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CFD model for ventilation assessment in poultry houses with different distribution of windows

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Abstract
The design of structures for animal husbandry has energy and environmental implications. Particularly, the design of broiler houses should consider the comfort of animals in different situations, which is crucial for their proper development. Building geometry and distribution of fans and windows determine critically the ventilation flows and temperature distribution. The use of fluid analysis techniques can be of valuable help in the initial phases of the design of farms, because potential alternatives may be explored. In this study, Computational Fluid Dynamics (CFD) simulations were used to evaluate the ventilation and temperature distribution in three tunnel, mechanically ventilated broiler houses with identical geometry but different distribution of inlet windows and exhaust fans. The three distributions were: (1) Tunnel (fans at the end of the building); (2) Semitunnel (fans at the middle of the building); and (3) Improved Semitunnel (with improved window distribution). For each distribution, air velocity and temperature at the height of the broilers are evaluated at different outdoor conditions. The Index of Temperature and Velocity (ITV) was used as an indicator of animal comfort. Improved tunnel presented more homogeneous values of velocity and air temperature, with average velocity of $0.89 \pm 0.30 m.s^{-1}$ and average temperature of 23.37 ± 0.79ºC. This distribution had the highest comfort area considering air velocity and temperature (88.45% and 94.52% of the area, respectively). The lowest average ITV corresponded to tunnel type (23.24 ± 1.54ºC) but the highest proportion of comfort zone considering ITV (ITV<25) corresponded to the improved semitunnel (90.35% of the area). The three configurations maintained a productive environment of ITV. The simulation results were similar to the literature indications for velocities and temperatures at animal level.

Keywords: Ventilation; Computational fluid mechanics; Poultry; Index of temperature and velocity.

1. Introduction
The application of Computational Fluid Dynamics (CFD) allows considering complex mathematical models based on the equations of fluid dynamics, numerical methods and algorithms that simulate fluids behavior in 3D spaces. These techniques have been used since 1960 in the aerospace industry, and were implanted in 1980 as a fundamental tool applied to the prediction of fluid flow. Currently CFD applies in other areas of engineering to evaluate the behavior of climatic variables such as ventilation, heat and

mass transfer, air conditioning, chemical reactions, dispersion and transfer of internal and external pollutants emitted in plant and animal structures [1].

CFD simulations easily allow modelers to evaluate different design configurations, especially when different alternatives are a priori embedded within the same computational domain and mesh [2]. Nowadays, CFD techniques are used to analyze airflow distribution in ventilated buildings. This ventilation can be either natural (induced by wind, thermal buoyancy or both) or mechanical (forced by exhaust fans). In the case of livestock buildings, the type and design of ventilation has significant impacts on indoor air quality, thermal comfort animals and energy efficiency [3].

Particularly, in the last decade CFD techniques were used in the poultry sector to analyze the distribution of air velocity and turbulence intensity. Authors as Bustamante *et al.* [4]; Osorio *et al.* [5]; Wu *et al.* [6]; Blanes *et al.* [7] and Lee *et al.* [8], represented the convective heat and mass transfer processes to assess changes in ventilation structures in livestock houses. However, other researchers (Roy *et al.* [9]; Norton *et al.* [10]; Seo *et al.* [11]) evaluated the dispersion of internal and external contaminants as the carbon dioxide (CO_2), ammonia (NH_3) [1, 12] and volatile organic compounds (VOC). Due to implications for energy consumption and environmental conditions, these studies are becoming of relevance for manufacturers and producers.

Animal comfort is crucial for the correct development of a farm industry, and these conditions depend on the internal indoor environmental of the building. Sandoval *et al.* [13] mentions that there is clear evidence that modern breeds selected for intensive production have lost their adaptability to varying environments, thus becoming more susceptible to the biophysical effects derived from adverse environments [14].

In regions exposed to warm climate conditions, broiler buildings are frequently ventilated by means of cross or tunnel mechanical ventilation systems [7, 15]. However, inadequate ventilation systems can cause high mortality rates as warm air is accumulated inside all or part of the poultry building. In these cases, gas concentrations or humidity can also increase dangerously at the broilers heigth.

Thus, the environmental control in poultry buildings requires a proper control of environmental factors (temperature, humidity, radiation and air velocity), physical factors (space, light, sound and pressure) and social factors (number of broilers per farm). For these reasons, all these aspects must be taken into account when designing a farm, together with the local weather conditions and economic characteristics of the farm. These aspects are further described below.

1.1 Air velocity and ventilation rate

The selection of the ventilation rate depends on animal type and size, and is directly related to differences in internal and external temperatures in the building. Farm design must be also considered because heat flows also depend on the thermal resistance through the walls and floor (depending on the overall coefficient of heat transfer to the perimeter of the structure and the same area), the sensitive heat generated by lights and internal equipment [5].

The building design must ensure a uniform distribution of air flow, not exceeding particular maximum velocity limits, to maintain thermal comfort of the broilers. Particularly, this airflow should not affect the homoeothermic condition of animals under extreme temperatures [16, 17].

Maintaining a homogeneous velocity inside a building is desirable to achieve a proper productivity. However, according to Blanes-Vidal *et al.* [7]; Bustamante *et al.* [4]; Osorio *et al.* [5], the uniformity of the air velocity in the area occupied by broilers is modified by different reasons:

- The presence of animals on the farm influence the indoor environment of the poultry building due to the release of convective heat,
- The air inlets and outlets distribution affect the mixture, circulation and air renewal inside the building.
- The air may be physically obstructed: higher density of animals decreases the airflow at broiler level, which reduces heat dissipation from the body to the air. This also reduces air quality due to inadequate air exchange, increases ammonia concentrations, and reduces access to water and feed [18].

Insufficient airflow may also cause migration of broilers to better ventilated areas, thus contributing to increased mortality and a production decrease [1, 19]. Air velocity is also related to the perception of temperature. Higher air velocity increases sensible heat loss and reduce latent heat loss in broilers exposed at temperatures of 29.5 and 35ºC [20].

1.2 Temperature

The thermal environment affects the health and productive development of the broilers. The temperature distribution is affected by air streams and determines the thermal environment inside the poultry house. Therefore, the heat generated inside the poultry house should be considered when designing the climate control systems in order to maintain a suitable temperature. Temperature should be kept within certain limits for normal operations of the physiological activities of broilers. These limits define a thermoneutral zone [21-23], which is defined as the temperature ranges at which animals devote the minimum physiological resources to cope with the environment. Lower and higher environmental temperatures affect sensible and latent heat production rates, and eventually produce heat stress which have negative effect on economy of production and animal welfare, demonstrating changes in the cardiovascular system [24] and endocrine activity [25].

1.3 Temperature humidity and velocity index -THVI

Both temperature, velocity and humidity interrelate in the animal response and therefore are crucial to determine the comfortable environment for the animals. Both parameters are unified in the Temperature Humidity and Velocity Index (THVI), formula proposed by Tao and Xin [15]. These authors describe the response of the body temperature of broilers under heat stress interaction with environmental factors dry bulb temperature from 35 to 41ºC, and dew point from 19.4 to 26.1ºC and air velocity from 0.2 to 1.2 $m.s^{-1}$. These factors influence the body temperature of the animal, defined as normal, warning, danger and emergency when body temperature increases at 1, 2.5, 4 and more than 4ºC.

As mentioned, the environment management within the poultry house is then of paramount importance. For this reason, this paper aims to use a methodological analysis to characterize comfort in poultry house using three CFD simulations with different designs of poultry building, changing window locations, mechanically ventilated with different boundary conditions of velocity and temperature.

2. Materials and methods

2.1 Farm description: Geometry and configuration of windows

The geometry of the house building was defined according to usual dimensions of commercial farms. Building dimensions were 15m wide, 120m long and 3m high with flat roof. Eight fans of diameter 1.40m (airflow 38,072, m^3/h) and two fans of diameter 1.10m (13,406 m^3/h) were considered in order to exhaust air from the building. Fans create a negative pressure forcing air to enter through inlet windows of 0.9m x 0.4m. Different distributions of windows and fans in the house building were considered as variation factors.

The comparison between three designs (Figure 1) was carried out analyzing the air velocity, temperature distribution and their interaction on the broiler zone in terms of uniformity, suitability, and the stability. The Tunnel (T) design had open windows on both lateral sides which allow air entrance for approx. 2/3 of its length and all fans were located in the front of building house. This tunnel is commonly used to achieve high air velocities in the same direction. The Semitunnel (ST) configuration consisted in changing the location and distribution of the fans and blocks of windows. In this case all fans were located at both sides in the middle of the building, thus avoiding excessively long air paths inside the building. Finally, the Improved Semitunnel (IST) configuration, which had identical fan distribution as ST, but differed in window distribution. Particularly, in this geometry windows were not regularly distributed but decrease progressively when approximating to the fans.

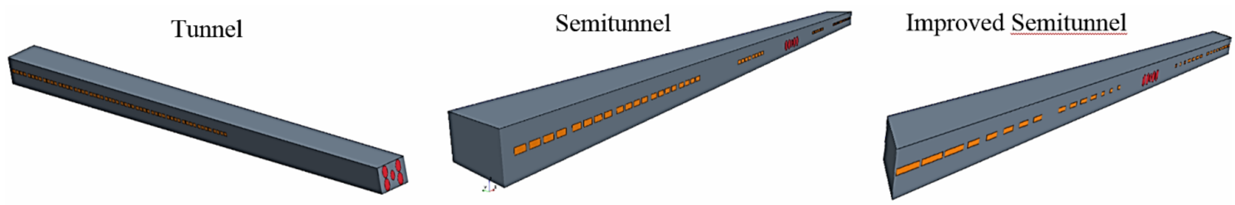

Figure 1. Tunnel (T), Semitunnel (ST) and Improved Semitunnel (IST) Configuration. Only half building is presented because symmetry was applied to CFD calculation

2.2 Computational fluid dynamics

2.2.1 Computational fluid dynamics applied for simulating the air movement

The commercial CFD code StarCCM+ by CD-Adapco (version 9.004.009) was used. The CFD technique numerically solves the Navier-Stokes equations within each cell of the computational domain. Streamlines of fluid using numerical algorithms were solved, calculating complex simulations of turbulent flows, thermal distributions, air velocity and convection inside the buildings [26].

The solved equations of Fluid Dynamics applied in a geometrical domain are described, considering turbulence. A discrete manner is applied for calculating variables, at the nodes of a particular mesh and later represented. The continuity or mass conservation equation solved by the software used is expression (1).

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

where ρ is the fluid density, $\vec{v}$ is velocity and S_m represents the mass source contained in the control volume. Furthermore, momentum equation is considered by equation (2).

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

where p is the static pressure, τ the stress tensor defined in expression (3) and the gravitational (g) and outer forces (F) defined on the control volume, respectively. In (3) μ is the eddy viscosity and I is the unit tensor. A third term is considered for taking into account the effect of the expansion of volume.

$$\bar{\tau} = \mu\left[\left(\nabla\vec{v} + \nabla\vec{v}^T\right) - \frac{2}{3}\nabla\vec{v}I\right] \tag{3}$$

2.2.2 Computational characteristics

All calculations were performed with a 2.4 GHz processor, RAM memory 8 GB. The numerical method was solved by the finite volume technique with tetrahedral volume mesh. Thus, a grid independence study has been performed to find optimize number of cells for which the solution is independent. Seven different mesh sizes were tested ranging from 1.0m to 0.1m, obtaining from 19 208 to 890 363 control volumes for the larger and finer mesh sizes, respectively. For the 0.4 m mesh case, about 1.5 hours CPU time was needed to finish and for the fine mesh case, about 12 hours CPU. Convergence was evaluated after 5000 iterations and we adopted as convergence criterion the mean square error (RMS) value equal or lower than 10^{-5}, as recommended by CFX [27] and COST [28].

2.3 Boundary conditions

In the present model, once the volume was discretized in the mesh, the numerical models were chosen for the representation. 2D steady state model was implemented, with constant density fluid flow and second order segregated flow. The CFD analysis was carried on under a steady state. The gravity model was implemented, as it permits the inclusion of the buoyancy source terms in the momentum equations when using the segregated flow model. K-Epsilon turbulence model was used for representing turbulence, to predict velocity flow rate and the temperature distribution in the poultry house, evaluating the viscosity from a relationship between the turbulent kinetic energy (k) and dissipation of turbulent kinetic energy (ε) [8, 26, 29]. The entire domain was defined as a single fluid region (air). The geometry indicated above enclosed a volume domain in space defined by boundaries. A boundary is each surface that surrounds and defines a region in the model. After different initial trials, a symmetry plane was defined as a boundary condition. The three configurations were modeled considering the boundary conditions of the outlet velocities, and the solid surface boundary conditions (Table 1). Identic materials were selected for all geometries among the usually recommended for broiler houses. Air velocity was calculated from fan performance (considering that all fans are in operation) and a single outdoor temperature was considered. The production of sensible heat was estimated from CIGR equation [30], corresponding to animals of 5 weeks of age and 2.5kg of body weight. This heat production was introduced in the model as a uniform flux of sensible heat from the concrete floor.

Table 1. Boundary conditions specifications

Surface	Type	Properties
Windows	Outlet pressure	Outdoor temperature 21.5ºC
Fan center or 1.10m	Velocity inlet	Velocity and direction (-3.92m.s^{-1}) Internal temperature 22ºC
Fan side or 1.40m		Velocity and direction (- 6.87m.s^{-1}) Inside temperature 22ºC
Ceiling polystyrene sandwich panel ([1]e = 5cm, [2]λ = 0.033 W/m ºK)	Wall	[3] U = 0.58 W /m^2 ºK
Concrete walls consists: Precast concrete (e = 20cm; λ = 0.45 W /m ºK), plaster cement (e = 4cm; λ= 0.4 W/m ºK), insulating polyurethane (e = 2cm; λ = 0.04 W/m ºK)		U = 0.81 W /m^2 ºK
Concrete floor (e = 2cm; λ = 2.5 W/m ºK), insulating polystyrene (e=1.5 cm; λ= 0.046 W/m ºK)		[4] Heat flux sensible 101.94 W/m^2
Side wall symmetrical	Symmetry plane	

Where [1]e is thickness; [2]λ is thermal conductivity W/m ºK; [3]U is thermal transmittance W/m^2 ºK, [4]Production of sensible heat $\phi_s = 0.61\phi_{total} - 0.228 * t^2$, W; ϕ_s is sensible heat production; ϕ_{total} is total heat dissipation animal in animal houses, *t* is internal temperature - International Commission of Agricultural Engineering. 2002

2.4 Analysis of results

Theoretical comfort of animals was evaluated according to temperature, wind speed and ITV. To analyze the ITV formula proposed by Tao and Xin [15] was adapted considering constant relative humidity (100%) to determine the effect of temperature and velocity on the broiler comfort. It can be expressed as follows:

$$ITV = t_{db} * V^{-0.058} \tag{4}$$

where t_{db} is the dry bulb temperature ºC, *V* is velocity m.s^{-1}, defined in expression (4).

According to the equations proposed by these authors, an optimal ITV was considered to be within the range 18-25ºC [21, 22], outside these values we considered that animals would be in discomfort. We calculated that broilers can accelerate heat stress for 24 hours with ITV higher than 30.11ºC. ITV higher than 32.56ºC and 35.5ºC involve a critical thermal environment for broilers for 6 hours and 1 hour, respectively.

Therefore, we analyzed the CFD results to obtain averages standard deviations and spatial distributions of air velocity (m.s^{-1}), temperature (ºC), and ITV at 0.20m height (broiler height) and 1.4m too observe the behavior of air flow in different planes. The distribution and proportion of area in which animals could be subjected to discomfort due to improper temperatures (higher than 25ºC or lower than 18ºC) was determined [31, 32] An air velocity comfort range between 0.5 and 2.0m.s^{-1} was established [17 ,33] and ITV was thus calculated considering the limit for heat stress indicated above (higher than 30.11ºC). Finally, the three configurations analyzed in this study were compared.

3. Results and discussion

3.1 Sensitivity analysis

According to the calculation with various mesh sizes, it was observed that all mesh sizes predicted the velocity at 0.20m height with similar results. The maximum range of variation of the simulated data is lower than 13.61% of the mean velocity for mesh 0.4m with 122289 cells, 102150 tetrahedral volume elements and 303589 internal faces (Table 2), as shown for each configuration in Figures 3, 4 and 5, acceptable according to literature [34]. Figure 2 shows the independence between the mean velocities in the simulations with different mesh sizes. The mesh size has been changed from 1.0 to 0.1m. With mesh sizes smaller than 0.1m mean velocity at 0.2m high becomes constant, which is also considered a signal that the sensitivity analysis is satisfactory. The convergence criterion of RMS lower than 10^{-5} was accomplished for different mesh sizes.

Table 2. Volume mesh characteristics with mesh size 0.4m

Characteristics	Tunnel	Semitunnel	Improved Semitunnel
Number of cells	100585	102150	103245
Number of internal faces	298035	303589	306669
Number of vertices	119796	122289	123158

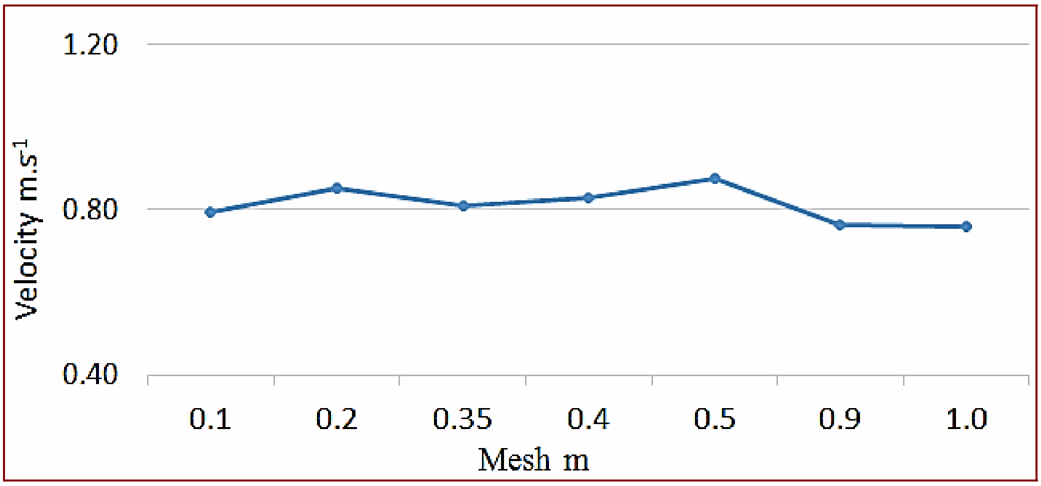

Figure 2. Mean velocity versus different mesh sizes

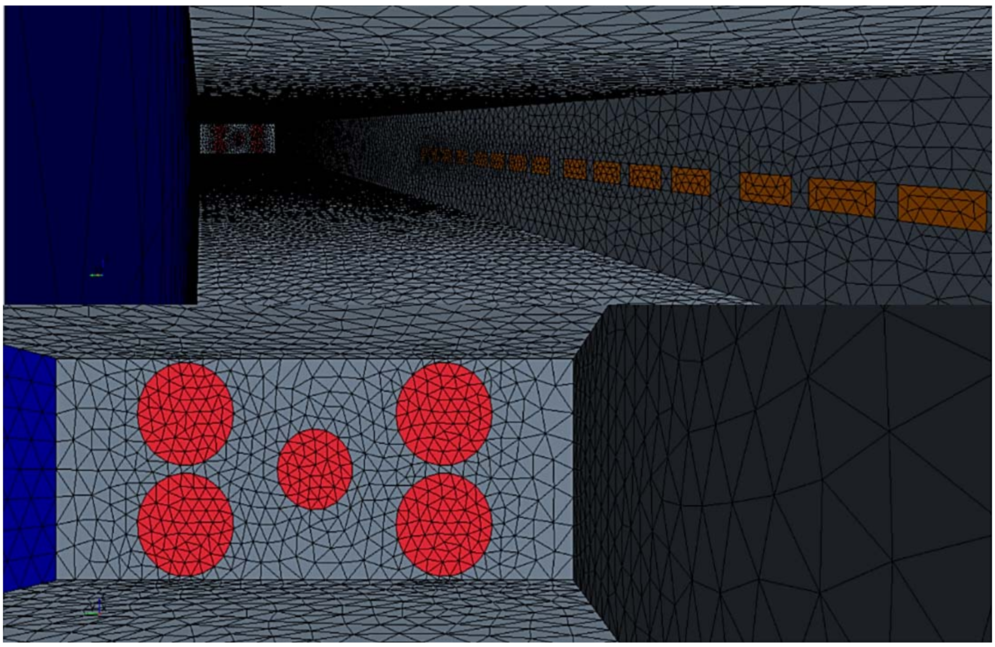

Figure 3. Tunnel mesh

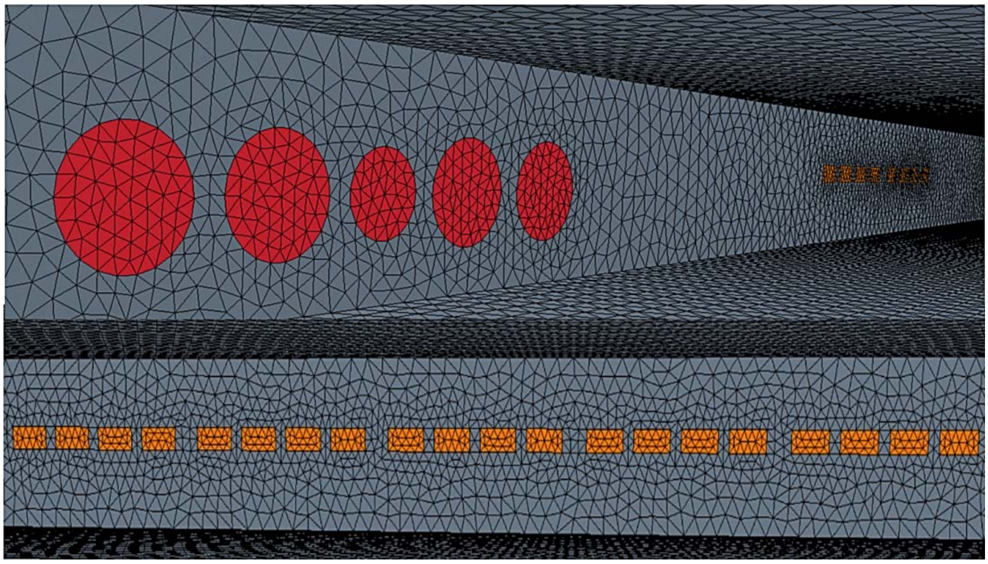

Figure 4. Semitunnel mesh

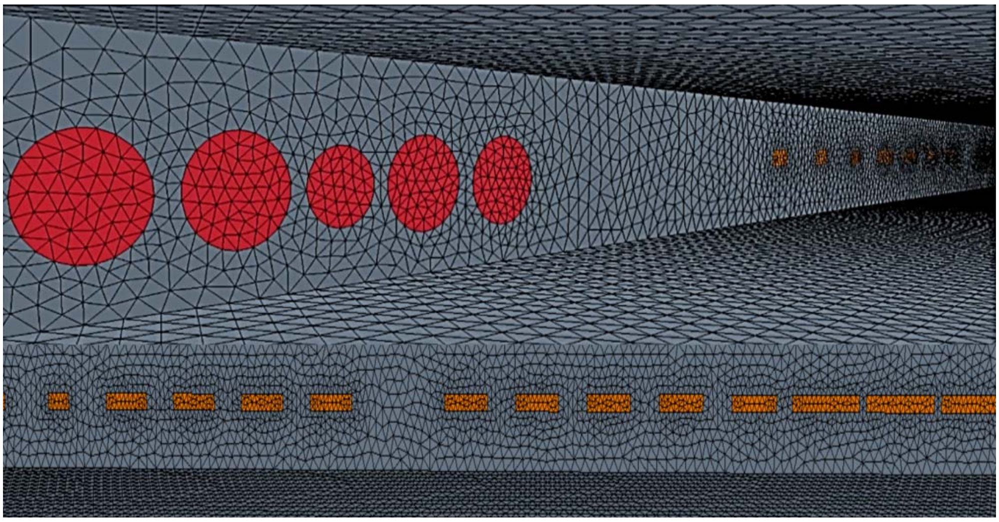

Figure 5. Improved tunnel mesh

3.2 Velocity

The distribution of air velocity (magnitude and direction) at 1.4m height is represented in Figure 6. As seen, in all configurations the presence of windows affected flow patterns. In all configurations, as expected, higher velocities were found near exhaust fans, whereas lower velocities occurred in the extreme walls of the building. As air enters the building through the windows, airflow is progressively accelerated, but as expected, velocity magnitude is lower in configurations ST and IST than in tunnel configuration.

Considering the velocity vectors in a 1.4m height plane, the air velocity increases at the nearest windows to the fans, whereas the lowest air velocity was found in the extreme wall of the poultry house ($0.03m.s^{-1}$). The airflow in the poultry house space is being accelerated progressively, and the air velocity values increase with windows nearest to the exhaust fans, concentrating the air flow in the center the building. In the case of IST, velocity vectors are more uniform than in ST, observing that windows distributed in blocks of two or three consecutive windows have more uniform velocity vectors than the window distribution in ST.

In tunnel the walls tend to divert the airflow from the side wall towards the center of the farm, resulting higher velocities towards the center of the poultry building and lower velocities near the side walls (Figure 7). In this work, the mean air velocity at the height of the broilers was $1.54 \pm 0.74 m.s^{-1}$. According to Yamamoto [35] a total air exchange should be done every 1 min 15 s through the entire length the building at high velocities (which is from 1.77 to 2.0m.s^{-1}). This velocity could provide a better environment for broilers mainly in warm periods, compensating to the addition of sensible heat generated by the broilers themselves. According to Simmons *et al*. [20], at about 2m.s^{-1} of air velocity total heat loss remains relatively constant if temperature increases, but below 0.5m.s^{-1} broilers are more exposed to heat stress.

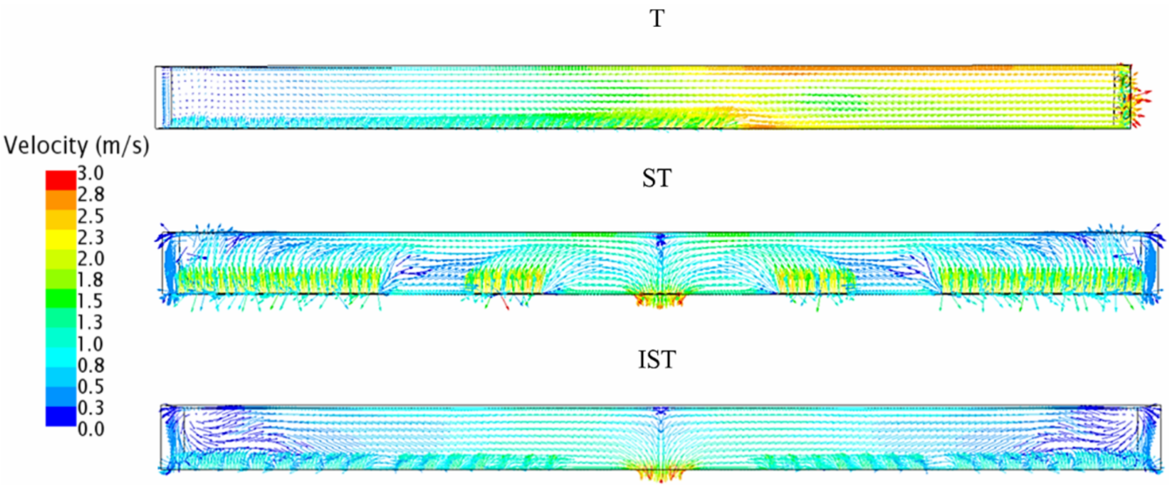

Figure 6. Velocity vector distributions1.4 m height plane: Tunnel (T), Semitunnel (ST) and Improved Semitunnel (IST) configuration

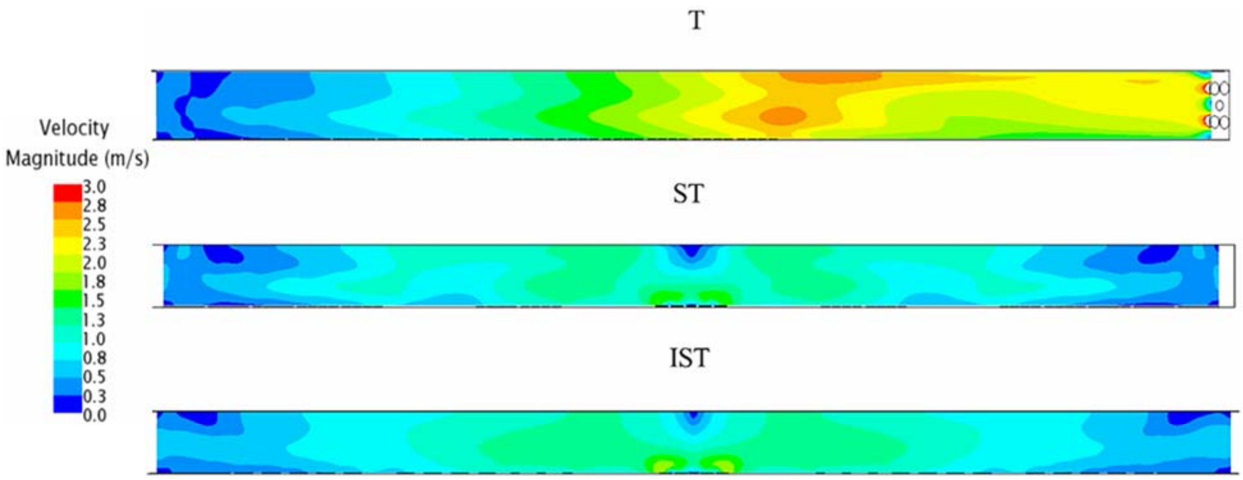

Figure 7. Tunnel (T), Semitunnel (ST), Improved Semitunnel (IST) Configuration velocity modulus: plane z: 0.2m

As shown in Table 3, the average air velocity at the height of the broilers in ST and IST is 0.83 ± 0.32 and 0.89 ± 0.30m.s^{-1} respectively. We also observed a higher percentage of area with air velocity ranging between 0.5 and 2.0m.s^{-1} (80.05% and 88.45% in ST and IST, respectively). On the contrary, in the Tunnel configuration only a 49.95% of the area achieves velocities between 0.5 and 2.0m.s^{-1}, while 50.05% of area has air velocities higher than 2.0m.s^{-1}, particularly near the fans.

Therefore, ST shows the highest proportion of surface with air velocity between 0.5 and 2.0m.s^{-1}. According to Blanes-Vidal *et al*. [7] the air velocity at the height of the broilers predicted by the CFD simulation was 0.54 ± 0.22m.s^{-1} in a cross mechanically ventilated broiler building. However, the air velocity obtained in this study is within the ranges provided by Bustamante *et al*. [4], who found similar results of air velocity both in CFD simulations (0.60 ± 0.56m.s^{-1}) and in direct measurements (0.64 ± 0.54m.s^{-1}) in poultry building with tunnel mechanical-ventilation. Also our values are similar with Feddes *et al*. [19], who found levels of air speed between 0.32 and 0.82m.s^{-1}. Finally, this fulfills the recommendations by Yahav *et al.* [17], who suggest velocities from 1.5 to 2m.s^{-1} when broilers are under very hot conditions (about 35ºC).

Table 3. Average ± standard deviation air velocity (m.s^{-1}) in the three configurations, comfort and discomfort area (m^2 and %) at 0.2m of floor

Configuration	Average velocity [m.s^{-1}]	Discomfort		Comfort	
		m^2	%	m^2	%
Tunnel	1.54 ± 0.74	450.48	50.05	449.51	49.95
Semi tunnel	0.83 ± 0.32	179.53	19.95	720.47	80.05
Improved Semitunnel	0.89 ± 0.30	103.94	11.55	796.06	88.45

3.3 Temperature

The average temperature at the height of the animals by CFD in Tunnel (Figure 8) is 23.55 ± 1.01ºC, and has comfort area of 91.37% with temperatures between 18 and 25ºC according Baeta and Souza [31], Tinôco [36] and Olanrewaju *et al.* [21]. However, Xin *et al.* [23] found in tunnel ventilation type at bird-level, lengthwise temperature gradients distribution across the building poultry, with the center slightly warmer (1.8ºC) than the sides, which is similar to the temperature gradients found by Osorio *et al.* [5].

The air temperature increases as it travels throughout the poultry house due to the addition of sensible heat produced by the broilers of 2.5kg (21.11 W animal^{-1}), however if air velocity changes, the broilers modifies the production of sensible heat. Increasing air velocity makes the animals increase the sensible heat loss, which is needed to cope with high temperatures. However, the energy used for removing heat is not available for growth and, as a result, the growth rate may be altered. According to Simmons et al. [20] for broilers in fifth week of age with ambient temperature of 29ºC and air velocity increasing from 1.01 to 3.05m.s^{-1}, the loss of sensible heat increases from 1.19 to 2.09 W kg^{-1} and the sixth week of age from 1.30 to 2.33 W kg^{-1}. On the contrary, latent heat loss decreases from 2.89 to 2.09 W kg^{-1} and 2.59 to 2.30 W kg^{-1} for the two respective groups of age. Consequently, the animals spend less metabolic energy to remove excess heat at higher air velocity [37]. Xin *et al.* [23], found temperature ranging from 24.9 to 29.6ºC with an average of 28.1ºC, and higher temperature near the ridge or ceiling of the poultry house than near the floor. The operation of the tunnel is efficient as long as the ambient temperature doesn't exceed 32ºC because at higher temperatures the heat introduced by ventilation can't be compensated with the effect of air velocity [38].

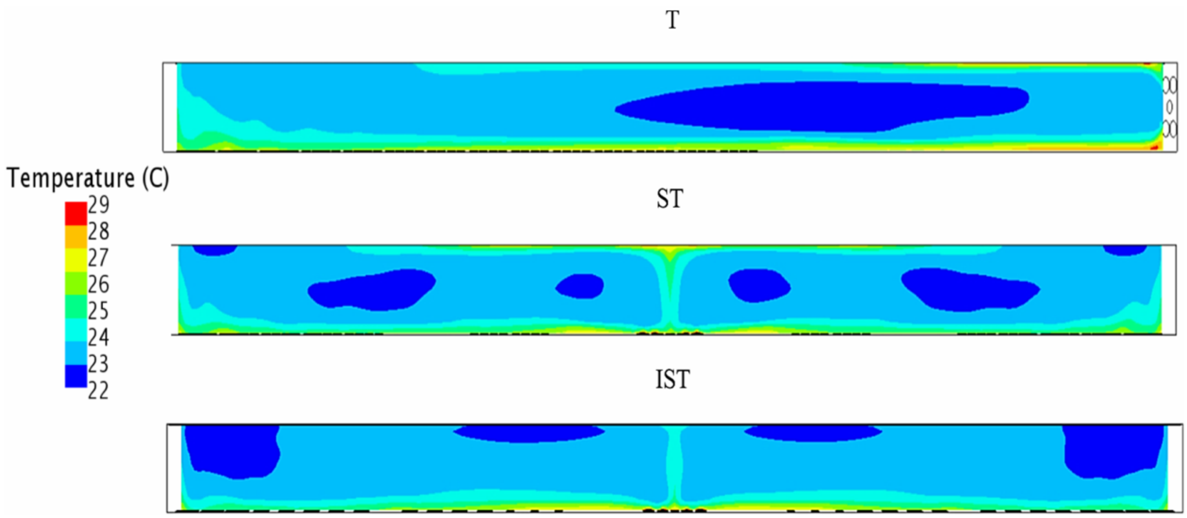

Figure 8. Temperature distribution the Tunnel (T), Semitunnel (ST) and Improved Semitunnel (IST) configuration at 0.2m height plane.

In the semitunnel the temperature decreases as a consequence of the different configuration of air velocity, and was on average 23.45 ± 0.82ºC. The comfort area of temperature at 0.2m above floor level was 93.03%, concentrating the largest amount of hot air in the central part of the building. Besides, in the improved semitunnel configuration air entrances were distributed more homogeneously, as well as temperature at the height of the broilers [39]. IST had the lowest average temperature (23.37 ± 0.79ºC) of the three configurations analyzed, and the greatest comfort area (94.52% of total surface). Contrarily, the tunnel configuration had a discomfort area of 8.63% (Table 4). The average temperature obtained in this study are similar to Mostafa *et al*, [12], who found 23.86ºC at the height of the broilers, and also were in accordance with Blanes-Vidal *et al.* [40], who found the minimum temperature of 23.5ºC and the maximum of 26.3ºC in the poultry house. On the contrary, Xin *et al.* [23] found bird-level average temperature of 29.3ºC and described a higher vertical temperature gradient in conventional model compared with tunnel model from the bird-level to the 3m height. Finally, Medeiros [41] obtained greater yield with temperature range from 21 to 29 ºC, air velocities from 1.5 to 2.5m.s^{-1}, and broilers from 21 to 42 days showed higher performance with temperatures between 21 and 27 ºC with air velocities between 0.5 and 1.5m.s^{-1}.

Table 4. Average ± standard deviation temperature (ºC) in the three configurations, comfort and discomfort area (m^2 and %) at 0.2m of floor

Configuration	Average temperature [ºC]	Discomfort		Comfort	
		m^2	%	m^2	%
Tunnel	23.55 ± 1.01	77.67	8.63	822.33	91.37
Semitunnel	23.45 ± 0.82	62.69	6.97	837.31	93.03
Improved Semitunnel	23.37 ± 0.79	49.30	5.48	850.70	94.52

3.4 Index of temperature and velocity – ITV

In the tunnel configuration, the average ITV at 0.2m height was 23.24 ± 1.54ºC (Table 5), observing higher values in the opposite extreme to the fans in the building. This is a consequence of the low air velocity and high exchange of sensible heat in these areas. The outside air in the current model (21.5ºC) reduces the increase of temperature inside the poultry house, which depends on the location of the fans and distributions of windows. In Figure 9 it can be observed that in the semitunnel (average ITV of 23.85 ± 1.18ºC) the higher ITV was registered at the center of the poultry building, which concentrates the heat produced by broilers in the building through the exhaust fans. However, in the improved semitunnel (average ITV 23.64 ± 0.98ºC) the distribution of ITV was more homogeneous as a consequence of the distribution of inlet windows and fans. This distribution achieved the highest comfort zone according to ITV (90.35% of total area has ITV below 25ºC).

Considering the previous results, tunnel ventilation system is frequently used for hot and humid climates by turbulent flow and the sensitivity of the energy that is important in the lateral direction to form a tunnel of high velocity flow that goes through the poultry building and helps the system birds to cool off with a greater loss of sensible heat, removing the warm air inside the farm and improving index of temperature and velocity to maintain a productive environment.

Table 5. Average ± standard deviation ITV (ºC) in the three configurations and area (m^2) at 0.2m of floor

Configuration	Average ITV [ºC]	Expressed in m^2 area ITV			
		Discomfort	24 hours	6 hours	1 hour
		ITV >25 [ºC]	ITV >30.11[ºC]	ITV >32.56 [ºC]	ITV >35.5 [ºC]
Tunnel	23.24 ± 1.54	145.51	0.27	0.0	0.0
Semitunnel	23.85 ± 1.18	141.94	1.58	0.04	0.01
Improved Semitunnel	23.64 ± 0.98	86.78	0.44	0.05	0.01

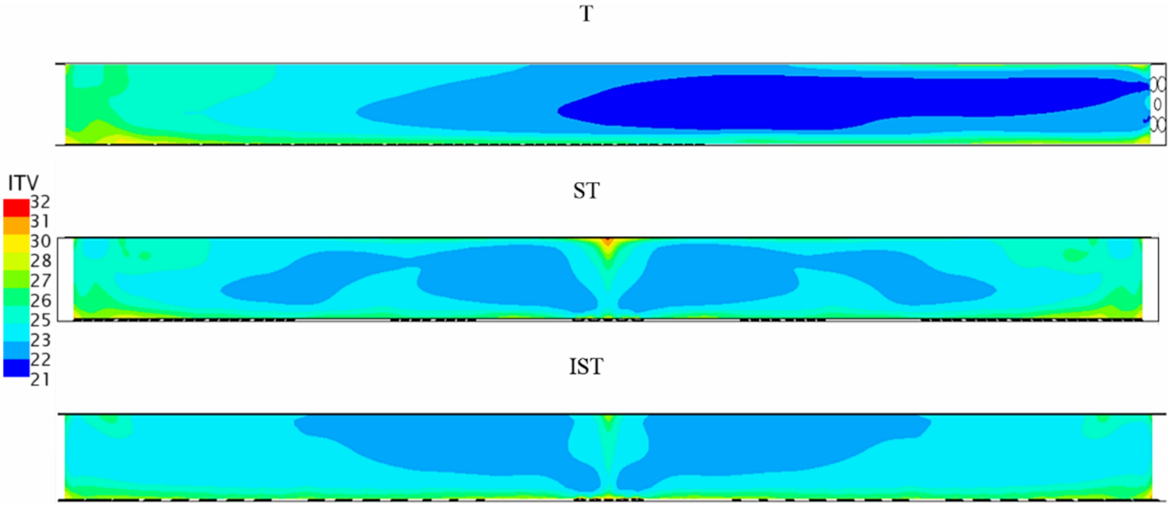

Figure 9. ITV model distribution the Tunnel (T), Semitunnel (ST) and Improved Semitunnel (IST) configuration

4. Conclusion

Determining comfort in poultry farms is a complex task, which can be assessed with the use of computational fluid dynamics modeling. In this paper a methodology to quantify the parameters controlling the comfort of the animals is presented. This methodology is implemented for designing buildings with adequate conditions for animal welfare characteristics. Three different poultry house designs were analyzed using CFD. These simulations are useful for investigating the behavior of the location of windows and fans and their effect on the parameters of comfort. A system that aims to improve the mechanical ventilation for depression has been analyzed to improve comfort broilers of six weeks with 2.5kg. The results of the three case studies are compared to determine the effect of temperature. Some conclusions can be achieved:

The CFD shows the calculation of turbulent model predicting the air flow and the fields of temperature, which can be used for various practical purposes.

The poultry building improved using the semitunnel configuration. At 0.20m more homogeneous values of average velocity of $0.89 \pm 0.32 m.s^{-1}$ and air temperature of 23.37 ± 0.79ºC with greater comfort area of velocity 88.45% and temperature 94.52%. Although ITV is lower on average using the tunnel type (23.24 ± 1.54ºC), the comfort zone is highest with IST (90.35% of total area with ITV lower than 25ºC), These results suggest that the improved semitunnel configuration may perform better than the tunnel and semitunnel.

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