Web site: http://aesop.rutgers.edu/~horteng

CCEA Newsletter

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CCEA is a research organization dedicated to the improvement and vitality of the Controlled Environment Agriculture Industry. CCEA is funded by Industrial and Grower Partners who contribute a yearly partnership fee. Satellite partnership is also available to growers. Information about **CCEA** is available from:

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In this issue:

Potted Chrysanthemums are the first crop being grown in the open-roof greenhouse. We hope to discover any potential problem with the various control systems before we grow a Poinsettia crop in the fall.

C E C A

Vision Statement
CCEA, The Center for Controlled Environment Agriculture of NJAES at Rutgers University, a partnership among growers, industry, and researchers, will devote itself to research and transferring information required for an economically viable and environmentally aware controlled environment agriculture industry. We will particularly strive to identify future trends, critical issues, appropriate emerging technologies and provide leadership for opportunities which challenge world-wide controlled environment agriculture in the 21st century.

A Natural Ventilation Model for Open-Roof Greenhouses

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Introduction

During the last five years, open-roof greenhouse designs have become very popular in the US. Most greenhouse manufacturers in North America sell at least one type of an open-roof greenhouse design. Growers have reported two main advantages of open-roof greenhouses compared with traditional fan ventilated greenhouses: (1) during warm(er) conditions, the greenhouse temperature closely tracks outside temperatures with little or no energy requirements (to operate the fans), and (2) spring plants can be easily hardened off by opening the roof. Despite their popularity, little research data is available to support the grower enthusiasm for open-roof greenhouses. In an attempt to study open-roof greenhouse design and operation, a small greenhouse (Van Wingerden Greenhouse Company, Horse Shoe, NC, USA, the MX-II style) was constructed on one of the research farms at Cook College, Rutgers University in New Brunswick, NJ, USA. Because the design of open-roof greenhouses differs significantly from traditional mechanical or natural ventilated greenhouses, it became clear that a study of the ventilation in open-roof greenhouses was warranted. In particular, it is necessary to verify that open-roof greenhouses provide sufficient and uniform air exchange rates between the inside and outside greenhouse environment. In this paper, we have attempted to model the natural ventilation patterns in a small open-roof greenhouse.

Materials and methods

The greenhouse environment measurements we conducted at the open-roof greenhouse on Hort Farm #3 (for pictures see http://www.aesop.rutgers.edu/~horteng). The greenhouse environment was controlled with a commercial control system (Argus Control Systems, Ltd., White Rock, BC, Canada). The temperature set point for ventilation was 21 °C (70 °F) and the roof position was operated based on the measured temperature at a height of 1.2 m (4 ft). In some cases, the roof position was kept manually at a constant opening. When the roof sections were fully opened, the ratio of the roof opening area to the greenhouse floor area was 0.66. No crops were grown in the greenhouse during the period of data collection, except for a short period of several days when approximately 30% of the floor area was filled with potted plants. All measurements were recorded as 15-minute averages.

Outside the greenhouse, a weather station was installed containing sensors to measure outdoor conditions. The weather mast was equipped with instrumentation to measure the following parameters: temperature, relative humidity, wind speed and direction, and rain detection. In addition, a quantum sensor was installed to measure photosynthetically active radiation (PAR, with wavelengths between 400 and 700 nm), as well as a pyranometer to measure total solar radiation (short wave, with wavelengths between 280 and 2,800 nm).

Inside the greenhouse, temperature was measured at three different heights: 1.2, 2.4, and 3.6 m (4, 8, and 12 ft) above the floor. A quantum sensor, a pyranometer, and a net radiometer measuring wavelengths between 250 and 60,000 nm, were mounted at 1.2 m (4 ft) above the floor, and positioned underneath one of the roof ridges, to measure radiation conditions inside the greenhouse.

Model Description

The model proposed by Boulard et al. (1996) to estimate the natural ventilation rate in greenhouses with only roof openings was used. The model is based on the two driving forces for natural ventilation: thermal buoyancy and wind forces. The model can be written in the following form: $G = A_o (a_1 H/2 \Delta T + a_2 V^2)^{1/2}$ (1)

where G is the ventilation rate per unit greenhouse floor area ($m^3/m^2/s$), A_o is the ratio of roof opening area to the greenhouse floor area, H is the height of the opening above the floor (m), ΔT is the air temperature difference between inside and outside (°C), V is the wind velocity (m/s) at a height of 6.9 m, a_1 is the buoyancy constant ($m^2/s^2/°C$), and a_2 is the wind effect coefficient (dimensionless). The parameters, a_1 and a_2 include the discharge coefficient of the roof opening (s).

A typical model for the sensible heat balance was incorporated to calculate the ventilation rate and the temperature difference between inside and outside simultaneously. It is based on a steady state condition and can be expressed as follows:

$$G = (\alpha R_n / \Delta T - U \beta) / (C_p \rho) \quad (2)$$

where G is the ventilation rate per unit greenhouse floor area ($m^3/m^2/s$), α is the ratio of sensible heat gain to the inside net radiation, R_n is the inside net radiation (W/m^2), U is the overall heat transfer coefficient ($W/m^2/°C$), β is the ratio of the greenhouse surface area to the greenhouse floor area, C_p is the specific heat of air (1006 J/kg/°C), and ρ is the specific mass of air (kg/m^3).

Approximately 500 data points collected during the period of March through May, 2000, were used to determine the parameters a_1 and a_2 using least squared residuals between the observed and predicted temperature differences. Prior to the analysis, other necessary parameters were determined or normalized. The sensible heat gain can be related to the evapotranspiration in a greenhouse and varies according to the greenhouse environment in general. During the observation, no crops were grown in the greenhouse and the soil surface condition was mostly dry. The value of α was determined using Equation (2) when the roof segments were closed. This value gradually decreased from 0.78 to 0.67 during the time period of the measurements. This is likely due to the fact that weeds started growing inside the greenhouse and due to the time a batch of potted plants covered approximately 30% of the greenhouse area during the month of May. The observed inside net radiation fluctuated markedly on clear days because of the shadows caused by the construction materials and the light reflection from opened roof surfaces. Such data of net radiation were normalized using the statistical relation between the outside solar radiation and the inside net radiation, and then used as model input data. The U value was assumed to be 4 $W/m^2/°C$ for the experimental greenhouse covered with two layers of air-inflated polyethylene film. The term β for the experimental greenhouse was 2.18.

Results and Discussion

Using approximately 500 measurements, the parameters, a_1 and a_2 for the height of 1.2 m (4 ft) were determined to be 0.0067 and 0.023, respectively. They are slightly larger than the parameters (0.004 and 0.017, respectively) Kittas et al. (1997) determined for a twin-span greenhouse with continuous roof ventilators using the tracer gas method. On the other hand, the determined parameters for the measurement height of 2.4 m (8 ft) were 0.0026 and 0.0077, respectively. They were smaller than those for the height of 1.2 m (4 ft). This reflects the warmer temperature at the measurement height of 2.4 m (8 ft) compared to a height of 1.2 m (4 ft) because of the vertical temperature gradient in the greenhouse. The observed temperature at 1.2 m (4 ft) was always lower than that at 2.4 m (8 ft) during the daytime.

Figure 1 shows an example of the diurnal changes in predicted and observed temperature differences between inside and outside. Note that the control system operated the position of the roof segments based on the deviation from the measured temperature at a height of 1.2 m (4 ft) from the temperature set point (21 °C or 70 °F), and to a lesser extent based on the outside temperature and solar radiation. Figure 2 shows that the predicted temperature differences agreed closely with the observed temperature differences at a small opening, while those were overestimated when the roof segments were more widely opened. The temperature difference decreased with an increase in the outside temperature, which peaked in the late afternoon on clear days. When the roof segments were widely opened, the inside temperature, particularly at a height of 1.2 m (4 ft) occasionally dropped below the outside temperature. This negative temperature difference might be due to cooling caused by evaporation and/or long-wave radiation from the greenhouse floor. Furthermore, an outside temperature gradient might exist. Note that the outside temperature was measured at a height of 6.9 m (22.5 ft). The outside temperature generally decreases with an increase in height above the ground during the daytime. It was assumed that the temperature difference at 2 m (6.6 ft) height above the ground is up to 0.3 °C (0.5 °F) larger than that at 6.9 m (22.5 ft) height. However, the model described here does not take this into account and is not capable of predicting negative temperature differences.

A comparison of the observed and predicted temperature differences for four ratios of roof opening area to the floor area is shown in Figure 2. The standard errors of the temperature differences for the heights of 1.2 and 2.4 m (4 and 8 ft) were 0.82 and 0.89 °C (1.5 and 1.6 °F), respectively. The predicted temperature difference was found to be highly sensitive to the changes in the roof opening and the inside net radiation. This feature seems reasonable since they have linear relations with the ventilation rate as shown in the Equations (1) and (2).

In order to demonstrate the general ventilation characteristics under typical conditions, Figure 3 shows the predicted effects of the opening area and the inside net radiation on the temperature difference and the ventilation rate. The parameters for the height of 1.2 m (4 ft) were used to predict the environment at crop level. The term α was assumed to be 0.5 representing a greenhouse with moderate vegetation. The wind velocity of 1 m/s (197 fpm) was chosen as an expected minimum under normal conditions. The temperature difference decreased rapidly

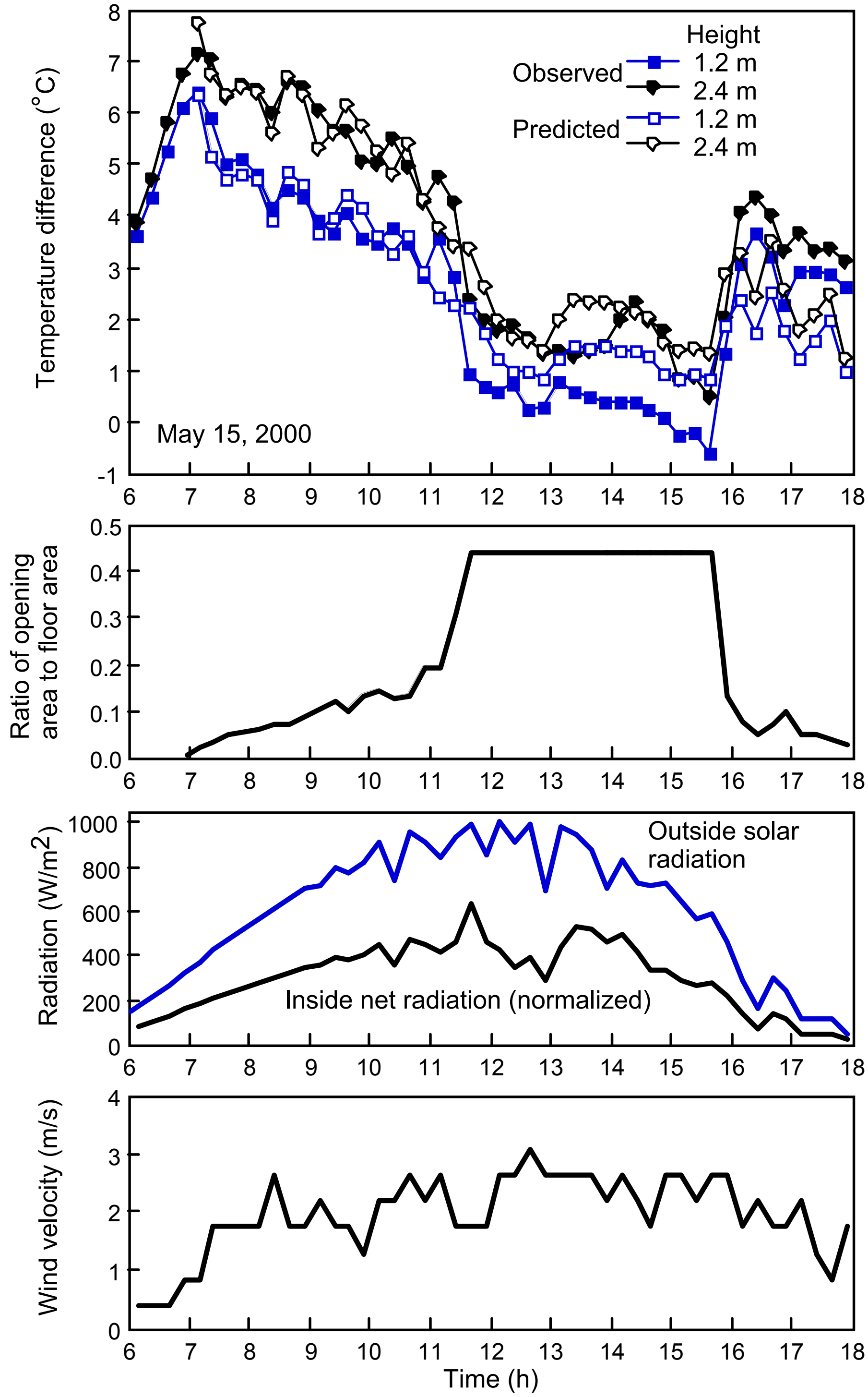

Figure 1. Comparison of the diurnal changes in predicted and observed temperature differences between inside and outside. The changes in the input parameters used for the model predictions are also illustrated.

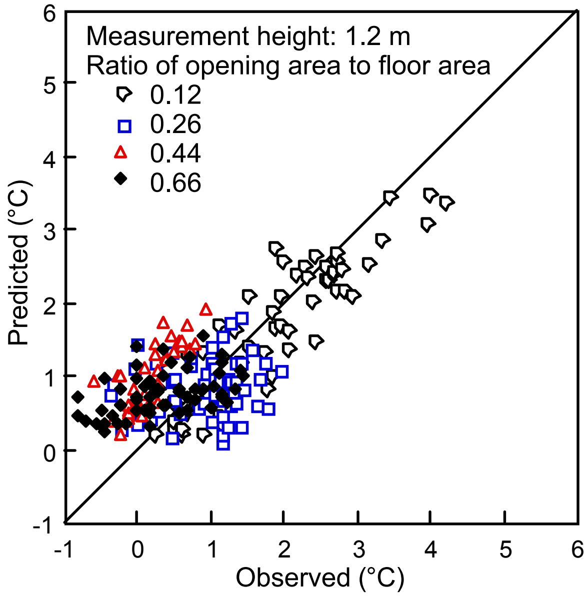

Figure 2. Comparison of observed and predicted temperature differences for four ratios of opening area to the floor area: 0.12, 0.26, 0.44 and 0.66.

with an increase in the opening area when the ratio of the roof opening area to the floor area was smaller than 0.3 to 0.4. At larger opening areas, the slope of the temperature difference curve decreased and the temperature difference was less affected by the opening area. Under these conditions, the temperature difference was almost proportional to the inside net radiation. The ventilation rate showed a linear increase with an increase in the opening area.

The predicted effect of the outside wind velocity on the ventilation rate at a constant opening is illustrated in Figure 4. It was shown that the ventilation rate was less dependent on the wind velocity when the wind velocity was approximately 1 m/s (197 fpm) or less, which indicates that the thermal buoyancy effect is predominant for such a low wind velocity. At a higher wind velocity, the ventilation rate increased almost linearly with an increase in wind velocity, and the differences in ventilation rate due to different levels of net radiation decreased.

Continued on the next page

High Tunnels

Construction was started on six so-called high tunnels that will be used as season extenders for fresh tomato production. Four of these single layered plastic structures will be constructed at the Rutgers Agricultural Research and Extension Center in Centerton, southern NJ, and two at one of the research farms near campus in New Brunswick. Each high-tunnel measures 17 feet wide by 36 feet long. Roll-up side walls will provide ventilation and the end walls will open completely to allow for equipment to install four rows of plastic mulched beds.

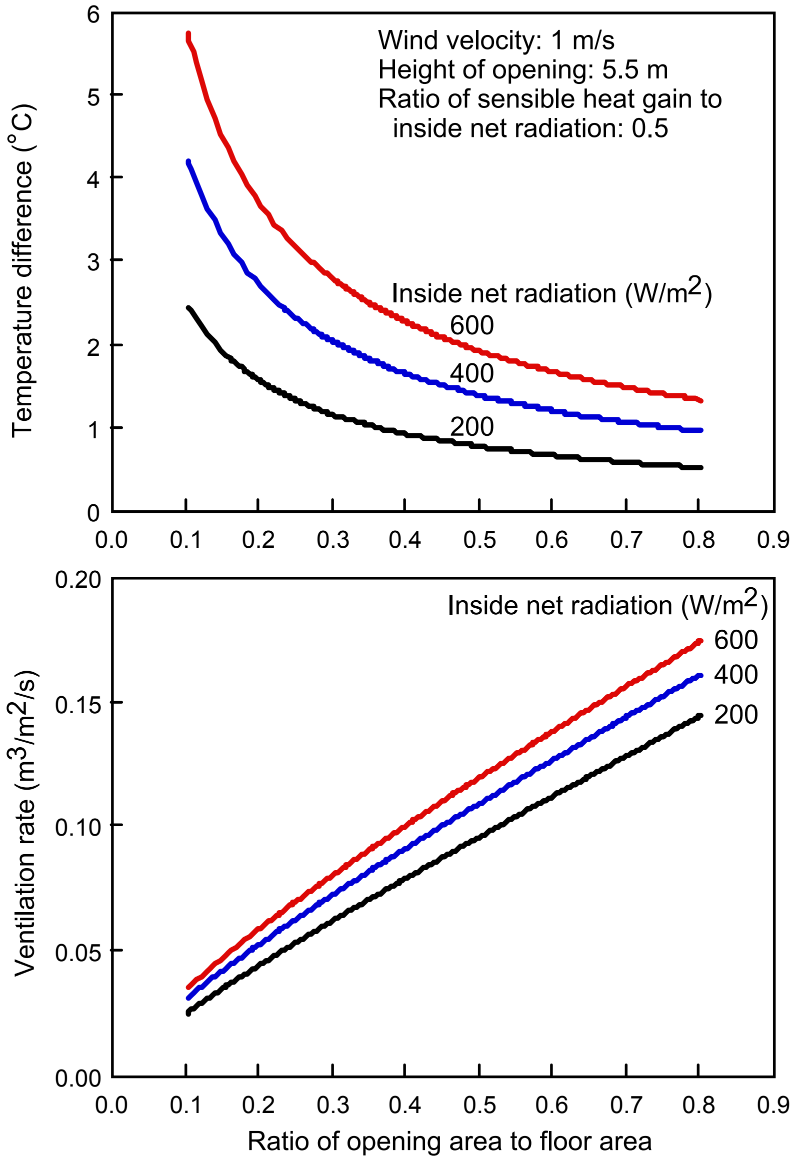

Figure 3. Predicted effects of the opening area and the inside net radiation on the temperature difference and the ventilation rate.

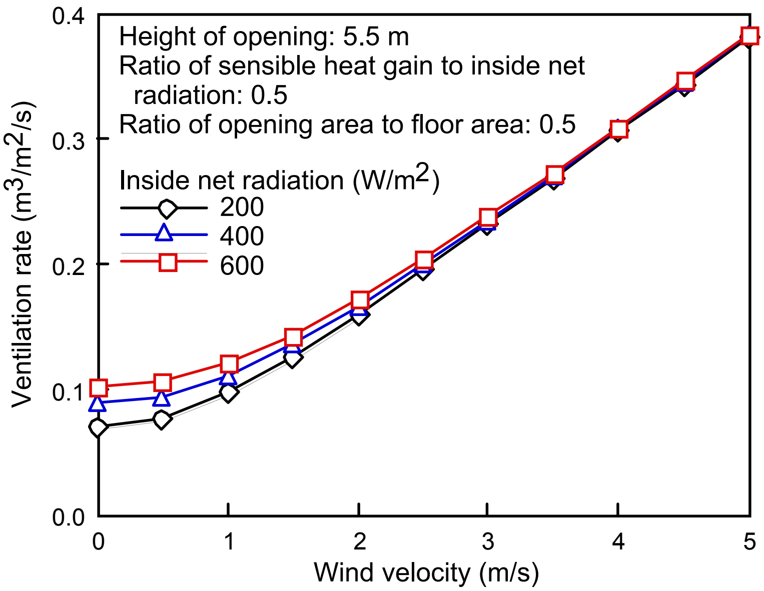

Figure 4. Predicted effect of the outside wind velocity on the ventilation rate using a constant ratio of opening area to floor area (0.5).

Conclusions

A simulation model for open-roof greenhouses was developed to predict the temperature difference between inside and outside and the natural ventilation rate simultaneously. The model parameters were calibrated statistically using the observed conditions of an open-roof greenhouse. The standard errors of the temperature differences for two measurement heights were within 0.9 °C (1.6 °F). There was a trend for the predicted temperature difference to be slightly overestimated when the roof segments were more widely opened. In addition, the observed inside temperature occasionally dropped below the outside temperature. The model is not capable of predicting such negative temperature differences. Although further modification is required, the model can provide a useful means to implement new environmental control strategies for open-roof greenhouses.

Acknowledgements

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Cook College and Departmental Leadership Changes

The following key appointments have been announced during recent weeks.

At the college level:

Dr. Adesoji O. Adelaja, a faculty member of Cook College since 1986, has been named Executive Dean of Agriculture and Natural Resources, Executive Director of the New Jersey Agricultural Experiment Station and Dean of Cook College. Dr Adelaja appointed several new and continuing members to the Cook College Administration Team. The new organization will accommodate stronger budgetary oversight by the Executive Dean as recommended during the strategic planning activities recently completed at the College. Dr. Michael W. Hamm, a renowned proponent of community food security, has been appointed Dean of Academic and Student Programs at Cook College. Dr. Karyn Malinowski, an accomplished equine scientist, has been appointed Dean of Outreach and Extension Programs for Cook College and Senior Associate Director for Extension at the New Jersey Agricultural Experiment Station. Dr. Zane R. Helsel, who has served as Director of Rutgers Cooperative Extension and Dean of Outreach for Cook College, becomes the new Director of Regional and National Partnerships. Dr. Helsel also serves as the Interim Chair of the Department of Extension Specialists. Dr. Daniel Rossi has been appointed Senior Associate Dean for Administration and Senior Associate Director of the New Jersey Agricultural Experiment Station (NJAES). Dr. Keith R. Cooper, an eminent toxicologist, has been appointed Dean of Research and Graduate Programs for Cook College and Senior Associate Director of Research for the New Jersey Agricultural Experiment Station (NJAES). Dr. Ian Maw, who served for the past ten years as Dean of Academic and Student Affairs and for the past year as Interim Executive Dean, has been appointed Senior Associate Dean for Special Initiatives. Dr. Maw will be providing leadership for the Cook College Teacher Education program and working with the Graduate School of Education to fashion new long-term directions for the teacher and science education programs. The Office of the Executive Dean (Dr. Adelaja) will retain Directorship of the New Jersey Agricultural Experiment Station and Rutgers Cooperative Extension.

At the department level:

Dr. James F. White, Jr., Professor in the Department of Plant Biology and Pathology, has been appointed to the position of Chair of the Department of Plant Biology and Pathology. Dr. White is an expert on how fungi, particularly ones that grow inside plants, develop resistance to insects and fungus diseases, increase stress tolerance, or cause disease in plants.

Ruth Novak Retires

After many years of dedicated service, Ruth Novak retired as of July 1. In honor of Ruth's exemplary service, a recognition luncheon was organized at the Rutgers Club on June 21. As a small token of our appreciation, Ruth and her husband Milt will be enjoying a weekend at a bed and breakfast of their choice somewhere along the Delaware River. Needless to say, we would miss Ruth's presence very much both from a professional and a personal point of view, and therefore, we are trying to secure approval to bring her back on a part-time basis. Thus, if you call us in the future, there is a chance you may still be able to get her on the phone! Thanks Ruth for all you've done for us!