

MATHEMATICAL MODEL AND SIMULATION STUDY OF A CLOSED-POULTRY HOUSE ENVIRONMENT

Teerapon Upachaban¹, Kannika Khongsatit², Thana Radpukdee^{2*}

¹*Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand*

²*Department of Industrial Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand*

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ABSTRACT

The temperature and humidity inside poultry houses are highly coupled through nonlinear psychrometric processes, and the limitation of actuators makes this type of system difficult to control. To understand the dynamics of such systems and further to design a suitable controller, in this study, the mathematical model for a closed poultry house was derived from the governing equations of the various components related to the poultry house, including the energy and mass balance and the psychrometric correlations of the moist air. The model was simulated and the simulation result was compared to the data collected experimentally for model verification and control gains estimation. Under the assumptions of 70 percent Active Mixing Volume (AMV) with the constant maximum ventilation rate in the case study, the temperature and the relative humidity simulated results were in the good agreement with the real physical plant data. At the front, the middle and the rear part of the poultry house, the root-mean-square error (RMSE) obtained for internal temperatures are 1.17°C, 0.68°C, and 0.46°C, respectively. And those data for relative humidity are 4.31%, 8.07%, and 53.54%, respectively.

Keywords: Broiler house environment; Livestock building; Poultry house model; Temperature control; Tunnel ventilation

1. INTRODUCTION

Cumulative population growth is increasing at a much faster rate than food supply in all parts of the world. According to the United Nations, “The world population is predicted to grow from 6.9 billion in 2010 to 8.3 billion in 2030 and to 9.1 billion in 2050. By 2030, food demand is predicted to increase by 50% (70% by 2050). The main challenge facing the agricultural sector is not so much growing 70% more food in 40 years, but making 70% more food available on the plate.” (UNDESA, 2015). Therefore, modern technologies are being applied to overcome the limitations of food manufacturing. The air conditioning of agricultural buildings for horticulture, planting and livestock plays an important role presently. The livestock building system is one of the applications that provides for the ability of high-density production and enables the manufacturers to solve the productivity problems. However, the raising of domesticated birds, such as layers and broiler chicken in a small area is a big challenge. Poor management of the air conditioning systems could cause an excessive level of internal temperature and humidity, which could reduce poultry house productivity and result in severe consequences, such as lower feed conversion ratio, excessive energy consumption and

*Corresponding author's email: tthanar@gmail.com, Tel. +66-43347227
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accelerated mortality rate. Thus, new technologies, equipment, as well as new control methods, are still required to meet the target for the sustainable development of chicken production. (Linker et al., 2011; Daskalov et al., 2006; Xin et al., 2001)

To maintain the air temperature and humidity inside the poultry house at the desirable level in a hot, humid climate in a country, such as Thailand or Indonesia, ventilation fans, evaporative cooling systems, and electronic controllers are essential components. Moreover, many recently developed devices and technologies have been applied to the poultry house environment control related works (Tiwari et al., 2006; Alimuddin et al., 2012). But studying the effects of implementation of a new device or a new control method in real poultry houses can be difficult to achieve, not only because of the potential for errors and potential side effects on the production process, but also the time allocation required to study and collect the data throughout the breeding cycle.

Among some previous works developing the model on computational fluid dynamics (CFD) to study the building's climate behavior, most of the case studies are about the minimum ventilation schemes for cold weather regions, and others are naturally ventilated cases (Tiwari G.N, et al., 2006; Alimuddin, et al., 2012; Rojano et al., 2015). Many studies focus on temperate or air distribution of the poultry house, regardless of the humidity, which is one of the factors that indicates the heat stress index for chickens (Alimuddin et al., 2012; Rojano et al., 2015; Nääs et al., 2010; Calvet et al., 2010; Agbi et al., 2012). The dynamical model of temperature and humidity of the building can be used for the nonlinear control law design properly (Daskalov et al., 2006; Rojano et al., 2015; Senawong et al., 2012; Abdel-Ghany & Kozai, 2006; Upachaban et al., 2013). For this study, the dynamical nonlinear model of a closed broiler house equipped with the evaporative air cooling system was developed for the purpose of understanding the process dynamics and further to design a suitable controller. The model was simulated and compared to the real plant data collected at the front, the middle, and the rear of the poultry house to determine the appropriateness of the model.

2. MODEL AND VERIFICATION

2.1. Mathematical Model for a Poultry House

The mathematical model for a poultry house was derived by employing thermal and mass conservation concepts. The heat and moisture generated inside as well as those amounts transferred through the building's components were considered as shown in Figure 1.

The thermal components of the poultry house were composed of heat generated by animals (Q_{an}), heat conducted through the building structure (Q_c), heat loss from the evaporative cooling pad (Q_{ev}), and heat loss due to ventilation (Q_v). The moisture balance of the poultry house were considered as a function of the moisture production rate of the chickens (W_{an}), moisture gain rate from external air (W_{ext}), moisture production rate from evaporative cooling system (W_{ev}), and rate of moisture leaving the poultry house by ventilation (W_v). Therefore, dynamical Equations 1 and 2 can be derived, and the equations of heat and moisture balance of the poultry house still will require some real plant information to determine the gains of the variables and constants. The details of the equations were presented in the previous works (Daskalov et al., 2006; Senawong et al., 2012; Upachaban et al., 2013). The corresponding equations in this work which concern a real plant located in the middle of Thailand will be shown in Section 2.2.

$$\rho C_p V_T \frac{dT_{int}}{dt} = Q_{an} + Q_c - Q_v - Q_{ev} \quad (1)$$

$$\rho V_H \frac{dw_{int}}{dt} = W_{an} + W_{ext} - W_v + W_{ev} \quad (2)$$

where ρ is the air density (kg/m^3), C_p is the specific heat of air (kJ/kg.K), V_T and V_H are the temperature and humidity in an active mixing volume of the air inside (m^3), T_{int} is the inside air temperature ($^\circ\text{C}$), and w_{int} is the humidity ratio of air ($\text{kg(H}_2\text{O)/kg(dry air)}$).

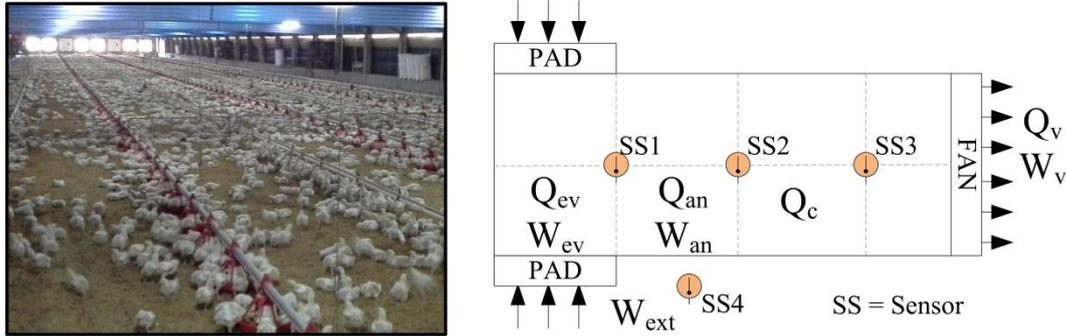


Figure 1 Heat and moisture components of the closed poultry house with tunnel ventilation

2.2. Real Plant Data

In order to verify and adjust the mathematical model to match the poultry house, a real-time data acquisition system was developed. A set of temperature and relative humidity sensors as well as a set of pump and fan data logger were mounted on the feeding line and the main distribution board of the poultry house. The high-level block diagram of the data collection system and installation are illustrated in Figure 2. The data was collected every 15 seconds for the whole period for chicken raising of 39 days, both inside and outside of the poultry house. However, for this study, the temperature and the humidity data were selected to represent data only obtained during the adult period. In such a period, the maximum ventilation rate (12 fans) and the evaporative cooling (2 pumps) were required. The sensors were installed at the front (18 m.), the middle (60 m.), and the rear (102 m.) of the 120-meter long poultry house with the level of 0.3 m. to measure the air temperature and relative humidity at the chicken level (SS1-SS3).

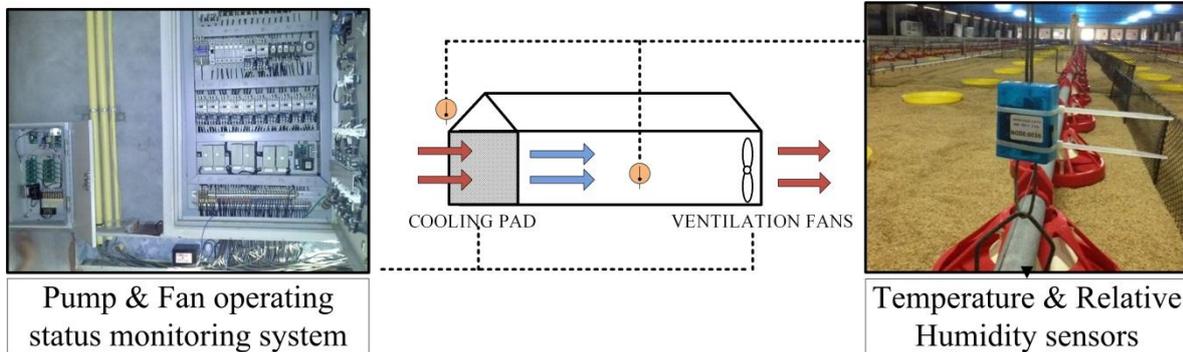


Figure 2 High-level block diagram of the air sensor set and the data logger

From collected data, characteristics of the real plant, ASHRAE and CIGR standards, the bundle of the constants can be defined as shown in Table 1. The corresponding equations for this work were derived, as shown in Equations 3 and 4.

$$\frac{dT_{int}(t)}{dt} = \frac{N_{an} \times 0.013 \times [0.8 - 1.85 \times 10^{-7} (T_{int} + 10)^4] + UA(T_{ext} - T_{int})}{\rho_{air} C_p V_T} - \frac{\lambda}{\rho_{air} C_p V_T} W_{ev} - \frac{(T_{ext} - T_{int})}{V_T} V_R \quad (3)$$

$$\frac{d\omega_{int}(t)}{dt} = \frac{N_{an} \times 0.001 \times [0.26 T_{int}^2 - 6.465 T_{int} + 81.6]}{\rho_{air} V_H} + \frac{1}{\rho_{air} V_H} W_{ev} - \frac{(\omega_{ext} - \omega_{int})}{V_H} V_R \quad (4)$$

where, N_{an} is the number of chicken in the poultry house, UA is the overall heat transfer coefficient of the poultry house in (kW/K), T_{ext} is the outside air temperature ($^{\circ}\text{C}$), λ is the heat of vaporization of water (kJ/kg), w_{int} is the humidity ratio of outside air (kg(H_2O)/kg(dry air)), and V_R is the ventilation rate (m^3/s).

2.3. Simulation Approach and Assumptions

As shown in the previous equations, the control inputs of the poultry house are the ventilation rate and the evaporative water pump operation period, while the external air conditions changes, including that of solar radiation flux, were considered as disturbance as showed in the first nonlinear term on the right-hand side of Equations 3 and 4, (See Figure 3). Note that the evaporative cooling water pumps were set to operate when the inside temperature at the middle of the poultry house was greater than the pre-set value (28°C for the research period). The control inputs are highly coupled to each other.

Table 1 The main parameters for the real plant modeling

| Parameters | Value (dimension) | Parameters | Value (dimension) |
|------------|---|--------------|---------------------------------------|
| N_{an} | 19,000 (birds) | V_T, V_H | 4,900 (m^3) |
| m_{an} | 1.9 (kg) | ρ_{air} | 1.2 ($\text{kg}\cdot\text{m}^{-3}$) |
| C_p | 1.006 ($\text{kJ}\cdot(\text{kg}\cdot\text{K})^{-1}$) | V_R | 1.9 (kg) |
| UA | 37 (kW/K) | λ | 2,257 (kJ/kg) |

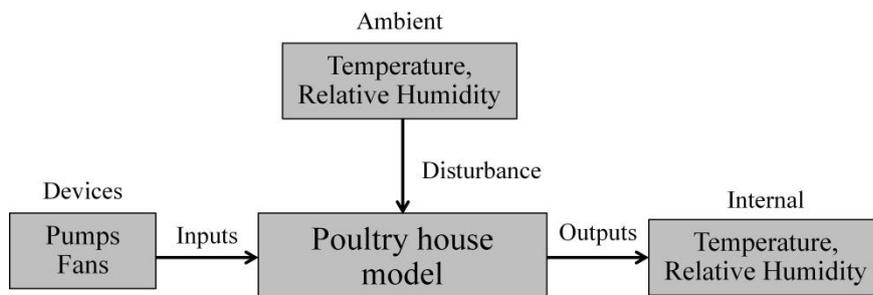


Figure 3 Feedforward climate control diagram of the poultry house

Nonetheless, the control distribution matrix for the first term in Equations 3 and 4 can be estimated by using the real plant data as shown in Table 1. Results of feed forward control of the model will be illustrated in the next section.

3. RESULTS AND DISCUSSION

The mathematical model of the house was simulated by MATLAB Simulink under the operating conditions of the real plant at Lopburi province of Thailand during August 16-18, 2013. The broiler has ages of 33 days with maximum ventilation. The simulation results of temperature (T_{sim}) and relative humidity (RH_{sim}) compared to those collected by the sensors at a different part of the house are provided in Figures 4 and 5, respectively.

The temperature was increased along the length of the house due to the heat accumulated in the air, and vice versa for the humidity. The simulated temperature shows the best agreement with the rear sensor data, while the relative humidity prediction seems to be more accurate at the front part of the house due to the active mixing volume assumption.

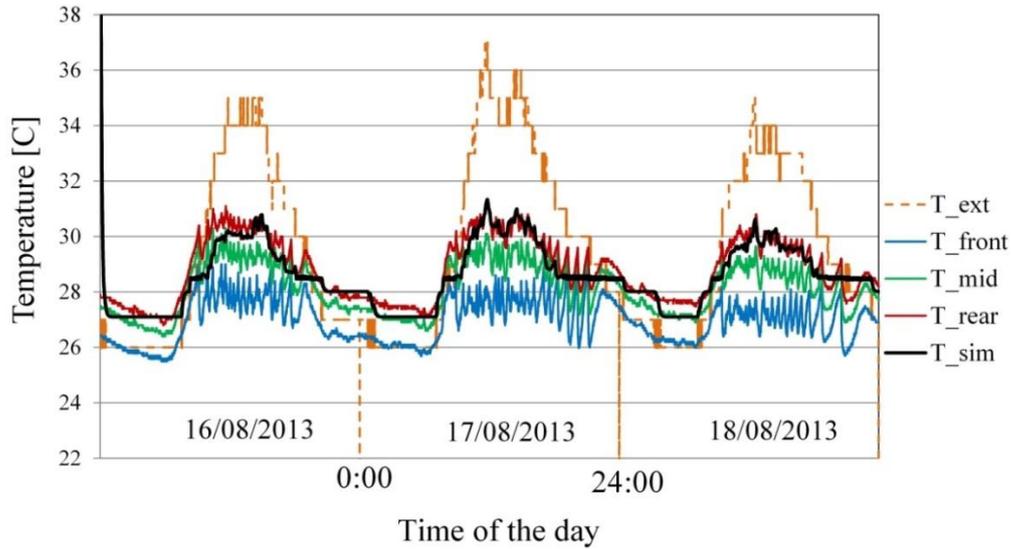


Figure 4 The simulated temperature compared to real plant data

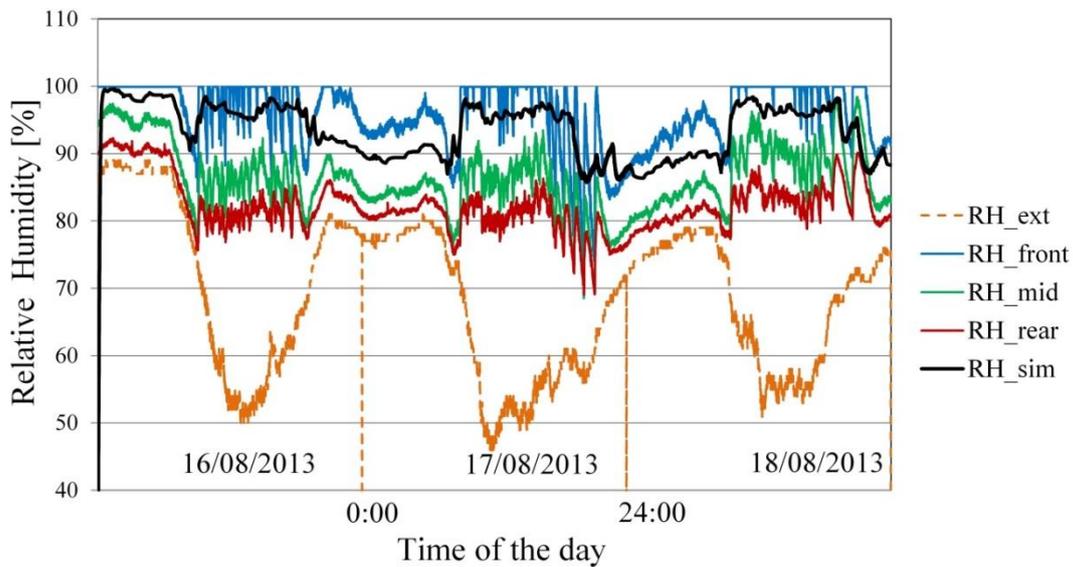


Figure 5 The simulated relative humidity compared to real plant data

Comprehensive analysis of the experimental and simulated temperature and relative humidity data are displayed in Figure 6 and Table 2. At the start of the simulation (Figure 6a), there was a transient period of about 150 sampling (2,250 seconds). The simulated temperature result showed the best agreement with the rear sensor data (RMSE = 0.46°C), and the best for humidity was at the front of the house (RMSE = 4.31% RH). The normalized RMSE displayed in Table 2 can imply that the model can be used to represent the temperature and relative humidity at the center of the house appropriately. And it can be developed for feedback control in the future work.

Table 2 Root-mean-square error between the simulation result and the real plant data

| Sensor | Position | RMSE (°C) | Normalized RMSE | RMSE (%RH) | Normalized RMSE |
|--------|----------|-----------|-----------------|------------|-----------------|
| 1 | Front | 1.77 | 0.07 | 4.31 | 0.04 |
| 2 | Middle | 0.68 | 0.02 | 8.07 | 0.09 |
| 3 | Rear | 0.46 | 0.02 | 53.54 | 0.65 |

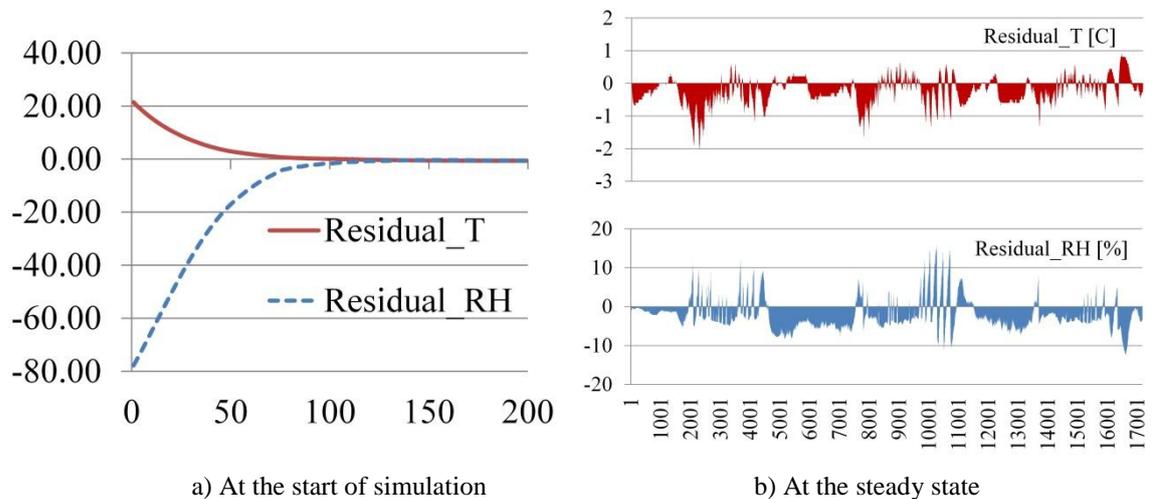


Figure 6 Residual plots of temperature at the rear part and relative humidity at the front part of the poultry house

4. CONCLUSION

In this paper, a dynamics model of a close poultry house, which represents the indoor temperature and relative humidity, has been validated. In comparison to the real plant data, the model provides an acceptable temperature prediction result, especially for the rear part of the house which is the most critical area. The relative humidity prediction result shows that the model gives a good performance only at the front and the middle parts of the house. By the way, this is an unsurprising result because the mixing volume is verified to be about 70% of the length from the front end. Further study using the proposed model should be conducted with some proper compensation and the advance nonlinear controller should be developed by this validated model.

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