

VIRTUAL LAB FOR TEACHING GREENHOUSE CLIMATIC CONTROL

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Abstract: This work presents a virtual lab for teaching greenhouse climatic control. The objective of this kind of tools is to help the students using consolidated research works in a straightforward way. Particularly, the tool developed in this article consists on a structured graphic screen allowing the access to a full greenhouse climate model with a collection of specific controllers, in such a way that the students can put into practice the knowledge acquired in the theoretical lessons without space-temporal constraints.
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1. INTRODUCTION

Nowadays, the agro-alimentary sector is incorporating new technologies, due to the large production demands, and the diversity, quality and market presentation requirements. Thus, a technological renovation of the sector is required and the control engineering plays a decisive role. It incorporates automatic control and robotics techniques in all the agricultural production levels: plantation, production, harvest, post-harvest processes and transportation. Therefore, introductory courses of automatic control and robotics are being included in the modern agronomy studies. Future engineers will have to use, understand and implement the new advances in automation in the sector. This paper presents a tool which helps to perform this task. A development of a great number of projects and research works for improving the education in the Automatic Control field has been carried out during the last years (Dormido, 2004). There are many works about interactivity, web-based simulation, and virtual and remote labs (Dormido *et al.* 2003; Guzmán *et al.*, 2004; Martín *et al.*, 2004; Sánchez *et al.*, 2002), that open a wide range of possibilities as support to the students' education. Some of these works, such as remote labs (Guzmán

et al., 2003) and virtual courses (Rodríguez *et al.*, 2004), are being used for teaching greenhouse climatic control, in undergraduate and doctorate courses. In order to complement the previous works and advance in this field, this paper presents a virtual lab for teaching greenhouse climatic control. This tool has been developed using *Easy Java Simulation* (Esquembre, 2004) and the research results obtained by Rodríguez (2002) regarding greenhouse modeling and climatic control. This virtual lab permits the students to put into practice their knowledge from any place connected to Internet and without timetable constraints. A full greenhouse climatic control course composed of three elements is now available: the theoretical lessons can be learned using a virtual course (Rodríguez *et al.*, 2004), then they can be putted into practice using the virtual lab presented in this article and finally real tests can be performed remotely using a greenhouse scale model (Guzmán *et al.* 2003).

The paper is organized as follows. Section 2 presents the main concepts involved in greenhouse control algorithms. The next section describes the main features of the tool. Section 4 shows some examples of climatic control and finally the conclusions are outlined.

2. GREENHOUSE CLIMATIC CONTROL

2.1. Description of the climatic control problem

Crop production in a greenhouse is affected by the inside climate, and therefore, it is necessary to keep the main variables within a specific range. The variables used in the control problem are shown in figure 1: controlled variables (PAR radiation, inside temperature, relative humidity and CO₂ concentration, although the last one is not very used in the Mediterranean zone), manipulated variables (common actuators such as lateral ventilation, shade screen and heating), and disturbance variables (outside climate, the crop and other greenhouse elements such as the cover and the soil).

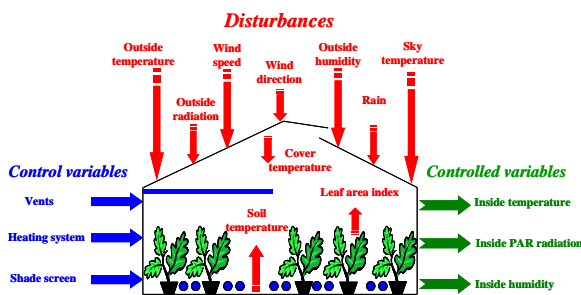


Fig. 1. Climatic control variables

2.2. Temperature control

Temperature control problem. Temperature is the main climatic variable affecting the crop growth, and thus, this variable has been traditionally controlled in the greenhouses. The plants require usually the daylight and high temperature to correctly perform the photosynthesis and growth. However, it is not necessary to keep high temperatures during the night, because the crop is inactive. In order to control the temperature, usually the ventilation is used during the day and heating during the night. Therefore, there are two setpoints: the ventilation setpoint and the heating setpoint (Rodríguez, 2002; Rodríguez *et al.*, 2003). So, it is possible to define five periods during the day with different setpoints (see figure 2), some of which do not require the use of control actuators.

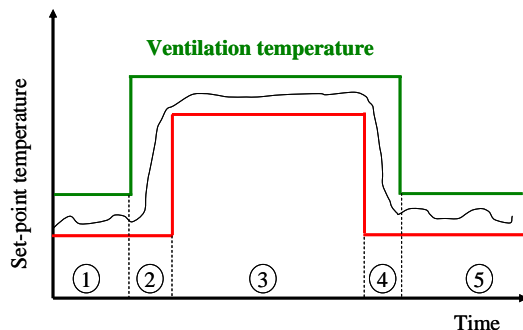


Fig. 2. Temperature setpoint periods

Temperature control using natural vents. The use of natural ventilation produces an exchange between inside and outside air, usually in the greenhouse decreasing the inside temperature. The controller

must calculate the necessary vents opening to reach the desired setpoint. The most common controller used is a gain scheduling PI scheme where the controller values are changed based on some disturbances: outside temperature and wind speed. The basis of this technique will be treated in next sections.

Temperature control with heating. The heating system consists of several steel pipes distributed along the greenhouse (figure 3). These pipes are heated by hot water circulating through them, transmitting heat to the air by convection. This physical phenomenon produces an increase in the greenhouse inside temperature. Then, the control problem consists of calculating the required temperature of the water within the pipes to let the inside temperature reaching the desired value. In order to perform this task, the system has one three way valve to mix the water of the boiler (constant temperature) with the water returning from the greenhouse in a cascade structure.

The actuators have constraints as the water temperature through the pipes is lower than the water temperature in the boiler. A classical antiwindup scheme is used to take into account this problem and avoid integrator windup. The pipes temperature cannot be bigger than that of the boiler, but either smaller than the greenhouse inside temperature (changeable lower saturation).

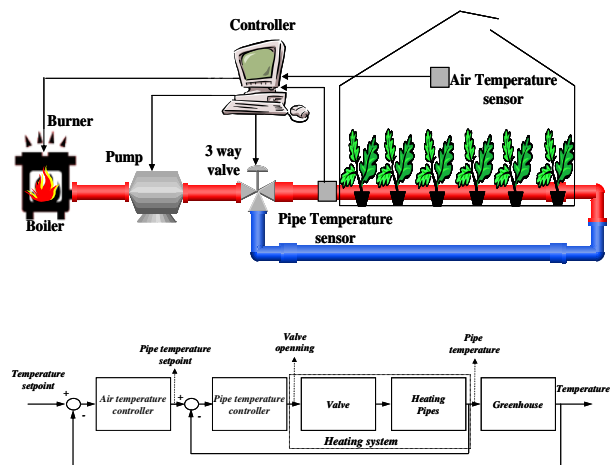


Fig. 3. Greenhouse heating system and control

2.3. Humidity control

Water vapour inside the greenhouse is not one of the most important variables affecting the crop growth. However, the humidity control has a special interest, because high humidity may produce the appearance of diseases and decrease the transpiration, and low humidity may cause hydric stress, closing the stomata, and reducing the photosynthesis. Therefore, it is necessary to keep the humidity within a certain range.

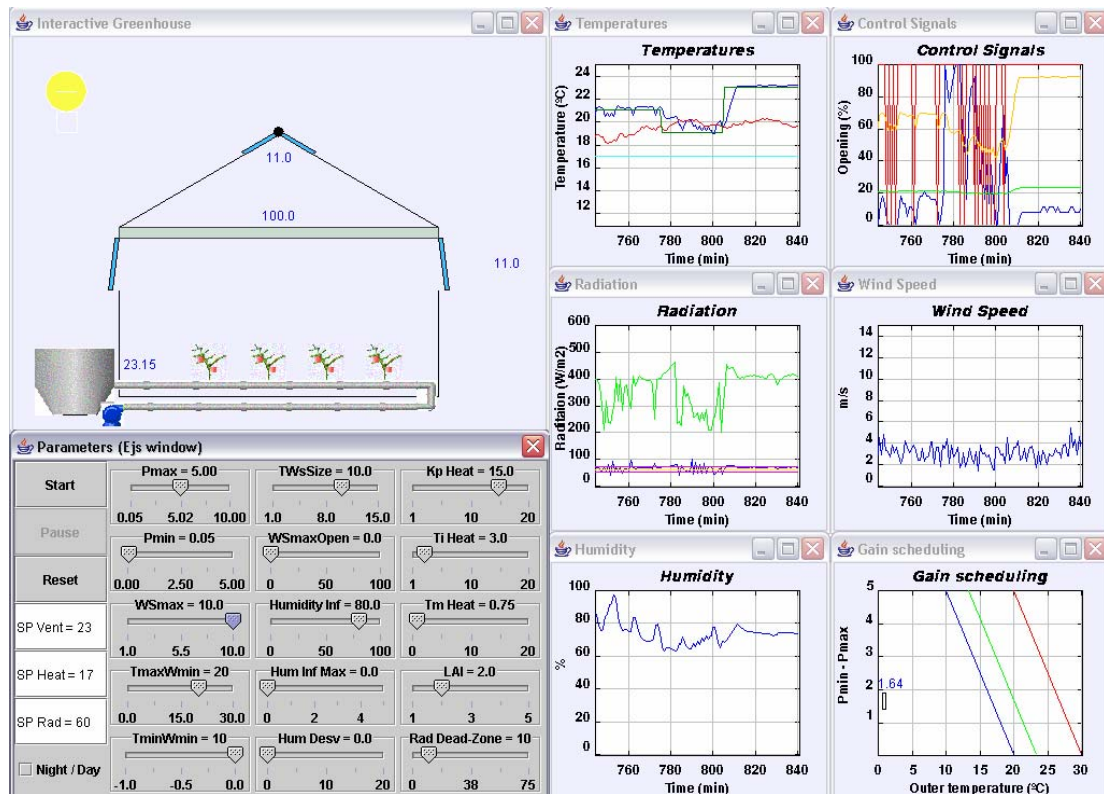


Fig. 4. Main screen of the virtual lab

There are two problems involved in the humidity control: (1) the greenhouse inside temperature and the relative humidity are inversely related (when one of them increases the other one decreases and vice versa); (2) for controlling temperature and humidity the same actuators are used. The temperature control has the main priority because it affects to the crop growth directly. In order to keep the humidity within a determined range, the temperature setpoint can be changed based on the inside relative humidity value.

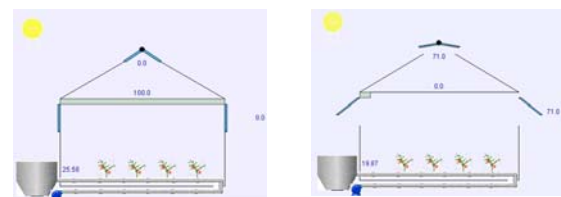
2.4. Radiation control

The most widely used method to control the solar radiation in the Mediterranean area is based on shade screens to reduce the incoming radiation onto the crop and the soil, causing two effects: reducing PAR radiation and slowing the crop growth due to the decrease of the photosynthesis activities. The shade screen is always completely opened or closed to obtain a uniform crop growth by on/off control with dead zone to avoid frequent changes in the actuators.

3. VIRTUAL LAB DESCRIPTION

As said before, the main aim of the tool is to facilitate the study and understanding of the issues involved in modeling and climatic control of greenhouses. The tool consists of a graphic screen connected to the algorithms and a model implemented in *Matlab/Simulink* (Rodríguez, 2002). In a previous exercise this model is used by the students to understand the process dynamic in order to obtain the model parameters. In this way they can design the controllers and to test them in

the virtual lab. The environment EJS (Esquembre, 2004) has been used for developing the tool due to many reasons: easy to use, development language available in many platforms (java), connection with *Matlab/Simulink*, and many virtual labs developed (Dormido, *et al.*, 2003; Marin *et al.*, 2004; Sánchez *et al.*, 2002). The tool is shown in figure 4 where the laboratory screen has been divided into three parts: greenhouse synoptic, a set of graphics to show the different variables, and several buttons and sliders to allow the modification of the control parameters.



(a) Vents and screen closed (b) Vents and screen opened
Fig. 5. Vents and shade screen operation.

In the left upper part of figure 4 the greenhouse synoptic is shown. In this zone it is possible to monitor the crop growth and the effect of the control signals through the actuators movements: natural ventilation, shade screen and heating based on a boiler. The lateral and zenital ventilations are represented in sky blue colour and their positions are changed taking into account the value of the associated control signal. The actual value of the vents opening is shown in percentage below the zenital ventilations and next to the right side ventilation. Figure 5 shows an example with different vents positions. The shade screen is located between the greenhouse and its cover; it is

represented in grey colour and its length is modified based on the associated control signal.

The third actuator is the heating. This system has been represented with a boiler, a pump and several pipes (figure 3, 4 and 5). A colour code is used: pump off/on - blue/green; pipes off/on – grey/based on their temperature. The value of the pipes temperature is shown next to the boiler, as it can be seen in figure 6, where an example of the heating is shown. The crop growth is considered as a disturbance for the system being possible to modify this parameter in the graphic screen. Several plants are shown in the synoptic and their size is changed based on the value of this disturbance.

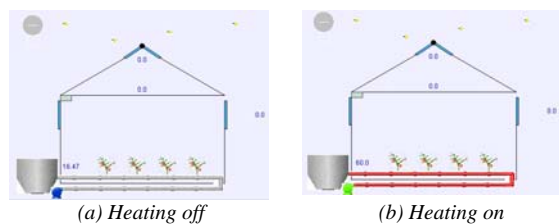


Fig. 6. Heating system operation

Some effects have also been represented to distinguish between the day and the night. During the day the sun intensity is changed based on the solar radiation (figure 5) obtained from the model or the disturbances database. During the night the sun changes to grey colour and several stars appear (figure 6).

Regarding the other parts of the tool, a set of graphics with the different variables are shown in the right side of figure 4. From left to right and up to down, the graphics contain the following information: (1) variables related with the temperatures evolution: inside temperature (blue), outside temperature (red), and day and night setpoints (green and sky blue respectively); (2) information about the control signals: vents opening (blue), shade screen opening (red), temperature of the heating pipes (green) and integral signal of the heating controller to study the antiwindup scheme (orange); (3) information about the radiation: outside PAR radiation (green), inside PAR radiation (blue), radiation setpoint (yellow), and the dead-zone for shade screen controller (pink); (4,5) wind speed and the relative humidity respectively (both in blue colour). With these graphics it is possible to analyze the effects of these variables in the temperature control; (6) information about the gain scheduling controller for the temperature control with ventilation: the proportional gain changes based on the wind speed and the outside temperature. Some specific situations and interpretations of these graphics will be commented in the next section.

The last part of the tool corresponds to the control parameters. This zone is located below the greenhouse synoptic as seen in figure 4. In the first column of parameters there are three buttons, three edit fields and one checkbox. The buttons allow initializing, pausing and reinitializing the

simulation; in the edit fields it is possible to modify the temperature and radiation setpoints. The checkbox is used to start the simulation during the day or the night. The next two columns contain the control parameters related to temperature control with ventilation (see figure 7). These parameters are the maximum (P_{max}) and minimum (P_{min}) values for the calculation of the proportional controller ($Kp = P^{-1}$) (Kamp and Timmerman, 1996). The next four ones determine the influence of the wind speed and the outside temperature in the calculation of this proportional constant (WS_{max} , $T_{max}W_{min}$, $T_{min}W_{min}$, TW_{Size}). These parameters are used to set the limit values of the proportional constant of the controller. The other parameters of these columns allow setting the maximum opening ($WS_{maxOpen}$) for the ventilation when the wind exceeds the maximum set speed (WS_{max}), and also to modify the parameters associated to the setpoint modification based on the humidity ($Humidity\ Inf$, $Hum\ Inf\ Max$, $Hum\ Desv$) as it will be better described in the next section using an example. With respect to the last column, the three first parameters are used to modify the PI controller with antiwindup to control the temperature with heating (Kp_{Cal} , Ti_{Cal} , Tm_{Cal}). The last two parameters allow modifying the effect of the crop growth (LAI -Leaf Area Index) and the dead zone of the on/off controller for the radiation control with shade screen ($Rad\ Dead-Zone$) respectively.

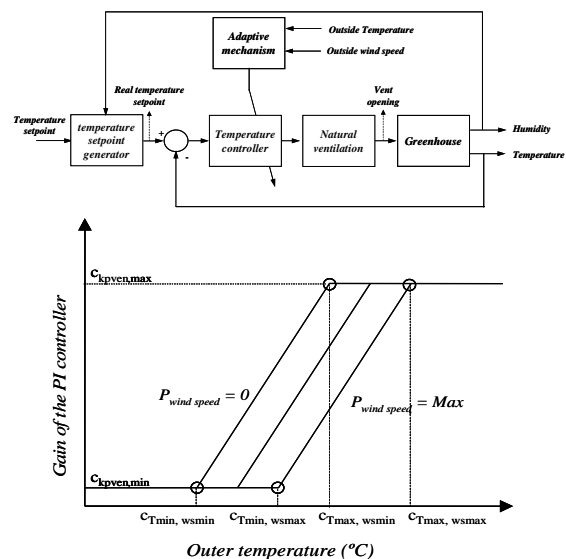


Fig. 7. Gain scheduling example

4. EXAMPLES

This section shows some illustrative examples of the use of the different controllers available in the tool, as well as several typical situations encountered when controlling greenhouse climate. Real climatic data obtained from industrial greenhouses have been used in order to simulate the system.

4.1. Gain scheduling temperature control with natural ventilation

As said in previous sections, this kind of control consists in a gain scheduling proportional controller based on the wind speed and the outside temperature. The configuration of some parameters is required in order to run this control. First, the maximum and minimum values for the proportional constant must be set using the sliders P_{max} and P_{min} respectively. In this example the selected values have been $5\text{ }^{\circ}\text{C}\%^{-1}$ for P_{max} and $1\text{ }^{\circ}\text{C}\%^{-1}$ for P_{min} . After that, the limits of the outside temperature based on the wind speed are modified. The maximum and minimum temperatures for the minimum wind speed (0 ms^{-1}) are set to $20\text{ }^{\circ}\text{C}$ and $10\text{ }^{\circ}\text{C}$ respectively using the sliders $T_{maxWmin}$ and $T_{minWmin}$. In the same way the maximum and minimum temperatures for the maximum wind speed (V_{max}) are calculated adding the value of $TWSSize$ to the temperatures selected for the minimum wind speed. In this example $TWSSize$ is set to $10\text{ }^{\circ}\text{C}$, being $30\text{ }^{\circ}\text{C}$ and $20\text{ }^{\circ}\text{C}$ the values for the maximum and minimum temperatures with maximum wind speed. The red and blue lines shown in the graphic *Gain Scheduling* are calculated, taking into account these values, to indicate the limits based on the wind speed and the outside temperature. Once the system is working, a third new line in green colour appears between the other two lines, to show the effect of the wind speed. The proportional value is obtained as the ordinate value of a point belonging to this line, the x value of this point obtained based on the outside temperature at each sample time, as seen in the plot.

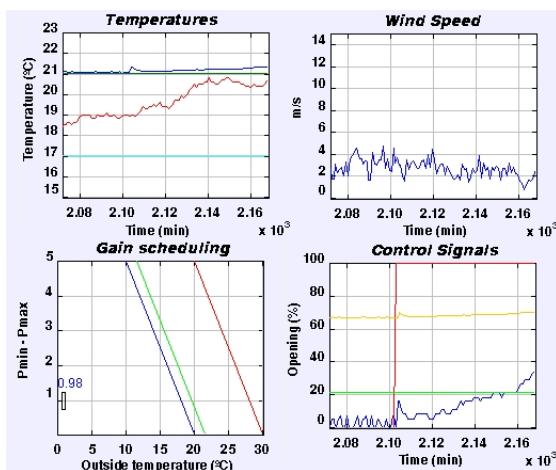


Fig. 8. Gain scheduling control results

Figure 8 shows an example where the temperature setpoint is set to $21\text{ }^{\circ}\text{C}$. An increase in the outside temperature and how the inside one is affected is also shown. Taking into account this fact and with a wind speed relatively constant, the gain scheduling controller decreases the value of the proportional constant ($Kp=P^{-1}$) to increase the ventilation opening, thus avoiding the increase of the inside temperature.

4.2. Setpoint modification based on humidity

The temperature setpoint has to be changed when humidity surpasses defined constraints, in such a way that it is necessary to set the reference value of the humidity from which the temperature setpoint is influenced ($Humidity\ Inf$), and the range where this change will be performed ($Hum\ Desv$). In this example the influence of the humidity has been set to 80% and the range to 20% . The maximum change for the temperature setpoint based on the humidity must be also determined ($Hum\ Inf\ Max$), and in this example is set to $\pm 1.5\text{ }^{\circ}\text{C}$. The result when using these parameters is shown in figure 9, where it is observed how the setpoint is modified when the humidity changes, the temperature following these changes of the reference.

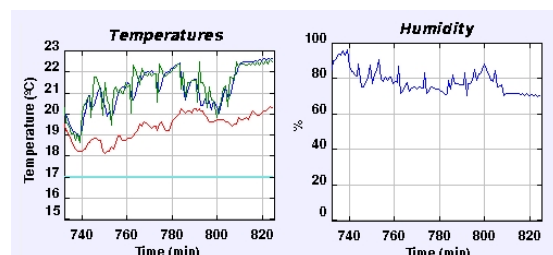


Fig. 9. Setpoint modification based on humidity

4.3. Temperature control with heating

The temperature control with heating is performed using a PI controller with an antwindup scheme. Therefore, it is necessary to tune the three parameters used in these cases: proportional gain, integral time, and correction time ($KpCal$, $TiCal$, $TmCal$). In this example the values selected have been $15\text{ }^{\circ}\text{C}_{water}\text{ }^{\circ}\text{C}_{air}^{-1}$ for Kp , 3 min for Ti and 0.75 min for Tm . Figure 10 shows the result of applying this control starting with a setpoint change from 16 to $18\text{ }^{\circ}\text{C}$. The reference is changed later twice. From 18 to $16\text{ }^{\circ}\text{C}$ at 312 min, and from 16 to $18\text{ }^{\circ}\text{C}$ at 340 min. In the first change the parameters are not modified. However in the second one the parameter Tm is set to 3.5 min, and it is observed how the response of the controller and the integral effect react faster.

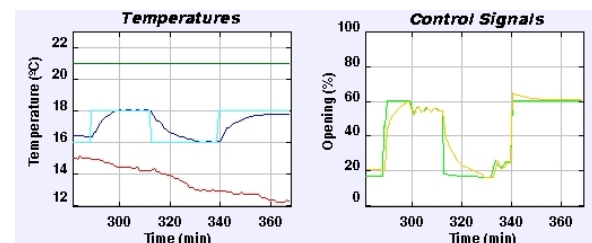


Fig. 10. Temperature control with heating

4.4. Radiation control with shade screen

In order to control the radiation with shade screen an on/off controller with dead zone has been implemented. In this case there are only two parameters, the value of the dead zone ($Rad\ Dead-Zone$) and the radiation setpoint. Initially,

the setpoint has been set to 60 Wm^{-2} and the dead zone to 7.5 Wm^{-2} . The result of this example is shown in figure 11 where it can be seen how using this values the shade screen is closed during a lot of time. In the minute 895 the dead zone is reduced to 5 Wm^{-2} , and the shade screen remains closed up to minute 945 when the radiation leaves the dead zone causing several times the opening and closing of the shade screen.

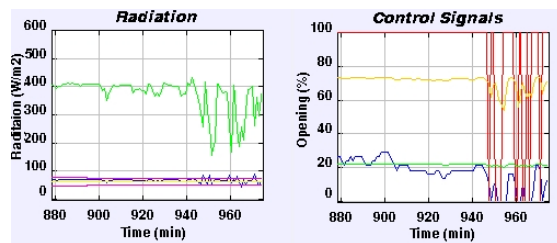


Fig. 11. Radiation control with shade screen.

4.5. Extreme situations

The different actions which would be necessary to perform in presence of extreme situations can be studied in the tool. One of them it is the possibility of limiting the ventilation opening ($WS_{\max OPEN}$) when the wind speed exceeds a determined value (WS_{\max}). An example it is shown in figure 12 where the ventilation opening has been limited to 10 % when the wind speed exceeds 4 ms^{-1} . This effect is observed from minute 906.

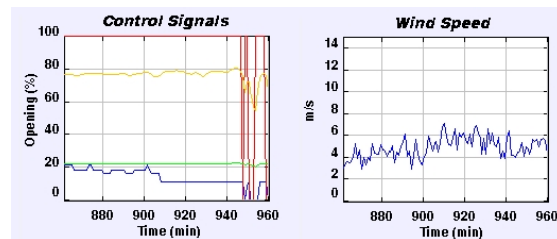


Fig. 12. Study of extreme conditions

5. CONCLUSIONS

The tool presented in this paper tries to cover education aspects involved in the teaching of greenhouse climate control. Thanks to the creation of new development tools, such as EJS, it is possible to facilitate the students the understanding of classical and new control techniques used in the agriculture sector. In this way and using the ideas of the many works developed in the scope of Automatic Control, this paper presents a virtual lab for teaching greenhouse climatic control developed with EJS, and which uses the model and controllers reported by Rodríguez (2002). The future works will include:

- Taking into account other extreme situations in the temperature control with ventilation, such as: presence of rain, wind direction, etc...
- Possibility of studying different actuators and modifying the parameters of the actual actuators.

- Inclusion of other control algorithms, such as, predictive control.
- Easy and manual manipulation of disturbances.

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