

Estimating Thermal Comfort for Piglets Considering Ammonia Concentration

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ABSTRACT

Swine production in tropical climate is mainly housed in open sided buildings predominantly with natural ventilation. Ammonia is produced from the animal's excreta and it has particularly high concentration during the afternoon when the environmental temperature increases. The overall housing environment can be understood as the thermal environment associated to other sources of aerial agents such as ammonia, and when exceeding certain limit it may affect the swine's performance. This research aimed to develop an algorithm to estimate the piglet limit to ammonia exposition associated to ambient temperature in the housing environment. Wet bulb temperature and black globe temperature index (WBGT) were registered continuously in a piggery in Southeastern Brazil from November 2002 to October 2003. A statistical analysis was applied to the registered input data for determining the significance of the obtained values in order to build a base of rules and generate input data related to the local weather and housing conditions. Fuzzy inference was made using Mamdani method in the software Matlab® 6.0 Toolbox. A surface function of the thermal comfort values and the interaction between WBGT and ammonia concentration values was generated based upon data simulated using the set of collected data and published references. Results showed a negative correlation between ammonia concentration and piglet thermal comfort values, reaching just 60% of the potential piglet's thermal comfort when ammonia values reached 10 ppm. The use of fuzzy logic is well suited for predicting a process that is nonlinear, and this approach using fuzzy inference technique could allow estimating the thermal tolerance limit of pigs to housing environment with a known ammonia concentration, for a specific climate and housing condition.

Keywords. Pig nursery, temperature, ammonia, modeling, fuzzy logic

1. INTRODUCTION

Swine production increased considerably in the last decades and nowadays intensive production is practically found in all regions and climates. Compared to other species of farm animal pigs are more sensitive to high environmental temperatures because they have underdeveloped sweat glands and the panting mechanism is not very efficient. They respond to heat stress by invoking a complex of physiological, behavioral and anatomical mechanisms aimed at facilitating heat loss to (or minimizing heat gain from) the environment. Due to its metabolism swine produces heat, evaporative water and gases from their breathing, and dust from its movement over the dried residues. Swine can be considered as an open thermodynamic system in continuous energy exchange with the surroundings and it can affect the housing environment in return. Internal mechanisms for physiological adjustments to

keep the dynamic balance in level of normal body temperature are generally necessary in order to maintain heat balance.

Several authors studied the interaction of swine housing and the environment (Sainbury, 1981; Curtis, 1983; Verstegen et al., 1987; Albright, 1990; and Wathes, 1998). This knowledge has been used for designing swine housing; however this concept of thermal environment does not include the physiological response to the influence of ammonia found in swine nursery. Acute and chronic exposure of pigs to aerial pollutants has been implicated for many years by veterinarians and farmers in the etiology of multifactorial respiratory diseases. Even though Donham (1991) found positive correlation between level of ammonia inside the housing and productivity, Wathes et al. (2002b) studying weaner pigs exposed to controlled concentrations of airborne dust and ammonia in a single, multi-factorial experiment and measuring production and health responses, concluded that exposure to both aerial pollutants depressed performance depending upon dust but not on ammonia concentration.

CIGR (1994) recommends ammonia limits within animal housing up to 20ppm suggesting that above this limit health may be affected. Inhaling large concentration of ammonia, emitted by the conversions within swine excreta, may lead to health problems in both animal and human. In a study at 28 swine farms in Sweden, the incidence of arthritis, porcine stress syndrome lesions, and abscesses was positively correlated with levels of aerial ammonia in the facilities (Donham, 1991). Aarnink et al. (1995) investigated ammonia emission variations from fattening pig buildings with partially slatted floors, and found that the diurnal variation seemed to be related to the activity of pigs. Sousa and Pedersen (2004) studied the impact of animal activity on the variation of the diurnal ammonia emission in a controlled environment with a low variation in indoor temperature. The authors also found a high correlation between animal activity and ammonia emission.

Thermal comfort is often correlated to air temperature. However the air temperature is only one factor in the assessment of thermal stress/comfort. In climates where other important factors mainly humidity, can vary widely from day to day, there is the need to measure more than just the temperature for a more realistic assessment of comfort. According to Macari et al. (1994) an adequate definition of thermal comfort zone can be the limits of the combination of environmental temperature and relative humidity leading the animal to maintain physiological thermal balance within the lowest use of metabolic energy. It is useful to be able to estimate thermal comfort into a single number (ISO, 1989) and for that the wet bulb and black globe temperature index (WBGT) shown in Eq. 1 has been used by researchers as an easily measured general heat-stress index uniting the effects of air temperature, radiation (through the T_g measurement) as well as relative humidity.

$$\text{WBGT} = 0.7 \text{ wbT} + 0.2 \text{ Tg} + 0.1 \text{ dbT} \quad \text{Eq. 1 (Bureau of Meteorology. 2005)}$$

Where: wbT = wet-bulb temperature;
 Tg = Black globe temperature; and
 dbT = dry bulb temperature.

Fuzzy logic makes it possible to organize known rules from a set of statistically significant data or published and accepted values and limits, as natural human thoughts analyzing specific conditions and generating inference possibilities. The data-dependent model

consisting of certain inputs and one output can be implemented. A fuzzy inference system can be developed using a set of data as a training set, and another set of data as the testing set. Fuzzy inference is a method that interprets the values in the input vector and, based on user-defined rules assigns values to the output vector. The fuzzy logic toolbox in Matlab 6.1[®](2004) provides a set of editors that let build a fuzzy inference system. The use of fuzzy logic for predicting a certain function is well documented (Tsoukalas and Uhrig, 1997; Shaw and Simões, 1999) as well as the use of this tool for estimating thermal comfort limits in animal production based on published data (Amendola et al, 2004). Its fundamentals are based on the fuzzy logic theory and the knowledge base is compiled from recorded and known published data with the help of a specialist, using abstract verbal expressions such as good, bad, average, etc., and each defined circumstance is weighted according to the proximity of known scientific truth.

2. OBJECTIVE

The objective of this research was to develop an algorithm using fuzzy inference that enable the estimation of piglet's thermal comfort limits as function of wet bulb and black globe temperature index (WBGT) and ammonia concentration in side opened swine nursery.

3. METHODOLOGY

The experiment was carried out during both summer and winter, from November 2002 to October 2003 in Southeastern Brazil in three distinct swine nurseries with the floor's typology as described in Table 1, and shown in Figure 1a and 1b.

The buildings typologies were similar with side opened with natural ventilation. Wind speed (ws) inside housing was low ($ws < 0.5\text{m/s}$). Lateral plastic curtains were used to control excess of ventilation ($ws \geq 0.5\text{m/s}$). The side walls were 1.10m and the lateral average height of the roof was 2.30m in all studied buildings. The most important difference between the buildings was the floor type.

Table 1. Typology of the studied swine nurseries housing

Housing	Type of swine nursery floor	Period of data collection
1	Slotted ¹	summer
2	Compact ²	summer and winter
3	Compact	summer and winter

¹ Metal slotted floor covered by hard plastic

² Compact concrete floor



1a (slotted floor)

1b (compact floor)

Figure 1. View of the two type of studied swine nurseries.

Environmental variables were registered continuously in the geometrical center of the houses: dry bulb temperature (dbT) and wet bulb temperature (wbT) and wet bulb and black globe temperature index (WBGT) using QuestTemp[®] 34 data logger placed 1.0 m above the floor. Relative humidity was calculated from wbT. Data were recorded when the piglets were from 48-67 days old with an average animal density of 15.86 kg/m². Wind speed inside the buildings was recorded in the geometric center of the rooms in the morning and in the afternoon using anemometer HTA 4.2000 Pacer and the collected values was below 0.5 m/s in average during the experiment. Ammonia concentration was measured in the center of the housing using Multigas Multilog 2000 Quest[®] USA with computer interface and operational recording range of 0-50 ± 1 ppm.

Statistical analysis on all environmental measurements was performed applying Tukey test at a significance level of 5% using the software Minitab[®] (2004), in order to build up the data-dependent model aggregating the independent variables and allowing to build a Mamdani type fuzzy inference system based on recorded data under Brazilian climatic conditions and swine housing. Heuristics and conventional data from literature were also applied in intervals not covered by collected data. Fuzzy logic has the advantage of dealing with subjective concepts such as almost, approximately, etc. Subjective concepts which are not understood by the computer provide a higher degree of confidence compared to classical probability theory. Fuzzy inference is a method that interprets the values in the input vector and, based on user-defined rules, assigns values to the output vector. The Fuzzy Logic Toolbox (Matlab 6.1[®], 2004) provided a set of editors that was used to build a fuzzy inference system.

Independent variables (input) for applying fuzzy logic were set as: wet bulb and black globe temperature index (WBGT) and ammonia concentration (ppm), defined through linguistic expression as good, bad and average, as shown in Table 2. The dependent variable (output) was characterized as thermal comfort for piglets weighting 20-50 kg housed in side open nursery. The selection function was trapezoid and the method used was Mandani. Data were analyzed using the software MatLab 6.1[®] (2004) Fuzzy Logic Toolbox.

4. RESULTS AND DISCUSSION

For classifying the levels of thermal comfort the variables were statistically evaluated and organized in such a way that the linguistic (bad, average and good) nominations were weighted according to their closeness of each statistically significant value from recorded data ($p < 0.005$). Studying the behavior of piglets and the trade-off between thermal comfort

and fresh air by single and grouped animals Wathes et al. (2002a) found that juvenile pigs made more visits of longer duration to fresh air compared with ammoniated atmospheres ($p < 0.01$). Overall, 80% of their time was spent in an atmosphere of 10 ppm or lower ($p < 0.001$). These findings also illustrated that single pigs are more motivated by thermal comfort than access to fresh air. Pairs of pigs preferred to maintain thermal comfort rather than endure a cold environment of fresh air, and the motivation to retain social contact by dwelling in the same compartment was stronger than either individual's preference to seek an alternative environment. In all experiments that constitute the reference the aversion to ammonia was delayed. In the other hand for Jones et al. (1999) the choice between the heated and cool environments was determined by the ambient temperature when it fell below the lower critical temperature when the pigs moved from the cool compartments to the warm compartments.

Based on this knowledge, the data from the field experiment, and using the already mentioned references on estimative for swine piglets critical temperature limits, a base of rules was built using the average recorded data in two distinct type of flooring. Measured values of WBGT were correlated to the performance of the piglets under different ammonia exposition within the two types of housing. The weight varying from 0 to 1 and shown inside the parenthesis in Table 2, means the accuracy (from set of data and referred knowledge) of the dependent variable "thermal comfort" (output). For instance when the wet bulb and globe temperature index is low, no matter the ammonia concentration, the piglets will feel thermal discomfort. In the other hand when environmental variables increased their thermal sensation varies up to the extreme, as mentioned by Wathes et al. (2004a).

Table 2. Base of rules relating thermal comfort with wet bulb and black globe temperature index (WBGT) and ammonia concentration

WBGT	Ammonia concentration (ppm)			
	<5	5-10	10-15	>15
<20	bad(0,8)	bad(0,8)	bad(0,8)	bad(0,8)
20-25	good(1,0)	good(0,7)	average(0,7)	bad(0,9)
25-30	good(1,0)	good(0,9)	bad(0,9)	bad(0,9)
>30	bad(1,0)	bad(1,0)	bad(1,0)	bad(1,0)

For developing the linguistic variable (input) WBGT the domain was considered in accordance with the interval found within the collected data (<20, 20-25, 25-30 and >30) and specified as *low*, *average*, *high*, and *very high*. Using the trapezoid function and the Mandani method used in the Matlab Toolbox, a function was built within the fuzzy inference system. The Mandani model is a type of fuzzy relation model where each rule is represented by an *if – then* rule. It is called a linguistic model based on fuzzy propositions. Based on this a trapezoid function was built within the limits of WBGT and estimating (by simulation) the thermal comfort that if based only on WBGT index where it could represent only slightly above 0.4 in a 0-1 scale. Figure 2 shows the trapezoid function plot of the choices for WBGT and the defined best thermal comfort sensation zone for piglets. The measured values were low as no heating was used during the trial.

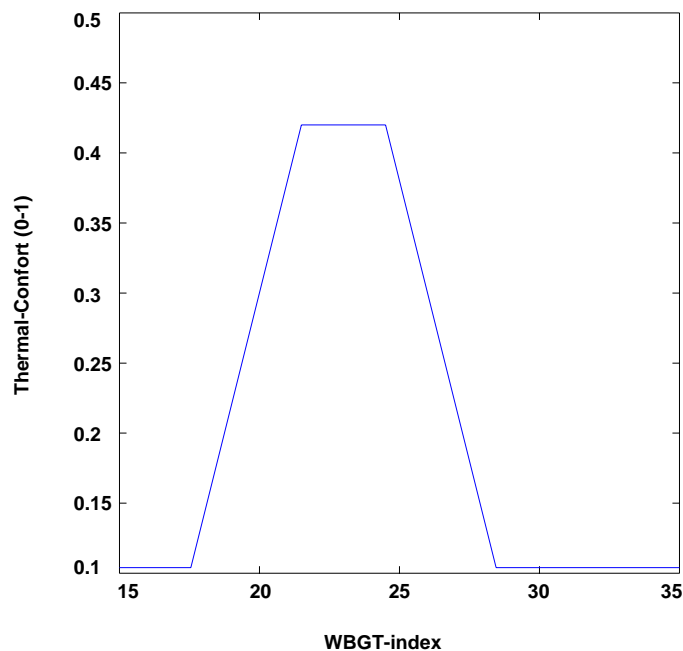


Figure 2. Wet bulb and black globe temperature index (WBGT) trapezoid function in relation to the thermal comfort prediction.

For the linguistic variable (input) ammonia concentration the considered domain was within the collected data (<5, 5-10, 10-15 and > 15) where the following denominations were specified: *low*, *average* *high* and *very high*, for the distinct ammonia levels. As the wind speed inside the housing was below 0.5m/s the ammonia concentration was considered stable and the measured change throughout the day was slow and highly dependent on dry bulb temperature, distinct that found by Aarnink et al. (1995) and Sousa and Pedersen (2004) who worked within closed housing.

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves: membership functions, fuzzy logic operators, and *if-then* rules. Still based on collected data and using Mandani model, a trapezoid function was built (Figure 3) showing that the ammonia concentration variation indicates that when it was, for instance in the level of 16-18 ppm the environment was relatively aggressive to the piglets (when associated to hot environment it reflected discomfort). Based on that, the function described traduces that a level of ammonia concentration within the proposed limits may lead the piglets to be more sensible to heat stress, under the specific experimental conditions.

The base of rules derived from the fuzzy propositions *if-then* was done from the information initially organized in Table 2 associated to Mandani method combined the levels of pertinence with relation to each value entered through the minimum operator, adding rules through the maximum operator. In more general terms it has been defined as the fuzzy intersection or conjunction (AND) and the fuzzy union or disjunction (OR).

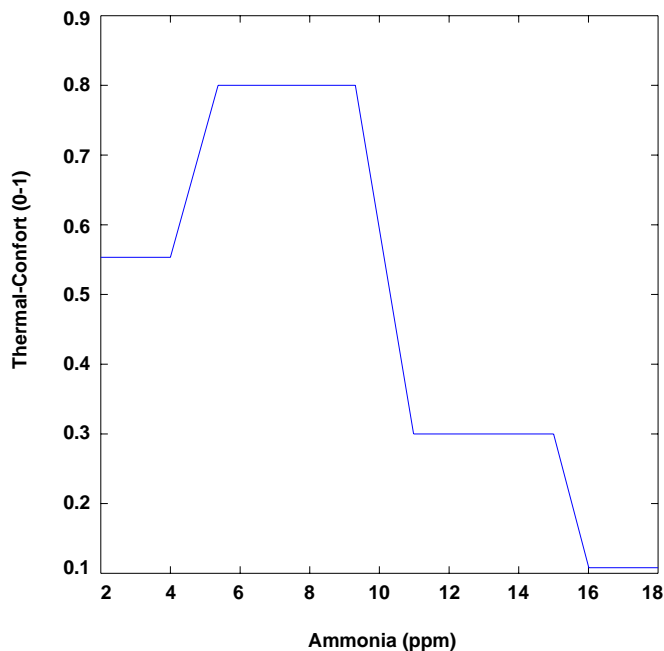
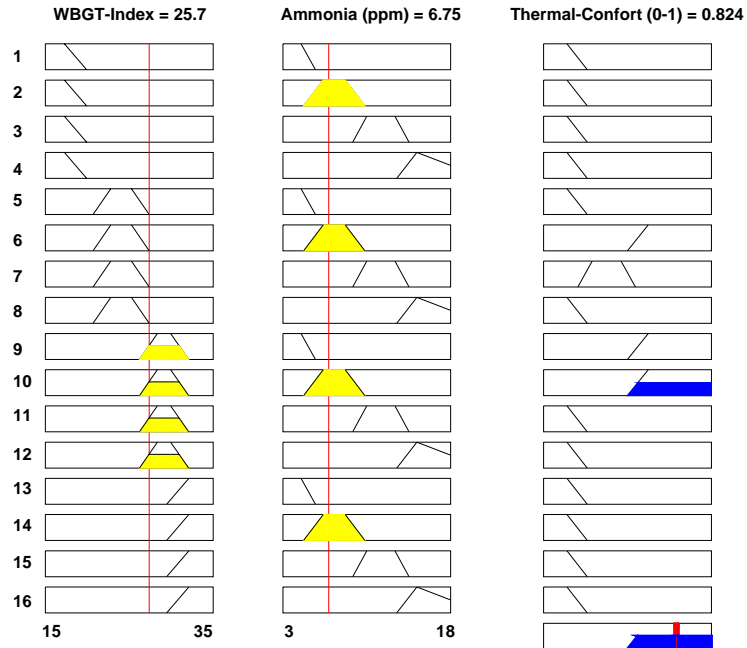


Figure 3. Ammonia concentration trapezoid function in relation to the thermal comfort prediction.

The results could be tested by changing the input variables values in the Matlab® (2004) rule viewer (Figure 4) and checked through the surface charts of any combination of the input variables (WBGT and ammonia concentration) with the output variable (thermal comfort possibilities). Figure 4 shows then possibilities of simulation with the values of WBGT and ammonia concentration levels at the same operation for representing the overlapping of both data, understood as the aggressive or non-aggressive environment for piglets housed at side open buildings. The output was done using the method of the gravity center. Figure 5 is an example of the calculated surface for any given combination of two input/output variables. The thermal comfort estimation surface was built as function of WBGT and ammonia concentration, as seen in Figure 5 where the intermediate points can be estimated. The range was established within 0-1 where 1 indicates the best thermal comfort condition while zero is the worst.

The best simulated values for a non-aggressive environment for piglets were found when ammonia concentration was below 8 ppm (the ruler was between 7-8ppm). This agrees with Wathes (1998) who recommends low level of ammonia in housing environment for piglets. In relation to the WBGT values the best zone was in the range of 28-31 using relative humidity within 70-80%, agreeing with several authors who point the thermoneutral zone for piglets within the same range (Curtis, 1983; Verstegen, 1987; and Albright, 1990). Ideal housing ambient temperature was estimated to be around 28-31°C and relative humidity in the range of 70-80%. This range shown in Figure 2 just applies this assumption in part of the resulting function, meaning that more bases of rules should be added to accomplish a better estimation function. When using both rules together the highest value found for the thermal comfort was 0.824, as shown in Figure 4.

Results showed a negative correlation between ammonia concentration and piglet thermal comfort values, reaching just 60% of the potential piglet's thermal comfort when ammonia values reached 10 ppm. As these overall housing conditions are dependent of the outside weather conditions these results suggest limited application for housing under temperate climate, for instance.



- Yellow area means the simulation based on Mandani inference for the input variables
- Blue area means result of the simulated output
- Red line is a cursor towards the trapezoid gravity center correlating input variables and showing the output simultaneously

Figure 4. Visualization of the rules for simulating the thermal comfort (output) as function of web bulb and black globe temperature index (WBGT) and ammonia concentration (input variables).

Having knowledge of several environmental conditions a large number of base of rules can be built. In this aspect the use of fuzzy logic is well suited for predicting or controlling a process that is nonlinear or too poorly understood to use conventional control designs. Results may enable control engineers to systematically implement control and monitoring strategies used by human operators with experience and/or expertise.

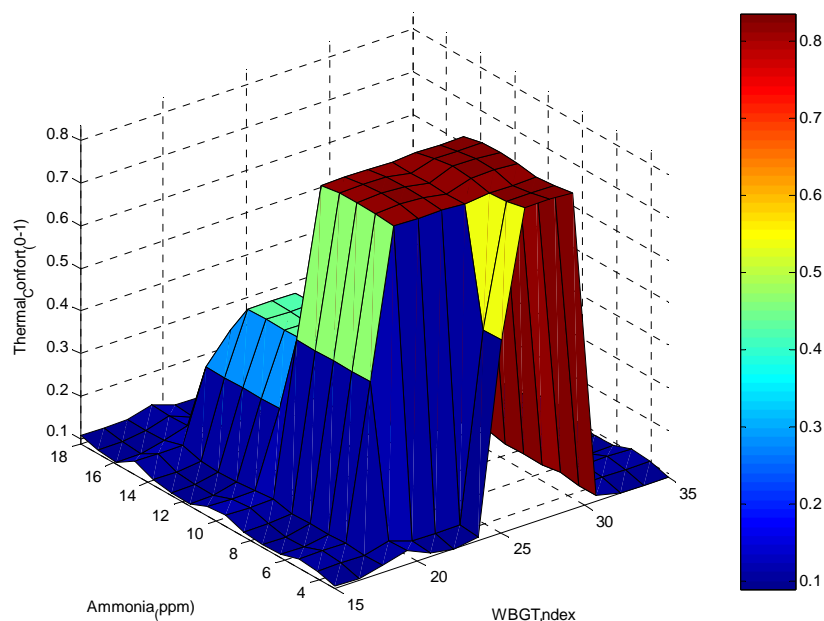


Figure 5. Surface generated by the input data of web bulb and black globe temperature index (WBGT) and ammonia concentration for estimating the thermal comfort of piglets.

5. CONCLUSION

Through the use of fuzzy inference and using the data collected in three piglet nursery housing it was possible to estimate the thermal comfort limit for the housed piglets. Intermediate points of thermal comfort for the specific conditions of this experiment could be predicted within the range of $31 > \text{WBGT} > 23$ and ammonia level of 4-8 ppm.

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