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CFD Study of Ventilation Systems in Cowshed: Mitigating the Spread of Foot-and-Mouth Disease (FMD)

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ABSTRACT

The ventilation system in cattle sheds plays an important role in maintaining cattle health and production efficiency, especially in controlling the spread of disease. This study evaluated the performance of cowshed ventilation systems on airflow distribution and movement of Foot-and-Mouth Disease (FMD) virus-carrying particles using a CFD simulation approach. Two scenarios were compared, namely natural ventilation and mechanical ventilation with the addition of a supply fan. Analysis was performed on velocity contours, streamline patterns, fraction of suspended and escaped particles, and visualization of particle residence time transiently at 210 seconds. The results show that in natural ventilation, the airflow pattern is uneven with significant recirculation zones, a high number of suspended particles, and longer particle residence time. At 210 seconds, the fraction of suspended particles in the natural and mechanical ventilation systems was 86.1% and 12.1%, respectively. The number of escaped particles in the natural and mechanical ventilation systems was 13.9% and 87.9%, respectively. These findings indicate that mechanical ventilation is more effective in improving air mixing, accelerating the removal of contaminated particles, and reducing the risk of airborne FMD virus spread in cattle sheds.

I. Introduction

Foot-and-Mouth Disease (FMD) is a highly contagious disease of cloven-hoofed animals, such as cattle, pigs, and sheep. Transmission of the disease can be through direct contact, fomites, or airborne. Airborne transmission can occur through aerosols, especially in enclosed spaces. Attention to the transmission of this disease is of great social and economic importance, both in regions of the world where it is endemic and in countries where its presence can threaten a country's disease-free status, as recognized by the OIE (World Organization for Animal Health). One of the main routes of FMD spread is through aerosols, especially in closed environments such as cages. Airborne transmission is difficult to control as the virus can be carried by the wind for tens to hundreds of kilometers. For example, aerosol transmission has been recorded as far as 50 km inland and up to 200 km over the sea [1]. Factors supporting the spread of this disease include high virus transmission, climatic conditions with high relative humidity, and the light molecular weight of aerosols that make it easier to be carried by airflow [2]. Poorly ventilated cages can exacerbate the concentration of harmful aerosols and increase the risk of transmission.

The ventilation system in cattle sheds plays an important role in maintaining livestock health and production efficiency, especially in controlling the spread of disease. This is in line with Sustainable Development Goals (SDGs) 2, namely zero hunger, which emphasizes the importance of food security through increasing livestock productivity to ensure the sustainable availability of animal food. In addition, ASTACITA, as a national food security agenda, also emphasizes more efficient and healthy animal husbandry to support the sustainability of the livestock sector. A major external factor in cattle barn design is the ventilation system, including air humidity, temperature, and airflow distribution within the barn [3-6]. The effectiveness of the ventilation system has been evaluated using CFD and experimentally validated, as it is considered a significant factor in preventing heat stress due to hot weather [7]. Additionally, it can be optimized by maximizing airflow to prevent heat stress in cattle [8]. The application of cross ventilated cooling techniques is carried out to reduce hot spots in the building [9]. The Evaporating Cooling Pad System (ECP) has been developed to provide the best environmental conditions in the cage through the parameters of temperature, relative humidity, and air velocity entering the cage [10]. In addition, the greenhouse gas and ammonia exhaust factors can be accurately estimated by determining the air exchange rate (AER) using the Computational Fluid Dynamics (CFD) method [11].

In general, there are two types of ventilation systems used in animal husbandry, namely Open House and Closed House [12]. Open House systems still rely on natural ventilation with open or half-open walls, so airflow depends on environmental conditions and is difficult to control, causing fluctuations in temperature and relative humidity that can have an impact on livestock health. The urgency of this research is based on the high risk of Foot-and-Mouth Disease (FMD) transmission in cattle, which can spread through the air in cages. Meanwhile, the Closed House system uses mechanical ventilation consisting of exhaust fans and supply fans to regulate airflow, temperature, and humidity more stably, thereby reducing the risk of disease spread and improving livestock comfort. However, the implementation of the Closed House system requires greater energy consumption, especially for fan operation, so it is necessary to conduct an in-depth analysis of energy requirements and airflow effectiveness to optimize an efficient and energy-saving ventilation system. Therefore, the formulation of the problem studied is how the effect of changing the ventilation system from natural ventilation to mechanical ventilation affects airflow characteristics, temperature distribution, relative humidity, and system effectiveness in reducing the spread of FMD disease.

II. Method

This research uses a Computational Fluid Dynamics (CFD)-based numerical simulation approach to compare the ventilation system of cowsheds from natural ventilation to mechanical ventilation. In general, there are three stages in this research. First, pre-processing. Second, processing. Third, post-processing. In the pre-processing stage, geometry is created in the form of a simulation domain, mesh creation, determination of fluid properties, and determination of simulation boundary conditions. The next stage is processing, which is a numerical computation process with a solver to solve the mass, momentum, and energy conservation equations iteratively until convergence is achieved. After the solution is obtained, the post-processing stage is carried out by displaying the simulation results in the form of contours, graphs, and quantitative data in the form of the distribution of disease-carrying aerosol particles.

A. Simulation Domain

The simulation domain is a physical representation that is being analyzed and is limited by boundary conditions. At the same time boundary conditions are rules or conditions set at the boundaries of the simulation domain to represent objects. The simulation domain in this research is a cowshed measuring 15 m x 10 m x 4 m. The real condition of the cage (in Figure 1) is sometimes that of broiler cows located in the tropics, namely the Magetan district, with the outside temperature of the cage around 35 °C - 40 °C, which significantly affects the comfort of farm animals in the cage. This cage still uses a mechanical ventilation system, which is a natural ventilation system without mechanical control, so it depends on the windows or doors on the cage wall.

Fig. 1. (a) Real condition of the cowshed and (b) Cattle infected with Foot-and-Mouth Disease (FMD)

From the existing cage design, a simulation domain will be developed (as shown in Figure 2). The geometry of the cowshed, measuring 15 m x 20 m x 4 m, was created using ANSYS FLUENT 2022/R21 software to represent the actual size of the cage. The geometry is drawn in the form of walls, floors, windows, doors, supply fans, and exhaust fans. Then, given Boundary conditions that are adjusted to real conditions, such as incoming and outgoing air velocity, temperature, relative humidity, and supply or exhaust fan (Table 1). This is done so that the simulation results do not deviate or even fail to converge.

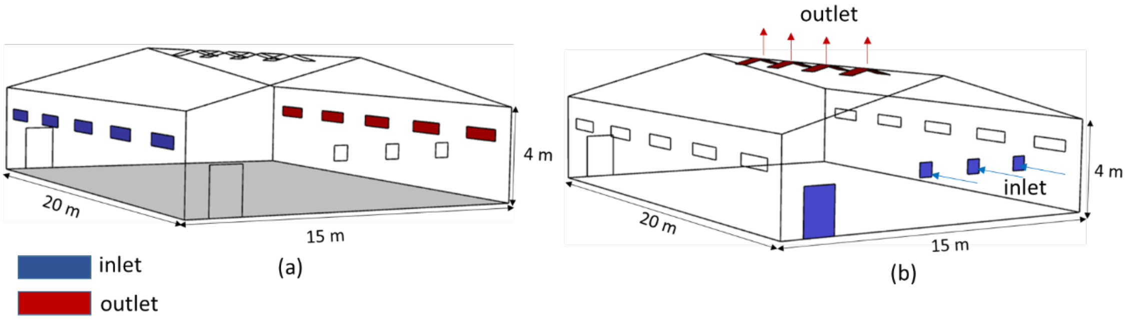


Fig. 2. Simulation domains of (a) natural ventilation and (b) mechanical ventilation.

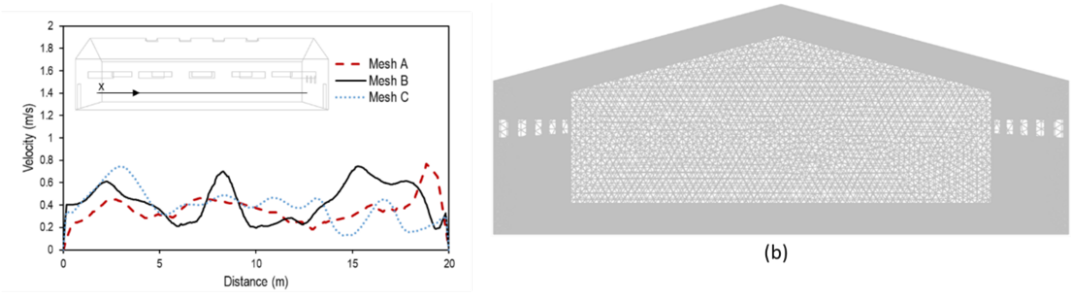
Table 1. Boundary condition

Boundary condition	Tipe	Parameter	Deskripsi
Inlet – natural ventilation	velocity Inlet	velocity inlet = 2.7 m/s Turbulence Intensity = 5%	Simulation of natural flow from outside to inside
Inlet – mechanical ventilation	Velocity Inlet	Velocity = 7.67 m/s Temp = 30°C RH = 75%	Inlet air flow from supply fan
Outlet - Open House system	Pressure Outlet	Gauge Pressure = 0 Pa Temp = 30°C	Depicts a natural outflow
Outlet - Closed House system	Outflow	Velocity 4 m/s (determined from fan)	Exhaust fan exhausts air to the outside
Wall (Wall and Roof)	Wall	No-slip condition Material: concrete/galvalume	The heat from the wall/roof can be calculated if the energy model is active
Floor (Cage Floor)	Wall	Heat flux: as per thermal conditions Roughness optional	Determines thermal contact with surfaces
Domain Interior	Fluid Domain	Air (ideal gas, if using the energy model)	Air space in the cage
Droplet Injection (optional)	Discrete Phase Injection	Diameter = 5–20 µm Inlet Position = cow mouth/nose	For FMD droplet dispersal simulation

B. Grid Independence Test

Grid Independence is a condition in numerical simulation, where the calculation results have not changed significantly even if the size or number of mesh (grid) elements is refined. The following

Figures 3(a) and 3(b) present the three mesh types and meshing shapes in the simulation domain, respectively.



(a)

(b)

Fig 3. (a) Mesh sensitivity and (b) tetrahedral mesh distribution

Figure 3. The simulation domain shows three types of mesh, namely Mesh A, Mesh B, and Mesh C. The total elements in Mesh A are 52663, the total elements in Mesh B are 991556, and the total elements in Mesh C is 1391472. Of the three mesh alternatives, this study chose Mesh B because it provides better solution accuracy and computational cost. Mesh A is too coarse, which risks producing a significant discretization error. In contrast, Mesh C offers only a slight improvement over Mesh B, but it requires significantly more computation time and memory. In other words, Mesh B has reached a practical grid-independent state, and further refining (to Mesh C) no longer changes the results significantly; thus, the selection of Mesh B is more efficient and justifiable.

III. Results and Discussion

The CFD simulation results in the research are presented as visualizations of velocity contours, streamline patterns, and the fraction of particles in the room (Suspended) and outside the room (Escape). The velocity contour provides information on the distribution of velocity magnitude at each point in a particular plane, so that areas with faster-moving airflow and slower airflow can be clearly identified. Meanwhile, the streamline describes the ideal trajectory of fluid particles followed by the distribution of disease-causing viruses. This can facilitate the observation of flow direction, recirculation areas, and potential vortex formation.

A. Velocity contours and streamlines in the ZY plane

Velocity contours were analyzed in the ZY plane, i.e. at the relative positions of the x/L=0.25, x/L=0.5, and x/L=0.75 planes as shown in figure 4. The airflow pattern in the cowshed for natural ventilation and mechanical ventilation has been analyzed. This was done to evaluate the airflow distribution in both conditions.

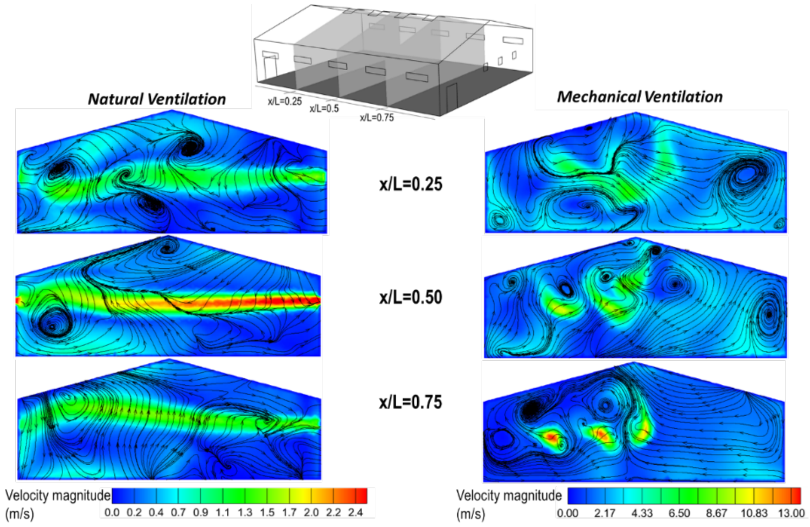


Fig. 4. Velocity magnitude in the vertical plane XY.

Figure 4. Shows the distribution of airflow pattern through velocity magnitude and airflow streamline pattern on the XY plane. The simulation results show that in the natural ventilation system, the airflow pattern tends to be uneven with the formation of recirculation zones and low velocity areas that can cause stagnant air, especially in the x/L=0.25 plane. This condition has the potential to increase the accumulation of aerosol particles that carry the FMD virus. In contrast, in the mechanical ventilation system with the addition of a supply fan, the air velocity distribution is more uniform and the flow direction is more controllable, thus reducing the formation of stagnant zones and improving the mixing and dilution process of air in the cage. This difference in flow patterns confirms that mechanical ventilation performs better in reducing the risk of FMD virus spread than natural ventilation.

B. *Velocity contours and streamlines in the XY plane*

As a comparison in analyzing the airflow pattern in the cowshed, velocity contours and streamlines in the XY plane have been analyzed. Three vertical planes have been analyzed, namely at planes z/W=0.25, z/W=0.5, and z/W=0.75 (Figure 5).

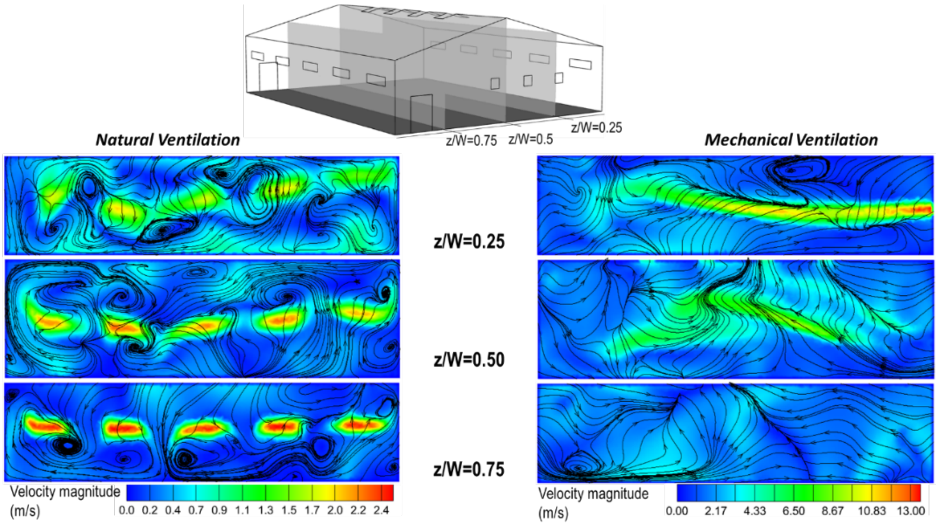


Fig. 5. Velocity magnitude in the vertical plane XY.

Figure 5. Shows velocity magnitude in the vertical plane XY. By observing the XY plane, the lateral distribution of air velocity and flow direction can be identified in more detail, including the possibility of stagnant areas on the sides and in the center of the cage. Through visualization of the velocity contours comparing natural ventilation (left side) and mechanical ventilation (right side) conditions, a more comprehensive three-dimensional picture of the ventilation pattern can be provided, so that the purpose of evaluating the ventilation system in the context of mitigating the risk of FMD spread can be achieved. The simulation results show that under natural ventilation conditions, the airflow pattern is strongly influenced by the direction and intensity of the wind coming from outside the building so that it tends to be unstable and asymmetrical. Natural ventilation tends to produce sharp velocity differences and more recirculation zones, observed in almost all planes z/W=0.25, z/W=0.5, and z/W=0.75. In contrast to the mechanical ventilation condition, it is observed that there are no recirculation zones in almost all planes. The recirculation zone formed indicates low velocity airflow, allowing FMD virus particles to be trapped in the room.

C. *FMD Particle Count Fraction*

The number of particle fractions in this simulation is divided into two conditions, namely suspended and escaped. In the suspended condition, particles are still carried by the fluid flow and scattered in the simulation domain without settling, so that the particle fraction is relatively evenly distributed in certain areas. In contrast, the escaped phenomenon occurs when particles follow the path of the airflow and exit towards the outlet. Figure 6 illustrates the particle number fraction under suspended and escaped conditions for both natural and mechanical ventilation. Analysis of these two conditions is important to evaluate the effectiveness of the ventilation system in suppressing the accumulation of virus particles in the cowshed while reducing the risk of airborne disease spread.

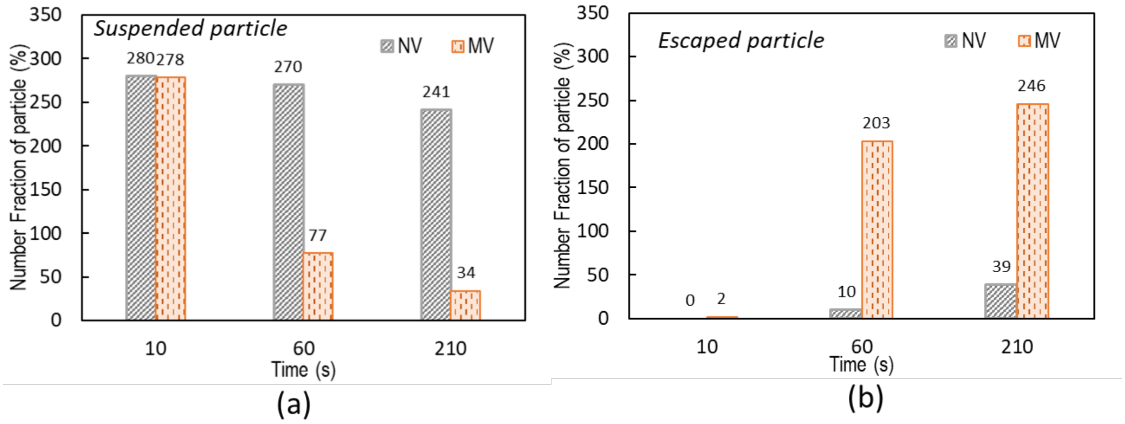


Fig. 6. Fraction of FMD virus-laden particles: (a) suspended inside the cowshed and (b) escaped through the outlet.

Figure 6(a) shows the distribution of the fraction of FMD virus-carrying particles under two conditions, namely particles that are still suspended in the cage and particles that escaped through the outlet of the ventilation system. The analysis was performed transiently at 210-second intervals, starting from 10 seconds to 210 seconds. The results show that the number of suspended particles in the natural ventilation system is much higher than the mechanical ventilation system. At the end of the simulation, i.e., the 210th second, the number of particles still suspended in natural ventilation was recorded as 241 particles, while in mechanical ventilation, only 34 particles remained. This indicates that the number of suspended particles in natural ventilation accounted for 86.1% and 12.1% of the total particles in the cage for mechanical ventilation. This difference indicates that the mechanical ventilation system with a supply fan can to significantly reduce the accumulation of virus particles in the cages by increasing the dilution and removal of particles out of the chamber. Thus, mechanical ventilation is more effective in reducing the risk of airborne disease spread than natural ventilation.

Figure 6(b) shows the fraction of particles that escaped from the cowshed through the ventilation system. The results show a significant difference between natural ventilation and mechanical ventilation. At the end of the simulation, i.e., the 210th second, the number of escaped particles in natural ventilation was only 39 out of 280 particles (13.9%), while in mechanical ventilation it reached 246 out of 280 particles (87.9%). This difference confirms that mechanical ventilation systems with supply fans are much more effective in accelerating the removal of virus-carrying particles from the cage space, thereby reducing particle accumulation inside and lowering the potential for FMD disease spread.

D. Particle residence time of virus-laden particles

Visualization analysis of particle residence time is needed to understand how long virus-carrying particles stay in the cage space before being discharged through the outlet of the ventilation system. This parameter is very important because the longer particles stay in the room, the more likely they are to be inhaled by the animals and increase the risk of disease transmission such as FMD. By comparing natural and mechanical ventilation conditions, residence time analysis can visually demonstrate the effectiveness of the ventilation system in accelerating the particle removal process. Figure 7. Visualization of particle residence time under two conditions of natural and mechanical ventilation.

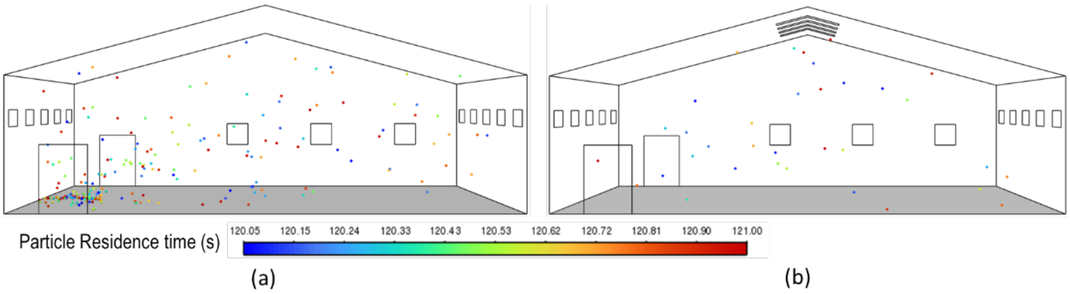


Fig. 7. Particle residence time under (a) natural ventilation and (b) mechanical ventilation.

Figure 7. Shows the discrete particle distribution based on particle residence time inside the cowshed under the two ventilation system conditions. Under natural ventilation (Figure 7(a)), particles are more abundant and dispersed in almost the entire space with high concentrations especially near the floor and walls. This indicates that many particles stay longer in the pen due to weak airflow and the formation of stagnant zones. In contrast, with mechanical ventilation with a supply fan (Figure 7(b)), the number of particles remaining in the room is much less and the distribution is more compact. This indicates that the mechanical ventilation system is able to accelerate the exhaust of particles out of the room, resulting in a shorter residence time of particles in the cage. This difference in visualization supports the previous analysis that mechanical ventilation is more effective in reducing the accumulation of virus-carrying particles and increasing the dilution efficiency of polluted air than natural ventilation.

IV. Conclusion

This study compared two cattle barn ventilation systems in controlling the spread of virus-carrying particles by CFD. The results showed that the mechanical ventilation system with the addition of a supply fan performed better than the natural ventilation in controlling the airflow distribution and controlling the movement of FMD virus-carrying particles in the cowshed. At the 210th second, the number of particles still suspended in the natural ventilation system was 241, while only 34 particles were suspended in the mechanical ventilation system. When compared to the total 280 particles, the suspended condition is equivalent to 86.1% for natural ventilation and 12.1% for mechanical ventilation. Meanwhile, the number of particles that escaped from the cage in natural ventilation conditions was 39 particles, while in mechanical ventilation it reached 246 particles. This value indicates that of the total particles, those that escaped were equivalent to 13.9% under natural ventilation and 87.9% under mechanical ventilation. This data shows that natural ventilation results in uneven flow patterns, stagnant zones, and longer particle residence times, potentially increasing the risk of virus accumulation and transmission. Meanwhile, mechanical ventilation can accelerate the removal of particles out of the room, reduce the accumulation of particles in the cage, and increase the effectiveness of dilution of polluted air. Thus, the application of mechanical ventilation is proven to be more effective in reducing the risk of airborne disease spread and is recommended as a more reliable strategy in the design of cattle barn ventilation systems.

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References

[1] D. Schley, L. Burgin, and J. Gloster, "Predicting infection risk of airborne foot-and-mouth disease," (in eng), *J R Soc Interface,* vol. 6, no. 34, pp. 455-62, May 6 2009, doi: 10.1098/rsif.2008.0306.

[2] E. Brown, N. Nelson, S. Gubbins, and C. Colenutt, "Airborne Transmission of Foot-and-Mouth Disease Virus: A Review of Past and Present Perspectives," (in eng), *Viruses,* vol. 14, no. 5, May 9 2022, doi: 10.3390/v14051009.

[3] B. Kavolelis and I. Sateikis, "Effective cowshed insulating and ventilation system parameters," *Energy and Buildings,* vol. 36, no. 9, pp. 969-973, 2004/09/01/ 2004, doi: https://doi.org/10.1016/j.enbuild.2004.04.001.

[4] R. Bleizgys, V. Naujokienė, and J. Čėsna, "Humidification–Cooling System in Semi-Insulated Box-Type Cowsheds Prevent the Loss of Milk Productivity Due to Thermal Stress," *Agronomy,* vol. 12, no. 5, p. 1131, 2022. [Online]. Available: https://www.mdpi.com/2073-4395/12/5/1131.

[5] R. Bleizgys, J. Čėsna, S. Kukharets, and O. Medvedskyi, "Statistical Analysis of the Air-Cooling Process in a Cowshed," *Agriculture,* vol. 13, no. 11, p. 2126, 2023. https://www.mdpi.com/2077-0472/13/11/2126.

[6] A. Pajumägi, V. Poikalainen, I. Veermäe, and J. Praks, "Spatial distribution of air temperature as a measure of ventilation efficiency in large uninsulated cowshed," *Building and Environment,* vol. 43, no. 6, pp. 1016-1022, 2008/06/01/ 2008, doi: https://doi.org/10.1016/j.buildenv.2007.02.015.

[7] N. Tomasello, F. Valenti, G. Cascone, and S. M. C. Porto, "Development of a CFD Model to Simulate Natural Ventilation in a Semi-Open Free-Stall Barn for Dairy Cows," *Buildings*, vol. 9, no. 8*,* doi: 10.3390/buildings9080183.

[8] N. Tomasello, F. Valenti, G. Cascone, and S. M. C. Porto, "Improving natural ventilation in renovated free-stall barns for dairy cows: Optimized building solutions by using a validated computational fluid dynamics model," *Journal of Agricultural Engineering,* vol. 52, no. 1, 03/18 2021, doi: 10.4081/jae.2021.1135.

[9] L. Jiang, Y. Yi, and N. Akdeniz, "CFD simulations of supplemental cooling techniques in cross-ventilated dairy buildings and associated greenhouse gas emissions," *Computers and Electronics in Agriculture,* vol. 216, p. 108480, 2024/01/01/ 2024, doi: https://doi.org/10.1016/j.compag.2023.108480.

[10] F. A. Obando Vega, A. P. Montoya Ríos, J. A. Osorio Saraz, R. R. Andrade, F. A. Damasceno, and M. Barbari, "CFD Study of a Tunnel-Ventilated Compost-Bedded Pack Barn Integrating an Evaporative Pad Cooling System," *Animals,* vol. 12, no. 14, p. 1776, 2022. https://www.mdpi.com/2076-2615/12/14/1776.

[11] W. Wu, J. Zhai, G. Zhang, and P. V. Nielsen, "Evaluation of methods for determining air exchange rate in a naturally ventilated dairy cattle building with large openings using computational fluid dynamics (CFD)," *Atmospheric Environment,* vol. 63, pp. 179-188, 2012/12/01/ 2012, doi: https://doi.org/10.1016/j.atmosenv.2012.09.042.

[12] A. R. Laili, R. Damayanti, B. Setiawan, and S. Hidanah, "Comparison of Broiler Performance in Closed House and Open House Systems in Trenggalek," *Journal of Applied Veterinary Science And Technology,* vol. 3, no. 1, pp. 6-11, 04/29 2022, doi: 10.20473/javest.V3.I1.2022.6-11.