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Thermal-Acoustic Comfort Index for Workers of Poultry Houses Using Fuzzy Modeling

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ABSTRACT
Thermal-acoustic comfort is considered an essential factor for the performance of industrial activities. As well as harm the health of the workers, environments outside the adequate conditions provoke losses in productivity. The objective of this work was to develop a system capable of evaluating and classifying the working environment in poultry houses. A working regime of 8 hours per day in a poultry house was simulated and the results provide support for the classification of the comfort level based on different climate and noise conditions. Two input variables were used: wet bulb globe temperature (WBGT) and noise level (dB), and the correspondent output variable was the human welfare index (HWI). The results indicate that the proposed methodology is a promising technique for the determination of the level of thermal comfort endured by poultry house workers, capable of assisting in making decisions on control of the working environment.
KEYWORDS: human welfare, environment control, mathematical modeling.

I. INTRODUCTION

Information on noise and its effects on the welfare of animals and workers in intensive animal production systems are scarce. Knowledge of the working environment facilitates understanding of difficulties, discomforts, dissatisfactions and occurrence of accidents and occupational illnesses [1].

The main characteristics which contribute to emergence of hearing illness, the following are highlighted: intensity related to the sound pressure level, sound type (continuous, intermittent or of impact), exposure time to each type of agent and its quality with respect to the frequency of the sounds which comprise noise in the determined analysis [2].

Based on the environmental variables, decisions must be made so that the environment is adequate for the worker. In this context, application of fuzzy logic is an interesting option to aid in prediction of the welfare index, allowing for control of the working environment and avoiding situations of unhealthiness and harm to worker health. Fuzzy methodology is based on construction of fuzzy sets, which represent the information in linguistic terms. Therefore, the fuzzy sets express vague concepts similar to natural speech [3]. According to [4], fuzzy logic is a technique that incorporates the human form of thought in a control system, which can principally be applied when physiological responses are incorporated to agents of environmental stress, for example, ambient temperature interfering on the responses of body temperature and productivity [5, 6, 7, 8], which thus adds greater complexity to this type of analysis.

Typical fuzzy control can be projected to behave according to deductive reasoning. However, a fuzzy controller can be viewed as a method of decision making, based on approximate reasoning.

Based on this information, the objective of the present study was to develop a fuzzy system to estimate welfare of workers in poultry houses based on the thermal- acoustic environment.

II. MATERIAL AND METHODS

To estimate situations with a high degree of randomness, such as welfare, based on empirical analysis of physiological measurements, studies point to the potential use of specific criteria based on previous knowledge, utilizing a theory of fuzzy sets used for decision support systems which are characterized by the uncertainty between the affirmations of “yes” and “no” [9]. Fuzzy logic allows for treatment of the logical implications according to natural reasoning laws, analyzing conditions and stipulating consequences [10].

The following variables were defined as inputs for development of the fuzzy logic system: wet bulb globe temperature (WBGT, °C) and noise level (dB). Based on the input variables, the fuzzy system predicts the Human Welfare Index (HWI), evaluating the level of human comfort by means of the thermal and acoustic variables of the working environment in poultry houses.

In the analysis, the Mamdani's interference method was used which provided a fuzzy set originating from a combination of input values with their respective degrees of pertinence using the minimum operator, and was followed by superposition of the laws by means of the maximum operator. Defuzzification was performed using the center of gravity method (centroid or center of area), which considered all output possibilities, transforming the fuzzy set originated by the inference by a numerical value, as proposed by [11] and [12].

2.1 Input variables

Considering that the main variables which influence the thermal environment inside the broiler houses are dry bulb temperature, wet bulb temperature, relative humidity, solar radiation and air velocity, it was opted to use the WBGT (°C) as the input variable, with five classification ranges, where its limits were defined according the NR-15 regulatory norms [13] which contain the estimates of metabolism rate per activity type. Based on this information, activity in the broiler houses was classified as moderate (metabolism 150 to 300 kcal h^{-1}).

The WBGT is determined considering the internal environment or external environment without the solar load using equation 1. It functions as an indicator which encompasses the principle factors which cause thermal overload (high temperature, metabolism, radiant heat and high relative humidity of the air) and, also the principle constraining factors (wind, low relative humidity of the air and low temperature) providing a time scale of work and rest for a determined situation [14].

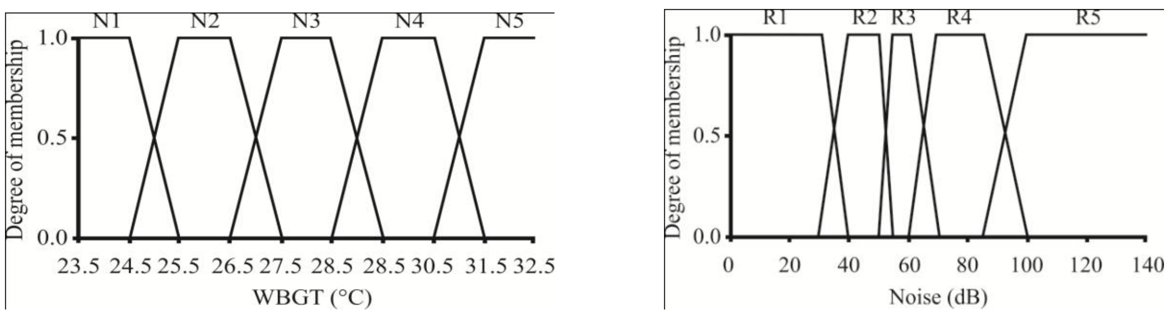
$$WBGT = 0.7\, t_{bn} + 0.3\, t_g \quad (1)$$

For the noise variable (dB) five levels were used, where R1 was based on [15] who considers this range having no effect; R2 in accordance with [12], being sound rated at 50 dB, characterized as disturbing but adaptable; R3, according to the World Health Organization [16], is greater than 55 dB and can cause light stress accompanied by discomfort; R4 results in wear on the organism and liberation of endorphins in the body [16] and is the maximal acceptable noise level for health activity during 8 hours of uninterrupted work [13]; and level R5 causes irreversible alteration and damages to the hearing device [15], as well as the possibility of hearing loss. The fuzzy sets of the input variables are shown in Table 1.

Table 1. Fuzzy sets for the input variables.

Variable type	Variable	Fuzzy set	
Input	WBGT (°C)	N1	[23.5; 25.5]
		N2	[24.5; 27.5]
		N3	[26.5; 29.5]
		N4	[28.5; 31.5]
		N5	[30.5; 32.5]
	Noise (dB)	R1	[0; 40]
		R2	[30; 55]
		R3	[50; 70]
		R4	[60; 100]
		R5	[85; 140]

The intervals admitted to the input variables of WBGT and noise are graphically represented by trapezoidal membership curves; these best represent profile of the input data and are most often used in literature [9, 17, 8], as illustrated in Figure 1.



(a) (b)

Figure 1. Membership functions for the input variables: (a) WBGT (°C) and (b) noise (dB).

2.2 Output variable

The output variable of HWI, used in construction of the fuzzy system, permits direct indication of the welfare level experienced by the workers. Its sets established intervals in the domain of [0,1], classified according to the same concept for the broiler chickens in terms of very poor, poor, average, good and excellent, according to [19]. Therefore, the following fuzzy sets were specified, as presented in Table 2.

Table 2. Intervals of the fuzzy sets for the Human Welfare Index (HWI) variable.

Fuzzy sets	Interval
Very poor	[0; 0.25]
Poor	[0; 0.50]
Average	[0.25; 0.75]
Good	[0.50; 1.0]
Excellent	[0.75; 1.0]

The intervals adopted for the output variable HWI were characterized by triangular membership curves (Figure 2).

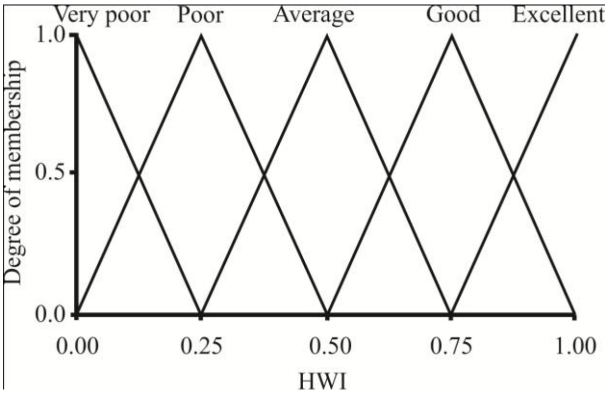


Figure 2. Membership functions for the output variable of Human Welfare Index (HWI).

2.3 System of Rules

The system of rules (Table 3) was developed based on the combinations of WBTI and noise level, where a specialist was consulted to elaborate the output result for each combination of input data. In the end, 25 rules were defined and for each rule a weighting factor equal to 1 was attributed.

Table 3. Composition of the system of rules in function of the characteristics WBTI and noise.

WBGT / Noise	N1	N2	N3	N4	N5
R1	Excellent	Excellent	Good	Average	Poor
R2	Excellent	Good	Average	Poor	Very poor
R3	Good	Average	Poor	Very poor	Very poor
R4	Average	Poor	Very poor	Very poor	Very poor
R5	Poor	Very poor	Very poor	Very poor	Very poor

III. RESULTS AND DISCUSSION

When new computational systems are created with the intention of providing decision support, it is necessary to adopt measures which analyze the descriptive power of the new system created. Such measures serve, for example, to evaluate the efficiency of a system to generate responses for welfare classification which are close to reality. Therefore, when a mathematical modeling system is developed, it is important to evaluate the classification potential of the system, in this case the potential to classify the thermal-acoustic environment for workers in broiler houses.

The surface presented in Figure 3 shows the interaction between the WBGT and noise affecting welfare in poultry buildings. The depressions in Figure 3 indicate the range where welfare is low. Considering that this condition implicates making a decision, the fuzzy system would be able to send an alert signal, therefore avoiding exposure of the worker to the unhealthy environment.

The peaks indicated that welfare is high for the considered variables. These results show that the working environment is within the healthy range for the type of activity developed, making no external action necessary to improve comfort of the worker.

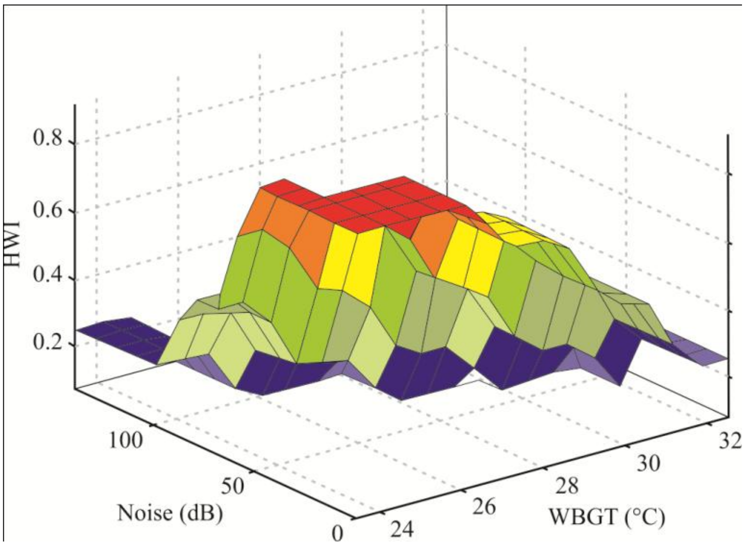


Figure 3. HWI simulated as a function of the WBGT and noise.

Figure 4 presents a situation of the HWI as a function of each combination of WBGT and noise values. The areas delimited by the level curves in Figure 4 indicate the ranges of welfare for the considered variables. Based on these results, it can be observed that the HWI diminished as values of the WBGT or noise increase, therefore in accordance with the results encountered by [19] and [8].

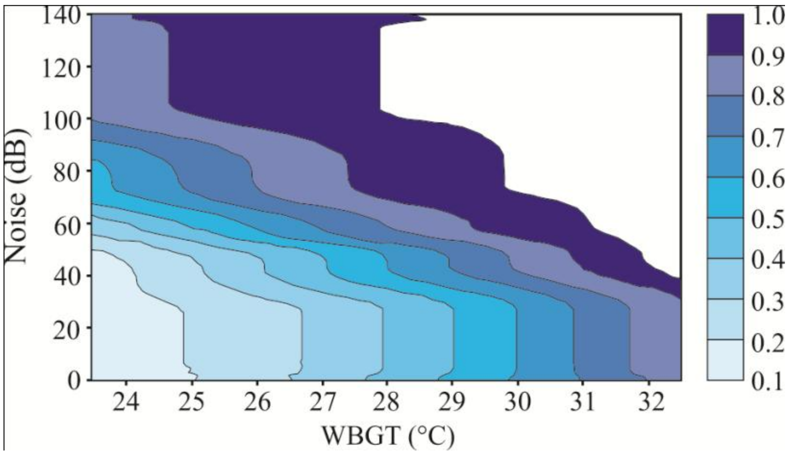


Figure 4. Variation of the HWI in function of the diverse combinations of WBGT and noise.

In Figures 3 and 4, can be seen the non-linear variation of welfare, as a function of noise and WBGT, which was generated from the rules base. In these figures we can observe that the best values of welfare were found in conditions involving WBGT values below 28 ° C with values below the noise level of 50 dB. From these values, it is clear the influence of these variables on comfort for the worker, which characterizes partial or total absence of welfare, according to [20], so these would be the limits of welfare great for the conditions of thermal-acoustic ambience prefixed.

IV. CONCLUSIONS

A human welfare index (HWI), for workers of poultry buildings was developed base on fuzzy methodology and utilizing the input variables of wet bulb globe temperature (WBGT, °C) and noise level (dB). This methodology showed to be adequate and promising to treat problems related to uncertainties, including human welfare.

Utilizing the developed system, it was possible to estimate comfort of workers in relation to the WBGT and noise in broiler houses for the scenarios with predetermined thermal and acoustic environment. It could also be used for decision making in order to reduce or eliminate the sources considered to cause stress to man.

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REFERENCES

[1] SAMPAIO, C. A. P.; NÄÄS, I. A.; SALGADO, D. D.; QUEIRÓS, M. P. G. Avaliação do nível de ruído em instalações para suínos. ***Revista Brasileira de Engenharia Agrícola e Ambiental***, Campina Grande, v. 11, n. 4, p. 436- 440, 2007.

[2] ASTETE, M. G. W.; KITAMURA, S. ***Efeitos da exposição Profissional ao Barulho. In: Medicina do Trabalho: Doenças Ocupacionais***. René Mendes. Sarvier S/A Editora Livro Médicos. São Paulo. 1980. 416-435p.

[3] KLIR, G. J.; YUAN, B. ***Fuzzy sets and fuzzy logic***. New Jersey: Prentice Hall PTR, 1995. 574p.

[4] SIMÕES, M. G. ***Controle e modelagem fuzzy***. São Paulo: Edgard Blücher, 1999. 165p.

[5] AERTS, J.M.; BERCKMANS, D.; SCHUMMANS, B. *On-line measurement of bioresponses for climate control in animal production units.* In: INTERNATIONAL CONFERENCE ON COMPUTERS IN AGRICULTURE, 6., 1996, Michigan. **Proceedings…**St Joseph: American Society of Agricultural and Biological Engineering, 1996. 147-53p.

[6] GOEDSEELS, V.; GEERS, R.; TRYEN, B.; WOUTERS, P.; GOOSSENS, K.; VILLE, H.; JANSSENS, S. *A data acquisition system for electronic identification, monitoring, and control of group-housed pigs.* **Journal of Agricultural Engineering**, Silsoe, v.52, May-August, p.25-33, 1992.

[7] LACEY, B.; HAMRITA, T.K.; MCCLENDON, R. *Feasibility of using neural networks for a real-time prediction of poultry deep body temperature responses to stressful changes in ambient temperature.* **Applied Engineering in Agriculture**, St Joseph, v.16, n.3, p.303-8, 2000.

[8] SCHIASSI, L; YANAGI JUNIOR, T.; DAMASCENO, F. A,; OSORIO, S. J. A.; SILVA, M. N. *Fuzzy modeling applied to the welfare of poultry farms workers.* **Dyna**, ano 79, n. 174, pp. 127-135, 2012.

[9] AMENDOLA, M.; CASTANHO, M. J.; NÄÄS, I. A. *Análise matemática de conforto térmico para avicultura usando a teoria dos conjuntos fuzzy.* **Biomatemática**, n.14, p. 87-92, 2004.

[10] TSOUKALAS, L. H.; UHRIG, R. E. ***Fuzzy nd Neural Approaches in Engineering***. A Wiley-Interscience Publication. (1997).

[11] TANAKA, K. ***An introduction to fuzzy logic for practical applications***. Tokyo: Springer, 1997. 138p.

[12] SIVANANDAM, S. N.; SUMATHI, S.; DEEPA, S. N. ***Introduction to fuzzy logic using MATLAB***. Berlin: Springer, 2007. 430p.

[13] MINISTÉRIO DO TRABALHO E EMPREGO. Portaria 3.214 de jul. 1978. *Normas regulamentadoras de segurança e saúde no trabalho (NR-15): Atividades e operações insalubres.* Brasília,1978. Disponível em: http://www.mte.gov.br/temas/segsau/legislacao/normas/conteudo/nr15. Acesso em: set. 2008.

[14] COUTO, H. A. ***Ergonomia aplicada ao trabalho: o manual técnico da máquina humana***. Belo Horizonte: Ergo, 1995. v. 1, 353 p.

[15] ROBIN, P. ***Segurança e ergonomia em maquinaria agrícola***. São Paulo: IPT, 1987. 24 p.

[16] ORGANIZAÇÃO MUNDIAL DA SAÚDE. *Occupational and community noise.* Geneva: World Health Organization; 2001.

[17] YANAGI JUNIOR, T.; XIN, H.; GATES, R.S.; FERREIRA, L. *Fuzzy logic model to predict laying hen body temperature rise during acute heat stress.* In: Congresso Brasileiro de Engenharia Agrícola, 35, 2006, João Pessoa. **Anais…** João Pessoa: SBEA, 2006.

[18] SCHIASSI, L.; YANAGI JUNIOR, T.; FERREIRA, L.; DAMASCENO, F. A.; YANAGI, S. N. M. *Metodologia fuzzy aplicada à avaliação do aumento da temperatura corporal em frangos de corte.* **Engenharia na agricultura**, Viçosa, MG, v. 16, n. 2, p. 181-191, Abr./Jun., 2008.

[19] OWADA, A. N.; NÄÄS, I. A.; MOURA, D. J.; BARACHO, M. S. *Estimativa do bem-estar de frangos de corte em função da concentração de amônia e grau de luminosidade no galpão de produção.* **Engenharia Agrícola**, Jaboticabal, v.27, n.3, p.611-618, set./dez.2007.

[20] YANAGI JUNIOR, T.; SCHIASSI, L.; ABREU, L. H. P.; BARBOSA, J. A.; CAMPOS, A. T. *Procedimento fuzzy aplicado à avaliação da insalubridade em atividades agrícolas.* **Engenharia Agrícola**, Jaboticabal, v.32, n.3, p.423-434, maio/jun. 2012.