On-line Monitoring of the Energy and Moisture Flows in Greenhouses

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Abstract: As the size of greenhouses in the Netherlands is increasing more and more, the on-line monitoring of certain, not directly measured, climate quantities and crop properties becomes important for good management of the greenhouse production system. For the ventilation rate, the crop evaporation and the air exchange through screens several monitors are developed, which calculates these quantities on-line from standard climate measurements. The design, implementation and performance in practice of the proposed methods will be shown.

Keywords: horticulture, unknown input observer, energy screens.

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1. INTRODUCTION

In modern greenhouse climate control the role of the grower is to define, among other things, temperature trajectories, carbon dioxide setpoints and relative humidity bounds, in such a way that during the growing season the crop is maintained in an optimal condition and the crop production is maximized. The climate computer will then realize the desired climate. Beside the heat supply and the carbon dioxide supply, a main variable to control the inside climate in a greenhouse is the natural ventilation through the windows in the roof of the greenhouse. The ventilation is controlled by adjusting the window openings and is heavily depending on the outside wind conditions and the difference between inside and outside temperature. An easy method to estimate the ventilation on-line would give the grower valuable insight into the process of his greenhouse climate.

Ventilation in a greenhouse can be determined by a model. These models are calibrated on, for instance, hourly averages of measurements of greenhouse climate variables, but are erroneously applied on a timescale of minutes.

In Bontsema et al. (2005) a method was described to monitor the ventilation rate in a greenhouse production system, using an observer technique for estimating unknown inputs of a system. The observer technique was applied on a dynamic energy balance of the greenhouse.

Ventilation rate is a "control" for the physical greenhouse. However in the end the grower wants to control his crop. An important process concerning the crop is the evaporation of the plants. In practice it is possible to measure the transpiration with a measurement gully; however this is only possible for some crops. Also models are available, but they require calibration for each crop and need for instance a parameter like leaf area index, which is not measured in practice. In Bontsema et al. (2007) a method, also based on an observer technique was described to determine the evaporation of the crop. The observer technique was in this case applied on dynamic mass balance for the humidity. For the unknown ventilation rate in this mass balance the ventilation monitor from Bontsema et al. (2005) was used. So the evaporation monitor can be considered as a sequence of two monitors.

Both monitors were applied in a network of several growers in the Netherlands. The climate data were on-line available and the outcome of both monitors was on-line available for the growers. The ventilation monitor worked quite satisfactory. At some growers it was noticed that in summer in the afternoon the inside temperature of the greenhouse is lower that the outside temperature, so the crop is cooling the greenhouse by evaporating. Since in the energy balance used for the ventilation monitor this phenomenon is not taken into account, one can expect an error in the on-line monitor in that case. This effect was also noticed when the monitor was applied on data from greenhouses in semi-arid areas. Since the evaporation monitor is directly depending on the ventilation monitor the errors from the ventilation monitor will be passed through to the evaporation monitor.

Therefore a new technique is proposed, where the ventilation rate and the evaporation will be estimated simultaneously, directly from the coupled energy and humidity mass balance of the greenhouse. In this case static balances for both energy and moisture are used.

Finally the situation for greenhouses with energy saving screens and shadow screens is considered. A method is designed which simultaneous calculates on-line the air exchange between the space under and above the screens and the air exchange between the space above the screens and the outdoor environment.

The methods will be demonstrated by using real climate data from several commercial growers in the Netherlands.

2. EXPERIMENTAL SETUP

The experiments were performed with the help of several growers. We describe here the growers who have either a PRIVA Integro climate computer or a Hoogendoorn Economic. For this paper the climate data of four growers are used, all having a Venlo-type greenhouse:

1. A 1.5 ha cucumber grower in Heerde, in the middle of the Netherlands. The grower has a sprinkler installation on the roof to cool the cover of the greenhouse and so the inside temperature. The climate computer is a PRIVA Integro.
2. A 2.1 ha cucumber grower in Bruinisse in the south-west of the Netherlands, which in winter time sometimes grows tomatoes. This grower has also a sprinkler installation on the roof. The climate computer is a PRIVA Integro.
3. A 2 ha tomato grower in Sexbierum in the north-west of the Netherlands. The climate computer is a PRIVA Integro.
4. A 5 ha cut flower (Matricaria) grower in Venlo, in the south of The Netherlands. This grower uses extensively an energy saving screen as well as a shadow screen , also in combination The climate computer is a Hoogendoorn Economic

In Fig. 1 an impression of the greenhouses is given.
In the greenhouse the climate is measured with a standard climate measuring box. The outside weather conditions are measured with a weather station, standard used in practice in the Netherlands. For the development of the transpiration monitor at all growers a relative humidity sensor for outdoor use was installed. At the cut flower grower also a climate measuring box was installed above the screens. All signals are recorded in the climate computer. For the growers with a PRIVA Integro climate computer these signals, together with control signals as for instance window apertures and heating pipe temperatures, are then transferred to the desktop of the monitors using the so-called Priva logger, which is a small software package which can read out the data of the PRIVA Integro. This software package is running in most cases on the same desktop as the monitors, but this is not necessary. The configuration is shown in Fig. 2. For the grower with a Hoogendoorn Economic climate computer the configuration is as in Fig. 3. The signals recorded in the climate computer are send to the LetsGrow.com®-database. Both monitors are written in C# (www.microsoft.com). The algorithms in the monitors calculating on-line the ventilation rate and the crop evaporation are written in Matlab® (www.mathworks.com) and compiled using the Matlab Compiler to a dll, which can be called on inside C#.

	
Tomatoes, Sexbierum	Matricaria, Venlo
	
The ventilation monitor in Bruinisse	Young cucumber in Heerde

Fig. 1. Impression of the different greenhouse and the equipment.

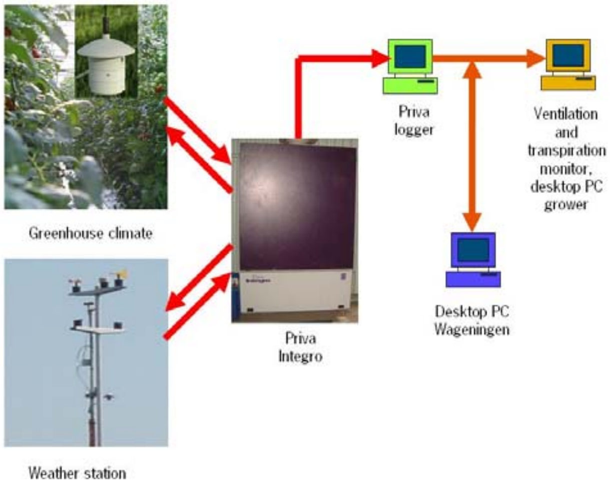


Fig. 2. The communication set-up for the Priva growers

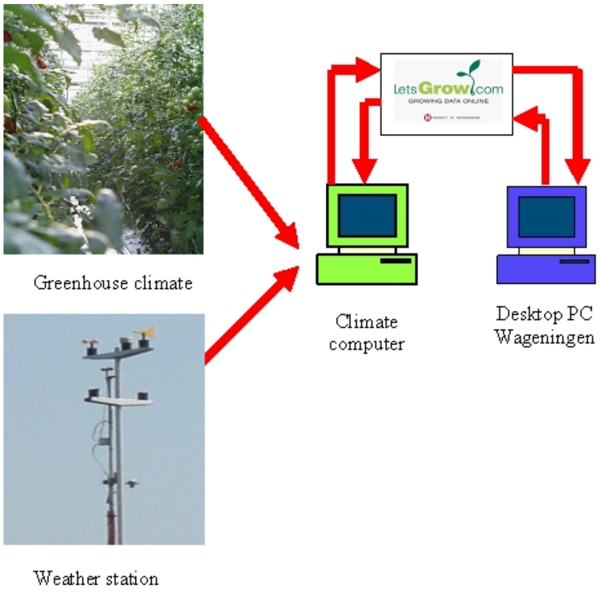
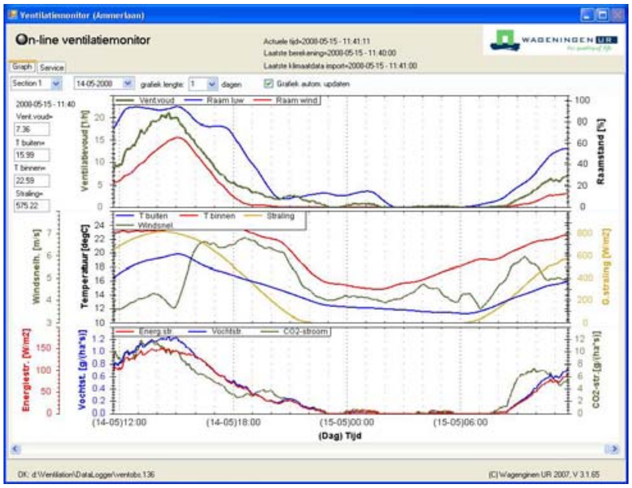


Fig. 3. The communication set-up for the Hoogendoorn grower.

On the desktop placed at the grower the ventilation monitor looks as shown in Fig. 4. The screen is produced by means of the program Zedgraph (www zedgraph.org.). In the screen always the data from the last 24 hours are shown. The figures are updated every minute. The grower can not only see the last 24 hours, but also several days back. Also the data of an arbitrary date can be shown. Furthermore he can switch between different sections of his greenhouse. The actual value of the ventilation rate is also given in a number (see left top of the screen). In the top figure the ventilation rate is shown together with the window apertures at the lee and wind side. In the middle figure the inside and outside temperature, the wind speed and the global radiation are shown. In the bottom figure the energy loss, CO_2-loss and moisture removal are shown.



Actuele tijd=2008-05-15 - 11:41:11
Laatste berekening=2008-05-15 - 11:40:00
Laatste klimaatdata import=2008-05-15 - 11:41:00

2008-05-15 - 11:40
Vent.voud= 7.36
T buiten= 15.99
T binnen= 22.59
Straling= 575.22

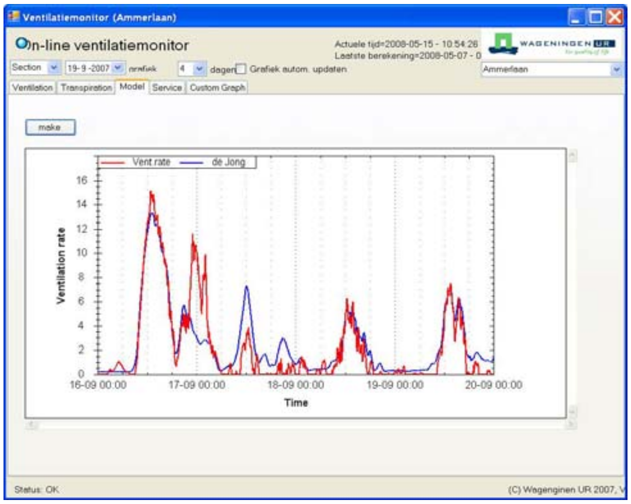
OK: d:\Ventilation\DataLogger\ventobs.136

(C) Wageningen UR 2007, V 3.1.65

Fig 4. The ventilation monitor as shown to the grower.

The button "service" is not for the grower, but for the software developers. The desktop computer at the grower's is through internet connected to several desktop computers at Wageningen UR. Using the program LogMeIn (www.logemein.com) the researchers have access to the desktop computer at the grower's. For research purposes a database has been built using MySQL (www.mysql.com), which has the same graphics interface as the ventilation monitor of the grower. The database is updated every week, by connecting to the desktop at the grower and transfers the data to the database. The first screen of the database looks similar to that of the grower (see Fig. 4), however the researcher can choose from which grower he wants to see the data. In the database one has direct access to more screens, like transpiration, model and custom graph.

The screen "Model" makes it possible to compare the results of the ventilation monitor with a model (De Jong, 1990), see Fig. 5.



Actuele tijd=2008-05-15 - 10:54:26
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Fig. 5. The third screen of the database

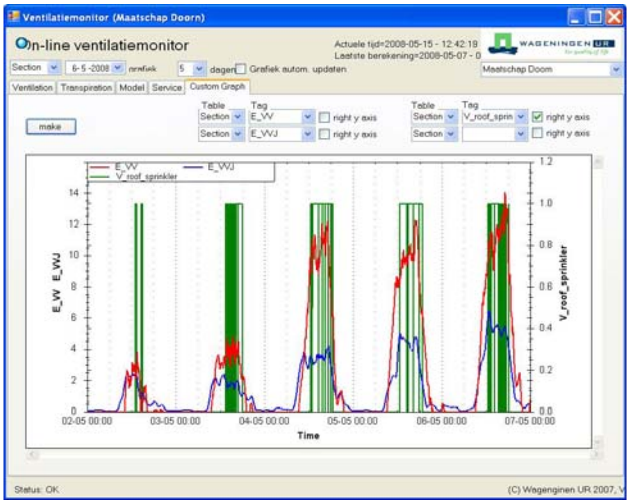

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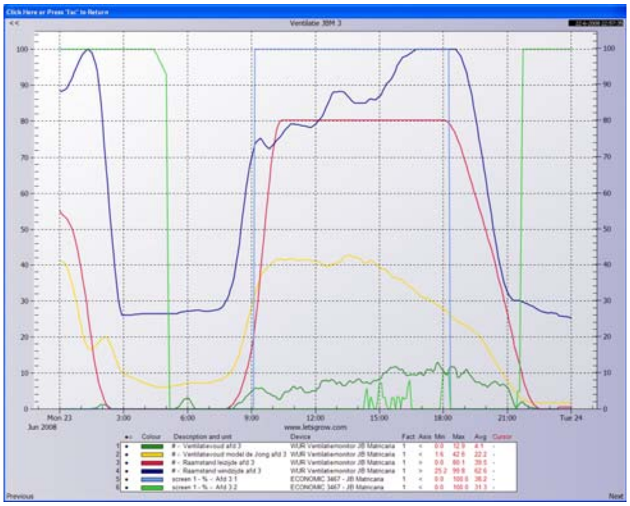
Fig. 6. The screen "Custom Graph" of the database.

The screen "Custom Graph" can be used to show data which are not in the standard screens. In Fig. 6 an example is shown of a grower with a roof sprinkler installation, for cooling the greenhouse cover with water.

Finally from the "service" screen a researcher can import data from every grower from the database.

For the grower with the Hoogendoorn climate computer the situation is different. The climate data and the results of the monitors are stored in the LetsGrow.com®-database. From this database arbitrary graphics can be made both by the grower as by the researcher on their desktop, see Fig. 7.



	Colour	Description and unit	Device	Fact	Axis	Min	Max	Avg	Cursor
1	🟩	# - Ventilatievoud afd 3	WUR Ventilatiemonitor JB Matricaria	1	<	0.0	12.9	4.1	-
2	🟨	# - Ventilatievoud model de Jong afd 3	WUR Ventilatiemonitor JB Matricaria	1	<	1.6	42.6	22.2	-
3	🟥	# - Raamstand lijzijde afd 3	WUR Ventilatiemonitor JB Matricaria	1	>	0.0	80.1	39.5	-
4	🟦	# - Raamstand windzijde afd 3	WUR Ventilatiemonitor JB Matricaria	1	>	25.2	99.9	62.6	-
5	🟦	screen 1 - % - Afd 3.1	ECONOMIC 3467 - JB Matricaria	1	<	0.0	100.0	38.2	-
6	🟩	screen 1 - % - Afd 3.2	ECONOMIC 3467 - JB Matricaria	1	<	0.0	100.0	31.3	-

Fig. 7. An arbitrary screen for the Hoogendoorn grower.

3. THE ENERGY AND MASS BALANCES

3.1 Energy balance

The energy balance for a Venlo-type greenhouse is given by Van Henten (1994):

$$C_{cap,q}\frac{dT_{air}}{dt}=Q_{pipe}-Q_{vent}-Q_{trans}+Q_{rad} \qquad (1)$$

where T_{air} is the temperature inside the greenhouse, Q_{pipe}, Q_{vent}, Q_{trans} and Q_{rad} are respectively the heat supply by the heating pipes, the energy loss due to natural ventilation, energy loss through the greenhouse cover and the heat load due to the global radiation of the sun. $C_{cap,q}$ is the combined heat capacity of the greenhouse air, the crop and the construction of the greenhouse.

The heat supply is described by $Q_{pipe}=c_{pipe,air}(T_{pipe}-T_{air})$ with $c_{pipe,air}$ the heat transfer coefficient between the heating pipes and the greenhouse air. T_{pipe} is the temperature of the heating pipes. The energy loss due to the ventilation is: $Q_{vent}=c_{air}\phi_{vent}(T_{air}-T_{out})$ with c_{air} the heat capacity of air, ϕ_{vent} is the ventilation flux and T_{out} is the outdoor temperature. The energy loss through the greenhouse cover is given by $Q_{trans}=c_{cov}(T_{air}-T_{out})$ where c_{cov} is the heat transfer coefficient of the greenhouse cover. Finally the heat load due to global radiation is $Q_{rad}=c_{rad}I$ with c_{rad} is the fraction of the global radiation, responsible for the heat load on the greenhouse. I is the global radiation.

3.2. Moisture balance

The humidity balance, expressed per m^2 soil, for a greenhouse, is given by Van Henten (1994) Stanghellini (1987), Stanghellini and de Jong (1995):

$$h\frac{d\chi_{air}}{dt}=E-C-V \qquad (2)$$

Where h is the average height of the greenhouse (m), χ_a is the vapour concentration of the greenhouse air (gm^{-3}), E is the crop transpiration, C is the condensation on the greenhouse cover and V is the moisture loss through the ventilation windows, all in $gm^{-2}s^{-1}$.

The moisture loss caused by ventilation is given by $V=\phi_{vent}(\chi_{air}-\chi_{out})$, where χ_{out} is the vapour concentration in the outdoor air and g_V is the ventilation flux (ms^{-1}).

The loss through condensation is calculated as a function of T_{air}, T_{out} and χ_{air}, see Stanghellini (1987), Bontsema et al (2007).

The unknown term in the humidity balance is the transpiration E.

3.3 Energy balance in case of screens

In the situation of the use of an energy screen or a shadow screen or both, it is still possible to use the energy balance given by (1). In that case the constants c_{cov} and c_{rad} will depend on the screen openings. The energy loss through ventilation is then a kind of average and not the energy loss from the compartment below the screens. For that reason two energy balances were considered, one for the compartment below the screens and one for the compartment above the screens. In contrast to (1), also the energy loss to the soil is taken into account. In case the screens are fully opened the two energy balances reduce to one.

For the compartment below the screens the following energy balance holds:

$$C_{cap,q,a}\frac{dT_{air}}{dt}=Q_{pipe}-Q_{screen}-Q_{\text{cov},screen}+Q_{I,a}-Q_{soil} \qquad (3)$$

For the compartment above the screens the energy balance is:

$$C_{cap,q,as}\frac{dT_{air}}{dt}=Q_{srceen}+Q_{\text{cov},screen}-Q_{\text{cov}}+Q_{I,as}-Q_{vent} \qquad (4)$$

where Q_{screen} is the energy loss through the screen opening, $Q_{\text{cov},screen}$ is the energy loss through the screens by convection, $Q_{I,a}$ is the heat load from the sun below the screens, Q_{soil} is the energy loss to the soil, $Q_{I,as}$ is the heat load from the sun above the screens and Q_{vent} is now the energy exchange of the compartment above the screens with the outside environment. The energy flows can be worked out similar as in section 3.1. In this case there are two unknown inputs, namely Q_{screen} and Q_{vent}.

4. THE MONITORS

Three monitors are considered. The first one is the ventilation the ventilation and the transpiration monitor as described in Bontsema et al. (2005) and Bontsema et al. (2007) respectively. The second monitor is a combined ventilation and transpiration monitor and the third one is a ventilation monitor for both the ventilation through windows as through screen openings.

4.1 Unknown input observer as ventilation and transpiration monitor

The ventilation monitor is based on the energy balance given by (1). The energy loss through ventilation is given as in section 3.1.. The transpiration monitor is based on a mass balance for the humidity in the greenhouse, as in (2). The moisture loss through ventilation is given in section 3.2. Both the energy loss as the moisture loss are considered as unknown inputs in the dynamic systems described by (1) and 2. These unknown input is then considered as a dynamic state variable, Dochain (2003), leading for both (1) as (2) to a second order system with one output (the greenhouse temperature, respectively the vapour concentration). Now standard observer theory, Luenberger (1971), is applied to estimate on-line the extra state (the unknown input). The simple energy balance it is very easy to adjust to different situations. For instance the heat supply in greenhouses with heating pipe is proportional to the difference in pipe temperature and greenhouse temperature, whereas in greenhouses with gas burners, like in the growth of lettuce, the heat supply can easily be derived from the power of the burners and the on/off signal for the burners. In case of roof sprinklers, which both the cucumber growers have in this case, the energy transmission through the roof could easily be adjusted for this case, which is also the case when energy saving screens are used. In case sun screens are used the light transmission can be adjusted. This can all be done automatically and on-line. The methods described in Bontsema et al. (2005) and Bontsema et al. (2007) have some shortcomings:

1. The determination of both ventilation rate as transpiration is a sequential process; errors in the ventilation rate will also lead to errors in the transpiration.
2. In the energy balance the fraction of the global radiation which is used for evaporation is assumed to be constant, what in practice is not always the case.
3. The third problem with these methods is the fact that the energy loss through ventilation is proportional with the temperature difference between inside and outside of the greenhouse. If there is no difference the ventilation rate is undetermined.

4.2. Combined ventilation and transpiration monitor

In order to overcome the difficulties mentioned in section 4.1. a new method is used based on two coupled differential equations for temperature and humidity.

In the energy balance the term for the fraction of the global radiation used for heating the greenhouse, $c_1 I_{glob}$ is replaced by the difference of the heat supplied by the sun and the amount of heat needed for transpiration, $c_2 I_{glob} - \lambda E$. Here c_1 includes both the effect of transmissivity of the greenhouse cover as the effect that part of the radiation, I_{glob}, is used for transpiration. The constant c_2 only represents the transmissivity of the cover, λ is the latent heat of vaporization of water and E is the evaporation of the crop. In this way both balances are coupled through the transpiration and the ventilation flux. The method for using an unknown input observer could be applied again for this second order system, when considering the unknown inputs ventilation rate and transpiration as states becomes a fourth order system, the observer would in this case a non linear observer. However for simplicity we start just with assuming that the two balances are static, so neglecting the heat storage and humidity storage in the greenhouse. In that case the method is nothing more that solving two equations with two unknowns. It turned out that now the singularity problem of zero difference between inside and outside temperature is in general solved, due to the fact that the humidity difference between inside ands outside is almost never zero.

4.3. Ventlation monitor for greenhouses with screens.

In this case we have two coupled differential equations (3) and (4) with two unknown inputs, respectively the energy loss through the windows and the energy loss through the screen openings to the compartment above the screens. Again the unknown observer techniques from section 4.1 can be used leading to a fourth order unknown input observer.

5. RESULTS

The ventilation monitor based on the unknown input observer gives a good result, when compared to a ventilation model of De Jong, 1990, see Fig. 5.

The results of the second monitor are given in Fig. 8. During daytime there is a good match between the first and second monitor and the model of De Jong, 1990.

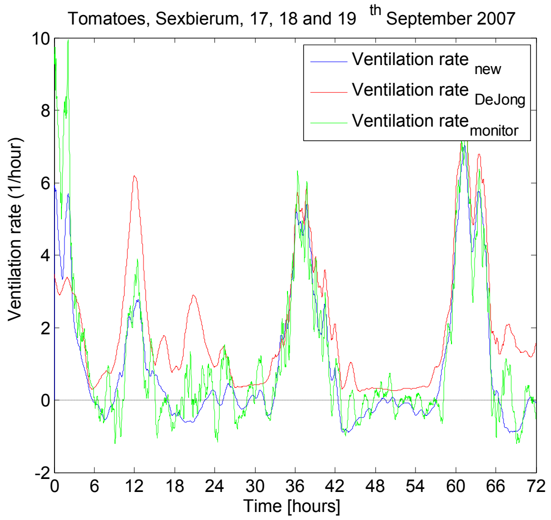


Fig. 8. Comparing the ventilation monitors with a model.

In Fig. 9 the ventilation flux and the energy loss through ventilation according to the third method (section 4.3) are shown. Although the ventilation rate was not measured it seems fair to state that the model of De Jong (1999) can not cope with screens.

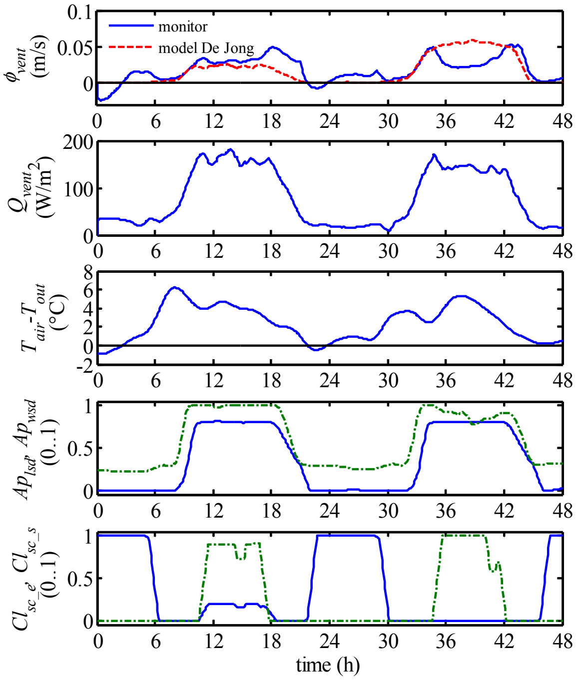


Fig. 9. The ventilation flux (1st sub figure) and the energy loss through ventilation (2nd sub figure). The 3rd and 4th subfigures give the window openings respectively the screen closures (17-18 June 2008).

In Fig. 10 the energy loss through the screen opening is shown and compared with the model of Wang (1999).

The new method is in good agreement with a model from literature.

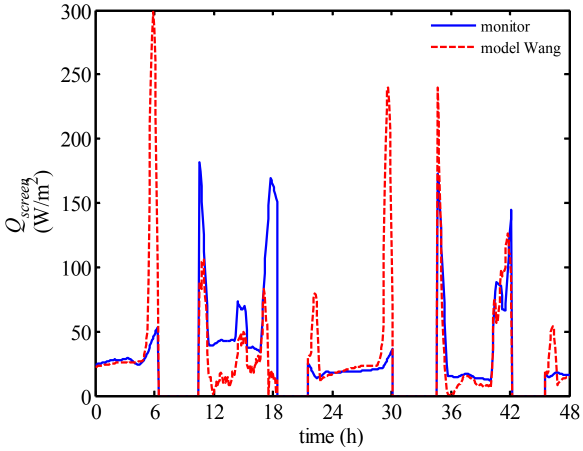


Fig. 10. The energy loss through the screen openings 17-18 June 2008. Blue: proposed method, red: model Wang.

6. CONCLUSIONS

On-line monitoring of the greenhouse ventilation rate, the evaporation rate from a greenhouse crop and the energy loss through screen openings has been shown to be readily possible, using modern internet techniques, both in commercial greenhouses and for research purposes.

ACKNOWLEDGEMENTS

This research was sponsored by the Dutch Ministry of Agriculture, Nature and Food Quality and by the Dutch Product Board for Horticulture (Productschap Tuinbouw) under the project numbers PT 11703, 12420, 12735, 12736 and 13289 and co-financed by the European Commission, under contract 211457, EUPHOROS.

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