Original Research Article

Climate Control and Irrigation Automation Systems in Turkish Greenhouses: A comparative study

Abstract

Today's modern greenhouse agriculture draws attention with its intensive plant production capacity and industrially advanced structure in which soilless agriculture technology is used. Computer, microprocessor-controlled information processing and automation systems are needed for the effective management and operation of greenhouses. In order to meet the demands according to the plant species planned to be produced in soilless modern greenhouses; Equipment such as signal-sensing, heating, ventilation, shading, irrigation, fertilization, fogging-cooling, carbon dioxide fertilization and greenhouse general climate control system are needed. According to the needs of the plant, sub-equipment (suitable for obtaining the correct climate conditions desired in the greenhouse) such as roof windows, heating, irrigation, cooling, shading, fan ventilation should work according to the signals coming from the sensors. In this study, the data of 4 different commercial automation systems (namely Priva, Hortimax, Hoogendoorn and Karaca) in 5 greenhouse enterprises in different parts of Turkey were examined and screenshots were obtained. The data obtained were compared with each other and evaluated in terms of ease of use, performance, measured elements, capacity etc. This research will provide added value to the greenhouse economy of countries in the next stages of undercover agriculture, as it will serve to understand greenhouse automation and subsequently to develop new systems. It will also be helpful to the greenhouse investors to make the right choice while choosing a greenhouse automation system.

KEYWORDS**:** Greenhouse Automation Systems, Modern Greenhouse, Climate Control Systems, Irrigation Systems

Introduction

In recent years, computer control and automation have provided great convenience and opportunities in all areas of human life. With the automation of the agricultural sectors, it can provide many advantages such as increase in earnings, increase in quality, minimization of errors caused by human factor, ease of work follow-up and reduction of accidents[1]. For this reason, automation has become an indispensable need for all business sectors today. With the advancement of today's technology, automation systems can perform on-off control depending on environmental conditions, as well as system control and automation without the need for human labour, thanks to microcontrollers that think like human beings[2]. It is possible to reduce energy costs and increase efficiency by increasing quality with fuzzy logic control. The concept of automation symbolizes a general situation used in all of these systems. Companies working on machine-automation systems are trying to be at the forefront of the competition with both semi-automation and full automation systems. On the other hand, although these systems have many advantages, the high initial installation costs are the first drawbacks. However, considering the benefits to be received in the medium and long term, this amount is no longer a problem.

1. Requirements of Modern Greenhouse Automation Systems

Modern greenhouse automation production systems, which meet the requirements of the product market as well as the design and operation requirements, are expected to cover aspects such as informing the consumer about the product, monitoring with climate control systems and operating data collection systems actively, healthy plant growth and biological pest control, stimulating natural defences and providing optimal environmental conditions for incorporating basic principles when desired. Greenhouse automation systems are systems that provide central control of all systems such as air circulation, fertilization, fogging-cooling, ventilation, artificial lighting, heating, thermal curtain, irrigation, and CO_2 system by using their own meteorological station data[3-5].

1.1. How the Greenhouse Climate Automation System Works

A computer can control the parameters of the "greenhouse environment", which consists of many sub-processes. The computer should be able to control different equipment parts such as ventilation, heating system, screen, etc. For example, during temperature control with ventilation, the ventilation temperature set value is entered on the computer control screen. When the measured greenhouse temperature exceeds the entered set value, that is, the ventilation temperature, the computer opens the ventilation windows to reduce the temperature. The control loop of this scenario consists of four parts; Processing Temperature, Measuring device temperature (sensor), Environmental control computer, Corrective equipment. Figure 1 shows a diagram for "temperature" control[6].

As seen in the diagram, the measured value is taken from the temperature sensor. A value for temperature control is assigned in the computer. The assigned value is abbreviated as SV (set value). It continuously controls the measured value and the set value simultaneously, and if a difference is detected in the values, the ventilation system is activated and adjusted to correct the temperature. In the example, the temperature set point is 18 °C, the measured value is 20 °C, therefore, the measured value should be reduced to 18 °C, the control loop opens the ventilation windows to lower the temperature. This example control loop is the one which is used to control the temperature operation with ventilation.

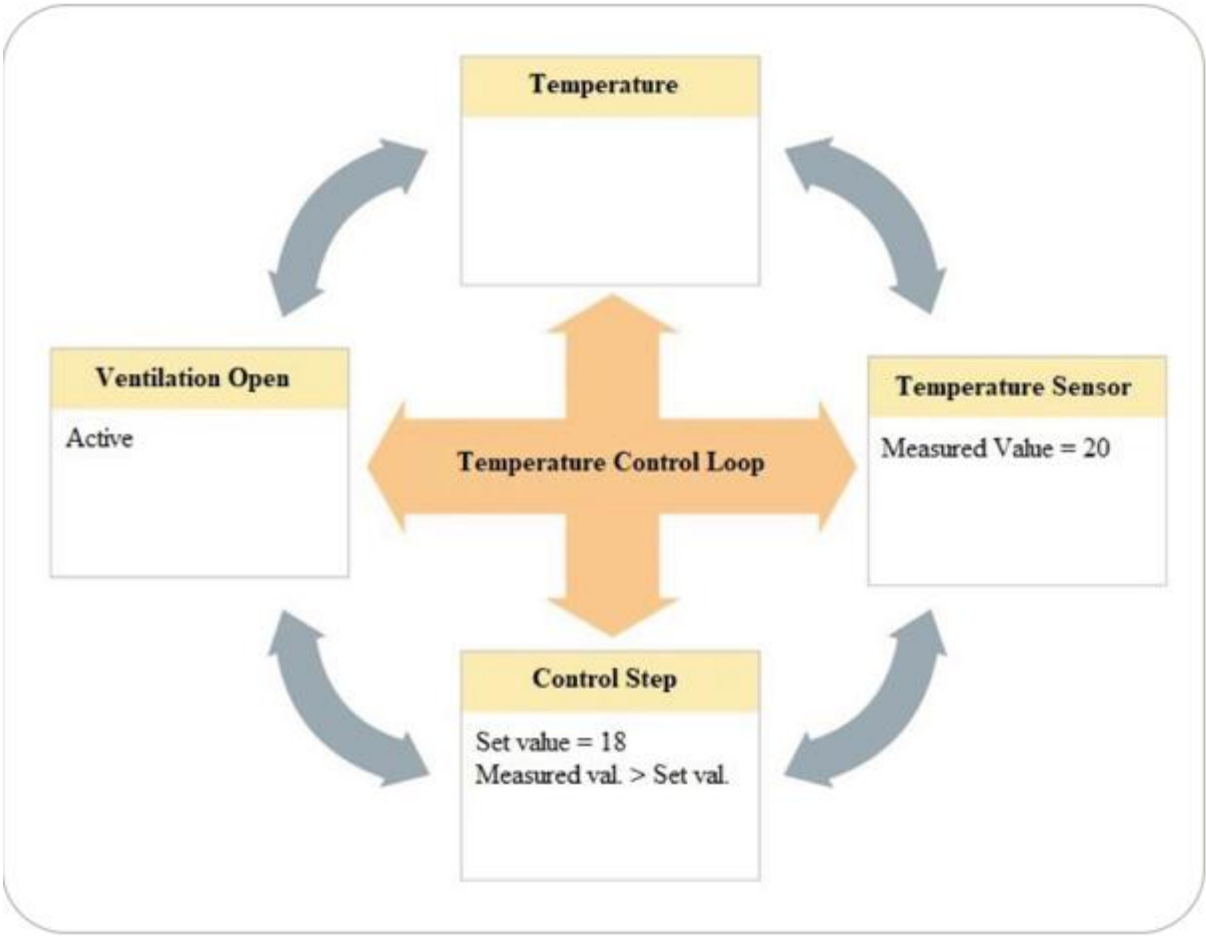


Figure 1. Greenhouse Temperature Control Loop

1.1.1. How ventilation systems work

If the relative humidity or temperature in the greenhouse is lower or higher than the desired value, with the help of ventilation windows the ventilation system ensures that the humidity and the temperature in the greenhouse reach the desired set values[2]. To maintain optimum temperatures during the summer months, the warm greenhouse air must be replaced with cooler outdoor air. To achieve this, mechanical or natural ventilation is used in greenhouses. In the ventilation automation system, windows can be opened to any desired degree between 0% - 100% opening[7]. After measuring the indoor greenhouse temperature, the opening percentage of the windows may decrease or increase depending on the set temperature. A P-Band (proportional control) is needed to adjust the window position. P-Band opens the roofs at a certain percentage for every degree of temperature difference between set and measured values. In order to adjust the window position, the system finds the required position by subtracting the desired set value from the greenhouse temperature and dividing it into the P-Band. The ventilation system has two separate roofs, wind-side and lee-side[8]. The heat exchange of greenhouse surfaces on the wind side is higher than the heat exchange on the lee side[9]. As shown in Figure 2, the wind side in the automation system should always be opened later and with less angle than the other direction.

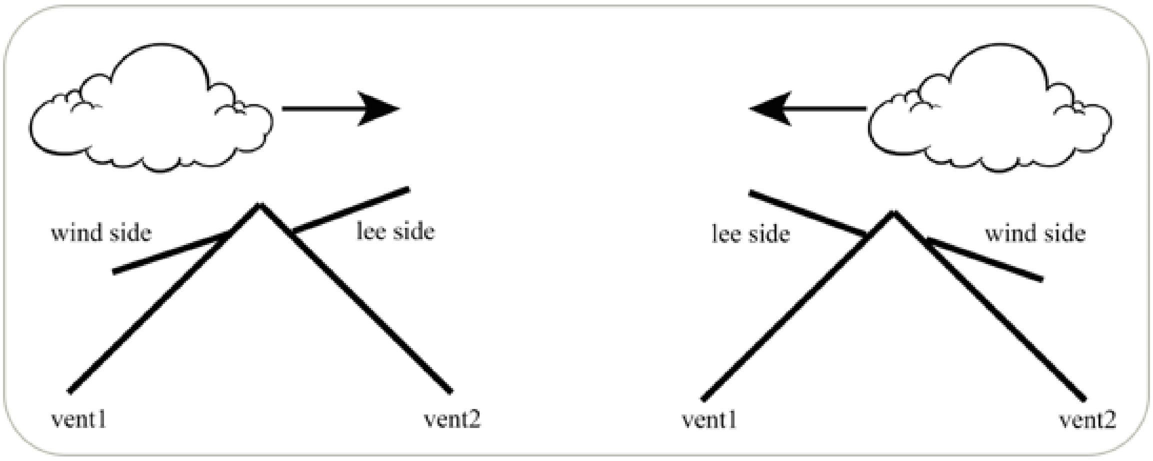


Figure 2. Ventilation lee-side and wind-side

1.1.2. How curtain(screen) systems work

The amount of light in the greenhouse directly affects photosynthesis. Maintaining the greenhouse temperature is also crucial. Curtains in modern greenhouses are used for darkening, energy saving and shading. Curtain systems enable manufacturers to provide precise climate control all year round. When the solar radiation value on the greenhouse surface is higher than a set value, curtains are closed. This process is controlled by the automation with the data coming from the light LDR (light dependent resistor) sensor or the radiation sensor. Curtains can also be used for energy saving, temperature and humidity control plus for the manipulation of growth of plants and maturity of the fruits. There are two curtain systems: push-pull (push-pull) and cable (rope) systems. Push-pull system is preferred in plastic greenhouses and cable system is preferred in glass greenhouses. Greenhouse automation system determines the use of curtains according to interconnected climate variables such as humidity, light, wind speed and temperature[7]. The automation adjusts the position of the curtains so that they do not go beyond the optimum values entered by the user[10-14].

1.1.3. How circulation fans work

Circulation fans are utilized to move or circulate the air inside the greenhouse. Circulation fans are used in naturally ventilated structures to assist air movement when ventilation is minimal. With these fans, the formation of dead climate zones in the greenhouse is prevented, thus contributing to a uniform climate and uniform plant growth in the greenhouse[15]. It is also used to suppress vegetative growth and direct the plant to generative growth by cooling the plants in general and the growing tip in particular, especially in hot times. Fans are controlled as sectorial (zoned) as each other climate control elements, each sector can be activated independently in the greenhouse[16]. The fan control is adjusted to operate according to the indoor temperature or at certain times for certain periods and they may have different speed levels(mostly max 6 steps). The fans can also be controlled as step by step according to the amount of the difference between the measured and set values in the sectors inside the greenhouse[17]. Small flow fans are preferred in modern greenhouses. When fans with large air flow rate are used in the greenhouse, it may harm the plan tips which is the growing point for the plants in the greenhouse[14]. Air movement should not be high in the plant growing environment, preferably less than 1m/s.

1.1.4. How the high-pressure misting system works

This system is used for indoor cooling and relative humidity control. Automation activates shading curtains when the light and the outdoor temperature are measured above the set values. But when the plant needs light, shading screen is opened and the automation system activates the fogging system. With the operation of the fogging system, the temperature is reduced. In the system, the relative humidity increase and/or evaporative cooling are provided with very small diameter water droplets given to the air. This prevents drying and fading and reduces the frequency of irrigation[18].

1.1.5. How the heating system works

Temperature plays an important role in growing plants in a greenhouse environment. In the environment where the plants are located, there are desired lower and upper temperature values so that the development can continue at a regular level. These values are determined as minimum and maximum values in greenhouse automation. Today, in advanced greenhouse automation, this situation can be left to the automation system and energy savings can be achieved. The automation system, taking the given values into account, fulfils the temperature demands of the plant and heats at a value close to the minimum value. Many elements are used for heating in the greenhouse. The main ones are: at ground level rail heating system, snow melting system, under gutter heating system, grow pipes, side heating system, greenhouse ceiling heating system, etc. Heating system is used for temperature and humidity control and works basically in line with curtain and ventilation system

1.1.6. How the carbon dioxide distribution system works

Carbon dioxide is given into the greenhouse from the flue gas of the natural gas boiler or from the liquid carbon dioxide tank. Automation keeps time intervals for the carbon dioxide system. The system is generally activated when the radiation is at its highest and the greenhouse temperature is at its optimum. The carbon dioxide system ensures the opening and closing of the valves by transmitting data to the automation computer with the concentration sensors in each sector.

1.1.7. How the irrigation-fertilization system works

In greenhouse irrigation automation systems, liquid fertilizers are taken from the macro and micro element tanks and added to the acid taken from the acid tank, and given to the dosing unit in a certain volume. Liquid fertilizers are taken from the fertilizer tanks by magnetic pumps[19]. When the fixed EC and pH sensors in the dosing unit read the set EC and pH values, this mixture is pumped together with the irrigation water through the underground main distribution pipes of the greenhouse to the plant irrigation drippers by the electro-valve groups. In such systems, instant and precise dosing is done. By the system, a homogeneous plant nutrient solution is obtained by pre-mixing water and fertilizer. In the automation system, the greenhouse irrigation valves can be adjusted to operate individually or together (if the pump capacity is appropriate). In advanced irrigation automation systems, irrigation control is also carried out depending on solar radiation. Accordingly, with the sunrise in the morning, radiation measurement starts with the solar radiation sensor in the meteorological station and when the radiation integral of 100 J/cm2 is reached, a predetermined cc of water per plant is given by the automation system. In modern applications, this value is 100 cc of water per plant for every 100 J/cm2 irradiation. After every 100 J/cm2 value is reached, the solar radiation value is either reset or cumulatively recalculated, and in this way, a large number of irrigation can be done during the day, especially in spring-summer times.

1.2. Greenhouse Automation Functional Modules

The most critical part in the greenhouse environment information monitoring system is the monitoring software of the system server. User access to the system is possible with the software developed for receiving and evaluating wirelessly transmitted sensor information by the automation system. The main function of monitoring software includes parameter setting, display, query, analysis, report processing and real-time data alarm, online real-time monitoring, real-time graphical data display and remote real-time communication.

1.2.1. Imaging and monitoring system structure

The imaging and monitoring system performs operations such as analysing, saving and printing the environmental information of the greenhouse and all the values measured during the day, from a web browser or a server computer. This system not only obtains real-time environmental data, but also provides remote monitoring over the internet[5].

1.2.2. User interface

The monitoring interface for greenhouse environment information consists of interfaces such as system parameter setting interface, data acquisition interface, real-time data display interface, alarm setting interface and data processing. Real-time data display interface can display real-time environmental conditions graph. Sensor information is displayed with dynamic real-time graphics mode. The user should be able to see the system's menu tree on a single screen. Parameter pages should be accessible from this menu in order to view or to make changes to their settings. It should be able to provide quick access to frequently used pages by assigning shortcuts. The alarm setting interface can apply settings for alarm conditions and alarm display format. The data processing module is able to handle the received data packet, such as digital filtering, numerical computation, scale conversion, logical judgments. The user interface is used to track and monitor collected data, including storage, querying, printing, data analysis and statistics. The main interface should be displayed in full screen so that the operator can easily monitor the greenhouse conditions.

1.2.3. Alarm system

The alarm system is activated in vase of greenhouse systems not working properly, sensor failure and abnormal data from the meteorological station. The alarm system is designed to give an audible warning, to give information over the program or to perform different operations to be specified. The effective operation of the alarm system depends on the design of the greenhouse systems and getting information from the systems. This increases the efficiency of the automation system.

1.2.4. Data security and backup

In order to minimize the downtime of the systems and possible information loss in the face of errors that may occur in the Automation System, the configuration, system information and corporate data on the systems should be regularly backed up. For data security, uninterruptible power supply and generator (automatic circuit) systems must be present in the current working environment.

2. Materials And Methods

Within the scope of this study, commercial automation systems developed by 4 different companies(namely; Priva, Inta, Hoogendoorn and Karaca) widely used in soilless greenhouses in Turkey were examined and compared. In this context, 3 greenhouse operations in Antalya, 1 in Uşak, and 1 in Afyon cities were visited and the automation software were examined in in depth as much as possible. Evaluations and comparisons were made on different aspects such as the basic data, what these commercial automation systems controls in the greenhouse, the status of alarms, whether there is a lower and upper limit control in user data entry, data storage status, ease of use and graphical representation. Besides, a separate comparison was made by taking the main and sub-screen images of the related software. The commercial automation software examined within the scope of the research are shown in Table 1.

Automation System	Model / Version	Country
Hoogendorn	iSii version 6	Holland
Priva	Integro version 724	Holland
Priva	Office version 4	Holland
Inta(Climate control)	EVO AP 170701	Spain
Inta(Irrigation)	CDN version 2	Spain
Karaca	KRSS version 014.002	Turkey

Table 1. Examined Automation Software

3. Results

3.1. Hoogendoorn Automation System

The system consists of 4 parts: Control Climate (climate control), Control General (general control), Control Water (irrigation-fertilization control) and Energy Management (energy management). The Hoogendorn Climate control System includes thermal and shading screens, fogging, CO2, circulation fans, ventilation, humidity control, greenhouse heating control and daily climate data. Screenshot of the menu of Instantly measured climate values is shown in Fig.4 for this control software.

As can be seen from the screenshot photo, the greenhouse is divided into separate zones as Comp1-1, Comp1-2, Comp1-3, Comp1-4, Comp1-5 and Comp1-6. Each zone also makes measurements with 1 sensor group. It can also be used for curtains, windows, etc. The climatic elements are also divided into separate sections. The figure shows indoor temperature, outdoor temperature, relative humidity, window positions, heating pipes, heating pumps, CO2 and fans status, measured and calculated values. Minimum temperature set value for the heating system to operate and the entry screen for the ventilation temperature set values (as wind side and lee side) are shown in Figure 4.

Greenhouse climate		Compl-1	Compl-2	Compl-3	Compl-4	Compl-5	Compl-6
greenhouse temperature climate: measurement	°C	27.7	26.4	27.7	28.1	27.1	28.9
RH climate: measurement	%	78	81	66	66	56	46
RH: ViP	%	80	80	80	80	80	80
HD climate: measurement	g/m³	5.9	4.6	9.2	9.4	11.4	15.5
Ventilation general		Compl-1	Compl-2	Compl-3	Compl-4	Compl-5	Compl-6
Ventilation lee side		LeeSide1-1	LeeSide1-2	LeeSide1-3	LeeSide1-4	LeeSide1-5	LeeSide1-6
lee side vent position: measurement	%	85	85	85	85	85	85
lee side vent position: computed	%	85	85	85	85	85	85
lee side ventilation temperature: computed	°C	19.0	19.0	19.0	19.0	19.0	19.0
Ventilation wind side		WindSide1-1	WindSide1-2	WindSide1-3	WindSide1-4	WindSide1-5	WindSide1-6
wind side vent position: measurement	%	85	85	85	85	86	85
wind side vent position: computed	%	85	85	85	85	85	85
wind side ventilation temperature: computed	°C	20.0	20.0	20.0	20.0	20.0	20.0
Curtain general		Compl-1	Compl-2	Compl-3	Compl-4	Compl-5	Compl-6
Curtain		Screen1-1	Screen1-2	Screen1-3	Screen1-4	Screen1-5	Screen1-6
curtain: measurement	%	0	0	0	0	0	0
curtain: position	%	0.0	0.0	0.0	0.0	0.0	0.0
curtain: open/close status		curtain open	curtain open	curtain open	curtain open	curtain open	curtain open
Heating general		Compl-1	Compl-2	Compl-3	Compl-4	Compl-5	Compl-6
Heating circuit		Tuberail1-1	Tuberail1-2	Tuberail1-3	Tuberail1-4	Tuberail1-5	Tuberail1-6
circuit pipe: measurement	°C	0	0	0	0	0	0
circuit pipe: computed	°C	0	0	0	0	0	0
circuit pump: status		off	off	off	off	off	off
circuit pipe: measurement (I/O)	°C	31	30	31	33	31	32
		Growtube1-1/3	Growtube1-1/3	Growtube1-1/3	Growtube1-4/6	Growtube1-4/6	Growtube1-4/6
circuit pipe: measurement	°C	0	0	0	0	0	0
circuit pipe: computed	°C	0	0	0	0	0	0
circuit pump: status		off	off	off	off	off	off
circuit pipe: measurement (I/O)	°C	31	31	31	33	33	33
		Snowtube1-1/3	Snowtube1-1/3	Snowtube1-1/3	Snowtube1-4/6	Snowtube1-4/6	Snowtube1-4/6
circuit pipe: measurement	°C	0	0	0	0	0	0
circuit pipe: computed	°C	0	0	0	0	0	0
circuit pump: status		off	off	off	off	off	off
circuit pipe: measurement (I/O)	°C	32	32	32	32	32	32
CO2 general		Compl-1/3	Compl-1/3	Compl-1/3	Compl-4/6	Compl-4/6	Compl-4/6
CO2 measurement	ppm	96	96	96	306	306	306
Fans		Compl-1/4	Compl-2/5	Compl-3/6	Compl-1/4	Compl-2/5	Compl-3/6
fans: status (1=off, 2=on)		off	off	off	off	off	off
Meteo		Gr 1					
outside temperature: measurement	°C	30.8					

Figure 3. Screenshot of the menu of instantly measured climate values

File Edit View Options Help

Settings | Status | Alarms | Measure & Actuate

Settings	Unit	Value
heating temperature: ViP	°C	19.0
ventilation temperature lee side: ViP	°C	20.0
ventilation temperature wind side: ViP	°C	21.0
RH: ViP	%	80

Figure 4. Screenshot of indoor temperature adjustment screen

On this screen, when the indoor temperature of the greenhouse falls below the heating set temperature, the heating operation is performed. If the indoor temperature of the greenhouse is above the ventilation set temperature on the lee side, the ventilation windows on that side are opened. When the indoor temperature of the greenhouse is above the wind-side ventilation set temperature, the wind-side ventilation window is opened. The function of the RH-ViP (Relative Humidity) parameter is to open the ventilation windows when the relative humidity in the greenhouse is higher than 80%. Apart from the climate control part, irrigation system has the following controls; pumps, valves, crop-section, recipes for fertilizers. In Figure 5, the input screen of the recipes and their working mode are shown.

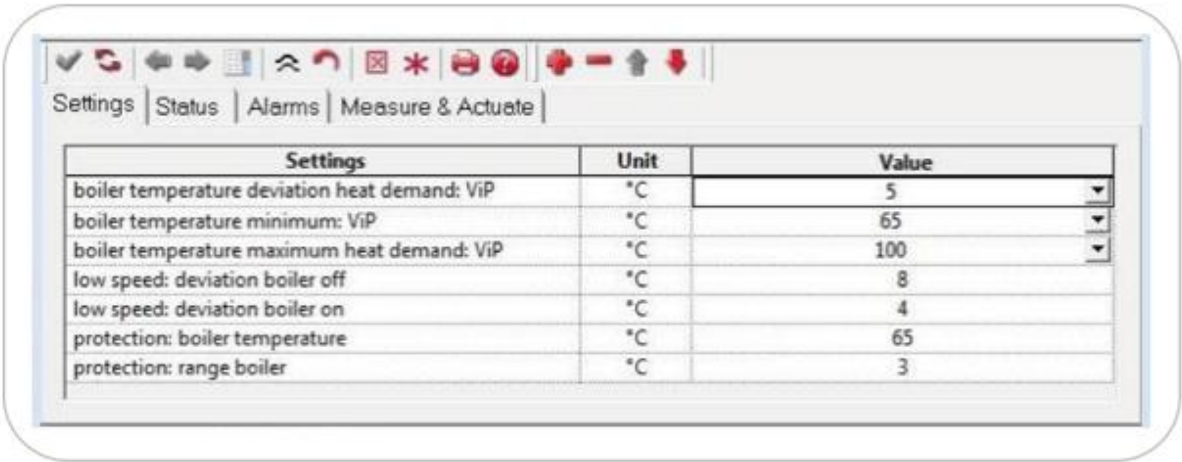
Ayarlar | Durum | Alarmlar | Ölç & Uyar | Hizmet |

Ayarlar	Birim	Değer
unit phase 2 supply		cc/plant
phase 2 supply amount: ViP		60.0
phase 2 supply time: ViP	m:s	00:00
EC control EC value: ViP	EC	2.4
recirculation EC value: ViP	EC	0.3
pH control: pH value	pH	6.8
fertilizer phase 2: number		1
interval: ViP	m	18
delay time: ViP	m	0
start- en stopconditions		Seçim
time: start relative to		sunrise
time: start time	h:m	02:00
time: stop relative to		sunset
time: stop time	h:m	-02:00
radiation: start relative to		sunrise
radiation: start time	h:m	02:00
radiation: stop relative to		clock
radiation: stop time	h:m	18:00
radiation sum start: ViP	J/cm²	75
radiation threshold start: ViP	W/m²	50

Figure 5. Recipes entry screen

The “Unit phase 2 supply” parameter determines the irrigation method of the system. If irrigation is timed, “phase 2 supply” time is on. VIP parameter can be used in minutes-seconds. If the irrigation automation does not irrigate according to time, “phase 2 supply amount- VIP” parameter is used. In the “EC control-EC values”, “recirculation EC values” and “pH control-pH value” parameters, EC and pH units are adjusted, the automation works for a while to catch these values before irrigation and when it reaches the entered value, it starts irrigation. “Fertilizer phase 2 number selection” setting is used to select different fertilizer mixes. “Interval VIP” and “delay time VIP” parameters can be used to set the irrigation program in a 24-hour period. When an irrigation cycle is started, it starts with a time, followed by a delay time. A cycle can start during the delay time when a start condition is met. Repeated irrigation always waits for the delay time after the start time. “Time-start relative to”, “time-start time”, “time-stop relative to”, “time-stop time” settings allow to set the time that water can be applied depending on the time and can start irrigation with options such as sunrise or sunset. “Radiation start relative to”, “radiation.-start time - h.m”, “radiation.-stop relative to”, “radiation-stop time - h.m”, “radiation sum start-VIP - J/cm²”, “radiation threshold start-VIP -

W/m²” parameters allow to adjust the time that water can be applied depending on the sum of radiation. If the total measured radiation is higher than the “radiation sum start-VIP” setting and the currently measured radiation is higher than the “radiation threshold start.-VIP” setting, the system can start during the delay time. Hoogendoorn energy management consists of the following program parts; water boiler, heat storage tank and energy manifold (collector group). Boilers provide heat and CO2. Heat storage tanks are designed as an "open buffer system". This means that when there is a demand for heat in the greenhouse that will be supplied by the buffer tank. If there is no heat demand in the greenhouse and the boiler is on, heat produced will be sent to the buffer tank. The boiler adjustment screen is shown in Figure 6.



Settings	Unit	Value
boiler temperature deviation heat demand: ViP	°C	5
boiler temperature minimum: ViP	°C	65
boiler temperature maximum heat demand: ViP	°C	100
low speed: deviation boiler off	°C	8
low speed: deviation boiler on	°C	4
protection: boiler temperature	°C	65
protection: range boiler	°C	3

Figure 6. Boiler control screen

In the “Boiler temperature deviation heat demand-VIP” line, it is set that the temperature is increased according to the parameter value entered in addition to the highest pipe temperature demand. “Boiler temperature minimum-VIP” and “boiler temperature maximum heat demand. VIP” parameters determine the lower and upper limits of the calculated boiler temperatures. “Low speed-deviation boiler off” and “low speed-deviation boiler on” turns the boiler on and off according to the entered values. If the boiler temperature is higher than the calculated temperature plus the adjusted deviation, the boiler is turned off. If the boiler temperature is lower than the calculated temperature plus the adjusted deviation, the boiler is switched on again. “Protection-the “boiler temperature” parameter prevents the boiler temperature from being too low in case of a sudden high heat demand from the greenhouse. If the measured boiler temperature is lower than the set protection boiler temperature, the boiler protection is activated. Hoogendoorn automation provides access to real-time growth data on greenhouse climate, energy consumption and production via graphs. For example, the data received from the automation process computer can be compared for more than one period and more than one location. Users can create their own indicator charts to create an overview and provide a control period. Figure 8 shows the graph created by a Hoogendoorn user for irrigation.

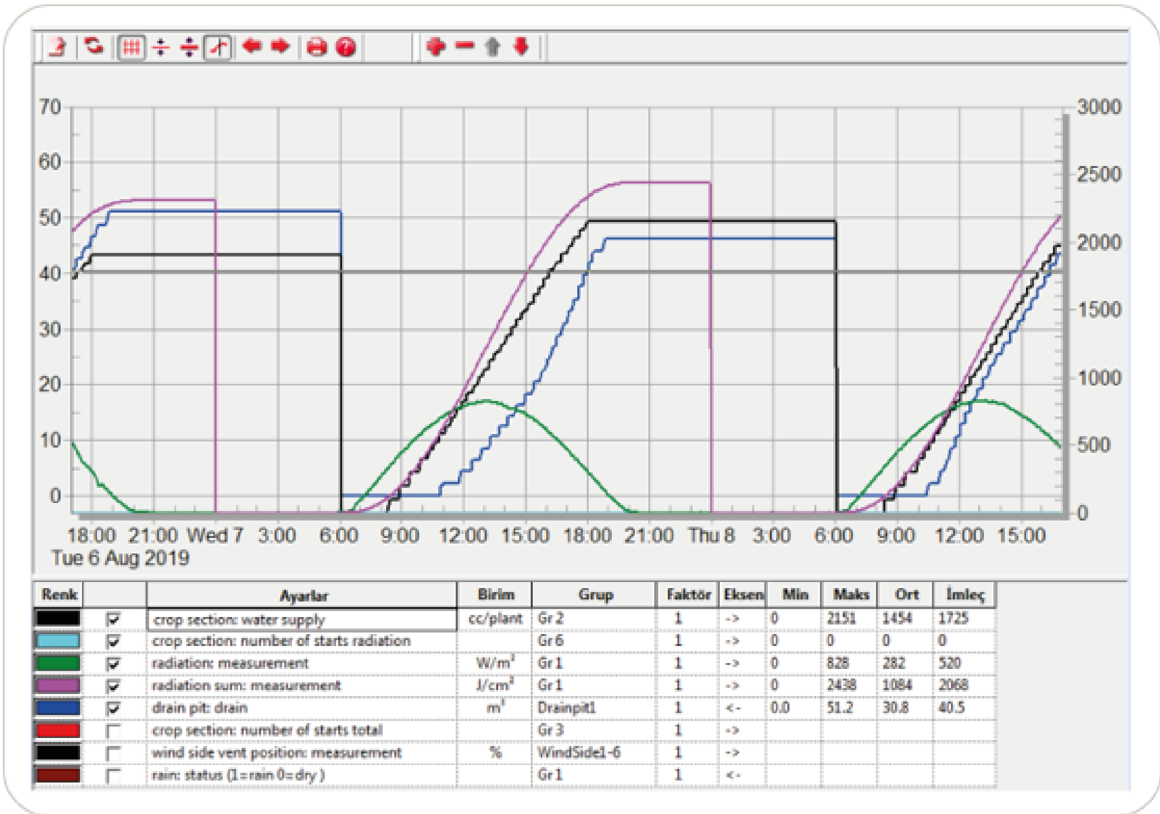


Figure 7. Hoogendoornirrigation graph

3.2. Priva Automation System

Priva automation system was investigated in two different versions: Priva INTÉGRO 724 (released 2005) and Priva Office. Priva automation system is based on program classification setup and measurement sections. Setting sections are used to apply or change settings. The measurement sections are used to display measured or calculated values. Adjustment and measurement sections are accessed with the [I] and [M] keys and these menus are formed with these letters. Priva automation system, Priva INTEGRO and Priva Office versions only differ in the user interface and ease of access to the menus. In the Priva INTEGRO version, the search bar can be accessed by typing the code of the page. Priva Office, on the other hand, provides ease of access both by typing page codes and by clicking. The program is based on a tree structure. Each menu (option) is represented by another menu (option). To navigate the menus, the arrow keys are used to move the cursor across the screen. The selections will be confirmed by pressing the [E] key, and the next menu will open. Finally, access will be provided to sections where settings can be viewed or changed.

Indoor climate control alarm limits are shown on screen I 100 in Figure 8. This screen is based on absolute alarm limits for air temperature, indoor temperature, humidity and CO2 content. It has relative alarm limits for temperature, heating and ventilation temperatures as well as absolute alarm limits.

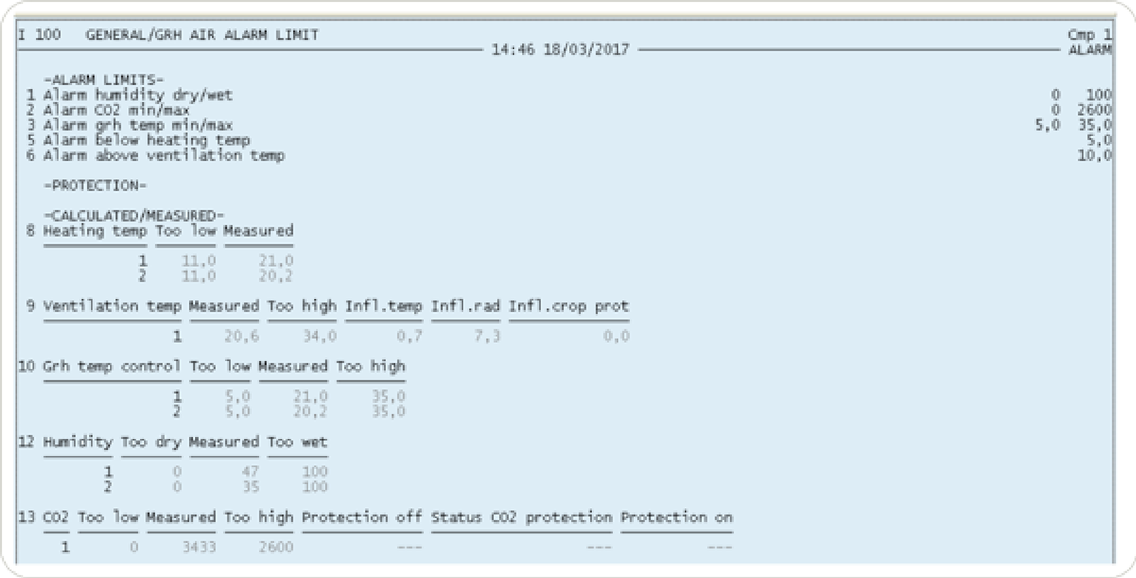


Figure 8. Indoor climate limits I100 screen

The “Alarm humidity dry/wet” parameter measures absolute humidity with dry and wet sensors. In this setting section, the maximum values for triggering the dry and wet sensors are entered in g/m3. “Alarm CO2 min/max” is the minimum and maximum CO2 value in ppm at which the alarm is triggered. “Alarm grh temp min/max” is the minimum and maximum °C temperature value for activation of the indoor temperature alarm. The parameter “Alarm below heating temp” is kept in °C and represents the maximum temperature difference below the heating temperature calculated before the alarm is triggered. The “Heating temp - Too low – Measured” line show the heating sections, the “too low” tab is the calculated alarm limit to trigger the alarm. This limit is calculated based on the calculated heating temperature. The “Measured” tab indicates the measured indoor temperature value in °C. “Ventilation temp - Measured - Too high - Infl.temp - Infl.rad - Infl.cropprot” tabs show numbers of roof vents, measured ventilation temperature, high alarm limit, effect of measured outdoor temperature in °C on the calculated alarm limit, measured radiation, the effect of °C temperature difference on the calculated alarm limit and the °C temperature difference effect of plant protection on the calculated alarm limit. The “Grh temp control - Too low - Measured - Too high” tabs show the numbers of the measurement sensors that measure the air temperature, the air temperature at which the greenhouse temperature can be minimum, the measured indoor air temperature and the air temperature at which the greenhouse temperature can be maximum. The “Humidity - Too dry - Measured - Too wet” tabs show the numbers of the sensors that measure the relative humidity, the values measured by the wet and dry humidity sensors and the instantaneous measured humidity in g / m3. In the tabs “CO2 - Too low - Measured - Too high - Protection off - Status CO2 protection - Protection on”, it measures the numbers of the sensors that measure CO2, low and high measured CO2 values, instantaneously measured CO2 value in ppm and shows the on-off status of CO2 protection. In Figure 9, the instantaneous climate data received from the meteorological station and the indoor climate values measured from the sensors are shown on the M 100 screen.

Figure 9. Instantaneous measured climate values M 100 screen

"OT" °C stands for measured outdoor temperature, "WS" m / s for the measured wind speed, "WD" for the measured wind direction, "Rad" W / m2 for the measured radiation, "Radsum" J / cm2 for the measured radiation amount. "MARSum" J / cm2 represents the average daily solar radiation sum over the programmed number of days, measured at the weather station. "Rain" indicates whether rain is active, "Storm" indicates whether there is a storm, "Frost" indicates whether there is frost and if any, the frost limit is active. "GrhT" °C stands for measured greenhouse air temperature, "RH" for the relative humidity measured in percent, "HD" g/m3 for the measured absolute humidity requirement, "CO2" ppm for the measured carbon dioxide, "V1" and "V2" for the measured roof on 1st and 2nd side position(wind and lee sides), "WT1" and "WT2" show the measured water temperature in ° C, "Ret1" and "Ret2" indicate the measured heating pipe temperature in ° C. "Curtain" shows the measured thermal curtain position, "Assim" W/m2 stands for the solar radiation obtained from artificial light system, "CalRad" W/m2 for the calculated solar radiation on plant, "Rad" W/m2 for the measured solar radiation, "RadSum" W/m2 for the daily measured total radiation. In the "Extra1-2-3" tabs, the user can view any parameter measured by the automation system. Priva greenhouse automation controls greenhouse heating-cooling, ventilation roofs, thermal curtains, CO2, fogging and circulation fans in the climate control section. The heating strategy is determined as shown in Figure 10. The heating temperature progression over a 24-hour cycle is controlled by a clock at which the cycle can be divided into a maximum of 6 periods.

Figure 10. Priva heating strategy I 110 screen

“Activated” indicates the active heating period and off periods, “Period” indicates the on and off heating periods. “Start Time” indicates the start time of heating, this value can be entered in a 24-hour period. “Heating temp” °C is the tab where the desired heating temperature value is given. “Rad. : adj. Heating” and “Rad.sum. : adj. Heating” tabs show the levels at which the radiative heating temperature should be lowered or increased. The “Max pos compensation” and “Max neg compensation” parameters specify the maximum acceptable drop or increase in heating temperature calculated for temperature compensation. “Time cool down” and “Time heat up” are the desired delay times per °C for lowering or increasing the set heating temperature after a period transition in hours/minutes. Also, in Priva automation system, thermal curtains can be used for energy saving, shading and relative humidity control. Figure 11 shows the use of thermal curtains for energy saving.

Figure 11. Use of thermal curtains to save energy I 162 screen

The “Activated” tab shows the current status of the periods. “No” means inactive, “Yes” means active. When the “Clock” parameter is set to “ON”, it activates the current period when the time comes. “Start time” and “End time” parameters express the start time and end time of the thermal curtains. “Radiation limit” defines the limit of radiation in W/m2. In the “Use heat demand” tab, it is decided whether to use the expected heat demand as a condition for closing the thermal curtain or not. In the “Use temp limit” parameter, it is decided whether or not to use the temperature limit as a condition for closing the thermal curtain. In the "Active before end time" parameter, the time in hours-minutes is entered. The entered time is controlled by subtracting it from the end time. If the thermal curtain is not active before the end time, the thermal curtain cannot be activated based on the entered time. The value in % is entered in the “Max curtain position” parameter, it expresses the maximum curtain position when the thermal curtain is active. In the system, depending on the temperature difference between the calculated heating temperature and the measured outdoor temperature, the curtain can be opened with small steps or large steps to prevent energy loss. The Priva irrigation program consists of several starting options. These options determine the conditions under which auto start performs. Initiation can be carried out according to different conditions in each period and can include 6 periods in a maximum of 24 hours. The start program may give a start signal to one or more valve groups. It is possible to start with a time range by entering a maximum rest time. Separate rest periods can be entered for each period, and the minimum rest period acts as the maximum starting frequency for various starting conditions. Automatic irrigation strategy is shown in Figure 12 and recipe entry screens for irrigation are shown in Figure 13.

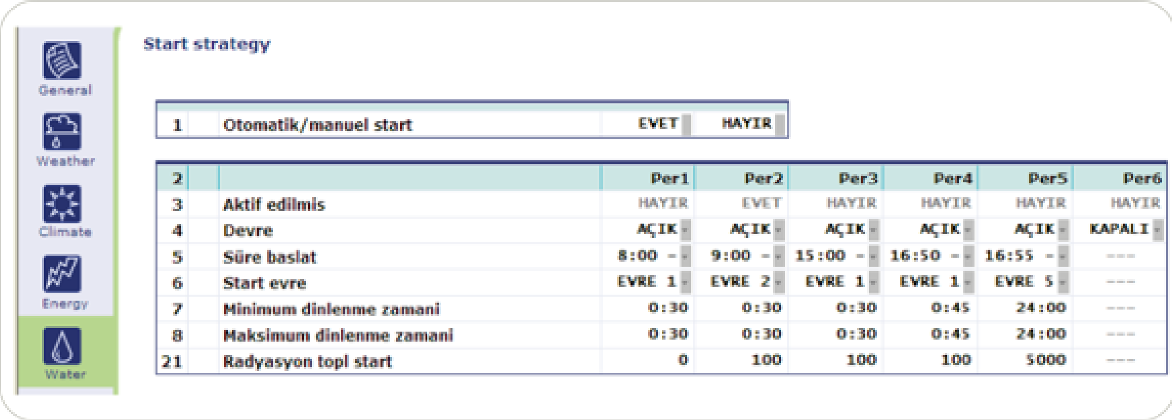


Figure 12. Priva Office automatic irrigation strategy I 400 screen

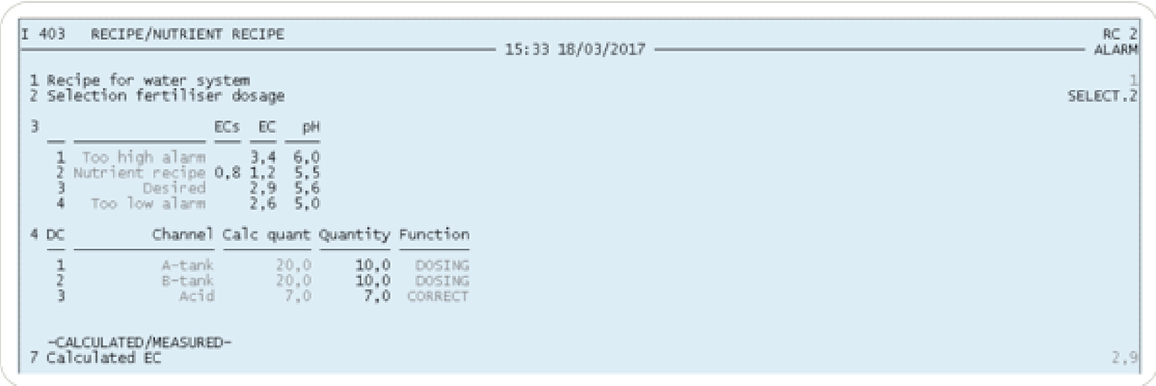


Figure 13. Recipe I 403 screen for irrigation

In the “Recipe for water system” tab, the number of the water system for which the recipe is used is entered. Recipes are assigned to a water system with a dosing unit. In the “Selection fertiliser dosage” tab, the current fertilizer stock used for the recipe is selected. If the “No Dosing” option is selected, no fertilizer is added to the water. In the “Too high alarm” section, the maximum alarm limits that can be set for EC and pH are entered and if the measured value exceeds this number, the irrigation system stops after an alarm is issued. The “Nutrient recipe” parameter displays the original composition of tanks A, B and process water. The contents of the fertilizer tanks are calculated based on these values. The computer uses the specified recipe for ECs, EC and pH supply to correct the measured values. Target values are entered in the “[Desired]” parameter. In the “Too low alarm” tab, minimum values for EC and pH are entered, if it falls below these values, the system automatically stops. “DC” stands for the number of dosing channels. The system consists of tank A, tank B, and acid tank. “Calc quant” indicates the amount of fertilizer calculated to be dosed for each tank, in quant/m3. The amount of fertilizer per “Quantity” dosing channel is entered. In the “Function” tab, two different states “DOSING” and “CORRECT” are seen. “DOSING” indicates instantaneous dosing. “CORRECT” indicates that if there is a deviation in the calculated and measured EC-pH values, it is trying to reach the desired set point for dosing. In the Priva graphical analysis section, users can freely choose the graphics that can be compiled by the computer. All measurements and calculations in automation can be seen in the graphic system. It does not matter in which section the measurement or calculation is made, all components in the system can be found in the same graphic with each other. Figure 14 shows the greenhouse indoor and outdoor temperature graphs.

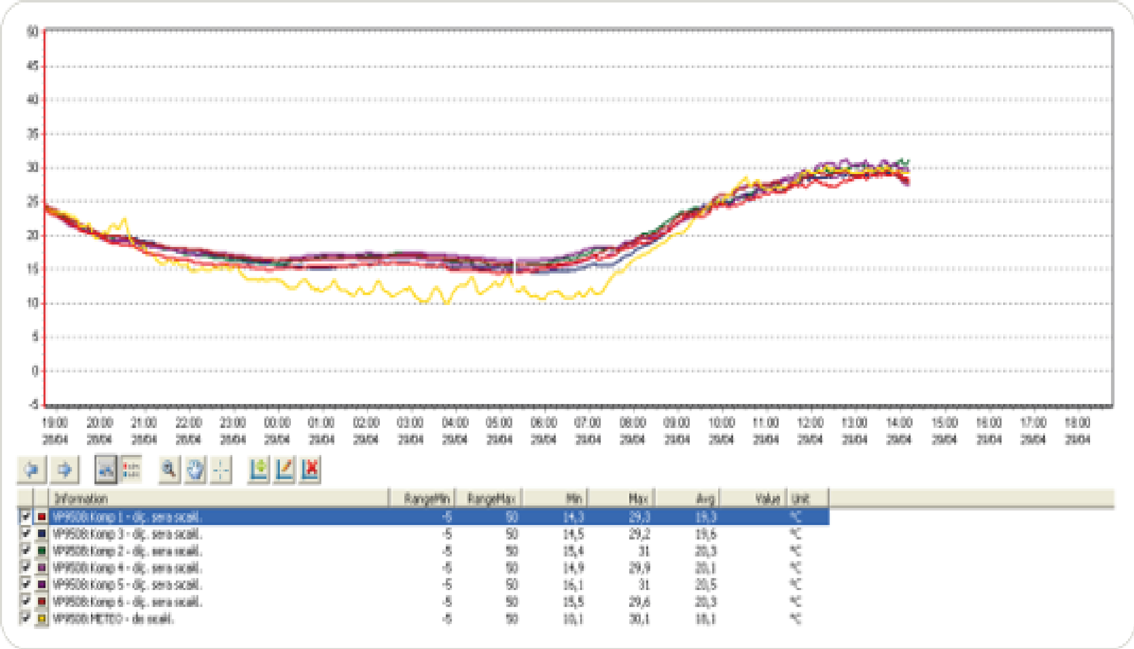


Figure 14. Priva Office Greenhouse temperature graph

It collects the information received from the temperature sensors in 6 different sections of the greenhouse and the outdoor temperature from the meteorological station and displays the temperature differences inside and outside the greenhouse on the screen. In the “Min”, “Max”, and “Avg” tabs, the minimum, maximum and average temperature values are shown during the time interval given on the graph during the day.

3.3. INTA Automation System

Inta automation system offers climate control and irrigation systems in different environments. The web interface was used for the climate control system system and the version “EVO AP 170701” (desktop application (CDN) program) for irrigation system has been examined. With the Inta EVO AP application, greenhouses can be managed and controlled from any workplace or any place with an internet connection. Any parameter or device can be reviewed and programmed from anywhere via the internet via a computer, mobile phone or tablet. Two different interface start screens are shown in Figure 15 and Figure 16.

Figure 15. Inta CDN program start screen

Within the tabs boxed in black in Figure 15, from right to left, “Start conditions” tab is used for irrigation activation planning, “Valves” tab for irrigation valve settings, “Dosing” tab for dosing settings, “Filters” tab for water filter settings for disinfection, “Manual” tab for manual start screen of irrigation-fertilization process, “Intervals” tab for settings for determining irrigation intervals, “Agitators” tab for settings for mixer for fertilization, “Alarms” tab for alarm limits settings, “Group Reports” tab for reporting screen and finally “Manual irrigation” tab for start settings of manual irrigation-fertilization system. Within the tabs boxed in red, from top to bottom, “Chart of sensor readings” tab displays the measured values from the sensors on the graph, “Drainage data” tab shows all data analysis of the drain, “Valves” tab offers graphical display of valves, and “Analog inputs” tab offers graphical display of digital values.

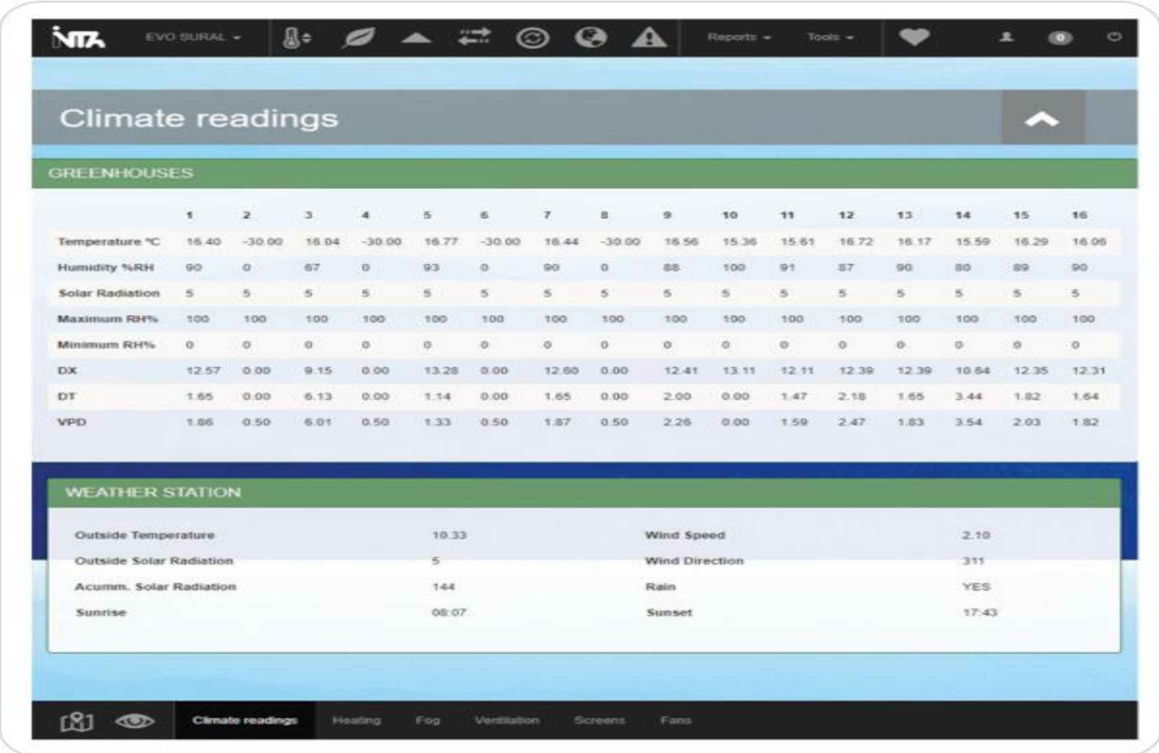


Figure 16. Inta climate control start screen

Within the tabs in Figure 16, from left to right, “Heating” tab shows the screens where heating is controlled, “Humidity” displays the screens where relative humidity can be controlled, “Ventilation” shows the screens where windows are controlled, “Screens” tab is used to control thermal curtains, “Fans” tab is used to control circulation fans, “Global” tab displays greenhouse minimum-maximum climatic values, “Alarms” tab shows the screens where alarms are controlled. In the “Reports” tab, users can create and view reports on greenhouse climate control. In the "Tools" tab, new user accounts can be created to login to the web interface. Passwords and authorizations of previously created user accounts can be changed. The Inta evo climate control program contains all the necessary climatic data on greenhouse sections and the environment. It receives this climate data from meteorological station and greenhouse sensors. The weather station displays a box containing the necessary data for the outdoor climate. “Outside Temperature” refers to outdoor temperature, “Outside Solar Radiation” represents instantaneous solar radiation in w/m2, “Acumm. Solar Radiation” refers to the accumulated solar radiation in Wh/m2, “Sunrise” shows the sunrise time, “Wind Speed” displays the wind speed in m/s, “Wind Direction” shows the wind direction measured in º, “Rain” shows the rain condition, “Sunset” displays the sunset time. As seen in the figure, the air-conditioning data obtained from the indoor sensors are displayed in the "GREENHOUSES" tab. Data are shown separately for 16 regions. Climate readings screen displays temperature, solar radiation, minimum-maximum relative humidity, missing m3 moisture grams of air at current temperature to have full saturation in “DX” delta x G / m3, “DT” delta t in ºC for air to absorb moisture and keep the humidity suspended in the air with a certain temperature capacity, and the measured value of the vapor gap of the greenhouse air in “VPD” millibars. Programming the Inta greenhouse automation heating control is shown in Figure 17.

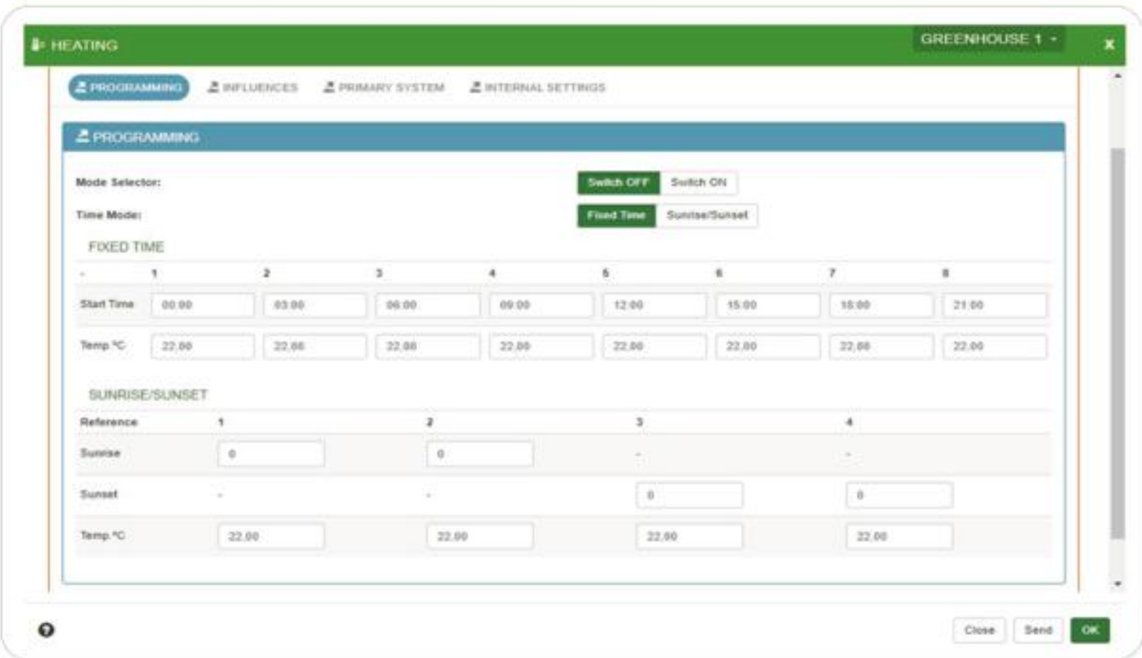


Figure 17. Inta heating programming

The “Mode Selector” tab is used to activate or deactivate the heating function of the climate program. In the “Time Mode” tab, when “Fixed Time” is selected, it is used independently of sunrise and sunset for the change between heating times. In “Sunrise-Sunset” selection, the limits between heating periods change according to sunrise and sunset. In the "Start time" tab, the start time of the heating is entered, the heating continues until the next period. If only one period is entered, the heating works continuously at the temperature setting below this period. In the "Sunrise" and "Sunset" tabs, values are entered as "+" or "-". For example, if the value entered in the "Sunrise" tab is "-30", the heating program starts 30 minutes before sunrise. Inta CDN desktop application allows irrigation management according to environmental conditions, and the parameters of other devices. While programming the valves, it is possible to program all the valves of the individual groups in their own time settings, in the required sequence and combination. Figure 18 shows the recipe and fertilizer dosing screen for irrigation.

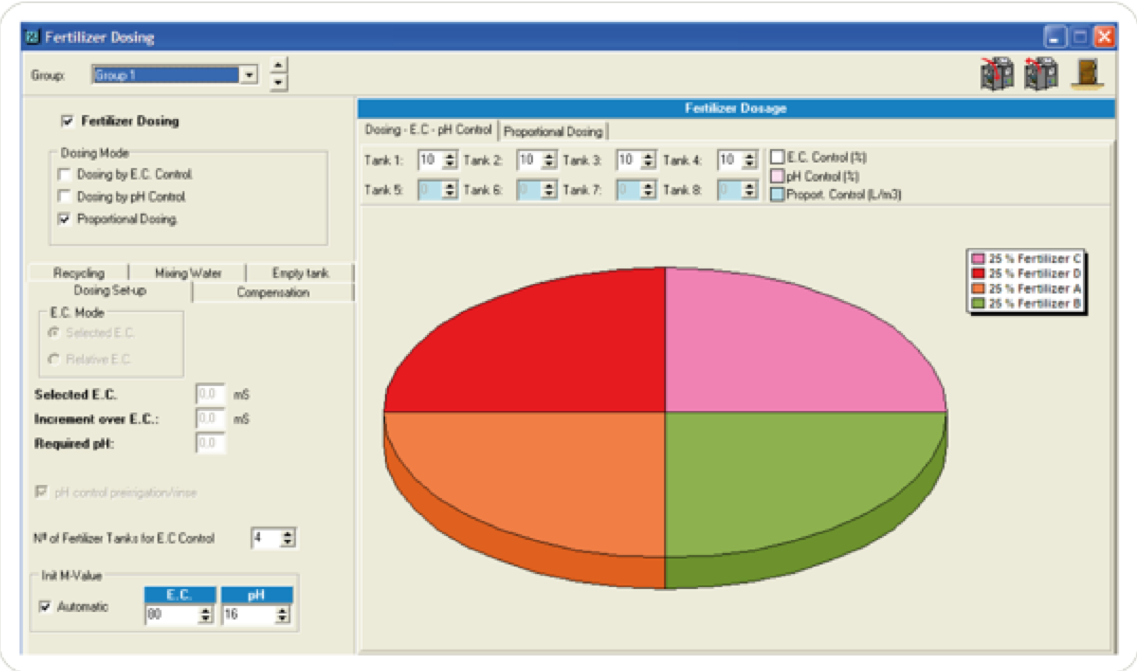


Figure 18. Fertilizer dosing setting screen

On this screen, fertilizer dosing can be set to active-passive status. Dosing mode selection allows "E.C. (electrical conductivity) fertilization with “Dosing by E.C. Control", reading electrical conductivity probes mounted in its installation, controlling fertilization by adding acid with “Dosing by pH Control” and proportionally E.C. and pH control with “Proportional Dosing”. By mixing the waters with the “Mixing Water” tab, you can create an E.C. entry is made. “Recycling” tab recycling control aims to reuse the water that is not used for irrigation of the plant for re-irrigation. The “Dosing Setup” tab can be used if only E.C or pH control is selected. The “Empty Tank” tab offers the option to empty the fertilizer tank at the end of the irrigation and fill it with clean water for the next irrigation. In the “No of Fertilizer Tanks for E.C Control” parameter, the number of the tanks required to be checked for E.C control is indicated. Inta irrigation automation can start the irrigation-fertilization process with 6 different situations. In the “Irrigations by Time” method, the irrigation activations of a certain irrigation program can be programmed at a certain time of the selected day or day. In the “Irrigations by Intervals” method, irrigation is done every set hour during the activity period. In the "Irrigation by Solar Radiation" method, irrigation is activated when the set solar energy accumulation is reached. Irrigation can be activated by any device that sends a voltage-free contact to the “Irrigation by External Signal” irrigation equipment. In the "Irrigation by Special Sensors" method, irrigation can be activated with an analogue input. With the “Irrigation by Drainage Control” tab, the irrigation frequency and volume are automatically controlled according to the percentage obtained in each irrigation. The “Irrigations by Time” method is given as an example in Figure 19.

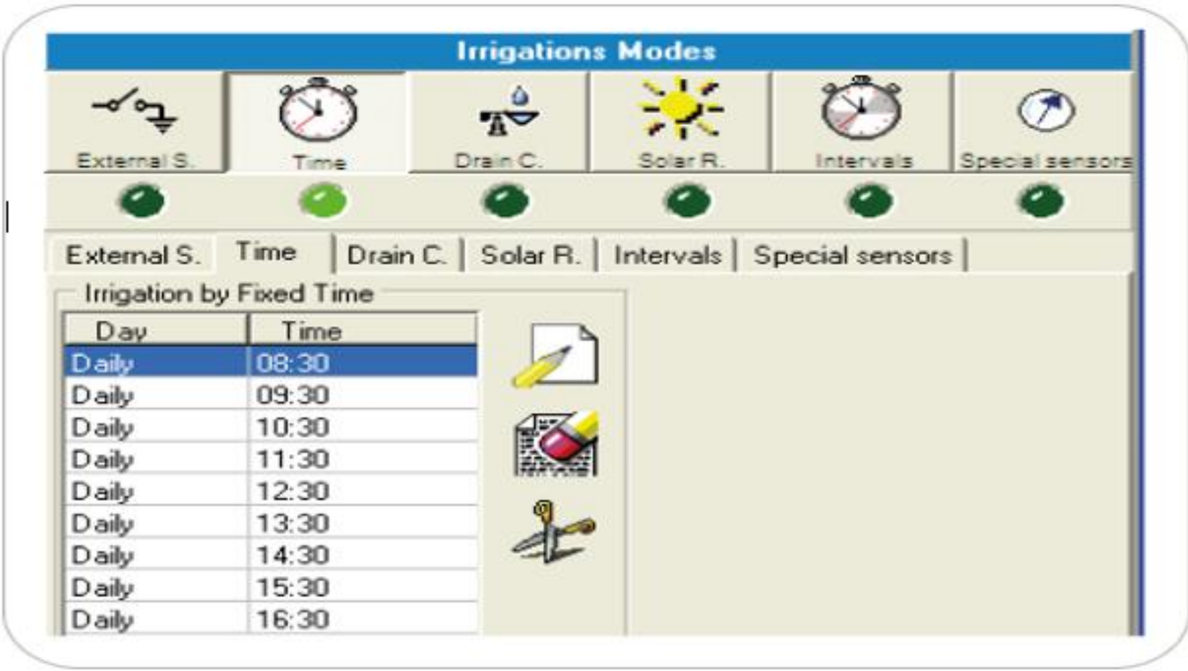


Figure 19. Timed irrigation setting screen

Unlimited time intervals can be entered for 24 hours. The entered intervals are repeated daily. Previously entered set values can be deleted and edited. To provide a graphical control screen, users can create their own display charts for the parameters they choose. Instantly measured data in the automation system can be observed on the graph depending on time. An example climate chart is shown in Figure 20.

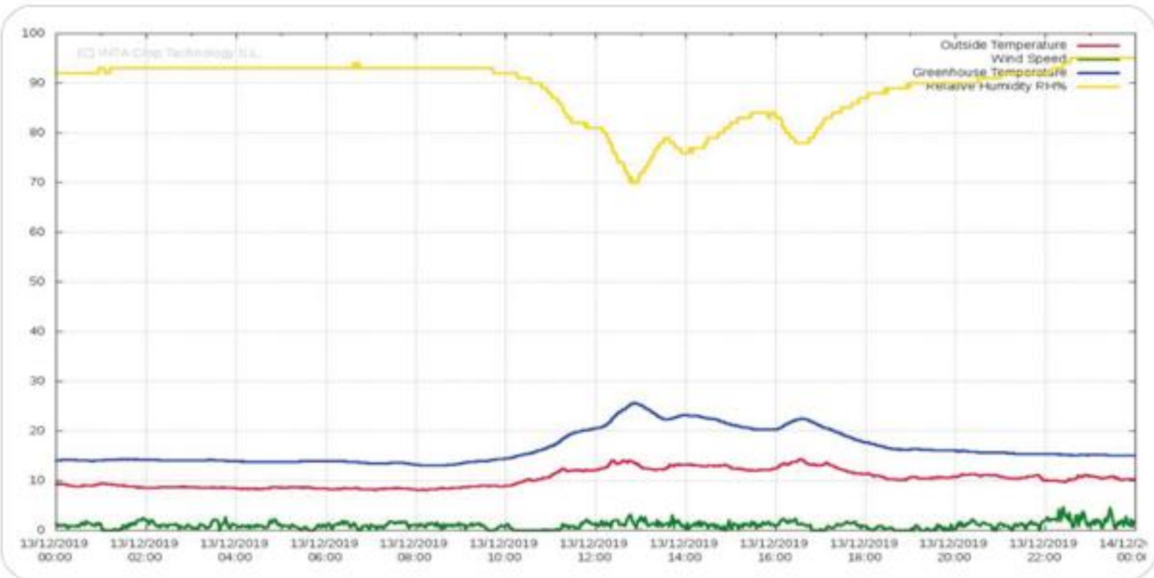


Figure 20. Graph of greenhouse indoor and outdoor climate values

3.4. Karaca Automation System

In this automation system(KRSS PRO version 014.002 (Turkish language supported version); indoor climate control equipment (window, heating, fogging, etc.), meteorological station and outside greenhouse climate data, boiler room control (Liquid, Gas or Solid Fuel), geothermal heat center control, irrigation and fertilization system control, drainage control and energy management systems are controlled in a coordinated manner. In the menu structure of the Karaca automation system, there is a menu tree on the left side of the automation system screen that can access the other pages. From this menu, one can access the parameter pages to be viewed or to make changes to the settings. Each page is opened in the form of tabs at the top of the screen. Quick access can be provided by keeping frequently used pages here. On the opening screen, the greenhouse monitoring screen is displayed. This screen displays greenhouse indoor and outdoor climate data. The start screen and menu structure are shown in Figure 21.

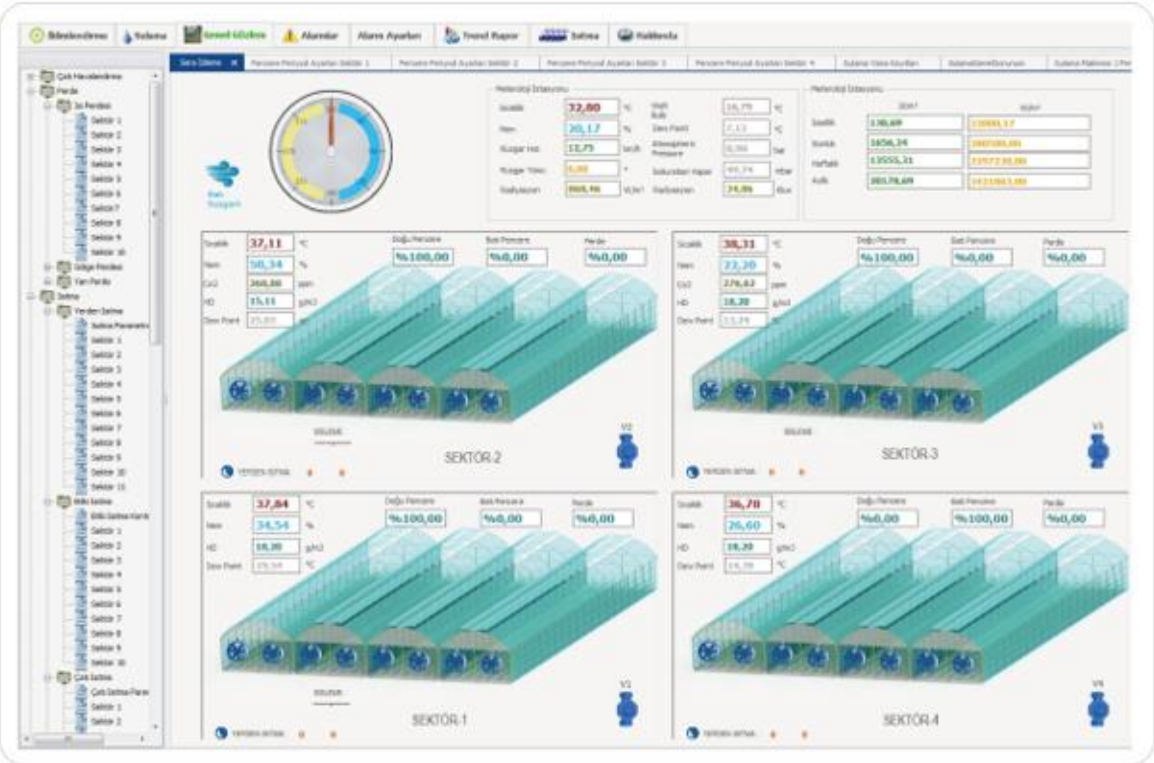


Figure 21. Karaca automation system start screen

The climate control system, while controlling the systems in the greenhouse, checks the outside weather conditions through the meteorological system. Temperature (°C), humidity (%), solar radiation (W/m²), light level (Klux), wind speed (km/h or m/sec), wind direction (°), rain (yes/no), wet bulb temperature (°C), dew point (°C) and atmospheric pressure (mbar) are measured or calculated. On the climate overview screen, it shows the measured and hourly, daily, weekly, monthly calculated values of the meteorological station. In Karaca greenhouse automation system, with a boiler system, floor heating, plant heating, roof heating and snow melting are carried out. The boiler room screen is shown in Figure 22.

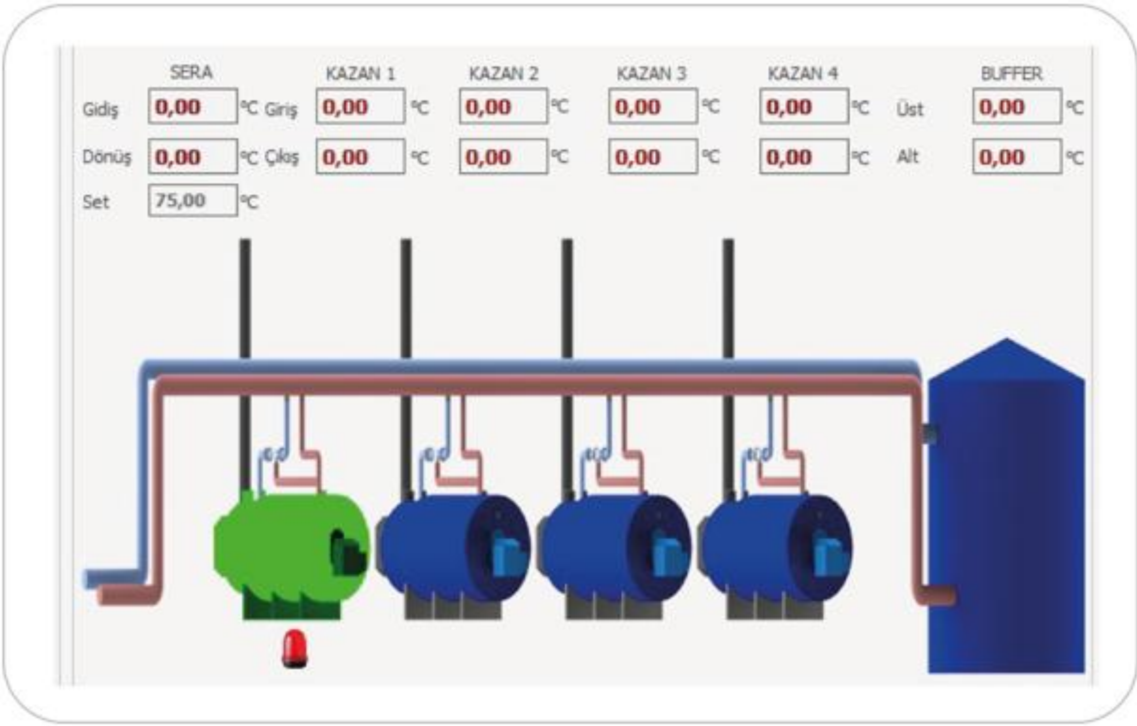


Figure 22. Boiler Room Screen

In the rail heating system, the heating process is carried out with the heating pipes located on the floor of the greenhouse, between the plant hanging gutters. Floor heating setting screen is shown in Figure 25.

Yerden Isıtma Periyod Ayarları Sektör 1

Periyod No	1	2	3	4
Periyod Adı	Periyod 1	Periyod 2	Periyod 3	Periyod 4
Periyod Aktif mi ?	✓ Aktif	✓ Aktif	✓ Aktif	✓ Aktif
Periyod 24 Saat Boyunca Aktif mi?	☐ 24 Saat Pasif	☐ 24 Saat Pasif	☐ 24 Saat Pasif	☐ 24 Saat Pasif
Periyod Başlangıç Zamanı	05:10:00	07:20:00	09:00:00	11:00:00
Kontrol Şekli	○ Sıcaklık	○ Sıcaklık	○ Sıcaklık	○ Sıcaklık
Set Sıcaklığı	16,00	19,00	21,00	22,00
Set Sıcaklığı Histerisiz	0,10	0,10	0,10	0,10
Emniyet Sıcaklığı	20,00	30,00	30,00	30,00
Pompa Min %	0,00	0,00	0,00	0,00
Pompa Max %	100,00	100,00	100,00	100,00
Sektör No	1	1	1	1
Kaydı Yapan	Karaca	Karaca	Karaca	Karaca
Kayıt Tarihi	04.11.2014 01:3...	04.11.2014 01:3...	04.11.2014 01:3...	04.11.2014 01:3...

Figure 23. Underfloor heating period setting screen

On this setting screen, A total of 12 periods in order to control the rail heating system in different working styles during the day can be set. When "Temperature" is selected in the "Control Type" tab, the system regulates the operating and pipe temperature values required to set the indoor temperature value to the desired set value. When “Off” is selected, floor heating does not operate within the specified period. When "set temperature" is selected, the underfloor heating system performs all its operations to set the desired set value for the indoor temperature. “Set Temperature Hysteresis” parameter shows the band gap of the desired temperature value inside the greenhouse. The “Safety temperature” tab determines the maximum heating water temperature value that will circulate in the greenhouse heating pipes. “Pump Min %” and “Pump Max %” parameters represent the minimum and maximum opening percentage of the 3-way valve used in the heating system. Karaca irrigation system provides the opportunity to perform different applications during the day by dividing the irrigations to be made during the day into periods. Period time intervals are arranged by simply writing the start time of the period. It is not compulsory to write the starting times regularly. The system starts the due period. The period number has no effect on the working order. The system processes the period whose start time is due and applies the period parameters. If there is an ongoing irrigation in the period change, the new period is activated after the active irrigation is finished. Different or same parameter values can be used within each period range. Irrigation can also be done by using a 24-hour controlled period in order to process with a single period throughout the day. On the screen where the general view of the irrigation system is displayed, the operation of the irrigation system and the measured values are displayed. EC (conductivity), pH, irrigation water temperature and irrigation flow measured during irrigation are displayed in the upper left part of the monitoring screen. The blue indicator on the clean water stock tank indicates that there is sufficient clean water in the solution tank. When the indicator on the clean water stock tank is red, it indicates that there is not enough clean water in the stock tank. Irrigation stops, an error message is given and when the water level in the clean water tank reaches a sufficient level, this indicator turns blue and irrigation continues after the error is reset. The green and red indicators on the Fertilizer Tanks show the fertilizer channels used. Indicators in green indicate that the fertilizer channel is used, and the channels in red indicate that the fertilizer channels are not used. During irrigation, the valve of the irrigation sector is green in order to show the irrigation sector on. When the irrigation and fertilization system is running, the irrigation pump and the dosing pump are shown in green color. There is also a manual irrigation menu on this screen so that the user can perform manual irrigation while irrigation is running in automatic mode. In this menu, there is automatic and manual selection at the top. Irrigation general monitoring screen is given in Figure 24.

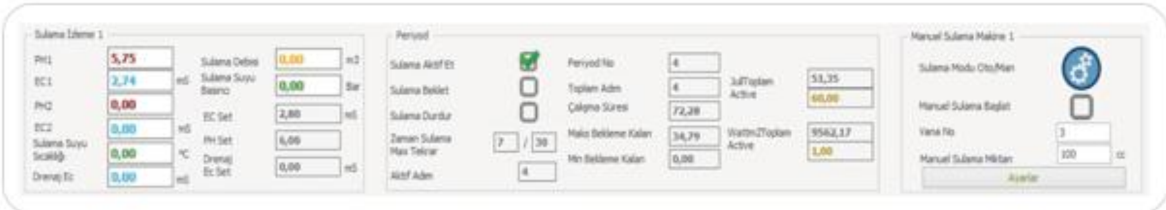
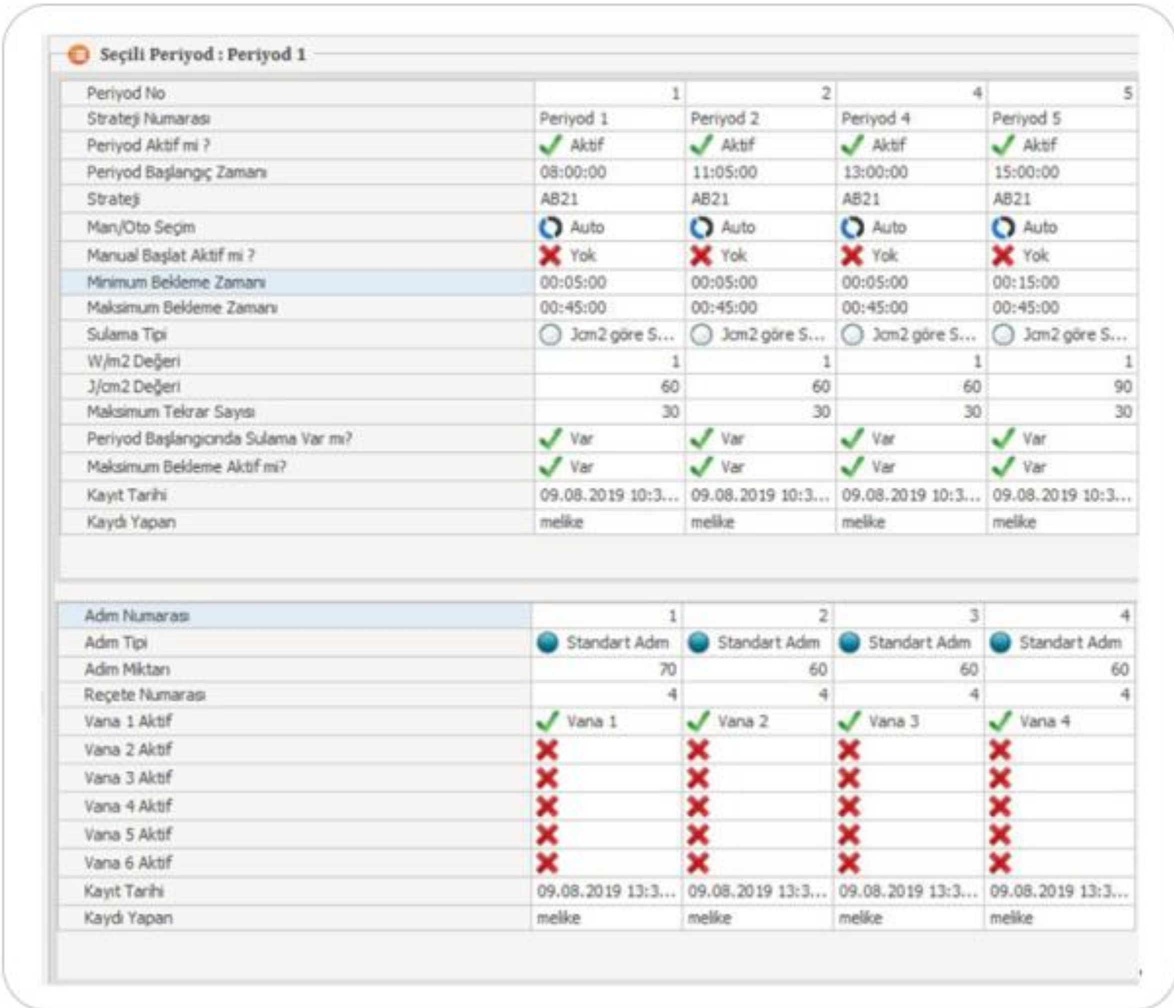


Figure 24. Irrigation general monitoring screen

While irrigation is done according to the period during the day, the start time of each period is entered. The period continues to operate according to the irrigation type and the entered parameters. Irrigation machine period settings are shown in Figure 25.



Seçili Periyod : Periyod 1

Periyod No	1	2	4	5
Strateji Numarası	Periyod 1	Periyod 2	Periyod 4	Periyod 5
Periyod Aktif mi ?	Aktif	Aktif	Aktif	Aktif
Periyod Başlangıç Zamanı	08:00:00	11:05:00	13:00:00	15:00:00
Strateji	AB21	AB21	AB21	AB21
Man/Oto Seçim	Auto	Auto	Auto	Auto
Manual Başlat Aktif mi ?	Yok	Yok	Yok	Yok
Minimum Bekleme Zamanı	00:05:00	00:05:00	00:05:00	00:15:00
Maksimum Bekleme Zamanı	00:45:00	00:45:00	00:45:00	00:45:00
Sulama Tipi	Jcm2 göre S...	Jcm2 göre S...	Jcm2 göre S...	Jcm2 göre S...
W/m2 Değeri	1	1	1	1
J/cm2 Değeri	60	60	60	90
Maksimum Tekrar Sayısı	30	30	30	30
Periyod Başlangıcında Sulama Var mı?	Var	Var	Var	Var
Maksimum Bekleme Aktif mi?	Var	Var	Var	Var
Kayıt Tarihi	09.08.2019 10:3...	09.08.2019 10:3...	09.08.2019 10:3...	09.08.2019 10:3...
Kaydı Yapan	melike	melike	melike	melike

Adım Numarası	1	2	3	4
Adım Tipi	Standart Adım	Standart Adım	Standart Adım	Standart Adım
Adım Miktarı	70	60	60	60
Reçete Numarası	4	4	4	4
Vana 1 Aktif	Vana 1	Vana 2	Vana 3	Vana 4
Vana 2 Aktif	✗	✗	✗	✗
Vana 3 Aktif	✗	✗	✗	✗
Vana 4 Aktif	✗	✗	✗	✗
Vana 5 Aktif	✗	✗	✗	✗
Vana 6 Aktif	✗	✗	✗	✗
Kayıt Tarihi	09.08.2019 13:3...	09.08.2019 13:3...	09.08.2019 13:3...	09.08.2019 13:3...
Kaydı Yapan	melike	melike	melike	melike

Figure 25. Irrigation machine period setting screen in Karaca

"Period number" is for naming periods. The ordering of the periods is arranged according to the starting times. "Strategy" parameter, valve step sequence, fertilizer (recipe) number and different irrigation strategies are determined and operations are carried out during the day without making any changes in the fertilizer program or irrigation program. The "Minimum Waiting Time" and "Maximum Waiting Time" parameters specify the minimum and maximum time the system will wait without irrigation. In the "Irrigation Type" tab, "time irrigation", "watering according to W/m² total", "irrigation according to J/cm² total" and "irrigation according to slap weight" options are selected. With the choice of strategy in irrigation, the step settings of the valves to be irrigated or fertilized are determined. In the strategy settings page, the duration/amounts of the valves to be irrigated, fertilization recipe selection and valve selections are made. The number of strategies is limited to 6. The aim of the strategy is to allow the correct watering of plants at different stages or of different types. On the strategy settings page, first the number of how many valve groups will operate at the same time and the unit of the irrigation amount (ml, lt or time min., sec.) are determined.

In the strategy step registration screen, valve group numbers to be operated, fertilizer (recipe) number to be used for fertilizing valve groups, irrigation times or amounts of valve groups are entered. Two ways of working can be determined for each step. The “Standard Step”, the numbers of the valve group(s) to be operated, the recipe number to be used in this step and the irrigation amount are entered. Strategy step registration screen is shown in Figure 26 as many steps as the number of valves can be entered so that each valve can be irrigated sequentially. Recipe numbers are entered at each step. In this way, it is possible to irrigate and fertilize by using different EC-pH and fertilizer channels of each valve. The recipe registration screen is shown in Figure 27.

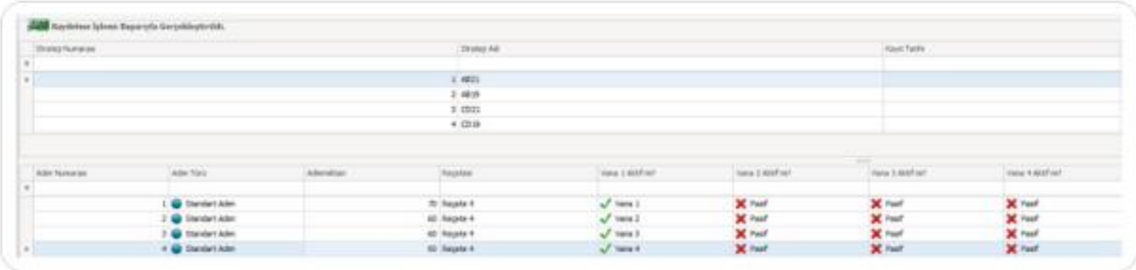


Figure 26. Strategy step registration screen

Figure 27. Recipe registration screen

In the "EC Set" and "pH Set" parameters, the desired EC-pH values for irrigation and fertilization are entered. In the "EC Upper Set" and "EC Lower Set" tabs, the EC lower and upper limits of the system are determined during irrigation and fertilization. If it is outside of this upper and lower range during the alarm waiting period, the system gives an alarm. In the "pH Upper Set" and "pH Lower Set" tabs, the PH lower and upper limits of the system are determined during irrigation and fertilization. If it is outside of this upper and lower range during the alarm waiting period, the system gives an alarm. In the "Fertilizer Amount" parameter, when the user requests EC control in the system, he/she fertilizes by typing the initial rate in the fertilizer channels. The value of "0" should be written on the fertilizer channels that are undesirable to be used. If the value "0" is written to all channels, no fertilizer is taken from any channel. The trend report page is used to see more than one of the values on the same graphic page in the irrigation and climate control system. All sensor values measured on the system can be selected. Each selected sensor value is displayed in a different colour and it is indicated on the screen which value is displayed in which colour. In order to see the historical records of the selected sensor values, the date range can be selected and the records between these dates and times can be seen. In the graphic display, labels showing the measurement values can be added on the graphic or these labels can be hidden.

4. Conclusions

It was observed that, in 4 different automation softwares investigated, a quite advanced information monitoring/distribution systems technology seemed to be present in order to solve the problems of higher automation level and real-time than current monitoring approaches for the greenhouses when compared to present literature data.

It seems that unlike the existing greenhouse automation systems, remote control inspection processes can be done over the internet, using an embedded hardware card instead of a computer on the server side, remote control and smart phones as well as a console application. Inta climate control system has a web-based application and can be controlled with mobile access. By connecting to the mobile and web interface, sensor values can be monitored and the system can be managed.

Hoogendorn, Priva and Karaca can provide all controls with a single application. The Inta automation system is controlled by a web-based application for climate control and a desktop application for irrigation and fertilization. This complicates the ease of use of the Inta system. The user has to change the screen for different controls.

Priva automation system uses a separate screen for each control, compared to other systems examined. The user has to go to separate pages one by one in order to monitor the greenhouse in the system. There is no general greenhouse monitoring screen. For example, before making the heating strategy, the user has to set the water temperature on a different screen.

Hoogendorn and Karaca have used an advanced new generation interface for both irrigation-fertilization and climate control, Inta only for climate control. In these systems, it is possible to display multiple pages on the same screen. Control can be provided on a single screen in order to perform operations and observations.

Karaca automation system visually displays the observed meteorological station, climate control and irrigation data for general monitoring of the greenhouse. The general view screen is descriptive and it is possible to observe all the factors affecting the greenhouse on a single screen.

In Inta and Karaca automation systems, the measurement values of climate control and irrigation sensors are recorded. There is a reporting screen for the recorded data in both automation systems. All sensor values measured on the system can be selected on the reporting screen. To see the historical records of the selected sensor values, the date range can be selected and the records between these dates and times can be viewed. Unlike other systems, all sensor values measured instantaneously in these two systems can be displayed one by one. In Priva and Hoogendorn automation systems, the average of the climate control and irrigation values measured in the past, which can only be found in the main menu, is shown on the screen as day, month and year.

In the automations examined, more than one different strategy can be set for irrigation cycles. The valves in the greenhouse can be divided into groups and can control a plant group or a part of the group.

Valve groups can be activated and deactivated depending on time and quantity. Irrigation can be done in all systems depending on radiation. There are screens where users can adjust the EC and pH values for dosing. In irrigation systems, the recipe, irrigation amount and irrigation duration can be arranged separately for each valve. With the strategy selection in irrigation, the step settings of the valves to be irrigated or fertilized can be determined. On the strategy settings page of the systems, the duration/amounts of the valves to be irrigated, fertilization recipe selection and valve selections can be made. This use in systems allows correct irrigation of plants in different stages or of different types.

The systems use the water filter screen to disinfect the valves, tanks and recycling system. Recycling control ensures that the water that is not used for irrigation of the plant is reused for re-irrigation. Unlike others, in the Inta irrigation system, when the irrigation program ends or by interrupting the irrigation program, cleaning and continuation of the previously interrupted irrigation program can be performed and the minimum irrigation time can be entered by the user before performing the cleaning process.

In Karaca irrigation system, unlike other systems, irrigation water temperature and irrigation flow measurements are displayed on the software interface. The system screen shows which user recorded transactions such as recipes and strategies. This prevents confusion during the use of the system by more than one user. In Karaca and Hoogendorn irrigation systems, EC recirculation control can be turned on and off.

The investigated climate control systems can check the outside air conditions by measuring the control of the systems in the greenhouse. They use meteorological station for this process. In general, in meteorological stations, it shows the outside temperature, the measured wind speed, the measured wind direction, the measured radiation, the measured radiation amount, whether the rain is effective or not, whether there is a storm, whether there is freezing, and if there is, the activity of the icing limit.

Climate control systems control heating-cooling, ventilation roofs, thermal curtains, CO2, fogging and circulation fans. The systems are based on absolute alarm limits for air temperature, indoor temperature, humidity and CO2 content. They have relative alarm limits for temperature, heating and ventilation temperatures as well as absolute alarm limits.

As a standard, two thermal curtains are controlled for each greenhouse compartment. These curtains are called energy curtain and shading curtain. Both curtains can be programmed one time for closing and another time for opening. Thermal curtains can be programmed for three climatic conditions: high temperature, low temperature and humidity required.

The graphical analysis and reporting sections of the commercial automation systems examined do not provide a decision support system to the users. Systems should provide users with input of data such as production and harvest. Considering these data and the data collected in climate control and irrigation, users should be able to analyze information for the next periods.

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