LITERATURE REVIEW OF NATURAL VENTILATION

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Natural ventilation is a passive technique for greenhouse cooling that can be applied in Mexico due to its relatively cheap cost, comparing to other cooling methods; however, it has not been completely analyzed and understood and moreover in Mexico where the number of growers producing crops under cover started increasing recently. Studies on natural ventilation have used several approaches to relate mainly ventilation rate response to other variables under many assumptions.

This report summarizes the elements considered as foundations to comprehend the phenomena involved in natural ventilation: processes and variables analyzed, main methods applied, instruments used, and results found.

- Introduction

The aim of study the natural ventilation is mainly to know the air volume that is actually being exchanged per time unit, examining both the environmental conditions at that time and some variables concerning to greenhouse geometry, such as area of vents, length, and volume, among others. We can express this air exchange rate in terms of the greenhouse volume, as follows:

$$N = 3600 \frac{G}{V_g} \quad (1)$$

where:

N = hourly air exchange rate, h^{-1}
G = volumetric flow rate, m^3/s
V_g = greenhouse volume, m^3

Bourlad *et al* (1996) states that air exchange rate is not generally affected by the wind direction; but if so, it is slightly and depends on the position and distribution of vents. Teitel and Tanny (1999) refer to many researchers that have defined and tested the two main causes of natural ventilation: wind speed and buoyancy forces. Ventilation rate is closely related to wind speed for values higher than 2 m/s, whereas buoyancy effect predominates for wind speed lower than 1 m/s (Sase *et al*, 2002). A theoretical model that considers both variables is based on the equation proposed by Bourlad *et al* (1996), whose general form is shown:

$$G = A_0 \left(a_1 \frac{H}{2} \Delta T + a_2 V^2 \right)^{1/2} \quad (2)$$

where:

A_0 = coefficient affected by exchange surface and discharge coefficient of vents, m^2
a_1 = buoyancy constant, $m^2\ s^{-2}\ ^oC$

a_2 = wind coefficient, dimensionless
H = height of opening above the floor, m
ΔT = difference temperature between outside and inside air, ºC
V = air velocity, m s^{-1}

- Methods

Many researchers have used the following techniques to analyze the natural ventilation: energy balance (Kozai *et al*, 1980), wind tunnel experiments (Sase *et al* 1984), and tracer gases techniques (Bot, Fernandez, Bailey, among others). Alternatively, Campen and Bot (2003) applied Computational Fluid Dynamics (CFD) in three dimensions to determine the specific aspects of ventilation, comparing experimental data using tracer gases techniques. Therefore, as seen in all the cases, most studies compare two methods to validate the models and to verify the results found.

Baptist *et al* (1999) did a wide experimental work using decay (static) and continuous (dynamic) injection for tracer gases technique, which is a method based on a mass balance of a tracer gas within the greenhouse, assuming that ventilation rate is proportional to the rate of loss of N_2O, nitrous oxide, a suitable gas for this kind of experiment because it does not interfere with the crop and can be sensed due to its undetectable quantities in the external air. Relationships between the ventilation rate and measured variables are then statistically analyzed for the case of a pure experimental work, but if some models are studied, researchers proceed to find coefficients necessary to predict the behavior of ventilation rate.

Applying this method implies to measure a large number of variables, having disadvantages because an extreme variation of one factor can produce a large effect in final result (Baptista *et al*, 1999).

Energy methods are based on the fact that when accumulation of energy within the greenhouse has reached certain point, ventilation tends to remove the energy and to avoid excessively high temperatures as a result of a natural balance. Fernandez and Bailey (1992) suggested an energy balance composed of five members: energy removed by processes of leakage, ventilation, solar energy, thermal losses and stored energy; however, most factors can be added as long as they do not present many difficulties when either measured or determined. Therefore, by some assumptions, ventilation rate is a variable involved in this energy balance, providing an alternative way to determine it.

- Instrumentation

Fernandez (1992) proposed for his experiment, the main variables to be measured in the tracer gases techniques and the sensors used to do so. In general, they are classified into those parameters measured inside the greenhouse and the meteorological parameters, and even though the list below is for a specific research, it provides a good idea of data required.

Parameter	Sensor
Greenhouse	
Solar radiation	Pyranometer and Quantum
Radiation reflected from the crop	Pyranometer
Air temperature	Aspirated platinum resistance thermometer
Crop temperature	Radiation thermometer
Leaf temperature	Platinum resistance thermometer
Soil temperature	Thermistor
Cover temperature	Radiation thermometer
Dry and wet bulk temperature	Platinum resistance thermometer
Dew point	Condensation hygrometer
N_2O concentration	Infrared gas analyzer
Meteorological station	
Solar radiation	Pyranometer
Total radiation	Pyrradiometer
Air temperature	Aspirated platinum resistance thermometer
Relative humidity	Capacitive hygrometer
Wind speed	Cup anemometer
Wind direction	Wind vane

- Results

Until now, I have presented a general view of natural ventilation as an important process of controlled environment agriculture, ventilation rate as variable of interest, and traces gases techniques as a method to find experimental data of air exchange rate. Therefore, in this section specific results are given according to the relationships studied by each researcher.

Teitel and Tanny (1999) worked on the response of air temperature and humidity ratio inside the greenhouse to the opening of roof vents. Their objective was to predict the behavior of those variables within a period relatively short after roof windows were opened, developing a model and validating it against experimental data in a full-scale greenhouse. They found that both temperature difference and humidity ratio decay under an exponential relationship with respect to time, whose extinction coefficient depends strongly on wind speed that not only induces to reach the steady state in a shorter time, but also reduces the value of this state.

Fernandez *et al* (1992) carried out experiments in a four-span Venlo type greenhouse to determine the ventilation and leakage rates by applying tracer gases techniques and comparing with an energy balance model to validate the results. He stated that there is no difference in the results found using either the effective (without crop) or physical (with crop) greenhouse volume. Results showed a strong linear relationship between wind speed and ventilation rate and correlation is closer to one as the vent opening angle decreases, whereas leakage rate is not affected by wind speed at all. At the end, he obtained a fitted curve of the ventilation rate as a function of the vent opening angle, probably a good conclusion for a specific experiment, but not to be extended to other cases. Energy balance model exhibits a good agreement mainly at high values of ventilation rate because the error linked to other non-considered components of energy is higher for low air exchange rates. A disadvantage of this method is the large number of variables that require to be measured, and as a consequence, the instrumentation needed.

Bourlad *et al* (1996) measured various components of the air exchange rate at the level of vent opening, analyzed them along the opening surface, and compared them with the results obtained from tracer gases techniques. Results are presented as distributions of the components (wind velocity and temperature difference, normalized) along a 32-m roof window of a two span greenhouse, and used to predict the ventilation rate. The technique applied in this experiment allows separating the mean and turbulent components of the variables. Additional useful information provided is that wind effect varies inversely to the surface of the experimental greenhouse, being the smallest for a "quasi-infinite greenhouse".

Sase *et al* (2002) determined coefficients to model the ventilation rate in a small open-roof greenhouse, using two driving forces assumption and comparing with a sensible heat balance. Hence it was found that observed and predicted temperature difference throughout the day agreed closely at small openings; however, predicted values were overestimated for large vent opening areas. Also, results allow us to see that temperature difference decreases as ratio opening area/floor area increases and that ventilation rate responses linearly to wind speed, although this tendency does not apply for low wind speed. According to the theoretical results, inside net radiation affects significantly the ventilation rate and ratio opening area/floor area relationship, which is linear as well.

Wang *et al* (1999) analyzed the air speed profiles within a naturally ventilated greenhouse, dividing it into two sections: with and without crop. Air speed inside the greenhouse was measured with a sonic anemometer, which has a good accuracy (1.3%) and fits appropriately to the inside air speed measured (0-1 m s^{-1}). Regardless the location of anemometers, inside air velocity depends linearly on the external wind speed, and it was obtained regressions for each position. For same external wind speed, inside air velocity tends to be smaller at the side with crop, which suggests the presence of resistance produced by plants. Using the model proposed by Bourlad and Baille (1995), inside air velocity exhibits a linear tendency with respect to ventilation rate, at all locations.

An experimental work of Baptista *et al* (1999) contains wide information concerning tracer gases techniques. It presents in detail the two procedures that were applied and the instruments used to measure the ventilation rate: continuous injection (static method) and pulse injection (dynamic method). It includes many assumptions and results found as well in the works exposed above; but it adds two important facts not prior stated. First, it considers a time delay between the moment of wind change and its significant effect on ventilation rate and does an experiment to determine it, finding that for higher wind speed, the time delay is shorter. Second, it suggests that wind direction does affect air exchange rate when that particular experimental greenhouse undergoes northeast and southeast winds instead of typical southwest wind direction; however, none conclusions could be drawn on this due to a lack of repeated measurements. In general, models obtained overestimate ventilation rates at high wind speed, but this work can be a very good reference on tracer gases techniques because of its step-by-step explanation of procedure.

- Conclusion

This literature review had as an objective to introduce me into the development of recent research on natural ventilation. As a conclusion, I can summarize some aspects as follows:

1. Natural ventilation is a passive technique for greenhouse cooling.
2. The main variable of interest is the ventilation rate.
3. Ventilation rate is composed by two driving forces that are a consequence of two effects: wind speed and thermal buoyancy.
4. Variables involved in natural ventilation have a mean component and turbulence.
5. Phenomenon can be analyzed by energy balance.
6. The aim of all experiments is to predict the ventilation rate as a function of the variables that can be easier measured (temperature difference, net radiation, wind speed, etc.)
7. Tracer gases techniques have been widely used to validate the models by comparing with experimental data.
8. Tracer gases techniques assume a proportional decreasing between tracer gas concentration with respect to time and air exchange rate.
9. Relationship between ventilation rate and external wind speed is linear for wind speed higher than 1-2 m s^{-1}, whereas at lower wind speed buoyancy effect governs the phenomenon.
10. Tracer gases techniques allow us to analyze other important effects of natural ventilation such as leakage, air speed profiles within the greenhouse, and time in order for a variable to reach a steady-state, among others.

References

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