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Computational Fluid Dynamics (CFD) Analysis of Two Types of Greenhouse in Humid Climates in Optimizing Air Flow Distribution for Organic Food Production in Times of Pandemic

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Abstract. In a greenhouse we find multiple variables that have great impacts on crops, for this a CFD model is built to simulate microclimate distribution and obtain optimal climate control for the growth of the crop. Analyzes of solar heat gains, heat losses, and temperature and air distributions for each special moment provide a good guide for product selection. In the CFD simulation the greenhouse volume and wind speed will be obtained for an optimal temperature distribution. The time required for maintenance, the need for sensor calibration, natural deterioration, and unexpected failures will have to be taken into account. The analyzes show a comparison between various variations of the air flow velocity in 0.5 m / s, 1 m / s and 1.5 m / s in two different models of greenhouses, which we will obtain the optimal model for the development and elaboration of a greenhouse. Demonstrating the efficiency of CFD models for the design, simulation and application of greenhouses.

1. Introduction

At present, a variety of climate problems arise, due to human-caused effects such as environmental pollution from the industrial sector, food security, and stable food supply [1]. The land from agriculture presents a variety of contamination, such as chemicals in water, soil among others [2]. Given this, greenhouses provide the best environmental conditions for plant development compared to most agricultural production systems [3].

Due to the distrust and insecurity of organic products, it is necessary to focus on a growing interest in adopting urban agriculture or controlled environment agriculture [1]. Therefore, a greenhouse is an effective strategy for the increase of modern agriculture, generating the appropriate microclimate for crops [4]. Due to the pandemic, the consumption of ideal foods based on its antivirals is essential, one of them, broccoli, which aims to stimulate the immune system and protect the body against infectious diseases [5], is a vegetable high in vitamin A, C, and E. Contains antioxidants like sulfate that can fight viruses and support the immune system [6].

Vitamin C is a determining factor to improve immunity, both in children, adults and the elderly, vegetables such as broccoli is one of the stimulants of immunity [7]. Also known as ascorbic acid, which is a soluble vitamin that is commonly found in citrus and diet foods [8]. Broccoli is a phytochemical substance found in fruits and vegetables that has a protective property against cancer; has as a percentage of water in boiled broccoli 91%, potassium content of 100-200 (mg / serving) [9]. For this reason,

simulations of models with meteorological parameters such as wind speed are ideal, which allow quantifying the short and long-term changes of the broccoli vegetable cycle [10].
The hydroponic greenhouse is of the passive type, therefore the climate control method used is natural ventilation [11], which is essential for the indoor vegetable production structure, which allows managing the best indoor climate by consuming minimum energy [12]. Greenhouses show variables that define environmental conditions, temperature, CO2 concentration and relative humidity, which are fundamental for the progress and expansion of greenhouses [13]. The outside air is essential for the replacement of the CO2 absorbed by the plants for the development of photosynthesis [14]; the deficient movement of the air, generates in certain areas of the greenhouse a deficiency of temperature and humidity, which leads to the crop yield not being the most essential [13]. For this reason, a suitable greenhouse design must be carried out to guarantee a minimum energy consumption and that it remains profitable with respect to agricultural production systems [15]. Due to this, for the schematization of a greenhouse, it is essential to carry out a study on the amount of humidity and optimal designations of the dehumidifiers [16], since these can help us in reducing the humidity rate and process various calculations, generating thus the relationship on the variables that influence various conditions [17].
In this and many cases, the CFD is a widely used tool for the prediction of various climates within greenhouses [3], which has been used for the study and prediction of difficult mechanisms of natural ventilation, due to its excellence in the prediction of complex airflow patterns [11]. CFD simulations can correctly predict the greenhouse effect in the microclimate [3].
In the present research work we will analyze the behavior of the air flow in two different models of greenhouses for the optimal distribution of humidity, temperature and amount of CO2 in a tunnel-type greenhouse and a triangular-type greenhouse, modifying the entry speeds of the air flow at 0.5 m/s, 1 m/s and 1.5 m/s using the CFD program.

2. Analysis and methods

2.1. Turbulent kinetic energy
Turbulent kinetic energy [18] is defined as:

$$k = \frac{1}{2}(\overline{u}'^2 + \overline{v}'^2 + \overline{w}'^2) \quad (1)$$

Boussinesq developed a closure proposal for the Reynolds tensor, who through an analogy with the Stokes model for viscous molecular stresses showed that:

$$-\rho\overline{u}_i'\overline{u}_j' = u_t\left(\frac{\partial\overline{u}_i}{\partial x_j} + \frac{\partial\overline{u}_j}{\partial x_i}\right) - \frac{2}{3}\,\rho k\delta_{ij} \quad (2)$$

Where u_t is the turbulent dynamic viscosity, δ_{ij} Kronecker delta and k the turbulent kinetic energy, which is defined as:

$$k \equiv -\frac{1}{2} * \overline{u_i'u_i'} = \frac{1}{2}(\overline{u'u'} + \overline{v'v'} + \overline{w'w'}) \quad (3)$$

Turbulent dynamic viscosity is a property that depends on the nature of the flow itself, and not on the fluid as in the case of molecular dynamic viscosity.
Substituting equation (2) in the Reynolds transient mean equations, the filtered Navier-Stokes equations are obtained:

$$\frac{\partial\rho\overline{u}_i}{\partial t} + \frac{\partial\rho\overline{u}_i\overline{u}_j}{\partial x_j} = -\frac{\partial\overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial\overline{u}_j}{\partial x_j} + \frac{\partial\overline{u}_j}{\partial x_j}\right) + \mu_t\left(\frac{\partial\overline{u}_j}{\partial x_j} + \frac{\partial\overline{u}_j}{\partial x_j}\right) - \frac{2}{3}\,\rho k\delta_{ij}\right] + \bar{f}_i \quad (4)$$

Since the turbulent kinetic energy depends only on the contour of the Reynolds tensor, the deviation of the surrounding term results in its gradient.

$$\frac{\partial}{\partial x_j}\left(\frac{2}{3}\rho k \delta_{ij}\right) = \frac{2}{3}\frac{\partial \rho k}{\partial x_i} \quad (5)$$

In this way, it can be incorporated into the term of the pressure gradient of equation (3.9) generating a modified pressure X [19]:

$$\overline{p^*} = \overline{p} + \frac{2}{3}\rho k \quad (6)$$

According to Tennekes and Lumley:

$$\underbrace{\frac{\partial(\rho k)}{\partial t}}_{a} + \underbrace{div(\rho k U)}_{b} = div(\underbrace{-\overline{p}'\overline{u}'}_{c} + \underbrace{2\mu\overline{u}'\overline{s}'_{ij}}_{d} - \underbrace{\rho\frac{1}{2}\overline{u}'_i * \overline{u}'_i\overline{u}'_j)}_{e} - \underbrace{2\mu\overline{s}'_{ij} * \overline{s}'_{ij}}_{f} - \underbrace{\rho\overline{u}'_i\overline{u}'_j * s_{ij}}_{g} \quad (7)$$

Where A is the rate of change of the turbulent kinetic energy K, B is the transport of K by convection, C is the transport of K by pressure, D is the transport of K by viscous forces, E is the transport of K by the Reynolds stress, F is the dissipation rate of K and G is the rate of production from K. In which the appearance of the quantities on the right side of the equation K indicates that the alteration in turbulent kinetic energy is governed mainly due to turbulent interactions [18].

2.2. Greenhouse design

Two greenhouse models with different geometries were created in AutodeskInventor 2020 for CFD Simulation, the first 3D CAD model as shown in figure 1 is a tunnel type greenhouse that will have the dimensions of 1890mm x 1421mm x 2000mm and the second 3D CAD model is a triangular type greenhouse as shown in figure 1 that will have the dimensions of 1100mm x 1000mm x 2000mm.

(a) **(b)**

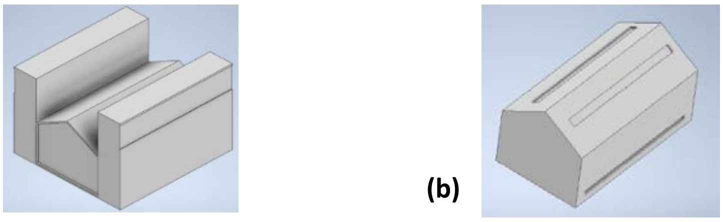


Figure 1. Tunnel (a) and triangular (b) type greenhouse.

2.3. Numerical study

The numerical calculations were carried out with the SimScale CFD simulator. The K-omega turbulence model is used to show a turbulent flow model. Air properties and initial conditions are shown in table 1 and table 2.

Table 1. Initial conditions

Properties	**Value**
Gauge pressure	1e+5 Pa
Velocity	0.5, 1, 1.5 m/s
Turb. Kinetic energy	3.75e-3 m^2/s^2
Specific dissipation rate	3.375 1/s

Table 2. Air flow properties

Properties	**Value**
Kinematic viscosity (v)	0.000015295 m^2/s
Density (ρ)	1.1965 kg/m^3

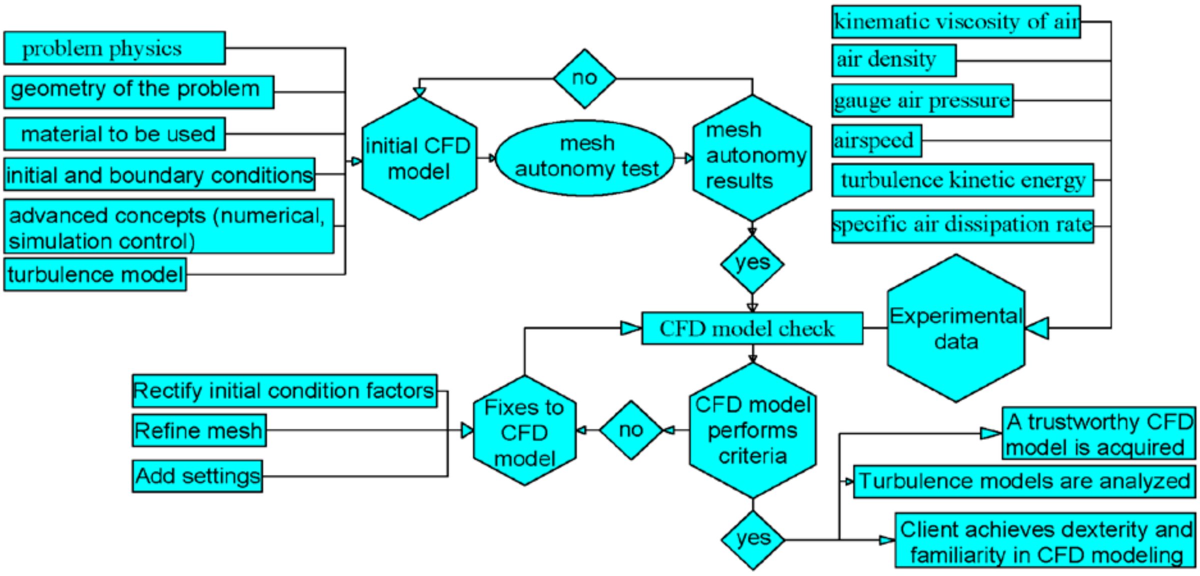


Figure 2. Procedure flow chart for simulation in SimScale CFD.

3. Discussion of results

To observe how the air flow distribution varies, we proceed to apply speeds with gradients of 0.5 m/s. The first speed to place in the software for the desired analysis is 0.5 m/s. The air flow obtained in the triangular type greenhouse figure 3(a), gets a top speed of 5.836e-1 m/s and the tunnel type greenhouse figure 3(b), get top speed 1.176 m/s.

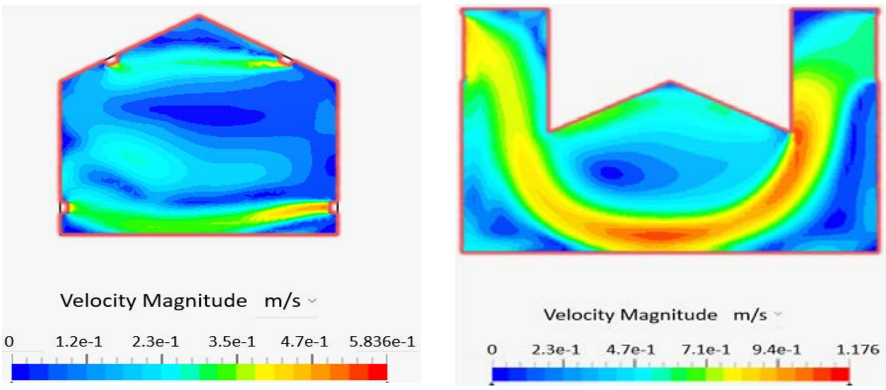
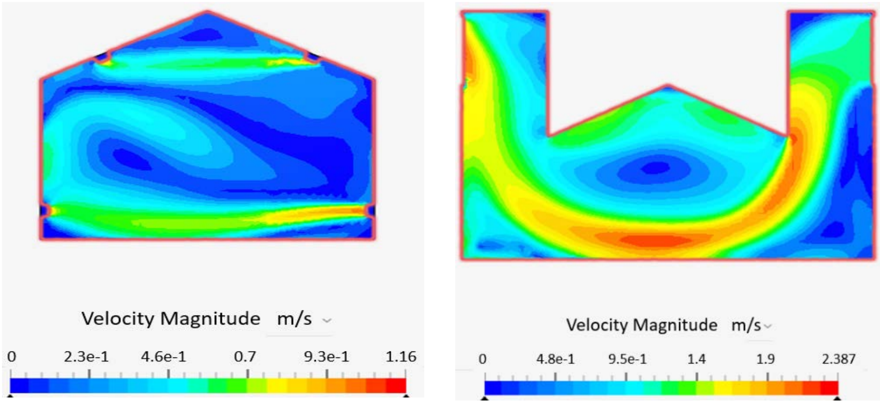


Figure 3. Air flow at 0.5 m/s entrance speed in triangular type greenhouse (a) and tunnel type (b).

(a) (b)

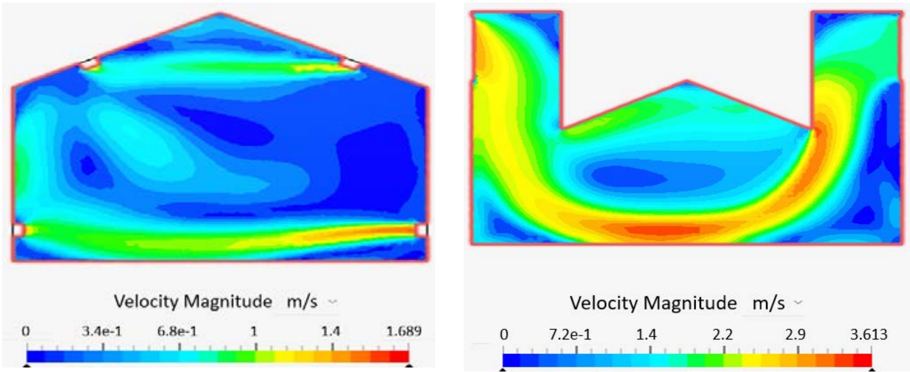
Airflow velocity profile with inlet velocity of 1 m/s. The triangular type greenhouse figure 4(a), gets a top speed of 1.16 m/s and the tunnel type greenhouse figure 4(b), gets a top speed of 2.387 m/s.



(a) **(b)**

Figure 4. Air flow at 1 m/s entrance speed in triangular type greenhouse (a) and tunnel type (b).

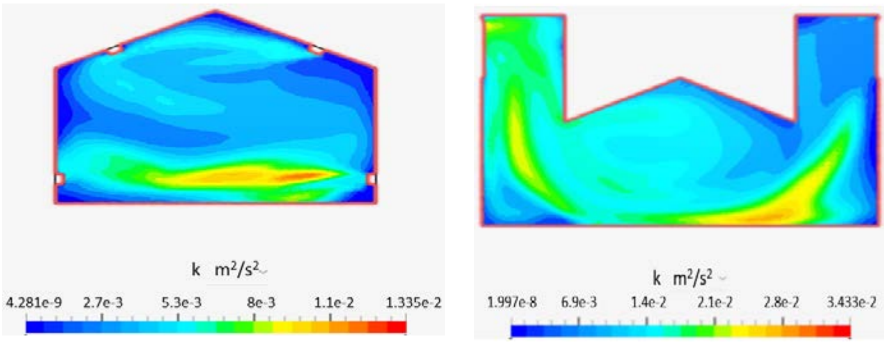
Airflow velocity profile with inlet velocity of 1.5 m/s. The triangular type greenhouse, figure 5(a), obtains a maximum speed of 1.689 m/s and the tunnel-type greenhouse, figure 5(b), obtains a maximum speed of 3.613 m/s.



(a) **(b)**

Figure 5. Air flow at 1.5 m/s entrance speed in triangular type greenhouse (a) and tunnel type (b).

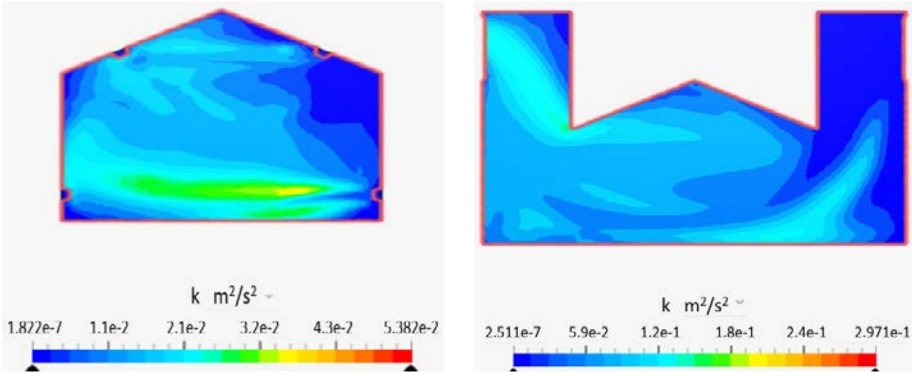
To observe the behavior of turbulence in the greenhouse, the entry velocity is 0.5 m/s. The triangular type greenhouse figure 6(a), obtains a maximum turbulence of 1.335e-2 m^2/s^2 and the tunnel type greenhouse figure 6(b), obtains a maximum turbulence 3.433e-2 m^2/s^2.



(a) **(b)**

Figure 6. Turbulent flow with an inlet velocity of 0.5 m/s in triangular type greenhouse (a) and tunnel type (b).

Turbulence profile with velocity of 1 m/s. The triangular type greenhouse figure 7(a), obtains a maximum turbulence of 5.382e-2 m^2/s^2 and the tunnel type greenhouse figure 7(b), obtains a maximum turbulence of 2.971e-1 m^2/s^2.

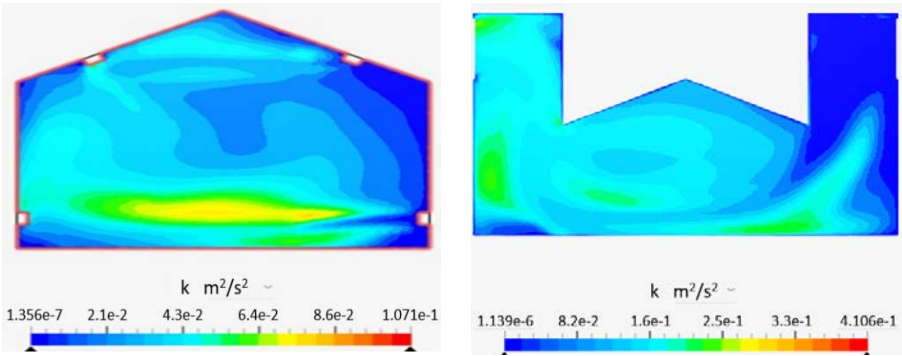


(a) **(b)**

Figure 7. Turbulent flow with an inlet velocity of 1 m/s in triangular type greenhouse (a) and tunnel type (b).

The velocities 0.5 m/s, 1 m/s y 1.5 m/s in the tunnel type greenhouse figure 1(a), we obtain that the speeds doubles in the lower zone of the greenhouse and in the triangular type model figure 1(b) the air flow in the zone lower is constant.

Turbulence profile with speed of 1.5 m/s. The triangular type greenhouse figure 8(a), obtains a maximum turbulence of 1.071e-1 m^2/s^2 and the tunnel type greenhouse figure 8(b), obtains a maximum turbulence of 4.106e-1 m^2/s^2. The most optimal air turbulence profile is figure 7(a) with 5.382e-2 m^2/s^2 allowing the lower zone to have air renewal for organic products.



(a) **(b)**

Figure 8. Turbulent flow with an inlet velocity of 1.5 m/s in triangular type greenhouse (a) and tunnel type (b).

4. Conclusions

To analyze the optimal location for the design of the ventilation grilles, several parameters must be considered such as the speed of the incoming wind, location of air inlets and outlets. In this article, an analysis was carried out of two types of greenhouses, triangular type and tunnel type, which present different shapes in the structure and the same direction of entrances and exits of natural ventilation, the greenhouses were simulated in the SimScale CFD obtaining graphs and parameters of average area on the different characteristics of the speed of the air flows that is concentrated in the greenhouse. Using the preliminary results, we obtain the effects of air conditions on the velocity and turbulence profiles. Through the types of greenhouses, we will modify the input speed parameters in 0.5 m/s, 1m/s y 1.5m/s to obtain the velocity profiles inside the greenhouse. It is concluded that the most optimal greenhouse for food production is the triangular type greenhouse, figure 4(a), with an entrance velocity of 1m/s since it allows the constant distribution of air with 0.8 m/s and with the turbulence profile in the triangular type greenhouse in figure 7(a), with 5.382e-2 m^2/s^2 since in the lower zone of the greenhouse where the organic products will be located, they will have a constant air flow; therefore, it is necessary to eat foods that help preserve the immune system since COVID-19 will affect the elderly and people with weakened immune systems.

5. References

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