International Journal of Smart Grid and Clean Energy

Optimal design for energy usage of cooling system in animal farm using CFD model

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Abstract

Animal farming is the significant propulsion for Thailand's economy. Animal house is not only the important contributor to their quality but also the factors controller for their hygiene. The major cost to operate an animal house is the energy cost to control the most suitable condition for animals. Thai agriculturists normally operated their farms based on their understanding or their own experiment without any analysis. This may lead to the wrong solutions and unsustainable condition. In this work, the swine house was considered as a study case to optimize condition between suitable condition (thermo-neutral zone) for pigs and energy cost. The cooling system includes cooling pad and exhaust fans were constructed to reduce and control both temperature and moisture in the house. Computational Fluid Dynamics (CFD) models were modeled and analyzed the factors of wind direction, temperature and temperature distribution throughout the swine house. The analysis result was used to determine the operation of exhaust fans. The result showed that, in average temperature day, the operation of exhaust fan can reduce to 80-40%. The results of all study cases were analyzed to create the operation chart for the automotive controlling system in the future.

Keywords: animal farm, cooling system, cooling pad, computational fluid dynamics (cfd) simulation, economize system

1. Introduction

Agriculture is the key sector for ASEAN (Association of South East Asian Nations) member's economic growth, particularly for Thailand. Thailand's development has been generally based on the export of agricultural products [1]. The major animal products are chicken, cow, and swine. Thailand continues to import the genetic materials from world top class breeding, thus the reproductive performance was improved following the figure of the origin such as Denmark. Reproductive performance in top rank farms is close to the average figure of front-line countries, 28 pigs weaned/sow/year are achieved [2].

The quality of animal can be controlled by an environmental condition which includes thermal, dietary, stress and management level. The swine house is the significant factor to contribute to the quality of pigs. According to pig characteristic, do not have sweat glands, pigs cannot stand the hot and high moisture weather [3]. Thus, swine house should be able to control the temperature and percentage of moisture and to protect heat from the sun. It should have located in the non-flooded and far from the community area with the efficiency to drainage pigs' feces to reduce the problem from air pollution. The internal temperature which suitable for pig is about 15-25 ℃ [4, 5], called the thermo-neutral zone of the pig as

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doi: 10.12720/sgce.8.6.655-661

shown in Fig.1.

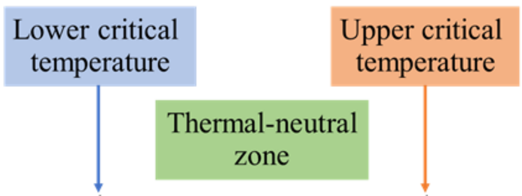
In this work, the model of swine house was collected from Punyapa Co. ltd., Buriram, Thailand. Punyapa farm operates a piglet breeding business of 2,400 pigs, 15 swine house included breeding house and piglet houses. The company concerned about the operation cost together with CO2 emission from swine house. Therefore, the installation of an evaporative cooling system using a cooling pad and exhaust fans. The cooling pad was installed at the front wall using room temperature water through the porous media to decrease intel temperature. Moreover, a fresh air inlet will help to keep pigs healthy and athletic [6]. The 14 set of exhaust fan was installed at the rare wall of the swine house to control the outlet air flow. Global climate change and its associated environmental issues have raised the concern about the sustainable development of the agricultural sector. Animal farming can make a considerable contribution to energy conservation as well as GHG removal.

According to Thailand's temperature profile all year round, full operation of exhaust fans may cause the excess air flow in swine house and the excess energy cost of production. The computational fluid dynamics (CFD) models will be designed under the factor of swine house size, heat load, and environmental temperature to analyze air flow direction, temperature profile through the house, and temperature distribution [7]. The simulation result will be analyzed to design the optimum operation plan for exhaust fans.

2. Data Collection

2.1 Thermal environmental needs of the pigs

It is important to maintain the pig within an equitable temperature range because pigs cannot bear the hot weather and high humidity. They prefer sleeping in the cold place to remain their body temperature. The high temperature will affect the decreasing of feed and water intake, decreasing of growth level and other problems as shown in Fig.1. These problems lead to the higher production cost and the worse quality of breeding.



Cold	Comfortable	Hot
Huddling Less floor contact	Normal contact with other pigs	Spread out Increase floor contact
Stable body temperature	Stable body temperature	Increasing body temperature and panting
Increasing feed intake	Normal feed intake	Decreasing feed and water intake
Shivering	Normal behavior Normal breaths per minute (20-30)	Increasing - Pen fouling - Splashing, wallowing - Respiration rate High breaths per minute (50)

Fig.1. The effect of temperature on pigs' behavior

This suitable temperature range is called the thermo-neutral zone (Fig.2). It is dependent upon the type of floor, its insulation properties, the air speed and temperature and the insulation of the building. In this work, the swine house used as the study case is the breeder house. The breeder is normal size about 150-180 kg. Reference [8] report that the thermo-neutral zone of breeder can be assumed as the pig size 60-90 kg. This work will use the thermo-neutral zone at 15-30 ℃.

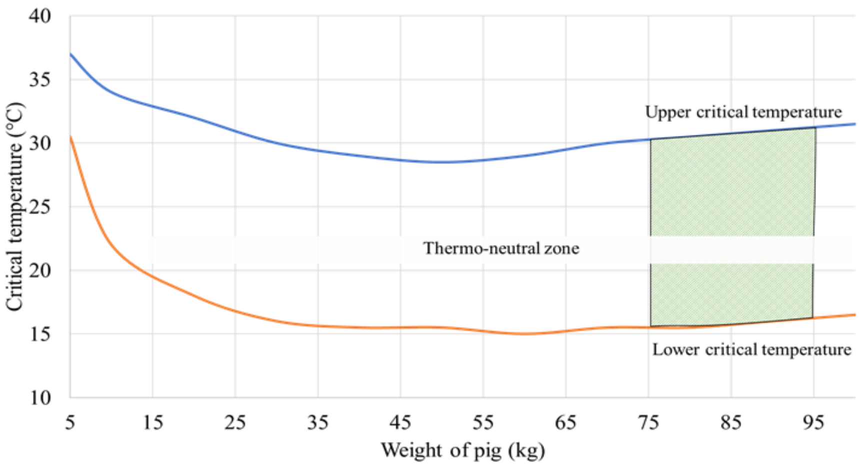


Fig. 2. The thermo-neutral zone for swine.

Besides temperature and air flow, moisture is another key factor of pigs' growth. Average moisture that suitable for swine house id 60-82%. Too hot and moist condition in swine house will cause disease organism to thrive and propagate [9].

2.2 Thailand's climate

The climate in Thailand can be both hot and dry or hot and wet. The average temperature of Thailand is 19-38 ℃. In the November to February period, mean temperatures are 25-28 ℃, while in the April to October period 27-31 ℃ is typical. The highest temperature can be above 42 ℃ for several weeks in a year. Buriram is the province that characterized as a plateau, high mountains and full of wild. The average temperature in the last 30 years is 27 ℃ with the maximum and minimum average temperature of 33 ℃ and 22 ℃, respectively [10].

2.3 CFD Model for the temperature profile

The CFD simulation was used to consider that the condition where the thermo-neutral temperature zone is kept at a temperature of 15-30 ℃. The main factor to maintain the temperature in the room is the inlet air volume and the air temperature. In this work, the absolute humidity of the incoming outdoor air was set at a constant value of 0.01 [kg/kg] and considered constant throughout the day.

3. Calculation & Modeling

This section will discuss the methodology of this work includes heat calculation from the wall, the roof of a swine house, heat emission from pigs, and the CFD model parameters. The calculation of heat from wall and roof of swine house based on the heat calculation method from the ministry of energy [11] and the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) [12]. The main heat parameters are the overall thermal transfer value (OTTV) and the roof thermal transfer value (RTTV) as shown in eq.1 and eq.2. OTTV and RTTV are a measure of average heat gain transferring into a building through the building wall and roof.

$$\mathrm{OTTV}_i=(\mathrm{U}_w)(1-\mathrm{WWR})(\mathrm{TD}_{eq})+(\mathrm{U}_f)(\mathrm{WWR})(\Delta\mathrm{T})+(\mathrm{WWR})(\mathrm{SHGC})(\mathrm{SC})(\mathrm{ESR}) \tag{1}$$

$$\mathrm{RTTV}_i=(\mathrm{U}_r)(1-\mathrm{SRR})(\mathrm{TD}_{eq})+(\mathrm{U}_s)(\mathrm{SRR})(\Delta\mathrm{T})+(\mathrm{SRR})(\mathrm{SHGC})(\mathrm{SC})(\mathrm{ESR}) \tag{2}$$

where $\mathrm{OTTV}_i, \mathrm{RTTV}_i$ is the overall thermal transfer value from wall and roof (W/m^2)

U_w, U_r are thermal transmittance of opaque wall and roof (W/m^{2}K)

WWR is the proportion of window or translucent wall on the considered wall

SRR is the proportion of window or translucent roof on the considered roof

TD_{eq} is equivalent temperature difference for opaque wall and roof (K)

U_f, U_s are thermal transmittance of translucent wall and roof (W/m^{2}K)

ΔT is a temperature difference between glazing surface and air (K)

$SHGC$ is shading coefficient through a window or translucent wall and roof

SC is shading coefficient

ESR is the solar radiation effect on the considered wall (W/m^2)

The heat production from animals can be estimated from the oxygen (O2) consumed, carbon dioxide (CO2), and methane (CH4) produced. Heat emission from pigs in relaxation conditions can be estimated be eq.3 from [13].

$$H = 6.6m^{0.75} \tag{3}$$

Table 1. Summary of calculation value

Calculation value	W/m^2	Calculation value	W/m^2
OTTV (north)	17.09	OTTV (east)	11.69
OTTV (south)	19.58	OTTV (west)	11.63
RTTV	10.76	Pig emission	25.51

3.2 Swine house model

CFD model was used to analyze and predict the flow of air and temperature profile in a swine house. This model used air as the fluid flowing into the house via cooling pad area and flow out through the exhaust fans. Size of swine model was as 21 m wide, 81.5 m long, and 2.45 m high as shown in Fig.

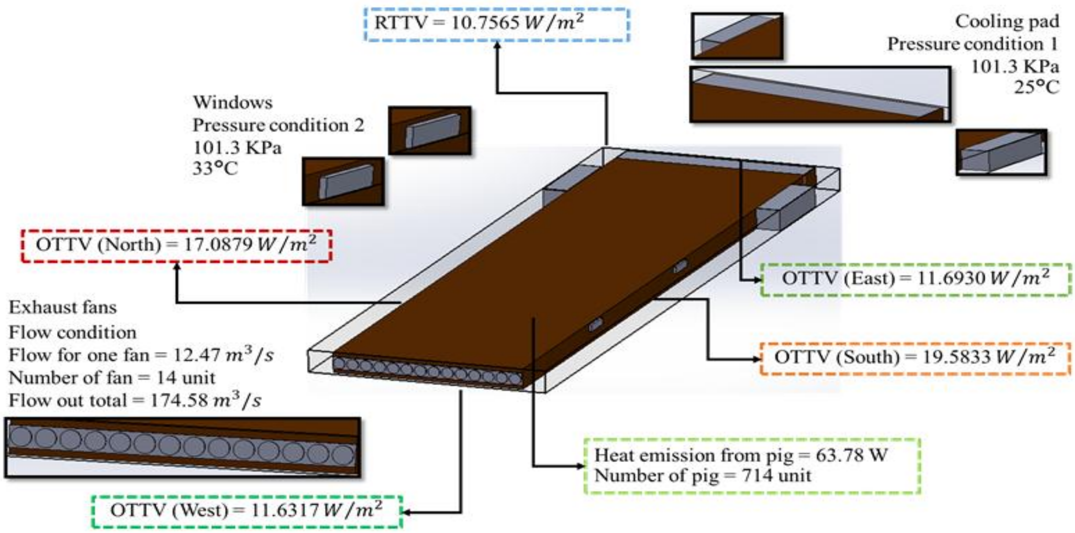


Fig. 3. The swine house CFD model

The house wall was separated into two sections; inner wall and outer wall. Inner wall has three layers include wall plaster, brick, and wall mortar. Each layer is 1.1 m high. The thickness of wall plaster, brick, and wall mortar is 0.015, 0.07, 0.015 respectively. The outer wall is as iso-wall which 2.45 m high, 0.05

m thickness. The cooling pad was installed full at front of the swine house and 9.8 m long on both side as the gray block in Fig.3.

The exhaust fans are a 50-inch diameter, 1 house-power, 3-blade propeller by the AL-blades. Fans operated at 26,430 CFM which consume about 24.40 CFM/W.

4. Simulation Result

The simulation result was sectioned into 4 levels (Fig.), every 0.5-m height. Section 1 and 2 were the main concern as the height of pig habitat. The base case was simulated at 20 ℃ cooling water and 33 ℃ environmental temperature. Section 1 and 2 showed two areas of temperature. The temperature of both areas was suitable for pigs at 21-24 ℃. Section 3 and 4 showed that the rare area of the house (exhaust fans area) had a range of 25-27 ℃, because of heat from the various loads such as pigs, walls, roof. Also heated from outside through the turbulent flow of air near the fans.

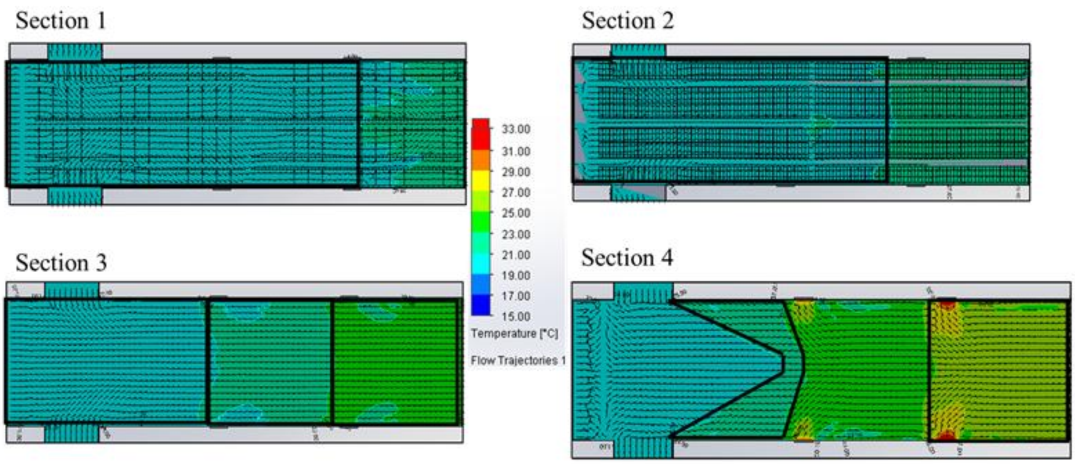


Fig. 4. The temperature profile of base case simulation (by the height).

The section by the length in Fig.5 was created to analyze the perfect length of a swine house. Section 1 is far away from side wall 0.5 m, while section 2 and 3 are far away from side wall 5.5 and 10.5 m respectively. Section 3 is in the middle of swine house. At 20 ℃ cooling water case, the temperature at the third level was accepted or about 25 ℃ (Green contour).

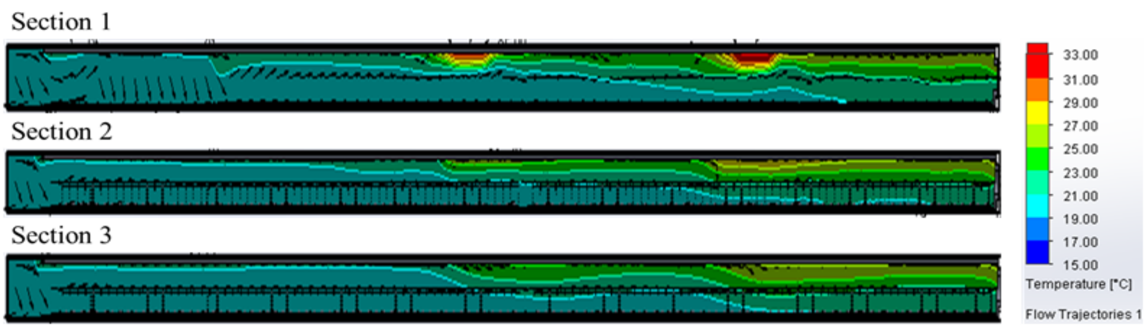


Fig. 5. The temperature profile of base case simulation (by the length) [3]

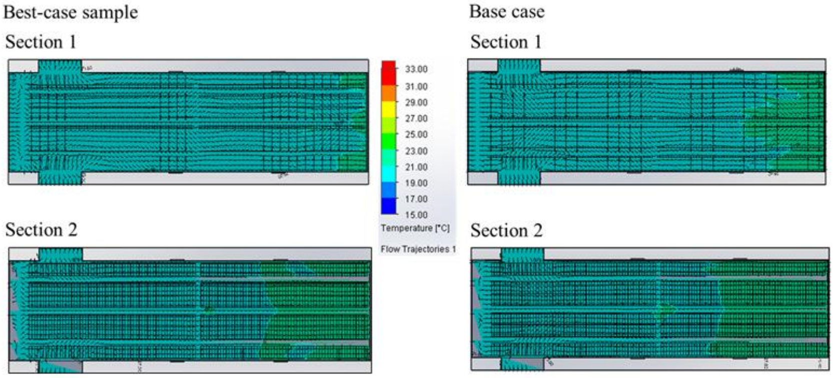


Fig.6. The temperature profile of a sample of the best-case simulation (by the height)

The sample cases in this paper will focus on 20 ℃-cooling water to be able to compare and analyze all results with the base case. In whole work, the temperature of the cooling water was varied from 20 ℃ to 30 ℃. Both Fig.6 and Fig.7 are the example of the best-case and the worst-case at deference environmental temperature considered at only sections of swine habitat. Fig.6 showed the case of environmental temperature at 23 ℃. The 95% of the area in section 1 was 20 ℃ and perfect for a breeder with 5 exhaust fans operation.

The worst-case sample is the case of environmental temperature at 33 ℃. There are 5% of the area in section 2 was 28 ℃ (near the exhaust fans) which may affect pigs' comfortable with 5 exhaust fans operation.

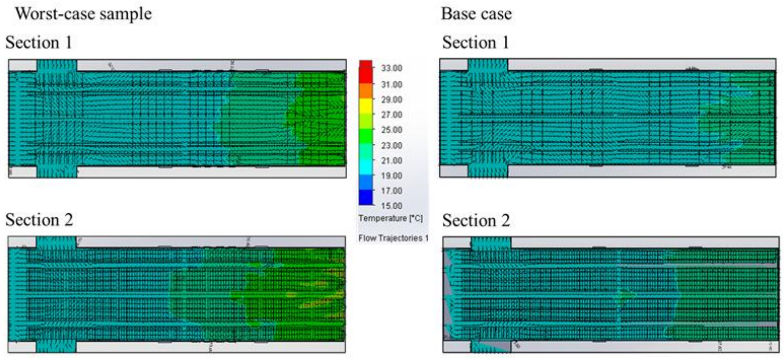


Fig.7. The temperature profile of a sample of the worst-case simulation (by the height).

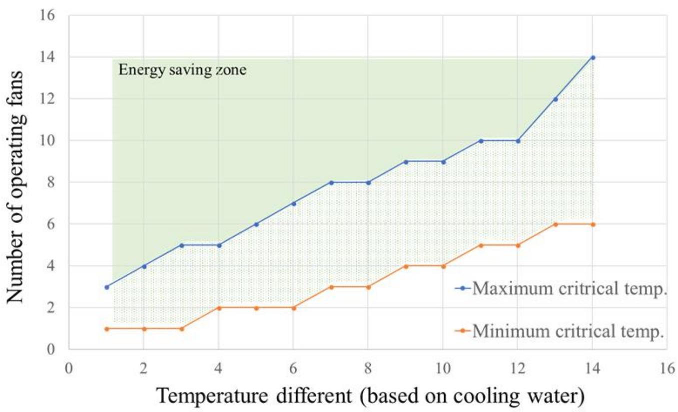


Fig. 8. The sample of temperature different system for exhaust fan operation at 20 ℃ of cooling water

The temperature different system to control the operation of exhaust fans was generated from the result of the study case simulations. Fig.8. showed the sample of temperature different system at 20 ℃ of cooling water. The condition of critical temperature from Fig.2 was used to estimate the number of operating fans. The green area was the energy saving zone at a various temperature different from 1 ℃ to 14 ℃.

5. Conclusion and Future Work

The results of this study showed the pattern of the temperature, temperature distribution, and the direction of air flow in a swine house. The temperature distribution slightly increases from the temperature of the cooling pad around the cooling pad through the swine house. The upper critical temperature was shown in the area of side windows and ceiling near exhaust fans. The direction of air flow showed that there is the turbulent flow around the windows and exhaust fans. This may affect the pigs' habitat. The study cases showed the opportunity to reduce the operation of exhaust fans which lead to the reduction of energy cost in swine pigs. Even though a temperature different system to control exhaust fans operation is more complex, the automatic control system will make it easier. With the temperature different system, it is not only pigs will be comfortable, but also help energy and cost saving. Future work should be considered the pollution and the pollution drainage from pig' excrement as the factor for air flow in the house.

Acknowledgments

Supports from ITAP, NSTDA (Thailand) and Mahidol University (Department of Mechanical Engineering) are highly appreciated. The authors also wish to thank Punyapa co. ltd. For provided information in this work.

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