2014 2nd International Conference on Agriculture and Biotechnology
IPCBEE vol. 79 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V79. 8

Gradients of Temperature and Relative Humidity of Air in Greenhouse with Wireless Sensor Network

Thais Queiroz Zorzeto [1 +], Paulo A Martins Leal [2], Victor de Souza Coutinho [3], Haroldo Ferreira de Araújo [1]

[1] PhD Student, College of Agricultural Engineering (FEAGRI), State University of Campinas (UNICAMP).
[2] College of Agricultural Engineering (FEAGRI), State University of Campinas (UNICAMP).
[3] Undergraduate Student, College of Agricultural Engineering (FEAGRI), State University of Campinas (UNICAMP).

Abstract. The distribution of temperature and relative humidity of air is one of the factors that influence the uniformity of crop growth in greenhouse. The heterogeneity of these elements distribution was evaluated in a greenhouse with different combinations of mechanical and natural ventilation, in Campinas (SP, Brazil). A wireless sensor network with nine SHT75 transducer spatially distributed and a meteorological station were used to measure the internal and external environment, respectively. In the closed greenhouse, there are strong vertical gradients in temperature and relative humidity of air. When the exhausters are turned on and the greenhouse is allowed to ventilate, transferring the thermal energy with external environment, these gradients decrease. When the greenhouse is ventilated only via mechanical ventilation, the temperature and relative humidity gradients are larger than those observed with roof ventilation associated with mechanical ventilation.

Keywords: mechanical ventilation, natural ventilation, protected environment, wireless sensor network.

1. Introduction

The distribution of greenhouse temperature and relative humidity of air is one of the factors that influence the uniformity of crop growth [1]. The study of environmental heterogeneity presents itself as an important issue because of the impact that it has on the quality of plants [2] and, thus, seeks to homogeneous spatial distribution of these elements, allowing the achievement of one of the major objectives of cultivation in protected environment: the development of plants in an uniform way and with good productive quality [3]. A uniform crop can be harvested in one single operation and sold at high price and, at smaller temperature gradients in the greenhouse, energy could be save to control smaller temperature margins [3].

Climate measurements with the function of environment control should be carried out at representative points. The location of the sensors in the greenhouse is an important issue because its measures can be used for all control and you can get different values at different points of the internal environment [4]. Different sensors in a greenhouse may result in different temperatures over time, depending on the location in which they are installed [5]. Several studies, considering the homogeneity of the environment, use only one sensor at the geometric center of the environment as representative of the whole environment, which may be a mistake in the case of a heterogeneous environment. Other papers worked with the measurement of meteorological elements with sensor network spatially arranged and discussed the heterogeneity of the environment [1], [3], [6].

+ Corresponding author. Tel.: + 55 19 3521-1123; fax: + 55 19 3521-1123.
E-mail address: thais.zorzeto@feagri.unicamp.br.

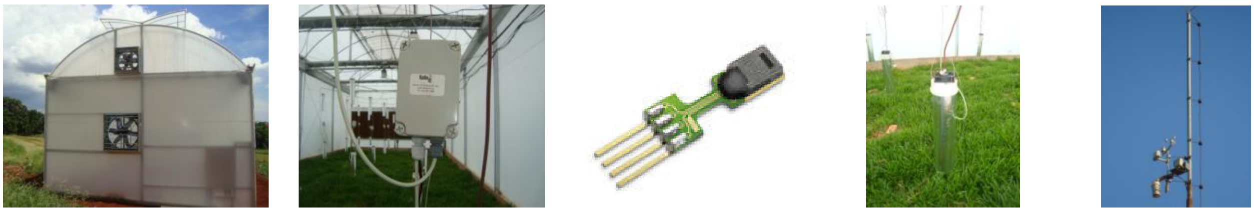
Horizontal temperature distribution patterns in two types of greenhouses were investigated by [1]. Homogeneous temperatures were found during the night hours, while significant daily temperature differences were found inside commercial greenhouses with different sizes and designs. Horizontal climatic variations of temperature and relative humidity cannot be obtained accurately enough with a single or very few sensor boxes per area, because the natural variations in greenhouses are high [3]. The solar radiation is one of the major driving forces defining the climate of a greenhouse [1]. Field measurements are essential to any improvement on the understanding of this complex system and focus on the amount and quality of data collected in the field, especially exploring spatial variations, it is necessary to develop and validate models of systems in protected environments based on real conditions [7].

The aim of this study was to evaluate the heterogeneity of the environment with different configurations of natural and mechanical ventilation.

2. Material and Methods

The experiment was conducted in the experimental field of the College of Agricultural Engineering (FEAGRI), State University of Campinas (UNICAMP), in Campinas (São Paulo, Brazil), in a greenhouse (Fig. 1a) with dimensions of 6.4 m wide, 18.3 m long, 4.0 m height, 5.5 m total height (ridge). The greenhouse was covered with a film of low density polyethylene (LDPE) light diffuser with a thickness of 150 µm and anti-UV treatment. The roofs are arched, with zenithal windows that open both sides of the greenhouse, and the mechanical ventilation includes two exhausters (model EM36, below the height, and ED24, above the height of the ceilings, Munters).

To collect internal data of temperature and relative humidity of air, it was installed a wireless sensors network (Fig. 1b), with two transducers SHT75 (Fig. 1c) per each of the three sensors below the channel height, and three sensors with one SHT75 transducer above the channel height. The transducers were protected by porous caps and these were placed in a polyvinylchloride (PVC) tube (0.4 m length and 0.1 m diameter), covered with aluminum foil for protection from radiation effects and with a micro ventilator at its upper end (Fig. 1d) for standardization of ventilation at all measurement points. To collect external data, a weather station was installed 2.0 m distant from the apex of the greenhouse and 7.0 m in height (Fig. 1e).



(a) (b) (c) (d) (e)

Fig. 1: Greenhouse showing the natural and mechanical ventilation systems (a), with detail to the wireless sensor network (b) and the SHT75 transducer (c) installed inside of PVC tubes (d) and the meteorological station (e).

The positions of each point are determined in Fig. 2.

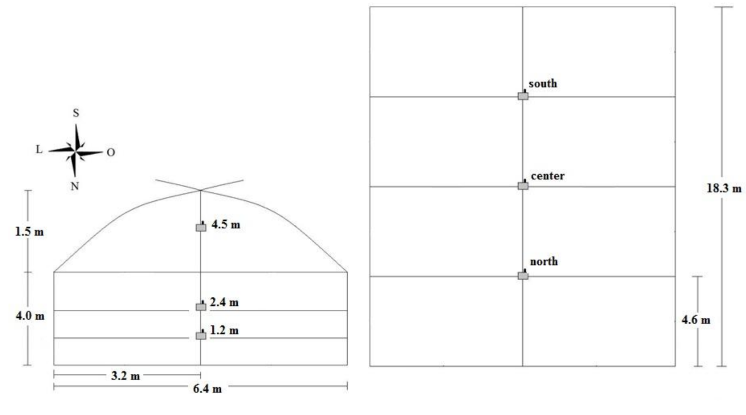


Fig. 2: Wireless sensor network and horizontal and vertical positions of the sensors.

SHT75 digital transducers [8] have an average accuracy of 1.8% for the measurement of humidity and 0.3 ℃ for temperature measurement. The wireless sensor network is based on the open platform of radio Radiuino [9], which communication is made in the 915 MHz band. The Radiuino aggregates functions of a transceiver, for wireless communication, and microcontroller, for data acquisition and inputs management of analog-digital converters and digital inputs or outputs. For communication, the Raduino uses its own open protocol, based on data packets with pre-defined functions and fixed size of 52 bytes. In this network, a base, connected to a computer, requests individually to each of the sensor nodes the execution and the return of measurements data of each transceiver connected to these nodes. Upon receiving the requested data, base registers this information in a database on the computer. At the end of requests to all nodes of the network, this sequence is restarted and repeated 24 hours a day.

Temperature and relative humidity were analyzed for the nine points measured every 10 days, for three configurations: (1) closed greenhouse; (2) greenhouse with two exhausters turned on during all the period; (3) greenhouse with open roof window and inferior exhauster turned on during all the period. Data were subjected to averages test and compared by Tukey test at 5% probability using ASSISTAT Software (version 7.6beta 2012 - Federal University of Campina Grande).

3. Results and Discussion

The study shows that the temperature gradient is larger in a closed greenhouse than in a mechanical or natural ventilated one, as expected [10]. Distributions of temperature and relative humidity inside the greenhouse vary with the intensity of solar radiation in relation to height above the ground surface and the largest gradients of temperature and humidity occurred with the solar radiation peak, around noon (Fig. 3).

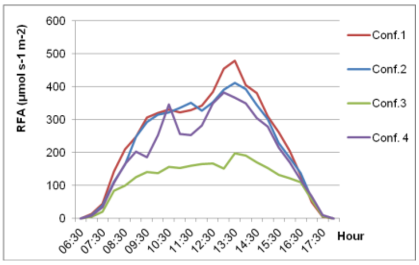


Fig. 3: Internal photosynthetically active radiation for each of the configurations of greenhouse.

The rate of temperature increase, in a closed greenhouse (Fig. 4), is smallest at the lowest position and it increases with height, agreeing with the study [10]. Comparing both internal and external environments, it’s observed an increase in internal temperature during the day (9 and 15 h) and its reduction during the night (3 and 21 h). The higher the position for measuring the internal temperature of the air, the higher also is the measured value, reaching 35.27 ℃ at the position 4.5 m north (10.64 ℃ above the average external value), due to the accumulation thermal energy and the north-south position of the structure with direct radiation incidence on the face nearest to that point. In the evening hours, the increase in relative humidity influenced the reduction of internal air temperature, a result of evapotranspiration process of grass internally installed, which converts sensible heat into latent heat, with average maximum of 98% at 3 h and 92% at 21 h.

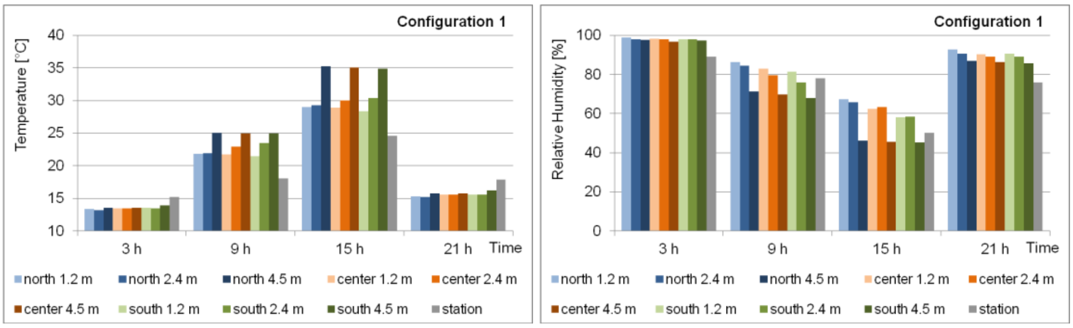


Fig. 4: Dynamic response of the greenhouse air temperature and relative humidity for configuration 1.

When allowing air exchange with the external environment, through the two exhausters turned on in configuration 2, the internal temperatures measured at 1.2 m and 2.4 m, in the daytime hours, tended to equate with the averages obtained externally (Fig. 5). The temperatures measured at 4.5 m remained high with a maximum average of 31.96 ℃, 5.31 ℃ above the external average value, at 15 h, at the south point, the farthest of the exhausters. With fans usually mounted at one end of the greenhouse and suck ambient air through openings at the opposite end, the air moves from one end of the greenhouse to the other and gradients of temperature and humidity develop along the structure, which result in an inhomogeneous microclimate [11]. With mechanical ventilation, the average relative humidity of air remained below of 80%, with the highest daytime average values observed at heights closer to culture.

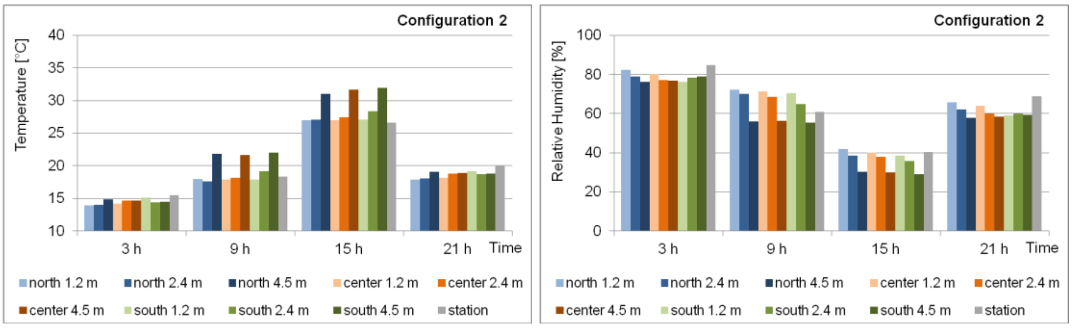


Fig. 5: Dynamic response of the greenhouse air temperature and relative humidity for configuration 2.

The association of mechanical with natural ventilation reduced the differences between temperatures and relative humidities measured in all points and times inside the greenhouse, tending to balance the internal with the external average values (Fig. 6). The point of measurement at 4.5 m north presented the highest average value (24.86 ℃) at 15 h, about 3 ℃ above the average external value. This result agrees with [12], who observed an increase in the exchange of air and uniformity of the internal environment, due to better indoor air mixture produced by natural ventilation through roof windows combined with mechanical ventilation, then if it was considered only mechanical ventilation.

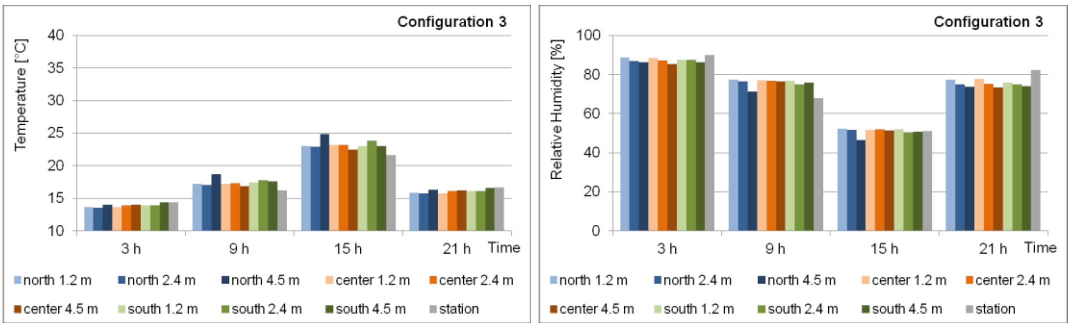


Fig. 6: Dynamic response of the greenhouse air temperature and relative humidity for configuration 3.

Table 1: Differences on temperature and relative humidity of air between the measurement point and the center point.

Point		ΔT (°C)			ΔRH (%)		
		Conf. 1	Conf. 2	Conf. 3	Conf. 1	Conf. 2	Conf. 3
north	1.2 m	-0,46	-0,71	-0,47	3,08	3,95	1,10
	2.4 m	-0,55	-0,47	-0,30	1,71	1,49	-0,07
	4.5 m	2,42	0,12	-0,35	-8,21	-1,94	-0,02
center	1.2 m	-0,42	-0,63	-0,47	0,79	2,17	0,99
	2.4 m	0,00	0,00	0,00	0,00	0,00	0,00
	4.5 m	1,66	-0,09	-0,62	-6,92	-1,85	-0,04
south	1.2 m	-0,55	0,03	-0,32	-0,65	-1,14	0,18
	2.4 m	0,24	-0,05	-0,34	-1,63	-1,50	-0,18
	4.5 m	1,81	-0,02	-0,36	-7,20	-1,33	-0,21

Although no values of acceptable differences for temperature and relative humidity have been set in the horizontal plane of the environment, defining its homogeneity, the Netherlands Organization for Environmental Certification [13, cited by 3] determines remain within ±0.75 ℃ for air temperature and ±3% for relative humidity of air. Excepted for configuration 1, which presented gradients of temperature and relative humidity (difference between the measurement point and the geometric center point at 2.4 m) above the recommended for 4.5 m heigh, the all others points were within the referred limit (Table 1). On literature, studies found differences of 1.51 ℃ and 1.75% between the points [6], or from 1.0 to 3.4 ℃ for temperature and from 10 to 40% for relative humidity [3], or maximum gradients of 3.2 ℃ and 3.5 ℃ [14].

4. Conclusions

In a closed greenhouse, there are strong vertical gradients in temperature and relative humidity of air. When the exhausters are turned on and the greenhouse is allowed to ventilate, transferring the thermal energy with external environment, these gradients decrease. When the greenhouse is ventilated only via mechanical ventilation, the temperature and humidity gradients are larger than those observed with roof ventilation associated with mechanical ventilation.

5. Acknowledgements

To College of Agricultural Engineering of the State University of Campinas (FEAGRI/UNICAMP), Foundation for Research Support in the State of Sao Paulo (FAPESP - Proc. n° 2013/11953-9), National Council for Scientific and Technological Development (CNPq), Coordination of Improvement of Higher Education Personnel (Capes).

6. References

[1] C.R. Bojacá, R. Gil, S. Gómez, A. Cooman. Use of geostatistical and crop growth modeling to assess the variability of greenhouse tomato yield caused by spatial temperature variations. *Computers and electronics in agriculture.* 2009, 65 (1): 219-227.

[2] T. Boulard, C. Kittas, J.C. Roy, S. Wang. Convective and Ventilation Transfers in Greenhouses, Part 2: Determination of the Distributed Greenhouse Climate. *Biosystems Engineering*. 2002, 83 (2): 129–147.

[3] J. Balendonck, E.A. van Os, R. van der Schoor, B.A.J. van Tuijl, L.C.P. Keizer. Monitoring spatial and temporal distribution of temperature and relative humidity in greenhouses based on wireless sensor technology. In: *International Conference on Agricultural Engineering - AgEng*. France: Cemagref. 2010, pp. 443. ISBN 978-2-85362-684-2.

[4] L. Gonda, C.E. Cugnasca. A proposal of greenhouse control using wireless sensor networks. In: F. Zazueta, et al (eds.). *Proc. of 4th World Congress on Computers in Agriculture - Computers in Agriculture and Natural Resources*. Flórida: ASABE. 2006, pp. 229-233.

[5] V.L. Narasimhan, A.A. Arvind, K. Bever. Greenhouse asset management using wireless sensor-actor networks. In: *International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies*. French Polynesia: IEEE. 2007, pp. 9-14.

[6] T. Ahonen, R. Virrankoski, M. Elmusrati. Greenhouse monitoring with wireless sensor network. In: *Proc. of International Conference on Mechatronic and Embedded Systems and Applications*. Beijing: IEEE. 2008, pp. 403-408.

[7] J. Tanny. Microclimate and evapotranspiration of crops covered by agricultural screens: A review. *Biosystems Engineering.* 2013, 114 (1): 26-43.

[8] Sensirion. (http://www.sensirion.com/fileadmin/user_upload/customers/sensirion/Dokumente/ Humidity/ Sensirion_Humidity_SHT7x_Datasheet_V5.pdf).

[9] Radiuino (http://radiuino.cc/?page_id=26).

[10] Y. Zhao, M. Teitel, M. Barak. Vertical temperature and humidity gradients in a naturally ventilated greenhouse. *Journal of Agricultural Engineering Research*. 2001, 78 (4): 431－436.

[11] M. Teitel, M. Atias, M. Barak. Gradients of temperature, humidity and CO2 along a fan-ventilated greenhouse.

Biosystems engineerging. 2010, 106 (1): 166-174.

[12] J. Flores-Velazquez, J.I. Montero, E.J. Baeza, J.C. Lopez. Mechanical and natural ventilation systems in a greenhouse designed using computational fluid dynamics. *International Journal of Agricultural and Biological Engineering*. 2014, 7 (1): 1-16.

[13] Stichting Milieukeur. Certificatieschema Groen Label Kas – Niveau A en Niveau B. (http://www.smk.nl/, 1 maart 2010).

[14] C.R. Bojacá, R. Gil, S. Gómez, A. Cooman, E. Schrevens. Analysis of greenhouse air temperature distribution using geostatistical methods. *Transactions of the ASABE.* 2009, 52 (3): 957-968.