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The effect of sensor errors on production and energy consumption in greenhouse horticulture ☆

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ABSTRACT

The accuracy of sensors used in Dutch greenhouses for climate control has been assessed and the influence of sensor errors on the energy consumption and crop production has been determined using model simulations. It is shown that currently used sensors are prone to errors exceeding current standards set for practice. The extra energy consumption, due to sensor inaccuracy, is mainly caused by the sensors for global radiation and relative humidity. Sensor errors may result in a higher crop production but at the expense of a higher energy consumption resulting in a loss in economic return of the crop production process. Results indicate that sensor maintenance is economically feasible because the resulting energy savings exceed the costs of the maintenance operation.

1. Introduction

Sensors for temperature, relative humidity, CO_2-concentration and global radiation play a crucial in the feedback and feedforward based control schemes commonly implemented in current greenhouse climate control computers (Bakker et al., 1995). In practice not much attention is paid to accuracy of sensors. They are considered to be accurate and to stay accurate for a long period of time if a yearly regular maintenance service is performed. The hypothesis that sensors used in horticultural practice are prone to significant errors and that this might induce an increase in energy consumption, was the starting point for this research.

In this paper, the results of an experiment are described in which the accuracy of the sensors used in current Dutch greenhouse climate control was determined and the effects of sensor errors on production, energy consumption and net economic return were assessed.

2. Materials and methods

2.1. The measurement sites

The measurements were conducted at four growers, hereafter referred to as Grower 1 to Grower 4. The greenhouses of these growers were located at respectively De Lier, Nootdorp, Naaldwijk and Monster, all in the western part of the Netherlands. Each of the growers produced a different crop, respectively eggplant, cucumber, tomato and radish. In this group all major brands of climate control computers were represented. Two growers had a similar brand of climate control computer, however with different types of measuring boxes for temperature and relative humidity. All growers used the same type of solarimeter, a CM11 (Kipp & Zonen, Delft, The Netherlands). Siemens sensors were used for measuring CO_2 concentration.

2.2. The reference sensors

The following set of reference sensors was used:

1. Two psychrometers (ASFG, Wageningen, The Netherlands) for indoor temperature and relative humidity. They were placed inside the greenhouse as close as possible to the measuring box of the grower. The average of the two sensors was used as the reference signal for temperature and relative humidity.
2. One Siemens Ultramat 21P for indoor CO_2 concentration. This sensor was positioned as close as possible to the CO_2 sample point of the CO_2 sensor system of the grower.
3. One CM22 (Kipp & Zonen) for the global radiation. The CM22 quality is one class higher than the CM11 commonly used by growers. It was mounted outside near the meteo-station of the grower in such a way that shading of the reference sensor was prevented as much as possible.
4. One HL2010 (Hanwell Instruments Ltd) for outside temperature. It was mounted as close as possible near the sensors of the meteo-station of the grower.

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Before the experiment, the psychrometers were calibrated by AFSG, Wageningen, The Netherlands, an institute with a certified calibration facility for temperature and humidity sensors. The Siemens Ultramat 21P CO2 sensor was calibrated by the technical staff of PPO Naaldwijk, The Netherlands. The solarimeter (CM22) was calibrated by its supplier, Kipp & Zn., Delft, The Netherlands.

2.3. Measurement procedure

Measurements were done from October 1st until November 1st, 2004. The experiment consisted of two series. First, to obtain an assessment of the current state of the available sensors, at the facility of each of the growers, reference sensors and associated data logging hardware were installed. During two or three days, data of the sensors of the grower and the reference sensors was simultaneously collected and stored for later analysis, after which the set of reference sensors was moved to the next grower. After this first series of measurements, the growers asked their supplier or dealer to carry out a standard maintenance service of their sensors, both inside and outside the greenhouse. Maintenance consisted of calibration of the sensors for inside and outside temperature, replacement of the wet bulb wick of the relative humidity sensor and refill of the storage distilled water, calibration of the CO_2 sensor and cleaning of the global radiation sensor. After this maintenance, a second series of measurements was executed at each of the four growers for another period of 2 to 3 days, to assess the quality of the sensors shortly after maintenance.

2.4. Data analysis

Once all data had been collected, the two series of data were processed using Matlab®. The difference between the sensors of the growers and the reference sensors was determined and from this signal the mean error, ε_{meas}, and its standard deviation, σ_{meas}, were calculated. From the error signal, corrected for the average, also the distribution was determined. The mean errors and/or standard deviations were compared with standards commonly accepted in Dutch horticultural practice (Van den Berg and de Ruiter, 1998).

2.5. Assessment of the impact of sensor errors through simulation

Based on the error data obtained, using the KASPRO model (De Zwart, 1996), simulations were done to assess the impact of sensor errors on energy consumption and crop production. These simulations focussed on a standard tomato crop. The greenhouse production system was simulated from December 11th to November 20th the next year, the standard tomato production season in Dutch horticultural practice. Simulations considered a 2 ha greenhouse facility, with a hot water heating system, a heat storage of 120 m^3/ha and an LS10 UltraPlus thermal screen. It was assumed that the error distribution of each sensor was a normal distribution. Simulations were performed for 100 realizations of sensor errors, including both single sensor errors and multi sensor errors. In the simulations, for the temperature error it was assumed that the mean error was zero, since it is expected that the grower will adjust a non-zero mean error by observing his crop. For the speed of change of the errors a period of 15 min was chosen.

3. Results

In Fig. 1 and Fig. 2 two representative results are shown of the measurement errors. In Fig. 1 the absolute error of the relative humidity (RH) measured at grower 3 before maintenance is shown. In Fig. 2 the absolute error of the RH measured at grower 3 after maintenance is presented.

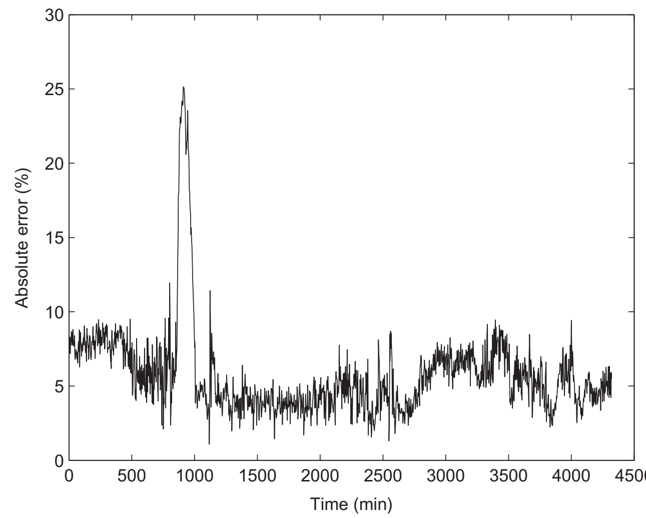

Fig. 1. The absolute error of the sensor for relative humidity at grower 3, before maintenance.

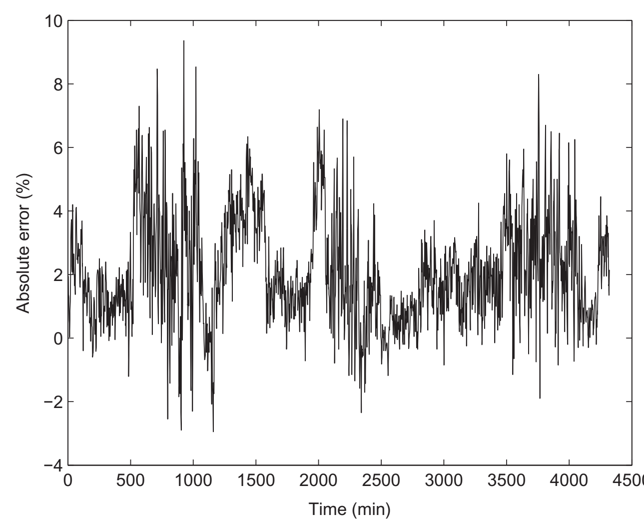

Fig. 2. The absolute error of the sensor for relative humidity at grower 3, after maintenance.

Since for the simulation a normal distribution is assumed for the sensor errors also the error distribution has been examined. The error distribution of the inside temperature before and after the maintenance service showed a normal distribution. A normal distribution was also found in the error in the CO_2-measurements. The distribution of the relative humidity was not an exact normal distribution; the distribution was a little askew. Before maintenance, the global radiation also showed a little askew distribution. But overall the assumption of a normal distribution of the sensor errors seemed to be reasonable.

The results of both series of measurements, before and after maintenance are listed in Tables 1–5, for indoor air temperature, indoor relative humidity, indoor CO_2 concentration, outdoor temperature and outdoor global radiation, respectively.

These results clearly indicate the following. First of all, in almost all cases sensors did not achieve the desired accuracy as listed by Van den Berg and de Ruiter (1998). Secondly, maintenance improved the performance, but still sensor accuracy did not reach the required levels. In case of the CO_2 measurements, data could be obtained only in a limited number of cases because in three cases the reference equipment failed.