Intelligent Control Based Fuzzy Logic for Climate Control of Livestock Buildings

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Abstract

Many traditional climate control systems of livestock buildings are based on on-off and proportional control methods, which are not so effective drawbacks of these methods are loss of energy, labor, productivity in order to maintain a steady climate a more sophisticated system must be used. The paper presents a solution for livestock buildings a climate controller based on the fuzzy-logic methodology. Hence, the developed fuzzy logic model is based on a Mamedani's fuzzy method and it is built on MATLAB software. The fuzzy rules are simple, therefore making the system attractive to use by all types of agriculturists. Membership functions of Fuzzy Inference System (FIS) are generated, simulation and analysis of the behavior of the designed control system is performed.

Keywords: Climate Control, Fuzzy Inference System, Fuzzy Logic Model, Livestock Buildings

1. Introduction

There are many factors that influence the health and productivity of those animals, including temperature, humidity, air movement and contaminant level, physical activity, bedding condition, body mass, group size and so on. The change of the livestock housing condition the indoor climate, is of particular importance for the animal's wellbeing and production performances. Effective and efficient ventilation control system plays crucial role on providing a comfort indoor environment which could enhance voluntary feed intake, alleviate thermal strain and humidity, as well as maintain an acceptable indoor air quality. Failure to provide the adequate environment will reduce profitability, growth rate and development, poorer feed conversion, and increase disease, condemnation and mortality, and eventually affect the animal product quality (Zuhang, 2009).

An optimal thermal environment is usually defined for each species in terms of its effects on production: there are a few specific recommendations in terms of disease. Several authors have discussed and reported the effects of temperature on the milk yield of dairy cows and the egg yield of laying hens (Charles, 1984) The lower critical temperature defines the lower limit of the range of optimal temperature: the upper limit is given by the upper critical temperature. The lower critical temperature is affected by factors such as age, sex, breed (Henken et al., 1991) food energy level and intake, feathering (Macleod, 1984), stocking density (Burmeister et al., 1986), bedding system (Bruce, 1981), etc. The CIGR commission (1989) recommended maximum and minimum values of RH as a function of indoor temperature, for example, an RH of 50-90% at 0°C followed by a steady decrease of RH to a tolerable range of 40-60% at 30°C.

The fuzzy logic control is one of the most useful approaches for utilizing the qualitative knowledge of a system to design a controller. Fuzzy logic control is generally applicable to plants that are mathematically poorly modeled and where the qualitative knowledge of experienced operators is available for providing qualitative control. On the basis of this idea, some fuzzy models based fuzzy control system design methods have appeared in the fuzzy control field (Wang et al., 1996; Tanaka, 1995). In this paper proposed a fuzzy logic control for climate control system in livestock buildings. The fuzzy Logic Toolbox in MATLAB software is used to design this algorithm. Two inputs and one output are designed with an application in mind.

2. Materials and Methods

The air flow can be directed inside to one side of the barn (Figure 1). This situation drastically reduces the airflow along the other side of the building. Compare an outside wind speed of 20 km/h to a typical tunnel air speed of 6 km/h to understand the potential for the wind to overpower the airflow pattern. Opening the side air inlet baffle board to introduce more air to the side with less airflow can help even out the airflow. Air deflecting baffles located at the tunnel inlet have also reduced this problem.

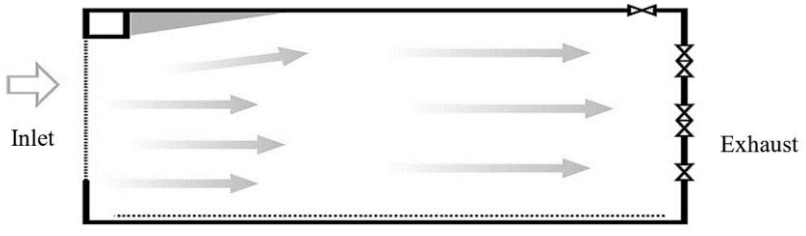


Figure 1. The air flow can be directed inside to one side of the barn.

The main method of air cooling livestock barns is tunnel ventilation. The entire air inlet is located on one end wall of the barn with all of the exhaust fans located on the opposite end (Figure 2. a, b). The idea is to create a high velocity wall of air moving down the long axis of the building like a wind tunnel. This provides a beneficial wind chill effect that cools the animals by convection (the removal of heat from the surface of an object by an airstream moving over it) and exhausts this heat out of the building. In many parts of the world, evaporative cooling pads are added to the air inlets of tunnel-ventilated barns because there is a critical upper temperature for tunnel ventilation. Excessive air movement above 40°C increases heat stress experienced by the animal. At these high temperatures, some form of evaporative cooling is incorporated into the system to reduce the effects of the incoming air temperature. With evaporative cooling, the incoming air is pulled through a saturated medium (cooling pad). The process of converting water from a liquid to a vapor removes heat energy from the incoming air, lowering its temperature but increasing its relative humidity. Until recently, these systems were not commonly used in Ontario. However, following several summers with prolonged periods of temperatures higher than 30°C, these systems are being used in more barns.

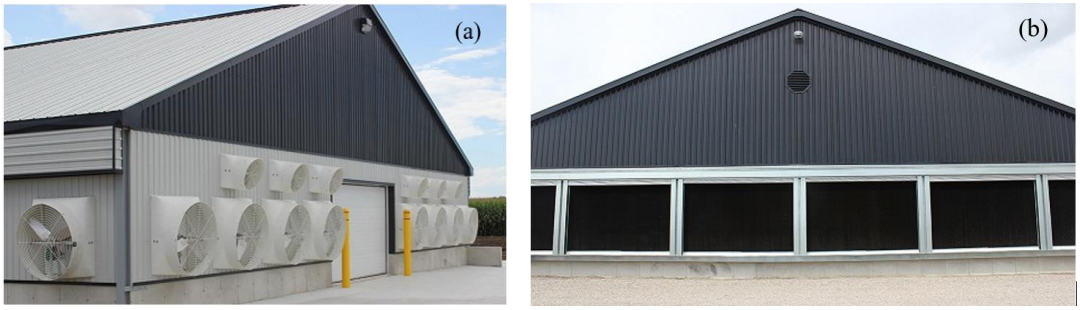


Figure 2. Fans across the end wall of the barn (a), tunnel ventilation inlet with evaporative cooling pads installed (b).

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data. A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier. These components and the general architecture of a FLS is shown in Figure 3 (Mendel, 1995).

The process of fuzzy logic is explained in Algorithm 1: Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

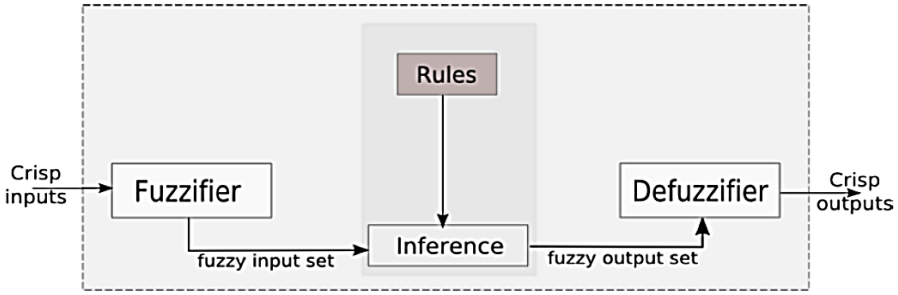


Figure 3. Fuzzy Logic System (FLS).

In this study, Mamdani fuzzy system is used for the illustration which uses Center of Gravity for Singletons algorithm for defuzzification. The FIS (Fuzzy Inference System) Editor in Fuzzy Logic Toolbox Graphical User Interface Tools defines the Fuzzy Base Class, two inputs which are Temperature and Relative Humidity (RH) and one output which is Fan Speed (Figure 4). To control the inside temperature, the fuzzy controller reads the inside temperature after every sampling period; to control the humidity, the controller calculates of the inside humidity in the same fashion as the temperature is calculated. There are five Membership Functions (MFs) that are equally determined over a scale range of -10°C to 40°C for the temperature input and 0% to 100% relative humidity (RH) for the humidity input. The optimum temperature values taken into consideration during the membership function are the values from the data provided by The CIGR commission. The five fuzzy input variables for the temperature which are "Cold", "Cool", "Optimum", "Warm", "Hot" and also for relative humidity five fuzzy input variables (RH) which are "Dry", "Not Too Dry", "Normal", "Not Too Wet" and "Wet". The fuzzy variables for the temperature and RH are represented in Figure 5 and 6 respectively. The fuzzy output signal with a scale range of 0 to 100 has five membership functions which are "Stop", "Slow", "Medium", "Fast" and "Blast" (Figure 7).

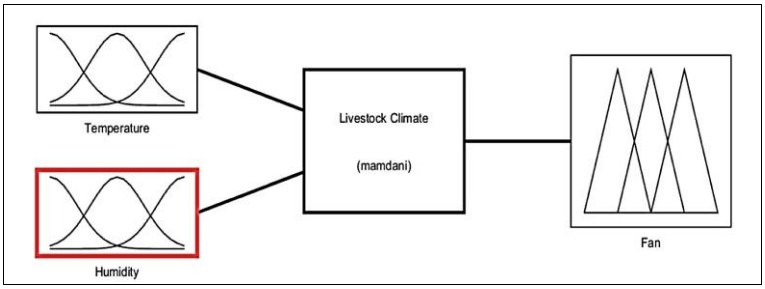


Figure 4. FIS Editor.

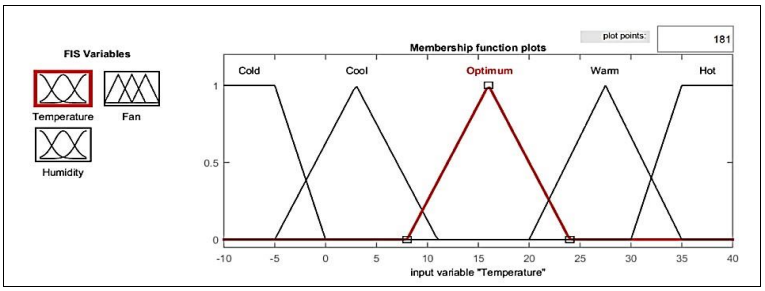


Figure 5. Membership of fuzzy set in temperature.

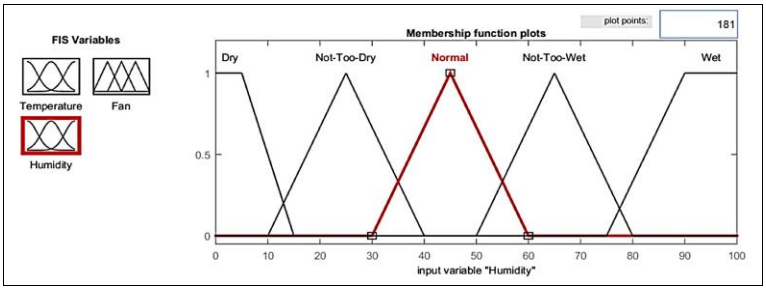


Figure 6. Membership of fuzzy set in humidity.

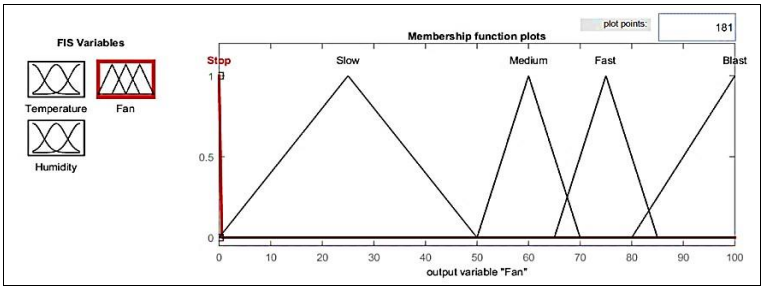


Figure 7. The fuzzy output.

Fuzzy rules were designed manually by a user, generates rules for all combinations of selected input variable and a user fills consequent fuzzy terms by the Rule Editor. Every rule can be deactivated and independent rule weight can be defined for each consequent variable. The rules are defined by selecting the right sequence in the If-Then sequence. The example of fuzzy rule is: "IF Temperature is *Warm* AND Humidity is *Dry* THEN Fan Speed is *Fast*". These rule sets form the basis upon which the fuzzy rules are implemented upon the provided inputs and sub sequentially provide the fuzzy outputs. The fuzzy rule sets of this designed fuzzy system include 25 rules as shown in Table 1. The Rule Viewer as shown in Figure 8 gives us the insight about the application of the fuzzy member function to input values of the simulation.

Table 1. The fuzzy rules.

Rules	Input		Output
	Temperature	Relative Humidity	Fan Speed
01	Cold	Dry	Stop
02	Cold	Not Too Dry	Stop
03	Cold	Normal	Stop
04	Cold	Not Too Wet	Stop
05	Cold	Wet	Stop
06	Cool	Dry	Stop
07	Cool	Not Too Dry	Stop
08	Cool	Normal	Stop
09	Cool	Not Too Wet	Stop
10	Cool	Wet	Stop
11	Optimum	Dry	Stop
12	Optimum	Not Too Dry	Stop
13	Optimum	Normal	Slow
14	Optimum	Not Too Wet	Slow
15	Optimum	Wet	Medium
16	Warm	Dry	Fast
17	Warm	Not Too Dry	Fast
18	Warm	Normal	Slow
19	Warm	Not Too Wet	Medium
20	Warm	Wet	Fast
21	Hot	Dry	Fast
22	Hot	Not Too Dry	Fast
23	Hot	Normal	Blast
24	Hot	Not Too Wet	Blast
25	Hot	Wet	Blast

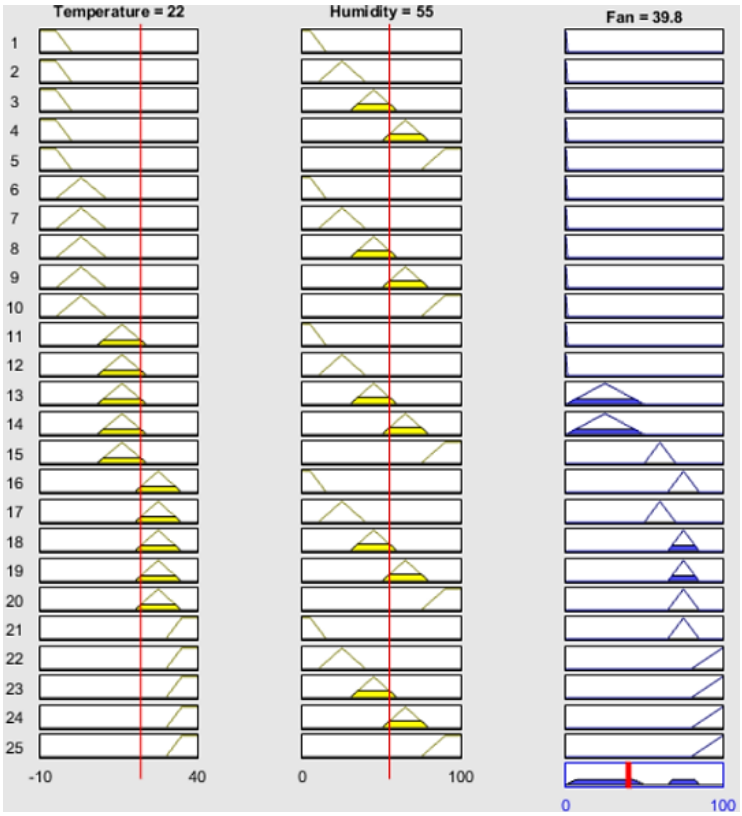


Figure 8. Fuzzy rule viewer.

3. Results and Discussion

The MATLAB fuzzy logic toolbox is used for fuzzy air condition system design. The fuzzy input parameters of Temperature (22°C) and RH (55%) are considered to design the proposed air conditioning system. The signal value of temperature (22°C) intersects with fuzzy variables "Optimum" and "Warm", similarly, for the input value of humidity (55%), the corresponding intersection of fuzzy variables are "Not Too Wet" and "Normal". The defuzzification process takes in four input values which are 13, 14, 18 and 19th rules. The process then produces the defuzzified output signal, "Fan Speed" used to control the actuators of the control system (Table 2).

Table 2. Singleton Values For The Fuzzy Output.

Rules	Temperature	RH	Fan Speed
R_0 (13)	Optimum	Normal	Slow
R_1 (14)	Optimum	Not Too Wet	Slow
R_2 (18)	Warm	Normal	Fast
R_3 (19)	Warm	Not Too Wet	Fast

The defuzzification scheme chosen was the Center of Gravity for Singletons algorithm (COG) as explain in equation 1 (Mamdani and Assilions, 1974).

$$COG = \frac{\sum_{i=1}^{p}[u_i.\mu_i]}{\sum_{i=1}^{p}[\mu_i]} \quad (1)$$

Where u is output variable, p is number of singletons, μ is membership function after accumulation, i is index. The following Table 3 demonstrates 10 test pairs to validate the fuzzy model as well as collect qualitative information on it. In addition, a simulation graph was obtained according to the test outputs (Figure 9). The graph is generated with the help of the Surface Viewer of the Fuzzy Logic Toolbox.

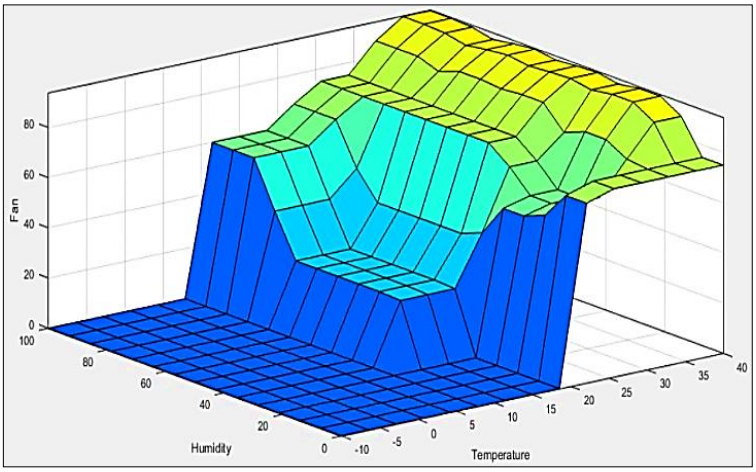


Figure 9. The simulation graph.

Table 3. Test Outputs of Fuzzy Model.

Temperature (°C)	RH (%)	Fan Speed (#)
-5	50	0
10	75	24.7
13	65	25
15	50	25
22	55	39.8
28	75	75
30	65	75
34	72	88.7
36	80	91.8
40	95	93.1

4. Conclusions

In this paper, the development of algorithm for fuzzy air condition controller system of livestock buildings has been presented. The designing and developing part of air conditioner fuzzy control system is providing more efficient operation at reduced energy cost while providing a more comfortable working environment. The analysis clearly maps out advantage of fuzzy logic in dealing with problems that are difficult to study analytically yet are easy to solve intuitively in terms of linguistic variables. In case of the air-conditioning system, fuzzy logic helped solve a complex problem without getting involved in intricate relationships between physical variables. Intuitive knowledge about input and output parameters was enough to design an optimally performing system.

The result obtained is again logical since at “Optimum” temperature with a "Not Too Wet" humidity, the motor fan speed applied should be "Slow" thus leading to a result of 39.8. The next set to be taken into consideration has inputs with temperature as 34°C and humidity as 72% RH which lead to a motor fan speed output of 88.7. This is still proved to be reasonable since temperature intersecting with "Warm" and "Hot"; humidity intersecting with fuzzy variables of "Wet" thus gives rise to a "Blast". Fan Speed output of the last set of inputs is 93.1 which is logical since very not temperature and very wet humidity may require fan speed to blast in order to cool down the environment. To further verify with the results obtained, the Fan Speed output values are analyzed to their corresponding input sets.

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