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CFD ANALYSIS AND COMPARISON OF FORCED-VENTILATION SYSTEMS OF POULTRY HOUSES IN KOREA

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ABSTRACT In Korea, the demand for broiler consumption continues to increase while the agricultural population in animal and livestock production continues to decrease. This scenario prompts poultry producers to venture on large scale production systems. To ensure maximum production, the thermal suitability as well as the air uniformity inside the broiler house must be maintained. However, in large scale production facilities, the environmental conditions such as temperature and air quality are very difficult to control. The four distinguishable seasons of the country make it more complex. The internal environmental condition is greatly influenced by the design of the ventilation system which is very critical. Investigating the internal conditions affected by the ventilation design through field experiment is the ideal method, however restricted because of limited measuring points. Therefore, computational fluid dynamics (CFD) which is a powerful tool to study fluid movements was used in this study. The FLUENT program was employed using the three-dimensional large eddy simulation (LES) model for six broiler structures with a forced-ventilation system design. Data measured during the cold season and other environmental conditions in Korea was used in the simulation. The tracer gas decay method was used to investigate the CO_2 distribution as well as validate the model. The suitability, uniformity and stability of temperature and air quality were analyzed at the breeding section at a height of approximately 0.4 m.

Keywords: Computational fluid dynamics (CFD), Forced ventilation, Large eddy simulation (LES), Poultry houses

INTRODUCTION The product of chicken in Korea in the fourth quarter of 2009 was approximately 140milion and almost half of it is broilers of approximately 67milion. The demands for broiler consumption continuous to increase while the agricultural population in animal and livestock production also continuous to decrease. To meet the demand, large scale farm are now being operated. Statistics have shown that for the span of 5 years, the number of farms with a capacity of 30,000 or more was doubled (KOSIS, 2010).

In general, the uniformity of weight of the broilers is better, because it has more market value. A uniform and optimized environment condition therefore is needed to maintain for equal growth of broilers, and probably require lesser amount of feed for their ideal growth. In addition, growing the broilers in a shorter period means high turnover ratio more profitable. However, the extension of broiler farms led to difficulties in controlling the breeding environments. These difficulties got the livestock into troubles of imbalance growth and increase in mortality rate, thus the optimum ventilation system for enlarged farms are needed to be developed (Lee et al., 2003).

Broiler houses in Korea with 6 type of forced ventilation were realized in a 3-dimensional structure model and CFD techniques were applied in the study. The simulation model used the ventilation method commonly practiced in Korea for broiler houses during the winter season. The studied cases were analyzed focusing on the airflow, air temperature and air exchange rate (AER) at the rearing zone. The thermal suitability and uniformity and AER at rearing zone were thoroughly investigated.

MATERIALS AND METHODS

CFD program

CFD is modelling tool designed to simulate things that flow. Movement of fluid is simulated in a meshed geometry usually known as the simulation domain. The CFD technique numerically solves the Navier-Stokes equations within each cell of the computational domain. The Reynolds-averaged process considers the instantaneous fluid velocity to be the sum of a mean and a fluctuating component of turbulence. CFD simulation can analyse any diverse structure with lower cost compared to field experiment. More so, the environmental conditions like temperature, humidity, etc can be easily controlled. Eqs. (1) ~ (3) are mass, momentum and energy conservation equations used in the CFD simulation (Fluent, 2008).

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla P + \nabla \cdot (\bar{\tau}) + \rho \vec{g} + \vec{F} \tag{2}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + P)) = \nabla \cdot (k_{eff} \nabla T - \sum{}_j h_j j_j + (\bar{\tau}_{eff} \vec{V})) + S_h \tag{3}$$

Where, ρ is density(kg m^{-3}), $\vec{v}$ is velocity(m s^{-1}), P is constant pressure(Pa), $\bar{\tau}$ is stress tensor(Pa), $\vec{g}$ is gravitational acceleration(m s^{-2}), $\vec{F}$ is external force vector(N m^{-3}), S_m is mass source(kg m^{-3}), K_{eff} is heat transmission coefficient, j_j is component of diffusion flux(kg m^{-2} s^{-1}), and S_h is total entropy(J K^{-1}).

There are many turbulence models to represent flow. Most of turbulence make many eddies and these eddies` size and movement are property of turbulence. Large eddy affect geographical feature and boundary conditions. Small eddy has isotropy and conservativeness in the system. Large Eddy Simulation (LES) model make artificial large eddy and compute the model by the eddy, so meshed geometry is less dense than Reynolds-averaged Navier-Stocks equations (RANS) (Fluent, 2008).

Trace gas decay method

The conventional method to calculate air exchange rate (AER) is to divide volume of the computational domain by inlet flow (Eq. (4)). However, it does not consider the mixing efficiency of gasses. In the broiler house, the very important area to be considered is the floor where the broilers are raised, but the conventional method just calculates all volume of poultry house.

$$AER = \frac{\sum v_o A_0}{V} \times 60 \tag{4}$$

where, AER is air exchange rate (min^{-1}), v_0 is velocity at inlet or outlet ($m\ s^{-1}$), A_0 is Area of inlet or outlet (m^2), V is the Volume of structure (m^3).

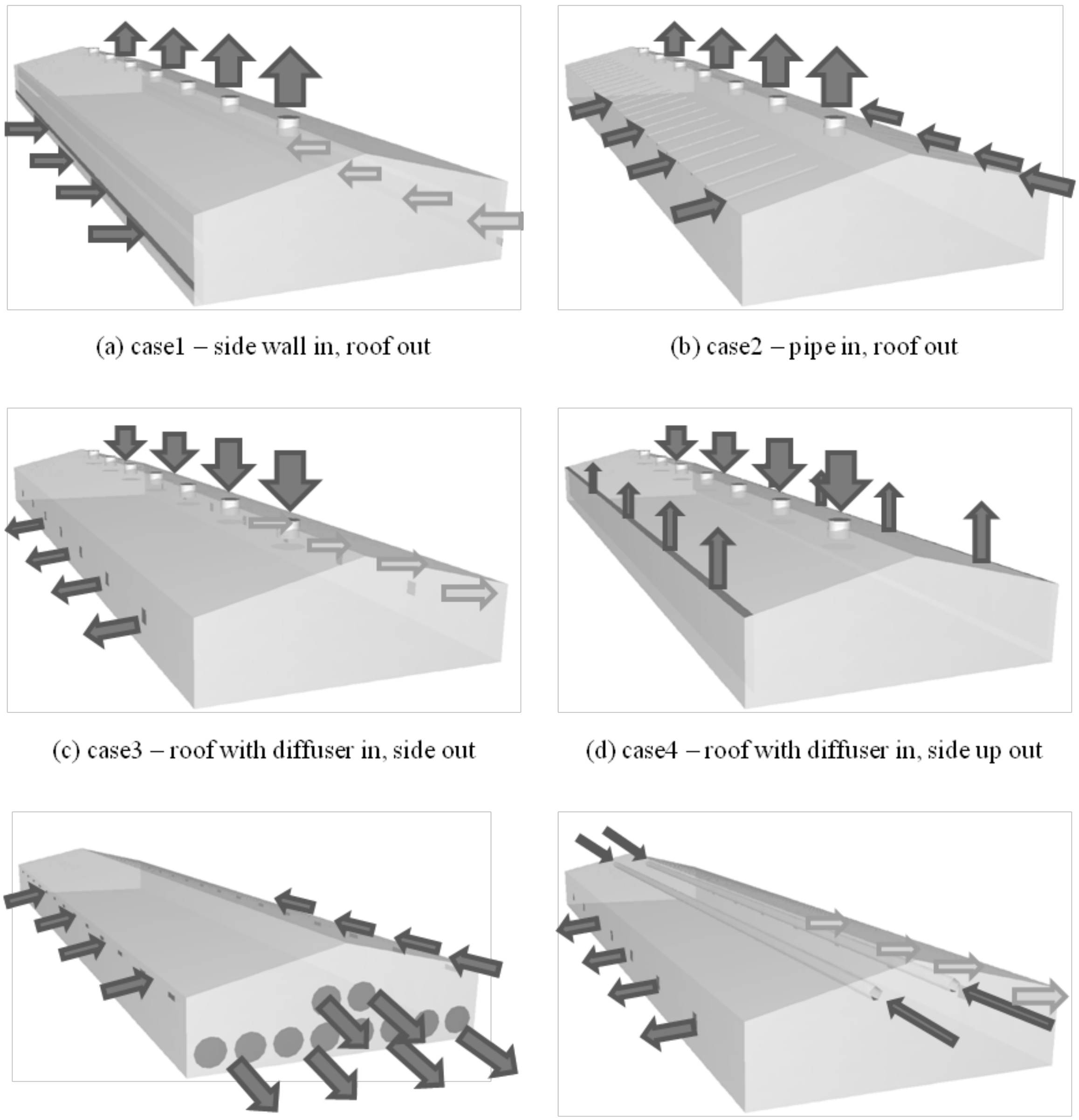
To complement these limitations and effectively find the AER at rearing zone, tracer gas decay (TGD) method was used in this study. TGD method detects the distributions of concentration of moving gases injected in the initial condition at different observation points. The formula for computing the AER by TGD method is presented in Eq. (5).

$$AER_{TGD} = \frac{\ln(C_0 / C_t)}{t - t_0} \tag{5}$$

Where, C is gas concentration at time t ($g\ m^{-3}$).

Size of broiler house

The studied broiler houses which can accommodate up to about 10,000 broilers are 50m long, 12m wide and 4.8m high. Other facilities and livestock inside the broiler house were not considered for convenience of modelling and simplification of computational calculation. Case 1 and 4 have twofold winch curtain beside both long side wall. Case 3 and 4 have diffuser under inlet on roof. Case 2 have inlet pipe on roof and case 6 have duct inlet. Case 5 is typical tunnel type broiler house. Each ventilation type was shown in Figure 1 (a) ~ (f) and arrows are inlet and outlet airflow direction in the broiler houses.



(a) case1 – side wall in, roof out

(b) case2 – pipe in, roof out

(c) case3 – roof with diffuser in, side out

(d) case4 – roof with diffuser in, side up out

(e) case5 – side vent in, fan out

(f) case6 – duct in, side fan out

Figure 1. Ventilation types of the broiler houses.

Experimental procedure

To make the 3-dimensional model, GAMBIT (ver. 2.4, Fluent Inc. Lebanon, N.H., USA) was used. Figure 2 shows the design geometry and mesh of case 1. Table 1 shows the design parameters, the initial and boundary conditions.

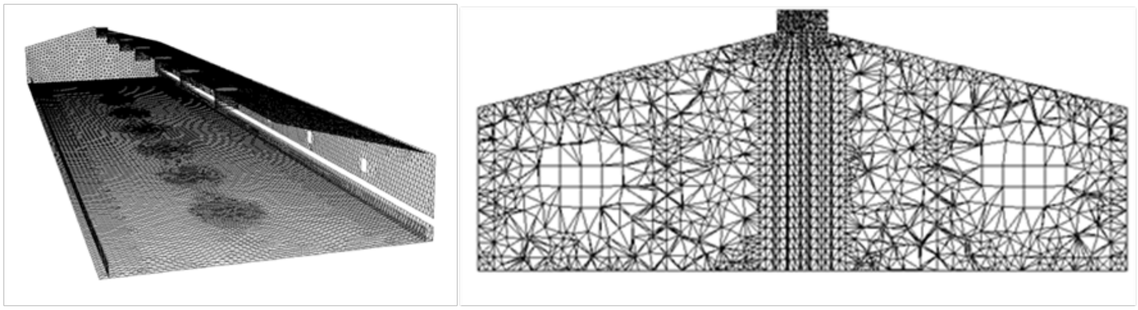


Figure 2. Constructed geometry and mesh design of case 1 using GAMBIT

Table 1. Values of the design factors, the initial and boundary conditions.

Contents	Value
Number of mesh	533.146~802,622
Type of mesh	Tetrahedron
Turbulence model	Large Eddy simulation
Internal air temperature	20°C
External air temperature	-1°C
Heat flux	$195Wm^{-2}$
Concentration of CO_2	90ppm
Ventilation rate	$0.1min^{-1}$
Ventilation time	20 seconds

TGD method was used to analyse the stability and uniformity of ventilation. Locations of detecting points are shown in Figure 3 and each location has 5 detecting point from 0.1m to 0.5 m height. The measured concentration of CO_2 was substituted in Equation 5 to calculate ventilation rate.

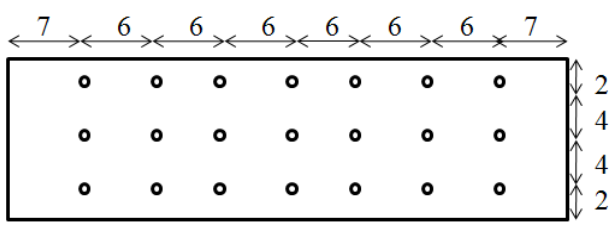


Figure 3. Detecting points using TGD method (unit : m)

The method of ventilation was conducted by the negative-pressure in forced-ventilation system. The AER and ventilation time used in the study are 0.1 times per minute and 20 seconds, respectively, following the process of ventilation during the winter season. Also, initial internal temperature is 20°C which is optimal temperature for broiler and external temperature is -1°C. The study considers the presence of broilers at the floor level. In Korea, the density in broiler house is recommended to have 22 broilers per $1m^2$ (MIFAFF, 2009) considering a clean internal environment and efficient prevention from diseases.

However, to generate more income, most of the farm have a density from 40~50 broilers per $1m^2$. In the simulation, the boundary condition of floor was set as heat source to consider the heat production from the broilers. Equation (6) is the heat production equation (CIGR, 2002) and 0.4m height plane is assumed as rearing zone to analyze the stability and uniformity of temperature.

$$\Phi_{tot} = 10.62 m^{0.75} \quad (6)$$

Where, Φ_{tot} is total animal heat dissipation in animal houses (W), m is body mass of the animal (kg).

RESULT AND DISCUSSION

Analysis of airflow field

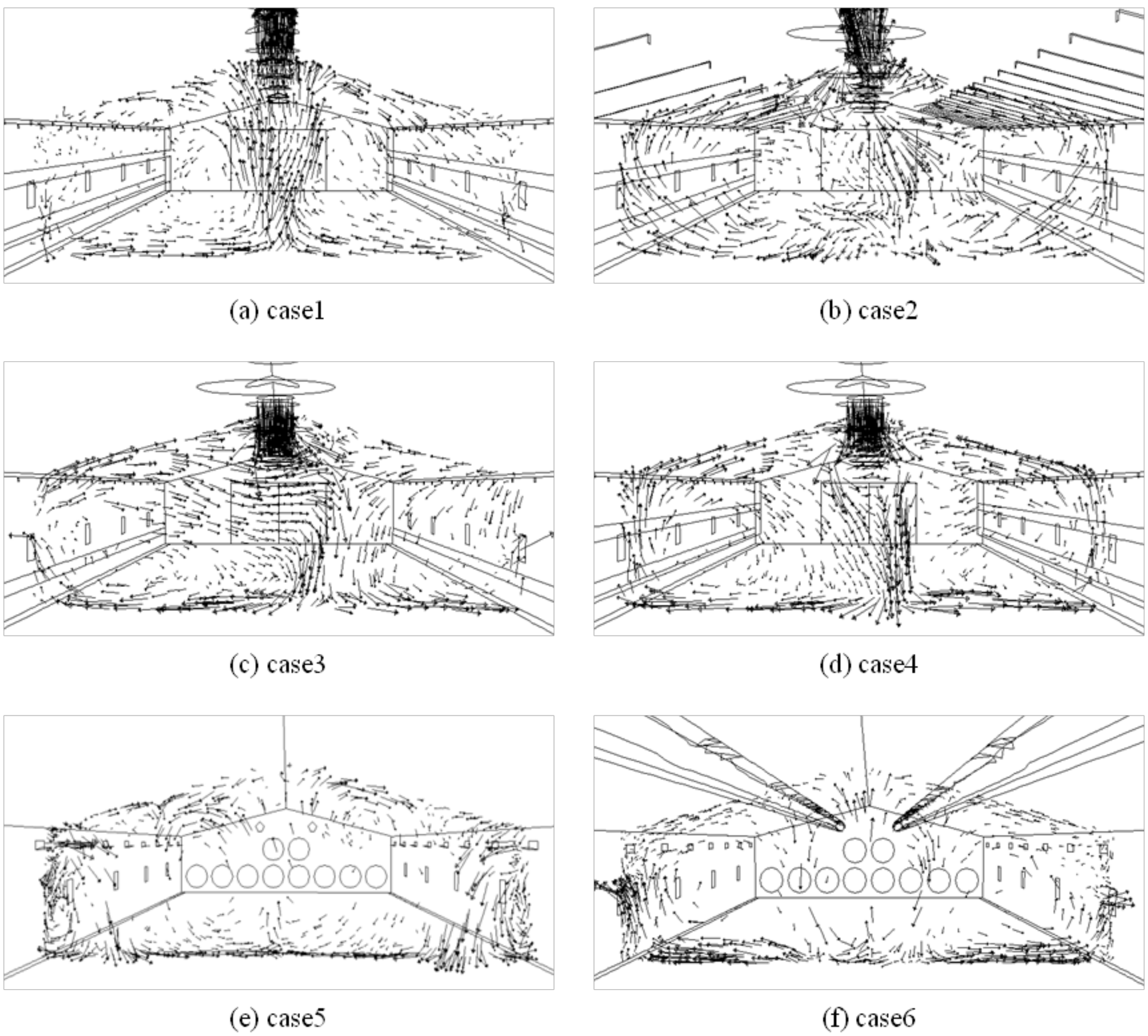


Figure 4. Air velocity vectors in the broiler houses.

Figure 4 show air velocity vectors in the broiler house using CFD simulation. During the winter season, the most important thing to consider in the ventilation is prevent the broilers from the very cold external air. In the case 1, external air from side inlet was directly injected to rearing zone. Besides, in case 2, cold air from pipe inlet was mixed with warm internal air and took more time for leach the rearing zone. A diffuser is present in cases 3 and 4, but it could not disperse the air but only increase more the velocity inflow at floor. Case 6 have also shown to have faster flow at rearing zone which is harmful to the broiler. Case 5 have shown to have few inside flows and also only few fast flows occur at the rearing zone.

Analysis of temperature distribution at rearing zone

Temperature distribution at the rearing zone from the CFD simulation is presented in Figure 5. The cold air directly coming from side of wall to the rearing zone made the suitability and uniformity of the temperature very poor. In cases 3 and 4, the cold air dropped from inlet at the roof, and cause lower temperature in the middle of the rearing zone. Similarly, lower temperature zone were found following the inlet vents in case 5.

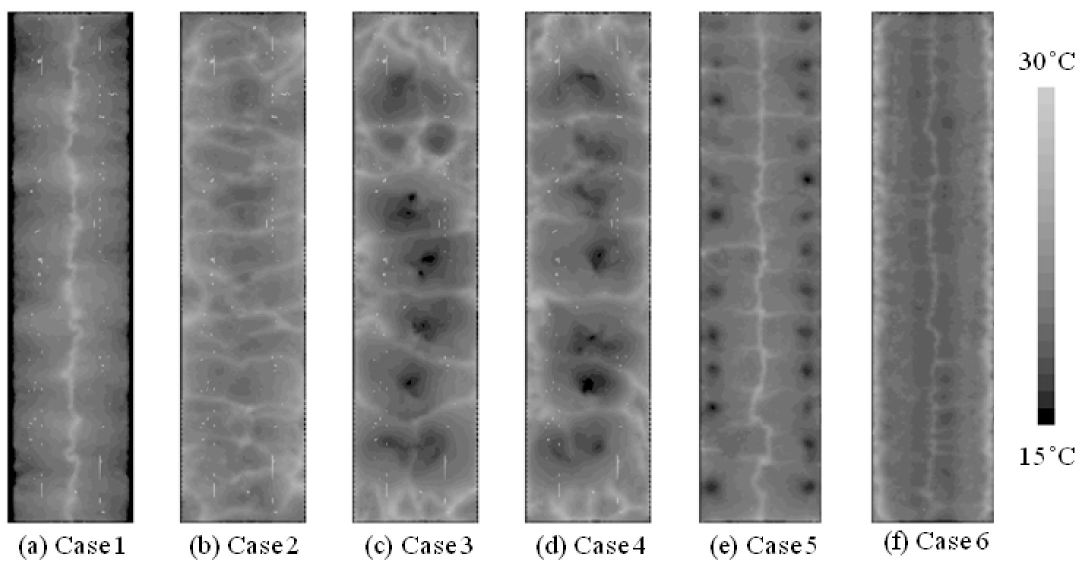


Figure 5. Contour of air temperature at 0.4m height from floor surface.

For the quantitative analysis, the average temperature and standard deviation at the rearing zone were investigated. Initial temperature in broiler house was 20°C and Table 2 show average temperature at 0.4m height of the broiler house after the ventilation. Case 1 have lowest average temperature even the though the outside of curtain was not considered and the difference is only 1.2°C. To evaluate ventilation efficiency, suitability and uniformity were compared. Optimal temperature for the broilers is 20°C and case 3 shows to be the same at 20.1°C. But most of broiler zone needs to have the optimal temperature. Standard deviation of Case 3 is 2.08 and it is rank third comparing all the cases. High standard deviation means uniformity of temperature is not good in the rearing zone.

Table 2. Average and standard deviation of temperature at 0.4m height from floor

Case	Average Temperature(°C)	Standard deviation
1	18.8	1.76
2	20.7	1.56
3	20.1	2.08
4	20.3	2.17
5	19.7	1.21
6	19.8	2.16

Analysis of ventilation efficiency at rearing zone

Analysis results of ventilation rate of each case are shown in Table 2. The results show that the ventilation efficiencies at rearing zone in all cases were different while the ventilation rate of the whole broiler house was controlled identically at 0.1 times per minute. This is influenced by the location and size of inlet, outlet or the installing of other facilities likes diffuser or the curtain. The ventilation rate at rearing zone for case 1 was shown to be very high, while the conventional type of ventilation system is only 0.129 min^{-1}. Case 2 had the lowest value as 0.073 min^{-1}.

Table 3. Ventilation rate and standard deviation at the rearing zone.

Case	Ventilation Rate(min^{-1})	Standard deviation
1	0.129	0.01023
2	0.073	0.00405
3	0.099	0.02304
4	0.096	0.01757
5	0.101	0.01570
6	0.108	0.01311

CONCLUSION

Typical broiler houses in Korea with 6 types of forced ventilation were studied and analyzed using aerodynamic simulation. Fitness of 3-dimensional aerodynamic model was judged by comparing the airflow stream and the ventilation rates. Then, the livestock suitability and uniformity were defined with analysis of temperature and air exchange rate at rearing zone. TGD was used for analysis of AER to observe suitability of each point in the broiler house. The results showed that the ventilation efficiencies at rearing zone in all cases were different while the ventilation rate of the whole house was controlled identically at 0.1 times per minute. The airflow vectors followed each locations and settings of inlet and outlet of each ventilation systems. It also showed how inflow paths reach the rearing zone. Cold external air for winter weather condition can harm the suitability specially when cold air directly reach rearing zone, so the case laten the incoming of external air with mixing in internal air more was chose as better case. Averages and standard deviations of temperature at rearing zone were measured to determine the suitability and uniformity of temperature. The systems with sufficient AER and lower standard deviations were selected for suitability and uniformity of ventilation. Optimum ventilation systems in this study were found in case 5 that have high suitability and uniformity of both temperature and AER.

Aerodynamic simulation can be used to analyze ventilation systems intended for airflow investigations considering the environmental conditions, the location of inlet and outlet vents and different type structures. Analysis method of this study suggested some interpretation standards of finding the suitability of other types and environmental conditions of broiler houses.

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