IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

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To cite this article: Y X Ma and H F Zou 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **789** 012036

IOP Conf. Series: Materials Science and Engineering **789** (2020) 012036 doi:10.1088/1757-899X/789/1/012036

Optimized design of air inlet devices based on environmental analysis of a broiler house model

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Abstract. A typical broiler house in the cold region of northern China was selected as the research object of this study. The environment of the broiler house was studied in depth by using the Airpak software. Then, an optimized design of air inlet devices for this typical broiler house in the cold region, under the condition of transverse ventilation, was made on basis of two influence factors: the length of the flow guiding device, and the direction of airflow. The optimized air inlet devices helped to improve the airflow in the broiler house, hence changing environmental factors such as internal temperature distribution, wind speed distribution, and carbon dioxide distribution. The length of the ideal flow guiding device should be approximately 1 m and not more than 2 m. Influence by the direction of the air inlet devices was affected by length of the guided airflow. Increase in the direction of the air inlet device led to rise of the body plane temperature of the chickens and the overall wind speed, while carbon dioxide distribution remained basically unchanged. The best direction of airflow (3) should be 30°～45°.

1. Introduction

In the cold regions of northern China, temperature is high in summer, the winter is long and severely cold, while the spring and autumn are short, causing the broiler houses closed design [1-2]. In this study, a typical broiler house in the cold regions of northern China was selected as the research object. The air inlet devices commonly used in broiler houses in northern China were studied and optimized using simulation software.

J A Osorio et al. conducted numerical simulation on a naturally ventilated chicken house in Brazil and obtained the distribution of wind speed inside and outside the chicken house and the distribution of harmful gas concentration.

Brian D. Luck et al. developed a scalable environmental assessment system for wind speed measurements and applied it to a commercial chicken house. Wisate et al. simulated a chicken coop with a size of 120 (length) 14 (width) 2.5 (height) m and equipped with multiple intake air system by CFD technology, analyzed the distribution of ventilation rate, temperature and wind speed of the internal air flow, and compared the results with experimental tests.

The experimental results showed that:

1) equipped with multiple air inlet system, the ventilation rate in the region was increased by 57%;

2) the average wind speed in the house increased by 25%, but the fluctuation value decreased;

3) CFD simulation results are very close to the experimental results, and CFD can completely replace the experimental results within the allowable error range.

In-bok LEE et al. simulated the wind speed field of a naturally ventilated chicken house by using CFD software's RNG model and k-two-path model respectively, and then tested the actual wind speed field of the chicken house. They concluded that the RNG model was the closest to the experimental results, with an error of -6.2%.

Menegali et al. selected broiler chickens as 3-week old and conducted a timed test and analysis on the air quality (carbon dioxide, ammonia and oxygen distribution) of broiler chicken houses under the conditions of minimum ventilation volume in winter, including positive pressure ventilation, natural ventilation and negative pressure ventilation. Research and analysis show that both positive pressure ventilation and negative pressure ventilation provide sufficient oxygen, and ensure that harmful gas, ammonia, carbon monoxide, etc. are within the standard range. However, for these three ventilation forms, the distribution level of ammonia and carbon monoxide in the negative pressure ventilation form is the highest under the minimum ventilation system.

The airflow structure of the broiler house was improved by optimizing the direction and length of airflow in the flow guiding device, thereby improving environmental factors such as temperature distribution, wind speed distribution and carbon dioxide distribution.

Despite numerous differences between the air inlet devices of broiler houses at home and abroad with respect to style, size, installation form and control mode, their functions and principles are basically the same in the following three main aspects:

- providing necessary volume of fresh air for the broiler house which can be controlled and adjusted during different seasons [3-4];
- implementing varying forms of ventilation in the broiler house during different seasons, such as transverse ventilation in winter [4-5]; and
- following the basic principle of submerged jet (referred to as jet) in airflow structure of air inlet device. The difference, however, is that most closed-style broiler houses abroad adopt wall-attached jet, while domestic broiler houses exclusively rely on jet from air inlet devices [6-7].

2. Jet and airflow structure of transverse ventilation

2.1. Jet

Jet refers to the flow of air formed by the injection through a nozzle, orifice, or slit [8]. Figure 1 is a turbulent jet structure diagram.

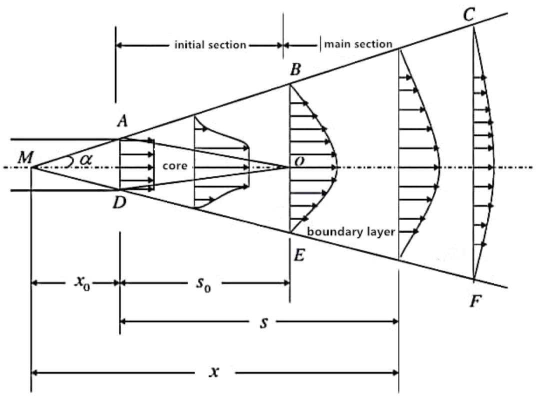

Figure 1. Jet structure diagram.

The following formula [9] can be obtained from the jet theory:

$$\frac{R}{r_0} = \frac{x_0 + s}{x_0} = 3.4a\bar{x} \tag{1}$$

Where: R - jet radius; r_0 –section radius; α - jet diffusion angle; x_0–jet range from the nozzle section; s- turbulence coefficient, taking 0.076 ~ 0.08; $\bar{x}$ - dimensionless distance from the pole, whose expression is as follows:

$$\bar{x} = \frac{x_0 + s}{r_0} \tag{2}$$

Through the jet theory, the range of the air inlet device in the broiler house can be theoretically calculated. Then, a theoretical quantitative basis is provided for the optimization scheme of the air inlet device through theoretical analysis.

2.2. Airflow structure of transverse ventilation

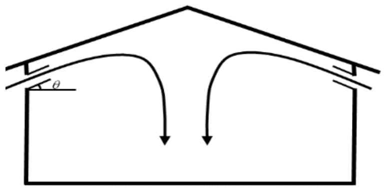

Figure 2. Schematic diagram of airflow in X cross section of transverse ventilation.

The low-temperature fresh air outside enters the broiler house through the air inlet device, and continues to rise while flowing transversely under influence of the jet. Then, after reaching the highest point, the air sinks and reaches the body plane of the chickens.

An abroad broiler house adopts a rectangular vent, which is located close to the ceiling. Therefore, the fresh air enters through the air inlet and forms a wall-attached jet, before sinking at the middle of the ceiling. Meanwhile, due to consideration of costs of the air inlet device, a domestic broiler house in cold region adopts the method of small vent with high wind speed, so that, in the absence of wall-attached jet, the airflow can reach the middle of the house before sinking [10, 11].

The house air inlet device is shown below:

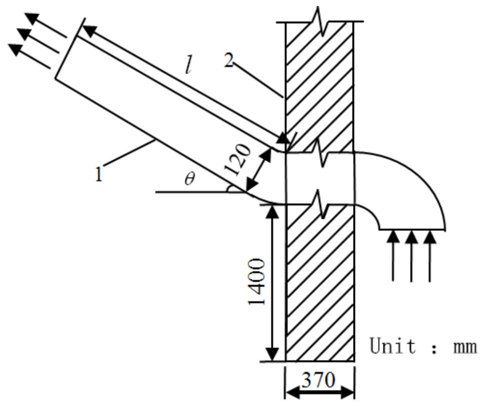

Figure 3. Air inlet device diagram of the broiler house.

Where l is the length of the flow guiding device, and θ is the angle between the flow guiding device and the transverse plane, i.e. direction of the airflow.

Regardless of interaction between multiple air inlet devices (including issues regarding installation spacing, single- or double-sided installation, etc.), as to the air inlet device itself, the length of the flow guiding device and the direction of the airflow are two major factors that influence the environment inside the broiler house. These factors may cause the incoming air to travel a longer distance before reaching the body plane of the chickens, or accelerate the airflow inside the broiler house, thereby increasing the heat exchange between the low-temperature fresh air and the internal air and saving energy while avoiding direct blow of cold air at the chickens. Altering the conditions of the air inlet device can influence the temperature, whilst changing the wind speed simultaneously. Therefore, the pros and cons should be considered when adopting transverse ventilation in winter [12, 13]. This study, through studying of the air inlet device, intends to find a reasonable length of the device and the direction of the airflow, which provides a theoretical basis for the standardization of the air inlet device.

3. Research on air inlet guiding device

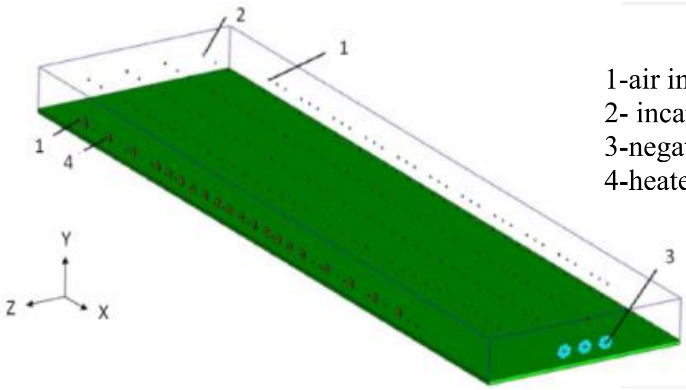

Figure 4. Model of the broiler house.

The theoretical model of the broiler house in this study substantially adopted relevant data and conditions of the tested broiler house. In order to simplify the model, certain parameters were approximately replaced in this study, on condition that such replacement had basically no influence on results of the simulation. A total of 11,307 broilers were farmed inside the broiler house, which was a closed space whose size was 112 m (X) x 13 m (Z) x 2.95 m (Y). The broiler house model is as shown in figure 4.

3.1. Study on the guide length of the inlet device

During winter, under the condition of transverse ventilation, flow guiding devices are commonly installed on basis of the air inlets in order to promote airflow. Thereby, the temperature distribution, wind speed and carbon dioxide distribution in the broiler house tend to become more homogeneous as a whole [14].

For the broiler house with a span length of 13 m, the height of the air inlet device is 1.4 m, and the guide direction is 30°C. Under these conditions, the guide lengths were set at 0 m, 1 m, and 2 m respectively. The effect of the length of the guiding device on the temperature field, wind speed and carbon dioxide distribution of the chicken body plane was studied.

3.1.1. Simulated analysis of temperature distribution in the broiler house with different guide lengths. As shown in table 1, the temperature distribution trends under different guide lengths are basically the same. At the initial section (X = 0 m to X = 20 m), the temperature was relatively low due to effect by the intrusion and infiltration of cold air. At the middle section (X = 20 m to X = 95 m), the temperature in the area close to the heater was relatively high, while the temperature in the area away from the heater was relatively low, due to effect by the air inlet device and the location of the heater. At the end section (X = 95 m to X = 112 m), the temperature was relatively homogeneous, which was close to the average temperature of the chicken body plane, due to the mixed airflow. When in the absence of flow guiding device, i.e. l = 0 m, the average temperature of the chicken body plane was 23.7°C. When l = 1 m, the average temperature of the chicken body plane was 25.1°C. When l = 2 m, the average temperature of the chicken body plane was 25°C. When in the absence of flow guiding device, the cold airflow entering the broiler house directly mixed with the internal air and sank to the chicken body plane. Because the flow guiding device increased the distance from the cold airflow to the plane of the chicken body while

IOP Conf. Series: Materials Science and Engineering **789** (2020) 012036 doi:10.1088/1757-899X/789/1/012036

reducing the pressure on the airflow by the heater, the heat exchange process was strengthened. If the airflow guiding device was excessively long, though the convective heat transfer process allowing the airflow to enter the house would be strengthened, the mixing process of cold and hot airflows, which was a more direct heat transfer process, would be shortened.

Table 1. Temperature distribution statistics (°C) of the broiler house with different guide length (*l*) (Section Y = 0.25 m).

X	*l*	Z = 0 m	3 m	5 m	7 m	9 m	11 m	13 m
Initial segment 0~20 m	0 m	22	21	23	23	24	25	26
	1 m	23	23	24	27	26	26	26
	2 m	23	21	24	27	26	25	26
Middle section 20~95 m	0 m	22	22	23	25	26	28	31
	1 m	27	23	25	28	29	28	25
	2 m	27	23	25	28	29	28	25
End section 95~112 m	0 m	23	22	24	24	24	26	27
	1 m	27	23	26	27	27	27	26
	2 m	27	23	27	28	28	28	27

As can be seen by comparing the data in the table, in terms of temperature, the effect of a flow guiding device was superior to that without a flow guiding device. An appropriate guide length ensured the temperature inside the boiler house while maintaining the homogeneity of temperature of the chicken body plane. If the guide length was too short, temperature of the chicken body plane would be too low. If the guide length was too long, though the average temperature of the chicken body plane would be basically unchanged, temperature in certain low-temperature areas would become even lower, while temperature in certain high-temperature areas would become even higher, thus increasing the construction costs.

According to the requirements of temperature control in the broiler house during winter, and due to the above analysis, in terms of temperature, the optimal length of flow guiding device for a typical broiler house in cold regions should be approximately 1 m.

3.1.2. Simulated analysis of wind speed distribution in the broiler house with different guide lengths.

Table 2. Statistical table of wind speed distribution (*m/s*) of the broiler house with different guide lengths (*l*) (section Y = 0.25 m).

X	*l*	Z = 0 m	Z = 3 m	5 m	7 m	9 m	11 m	13 m
Initial segment 0~20 m	0 m	0.05	0.25	0.1	0.15	0.15	0.25	0.45
	1 m	0.1	0.3	0.15	0.2	0.25	0.35	0.5
	2 m	0.1	0.3	0.15	0.2	0.3	0.4	0.5
Middle section 20~95 m	0 m	0.05	0.25	0.15	0.2	0.25	0.3	0.45
	1 m	0.1	0.35	0.25	0.3	0.3	0.4	0.5
	2 m	0.1	0.3	0.2	0.3	0.4	0.5	0.6
End section 95~11 2m	0 m	0.2	0.25	0.25	0.25	0.25	0.3	0.45
	1 m	0.15	0.3	0.3	0.35	0.35	0.4	0.5
	2m	0.15	0.35	0.35	0.35	0.4	0.45	0.5

As shown in table 2, with increase in the length of the flow guiding device, the wind speed in the broiler house was enhanced. Ventilation conditions in winter required that the wind speed to be less than 0.3 m/s, which was different from the requirement in summer.

When the lengths of the flow guiding device were between 0 m and 1 m, respectively, the wind speed of the chicken body plane basically met this requirement. However, when the length was 2 m, as could be known from the simulation process, the wind speed in the area of the broiler house from when X = 65 m to X = 112 m exceeded the requirement standard, and the areas of original wind speed exceeding the standard increased when closer to the heater. When l = 0~1 m, the wind speed requirements of the broiler house was met. Therefore, when equipping a typical broiler house with a flow guiding device, its length should be less than 2 m.

3.1.3. Simulated analysis of carbon dioxide distribution in the broiler house with different guide lengths.

Table 3. Level of carbon dioxide of chicken body in the broiler house with different guide lengths (*l*) (section Y = 0.257 m).

Guide Length	l = 0 m	l = 1 m	l = 2 m
Carbon dioxide average (mg/m3)	5008	4910	4910
Carbon dioxide maximum (mg/m3)	7145	6750	6866
Carbon dioxide minimum (mg/m3)	3301	3539	3673

As shown in table 3, when in the absence of flow guiding device, the mean carbon dioxide of the chicken body plane was 5008 mg/ m^3, with a maximum value of 7145 mg/m^3. When a flow guiding device had been installed, the mean carbon dioxide value of the chicken body plane was 4910 mg/ m^3, and the requisite fresh air in the broiler house came from the air inlet devices.

In terms of ventilation, the addition of flow guiding device, in essence, altered the location of the air inlet. Hence, influence by the span length of the broiler house was reduced, and the location of the air inlet was heightened, thereby improving the airflow and the heat exchange in the airflow. As can be seen from table 5, the addition of the flow guiding device helped improve the homogeneity of carbon dioxide distribution on the chicken body plane.

However, it did not reduce the overall carbon dioxide value of the chicken body plane. In this study, the reasonable length of the flow guiding device is about 1 *m*.

3.2. Study on the direction of airflow

The direction of airflow is another important parameter of the flow guiding device. Essentially, on the one hand, it influences the height of the air inlet jointly with the flow guiding device; on the other hand, it alters the path of the incoming cold airflow after it passes through the air inlet [15].

For small vents, the effect of the direction of airflow is affected by the guide length of the airflow guiding device. The longer the guide length, the more prominent the effect of the direction of airflow. For instance, when the guide length equals 0, the direction of airflow virtually no effect on the temperature field, wind speed and carbon dioxide distribution of the chicken body, so long as the value of direction is $0° \leq \theta \leq 90°$.

While considering the height limit of a typical broiler house, in order to better study the influence of the direction of airflow on the temperature field, wind speed and carbon dioxide distribution of the chicken body, this study performed simulation processes based on three direction values, i.e. θ = 30°, 45°, 60° respectively, on condition that l = 1 *m.* The simulation process was consistent with the above studies on the height of the inlet and the guide length.

The simulation data and results were as follows:

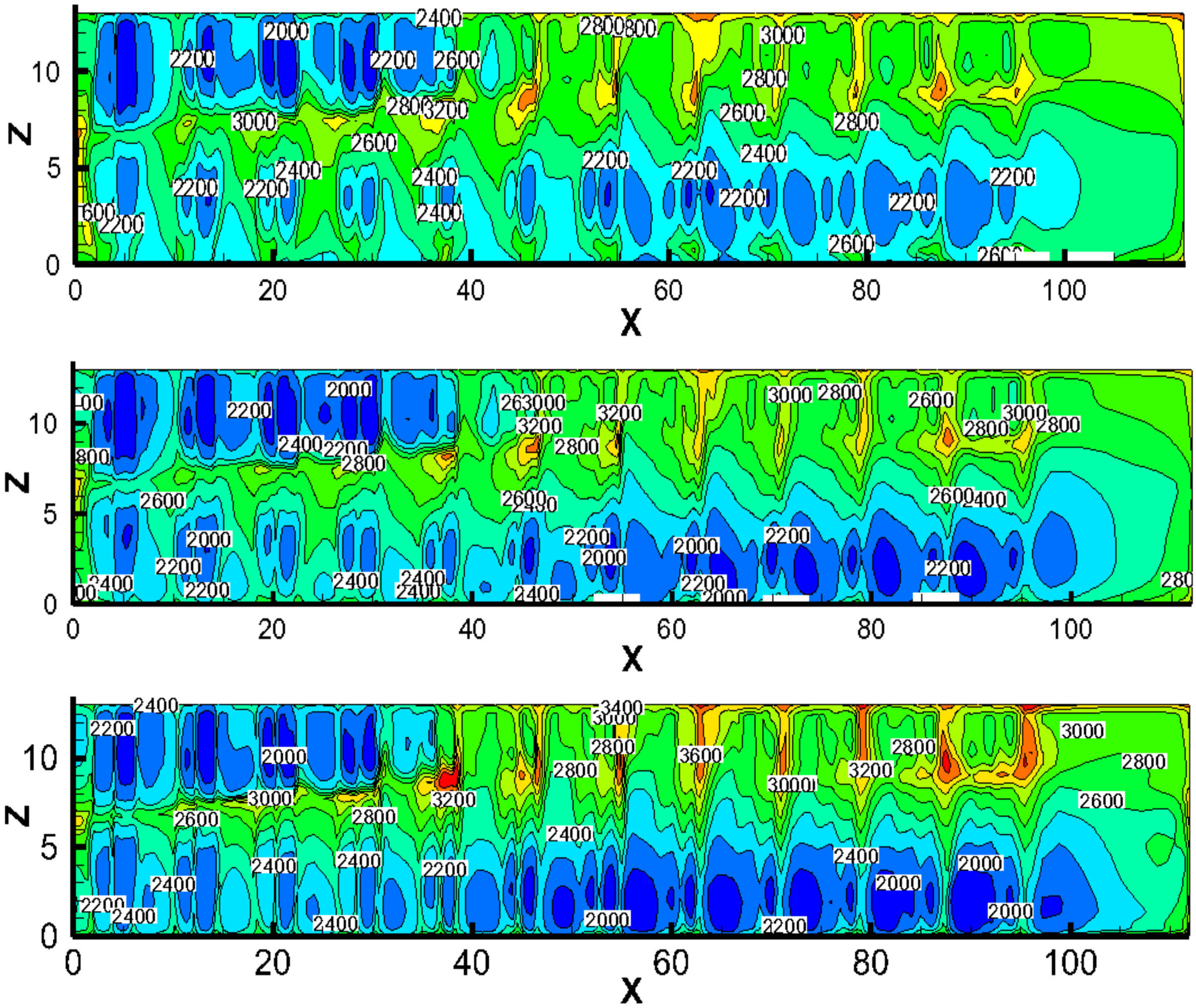

Figure 5. Carbon dioxide distribution map of Y = 0.25 section.

Table 4. Temperature distribution statistics table (°C) of the broiler house with different direction of airflow (section Y = 0.25 m).

θ (°)		Z = 0 m	3 m	5 m	7 m	9 m	11 m	13 m
Initial section 0~20 m	30	23	24	25	26	27	26	24
	45	23	24	25	27	27	26	24
	60	23	24	26	28.5	28.5	27	24
Middle section 20~95 m	30	26	24	26	28	28	27	25
	45	24	25	26.5	28	28	27	25
	60	25	26	27.5	28	28	28	27
End 95~112 m	30	26	25	26	27	27	26.5	26
	45	25	25	26	27	27	26.5	26
	60	28	26.5	27	28	28	28	27

Table 5. Wind speed distribution statistics table (m/s) for the broiler house with different direction of airflow (Y = 0.25 m).

θ (°)		Z = 0 m	3 m	5 m	7 m	9 m	11 m	13 m
Initial segment 0~20 m	30	0.15	0.25	0.15	0.2	0.25	0.35	0.4
	45	0.15	0.2	0.15	0.2	0.25	0.4	0.5
	60	0.2	0.35	0.2	0.2	0.25	0.4	0.5
Middle section 20~95 m	30	0.2	0.2	0.2	0.3	0.3	0.4	0.5
	45	0.25	0.25	0.25	0.3	0.3	0.4	0.5
	60	0.2	0.35	0.3	0.3	0.35	0.4	0.6
End 95~112 m	30	0.15	0.25	0.3	0.35	0.35	0.35	0.4
	45	0.15	0.25	0.3	0.35	0.35	0.35	0.4
	60	0.2	0.35	0.35	0.35	0.4	0.4	0.4

The simulation results showed that:

- increase of the direction of airflow within a certain range (30° to 45°) did not result in significant change in the temperature of the chicken body plane, and the temperature basically reached the standard. However, increase in the direction of airflow exceeding 45° would cause the temperature of the chicken body plane to rise with the increase of the direction of airflow, and the temperature of most areas of the broiler house exceeded the standard. By respectively studying the temperature of the chicken body plane in three direction values of 30°, 45° and 60°, the optimal direction of airflow in this study should be between 30° and 45° in terms of temperature.
- When the direction of airflow (θ) equaled 30° and 45° respectively, the wind speed of the chicken body plane basically met the requirements; high wind speed mainly concentrated on the side of the heater and the fan towards the end; while when θ equaled 60°, the wind speed in certain areas of the chicken body plane in the broiler house exceeded the standard and failed to meet the ventilation requirements, which was undesirable.
- As the direction of airflow increased, the carbon dioxide distribution remained basically unchanged. The distribution in certain low carbon dioxide regions was lower, and that of certain high carbon dioxide regions was higher. According to the relevant standards of ventilation, when the angle was 30°~45°, the carbon dioxide values basically met the requirements; when the direction of airflow was 60°, the carbon dioxide value of certain regions exceeded the standard. Therefore, according to carbon dioxide distribution, the optimal angle should be 30° ~ 45°.

4. Conclusion

In this study, Airpak software was used to study the influence of the air inlet device on the environment of a typical broiler house in cold region under the condition of transverse ventilation, including the guide length and the direction of airflow. Conclusions are as follows:

- increase in the guide length of the air inlet device helped to enhance the mean temperature of the chicken body plane and the airflow in the broiler house, thereby making the carbon dioxide of the chicken body plane more homogeneous. When the length of the flow guiding device was 0~1 m, the effect of the flow guiding device was particularly obvious; when the length of the guiding flow was 1~2 m, the rise in temperature was not obvious, and the wind speed in certain regions might exceed the standard. Therefore, the optimal length of the flow guiding device should be about 1 m and not more than 2 m.
- The effect of the direction of airflow of the air inlet device was affected by the length of the airflow. Increase in the direction of airflow caused the chicken body plane temperature and the

overall wind speed to rise, while the carbon dioxide distribution remained basically unchanged. When the direction of airflow was 30° ~ 45°, the rise in temperature was not obvious, while the rise in wind speed was more obvious. When the direction of airflow was 45° ~ 60°, the rises in temperature and wind speed were both obvious. However, as to this study, when the direction of airflow was 60° (θ = 60°), the overall temperature exceeded the standard and the wind speed in certain regions also exceeded the standard. Therefore, the optimal flow direction in this study (θ) should be 30° ~ 45°.

- This study performed more detailed research on the air inlet device based on relevant existing studies. However, there are still some shortcomings and defects: firstly, the influence between the air inlet devices was not considered, such as the spacing of the air inlet devices and the staggered arrangement of the air inlet devices on both sides. Secondly, the study on the direction of airflow and the guide length of the air guiding device can be further refined. For instance, the control group in the study on direction of airflow selected θ as 30°, 45° and 60° respectively. On basis of this study, a further comparative study can be performed when selecting θ as 30°, 35°, 40° and 45° respectively.

The air inlet device in a typical domestic broiler house is different from the common rectangular air inlet. This study on the air inlet device through CFD software has certain reference values for the design and construction of typical broiler houses in cold regions, and for the standardization of broiler houses.

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