Mathematical Modeling of an Evaporative Air-conditioning System and Cooling Loads in a Poultry House for Sliding Mode Control Analysis

Kritsadang Senawong[1] Thana Radpukdee[2*] and Ratchapol Suntivarakorn[1]

[1]Mechanical Engineering Department, Faculty of Engineering, Khon Kaen University,
Khon Kaen, Thailand 40002
[2]Industrial Engineering Department, Faculty of Engineering, Khon Kaen University,
Khon Kaen, Thailand 40002
*Corresponding Author: Tel: 043 343 117, Fax: 043 202 849
E-mail: krit_jae@hotmail.com

Abstract

This paper presents mathematical modeling of an Evaporative Air-conditioning System and cooling loads for a poultry house. The model is derived from evaporative air-conditioning process and characteristics of the poultry house having a size of 125x14x4 m^3 while the air-conditioning system is modeled by the well-know direct evaporative cooling process with assumption to occurred along a constant enthalpy line, an approach for constructing cooling load model is considered base on three components which are desired air temperature, internal and external heat load of the poultry house and relative-humidity of ambient and internal air zone. These mathematical will then be used to consider some control methods that suitable for air-conditioning control in the poultry house. Due to the model revealing uncertain characteristic a sliding mode control technique which has ability to against uncertainties and disturbances has been selected in this work to construct a guideline control law for air-conditioning in the poultry house. It has been noted that sliding mode control law in this work is in general form and used as a guideline to control such system only. Some components of the control law have to be update with special adaptation law which has still be developing. Although, such control law has not be completed yet in this work. Solution of heat load model showed that results from simulation of the mathematical models and real system are quite similar. So, it can ensure that the model can then be applied for an evaporative cooling system design and also controller design. This will increase convenience for a new poultry house development process and reduce faulty design of the cooling system.

Key words: Sliding mode control, Poultry houses, Evaporative cooling

1. Introduction

Currently, demand of energy has been increasing each year. A power plant must increase its power generation to serve this need. The closed system poultry houses in farm industry of Thailand are one sector that uses

Nomenclature

A_c	*Ceiling area (m^2)*	$Q_{inf\,il\,/\,vent}$	*Leakage heat from air into and out off the poultry house (kW)*
A_c	*Heat exchanger evaporation area of cooling pad (m^2)*	Q_{lamp}	*Heat load from a lamp system (kW)*
ACH	*Number of air change (h^{-1})*	Q_{room}	*Heat load of the house system (kW)*
A_{ground}	*poultry house ground area (m^2)*	Q_{wall}	*Heat load through the wall into the poultry house (kW)*
A_r	*The roof area (m^2)*	*SH*	*Heat exposure of Chicken (W / unit)*
A_w	*Area of wall (m^2)*	*t*	*time (s)*
C_{pa}	*Humid heat capacity (kJ / kgK)*	$T_{a,i}$	*Internal temperature of humid air (K)*
h	*Heat convection coefficient (W/m^2K)*	$T_{a,o}$	*Outside air temperature (K)*
$h_{c,i}$	*Coefficient of heat convection inside the ceiling (W/m^2K)*	T_c	*Ceiling Internal temperature (K)*
$h_{c,o}$	*Coefficient of heat convection outside the ceiling (W/m^2K)*	$T_{db,0}$	*Exiting dry-bulb temperature (^oC)*
$h_{c,ri}$	*Coefficient of thermal convection of internal the roof (W/m2K)*	$T_{db,i}$	*Entering (typically ambient) dry-bulb temperature (^oC)*
		T_{ground}	*Surface temperature at a depth L (K)*
$h_{c,ro}$	*Coefficient of convection of the external the roof (W/m^2K)*	T_h	*Poultry house temperature (^oC)*
$h_{c,wi}$	*Coefficient of heat convection inside the wall (W/m^2K)*	T_r	*Roof temperature (K)*
$h_{c,wo}$	*Coefficient of heat convection outside the wall (W/m^2K)*	T_s	*Air temperature under the roof (K)*
h_{fg}	*Latent heat of evaporation (kJ / kg)*	T_s	*Air temperature under the roof (K)*
$h_{r,ro}$	*Coefficient of heat radiation of the external the roof (W/m^2K)*	T_{sky}	*Sky temperature (K)*
$h_{r,wo}$	*Heat radiation coefficient of the external wall (W/m^2K)*	$T_{wb,i}$	*Entering (typically ambient) wet-bulb temperature (^oC)*
$I_t\theta_w$	*Solar radiation (W/m^2)*	*V*	*Internal air volume (m^3)*
k_{ground}	*ground conductivity (W / mK)*	V_0	*Specific air volume in the poultry house (m^3/kg)*
L_{ground}	*Ground depth with constant temperature throughout the year (m)*	V_g	*Internal poultry house volume (m^3)*
		W_0	*Humidity ratio out the poultry house (kg vapor / kg dry air)*
m_{air}	*mass flow rate of air (kg_{air}/h)*	W_a	*Humidity ratio in the poultry house (kg vapor / kg dry air)*
m_{water}	*mass flow rate of water (kg_{water}/h)*	*watt*	*total amount of watt in the lighting system (w)*
N	*Number of chicken (unit)*	w_s	*humidity ratio of the supply cooled air (kg_{H2O}/kg dry air)*
P	*Air pressure (kPa)*	α_R	*Coefficient of absorption of solar radiation on the roof*
P_g	*Saturated air pressure (kPa)*	ΔT_{lm}	*The difference in temperature between the cooling pad evaporation and air temperature outside and inside the poultry house (K)*
Q_{ce}	*Heat load from the Ceiling into the poultry house (kW)*		
Q_{ch}	*Sensible and latent heat from chicken (kW)*		
Q_{evap}	*heat used to evaporate water (kW)*	ε_{sat}	*Saturation effectiveness*
Q_{ground}	*Changing heat between ground and internal air (kW)*	θ_{wlt}	*Solar radiation (W/m^2)*

large amount of energy. Current selection of equipments such as a pump and a fan is not suitable and many farm owners construct their chicken's house by duplicating from an oversea company or a large company in Thailand. The lack of concern in specific atmosphere that varies from one region to other region and heat load leads to failure production and consuming more energy. If there are design features to save energy and provide effective power management for poultry industry, it will be a great help. In views of the country, it can reduce energy import and the farm owners can reduce production cost then get more benefit in manufacturing process.

Currently, Thailand has a large number of chicken farms that have been transformed their poultry house from open system to be closed system which has the better air condition control.

Although the closed system needs higher production cost but it gives more profit with small time period in return of investment compared to the old open system. The evaporative cooling system that is used to control temperature, moisture content, and amount of air change is one part of the closed house system this part consumes a lot of energy. Especially in tropical region such as Thailand, the need to use power in a pump and a fan motor for temperature, moisture, and air velocity control has been rising. So if the construction of poultry house and its evaporative cooling system are suitable with real heat load, the efficient energy using in the system will be occurred. Then energy conservation in the poultry house could be done. Moreover, the right heat load calculation leads to suitable air conditioning control and may increase productivity as well if chickens feel comfort. To achieve these goals, the mathematical models of heat load for a closed poultry house has to be derived firstly. The mathematical model is very important in an evaporative cooling system design and useful for construction planning of a new poultry house. Furthermore, in order to design some controller to control air condition in the house, the heat load model and its relation with the evaporative cooling system are unavoidable. This study interested in the heat load modeling that occurs in a poultry house of Figure 1 (a case study farm in Khon Kaen, Thailand). The sliding mode control technique also applied to the model of the system. To show relationship between heat load and evaporative cooling, section 2 and 3 explain idea and theory of evaporative cooling process. And all heat load portions will be discussed in section 4. Section 5 will express procedure to compare simulation and experimental results. The results of comparison and conclusion are given in section 6. Then, the application of sliding mode control method will be express in section 7.

Figure 1 The poultry house in this study (a case study of chicken farm in Khon Kaen, Thailand)

2. Evaporative air-conditioning system in a poultry house [1, 2]

The evaporative cooling system is shown in Figure 2. It can solve the problem of environmental control in the poultry house such as temperature and ventilation control with the lower energy consumption comparing to the vapor compression refrigeration. Principle of evaporative cooling is evaporation of water will reduce dry bulb temperature of hot incoming air and increase humidity simultaneously. This is because sensible heat in the hot air will be used in evaporative phenomena of water and change to be latent heat stored in the cooled air. Although high investment, the evaporative cooling system still be attractive due to its advantages as the followings.

The advantages of the close poultry house system

1. Prevent outbreak of disease effectively.

2. Can increase the number of chickens per unit area.
3. The growth rate and feed conversion rate (FCR) can be improved.
4. Shorten duration of a crop.
5. Chickens have higher weight than the chickens come from the open house system in same period.
6. Prevent bugs and pests to interfere the chickens.
7. Low fatality rate.
8. Can reduce the number of workers to take care of the chickens.

3. Evaporative Cooling System [1, 3]

An adoption of evaporative cooling system is to control weather so that ensure comfortable condition for the chickens. The evaporative cooling system is categorized by its characteristic of cooling into 2 processes which are direct and indirect mode. However, this work will discuss only the direct evaporative cooling process as shown in Figure 3. The cooling process starts with forcing hot air through a cooling pad (Figure 3a) which has high surface area of contact between water and hot air. Heat from the hot air passing through the pad will cause the evaporation of water flowing in the pad. The dry bulb temperature of the air passed through the cooling pad will be lowered and its relative humidity (RH) will be increased (Figure 3b).

This cooling process has a parameter to indicate the performance of an evaporative cooling device called “efficiency of evaporative cooling system(ε)”. This is usually expressed in term of performance saturation(ε_{sat}). It is the ratio between the actual reduced temperature of the system to the maximum reduced temperature in theory. This performance is evaluated by

$$\varepsilon_{sat} = \frac{T_{db,i} - T_{db,o}}{T_{db,i} - T_{wb,i}} \times 100\% \qquad (1)$$

Thus, the dry bulb temperature ($T_{db,o}$) out of cooling pad can express as

$$T_{db,o} = T_{db,i} - \frac{\varepsilon_{sat}}{100} \times (T_{db,i} - T_{wb,i}) \qquad (2)$$

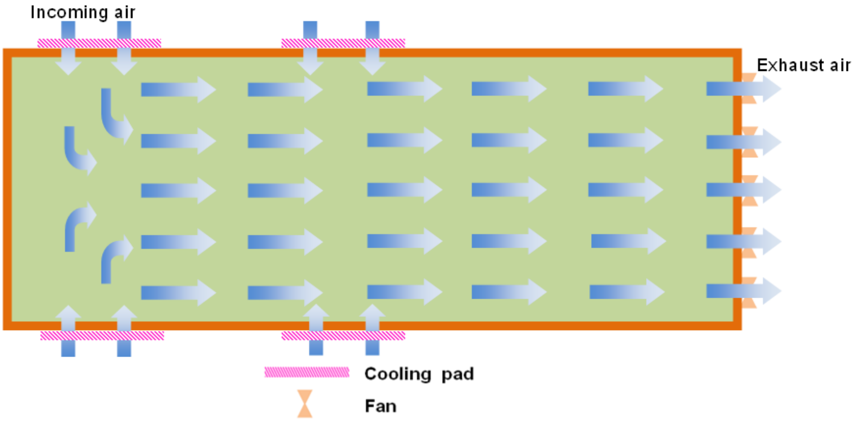
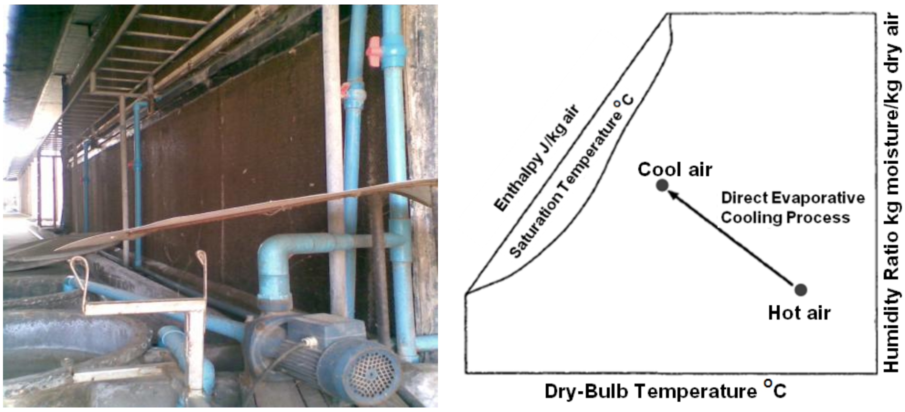


Figure 2 poultry Houses with Evaporative Air-conditioning System



(a) (b)

Figure 3 (a) A Cooling pad used in the process of evaporative Cooling
(b) Psychometric chart illustrating the constant enthalpy Process for Direct Evaporative Cooling [1]

Note that a nominal performance saturation and pressure drop can be obtained by specific air inlet velocity, cooling pad thickness. To reduce the poultry house temperature to be T_h , air mass flow rate through the cooling pad will vary under the heat load as written by,

$$\dot{m}_{air} = \frac{\text{Total sensible \& latent cooling heat load (Btu/h)}}{\text{[Enthalpy of the dired air zone − enthalpy of the supply air form cooling pad](Btu/kg dry air)}} \quad (3)$$

or

$$\dot{m}_{air} = \frac{Q_{sensible} + Q_{latent}}{C_{pa}(T_h - T_{db,0})} \quad (4)$$

Where $Q_{sensible}$ and Q_{latent} are total sensible and latent cooling load, respectively.

From eq.(3) and (4), the mass flow rate of air and water can be calculate then be used to control the system. However, in order to develops close loop control system, the cooling load analysis is necessary.

For the water consumption, it can be calculated by the air mass flow rate and humidity ratio of the air that leaves the cooling pad as given by

$$\dot{m}_{water} = \dot{m}_{air} \times w_s \quad (5)$$

where $\dot{m}_{air}$ is mass flow rate of air in kg_{air}/h
w_s is humidity ratio of the supply cooled air in kg H_2O/kg dry air

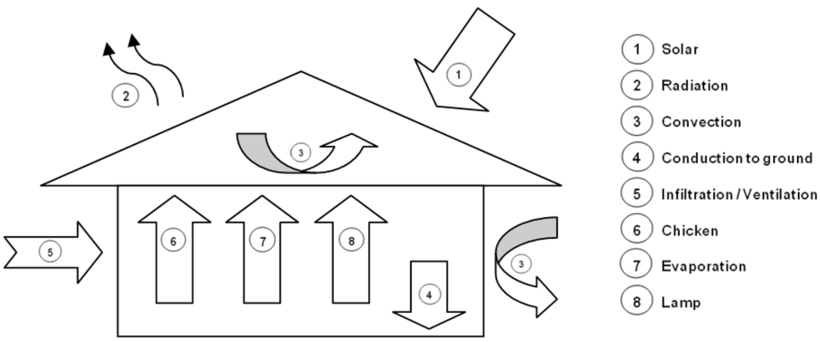


Figure 4 Heat balance within a poultry house

4. Thermal equilibrium within a poultry house [3,4,5]

The mathematical models of the poultry house will be constructed from heat occurring external and within the house (see Figure 4). Heat load from solar radiation and ambient temperature transferring through various parts of the house are detailed in section 4.1 to 4.4. And the internal heat load releasing from the chicken and lamp is formulated in section 4.5 and 4.6 then section 4.7 expresses relationship between heat used to evaporate water and the desired internal dry bulb air temperature out of cooling pad.

Thermal energy balance that occurs in the poultry house can be written as

$$Q_{room} = \Sigma Q_{wall} + Q_{ce} + Q_{infill/vent} + Q_{ch} + Q_{lamp} - Q_{ground} - Q_{evap} \quad (6)$$

And each term in the right hand side of equation (6) will be detailed as following.

4.1 Energy transfers through the walls to a poultry houses (Q_{wall})

Calculation of the heat transfer through the walls of the poultry house uses energy balance equation from three components which are radiation, inside and outside convection. That is

$$Q_{wall} = A_w[(\alpha_w)I_{t\theta w} + h_{r,wo}(T_{sky} - T_w) + h_{c,wi}(T_{a,i} - T_w) + h_{c,wo}(T_{a,o} - T_w)] \quad (7)$$

4.2 Energy balance through a roof and ceiling (Q_{roof}, Q_{ce})

The most of heat to the roof comes from the sun. When temperature of the roof increases, the heat will transfer into internal side. Some will go out to the sky and some will be accumulated in the roof. Equation (8) and (9) express heat load that comes from the roof and its ceiling.

For the roof, the equation is given by

$$Q_{roof} = A_r[(\alpha_r)I_{t\theta w} + h_{r,ro}(T_{sky} - T_r) + h_{c,ri}(T_s - T_r) + h_{c,ro}(T_{a,o} - T_r)] \quad (8)$$

Then, the energy balance equation of the ceiling is

$$Q_{ce} = A_c[h_{c,ci}(T_{a,i} - T_c) + h_{c,co}(T_{s,o} - T_c)] \quad (9)$$

4.3 Energy transfers through concrete floor (Q_{ground})

In this part, the convection and radiation can be neglected. Heat increasing within the house will be transferred to the floor by conduction expressed that as

$$Q_{ground} = \left[\frac{k_{ground}\ A_{ground}}{L_{ground}}\right](T_{a,i} - T_{ground}) \quad (10)$$

4.4 Heat load caused by infiltration and ventilation into a poultry house ($Q_{infil/vent}$)

Ventilation in a poultry house brings heat and humidity in and out of the house. The relation that explains infiltration and ventilation has been defined in equation (11)

$$Q_{infil/vent} = \frac{ACH\ (V)}{3600\,V_0}\left[C_{pa}(T_a - T_0) + (W_a - W_0)h_{fg}\right] \quad (11)$$

4.5 Heat load due to the chicken (Q_{ch})

The heat load that transfers from the chicken to a poultry house depends on the weight and number of chickens in a poultry house. It can be written as

$$Q_{ch} = N \times SH \quad (12)$$

4.6 Heat load from a lamp system (Q_{lamp})

Because of installation of lighting, heat from the lighting system will be released to the house's air zone. That can be calculated by equation (13)

$$Q_{lamp} = (watt \times 0.057)/1000 \qquad (13)$$

Where watt is total amount of watt in the lighting system.

4.7 Heat used to evaporate water (Q_{evap})

It is a part of heat used to evaporate water. This process will increase humidity of the air flowing through a cooling pad. The heat used in water evaporative process can be obtained from a model in equation (14).

$$Q_{evap} = \bar{h} A_c \Delta T_{lm} \qquad (14)$$

where

$$\Delta T_{lm} = \frac{(T_{db,i} - T_{wb}) - (T_{db,o} - T_{wb})}{\ln\left(\frac{T_{db,i} - T_{wb}}{T_{db,o} - T_{wb}}\right)} \qquad (15)$$

5. Heat load model verification

To calculate the heat load, the equations form 1 to 15 have to be used. Parameters in these equations were conducted from structure and weather details collected at a case study farm in Khon Kaen province, Thailand. The poultry house has size of 125 x 14 x 4 m^3. Its data has been collected on July 2009, November 2009, and March 2010 to analyze the real heat load and then used to verify the mathematical heat load model of the poultry house (information of the collected data see appendix A). The parameters that will be used in heat load calculation process consist of the internal temperature, internal relative humidity and the temperature and humidity of the surrounding. The heat load inside the house at the real condition can be calculated from those models. To verify those heat load models, the heat load at the real environment can be measured via the air temperature difference as will be discussed in section 5.1. The temperature and humidity inside the house can be measured by the pocket weather meter device (Kestrel 3500). Additionally, the internal temperature, humidity, and even heat load can be calculated by the procedure in section 5.2 to 5.4 as provided below.

5.1 Calculation of the thermal heat load at the real environment

The heat load at an actual circumstance can be roughly estimated by the changing of the temperature of the air before entering a poultry house and after leaving a poultry house. Amount of the air flowing through the house can be measured from the wind speed at the end of the house and fan performance curve. Then substitute all parameters into equation (16).

$$Q = mC_P\Delta T \qquad (16)$$

Where m is mass flow rate of air in kg_{air}/h

ΔT is The difference in temperature between exiting dry-bulb temperature of cooling pad and exhaust air (K).

5.2 Temperature in the house.

Due to there are infinity temperature value distributed along the poultry house, the mathematical modeling to estimate the temperature in the house will be focused on the air temperature out of the cooling pad as in the equation (2) from the evaporation process.

5.3 Relative humidity in the house.

The term of relative humidity can be calculated from the moisture ratio of the humid air out of the cooling pad and the saturated air pressure (P_g). This relations is shown below

$$RH_a = \frac{W_{a,i}P}{(0.622 + W_{a,i})P_g} \quad (17)$$

where

$$P_g = \exp\begin{bmatrix} \frac{-7511.22}{T_i} + 89.63121 + 0.02399897T_i \\ -1.1654551 \times 10^{-5}{T_i}^2 \\ -1.2810336 \times 10^{-8}{T_i}^3 \\ +2.0998405 \times 10^{-11}{T_i}^4 - 12.150779\ln(T_i) \end{bmatrix} \quad (18)$$

5.4 The heat load in a house

The mathematical model of heat load can be considered by the principle of heat balance occurring within a house. This has been expressed in equations (6) to equation (15).

6. Result Comparison and conclusion

After the mathematical models of heat load in a poultry house have been constructed, the farm side visit has been performed on July 2009, November 2009, and March 2010 for data collection. The three parameters from actual condition and the estimation of mathematical model are shown in Table 1.

Based on the results of the mathematical models were found. The values of the three parameters (internal temperature, internal relative-humidity, Heat load) compared with the actual condition have some margin of error. However, the occurred errors could be acceptable because these models will be used to design a control law for an evaporative cooling system in further research. Such control law will be design in the approach of robust adaptive control. This control method has its ability to overcome uncertainty and robustness again stings any disturbance. Therefore, the control method can compensate mismatch between the models and actual system and also refine the accuracy of the model.

7. Guideline for sliding mode control

From all mathematical models derived so far, the mass flow rate of humid air through the cooling pad is the most important parameter to be concerned while the mass flow rate of supply water can be easily obtained by multiplication between the humidity ratio of the supply cooled air from the cooling pad and the air mass flow rate (see Eq.(5)). Such air mass flow rate can be estimated from Eq.(3) as

Table. 1 Comparison of the results obtained from mathematical models and experiment.

Surrounding ambient	July'09			November'09			March'10		
	Real condition	Mathematical model	Error	Real condition	Mathematical model	Error	Real condition	Mathematical model	Error
External temperature (^{0}C)	25.29			29.4			33.41		
External relative humidity (%RH)	100			59.43			39.87		
internal temperature (^{0}C)	24.35	25.29	3.86%	23.38	23.28	0.43%	22.63	22.59	0.18%
Internal relative humidity (%RH)	100	99.39	0.61%	93.57	88.5	5.42%	90.68	88.54	2.36%
Heat load (kW)	394.82	379.19	4%	935.27	917.24	1.93%	971.93	931.24	4.19%

stated in section 3. By using the energy balance of a poultry house in section 4, the total sensible and latent heat load could be calculated and a poultry house temperature T_h should be defined by each operator (normally, temperature difference between the front and rear of a house should not be exceed 2 degree). Thus, from the $\dot{m}_{air}$ in Equation (3), air velocity that flows passing the cooling pad is given by

$$v_p = \frac{\dot{m}_{air}}{\rho_{air} A_p} \qquad (19)$$

Where ρ_{air} is density of the humid air out of the cooling pad and

A_p is total area of the cooling pad perpendicular to air flow.

In this work, the mass flow rate of water is not considered in control law design due to this parameter can be controlled quite precisely by any sophisticated flow control servo valve. By contrast, the air velocity through the cooling pad is very complicated. This is because it will be forced by a number of induced draft fans located at the end of a poultry house. To avoid complexity in computational fluid dynamics and the sliding mode control technique has its ability to design by an estimated system model, relationship between the number of operating fans (N_{Fan}) and the air velocity flows passing the cooling pad can be written in general form of the first order matching nonlinear uncertain system [6, 7] as

$$\dot{v}(t) = f(v,t) + B(v,t)N_{Fan}(t) + B(v,t)\eta(v,t) \qquad (20)$$

$$v(t_0) = v_0$$

Where v is the air velocity flows passing the cooling pad, $N_{Fan}(t)$ is the control input, η is the uncertain element that forms the lump uncertain element $B(v,t)\eta(v,t)$, $f(v,t)$ is the known nonlinear function, and $B(v,t)$ is the known control gain.

In practice, the above equation could be constructed by input/output measurement and system identification process using Matlab. By using the air velocity in Equation (19) to be reference, a control law can be formulated similar to the work of T. Radpukdee and P. Jirawattana [8]. That is

$$N_{Fan} = (B)^{-1}\left(-f + \dot{v}_p - B\eta_c - \rho k sat(Y)\right) \qquad (21)$$

where Y is a proportional term $Y = s/\phi$, $s_t(v) = v - v_p$,

$sat(Y) = \begin{cases} Y & if \ |y| \le 1 \\ \mathrm{sgn}(Y) & if \ otherwise \end{cases}$, ϕ is the boundary layer width [9],

$B\eta_c$ is the estimated uncertainty [8], k is the sliding gain which is positive definite and must be larger than the maximum possible value of $\|B\eta\|$, and ρ is a positive constant also added into the interpolation term in Equation (21) to cover an incorrect sign of the calculated uncertainty which could occur for fast varying uncertainty.

The block diagram represents the conventional boundary layer sliding mode control law with uncertainty learning and compensation is shown in figure 5.

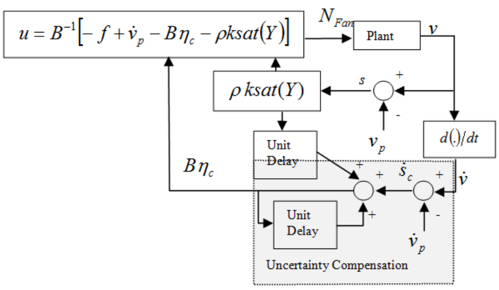


Figure 5 the conventional boundary layer sliding mode control law with uncertainty learning and compensation

Because of the uncertain element in Equation (20) is assumed to be bound, the stability of the control system will be achieved uniform ultimate roundedness similar to the system in [6,7,8]. To sum up, when the air velocity through a cooling pad is controlled to reach the reference value calculated from the estimated cooling load, the mass flow rate of water will be offered simultaneously. Then the air at low temperature out of the cooling pad will be occurred by evaporative process depending on wet and dry bulb temperature of the incoming outside hot air and the cooling pad efficiency. Due to variation of the incoming hot air properties, the temperature of the supply cool air from the pad is hard to be controlled by the air velocity only if some dehumidify device is not installed [1]. However, the difference between the supply cooled air temperature and temperature at the end of a poultry house could be controlled as implied from Equation (3).

Acknowledgement

This research was supported by Cleaner Technology Internship Program, Khon Kaen University Node and Faculty of Engineering, Khon Kaen University, Thailand.

Appendix A

Table A : Additional collected parameters for heat load calculation form the farm in case study

Parameter	Value	Unit
Size of Poultry house (width x length x height)	*13.8x125x4*	*m^3*
Size of Cooling pad (width x height x thickness)	*9x3.6x0.15*	*m^3/unit*
Thickness of wall	*0.0125*	*m*
Wall conductivity	*0.7200*	*W/m.k*
Density of Wall	*1860*	*kg/m^3*
Specific heat of Wall	*0.84*	*kJ/kg.K*
Thickness of Ceiling	*0.0008*	*m*
Ceiling conductivity	*80.4*	*W/m.k*
Density of Ceiling	*7860*	*kg/m^3*
Specific heat of Ceiling	*0.450*	*kJ/kg.K*
Thickness of Ground	*0.0125*	*m*
Ground conductivity	*0.7200*	*W/m.k*
Density of Ground	*1860*	*kg/m^3*
Specific heat of Ground	*0.84*	*kJ/kg.K*
Heat exchanger evaporation area of cooling pad	*320*	*m^2/m^3*
Number of air change	*3,600.00*	*h-1*
Internal air volume	*300.00*	*m^3*
Specific air volume in the poultry house	*1.61*	*m^3/kg*
Specific heat of internal humid air	*1.006*	*kJ/kg.K*
Ground depth with constant temperature throughout the year	*0.20*	*m*
Surface temperature at a depth L	*25.00*	*°C*
Heat exposure of Chicken	*0.0082060*	*W / unit*
Air velocity through Cooling pad		
- July'09	*1.53*	*m/s*
- November'09	*1.33*	*m/s*
- March'10	*1.20*	*m/s*
Out Temperature of poultry house		
- July'09	*26.13*	*°C*
- November'09	*28.42*	*°C*
- March'10	*28.47*	*°C*

References

[1] Bom, Gret Jan and etc., 1999, **Evaporative Air-Conditioning**, Washington, D.C., U.S.A, The World Bank

[2] Prayut Neamtang, 2546, **Reduction of Heat Loads Through Poultry Roof**, Department

of Energy Technology, King Mongkut's University of Technology Thonburi, Bangkok.

[3] João M. D. Pimenta and Wagner P. De Castro, 2005, **ANALYSIS OF DIFFERENT APPLICATIONS OF EVAPORATIVE COOLING SYSTEMS**, Department of Mechanical Engineering, University of Brasilia.

[4] Anusorn Rattanathanaopat, 2546, **Improving in Efficiency of Evaporative Cooling in Poultry**, Department of Energy Technology, King Mongkut's University of Technology Thonburi, Bangkok.

[5] Mills, A F., 1999, **Basic Heat & Mass Transfer**, California, Prentice Hall, pp. 274-276, 842-844.

[6] Corless, M. J. and Leitmann, G. (1981). Continuous state feedback guaranteeing uniform ultimate boundedness for uncertain dynamic systems. **IEEE Transactions on Automatic Control, 26** (5), 1139-1144.

[7] Barmish, B. R. and Leitmann, G. (1982). On ultimate boundedness control of uncertain systems in the absence of matching assumption. **IEEE Transactions on Automatic Control, 27** (1), 153-158.

[8] Radpukdee, T. and Jirawattana, P. (2009). Uncertainty learning and compensation: an application to pressure tracking of an electro-hydraulic proportional relief valve. ***Control Engineering Practice, 17(2009), 291-301***

[9] Slotine, J.J.E. and Li, W. (1991). **Applied Nonlinear Control**. New Jersey: Prince-Hall International Inc., USA.

[10] Giabaklou, Z. and Ballinger, J.A., 1996, "A Passive Evaporative Cooling System by Natural Ventilation," **Building and Enviroment**, Vol.31, No. 6 , pp. 503-507.

[11] Thepa, S., Kirtikara, K., Hirunlabh, J. and Khedari, J., 1999, "Improving Indoor Conditions of a Thai-style Mushroom House by Means of An Evaporative Cooler and Continuous Ventilation, "**Renewable Energy**, Vol. 17, pp. 359-369.

[12] Lawrence, S.A. and Tiwari, G.N., 1989, " Performance Study of an Evaporative Cooling System for a Typical House in Port Moresby," **Solar & Wind Technology**, Vol.6, No.6, pp.717-724.

[13] Prapas Roengruen, Songsri Roengruen, Taweepol Suesut, Viriya kongrata ,Suphan Kulphanich, **A Studying Of Automatic Control System On Poultry House**, Department of Instrumentation Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok

[14] Simmons, J.D. and Lott, B.D., 1996, "Evaporative Cooling Performance Resulting From Changes In Water Temperature," **Applied Engineering in Agriculture**, Vol. 12, No. 4, pp. 497-500.

[15] Sodha, M.S., Sawhney, R.L., Kaur, J. and Signh, S.P., 1991, "Thermal Performance of a Room Coupled to an Evaporative Cooling Tower," **Proceedings of The Biennial Congress of The International Solar Energy Society**, Vol. 3, Part 3, August 19-23, Colorado, USA., pp. 3095-3100.

[16] Yunus, A.C. and Michael, A.B., 1989, **Thermodynamics : An Engineering Approach**, Singapore