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Three optimization models for air inlet positioning to enhance air flow profile in forced ventilation poultry houses

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Abstract

This research aims to find the suitable location for installing side wall air inlet of the poultry house, which minimum Temperature Humidity and Velocity Index: THVI, by using three optimization techniques. The first is using Adaptive Differential Evolution Algorithm in MATLAB, sampling by Latin Hypercube Sampling design in pure quadratic model sample. Second technique is using GRG Nonlinear algorithm in Microsoft Excel Solver add-ins, sampling by Latin Hypercube Sampling design in Central Composite Design (CCD). The last one is using Nonlinear Programming by Quadratic Lagrangian (NLPQL) which is Design exploration function in Ansys^{TM}14.5 program, sampling by Latin Hypercube Sampling design in full quadratic model sample. After the side wall air inlet installation lengths have been calculated from each methodology above, simulation model then be made to simulate air flow of each approach by computational fluid dynamic (CFD). The best result then be chosen, by analyzing air speed consistency throughout the poultry house, to conduct real situation experiment to compare the efficiency with the original poultry house. The best simulation result has THVI of 28.38 °C with 0.84 standard deviation. And the experiment result shows that; average air velocity increase to 2.8 m/s from 2.2 m/s, air change rate increase to 53 ACH from 34 ACH (in case of maximum ventilation) and fan efficiency increase to 94.77% from 61.22% in poultry house without air inlet installation.

Keywords : Adaptive differential evolution, Air inlet, Closed-system housing, Livestock house

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1. Introduction

One of the challenges in broiler production is highest yield, highest feed conversion ratio (FCR), which directly reflect the sales and profit. One of the important factors that reflect the FCR and the growth rate other than food quality is housing environment. According to previous research, broiler have same comfortable level in the condition of 20 °C if it in the condition of 30 °C with air stream 1.5 m/s through them [1]. Another research found out that, proper air velocity increase broiler growth rate and weight ratio in both open and closed poultry house [2,3]. Yahav (4) found that, broiler raise in 2.0 m/s air flow grow 45-95 gram per week which is more than broiler raise in 0.25 m/s both in summer season. So, the farming environment is directly affected production efficiency. Davis [5] also found that, higher temperature increases broiler protein appetite but no more than 28 °C. However, broiler growth rate and appetite decrease when temperature higher than 35 °C which is relative with Yahav [6] study. Therefore, every broiler should have enough air flow through their body to increasing the efficiency of broiler production.

In current poultry design, air flow in the poultry house are most likely occurred from ventilation fan at the end of the house. Hence, air replacement rate is subjected to air inlet area and exhausted rate of the fan. In the case that the air inlet area is less than the fan capacity, causing excessive power consumption in the exhaust fan and the wind speed is too high. This will allow the chicken to evacuate from the area. In case of only cooling pad use as the air inlet, it can be blocked up by some dirt causing occur high pressure on cooling pad [7, 8, 9]. Otherwise, excess air inlet area would occur air flow around air inlet causing unable mixed fresh air and existing air within poultry house. The previous study of Bartzanas [10] suggest to retain static pressure approximately 0.04-0.08 inch H_2O for fan working efficiency and high energy saving. Besides, the optimal air ventilation rate with correct air flow direction through air inlet is also necessary. This air flow direction is upon inlet positioning. Air flow direction should not touch directly to broiler, it probably causes sickness and emigrate of broiler from their area [11]. Thus, designing air inlet or ventilation equipment have to consider the appropriate feature and installed position. There are lots of research applied flow simulations approach by CFD that is broadly used and reliable program such the achievement of Stinn, Kwon, Vidal [12, 13, 14]. They applied CFD to forecast flow pattern and observe temperature distribution in livestock house and greenhouse to enhancing internal condition appropriately. The air flow profile simulations would use in the study prior the actual installation that assist to shorten experiment period and saving budget including reduce the effect to broiler in case of unsuitable design before do installation. This study brings three technique of optimization as the tool for searching air inlet installation on side wall of poultry house. The objective of this study is to find out the lowest of Temperature Humidity and Velocity Index (THVI). Then to derive install length of each part that is the candidate from each technique and take to do flow simulation to observe air flow pattern by CFD. To select installation length at the position that occupy the most uniformly distribution of air speed to design for actual installation in the house. Including to collect data of efficiency in air change rate that increased when compare with the poultry house without air inlet installation.

2. Material and Method

Optimization technique to find the optimal equipment installation location can be divided in to four steps. First step is setting the design variable. Second step is using appropriate systemize random length technique to create set of variables that could be use as training points throughout the design domain all of which to define surrogate models. Third step is using surrogate model to find the best variable by the most appropriate solver technique. Last step is using result from previous step to simulate air flow pattern, then analyze the most appropriate installation length by using result from simulation and objective function, the length then be use as installation in real poultry house.

2.1 Optimization technique

Objective function in this study are consider two main variables. The first variable is temperature consistencies that indicated by the standard variable of THVI. The second variable is the mean of minimum THVI which represent the appropriateness of the air inlet installation length by analyze the air flow velocity and temperature throughout the poultry house. The objective function shown in equation 1.

$$min: f(\mathbf{x}) = 0.8f_1 + 0.2 \times f_2 \quad (1)$$

when f_1 , f_2 = The normalize standard deviation and the normalize mean of THVI at 30 cm. height

$\mathbf{x}$ = Set of design variables

where ; THVI show in equation 2

$$THVI = (0.85T_{db} + 0.15T_{wb}) \times V^{-0.058} \quad (2)$$

where T_{db} = Dry bulb temperature ,°C

T_{wb} = Wet bulb temperature, °C

V = Air velocity, m/s

According to required air inlet area in this study and standard size of air inlet, the number of air inlet in each side wall of the poultry house is finalize as seven. So, the design variables are the installation length of each seven air inlets, shown as X1-X7 in Figure 1.

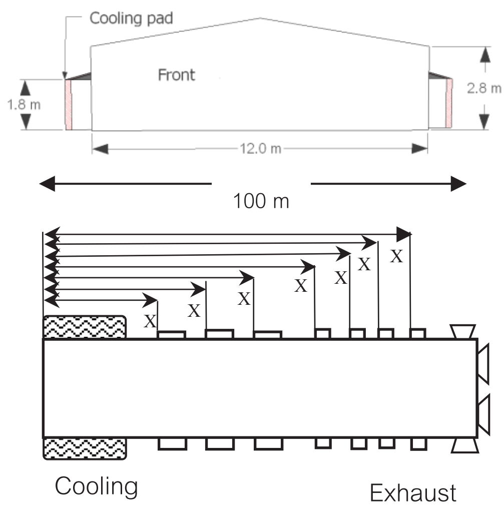

Figure 1 show each 7 length variables on top view.

Each design variable has its upper and lower bound shown in table 1

Table 1 Upper and lower bound of each design variable

Design Variable	X1	X2	X3	X4	X5	X6	X7
UB(m)	24.5	41	58	66	73.5	81	89.5
LB(m)	10	26.5	43	60	67.5	75	82.5

UB = Upper bound, LB = Lower bound

2. 1. 1 Adaptive Differential Evolution Algorithm

Adaptive Differential Evolution Algorithm can be explained in the following steps. First, design variable sampling by using Latin hypercube sampling (LHS) in pure quadratic model sampling to make 61 sample sets. Second, using Ansys 14.5™ program to simulate preliminary target value. Third, statistical analysis by Design-Expert® 7.0 program. All independent and dependent variable then be using to create surrogate model by boundary range estimation in radial basis function: RBF, using spline linear regression as main base function. Finally, the result will be quadratic equation. In order to find the objective function, the THVI need to be considered. According to the analysis, installation length factor significant impact the objective function in p-value of 0.0329 at 0.05 significant.

2.1.2 Generalized Reduced Gradient (GRG) Nonlinear

The second method applies technique GRG Nonlinear as the searching step due to this method is appropriate to manage nonlinear problem and it is the simple tool suitable for any types of problem. To random variable designed by latin hypercube sampling with central composite design and form equation of surrogate model with quadratic model by using the same objective function as the first method. This method has 55 series of random variable and bring to do simulation of objective function in program Ansys 14.5. The primary response would be analyzed statistically by program Design-Expert® 7.0. The result explains that the significant level is 0.05. The factor of installation length influences significantly to objective value with p-value as 0.0372.

2.1.3 Nonlinear Programming by Quadratic Lagrangian (NLPQL)

The third method is to random variable designed by Latin hypercube sampling design with full quadratic model sample. Then use for forming equation of surrogate model and apply the most optimal step of response searching by NLPQL that is ready-program of design exploration in program Ansys 14.5 and use the same objective function as the first method. This method has 36 series of random variable that is the function in program Ansys 14.5. These variables are used for initial response series for building responding surface of individual variable. The primary response would be analyzed statistically once again by program Ansys 14.5.

2.2 Computational fluid dynamic modelling

2.2.1 Case study information

This study uses the closed-system poultry house. The poultry house has dimension as 12 x 100 meters and height 3.6 meters and construct by steel construction, roof tile, masonry wall with plastering. The front of poultry house installs large cooling pad on both sides by length 8 meters, height 1.8 meters. The rear wall of poultry house installs six ventilation fans size 1.27 meters inches and one fan install on each side wall both left and right. This poultry house brings up 12,000 broilers and due broiler age at 25 days with average weight 1.5 kg. Otherwise, air inlet area required upon broiler age is shown in table 2.

Table 2 Air inlet area required upon broiler age

Broiler Age (days)	1-7	7-14	15-25
Broiler weight (kg.)	0.17	0.44	1.25
Number of broiler	12,000	12,000	12,000
Total heat production (kW)	13.92	28.73	59.61
Air change (ACH)	24	29	39
Total Inlet area (m^2)	6.01	8.41	10.80

2.2.2 Modelling and meshing

To initiate with modelling in 3D accordant size of poultry house in case study that is the actual size in industrial level by program Ansys 14.5. And assort mesh into two shapes as Hexahedral and Tetrahedral type with the smallest size of 30 cm. Size and number of mesh would firstly inspect mesh independent for the most accuracy under the limiting of calculation period and computer resources.

2.2.3 Boundary condition and numerical methods

Exhaust fans that install at the rear of poultry house are determined to adjust velocity follow graph of fan efficiency in linear function. All four wall sides of poultry house and roof are determined as Non-slip wall and scalable wall functions that contact to ambient air and have heat transferring from outside. Setting the initial value to determine as following.

1) Cooling pad and air inlet defined as Pressure inlet
2) Exhaust fan defined as Fan
3) Wall and roof defined as Wall

Thermal analysis of fluid flow by CFD in mechanically ventilation poultry house by finite volume that is one of potentially methods. The air property is determined as Newtonian fluid and incompressible. The air flow in poultry house behaves as turbulent flow and steady stage. Air property such air density 1.1770 kg/m^3, specific heat capacity 1006.00 J/kg-K, thermal conductivity 0.0267 W/m-K and viscosity 1.8832 x 10^{-5} kg/m-s. This study applies SIMPLE method because of lots of previous studies select this method to solve the problem in fluid flow. Furthermore, it simply calculation when matching velocity and pressure vector in space of problem and turbulent model applies Realizable k-ε.

3. Result and Discussion

Result of surrogate model for searching the optimal position in all three optimization technique bring about six candidates of differnce positions of installation lengths as illustrated in table 3 and result of velocity simulation by CFD is illustrated in figure 2.

Table 3 The optimal installation length derives from three optimization technique

Candidate	Installation length (m)						
	X1	X2	X3	X4	X5	X6	X7
M1-C1	10.0	41.0	54.5	66.0	70.7	75.0	89.5
M2-C2	24.5	41.0	43.0	60.0	72.3	81.0	89.5
M2-C3	10.0	40.9	58.0	61.3	67.5	75.0	85.5
M2-C4	24.5	28.5	43.0	66.0	67.5	75.7	89.5
M3-C5	20.8	41.0	58.0	66.0	69.3	75.6	89.5
M3-C6	24.5	26.5	50.9	60.0	71.5	79.5	82.5

M = Metho d, C = Candidate

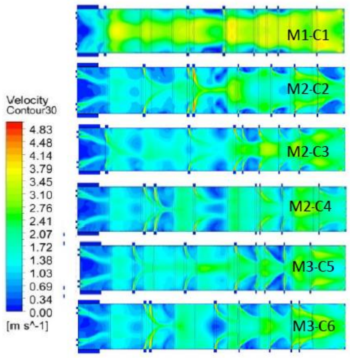

Figure 2 Velocity contour and air speed in a poultry house (Candidate1 - 6)

Result from surrogate model to search the optimal position derives from adaptive differential evolution by one candidate (M1-C1) indicate that air velocity in largely area of poultry house is approximately 2-3 m/s and small area in front and by side between the second and the third air inlet occupy air velocity lower 1 m/s. As result from the second method GHG Nonlinear take three candidates as M2-C2, largely area of house occupies air velocity lower than 2 m/s and partly area occupy air velocity over 2 m/s at the rear of house including area near the exit of air inlet. As M2-C3 occupy more uniform distributed of air velocity than M2-C2 and average of air velocity higher. However, area at the end of air inlet number 5,6, and 7 near the central of house occupy air velocity quite different from other area in the same cross section that probably occur high forced draft air to the broiler. Likewise, M2-C4 at the area between air inlet number 6 and 7 occur highly air velocity that different from other area and combine the area where occupy air velocity lower 1 m/s in quite large area around side and front of house. Result from NLPQL give two candidates indicate that M3-C5 occupy uniformly air velocity. Only side part of air inlet number 5,6, and 7 are dead zone of air flow where medium area side that occupy air velocity not over 1 m/s and including also the front part.

3.1 Comparison of searching performance

Result of modelling all six candidates to calculate objective value to select the most optimal sample. The result indicates M1-C1 derive from ADE produce the lowest of average THVI whereas standard deviation of THVI in the third order. To calculate by objective function the result shows that M1-C1 present 6.35 as the lowest objective value in table 4. Therefore, being chosen as the best candidate to the next step.

Table 4 The objective value from each candidate by three searching methods

Candidate	THVI-Avg	THVI-SD	Objective Value	Suitability
M1-C1	28.38	0.84	6.35	1
M2-C2	29.33	0.66	6.39	2
M2-C3	29.28	0.88	6.56	4
M2-C4	29.45	0.93	6.63	5
M3-C5	29.20	0.74	6.43	3
M3-C6	29.28	0.99	6.65	6

3.2 Air inlet design and Installation

This study is to design the air inlet as open square window size 0.5 x 1.0 meter and 0.5 x 0.5 meter likeness as the commercial size. Moreover, considering the convenience when installation and it not too heavy object that the operators are able to carry and install by themselves without hauling machine (as figure 3). The internal mechanism could be adjusted the direction of air flow through in the house. Including enable to adjust width of air inlet to controlling air velocity in case of require to adjust air speed depend on number of fan.

Figure 3 Installation of air inlet equipment and feature

Installation length from length selection that present the lowest objective value as 10.0, 41.0, 54.5, 66.0, 70.7, 75.0 and 89.5 meter respectively. These lengths would be measured from the front house and install on both of side wall. To collect air velocity on both sides at 2 meter-length from wall and at 6 meter-length from wall. To collect data every 10 meter- length from front house along the rear of house. Then compare data to case of not install the air inlet, the result show that average of air velocity raise up to 2.8 m/s in the house that install air inlet. Whereas, the comparison with without air inlet average air speed as 2.2 m/s even more air change rate is greater from 34 ACH to 53 ACH. To collect data when turn on all of fans to make maximum ventilation. When turn on all eight exhaust fans, fans efficiency raise up to 94.77% when install air inlet and comparing with the former condition with no air inlet, the efficiency such 61.22% as illustrated in table 5.

Table 5 Comparison performance of air inlet installation

Comparison	With air inlet	Without air inlet
Average air speed (m/s)	2.80	2.20
Air flow (m^3/s)	74	58
Total air flow (CFM)	166,796	107,740
Air change (ACH)	53	34
Fan efficiency (%)	94.77	61.22

In house temperature when install air inlet give average temperature as 25.73 °C that lower than house without air inlet give average temperature 26.05 °C. The steadiness of temperature at front and rear of house, the air inlet provides more constancy temperature. The different of temperature in house with air inlet is only 0.8 °C that lower than house without air inlet give the different up to 3.4 °C as illustrated in figure 4.

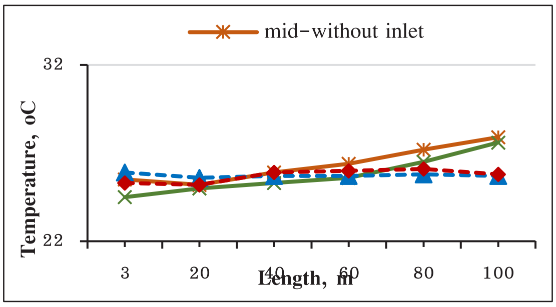

Figure 4 Temperature contour along poultry house

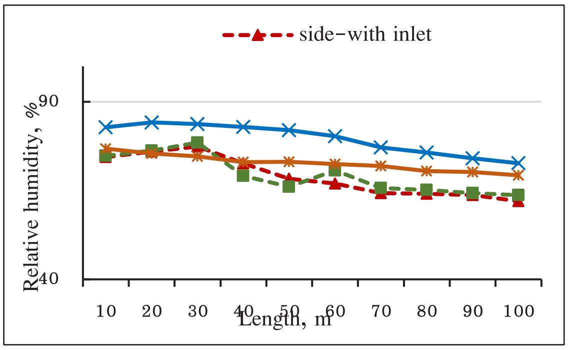

Figure 5 Relative humidity contour along poultry house

From the figure 5, the drainage of moisture accumulated in the house improved. When considering the graph, it is evident that if the device has air inlet installation, the graph will have more slope when the front of the house has similar humidity. To consider air inlet at the rear of house has lower relative humidity because of air from side part transfer rapidly humidity that not expect assist by air flow from the front. The average of relative humidity is 69.2% in case of with air inlet that lower than condition without air inlet as 76.4%. This is to explain the efficiency of air ventilation in poultry house when install air inlet is better than without air inlet.

4. Conclusion

Overall, to apply optimization technique searching the most optimal objective value to determine the air inlet installed position to shorten time of experiment. Due to the former method take the calculation and designing the uniform installation in the same length. However, to apply optimization technique searching the most optimal value would receive the opportunity to find more optimal installation position. The three optimization method are Adaptive differential evolution, Generalized Reduced Gradient (GRG) Nonlinear and Nonlinear Programming by Quadratic Lagrangian (NLPQL). The most optimal installation position derives from the first method that installation length of air inlet 1-7 as following order 10 meters, 41 meters, 54.5 meters, 66 meters, 70.7 meters, 75.0 meters, and 89.5 meters respectively. These installation length provides the average of THVI as 28.38 °C and standard deviation of THVI as 0.84 result to minimum objective value as 6.35. The result of air inlet installation show that average of air velocity raise up to 2.8 m/s in the house that install air inlet. Whereas, the comparison with without air inlet average air velocity as 2.2 m/s even more air ventilation rate is greater from 34 ACH to 53 ACH. To collect data when turn on all of fans to maximum ventilation. The result shows that fans efficiency raise up to 94.77% when install air inlet and comparing with the house without air inlet the efficiency such 61.22%.

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