DESIGN AND IMPLEMENTATION OF A SMART GREENHOUSE

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ABSTRACT

DESIGN AND IMPLEMENTATION OF A SMART GREENHOUSE

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In this thesis, a smart greenhouse design is proposed. The aim of the designed smart greenhouse is to employ less human power and to provide higher efficiency. In the designed system, air temperature, air humidity, soil temperature and soil moisture are measured by sensors. As a result of the analysis of the measurements, the control of mechanical appliances such as ventilation, heating and irrigation are provided according to the pre-defined rules. Such automation helps us reduce the amount of human power for irrigation and ventilation. Two greenhouses with the same characteristics were used for system comparison in the thesis. One is managed by the smart system, while the other is traditionally managed. Common to both greenhouses, human power was used for pruning control, pruning and harvesting. In the traditionally controlled greenhouse, human power is used for all operations. The crop growth period was shorter in the greenhouse managed by the proposed smart system. The smart greenhouse yields a larger amount of harvest in comparison to the traditional greenhouse. As a future work, other types of vegetables can be cultivated.

Keywords: Greenhouse, Smart System, Arduino

ÖZ

AKILLI SERA TASARIMI VE UYGULAMASI

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Bu tez çalışmasında akıllı sera tasarımı önerilmiştir. Tasarlanan akıllı seranın amacı daha az insan gücü kullanmak ve daha yüksek verim sağlamaktır. Tasarlanan sistemde, hava sıcaklığı, hava bağıl nemi, toprak sıcaklığı ve toprak nemi sensörler tarafından ölçülmektedir. Ölçümlerin analizi sonucunda havalandırma, ısıtma, sulama gibi mekanik cihazların kontrolü önceden belirlenmiş kurallara göre sağlanmaktadır. Bu tür otomasyonlar sulama ve havalandırma için kullanılan insan gücünün azaltılmasına yardımcı olur. Tezde, sistem karşılaştırması için aynı özelliklere sahip iki sera kullanılmıştır. Seralardan biri akıllı sistem ile yönetilirken, diğer sera geleneksel şekilde yönetilmiştir. Budama kontolü, budama ve hasat için insan gücü her iki serada ortak kullanılmıştır. Geleneksel yöntemle kontrol edilen serada tüm işlemler için insan gücü kullanılmıştır. Akıllı sistem tarafından yönetilen serada bitki büyüme süresi daha kısadır. Akıllı sera, geleneksel sera ile karşılaştırıldığında daha fazla ürün vermiştir. Gelecek çalışma olarak, diğer sebzeler ekilebilir.

Anahtar Kelimeler: Sera, Akıllı Sistem, Arduino

To My Daughter

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max	Maximum
min	Minimum
V	Volt
w	Watt
kw	Kilowatt
cal	Calorie
Kcal	Kilocalorie
std. dev.	Standard Deviation
L	Liter
GSM	Global System for Mobile Communications
ARM	Acorn RISC Machine
RISC	Reduced Instruction Set Computer
PH	Power of Hydrogen
TL	Turkish Lira
cm	Centimeter

CHAPTER 1

INTRODUCTION

The world population is increasing day by day. The population projections in Turkey and in the world are shown in Table 1 [10, 28]. In Figure 1.1 the supply of calories per capita is only slightly increased [10]. Agricultural areas, which play an important role in meeting the demand for food, decrease inversely proportional to the population growth. Arable lands per person in Turkey and in the world are shown in Figure 1.2 [9, 28, 29]. Given all these changes, fast and high-yield agriculture in small-scale agricultural lands have become important. Greenhouses are used to achieve fast and high-yield agriculture in small-scale agricultural lands. The environmental and climatic conditions in the greenhouse can be adjusted according to the vegetables to be grown. It is possible to get high efficiency and to grow most of the vegetables independent of the season. A structure for the protection of external factors and the need for many devices (such as heater, cooler) in the greenhouse to adjust the environmental conditions according to the plant, increase the setup costs of greenhouses. As the environmental conditions in the greenhouse need to be adjusted, larger amount of labor force is needed in greenhouses than in open-air farming.

Greenhouse farming is widely carried out in the Mediterranean region of our country [36]. The fact that greenhouses are widely constructed in a zone increases the cost of greenhouse cultivation, which is already high, by adding costs such as transportation cost and product damage. In addition, the use of more human power in the greenhouses also brings human errors. Errors in the greenhouse climate caused by human errors could affect the growth pace of the vegetables grown in the greenhouse and the quantity of the products negatively. In this thesis, an smart system design

Table 1.1: Population projections in Turkey and in the World, 2000- 2015 (billions) [10, 28]

	Turkey	World		Turkey	World
2000	64	6127	2008	71	6764
2001	65	6204	2009	72	6846
2002	66	6282	2010	73	6930
2003	67	6361	2011	74	7013
2004	68	6440	2012	75	7098
2005	68	6520	2013	76	7182
2006	69	6600	2014	77	7266
2007	70	6682	2015	78	7349

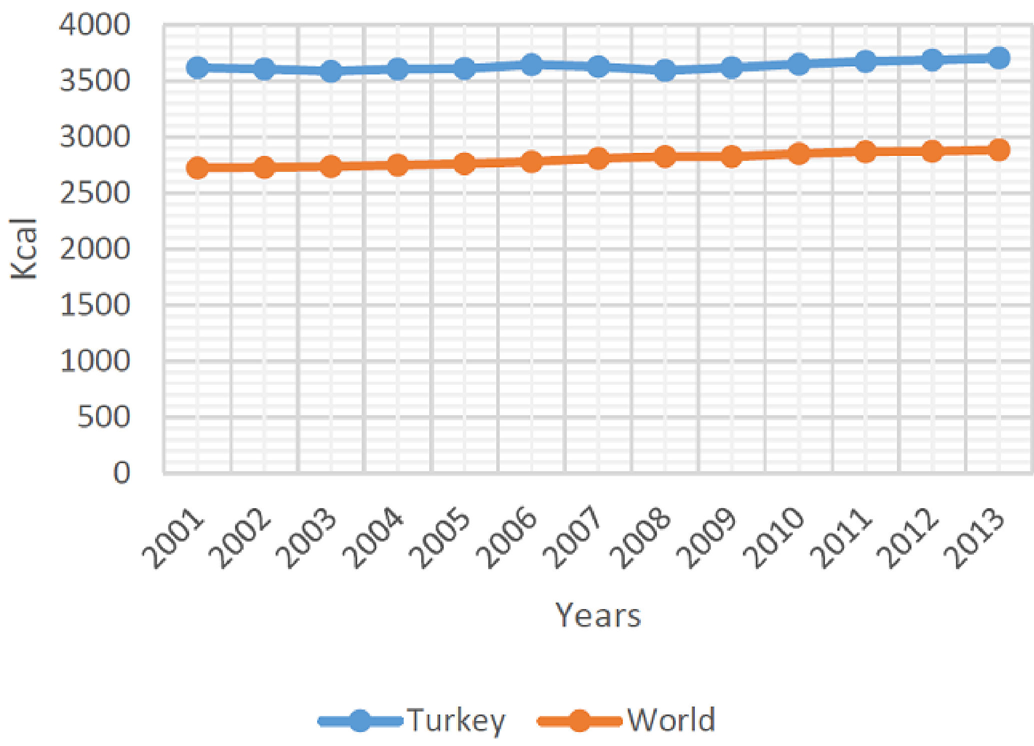

Figure 1.1: Daily per capita supply of calories [10]

which can be used in large commercial or small hobby greenhouses, is proposed. We aimed to use minimum human power, minimum water consumption so that greenhouse agriculture can be done in every region. Hence, human power and shipping costs as well as product damage will be reduced. In addition, with this smart system, human errors are minimized and faster and higher efficiency is obtained.

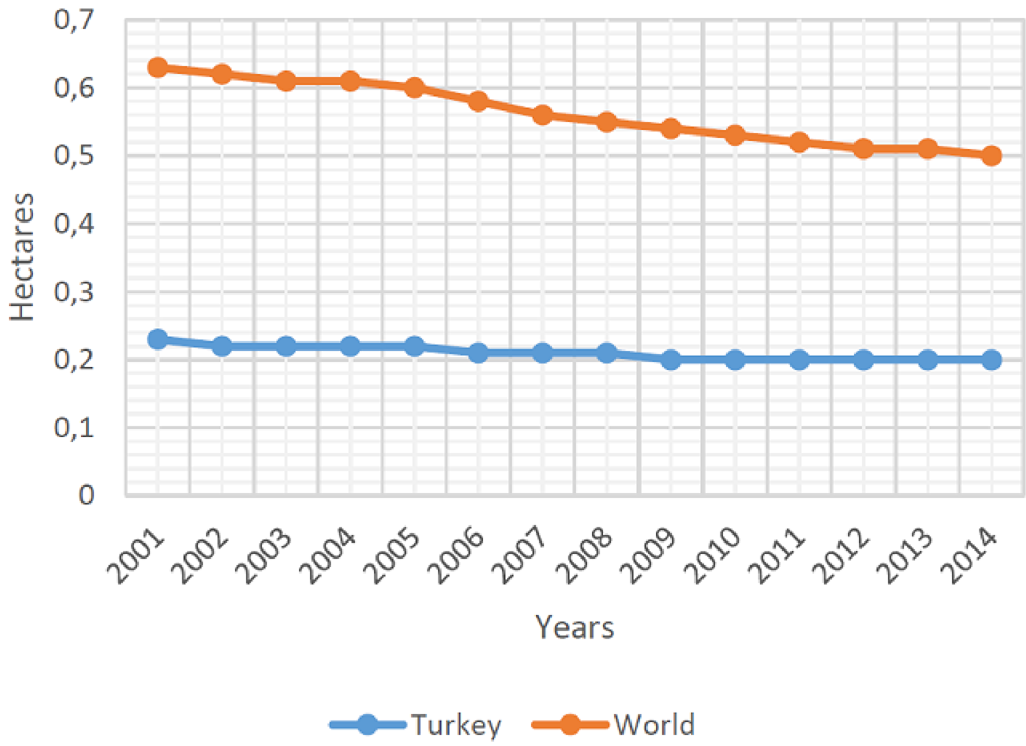

Figure 1.2: Arable land per person [9, 28, 29]

1.1 Problem Definition

As the world population increases, the demand for food also increases. However, the number of agricultural areas which play an important role in meeting the food demand is decreasing. Fast and efficient agriculture in small areas is required to meet the increasing demand for food. Greenhouses are used for fast and efficient agriculture in small agriculture areas. Greenhouses can also be artificially tuned for climatic conditions for rapid and highly efficient agriculture. The cost of first installation is very high because greenhouses are specially structured. It also requires a larger amount of human labor force than open-air agriculture because climatic conditions are artificially tuned [18]. The use of a large amount of human labor force in the greenhouse also increases the cost of greenhouse which is already high, and it introduces the human mistakes which cause the product loss. The usage of human power and cost can be reduced by using smart system in greenhouses,.

In this thesis, a smart system greenhouse that measures climatic conditions with sensors and produces solutions according to these conditions, is proposed. The designed smart system was evaluated by measuring the air temperature and humidity, and the ventilation and heating devices connected to the smart system were controlled according to the measurements. In addition, the soil moisture and temperature were evaluated and the irrigation system connected to the smart system was controlled according to the measurements. Climatic conditions were kept between the values set according to the plant. Greenhouse managed by traditional method and greenhouse managed by smart system were compared.

1.2 Methodology

In this thesis, two greenhouses were installed. One of these greenhouses was managed by our smart greenhouse system. The other one was traditionally managed. Air temperature, air humidity, soil temperature and soil moisture were measured with sensors in the smart greenhouse system. Mechanical and electronic solutions such as irrigation, ventilation and heating were connected to the system. Fertilization and pruning were carried out by the farmer. The measurements were evaluated according to the data previously entered into the system, and the mechanical and electronic devices connected to the system were controlled so that the values measured in the greenhouse were kept between predetermined values. The greenhouse managed by the designed system and the greenhouse managed by the traditional method were compared in terms of seedling length, total number of products, the product amount (in grams), time and water consumption.

1.3 Contributions

The smart system designed for these greenhouses aims to increase greenhouse efficiency and reduce cost by implementing pre-determined solutions by controlling five parameters (air temperature, air humidity, and soil moisture, soil temperature and light). The designed system is intended to be used both in hobby greenhouses and commercial greenhouses with wide area usage. The five parameters that the system controls for climating and irrigation, are suitable for all plants. Thus, if necessary threshold values are entered in the system during installation, all plant types can be cultivated in the greenhouse. The system has been designed so that the human power spent on greenhouse activities such as ventilation, lighting and irrigation will be gained. In addition, the designed system aims to use less water in terms of irrigation compared to the traditional method. The devices used by the system for climating, can be scaled according to the needs, which makes them easier to use.

CHAPTER 2

BACKGROUND / RELATED WORK

In this section, we present the devices used in smart system design and the related work on this topic.

2.1 Background

In the smart system design, Arduino Uno was used as the development platform. An Arduino compatible temperature sensor was used to measure soil temperature. An Arduino compatible soil moisture sensor module was used to measure soil moisture. An Arduino compatible temperature and humidity sensor were used for air temperature and air humidity measurement. The following sections contain information on the sensors and actuators used in the smart system design.

2.1.1 Arduino Uno

Arduino is an open source development platform in which circuits can be designed. Arduino Uno is one of many types of that has the ATmega328 micro controller on it. Micro controller programming is done by connecting to the computer's USB port. By programming the Arduino, the data can be read out and output can be generated by using the input/output pins. Arduino Uno is shown in Figure 2.1 [4, 8]. The properties of Arduino are given in Table 2.1 [3].

The voltage required to run Arduino can be provided by the adapter which generates 7-12V voltage or the USB port of the computer. Circuit supply voltages can be

Table 2.1: Arduino properties [3]

Hardware	Property
Microcontroller	ATmega328
Supply Voltage	7-12V
Working Voltage	5V
Number of Input-Output Pin	14
Current at Pin	40mA-50mA
FLASH	32KB
SRAM	1KB
EEPROM	1KB
Working Clock Speed	16MHz

provided through Arduino's 5V (40mA) and 3.3V (50mA) pins. Six of input-output pin (3^{th},5^{th},6^{th},9^{th},10^{th},11^{th}) can be used as Pulse Width Modulation (PWM). Four of input-output pin (10^{th},11^{th},12^{th},13^{th}) can be used for Serial Peripheral Interface (SPI) with using SPI library [13, 43].

Figure 2.1: Arduino Uno [4]

2.1.1.1 Arduino IDE

In order to use the Arduino on a computer, the Arduino driver must first be downloaded to the computer. Then, the Arduino driver must be installed on your computer manually through the device manager. After installing the driver, the virtual serial port number that the Arduino is connected to will appear. Then the Arduino IDE, the interface program of Arduino from [5, 8, 12], should be downloaded and run on the computer. Figure 2.2 shows the Arduino IDE and a sample program.

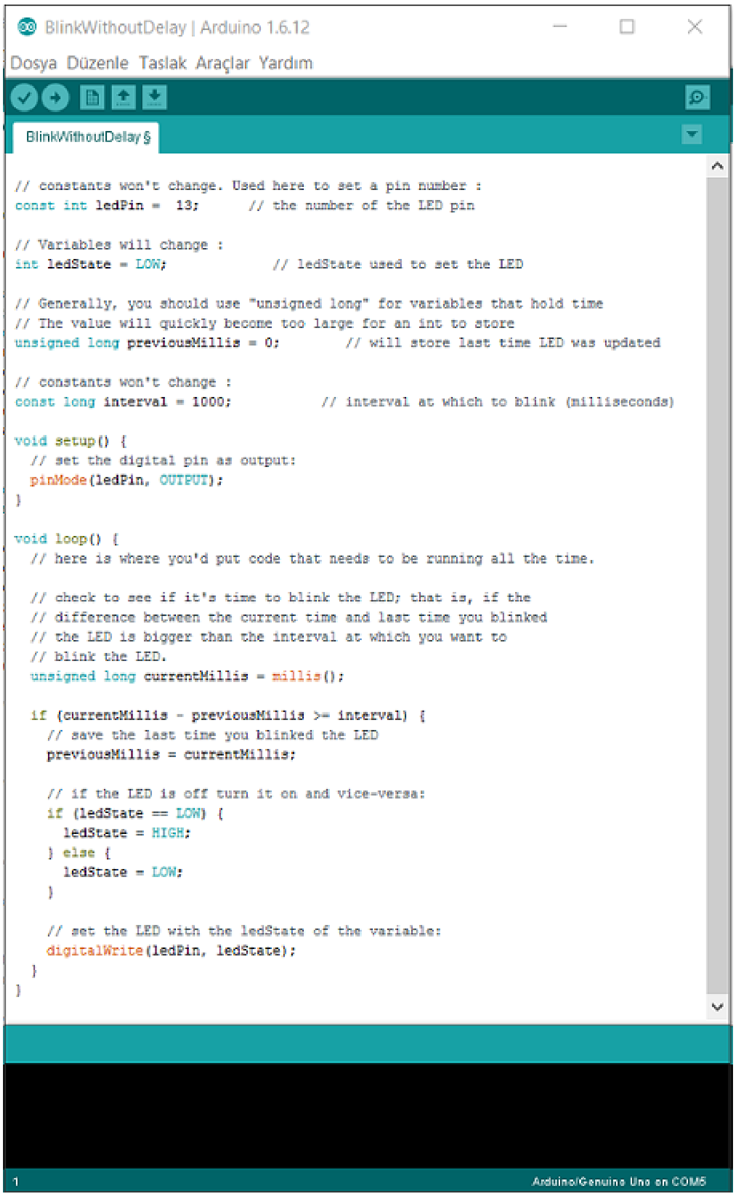

Figure 2.2: Arduino IDE and a sample program

2.1.2 Soil Moisture Sensor

The soil moisture sensor consists of 2 parts: Humidity meter probes and voltage comparison board. Figure 2.3 shows soil moisture sensor. Moisture measurement is carried out by immersing the probes in the soil. The resistance between the probes immersed in the soil causes a voltage difference between the probes [48]. Soil moisture can be measured with this voltage difference. Adjustable resistance (trim pot) in the voltage comparison board can be used to adjust the sensitivity. The voltage comparison board has a digital and analog output to which the value of the humidity can be transferred. Arduino is compatible with Analog output. The value readable from the analog output is in the range 0-1023 [49]. The properties of the soil moisture sensor are shown in Table 2.2.

Table 2.2: Soil moisture sensor properties [49]

Hardware	Property
Working Voltage	3.3V-5V
Output Voltage	0-4.2V
Current	35mA
Output type	Digital ve Analog

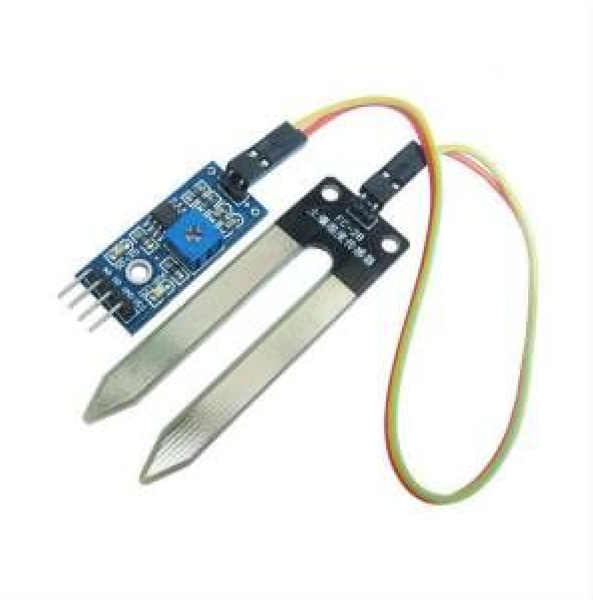

Figure 2.3: Soil moisture sensor [40]

2.1.3 Soil Temperature Sensor

The DS18B20 humidity sensor is used to measure the soil temperature [39]. Figure 2.4 shows soil moisture sensor. This sensor is the waterproof version of the DS18B20 sensor. It's a digital sensor. Nine or configurable 12-bit reads can be performed via the single-wire interface. The properties of DS18B20 are shown in Table 2.3 [20, 44].

Table 2.3: Soil temperature sensor properties [20, 44]

Hardware	Property
Operating Voltage	3.0V to 5.0V
Temperature measurement range	-10^{o}C to 80^{o}C
Accuracy	0.5^{o}C
Response time	<750ms
Cable length	1 meter
6mm diameter 30mm neck stainless steel case	
Waterproof	

Figure 2.4: Soil temperature sensor [21]

2.1.4 Air Humidity and Temperature Sensor

The DHT11 temperature and humidity sensor includes a resistance-type component for measuring moisture and an NTC temperature measurement component for measuring temperature. Figure 2.3 shows air humidity and temperature sensor. DHT11 can transmit measured values up to 20 meters, has low energy consumption and is small in size. The temperature sensivitiy is between 2% and 5% [6, 16]. For use with Arduino, the output pin must be connected to a 10 kΩ resistor. The DHT11 library needs to be added to Arduino such that Arduino acquire measurement results from DHT11.

Figure 2.5: Air humidity and temperature sensor

2.2 Related work

, The use of recent technology to increase productivity in agriculture is becoming widespread day by day. Parameters such as soil moisture, air temperature, air relative humidity are measured and controlled by systems designed for this purpose in order to increase productivity in agriculture. This section includes a review of some of these systems that are designed to increase productivity.

A smart system designed for agriculture, called AgriSys was introduced in [1]. In AgriSys, air temperature, air humidity, soil moisture, soil PH, and light were measured with sensors. In this system, the blinds unit was used to prevent more light, but no lighting unit was used for less light. Irrigation method was used for water and nutrient needs. The cooling unit was used to protect the plant from high temperatures, but the no heating unit was used for low temperatures. In the implementation of the designed AgriSys system, it is claimed that the system saves water and reduces the human power used in agriculture.

A system providing solutions for temperature and humidity for greenhouses is proposed in [15]. The system is made up with Internet of Things (IoT) sensors and automatic control over temperature and humidity is provided. The proposed system offers the ideal environment for plant growth, user-friendly interface for the user. The effect of the system on the plant in the study was not discussed with numerical data.

A system that control air humidity and air temperature, is designed in [22]. Designed system has AT89C52 microcontroller. In this designed system, air temperature and air humidity balance is ensured with some equipment like air humidity increaser equipment, air humidity decreaser equipment, air temperature increaser equipment and air temperature decreaser equipment. In addition, this designed system include a warning system. As a result, this system met air humidity and air temperature requirements of greenhouse.

A fully automatic irrigation system was designed in [23]. In designed system, GSM, ARM processor, soil moisture sensor, soil PH sensor and drip irrigation system were used. A solenoid valve is used as in [35] for irrigation system control. Because the irrigation system was provided also soil fertilizer, not only soil moisture but also soil pH was taken into consideration in order to open and close the irrigation system. System comparison in terms of water consumption was done with the sprinkler irrigation system. The designed system consumed less water compared to the sprinkler system. No human power was needed in the designed system.

Another system design that includes sensors, software technology and remote management of hardware with a website, is proposed in [31]. Greenhouse climating and irrigation are considered as basis in this system. In order to balance air temperature, air humidity and lighting in the greenhouse, various type sensors and equipment have been used. Depending on the user's experience and decision, some system units can be disabled. In addition, instant greenhouse status can be displayed on the website.

Greenhouse hardware use wireless communication technologies (Bluetooth, WiFi, Zigbee, etc.). Wireless communication is an advantage for small greenhouses, but can cause confusion in large greenhouses.

A spectroscopy sensor with light emitting diode that produce light of different wavelengths was used in [32]. The absorption of different wavelengths of light emerging from this light source by the leaf was monitored with different photo diodes for light in each wavelength. The information obtained from the photo diodes was analyzed for the nitrogen and potassium requirement of the plant. Using irrigation system, which is built on the field of farming and capable of moving horizontally, potassium and nitrogen were supplied to plant.

A system that measures the moisture of soil and manages the irrigation system according to these measurements was designed and introduced [35]. The irrigation in operation was made using a solenoid valve and drip irrigation system. When the soil moisture was lower than a certain threshold value, the valve was kept open until the soil moisture reaches the desired value and the valve was closed when the soil moisture reaches the desired value. In this way, excessive irrigation was prevented and the human power used for irrigation has been removed and electricity saving was achieved. The quality of product was increased by the system. Because the smart system we designed was used in the greenhouse, not only irrigation but also weather conditions were controlled to increase product yield.

A monitoring system which include soil moisture sensor, air humidity sensor and air temperature sensor, was introduced [37]. In this system, values measured form sensors, were transmitted wirelessly to the relevant units (irrigation, ventilation etc.) via microcontroller. Among of these units, only irrigation has been tested. Other units have not been tested because of the difficulty of implementing of all units together. We used same sensors for our designed smart system, but we tested not only irrigation units but also heater and ventilation system.

Another irrigation system designed using Arduino Uno is described in [38]. In this designed system, Arduino, Arduino compatible Ethernet shield and Arduino compatible Motor shield are used. In general, in the system, soil moisture is measured by soil moisture sensor. The measured value is evaluated by Arduino:If it is below a predetermined threshold value, the servo motor which is connected to motor shield is turned on and irrigation started. When the moisture value of the soil exceeds the threshold value, the servo motor is turned off and irrigation is finished. All of these processes and instant value information are presented to the user through Ethernet shield. Like the smart system we designed, this system also reduced thehuman power consumed for irrigation. However, the use of additional Motor shield has increased the setup cost.

A system of early detection of insects in tomato plants is described in [41]. Basically, the system is based on a robot walking between two rows of plants and monitoring the plants with the camera. While the robot camera is browsing through plants, the insect formation is determined from the color differences on the plant and the related region is sprayed. Thus, the manpower needed for spraying is reduced. In addition, spraying in accordance with the need do not harm the plant and fruit. A similar method exists in the irrigation system in our proposed system.

A system in which only the amount of water and light can be controlled for a single plant is designed in [42]. In this system, light and irrigation control was carried out in a greenhouse environment which could be called a mini greenhouse since only one plant grows. In the system, irrigation system which depends on soil moisture and a curtain system that prevents the plant from getting too much light were used. In this system, goals such as increasing the target quality of the plant, re-usability have been achieved. But the system cost was high because it was designed for only one plant.

Arduino-based control system for mini greenhouses is designed in [46]. For measuring greenhouse environment, a sensor module that includes temperature, humidity, light values of measurements is used. Heater, cooler, irrigation pump and lighting are used for greenhouse environment changes. In addition, a real-time module with its own battery is used for the real time required for the system to run. Ventilation method and the sensor used to measure air humidity and air temperature are same both the system described in [46] and our smart system implementation. But no detailed information has been given for other units used in [46]. The operation of the system is displayed on the led screen. However the system is not implemented on the greenhouse.

For small and medium-sized greenhouses, the RF-based system is applied in [47]. This system provides control over greenhouse using GSM networks and remote control technology. In the study, the hardware structure of the system and the software flow chart are given. It has been argued that the system can monitor the greenhouse, reliably, in real time. But the effect of the system on the greenhouse has not been investigated.

Table 2.4, Table 2.5 and Table 2.6 show the corresponding analyze of related works in terms of the sensors used, the appliances used, the type of connection, the application and the results. Data not indicated in the related work are indicated by "-".

Table 2.4: Comparison of related works

	Used Appliances		Appliance Types	Implementation	Results
	Controller & Sensors	Environment Appliance			
Our proposed system	Arduino Uno Air humidiy Air temperature sensor Soil moisture Sensor	Fan Heater Drip irrigation	Wired	Yes	Usage of human power decreased, Water consumption decreased, Yield increased, Product growing speed increased
[1]	Air temperature sensor Air humidity sensor Soil moisture sensor Soil PH sensor Light sensor	Blinds Irrigation	-	Yes	Usage of human power decreased Save water
[15]	Air temperature sensor Air humidity sensor	-	Wireless	Yes	-
[22]	AT89C52 microcontroller Air humidiy Air temperature sensor	Air humidity increaser Air humidity decreaser Air temperature increaser Air temperature decreaser	Wired	No	-
[23]	ARM9 processor Soil moisture sensor Soil PH sensor	Drip irrigation	Wireless	No	The system is designed to fertilize by drip irrigation.

Table 2.5: Comparison of related works (continue)

	Used Appliances		Appliance Types	Implementation	Results
	Controller & Sensors	Environment Appliance			
[31]	Humidiy sensor Temperature sensor Light sensor	Irrigation	Wireless	Yes	The use of wireless technology in large greenhouses can lead to confusion.
[32]	Spectroscopy sensor Moisture sensor Infraredsensor	Irrigation	Wired & Wireless	No	
[35]	ATMEGA 16 Soil moisture sensor	Irrigation	Wireless	Yes	Usage of human power decreased, Water consumption decreased.
[37]	Air humidiy sensor Air temperature sensor Soil moisture sensor	Irrigation	Wired & Wireless	Yes	The system only tested the irrigation system, Usage of human power decreased, Water consumption decreased.
[38]	Arduino Uno Soil moisture sensor	Ethernet shield Motor shield Irrigation	Wired & Wireless	No	Usage of human power decreased, System cost is high

Table 2.6: Comparison of related works (continue)

	Used Appliances		Appliance Types	Implementation	Results
	Controller & Sensors	Environment Appliance			
[41]	-	Camera Robot	Wired	Yes	Usage of human power decreased, Fertilizer consumption decreased,
[42]	Light sensor Moisture sensor	CurtainIrrigation	Wired	No	-
[46]	Air humidiy sensor Air temperature sensor Soil moisturesensor Light sensor	Heater Cooler LightingIrrigation pump	Wired	No	-
[47]	ATmega16A Temperature sensor Humidity Sensor	Irrigation	Wired & Wireless	No	-

CHAPTER 3

SMART SYSTEM DESIGN FOR GREENHOUSES

In this thesis, we designed and implemented a smart system for greenhouses. With the system designed in the thesis, tomato cultivation in the greenhouses was done. Important information on tomato cultivation is given in Section 3.1. Smart system design is explained in Section 3.2. The implementation of the designed smart system is explained in Section 3.3.

3.1 Tomato Farming

The yield of tomatoes in Turkey is decreasing day by day. The average tomato yield in Turkey is shown in figure 3.1. In order to investigate the increase of tomato yield with the smart greenhouse, the tomato plant was selected to be grown in the greenhouses. In addition, the growth of tomato plants depends on very few parameters. However, it is very important that these parameters remain within certain limits so that the plant can grow healthy and give high tomato yield. The parameters heard by the tomato plant and the ranges of these parameters are explained below.

Tomatoes are hot and temperate climate vegetables. Climatically, if temperature falls to -2^{o}C, -3 ^{o}C, the plant may be damaged or die. At temperatures below 14 ^{o}C and above 35 ^{o}C plant cannot grow enough and yield of tomato drops. The temperature must be constant between 22-26 ^{o}C for plant growth and tomato yield. Day and night temperature differences should be between 8 ^{o}C and 12 ^{o}C. When the temperature rises above 24 ^{o}C, the greenhouse should be ventilated. The humidity must be between 65% and 70% in the first growing period of the tomato seedlings, and the hu-

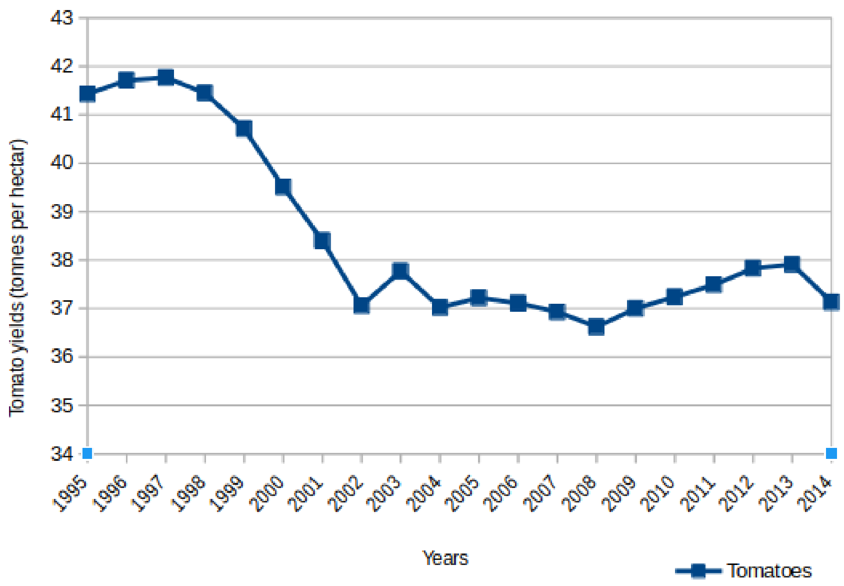

Figure 3.1: Average tomato yields in Turkey (tonnes per hectare) [11]

midity should be around 75%-80% when the first tomatoes come in sight. The plant needs to be exposed to direct sunlight at least 6 hours a day to grow well. Otherwise, plant growth is affected negatively. Tomato seedlings are not selective in terms of soil requirement. For the best yield, soil must be deep, permeable; water holding capacity should be high, rich in terms of nutrients; PH should be between 5 and 7. Conditions for irrigation are: Life water should be given after seedlings planted, irrigation should not be done until the first tomatoes of the plant are given. If the plant get darkened in color before the first tomatoes appear and if fluff appears on plant body, a small amount of watering should be done. After the first tomatoes appear, irrigation should be done 2-3 times a week. An important point to note when irrigation is done is that water should not be sprayed on the leaves while watering is being done. Otherwise, diseases may occur and may spread from the soil to the leaves. Therefore, drip irrigation is suitable for growing tomatoes [2, 7, 17, 19, 50].

3.2 Smart System Design

Figure 3.1 shows the general smart system design. In the designed smart system, all peripheral units (sensors and mechanical systems) are connected to the controller.

The measurements from the sensors, evaluation and operation of the mechanical systems are provided. For a correct operation of the system, ideal soil moisture, ideal soil temperature ideal temperature and ideal humidity information are needed. This information should be entered into the system depending on the plant property that grows in the greenhouse [25].

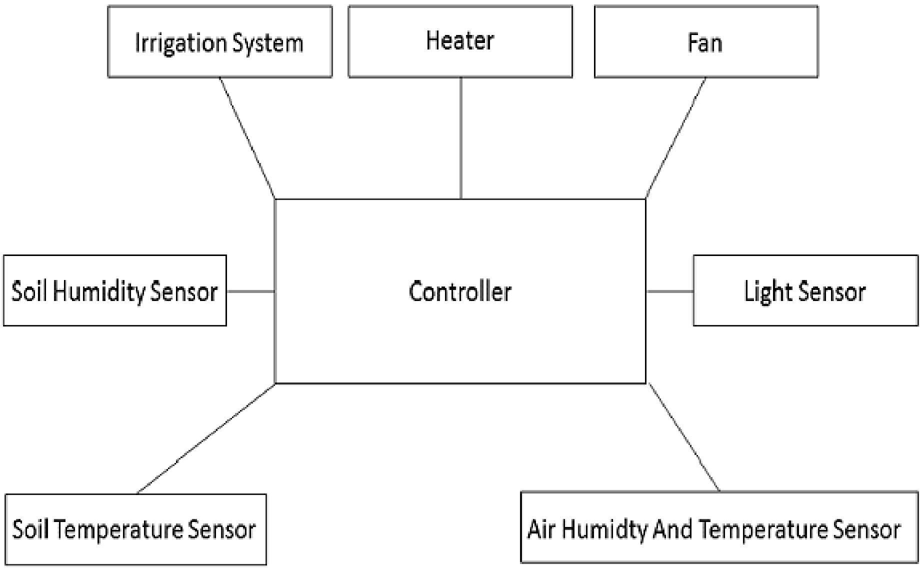

Figure 3.2: Block diagram of the designed smart system

In the designed smart system, the soil moisture and the soil temperature are measured separately for each plant. Drip irrigation system is used for balancing soil temperature and soil moisture. As each plant uses separate sensors, the soil moisture and soil temperature data of each plant may be different. The system needs a single temperature and humidity value to control the irrigation. For this reason, irrigation system is controlled by the average soil temperatures and average soil moisture of all the plants involved in the system. The irrigation system opens when the average soil moisture falls below the ideal soil moisture or when the average soil temperature exceeds the ideal soil temperature [24]. The irrigation system is turned off when any of the soil moisture and soil temperature reaches the ideal value. Therefore, soil moisture and soil temperature are kept in ideal value. Soil-related measurements are set to be between 6:00 - 8:00 and 17:00 - 19:00 which are ideal time range for irrigation. In this time periods, the data coming from the soil temperature and soil moisture sensors are taken into consideration at intervals of 2 minutes with the aim of preventing excessive irrigation. The pseudo code given in Algorithm 1 turn on/off irrigation according to min and max soil moisture value. where m_h max. soil moisture value, m_l min

Algorithm 1 Irrigation algorithm

```
procedure IRRIGATION(time, m_h, m_l)
    read soil moisture sensors
    if (time between 06:00 and 08:00) or (time between 17:00 and 19:00) then
        for Every two minutes do
            avg ← the average of soil moisture
            if avg < m_l then
                Irrigation system on
            else if avg>=m_h then
                Irrigation system off
    else
        break
```

soil moisture value. The air temperature and air humidity are designed to be read by a single sensor. Ventilation and heating are used to balance air temperature and air humidity. In the system, air temperature is evaluated separately for two cases, day and night. During the day, the ventilation opens when the air temperature or air humidity exceeds the ideal value. The ventilation is closed when any of the air humidity and air temperature reaches the ideal value. When the air temperature falls below the ideal value, the heating system is used until the air temperature reaches to an ideal value. In addition, air temperature information is collected every 30 minutes to prevent sudden temperature fluctuations during the day between 8:00-20:00 and an average is obtained. The operation of night heating and ventilation are based on this average daytime air temperature. When the night air temperature falls below a certain value below the average of the daytime air temperature, the heater works to warm up the greenhouse to reach the ideal temperature day-night difference. In the same way, when the night air temperature exceeds the average of the daytime air temperature by a certain value, the ventilation starts and continues working to reach the ideal temperature day-night difference. During the day, the ideal air humidity and temperature ratio in the greenhouse is ensured and the day-night temperature difference is kept at a certain value. The pseudo code given in Algorithm 2 turns on/off the ventilation. And the pseudo code given in Algorithm 3 turns on/off the heater.

Algorithm 2 Ventilation algorithm

procedure VENTILATION($time, t_h, t_l, t_{tl}, t_{th}, h_h, h_l$)
    for $Every\ second$ **do**
        $t \leftarrow$ air temperature
        $h \leftarrow$ air humidity
        if time between 8:00 and 20:00 **then**
            t_{avg} $\leftarrow$air temperature average
            if $t > t_h$ or $h > h_h$ **then**
                Ventilation system on
            else if $t <= t_l$ and $h <= h_l$ **then**
                Ventilation system off
        else
            if $t_{avg} - t > t_{tl}$ **then**
                Ventilation system on
            else if $t_{avg} - t <= t_{th}$ **then**
                Ventilation system off

where t_h is max air temperature value, t_l is min air temperature value, t_{tl} is min day-night temperature difference value, t_{th} is max day-night temperature difference value, h_h is max air humidity value, h_l is min air humidity value. The ambient light sensor in the system measures the amount of light the plant receives during the day. Since there is no need for the system to be implemented within this thesis, there is no management unit. It can be used to manage greenhouse lighting. where l_l threshold value for open and close light, hour is time for light requirement of plant.

3.3 Implementation of the Smart System Design

For the designed smart system application and comparison, two greenhouses with a width of 1 meter and a length of 1.5 meters and a height of 1.5 meters were installed. Figure 3.2 shows the greenhouses. Five seedlings with the same characteristics were

Algorithm 3 Heater control algorithm

procedure HEATER($time, t_h, t_l, t_{tl}, t_{th}$)
    for $Every\ second$ **do**
        $t \leftarrow$ air temperature
        if time between 8:00 and 20:00 **then**
            $t_{avg} \leftarrow$air temperature average
            if $t < t_l$ **then**
                Heater system on
            else if $t >= t_h$ **then**
                Heater system off
        else
            if $t_{avg} - t < t_{tl}$ **then**
                Heater system on
            else if $t_{avg} - t >= t_{th}$ **then**
                Heater system off

Algorithm 4 Lighting algorithm

procedure LIGHT($time, l_l, hour$)
    for every minute between 00:00 and 23:59 **do**
        $l \leftarrow$read light sensor
        if l < l_l and time < 12:00 **then**
            $t_1 \leftarrow$time
        else if l < l_l and time>12:00 **then**
            $h \leftarrow time$-t_1
            Break
    if h < hour **then**
        for hour - h **do**
            Open light
        Close light
    Close light

planted in both greenhouses. Arduino Uno was used as a controller in smart system design. Two fans were used for the ventilation system. For the irrigation system, a diver pump and drip irrigation system installed in the water tank were used. Cable

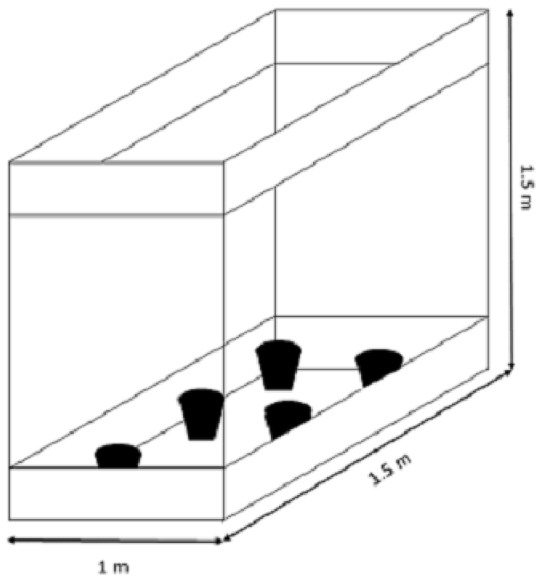

Figure 3.3: Installed greenhouses

heater was used for heating. The applied smart system is shown in Figure 3.3. For

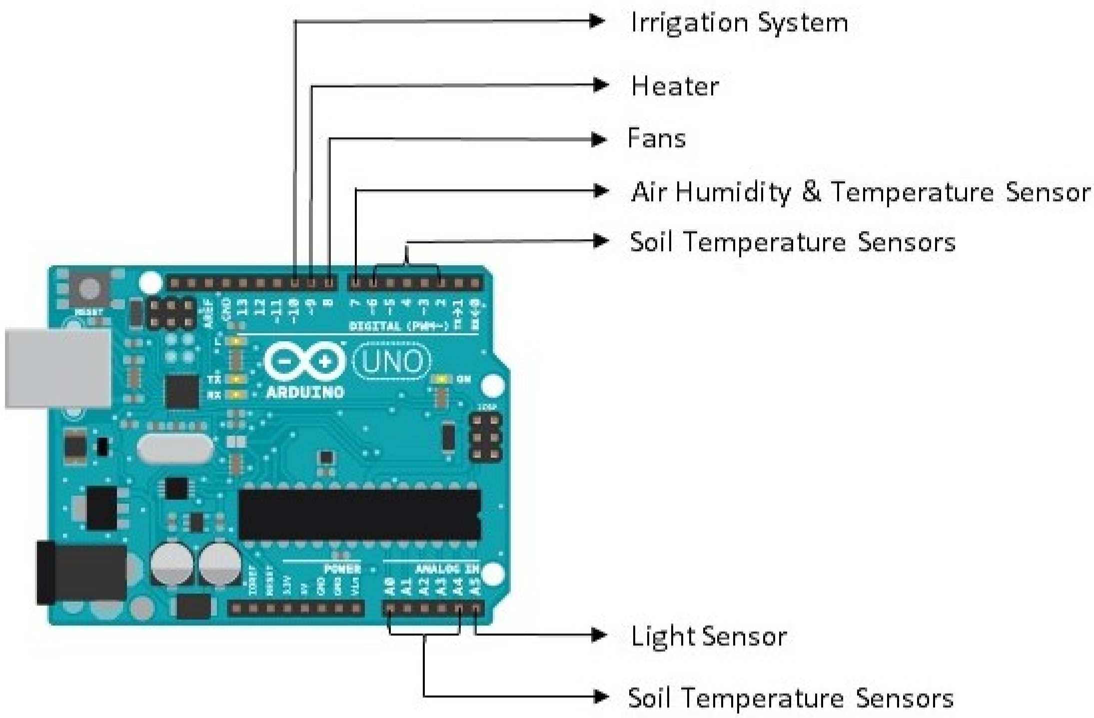

Figure 3.4: Implemented smart greenhouse schema

ventilation, two 220V two ventilation fans with $100m^3$ / hour were used. One of the fans was placed on the bottom of the greenhouse as shown in Figure 3.4. The other fan was placed on the top of the greenhouse. Due to the rise of the hot air, the fan placed on the top of greenhouse was used to transfer air from inside to outside. Also, another fan placed on the bottom of the greenhouse was used to transfer air from outside to inside. Hence, air flow was provided and air temperature and air humidity were reduced. Since the management of the fans was done with Arduino, the 220V-5V relay was used to control the fans [26]. Relay provided managing 220V voltage with 5V voltage. Fan management schema is shown in Figure 3.5. Calories

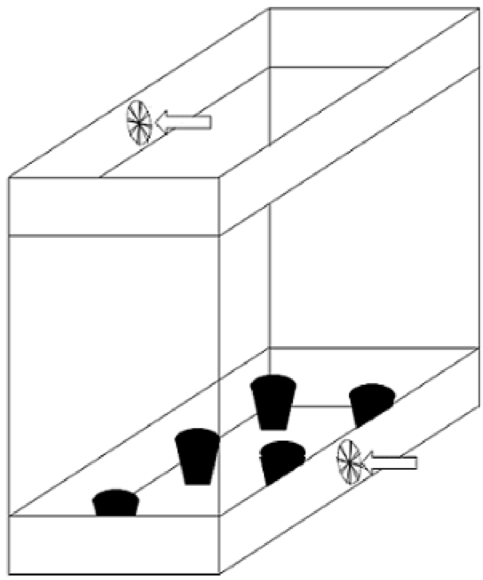

Figure 3.5: Fans of smart greenhouse

required for heating the air in the greenhouse is calculated by the following formula.

$$Q = MC\delta T,$$

where Q is the heat, M is the mass, C is the heating temperature (0.24 Kcal / kg), δT is the temperature difference. The amount of heat required to heat 1 m^3 air per degree and air weight per degree of air were shown in Table 3.1 [30]. According to the calculated temperatures, an average of 0.30 Kcal of heat is required to heat 1 m^3 of air.

A 1 kW heat source produces 860 Kcal heat per hour. A heat source of 30 W generate a heat of 25.8 Kcal per hour, 0.43 Kcal per minute. A heat source of 30 W is sufficient

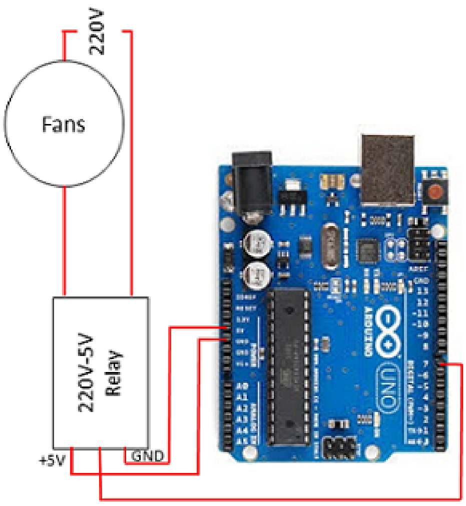

Figure 3.6: Fan management schema

Table 3.1: Air weight and required heat [30]

^{o}C	Air weight(kg/m^3)	Heat required(Kcal)
-10	1,342	0,32
0	1,293	0,31
10	1,247	0,30
20	1,205	0,29
30	1,165	0,28

for the above calculations. For this reason 12V 30W cable heater was used in the greenhouse. A transformer was used to transform the 220V supplied from the city network to 12V. The 5V-12V relay was used for the management of the heater with Arduino. Heater management schema is shown in Figure 3.7.

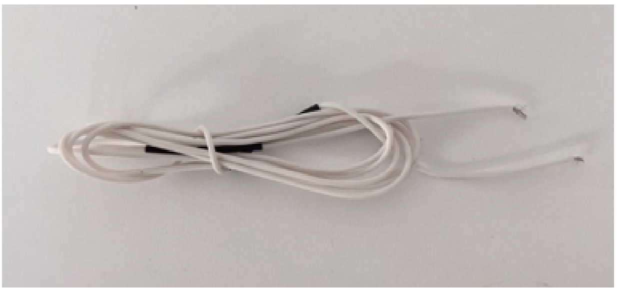

Figure 3.7: Cable heater [27]

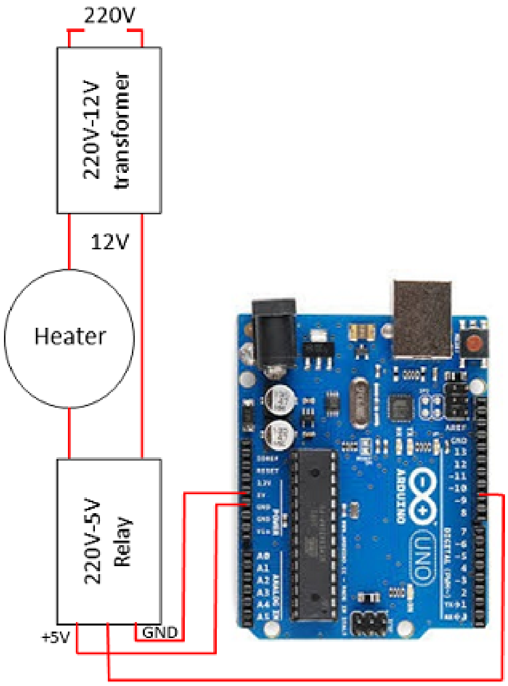

Figure 3.8: Heater management schema

In the application of the designed smart system, drip irrigation system was used for irrigation system. The system used a water tank as the water source because there was no water source of irrigation in the environment where greenhouses are built. A submersible pump is used to transfer water from the water tank [45]. The submersible pump is shown in Figure 3.8. The operation of the submersible pump was controlled by the system and irrigation was carried out. The submersible pump has a capacity of 12 liters per minute and 20 liters of water per minute. The submersible pump requires a 5V-12V relay for management purposes. Irrigation management schema is shown in Figure 3.9. One drip irrigation pit and dripper were used per pot [14]for drip irrigation. The use of pit and dripper is shown in Figure 3.10.

Implementation of smart system design is shown in Figure 3.11. The water requirement of the plants grown in the traditional method was provided by watering the soil by farmer. When the weather is hot, the greenhouse was opened and ventilated. The heater was not needed because the season in which the experiment was made was summer. Human strength has been used to prune plants in both greenhouses, to weed out weeds and to harvest.

Figure 3.9: Submersible pump [33]

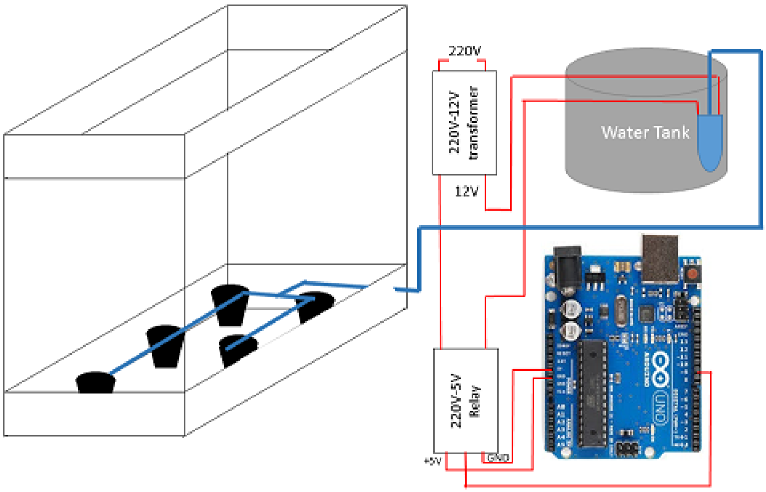

Figure 3.10: Irrigation management schema

Figure 3.11: Pit and dripper

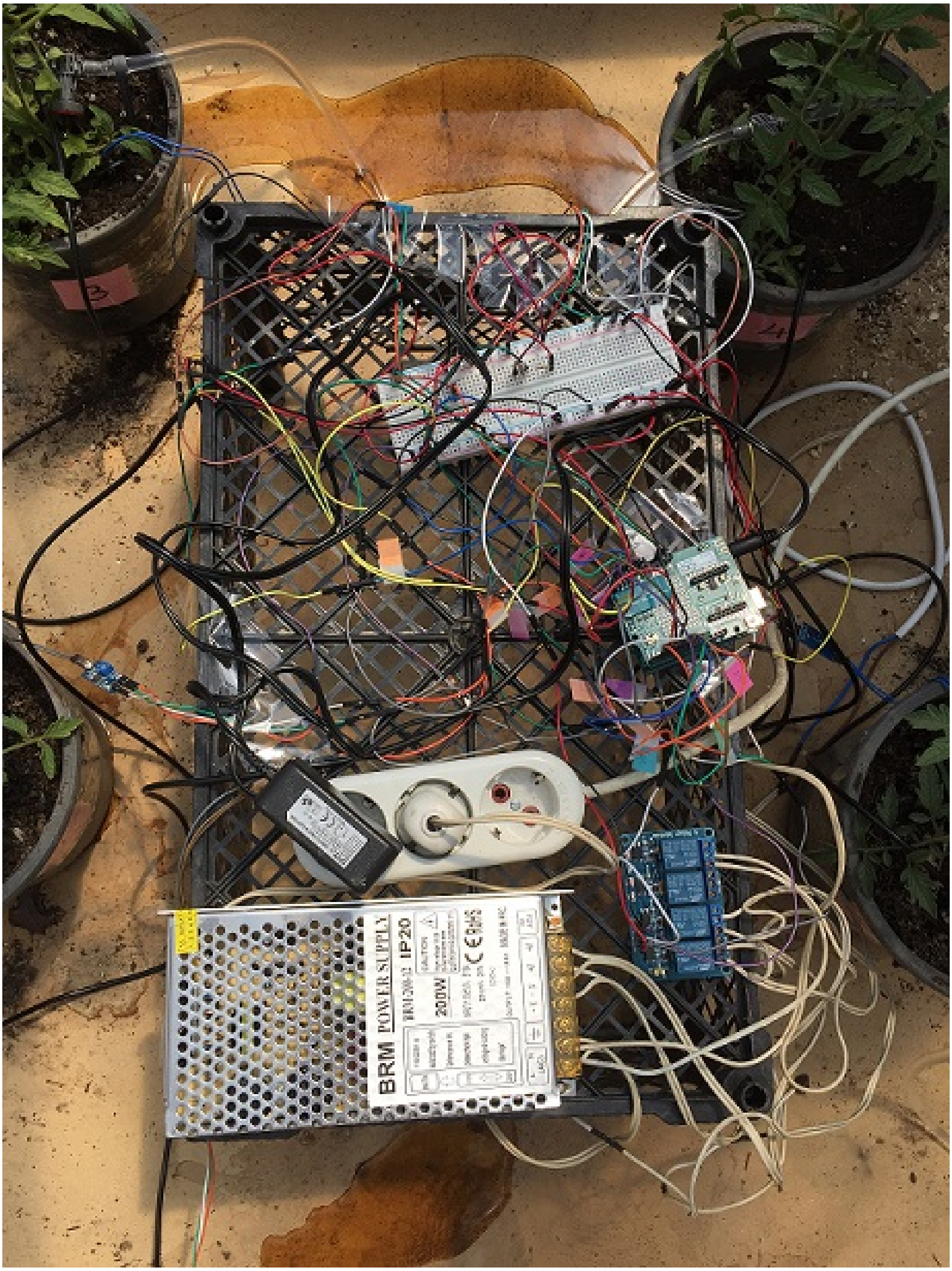

Figure 3.12: Implementation of the smart greenhouses

CHAPTER 4

RESULTS AND DISCUSSION

The results obtained from the application of the smart system designed in this chapter are explained. The results are explained by comparison with traditional greenhouse in terms of yield, speed, water consumption. The smart system's artificial climatic results in the greenhouse are also explained.

Five seedlings were planted in both greenhouses, managed by the smart system and managed by the traditional method. Six seedlings were planned to be planted in both greenhouses. A seedling was died in the traditional greenhouse because of damage while it was being transferred to the pot. If we had added a seedling later to the traditional greenhouse, the comparison would not be fair. Because it would not have the same conditions as other seedlings for a certain period of time. Therefore, a seedling was removed from the system in the smart greenhouse to make a comparison between the two greenhouses.

4.1 Results of tomato

This section contains the results of growing tomatoes grown in both the smart greenhouse and traditional greenhouse, during the experiment.

4.1.1 Duration of first tomato

Figure 4.1 shows time of first tomato occurrrence day for each pot. Pots with the same number have similar placement in the greenhouses. Ventilation in traditional greenhouse was done via greenhouse's door. When the door was opened for ventilation, plants were affected negatively by wind. Because of this, there was no tomato development in the 1^{st}, 2^{nd} and 4^{th} pots. In the greenhouse, which was managed by smart system, 4^{th} pot fruit development was slower than other seedling. The reason is that it was affected from fan which was used for ventilation. As a result, the mean of the first tomato occur time, in the greenhouse managed by the smart system was 14.7 days, in the greenhouse managed by the traditional method was 38 days.

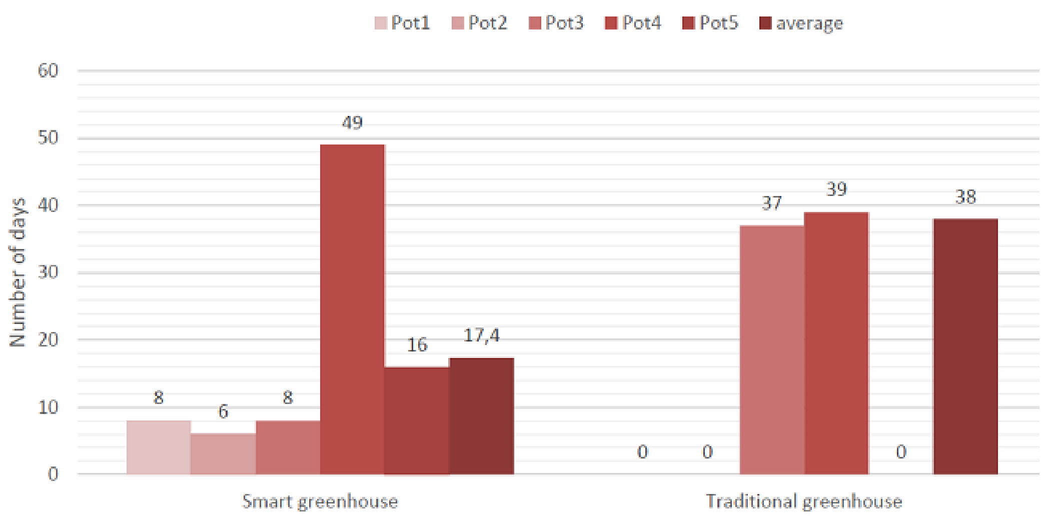

Figure 4.1: The number of days until the first tomato is seen at each pot (days)

4.1.2 Number of harvested tomato

Figure 4.2 shows number of tomatoes for each pot. As seen in this figure, the number of tomatoes of each plant is different. There is no direct relationship between the number of tomatoes and the location of the plant in the greenhouse. In the smart greenhouse, irrigation according to soil moisture and usage of fan for ventilation affected number of tomatoes positively. In the traditional greenhouse, number of tomatoes affected negatively due to wind which came from door opened for ventilation.

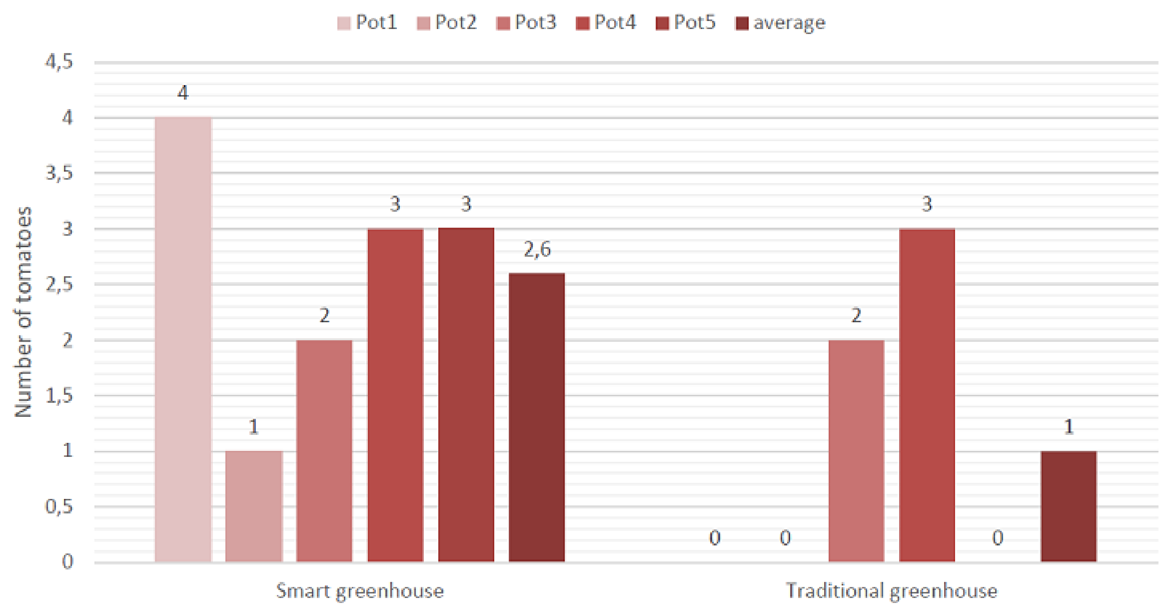

Figure 4.2: The number of tomato at each pot

4.1.3 Harvesting time of tomato

Figure 4.3 shows average harvest time of tomatoes for each pot. In the greenhouse managed by smart system, although tomatoes grow in the same seedling, they have different harvest times. The location of the tomatoes in the seedlings differed in terms of daylight. In the smart greenhouse, harvesting of some tomatoes were delayed because they could not take enough sun light because of leaves which are on top of tomatoes. The leaves which were on top of tomatoes, prevented tomatoes to obtain enough sun light. Removing these leaves with pruning, affected the growth of the tomatoes positively. In the smart greenhouse, early harvests were made as the tomatoes started to grow early. In the traditional greenhouse, harvest could be done 70 days later after seedlings planted.

4.1.4 Growing time of tomato

The time from the first tomato occur time up to the average harvest time is given in Figure 4.4. According to the figure, the harvest was made average in 17.2 days in the

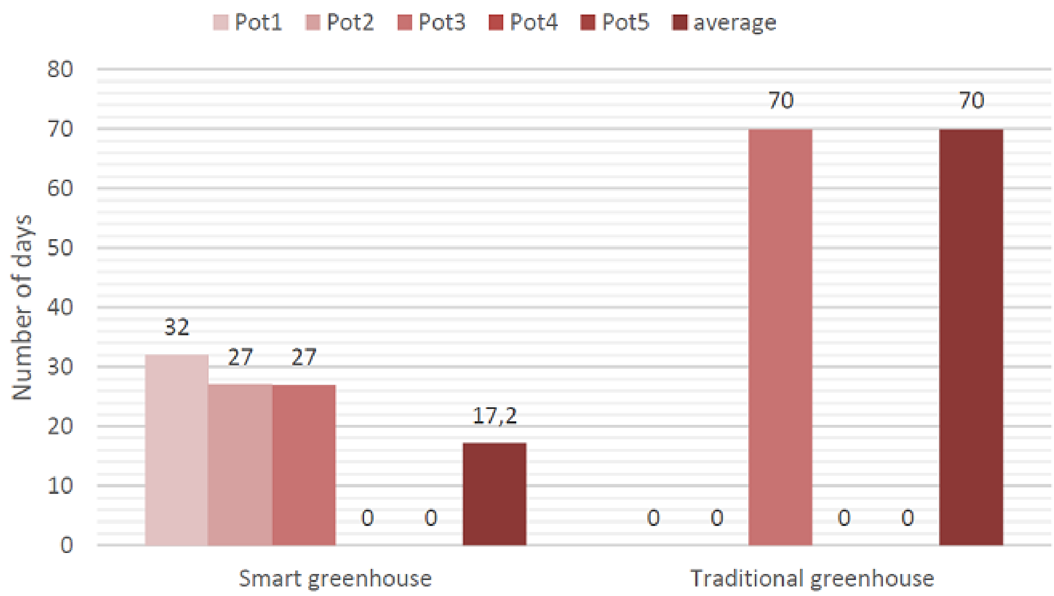

Figure 4.3: Average harvest time of tomatoes for each pot (days)

smart greenhouse. In the traditional greenhouse, the harvest was made 33 days after first tomato occurs. At the traditional greenhouse, tomato growing took longer time compared to smart system greenhouse.

4.1.5 Weight of tomatoes

Figure 4.5 shows the weights of tomatoes harvested in the greenhouse field in grams. The weight of the harvested tomatoes is 31 grams. 2 seedlings, pot1 and pot2, died after the tomato harvesting process. 2.5 liters of pots were used in the greenhouses. 1.5 liters of soil was put into each pot and the seedlings were planted. No fertilizer was given to soil during the experiment. For this reason tomatoes not big and heavy.

4.1.6 Water consumption

Figure 4.6 shows water consumption of greenhouses. Soil which was used for planting, is permeable and has low water holding capacity. With this soil properties, in

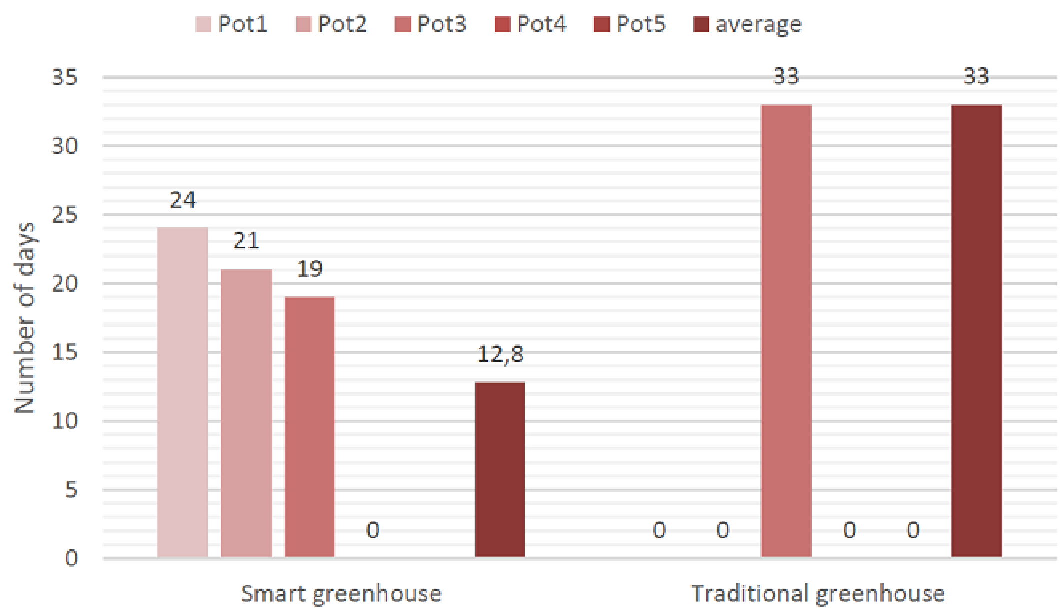

Figure 4.4: Average grow time of tomatoes for each pot (days)

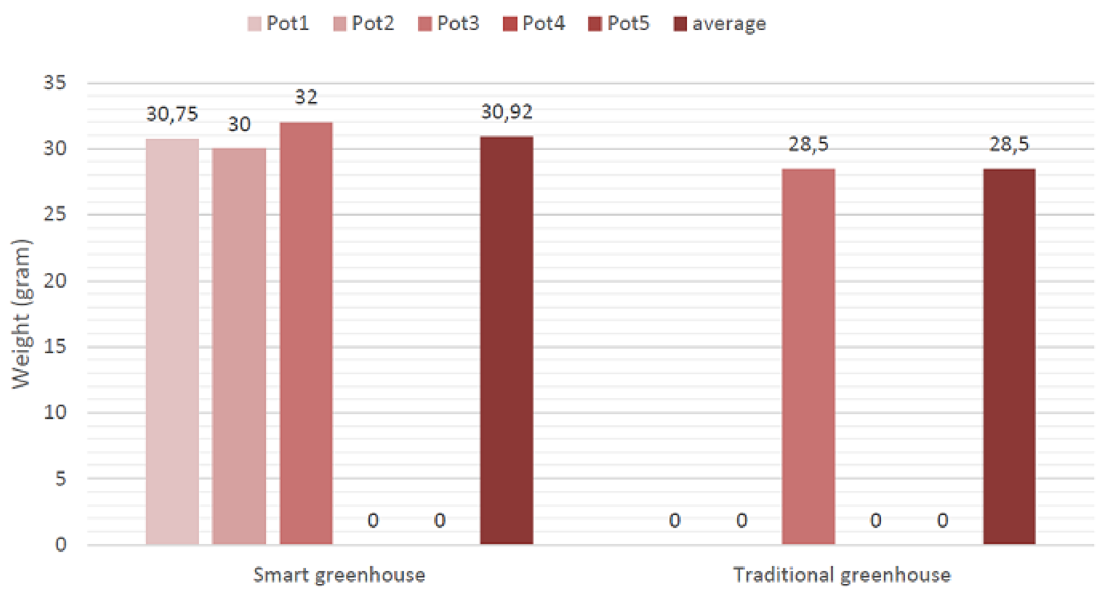

Figure 4.5: Average weight of tomatoes for each pot (gram)

case of over-irrigation, it is aimed that seedling roots are not affected by excess water. Each plant in the greenhouse managed by the traditional method was given an average of 0.5 liters of water per day. In the smart greenhouse, on the first day the system was operated, an average of 0.5 liters of water per pot was used. Therefore, it was decided 0.5 liter per day pot irrigation for the traditional greenhouse, and in the following days the irrigation was done accordingly. The greenhouse managed by smart system is also given according to irrigation soil moisture. The water consumption of the greenhouse managed by the smart system was measured by the amount of water added to the water tank. The greenhouse managed by the smart system consumed less water than the greenhouse managed by the traditional method.

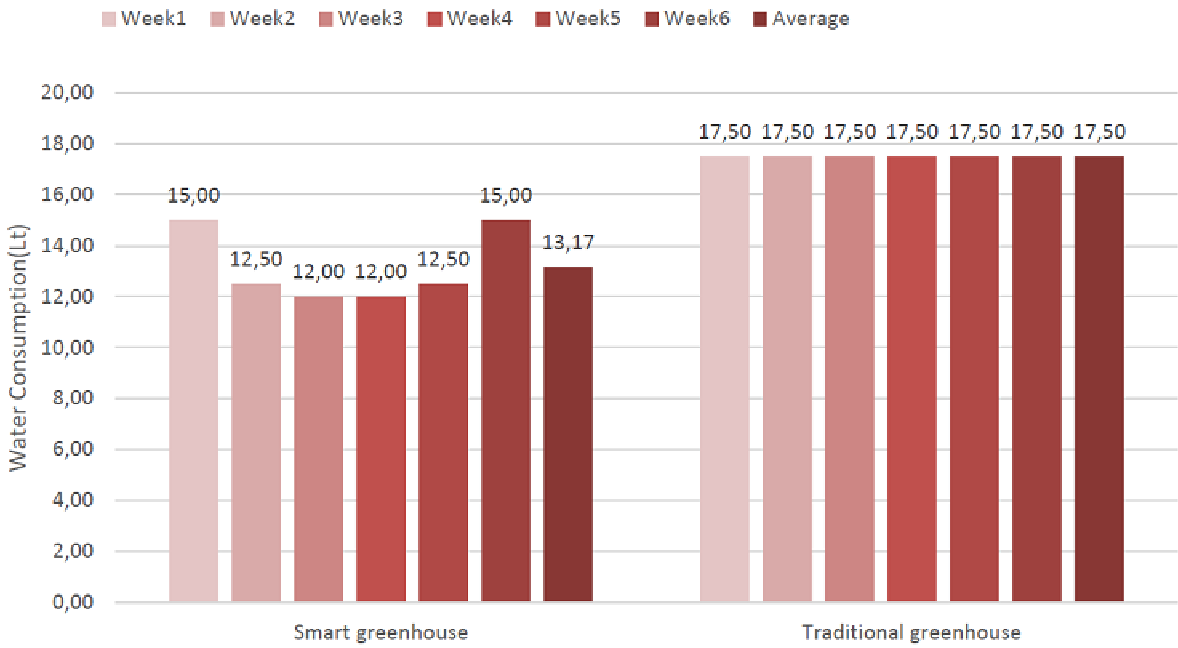

Figure 4.6: Weekly water consumption (Liters)

Compared to both greenhouses in general, in smart system-controlled greenhouse, tomatoes began to grow earlier, tomatoes matured earlier and consumed less amount of water than greenhouse controlled by the traditional method.

4.2 Greenhouse climate and irrigation results

This section contains the results of climatic changes and irrigation in the smart greenhouse during the experiment.

4.2.1 Temperature and humidity change in a day

Figures 4.7 and 4.8 show the change in air temperature and air humidity for the same day. Air temperature and air humidity measurements were taken into account in every 30 minutes. Therefore, the instantaneous changes in air temperature or air humidity, did not affect the fans. Figure 4.6 shows that when the air temperature exceeds 25 ^{o}C, the ventilation is turned on regardless of the air humidity. Ventilation was provided to keep the air level constant regardless of the outside air. When the fan that was opened one day ago and the day-night temperature difference of daytime is 11 ^{o}C, the fan is closed. Day and night difference was found by taking the average of the previous day temperature. Figure 4.7 shows that even if air humidity did not exceed 80%, the fans were working because the air temperature exceeds the threshold value. Fans are already working in the greenhouse environment where 80% of the air humidity is found.

4.2.2 Soil moisture change in a day

In Figure 4.9, the soil moisture changes from after 06:00 and after 17:00 are shown in 2-minute intervals. The irrigation system was set to the morning (06:00) and evening (17:00) hours, which is the best time for irrigation. Between 06:00 and 08:00 and between 17:00 and 19:00, soil moisture measurements were taken into account and irrigation systems were opened. The measurements were made every 2 minutes as the irrigation system was in the capacity to raise the water level of all the pots to the desired value within approximately 2 minutes. The watering system was opened at 06:00 because the average moisture value of the pots was below the threshold value. Within 2 minutes, the soil moisture reached the desired value and the irrigation was closed. After irrigation system turned off, some soil moisture changes were seen in the pots because of water remaining in the irrigation system pipeline.

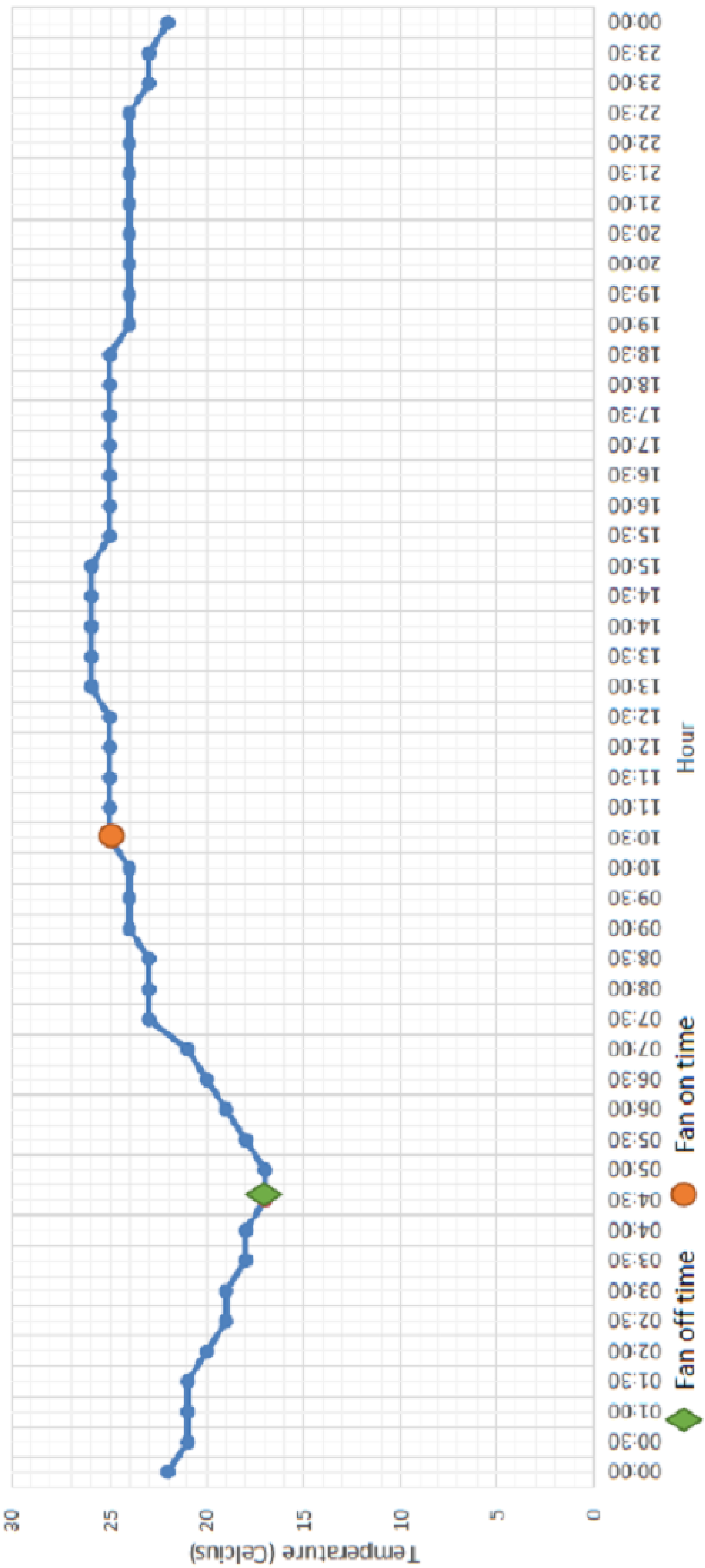

Figure 4.7: Air temperature change on 28.06.2017

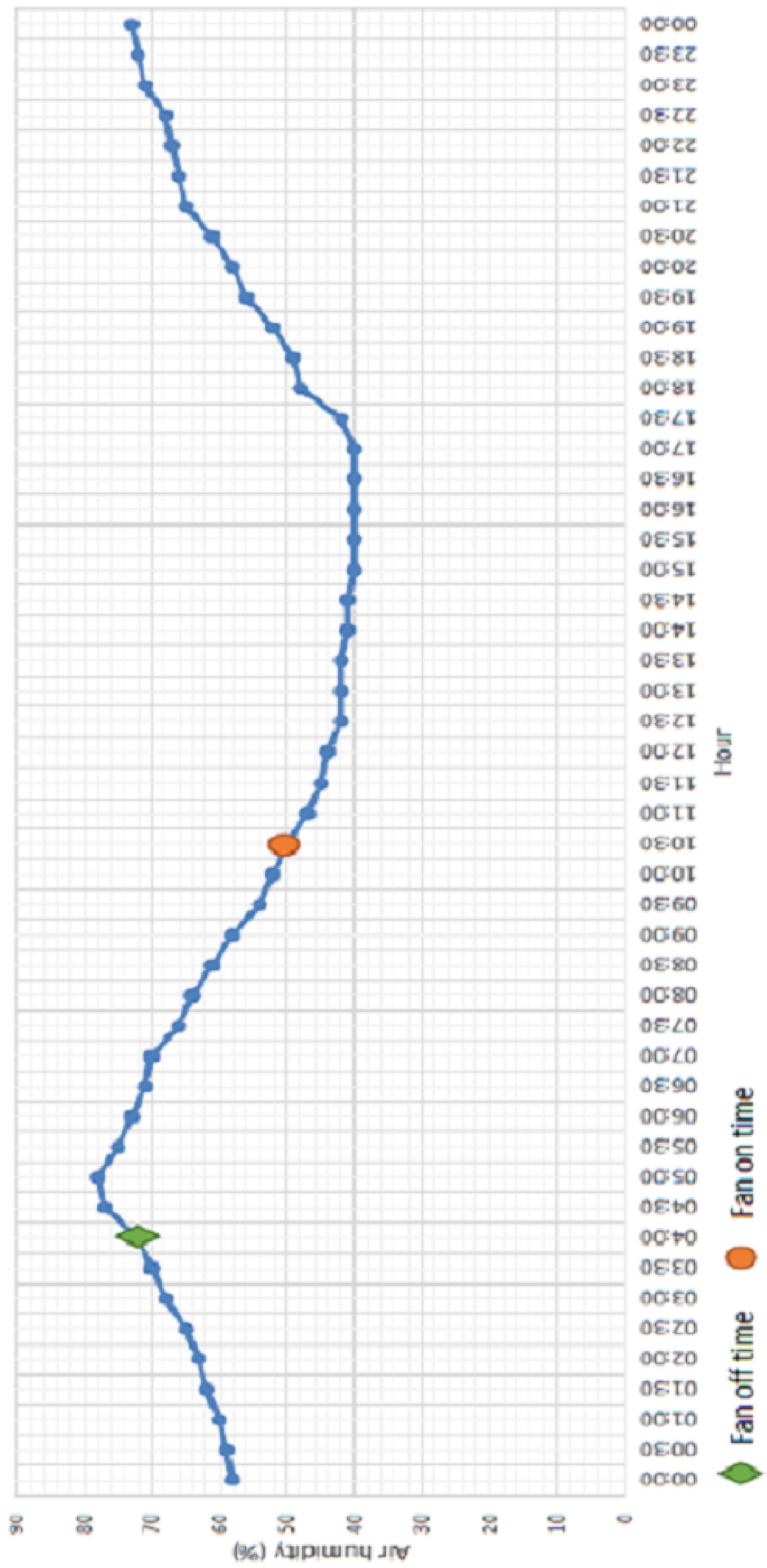

Figure 4.8: Air humidity change for on 28.06.2017

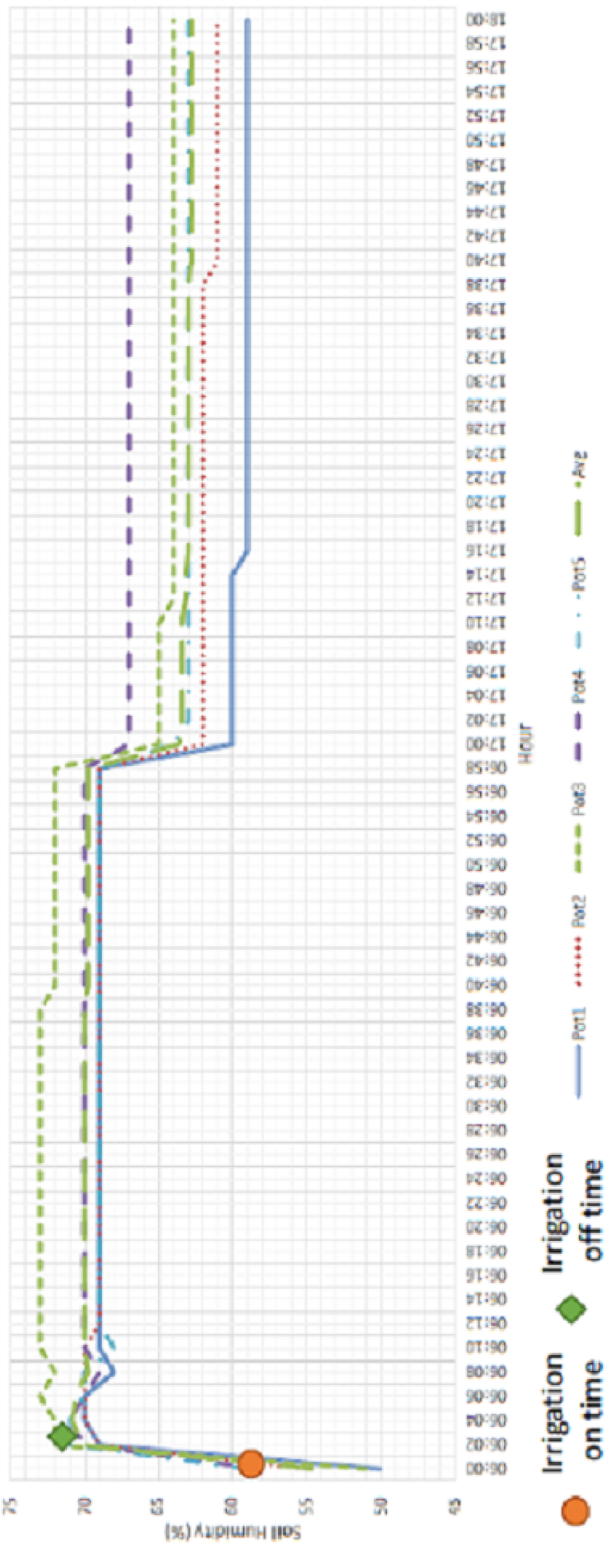

Figure 4.9: Soil moisture change on 28.06.2017

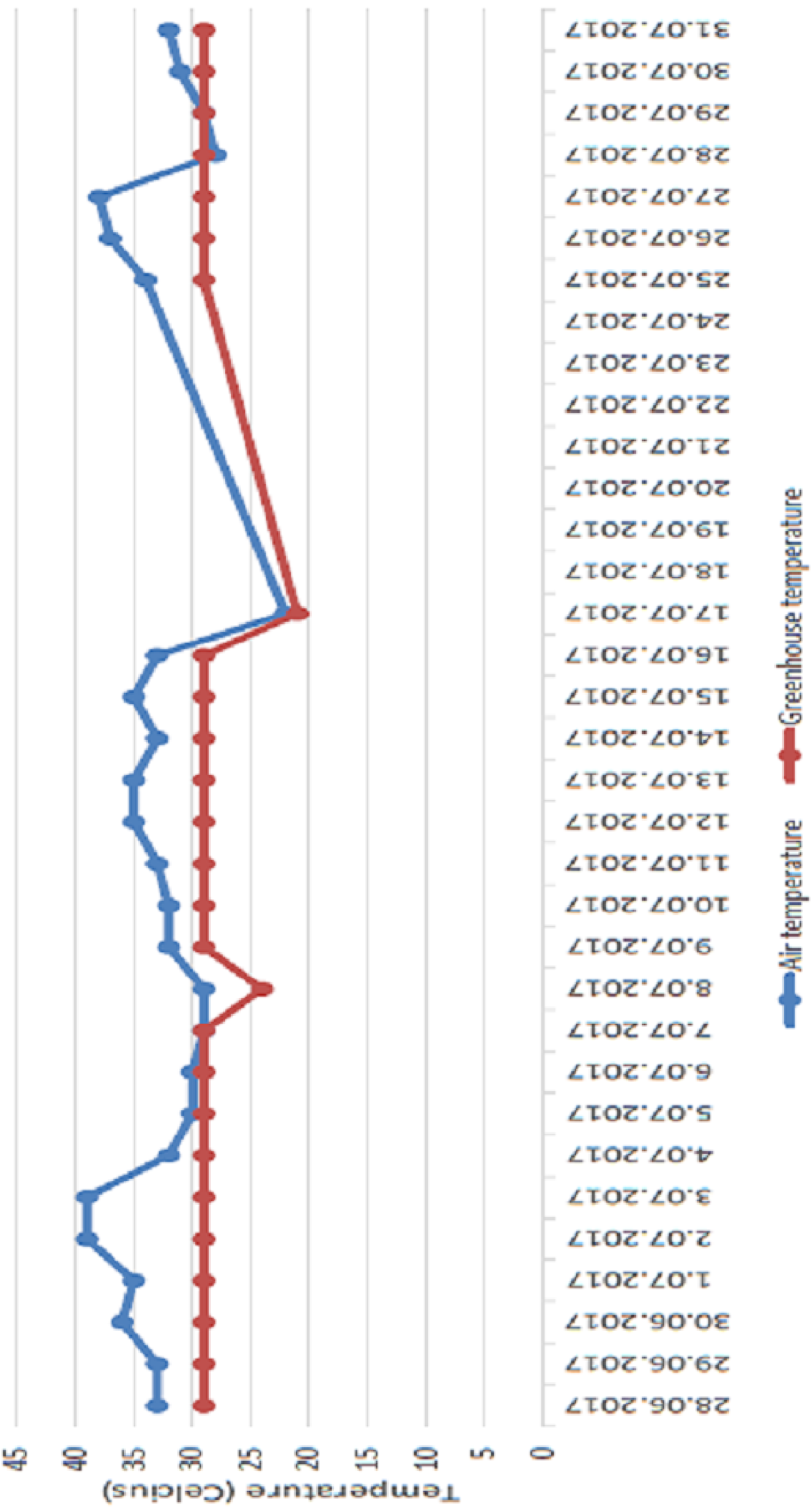

Figure 4.10: Open air and greenhouse temperatures change

4.2.3 Fan operation results during the experiment

Figure 4.10 shows the changes in indoor temperature and outdoor temperature [34]. The increase in outdoor temperature has affected the temperature inside the greenhouse and has risen to 29 ^{o}C, even though the greenhouse temperature fans have been working. The operation of the fans prevented the warmth in the greenhouse from rising further. Also, it reduced the negative effect of hot air on the plants. Figure

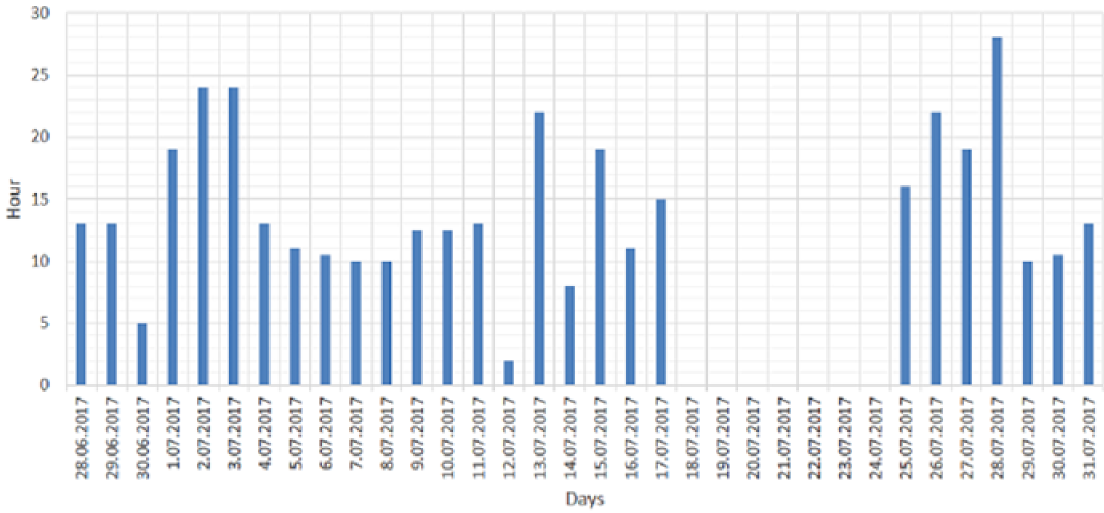

Figure 4.11: Daily fan operating duration (hours)

4.11 shows the daily operating time of the fans. The system did not work due to a fault in the system between 18-24 July. Therefore, no data belonging to these dates are available. Between these dates, both greenhouses were managed manually.

4.2.4 Heater operation results during the experiment

Table 4.1: Heater operating time range on July 17,2017

Heater on time	Heater off time
00:00	09:00
21:00	00:00

Heater only worked on July 17, 2017. Working hours of heater are shown in Table 4.1.

There has not been a significant temperature increase in the greenhouse temperature between the heating hours of the heater. The construction of the greenhouse on the concrete and the placement of the heater on the floor of the greenhouse did not allow the heat generated by the heater to be evaluated in the greenhouse.

4.3 Cost

The installation costs of both greenhouses and the system costs of the smart greenhouse are approximately 770 TL. The distribution of cost can be seen in the Table 4.2. Smart system for the smart greenhouse ventilation, heating and irrigation has been used instead of human power. Human power is needed for traditional greenhouse ventilation and irrigation. During the experiment, no heating was done because the traditional greenhouse nights were not checked. Usage of human power in the greenhouses is shown in the Table 4.3. Table 4.4 shows that comparison of traditional greenhouse and smart greenhouse in terms of tomato growth, smart greenhouse operations and water consumption.

Table 4.2: Greenhouse costs (Turkish Liras)

	Traditional Greenhouse	Smart Greenhouse
Greenhouse installation	225	225
Sensors	0	150
Fan	0	20
Heater	0	30
Irrigation system	0	40
Other circuit devices	0	80

Table 4.3: Human power use in the greenhouses

	Traditional Greenhouse	Smart Greenhouse
Irrigation	Yes	No
Ventilation	Yes	No
Heating	No	No
Pruning	Yes	Yes
Harvest	Yes	Yes

Table 4.4: Traditional greenhouse to smart greenhouse comparison

	Traditional Greenhouse				Smart Greenhouse			
	Min.	Max.	Average	Std.dev.	Min.	Max.	Average	Std.dev.
Number of days until the first tomato seen	0	39	18.63	15.2	6	49	16.17	17.40
Number of days until harvest	0	70	70	-	27	32	2.36	28.67
Number of tomatoes per pot	0	3	1.26	1	1	4	1.02	2.60
Harvested tomato weight per pot	0	57	57	-	30	123	38,42	72,33
Harvested tomato weight	26	31	28.5	2.12	25	37	3.45	30.57
Fan operation time per day	0	0	-	-	2	28	5.97	15.15
Heater operation time per day	0	0	-	-	0	12	-	-
Water consumption weekly (lt)	17.50	17.50	17.50	17.50	12	15	1.31	13.17

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

In the designed smart system application, tomatoes were grown in both greenhouses. Atfirst attempt new sprouts were planted in the greenhouses. Since they were not suitable for greenhouse conditions, they died. After one week, later seedlings which have 4 - 5 real leaves, were planted in the greenhouse. The smart system was not operated until flowers were seen in the tomato seedlings of both greenhouses. After the first flowers were seen on June 27, the smart system was started and started to collect data from the greenhouses. The systems' three parameters (air temperature, air humidity, and soil moisture) have been taken into consideration to ensure the climate conditions of the greenhouse tomatoes managed by the smart system. The water which has a significant effect on the heat exchange in the soil has been used from the tank instead of the source. Therefore, no changes in soil temperature were observed and soil temperature parameter was not used in the smart grennhouse. Since the system was tested insummer, the measurement related to the light was not taken into consideration. Because the amount of daylight by day throughout the system's operating period was more than 9 hours. Greenhouse managed by smart system operated for 2 months 8 days. During this period, the smart greenhouse has managed by the designed smart system, according to the threshold values, entered during the set up phase of system. In the traditional greenhouse, irrigation was made daily with using human power and ventilation of greenhouse was done according to the air temperature was again made using human power. When the smart greenhouse temperature reaches 25 ^{o}C, the fans were turned on to ventilate the greenhouse. The temperature of the greenhouse increased to 29 ^{o}C depending on the increase in the temperature of the air despite the operation of the fans. When the difference between day and night falls below the threshold, the heater worked. However, due to the environment in which the greenhouse is set up, heater operation has not affected the greenhouse temperature. Because the environment where the greenhouse, is installed is concrete, greenhouse elevated 10 cm from the ground with concrete blocks. With this concrete blocks, greenhouses are prevented against the affect of rainwater accumulation. Because of the increase in the amount of heat loss caused by the placement of these concrete blocks, the heater could not increase temperature of the greenhouse. When soil moisture fell below threshold value, the irrigation system turned on. For irrigation, drip irrigation method was used. In both greenhouses, pruning and harvesting were checked weekly and done by using human power.

The first tomato, in the greenhouse managed by the smart system, was seen on average 21 days earlier than the traditional greenhouse. The smart greenhouse more efficient in terms of the number of tomatoes. Average number of tomato per pot was 2.6 in the smart greenhouse while the average number of tomatoes in the traditional greenhouse was one. In the traditional greenhouse, harvest could be done 70 days later after seedlings planted. Irrigation according to the soil moisture done with smart system, consumed an average of 4.33 Lt less water per week than the traditional method.

According to the results described above, when smart greenhouse are compared to traditional greenhouse, smart greenhouse tomatoes have already been seen and matured and the number of tomatoes is more. The high number of tomatoes and the rapid growth of tomatoes indicate that the smart system is suitable for increasing productivity from design goals. Since human power for air conditioning and irrigation is not used in smart system, human errors has been prevented human power cost has been reduced. The control of the devices used for conditioning in the smart system with relays has made the selection of the device to be used for climating independent. Thus, the smart system, designed with the choice of devices, has been adapted to hobby greenhouses and commercial greenhouses. The smart system's use of water according to the soil moisture prevented both the plant from being damaged by overirrigation and also prevents the overuse of water. As a future work, the application of the system can be developed and targeted to grow more than one type of plant in the same greenhouse.

5.2 Future Work

As future work, more than one vegetable can be grown in the same greenhouse. By increasing the number of greenhouses, only one parameter in the greenhouse can be changed and the effect on the product of the measured parameter can be investigated. The effects of plant operation on the peripherals according to the average measurements within the predetermined time periods, rather than the instantaneous measured parameters, can be investigated. The effects of fertilizer and the amount of soil in pots, on the plants and products can be investigated. It would be better to measure the parameters of the traditional greenhouse in terms of evaluating the results. In addition, the open-air temperature and the open-air humidity had to be measured with sensors in order to evaluate the change of temperature of smart greenhouse.

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