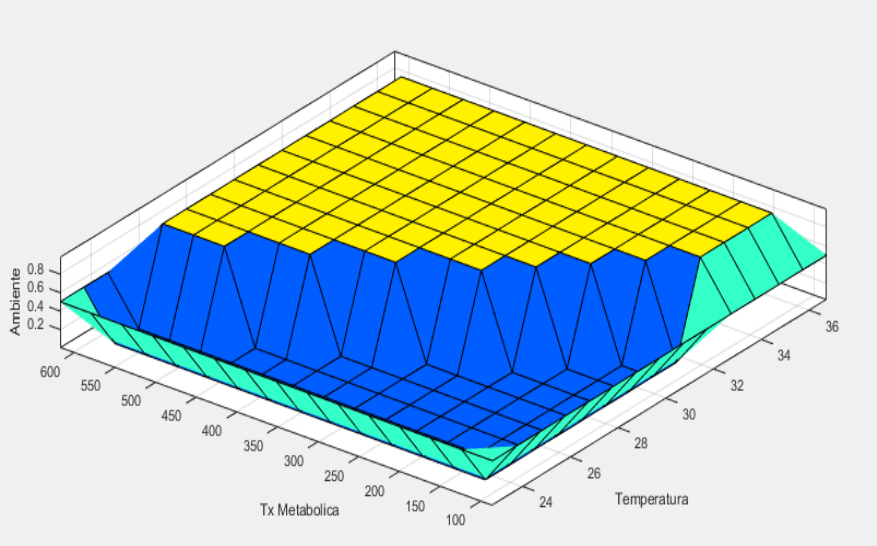
Source: Author.

From inference rules established, the

Figure *7* represents a tridimensional graphic (or surface) of the proposed model. According to

Figure *7*, could be seen has been expected around the 50% of cases correspond to insalubrious cases and remaining salubrious cases. These results are a consequence of a dyadic problem, in other words, each temperature corresponds to the metabolic rate set salubrious and insalubrious, only this way have been possible to respect current legislation NR15 and have a model that represents technical expertise and regulations.

Figure 7: Surface analysis of proposed model.



Source: Author.

4.2 Model Simulation and Validation

Initially, it is realized the measured with the thermometer that must be calibrated and fully charged. It have been necessary to leave it for 20 minutes to establish and calculate IBUTG. The thermometer is placed from a distance that not damage the operator on his activity, the Figures 8,9,10 represents moments of measured with the equipment.

Figure 8: Preparation of measurement.

Source: Author.

Figure 9: Operator on initial working process.

Source: Author.

Figure 10: Operator on final working process.

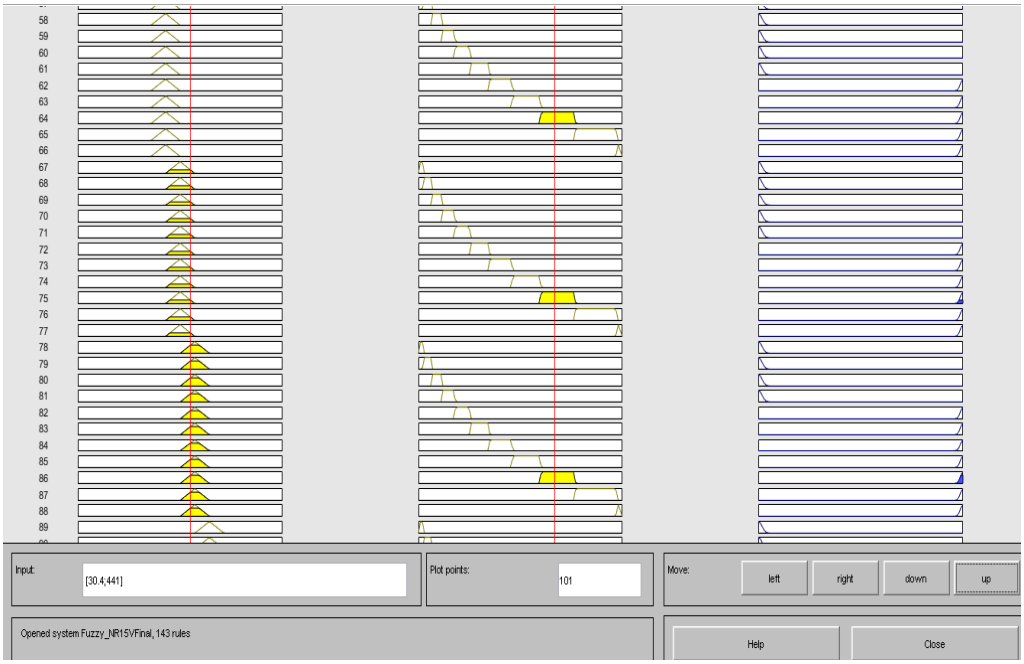
Source: Author.

It have been realized a quantitative analysis while registered the temperature, have been sensed a high temperature and thermal discomfort. Considering the operator transposes an injected product to an injection machine in conditions of high temperature and thermal discomfort that environment work would be insalubrious, this have been the expectation of results from the proposed model based on quantitative analysis.

In sequence on quantitative analyses and after calculated IBUTG that resulted in a measured temperature of 30,4°C with the estimated metabolic rate of 441, it is obtained from the proposed model the result of 0,992 that represent insalubrious conditions of environment work (Figure 11). Thus, the quantitative analysis results were the same as the model proposed, indeed, it sensed a relevant presence of agent heat on work that featuring insalubrious.

According to Figure 8, the more important rule that affect these results is the rule 75 and 86 because the measured temperature is the intersection area of temperature from temperature set “T7” and “T8”, respectively, metabolic rate sets “TM10” and “TM9”.

Figure 8: Results - TAXAMET..= 441 W ; TEMP. 30,4ºC ; RESULTADO: 0,992.



Source: Author.

Such result validates the proposed model because it is according to NHO06, the same result is found when search on current legislation. This approach satisfies technical and legislation issues with pertinent diagnosis about agent heat on work environment.

5. Conclusion

The physical risk heat is a factor of business unfeasibility for worker operations by law conditions determine limits of occupational temperature, if these limits get over it is not allowed the worker executes his activities. This research is relevant to the development of a solution for help with occupational quantitative environmental assessment.

The determination of salubrious is a fundamental principle for the health and security of all laborers principally in hot and humidity. In a juridic area, the heat is a challenge to perform the law for worker protection

Thus, the results were according to expected pertinent with the methods used. It has been possible to identify and definite all variables and inference methods to classifications of environment work conditions for model specification. The validation confirms the proposed model for the threshold value of classification. To summarize, it has been possible to automate the process of analyses for the evaluation of salubrious.

6. Acknowledgement

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