Field: TSF : Thermal Systems and Fluid Mechanics

Development of a Suitable Air Condition Control System for a Closed-System Henhouse

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Abstract

This work was performed to study and develop a suitable air condition control system for a closed-system henhouse. The size of the henhouse, 14x120x4 m^3., was selected to study the air conditioning. A multi-inlet unit with a cooling pad was installed at the middle of the henhouse wall in order to decrease the air temperature difference between the front and rear of henhouse. This unit is called a "Bus Windows System (BWS)" . From testing, it was found that the temperature difference between the front and rear of the henhouse had decreased from 5-6 degree Celsius to 2-3 degree Celsius. This decrease was due to the fresh, cool air from the BWS which entered and mixed with the hot air in the henhouse. The result also showed that the velocity profile was more uniform than before the addition of a BWS. The increased ventilation rate reduced the accumulation of ammonia in the henhouse from 7-10 ppm. to 0-2 ppm. Furthermore, from the viewpoint of production, the productivity was significantly increased to a level higher than that of the standard production. However, after using BWS, the relative humidity increased about 10%.

Key words: Bus Windows System, Evaporative Cooling System, Henhouse, Ventilation

1. Introduction

Thailand is an important country for livestock production and world export and the number of pig farms, broiler and eggs chicken farms have increased continuously to the present day. Farm owners who can manage their farms efficiently will be able to compete and often succeed in their business.

During the period starting 5 years ago to the present, farm owners have reported problems with farm management such as the death of animals, a size and weight of productivity lower than standard and a bird flu problem. The bird flu problem affected to society and had a direct and indirect effect on consumers and entrepreneurs. To prevent the bird flu problem, farm owners focused on a closed-system henhouse. The closed-system was the best method to solve this problem and the number of farns using a closed-system henhouse has increased.

Frequently the problems in controlling the climate conditions in a closed-system henhouse were the high temperature difference between the front and rear of the housing, an insufficient rate of air flow, a high difference in the air speed and the accumulation of ammonia within the henhouse. From the above mentioned problems, it can be seen that control of the air condition in the closed-system henhouse is very important for farm management. From a preliminary study it was found that the study of controlling the air conditions in the closed-system henhouse was rare in Thailand, so the farm owner lacked the appropriate knowledge and guidelines to control the air in the closed-system henhouse. Then, the aim of this research was to study the way and method of suitably controlling the air conditions in a closed-system henhouse. It was expected that the results would help the farm owner to reduce production costs, increase income, enhance competitiveness and to operate the business securely and sustainably.

2. Theory

2.1. Basic Equations of Flow

The flow of a fluid is generally analyzed in the form of differential equations as show below.

(1) Continuity Equation

(2). Momentum Equation

(3) Energy Equation

The equations in (1) and (2) are related to the velocity and pressure in the flow field. The equation in (3) is related to the thermal energy within the flow field. The characteristics of a flow can be divided into two categories such as Laminar flow and Turbulent flow. In this research, to solve the equation more easily, the conditions of steady flow and incompressible flow were assumed. The influence of temperature changes was also neglected.

From the principle of mass conservation, the continuity equation is shown below [1].

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \qquad (1)$$

Where t is the time, u , v and w are velocity in the x , y and z axis respectively, and ρ is the density

Given the balance of forces that occur on the volume control, the momentum equation or Navier-Stokes equation can be written in general from as

$$\rho\frac{D\mathbf{V}}{Dt}=\rho g-\nabla p+\mu\nabla^2\mathbf{V} \qquad (2)$$

Where $\mathbf{V}$ is the velocity vector, P is the pressure, g is the acceleration due to gravity, μ is the dynamic viscosity.

2.2. Finite Volume Method

The finite volume method is a method for representing and evaluating partial differential equations in the form of algebraic equations similar to the finite difference method and values are calculated at discrete places on a meshed geometry. "Finite volume" refers to the small volume surrounding each node point on a mesh. In the finite volume method, volume integrals in a partial differential equation that contain a divergence term are converted to surface integrals, using the divergence theorem. These terms are then evaluated as fluxes at the surfaces of each finite volume. Because the flux entering a given volume is identical to that leaving the adjacent volume, these methods are conservative. Another advantage of the finite volume method is that it is easily formulated to allow for unstructured meshes [2].

2.3. Evaporative Cooling System

Closed-system henhouses in Thailand most often use an evaporative cooling system to control the air condition inside. The process of an evaporative cooling system is flowing through a cooling pad into which water is flowing. When the air flows through the cooling pad, the air will exchange heat with the water, which absorbs heat from the air after which, the water will evaporate. This is the reason that the air was cooled and when the cooled air flowed into the henhouse, the temperature in henhouse was decreased as shown in Fig. 1.

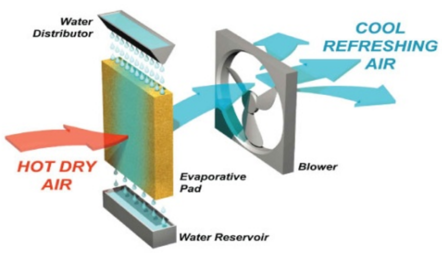

Figure 1 Process of an evaporation cooling system [3]

Figure 2 Characteristics of Cooling Pad [4]

The efficiency of a cooling pad for reducing the temperature is based on the air velocity, the area of the cooling pad and the relative humidity. The temperature of the air after passing throug the cooling pad can be calculated as follows [5].

$$t_{2db} = t_{1db} - \frac{\eta\left(t_{1db} - t_{1wb}\right)}{100} \quad (3)$$

When t_{1db} , t_{2db} are the dry bulb temperature of air entering and exiting the cooling panel.

t_{1wb} is the wet bulb temperature of air entering the cooling panel.

η is the efficiency of the cooling pad.

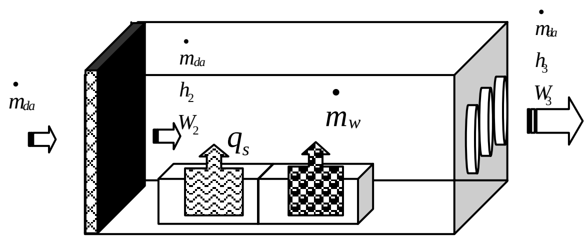

Figure 3 Outline of the consideration of ventilation in henhouse.

2.4. Heat and mass balance in the henhouse

The air in a henhouse will receive heat and moisture from many sources in the henhouse. The internal heat sources are heat from the chickens and lamps, and the moisture source is from the chickens. The equation of heat and mass balance in the henhouse can be written as follows.

$$\dot{m}_{da} h_2 + q_s = \dot{m}_{da} h_3 \quad (4)$$

$$\dot{m}_{da} W_2 + \dot{m}_w = \dot{m}_{da} W_3 \quad (5)$$

Where $\dot{m}_{da}$ is the flow rate of dry air

$\dot{m}_w$ is the flow rate of humidity from chickens in the henhouse

W_2 is the humidity ratio of the cooling pad

W_3 is the overall humidity ratio of the henhouse

h_2 is the enthalpy of the air exiting the cooling pad

h_3 is the overall enthalpy in the henhouse

h_w is the enthalpy of humidity

q_s is the rate of heat in henhouse

2.5. Standards of ventilation and conditions for closed system henhouse

To develop and improve Thai-agriculture product, the standard of animal husbandry is regulated by the Ministry of Agriculture as shown in the Table 1.

Table 1 Standard ventilation and air condition in closed-system henhouse [6]

Conditions	Standard Value
Ventilation rate	0.8 to 1.33 times of the henhouse volume per minute
Relative humidity	50-85%
Area per chicken	At least 452 cm^2 per chicken
Temperature.	20-32 $^{\circ}C$

3. Air condition control systems

3.1 Air Condition Control Systems

Air condition control systems in the closed-system henhouse are generally used by an evaporative cooling system for controlling the air condition in the house. The Components of the system are cooling pad, fan, pond, pump piping systems and temperature and humidity control units. Fans are installed at the end of the housing to ventilate the air out of the henhouse. This creates a pressure difference between the inside and outside the henhouse, resulting in a negative pressure inside the housing. Due to this negative pressure, air outside the house is sucked in and passed through the cooling pad (installed in the front of the house) into the house. The air is cooled and flows through the henhouse along the length of the house and is then ventilated out at the rear of the house as shown in Figure 4.

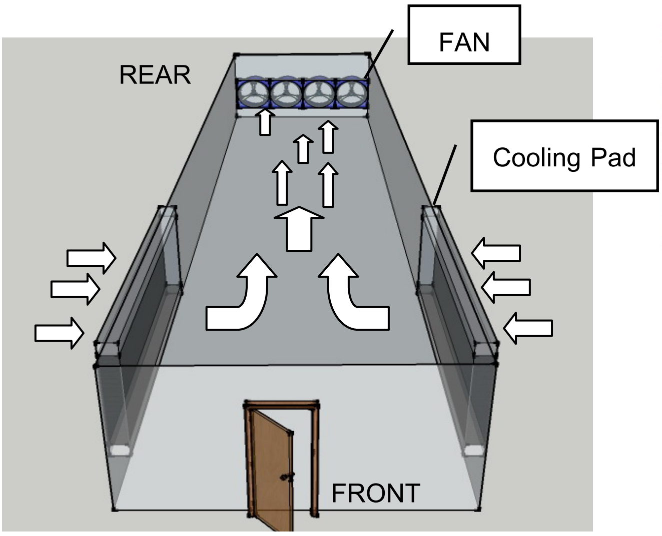

Fig. 4. The flow of air in henhouse with evaporative cooling system

To control the air condition in the closed-system henhouse, temperature and humidity sensors were installed inside and outside the house. Measured temperature and humidity values were transmitted to the controller in order to compare with reference values. Then the system will control the opening or closing of the cooling pad, the water flow rate, and the pump and fans for the appropriate condition.

This research studied the appropriate method for controlling the air condition in a closed-system henhouse which has 76,000 hens. The size of the henhouse is 14x120x4 m^3 with 20 fans installed at the rear of the house (42,000 cubic meters per hour per fan). Normally hens are bred in a cage which has 6-8 hens per cage. The cages were placed in 5 vertical stacks. There are 5 rows of stacks placed along the length of the house, as shown in Figure 5.

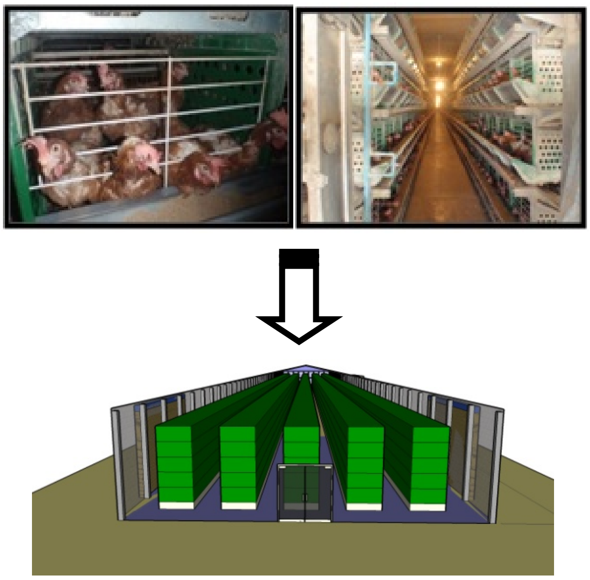

Figure 5 Characteristics of egg poultry cages in closed-system henhouse

3.2 Bus Windows System (BWS)

Bus Windows System (BWS) is a device that increases the rate of air change and the wind speed and reduces the temperature of the air inside the henhouse. The concept of BWS is bring in the appropriate amount of air with the appropriate velocity in to the middle of the house. The addition of this air will increase the ventilation in the house, and reduce the air temperature in the house. The BWS consists of two main parts which are the cooling pad and the windows. The BWS is a rectangular box shape in which the front and left side have different sizes of windows while the right side is a door for entering to adjust or to maintain the windows. The back wall is the cooling pad. All side of the BWS are shown in Figure 6.

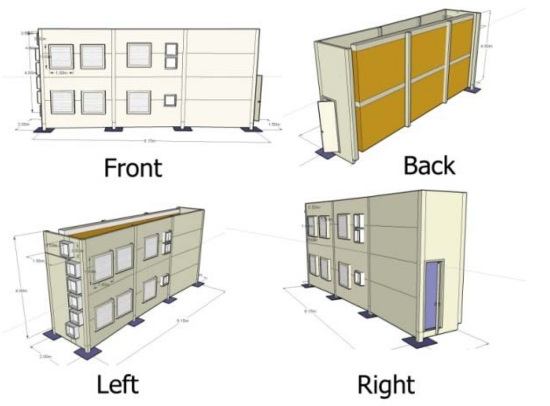

Figure 6. The characteristics of the Bus Windows System

The shape of the BWS is similar to a bus that has many windows which can be adjusted to control the amount of the air as needed for each passenger. Therefore, this system is called the “Bus Windows System”. The BWS can be installed in the house by drilling the wall of the house with a size equal to the size of the back wall of the BWS. The picture of an installation of the BWS is shown in figure 7.

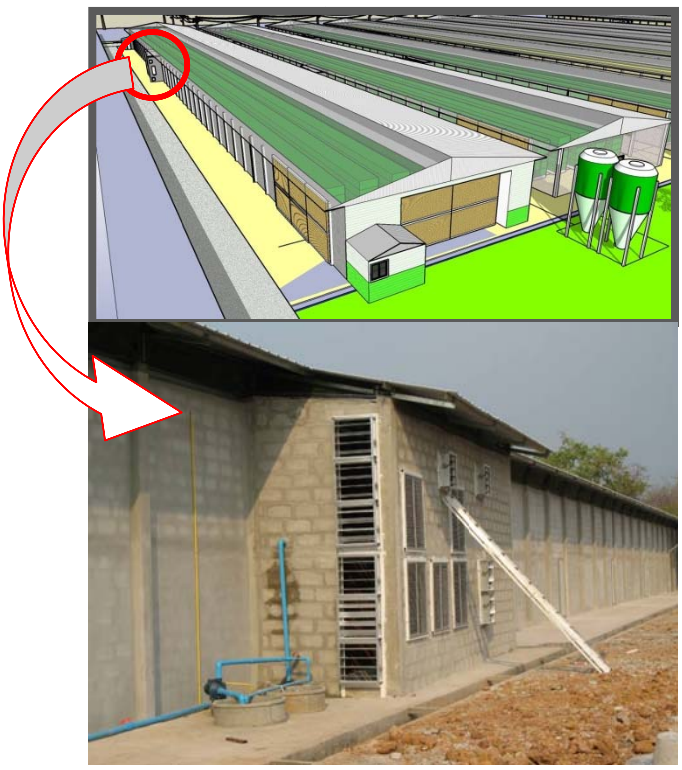

Figure 7. Installation of BWS in the house

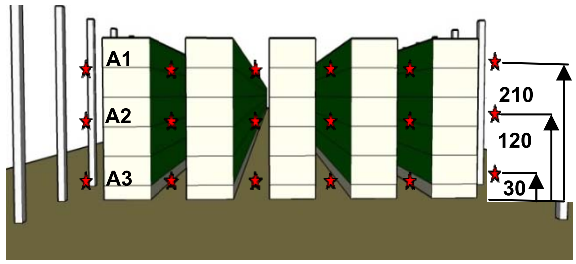

Figure 8. The measurement positions.

4. Procedures and Methods

4.1 Positions were determined where the values of temperature, relative humidity, wind speed and amount of ammonia were to be measured. The positions of measurement were the midpoint between the walls and rows of chicken cages and between every row of chicken cages. All of the positions were measured at three vertical levels which are 30, 120 and 210 cm high from the ground. The measurement positions are shown in Figure 8. The parameters are temperature, relative humidity, wind speed and amount of ammonia. Besides, the measurement at the vertical position, the position along the length of the house at every 4 meters are also measured. Then the total number of positions that were measured were 540 points.

4.2 The values of temperature, relative humidity, wind speed and amount of ammonia at the specified positions (540 points) before BWS installation were measured.

4.3 The BWS was designed and constructed. The size of the designed BWS was 2 x 9 x 4 m^3 (width x length x height) and it was installed at 60 meters from the front of house as showed in Figure 9. The size of the cooling pad used in this BWS was 35% of the cooling pad installed at the front of the house.

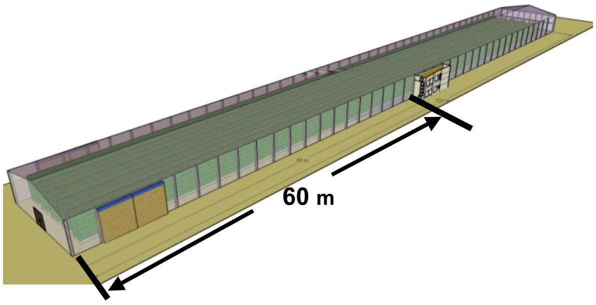

Figure 9. The position of BWS installation

4.4 The ventilator of the BWS was adjusted, then the temperature, relative humidity and wind velocity inside the house were measured until the difference of the temperature between the front and rear of the henhouse was less than 2$^\circ C$.

4.5 The measured values of temperature, relative humidity, wind speed and amount of ammonia from all 540 points were recorded after the ventilator of the BWS was adjusted for the optimal condition.

4.6 The flow pattern in the henhouse was determined before and after using the BWS by FVM method.

4.7 The results of the above study, before and after BWS installation, were compared and analyzed.

5) Results and Discussions

5.1 The installation of bus window system

From the installation of the bus window system (BWS) at the middle of henhouse (60 meters from front of henhouse), it was found that the temperature of the air passed through this system decreased lower than the temperature of the outside air by about 5-6 $^\circ C$. The air velocity was about 1.5-2.0 m/s and the relative humidity was about 85-90%.

5.2 The change of temperature in the henhouse.

The average temperature inside the henhouse during the period 18-21 July 2007 is shown in Figure 8. The result was divided into two intervals. The first interval was during 18-19 July 2007 which was the period that BWS was not used in the henhouse. The second interval was during 20-21 July 2007, when the BWS was used in the henhouse. From Figure 10, the difference temperature (between the highest temperature and lowest temperature (ΔT_D) on 20th July 2007) is 4 degrees Celsius while the ΔT_D on 18th July 2007 is 2 degrees Celsius. From the result, it was found that using BWS can reduce the temperature difference between maximum and minimum temperature during a day. This has an advantage for chicken health in henhouse because the chickens were very sensitive to the change of temperature. If the difference of temperature in each day fluctuates, this will affect to the feeling of the chickens and their productivity trends to fall down.

The temperature inside the henhouse along the length of the henhouse, with BWS and without BWS, is compared and shown in Figure 11. The results show that the temperature difference (ΔT_H) between the front and rear of henhouse was about 6 $^\circ C$ when the BWS was not used, while ΔT_H in the henhouse with the BWS was about 1.0 $^\circ C$ which was lower than the temperature of henhouse without BWS. The BWS could help to introduce fresh and cool air into the house. At the distance of 60 m. from the front of henhouse, the average temperature decreased about 2-3 $^{\circ}C$ due to installation of the BWS at this position. From this results, the owner need not reduce the temperature at the front of henhouse, which was a cause of sickness in the chickens. Before installation of the BWS, the variations in the temperature in the henhouse would gradually increase from the front to the rear of henhouse due to the accumulated heat from the chickens. Therefore the temperature of the air inside the henhouse gradually increased. However after the BWS installation at 60 m. from the front of henhouse, the temperature immediately decreased air at the middle of the house and was gradually increased toward the rear of the henhouse. Therefore the difference of air temperature between the front and rear of the henhouse was reduced. However this result occurred only at the left and right sides of the henhouse, and there was no effect on the temperature at the center of henhouse due to obstruction of the cages.

5.3. The distribution of velocity inside the henhouse

The measured velocity inside henhouse is shown in Fig. 12. Due to the BWS installation, the velocity was decreased at the front of the henhouse and was averaged about 2 m/s, while the average velocity before using BWS was 3.5 m/s (at 0-60 m. from the front). The averaged velocity when using the BWS was lower than that of the previous system by about 1.5 m/s. This results because operating with the BWS will reduce the velocity at the front of the house and add cool air at the middle of the house. Adding the air in the house was increasing the air change rate of the system. The decreased velocity in the front of the house will help reduce the number of sick chickens. Furthermore, the accumulation of heat at the front of the henhouse was too low, thus it was not necessary to have a high velocity in this area. In the section of 60 - 120 m, it was found that the average velocity of the air, with and without BWS, was nearly the same due to the principle of mass conservation.

From using the FVM method, the result of velocity profile is shown in Fig. 13 and 14. It was found that when using the BWS the velocity in the front area was lower than that without BWS and the velocity increased at the middle of the house (60 m.). This result shows that the results calculated from FVM method were similar to the values obtained from experiment, and it could be used to explain the other characteristics of flow.

5.4. Relative humidity and Ammonia accumulation

Before using the BWS, the average relative humidity was about 75-85% and the amount of ammonia accumulation at 120 m. was about 7-10 ppm. After installation of the BWS, it was found that the average relative humidity inside the henhouse was 80-95% which was an increase of approximately 10%. This was because the air that passed through BWS had high humidity. However there was no effect to the productivity. Moreover, it was found that the ammonia accumulation at 120 m. was decreased to 0-2 ppm. due to the increasing of air change rate.

5.5 Productivity

From the research, it was found that the productivity increased over the standard and the average weight of the hens was increased by about 5%.

6. Summary

The research of the Bus Windows System (BWS) development for controlling air in a closed-system henhouse was studied and it was found that the BWS can appropriately control the air-condition in a closed-system henhouse. The advantage of the BWS are shown below.

- Decrease the air temperature inside the henhouse : the inside temperature was lower than the outside temperature about 5-6 $^{\circ}C$
- Decrease the temperature difference between the front and the rear of the henhouse : the temperature difference was lower than that of the previous method by 3 $^{\circ}C$
- Reduce ammonia accumulation: the ammonia accumulation was reduced in the henhouse form 7-10 ppm. to 0-2 ppm.

From the above advantages, the productivity was significantly increased due to the BWS, which can solve the mentioned problem. However, the humidity was increased by 10% but this did not affect the productivity and the management of the henhouse.

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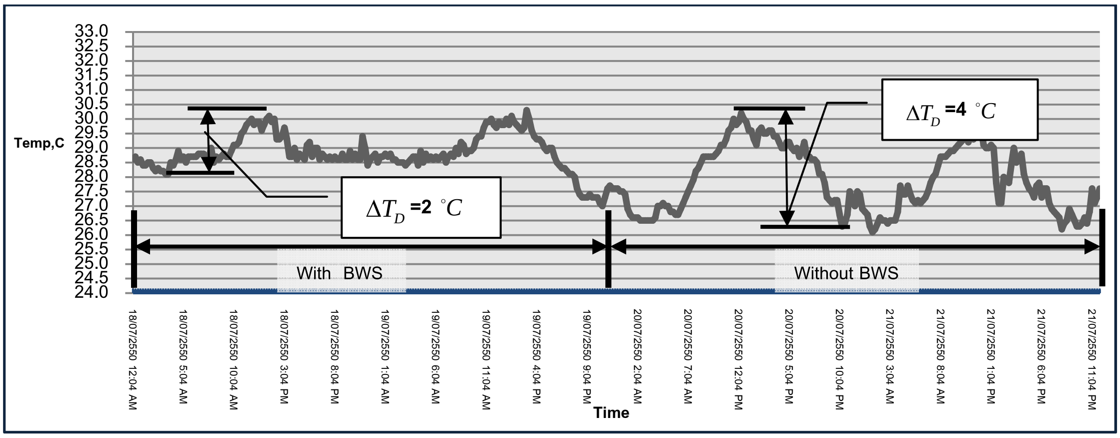


Figure 10. The average temperature inside the henhouse between 18-21 July 2007.

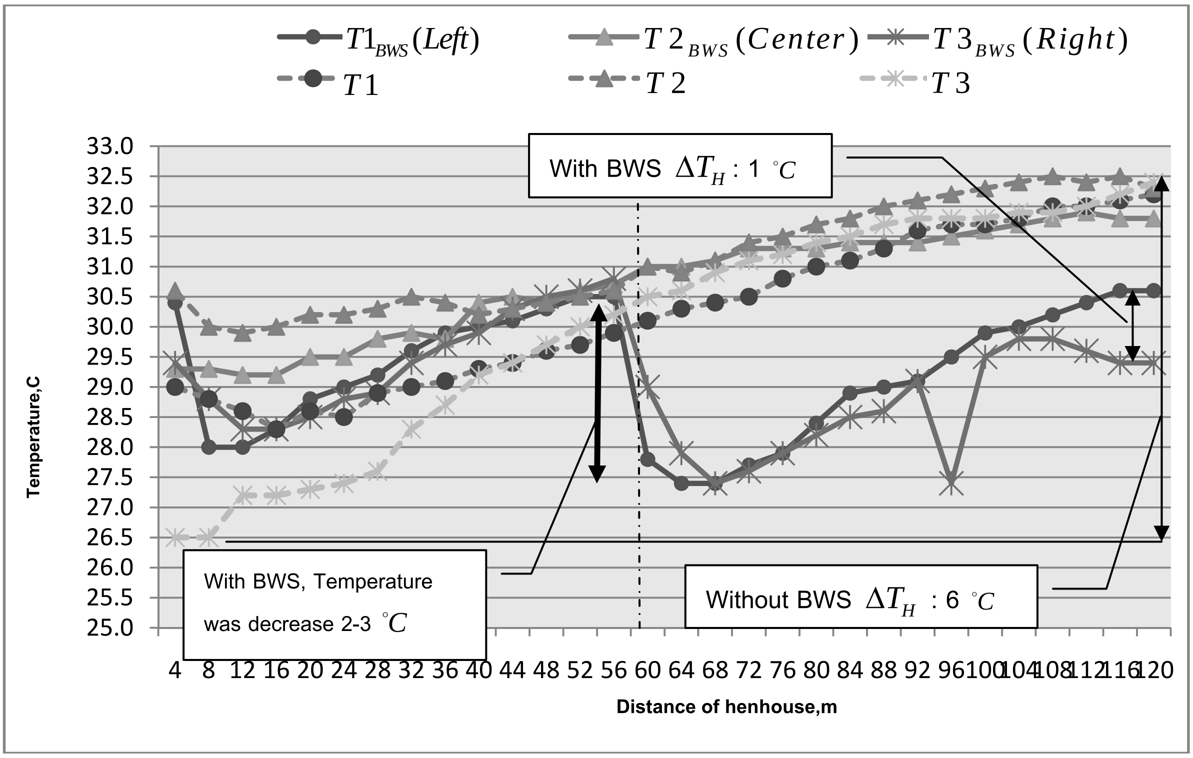


Figure 11. The comparison of temperature of air in the house with and without the BWS.

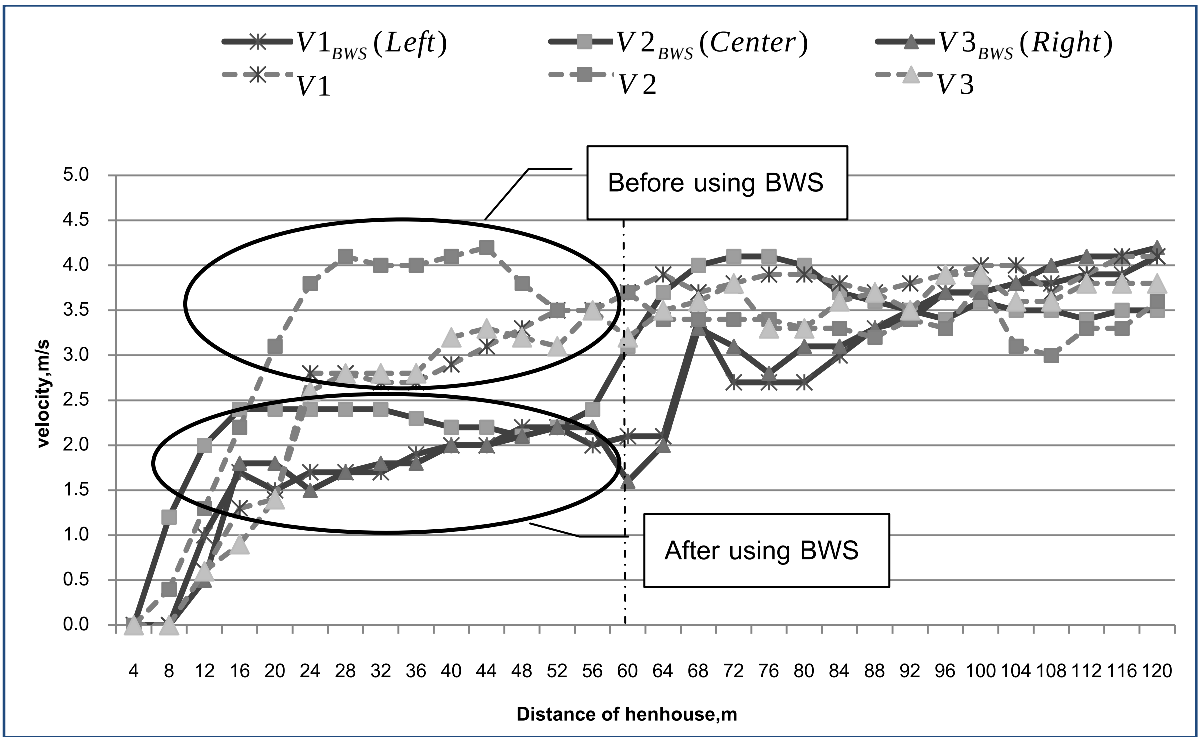


Figure 12 The comparison of air velocity before and after using BWS

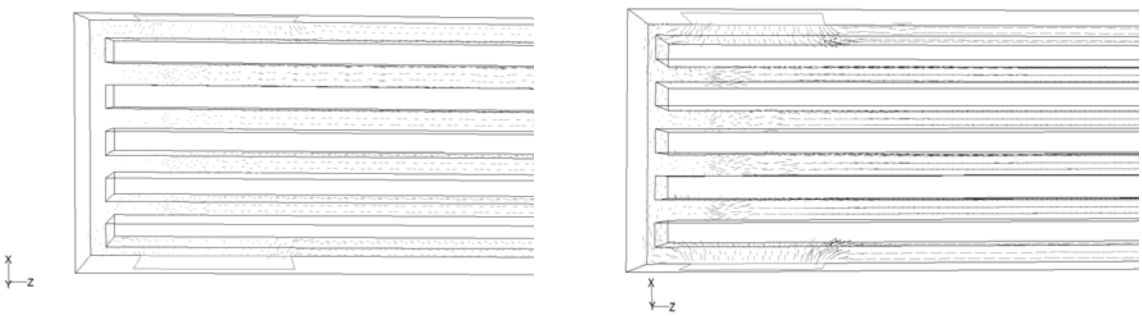
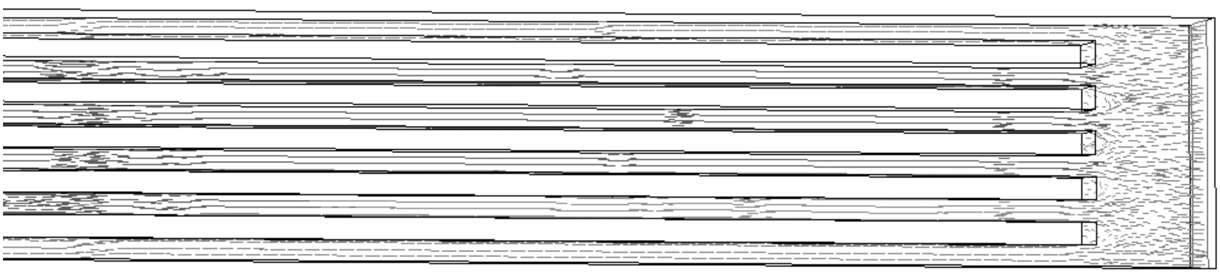


Figure 13. The comparison of velocity profile at front area of the henhouse with BWS (Left) and without BWS (Right)



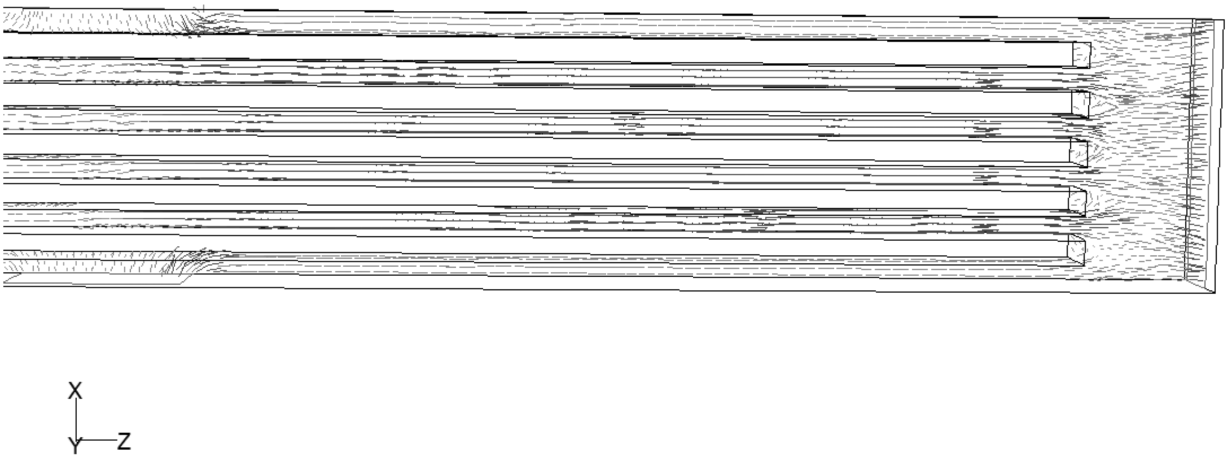


Figure 14. The comparison of velocity profile at 60-125 m. of the henhouse with BWS (Below) and without BWS (Top)