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MODELAGE FUZZY APLICADO AL BIEN ESTAR DE TRABAJADORES DE GRANJAS AVÍCOLAS

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ABSTRACT: The objective of this work was to develop a fuzzy model to classify the working environment in poultry farms. For this purpose, air temperature, relative humidity, noise level, and ammonia concentration were measured in a broiler house with lateral positive-pressure ventilation. Work days consisting of 8 hours were simulated and the results provide support for classifying the level of comfort under different thermal, noise and gas concentration conditions. Therefore, three input variables were used: temperature-humidity index (THI), noise level (dB) and ammonia concentration (ppm), and the output variable was the work environment classification (WEC). Sixty rules were defined based on combinations of THI, noise level and ammonia concentration and each result is a function of the combination of input data. Experimental data was used to test the application of the proposed model. The results indicate that the proposed methodology is promising for determining the worker well-being level, and as an aid in making decisions regarding the control of the work environment in order to reduce or eliminate sources considered stressful to humans.

KEYWORDS: Mathematical modeling, Human environment, Poultry house, Thermal comfort index

RESUMEN: El objetivo de este trabajo fue desarrollar un modelo fuzzy para evaluar y clasificar el ambiente de trabajo de las granjas de pollos de engorde. Para ello datos de temperatura del aire, humedad relativa, nivel de ruido y la concentración de amoníaco fueron colectados en un galpón avícola con ventilación positiva lateral. Un esquema de trabajo de ocho horas al día fue simulado y los resultados dieron un soporte para la clasificación del nivel de confort bajo las diferentes condiciones térmicas, acústicas y de concentración de gas. Por lo tanto, fueron utilizadas tres variables de entrada, índice de temperatura y humedad (ITU), nivel de ruido (dB) y concentración de amoníaco (ppm), y la de salida fue la clasificación del entorno de trabajo (CET). Fueron definidas sesenta (60) reglas con base en las combinaciones de ITU, nivel del ruido y concentración de amoníaco, donde cada resultado es una función de combinación de los datos de entrada. Los datos de campo fueron usados para validar el sistema propuesto. Los resultados indican que la metodología propuesta es viable para determinar el nivel de bienestar de los trabajadores pudiendo ayudar en la toma de decisiones relacionadas con el control climático y se puede utilizar con el fin de reducir o eliminar las fuentes que son consideradas como causantes de estrés en el hombre

PALABRAS CLAVE: Modelamiento matemático, Confort térmico humano, Galpón avícola, Índices de confort térmico

1. INTRODUCTION

The economic sector of poultry production and reproduction employs a large number of individuals who work approximately 44 hours per week in reproduction and production farms, exposed to some poorly defined situations with respect to healthy conditions [1]. Information on the thermo-acoustic environment and gas emissions in intensive production systems and their effects on animal and worker welfare are scarce. The information of the working environment facilitates understanding the difficulties, discomfort, dissatisfaction and the occurrence of occupational accidents and diseases [2].

With the objective of establishing criteria for the classification of environments, various thermal comfort indices were defined that aim to encompass, in a single parameter, the combined effect of meteorological elements and the environment constructed around the studied individual. Among the thermal indices developed for humans, some of the most cited are the index of thermal stress - SWreq [3], the wet bulb globe temperature index - WBGT [4] and the temperature-humidity index - THI [5].

Although there are more complete thermal comfort indices than the THI, this has been widely used because it includes only general meteorological information available at weather stations and from databases derived from satellite images [6,7].

Recently other variables have been studied in order to complement those related to the thermal environment, such as sound pressure and gas emissions.

Noise within the animal production installations can be studied according to two aspects. First, related to the processes of animal vocalization that permit that the conditions of welfare or stress can be measured.

The second factor is related to internal conditions that may cause harm to workers in these facilities [8]. According to the Brazilian Association of Technical Standards, NBR 10152 [9], the limit of health for people working 8 hours per week is 85 dB, and 7 minutes at 115 dB (a), not permitting exposure to noise levels above this limit for individuals who are not adequately protected, since these conditions may provoke serious or imminent risk.

One of the air pollutants often found in high concentrations in poultry farms is ammonia. There is evidence that the health of workers and animals may be compromised by continued exposure to this pollutant, resulting in respiratory diseases caused by opportunistic agents [10, 11]. The concepts of air quality measurement vary among countries, being influenced by housing conditions of the birds. According to [12] the ammonia emissions depend on several factors including the type of ventilation, age of the bedding, duration of the chicken cycle and measurement method.

Computational models can be used to quantify the interaction of thermal, acoustic and ammonia concentration variables with the comfort of workers. These include intelligent systems, which are able to perform tasks or solve problems utilizing a knowledge base, the most widely used and tested are fuzzy logic and artificial neural networks.

The fuzzy set theory, developed by Lofti A. Zadeh in 1965 [13], consists of a revolution in the classical set theory, allowing the introduction of degrees of uncertainty when dealing with sets. Thus, the application of fuzzy logic is an interesting alternative to aid in prediction of the welfare index, enabling control of the workplace and avoiding potentially unhealthy situations and harm to worker health.

Based on these facts, the objective of the present study was to develop a fuzzy model to estimate worker welfare in poultry farms based on the thermo-acoustic environment and ammonia concentration.

2. MATERIAL AND METHODS

To develop the proposed fuzzy model the following input variables were defined: temperature-humidity index (THI), noise level (dB) and ammonia emissions (ppm). THI was used as a function of environmental variables obtained in this study. Based on the input variables, the fuzzy system predicted the work environment classification (WEC), assessing the level of human comfort in the work environment in poultry houses. The proposed index ranges from 0 to 1, indicating healthy or unhealthy working conditions, respectively.

After completing the mathematical model, data of the air temperature, relative humidity, noise level and ammonia concentration were collected during six days at predetermined points (Figure 1) in a poultry shed with positive-pressure ventilation located in the "*zona da mata*", Minas Gerais, Brazil, and the collected data was used to test the developed model.

The poultry house measured 13 m in width, 100 m in length and 2.90 m in height, housing 15,380 male birds of the Avian lineage, resulting in a density of 11.8 birds m^{-2}. Ventilation was performed with 13 fans at a flow rate of 300 m^3 s^{-1}, positioned on a side wall (lateral ventilation).

The heating system of the building consisted of wood burning furnaces for indirect air heating, located inside the shed. Hanging feeders and waterers were installed. These systems are normally found in poultry houses in Brazil.

The thermal environment was assessed according to the environmental variables: dry bulb temperature (t_{db}), relative humidity (RH) and air velocity (V), where for the first two, sensors/recorders (accuracy of ± 3%) were programmed to collect these environmental variables every 15 minutes. The sensors/recorders were placed in three sections at 0.3 m off the ground along the length of each shed, whose distances from the entrance gate were 33, 50 and 67 m, as illustrated in Figure 1. In the case of V, a digital hot wire anemometer was used (precision ± 0.03 $m.s^{-1}$).

The variables that make up the acoustic environment and ammonia concentration were evaluated by decibel meters (accuracy of ± 1.5 dB) and an ammonia detector (resolution of 0.1 ppm and an accuracy of ± 1 ppm), respectively. Point samples of noise levels, ammonia concentration and V were performed at 0.3 m and 1.7 m off the floor, at positions close to sensors/recorders.

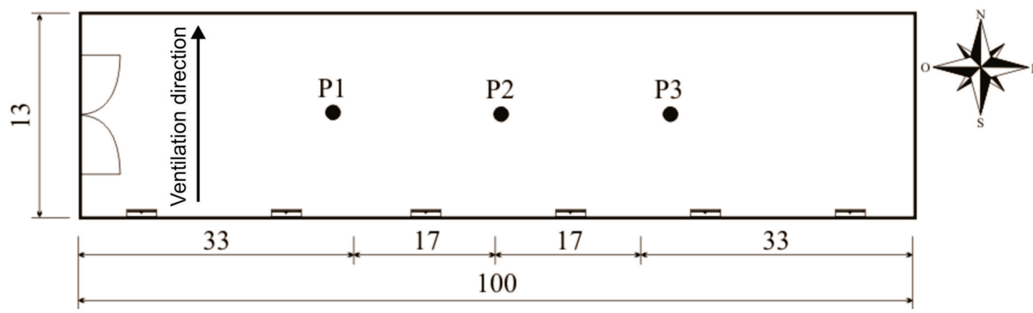

Figure 1. Location of the data collection points inside the poultry house

The Mamdani inference method was used in the analysis, which provides a fuzzy set as a response originating from the combination of input values with their respective degrees of membership via a minimum operator followed by overlapping of the rules with the maximum operator. Defuzzification was done using the Center of Gravity method (Centroid or Center of Area), which considers all the possibilities for output, transforming the fuzzy set originating from the inference into a numerical number, as proposed by [14].

2.1. Input variables

The temperature-humidity index (THI) developed by [5] (Equation 1) was used to evaluated the thermal environment in order to define zones of thermal comfort for people, and subsequently used to evaluate the thermal comfort for animals and people.

$$THI = 0.72\,(t_{db} + t_{wb}) + 40.6 \qquad (1)$$

where, t_{db} = dry bulb temperature (°C) and t_{wb} = wet bulb temperature (°C).

For definition of the thermal comfort and discomfort zones for workers the limits used were based on studies by [15, 16, 17] where the following intervals were defined with the respective classifications: THI < 74 (adequate thermal comfort), 74 ≤ THI < 79 (warm environment, thermal discomfort initiates and may cause health problems and reduction in productivity of rural workers), 79 ≤ THI < 84 (very hot environmental, conditions indicating danger and could bring severe consequences to the health of rural workers) and THI > 84 (extremely hot conditions, with very serious risk to the health of rural workers).

For the variable noise (dB) five levels were used, where R1 was based on [18] which considers no effect in this range; R2 according to [19], noise of 50 dB with disturbing but acceptable characteristics; R3 according to World Health Organization [20], greater than 55 dB can cause mild stress, accompanied by discomfort; R4 noise between 60 and 100 dB causes wear to the organis m and release of endorphins in the body, being the maximum noise acceptable for healthy activity during 8 hours of uninterrupted work (NR-15, 1978), and in R5 irreversible damage occurs to the ear drum [18], as well as the potential loss of hearing.

For definition of the ammonia concentration variable (ppm), as shown in Table 1, three classification ranges were used (0-50, 50-100, 100-200), where A1 is considered safe for worker health, in A2 ammonia can be inhaled without major consequences, and in A3 ammonia induces drowsiness, salivation, and loss of appetite [10].

Table 1. Fuzzy sets for the input variables

Variable type	Variables	Fuzzy sets	
Input	THI	Comfort	[65; 74]
		Hot	[73; 79]
		Very hot	[78; 84]
		Extremely hot	[83; 90]
	Noise (dB)	R1	[0; 40]
		R2	[30; 55]
		R3	[50; 70]
		R4	[60; 100]
		R5	[85; 140]
	Ammonia (ppm)	A1	[0; 50]
		A2	[40; 100]
		A3	[90; 200]

The ranges allowed for the input variables of THI, noise and ammonia were graphically represented by the trapezoidal membership function because they best represent the behavior of the input data and are the most used according to literature [21, 22, 23] as illustrated in Figure 2.

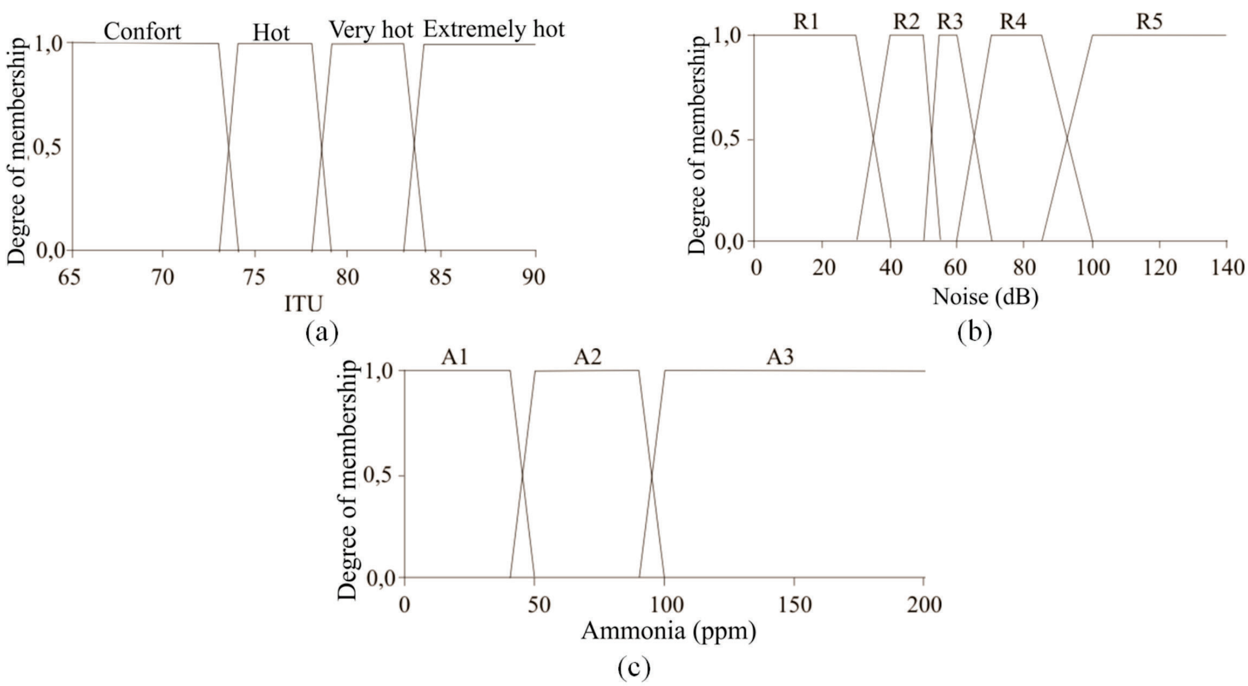

Figure 2. Membership functions for the input variables: (a) THI, (b) noise (dB) and (c) ammonia concentration (ppm)

2.2. Output variables

The output variable WEC, used in the construction of the fuzzy system, allows for direct indication of worker welfare. Their sets established intervals in the domain of [-0.25 ; 1.25], classified according to the degree of unhealthy environment conditions, where WEC values equal to one indicate the poorest health working conditions and zero the healthiest working conditions. Thus, the following fuzzy sets were specified, as shown in Table 2.

Table 2. Working environment classification (WEC) according to the degree of healthy working conditions

WEC	Unhealthy conditions
Grade 1 (-0.25 - 0.25)	None
Grade 2 (0.0 - 0.50)	Minimal
Grade 3 (0.25 - 0.75)	Average
Grade 4 (0.50 – 1.0)	High
Grade 5 (0.75 - 1.25)	Very high

The intervals adopted for the output variable WEC were characterized by triangular and trapezoidal membership functions, to best fit the data of the developed model (Figure 3). Moreover, these types of membership functions have been adopted in several fuzzy models reported in literature [24, 25, 26].

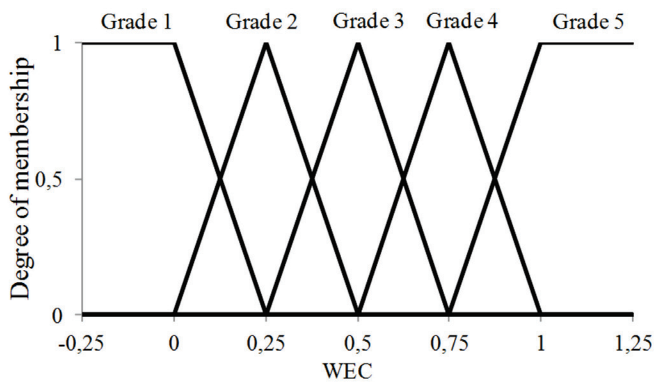

Figure 3. Membership functions for each work environment classification output variable

2.3. System rules

The system rules (Table 3) were developed based on combinations of THI, noise and ammonia concentration, and an expert was consulted to develop the output result for each combination of input data.. In the selection of experts their theoretical knowledge was considered (through experiences in scientific research). Researchers were chosen from the Engineering Department, Federal University of Lavras and researchers from the Department of Agricultural Engineering, Federal University of Viçosa. The researchers were selected in the areas of working environments with experience in acoustics for workers, and fuzzy modeling applied to working environments, as selection methodology proposed by fuzzy expert [30]. A total of 60 rules were defined and a weighting factor of 1 was assigned to each rule.

Table 3. Composition of the system rules in function of the characteristics: THI, noise and ammonia concentration

THI	Noise	Ammonia	WEC	THI	Noise	Ammonia	WEC
Comfortable	R1	A1	G1	Very hot	R3	A1	G3
Comfortable	R1	A2	G1	Very hot	R3	A2	G4
Comfortable	R1	A3	G2	Very hot	R3	A3	G5
Hot	R1	A1	G2	Extremely hot	R3	A1	G4
Hot	R1	A2	G2	Extremely hot	R3	A2	G5
Hot	R1	A3	G3	Extremely hot	R3	A3	G5
Very hot	R1	A1	G3	Comfortable	R4	A1	G3
Very hot	R1	A2	G3	Comfortable	R4	A2	G3
Very hot	R1	A3	G4	Comfortable	R4	A3	G4
Extremely hot	R1	A1	G4	Hot	R4	A1	G3
Extremely hot	R1	A2	G4	Hot	R4	A2	G4
Extremely hot	R1	A3	G5	Hot	R4	A3	G4
Comfortable	R2	A1	G1	Very hot	R4	A1	G4
Comfortable	R2	A2	G2	Very hot	R4	A2	G4
Comfortable	R2	A3	G3	Very hot	R4	A3	G5
Hot	R2	A1	G2	Extremely hot	R4	A1	G5

THI	Noise	Ammonia	WEC	THI	Noise	Ammonia	WEC
Hot	R2	A2	G3	Extremely hot	R4	A2	G5
Hot	R2	A3	G3	Extremely hot	R4	A3	G5
Very hot	R2	A1	G3	Comfortable	R5	A1	G4
Very hot	R2	A2	G4	Comfortable	R5	A2	G4
Very hot	R2	A3	G4	Comfortable	R5	A3	G5
Extremely hot	R2	A1	G4	Hot	R5	A1	G4
Extremely hot	R2	A2	G4	Hot	R5	A2	G5
Extremely hot	R2	A3	G5	Hot	R5	A3	G5
Comfortable	R3	A1	G2	Very hot	R5	A1	G5
Comfortable	R3	A2	G2	Very hot	R5	A2	G5
Comfortable	R3	A3	G3	Very hot	R5	A3	G5
Hot	R3	A1	G2	Extremely hot	R5	A1	G5
Hot	R3	A2	G3	Extremely hot	R5	A2	G5
Hot	R3	A3	G4	Extremely hot	R5	A3	G5

3. RESULTS AND DISCUSSION

When new computer systems are created in order to support decisions, it is necessary to adopt measures to examine the descriptive power of the new system introduced. These measures are used, for example, to evaluate the efficiency of a system to generate responses for the welfare classification that are very close to reality. Thus, when a mathematical modeling system is developed it is important to evaluate the power of the classification system, in this case, the power to qualify the working environment in the poultry production installation.

For this purpose the developed system was tested with field data (Table 4) obtained during the six sampling days at random times, thus representing the various situations found throughout the day on which the assessments were performed.

As can be observed in Table 4, the unhealthy working environment conditions in the installation studied were low during the days of assessment, the worst value was encountered on 15/07/09 at 14:00 hours when the WEC was 0.50, classifying the environment as presenting average health conditions. This classification is because the THI value was high during this period, whereas levels of noise and ammonia were average and low, respectively. This proves the effectiveness of fuzzy modeling for weighing the input data to obtain output values similar to reality.

In commercial control systems fuzzy logic may be used to trigger an alert system when this unhealthy situation occurred, connected to ventilation and cooling systems or even to prevent that the worker is exposed to this environment for a prolonged period.

Table 4. Simulation of the WEC utilizing data collected in commercial poultry production facilities

DATE	POINT	TIME	NOISE (dB)	THI	AMMONIA (ppm)	WEC
13/07/09	P1	07:00	39.9	75.0	20	0.25
		17:30	38.7	78.6	6	0.40
	P2	07:00	41.0	74.9	19	0.25
		17:30	43.3	78.8	6	0.44
	P3	07:00	46.2	75.9	9	0.25
		17:30	48.6	79.8	3	0.50
14/07/09	P1	10:40	32.5	71.3	3	0.00
		12:30	31.8	72.2	3	0.00
	P2	10:40	40.4	71.3	0	0.00
		12:30	45.7	71.3	0	0.00
	P3	10:40	41.5	74.7	0	0.25
		12:30	40.7	71.9	0	0.00
15/07/09	P1	10:30	46.6	69.1	0	0.00
		14:00	51.5	79.1	0	0.50
	P2	10:30	57.5	69.1	0	0.25
		14:00	54.1	68.3	3	0.19
	P3	10:30	26.4	70.5	0	0.00
		14:00	38.0	67.9	0	0.00

DATE	POINT	TIME	NOISE (dB)	THI	AMMONIA (ppm)	WEC
16/07/09	P1	09:30 15:00	41.6 31.6	66.7 71.2	4 0	0.00 0.00
	P2	09:30 15:00	46.5 46.2	67.5 72.6	0 0	0.00 0.00
	P3	09:30 15:00	24.6 24.4	65.9 71.3	0 0	0.00 0.00
17/07/09	P1	07:00 09:00	55.3 54.5	70.6 70.0	16 3	0.25 0.21
	P2	07:00 09:00	46.2 43.0	70.9 70.7	17 0	0.00 0.00
	P3	07:00 09:00	32.6 46.5	68.8 70.8	13 0	0.00 0.00
20/07/09	P1	08:30 17:00	43.6 43.2	67.9 66.6	40 0	0.00 0.00
	P2	08:30 17:00	43.6 44.0	67.5 67.0	45 0	0.10 0.00
	P3	08:30 17:00	54.4 54.2	68.8 68.2	36 0	0.21 0.19

Also comparing the system developed with data from the literature it was observed that fuzzy modeling is able to weigh the input data in order to generate an output that is closest to describing the real discomfort felt by the worker.

In a study conducted by [27] evaluating noise levels in the production of broiler breeders, the authors observed a peak of 97.1 dBA in the production facility, and they recommend the use of ear-plugs for this environment. Considering values within the comfort range for THI and ammonia, for this situation the fuzzy system classified the work environment as presenting unhealthy working conditions, with a value of 0.69 on the scale of healthy working conditions ranging from 0 (completely wholesome environment) to 1 (completely unhealthy environment).

Evaluating two commercial poultry installations in the Midwest region of Brazil, equipped with positive-pressure tunnel ventilation systems one with a cellulose pad and the other a moistened *sombrite* pad associated with misting, noise levels of 63.1 dBA and 62.9 dBA were observed, respectively [28]. This author described the working environment in the installations as providing no health risks to workers. Given these noise levels, the proposed system ranked the environment as providing minimal health risks, resulting in values of 0.34 and 0.32 for the evaluated poultry houses.

In a study on the potential use of evaporative cooling systems in southeastern Brazil, the authors of [7] obtained a maximum THI of 77.4 during the summer, claiming that this value represents a certain degree of heat stress for both animals and rural workers. For these thermal environment conditions, considering values within the comfort range for noise and ammonia concentration, the proposed fuzzy system ranked the environment as Grade 2 with value of 0.25 for WEC. Thus, this environment is classified according to the model developed as a minimum risk to health.

Assessing the concentration of dust and gases in conventional and tunnel poultry installations, reference [29] obtained maximum ammonia concentrations of 167 ppm and 86 ppm for the buildings assessed, stating that these values are high with respect to international recommendations. In simulation of the fuzzy system, considering minimum values of noise and THI, these environments are classified as presenting average and minimum levels of unhealthy working conditions, 0.50 and 0.25, respectively.

4. CONCLUSIONS

The developed fuzzy methodology appears to be promising for predicting the degree of unhealthiness related to poultry farm workers, the proposed system estimates the comfort of workers as a function of thermal, noise and gas environmental variables inside the facility, and may also be used to aid in decision making in order to control the internal environment in poultry production facilities.

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