TALLINN UNIVERSITY OF TECHNOLOGY
School of Information Technologies

Iurii Zvieriev a156392

CLIMATE CONTROL IN GREENHOUSES USING ALTERNATIVE ENERGY SOURCES

Master's thesis

Supervisor: Eduard Petlenkov
Associate Professor

Tallinn 2017

TALLINNA TEHNIKAÜLIKOOL
Infotehnoloogia teaduskond

Iurii Zvieriev a156392

KASVUHOONE KLIIMA JUHTIMINE KASUTADES ALTERNATIIVSEID ENERGIA ALLIKAID

Magistritöö

Juhendaja: Eduard Petlenkov
dotsent

Tallinn 2017

Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

Author: Iurii Zvieriev

15.05.2017

Abstract

The Master's thesis is focused on the energy savings and improvement of the automatic control of heating greenhouses using alternative energy sources in Ukraine with perspectives of implementing this technology in Estonia. It is proposed to develop a hybrid system using solar collectors to heat water for heating greenhouses and solar panels that produce electricity (lightning) for the industrial greenhouse technology area of 2592 m^2. The calculations were conducted on the feasibility of using alternative energy. In the software environment MATLAB Simulink and Mathcad, the simulation models show the heating system particularities of greenhouses when using solar collectors. Following functional, functional-structural and structural-algorithmic diagrams for temperature control automatic system in greenhouses are presented. The technical implementation of the proposed system is done in the last part of the thesis. This thesis is written in English and is 81 pages long, including 5 chapters, 59 figures and 7 tables.

Annotatsioon

Kasvuhoone kliima juhtimine kasutades alternatiivseid energia allikaid

Antud magistritöö põhineb energiasäästmisele ning alternatiivsete energiallikate arendamisele kasvuhoone temperatuuri kontolliks. Antud perspektiiv on seni olnud kasutuses Ukrainas ja lõputöö üheks eesmärgiks on tehnoloogia rakendamine Eestisse. Autor teeb ettepaneku arendada hübriid süsteemi kasutades selleks päikesepaneele, et soojendada vett, millega omakorda saab kütta kasvuhoonet ning päikese paneele, mis toodavad elektrit (valgust). Arvutustes on tehtud teostatavuse kohta kasutades alternatiivset energiat. Tarkvara keskkonnas Matlab Simulnik ja Mathcad koostatud simulatsiooni mudelid näitavad kasvuhoone kütte süsteemi eripärasid kui kasutatud on päikese kollektoreid. Järgnevad funktsionaalsed, funktsionaal-struktuurilised ja struktuurilised-algoritmi diagrammid, mis toovad välja automaat temperatuuri süsteemi, mida antud hetkel kasvuhoones kasutati. Tehniline teostus antud süsteemist on välja toodud magistritöö viimases osas.

Lõputöö on kirjutatud inglise keeles ning sisaldab 81 lehekülge, 5 peatükki, 59 joonist, 7 tabelit.

List of abbreviations and terms

RES	Renewable Energy Source
EBRD	European Bank for Reconstruction and Development
UKEEP	Ukrainian Energy Efficiency Program
HPP	Hydroelectric Power Plant
LED	Light-emitting diode
MATLAB	Matrix Laboratory
ACS	Automated Microclimate Control System
JSC	Joint-Stock Company
CPU	Central Processing Unit

Table of contents

List of figures

List of tables

1 Introduction

Currently, agriculture important for any country in the whole world the energy saving is the priority question. For Ukraine as well as for Estonia it is the most urgent one, which puts on the brink of survival of different industries.

In Ukraine, alternative energy sources have a high potential but little use.

Currently there are areas of alternative energy:

- wind power;
- hydropower;
- solar energy;
- geothermal energy;
- bioenergy.

Using alternative energy for greenhouse sector needs to reduce the cost of traditional fuels (natural gas) and increase profits.

In greenhouses, the most attention is focused on maintaining the microclimate, which is realized by means of the automatic control system that allows you to maintain an optimum level for the following parameters: temperature and humidity inside air temperature of the substrate temperature of irrigation water, light, CO2 concentration in the air.

2 Perspectives of using alternative energy sources in greenhouse production

2.1 Analysis of alternative energy sources using in Estonia, Ukraine and worldwide

Alternative energy sources are renewable energy source (RES), which include solar, wind, geothermal, hydropower, biomass, gas from organic waste, gas from sewage treatment plants, biogas, and secondary energy resources, which include blast furnace and coke gases, degassing of methane gas from coal deposits and converting waste energy potential for technological processes [16].

Dynamics of electricity production in Ukraine from RES for the period from 2012 to October 2016 is shown in Figure 1.

Figure 1. Production of electricity from renewable energy sources (2012-2016, 1000KWh) [14].

The global trend to shift towards renewable energy is confirmed by the following statistics. In 2007, investments in renewable energy worldwide totalled more than 100 billion US dollars, while the global amount of electricity generated from renewable sources, according to the experts reached a level of 240 GW. [16]

The International Energy Agency believes that in 2030, worldwide energy derived from the sun, wind, water, earth heat and biomass, will increase twice compared to the present day and will be 16% of total electricity production. The development and use of renewable energy (wind and solar energy, biofuels, etc.) is an important factor in strengthening energy security and reducing the negative anthropogenic impact on the environment [16].

The European Union, and Estonia as a member, have prioritized an increase in the share of renewable energy in production and consumption for several reasons. The most important of these is achieving a reduction in environmental pollution, and policies to cut greenhouse gas emissions are a part of this. There are also other important considerations with which higher production and consumption of renewable energy can help, such as energy saving, more efficient production and consumption, energy security, innovation in power engineering, and the promotion of technological development.

The potential for renewable energy in Estonia is strongest in wind power and bioenergy-based combined heat and power generation, and also in small-scale hydro-power [1].

Renewable energy is not an end in itself – it must be viewed in the context of the strategic choices of Estonia's electricity generation industry. The development plan for the Estonian electricity sector outlines the following conditions for electricity generation:

- The need to reduce environmental emissions from power generation;
- The obligation taken when Estonia joined the EU to cut CO emissions from the power plants in Narva in 2012 and 2016;
- The need for more sustainable use of oil shale reserves;
- The aim of making Estonian electricity prices more competitive through carbon emissions trading.

The potential for renewable energy in Estonia is the strongest in wind power and bioenergy-based combined heat and power generation, and also in small-scale hydro-power. For instance company "Elering" is an independent electricity and gas transmission system operator with main task to ensure high-quality energy supply to Estonian consumers. For that Elering manages, maintains and develops the internal and cross border energy infrastructure. Elering ensures conditions for efficient energy market operations and economic development.

The development of alternative energy in Ukraine with their energy source has a great potential which is not used in full amount. The reason is the low level of legal and institutional framework that is not committed to the implementation of many potential projects undertaken in this area.

European Bank for Reconstruction and Development (EBRD) has launched the Ukrainian energy efficiency program (UKEEP). UKEEP is credit facility developed by the European Bank for Reconstruction and Development (EBRD), targeting Ukrainian private companies in all sectors of private property (51%) to make investments to improve the use or creation of alternative energy, the result of which should be a reduction in consumption energy, increasing their production and efficient.

The main areas of alternative energy are:

- wind power;
- hydropower;
- solar energy;
- geothermal energy;
- bioenergy (biofuels).

Hydropower is a type of renewable energy, specializing in the use of energy from water flow. The power plant, which through turbine converts the kinetic energy of water into electricity is called hydroelectric power plant (HPP) (Figure 2).

Figure 2. Hydroelectric power plant.

In Estonia the biggest power plants are: The Narva Hydroelectric Station, Linnamäe hydro-electric power station, etc. In Ukraine there are Kiev, Kanev, Kremenchug, Dneprodzerzhinsk, Dnieper (Zaporizhia) and Kakhovskaya hydroelectric power stations.

Wind energy. Wind has served mankind for thousands of years, providing energy for sailing ships for grinding grain and pumping water. [16]

At this time the wind is used to generate electricity using wind energy or wind turbine unit (Figure 3), which are produced not only in the United States and of Denmark, but also the UK, Canada, Japan and some other countries.

Figure 3. Wind generators.

The largest wind turbines are designed to operate at wind speeds 17-58 kilometers per hour. Wind with a speed less than 17 kilometers per hour gives little useful energy, and at speeds over 58 kilometers per hour, there is a possibility of engine damage.

According to Global wind energy council, to generate energy from wind, the 40% of the territory of Ukraine is suitable for this. Currently, in Ukraine are about 151 MW of wind power is in operation. In the medium-term prospects can develop the capacity to about 5,000 MW of wind energy, which 20-30% of the total electricity consumption in the country.

Solar power. Today one of the most prominent places in alternative energy covers solar power. Using solar energy helps to increase the part of renewable energy to meet the energy needs of the world [16].

More than 100 countries introduced energy programs that require network operators to buy electricity, which produce alternative energy. But for the research of solar energy potential and for the most effective usage of solar energy technologies, there is a need to involve energy industry professionals.

Geothermal energy is a direction of alternative energy, which includes production of energy from hot springs and thermal groundwater. The main source of energy is a constant flow of heat from the heated mineral resources directed to the ground. The crust gets heat through friction cores, chemical reactions, and radioactive decay of elements.

For obtaining electricity from the above mentioned energy sources, geothermal power plant is used (Figure 4).

Figure 4. Geothermal power plant.

Geothermal energy is widely used for heat and power generation in the following countries: Hungary, Iceland, Italy, Mexico, New Zealand, Russia, the USA and Japan. In Iceland, geothermal energy is provided through more than a quarter of electricity generation [7].

In 2008 the largest capacity in the world of geothermal electricity generating plants was achieved in about 11 million kW of output of 55 billion kWh [7].

Bioenergy is the energy, based on the use of biofuels produced from biomass.

Biomass is the renewable biological substance of organic origin, undergoing biological decomposition (agricultural waste of plants and animals, forestry and technology-related industries), as well as an organic part of industrial and household waste.

2.2 An overview of advanced technologies for greenhouses

Greenhouse production has an important role in providing people with fresh vegetables in the off-season (Figure 5).

Figure 5. Industrial greenhouse

With the increasing of the cost for traditional energy, the importance of energy saving increases as well. Thus in the cold seasons, greenhouse complex should be provided with the necessary amount of heat energy and optimal conditions for growing vegetables.

To save energy for heating greenhouses it is important to improve the heating system through the use of alternative energy sources. Therefore, this master thesis project uses a hybrid system consisting of solar collectors for heating and solar panels for lighting.

Greenhouses are meant for growing tomatoes, cucumbers, paprika, grapes, flowers, lemons, strawberries etc. In modern greenhouses, the harvest amount of cucumbers is 36-40 kg per 1 m^2, tomatoes - 55-60 kg per 1 m^2, but that amount changes depending on the culture and plant varieties.

Greenhouse is a set of steel constructions. Body is made of lightweight steel. The thickness of the zinc coating is 80 micron. Walls are made of a sheet of window glass of 4 mm thick, connected with aluminium ropes. The base of greenhouse is made from concrete plates to a depth of 55 cm. The cap is made from mix of iron and concrete.

Modern greenhouses have controlled and adjust almost all of the parameters that determine the intensive growing of plants. Using high-performance technology makes possible to get stable crops throughout the year. Thus, the automation of processes in greenhouses is a very important part and it is partially illustrated in this master thesis.

The main functions of the viability of the plants in the greenhouse are executed by means of automation:

- temperature and substrate control;
- control of irrigation (incl. temperature of irrigation water);
- humidity and light conditions control;
- CO2 dosage.

Modern greenhouses have controlled a wide range of microclimate processes: heating, ventilation, curtaining, lighting system, fog-forming equipment, etc. With the climate control equipment (PCs, workstations, etc.) all values are controlled and adjust from one place and it is important to know how it works.

Current requirements for growing vegetables in the protected ground is closely related to material costs and more economical care of plants with guaranteed high quality and quantity of production. Currently, these requirements are met by Dutch technology.

The representative of the Dutch technology is company by name Hoogendoorn, which offers reliable and convenient solution for automation process control in greenhouses worldwide. The company also supplies all the necessary materials for industrial greenhouses, namely heating systems, shielding systems curtain systems lightning, irrigation systems, fog irrigation systems of low and high pressure, fertilizers, automation means, climate control equipment for sorting, packing, care for plants, internal transport and many other components and materials used in greenhouses.

Usage of the above mentioned technology provides an innovative and advanced process control systems in the greenhouse. A distinctive feature of the Dutch technology is the possibility of growing crops in all tanks, containers, plastic bags, etc.

Drip irrigation is a system in which irrigation water is pumped in straight portions into plant roots using droppers for dosing water. That is the most effective and advanced system of water saturation in terms of supplying water plants (Figure 6).

Figure 6. Drip irrigation system.

This type of system of targeted feeding water to the root system combined in single infrastructure processes of irrigation and fertilizing.

The method allows growing in those areas where every litre of water is very important.

Fog irrigation system (high pressure) is the innovative system, which can change the microclimate of premises with thermodynamics of water (Figure 7).

Figure 7. Fog irrigation system

The principle of work is to increase the water pressure to tens of atmospheres, due to the high pressure water turns into fine droplets and sprayed from the hole in the form of fog. Due to fog the humidity increases but the temperature decreases (in hot weather is especially important).

The system consists of a high pressure pump (90 bar) sputtered sprayers, metal or nylon conduit, program controller and filtration system.

Curtaining system is used to achieve the most optimal climatic conditions and energy savings (Figure 8).

Figure 8. Curtaining system.

Curtaining provides lower solar radiation, humidity control, reducing heat loss in cold period.

The heating system consists of heating supply networks, heat sources inside and outside the greenhouse complex. The non-regular heating system can be implemented by solar panels and collectors (Figure 9).

Figure 9. Solar collectors.

The usage of solar panels is currently a promising direction, as the cost of it is constantly decreased. The solar energy that uses the collector is completely free, environmentally friendly and able to heat almost any greenhouse.

Efficiency is achieved by using collectors in the production of special insulation materials and high-quality sealing elements of the system, thus creating a complete vacuum. This can warm a greenhouse in the worst weather conditions up to -25 ° C. This temperature range allows growing vegetables whole year and having high amount of crops.

The base ingredient of modern solar coolant is antifreeze.

Antifreeze based heat carriers are considered environmentally friendly and able to be terminated themselves biologically. Another important feature is a mixture of antifreeze and water which does not freeze at negative temperatures. Roof-mounted solar systems should not lose efficiency even in winter -30 ° C.

Electric lighting of plants is one of the most important systems engineering and technological systems in the greenhouse (Figure 10).

Figure 10. Electric lighting in greenhouses

With the help of this lightning, the amount of crops and theirs weights can be increased. Lighting control is done automatically by the central climate computer which allows adjusting technical parameters, time of day and solar radiation outdoors.

The main equipment used for lighting is sodium lamps with an output of 600 ... 1000 W with integrated or remote ballast (Figure 11).

Figure 11. Sodium lamps

Those lamps are placed in a greenhouse with all the design parameters: the height of the plant, span width, height of mounted trays, etc. The level of artificial lighting ranges from 6000 to 24000 lux and is determined depending on the type of plant growing technologies and features of crops. In the central areas of greenhouse, the lighting can be set timely, and in the nights the lighting – by perimeter outside of the greenhouse.

During lightning, the monochromatic light field is created, which has a light yellow-orange colour. That lamp perfectly simulates natural sunlight.

LED lamps are expensive, but consume electricity efficiently (Figure 12).

Figure 12. LED lamps.

These lamps are able to produce blue or red light, or even combine the light.

In this thesis, as an additional source of electricity for lighting purposes, solar panels are used (Figure 13).

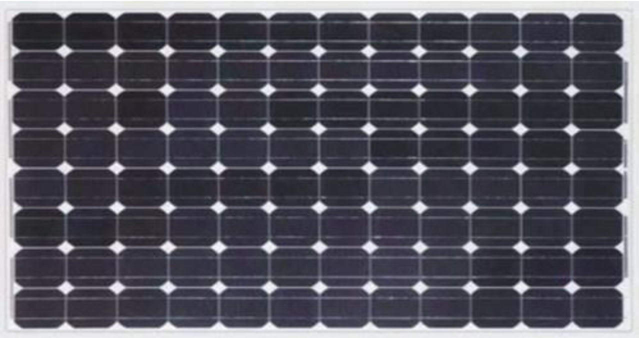


Figure 13. Solar panels

Setting the proper lighting for greenhouse complex is the key to success in achieving good crops.

In modern greenhouses must be a ventilation system (transoms) (Figure 14).

Figure 14. Ventilation system (transoms).

This ventilation system provides natural ventilation of greenhouses and corridors with outside air through the vents, which are on top of the roof or the fence.

Automated microclimate control system (ACS) is meant to control all parameters of microclimate in greenhouses automatically (Figure 15).

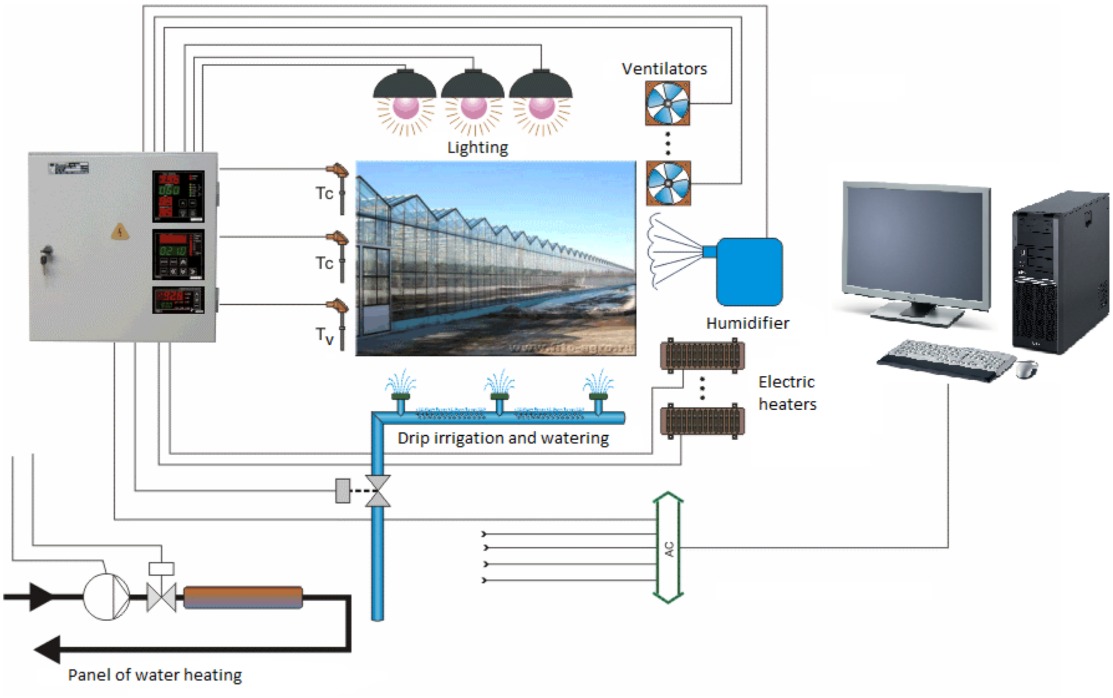


Figure 15. Automated control system of microclimate.

ACS of microclimate provides high accuracy of maintaining pre-set climatic regimes separately for different blocks of industrial greenhouse through using appropriate equipment, technological systems and processes. The system also provides the ability to measure the power consumption of each branch, performing various agronomic calculations.

The complex of ACS means includes: a central control unit, microprocessor controllers, sensors for various parameters, analogue measurement channels and discrete channels of control.

Air recirculation system in greenhouse includes a ventilator for air recirculation (Figure 16), and is designed for an artificial stirring of temperature even distribution, reducing overheating of plants, increasing physiological processes in plants, the elimination of zones with high humidity especially during periods when natural ventilation is not possible or ineffective.

Figure 16. Ventilator for air recirculation.

The air recirculation system is using special greenhouse ventilators (fans) for optimal air distribution and for normalizing the microclimate conditions and creation of an active climate that helps with growing of plants. Ventilators are delivered complete with 6-speed variability control and power cables.

Modern greenhouses use the water supply and sanitation. This system includes the following systems engineering equipment: drinking water supply system, drip irrigation (or more) backup system with hoses and evaporative cooling system, internal drainage system of technological drainage and industrial sewage.

Advantages of Dutch technology in greenhouses production are in using metal aluminium and glass constructions. The essence of using metal ones is in the selection of the optimum ratio of steel thickness structure and the amount of light in the greenhouse. The standard among Dutch agronomists is: 1% of the light equal to the 1% of crops. [15]. The system of aluminium structures is recognized as the most advanced in the world, due to the experience of large investments in new developments, continuous feedback from customers, large quantities of supplies (hundreds of hectares per year only in the Netherlands), stringent standards certification in the EU. As a result of greenhouses consolidation, aluminium gutter for drainage and collection of rainwater with special seals for glass and integrated drain condensate became irreplaceable. Aluminium system is enhanced at the top of the ridge. This development provides additional protection from the destructive force winds [15]. Benefits of glass constructions "float" which are used in greenhouses, is that this glass is manufactured by fundamentally new technology by filling in forms and it provides at least 90% light saturation (crops growing amount increasing) in the admission rate of +/- 1 mm (i.e. ease of installation, isolation and durability). [15]

2.3 Goal of the master thesis

The goal of this thesis is to improve control systems in greenhouses, and saving of energy by using alternative energy sources as a solar collectors for heating and solar panels that generate electricity for lighting and improve the optimal conditions for plant growing and to increased profit from its sale.

To achieve the those aims, the following problems are to be solved:

- System analysis of the greenhouse and the control system.
- Analysis of the dynamic characteristics of the greenhouse complex.
- Selection the mechanism of climate control system in the greenhouse.
- Plotting the functional diagram of temperature control in greenhouse

3 Technological part

3.1 Analysis of the technological object

The range of greenhouses, used in Estonia, is divided into amateur (home usage) and industrial. The biggest companies in Estonia from where you can order a greenhouse are: Heikkinen OÜ; Rentatex; Kasvuhoonemeister, ECO, etc.

For instance, greenhouses Ecoslider by Heikkinen OÜ originally designed for usage in cold countries with snowy winters (Scandinavia, Finland, Baltic countries). The construction of greenhouses is very strong and designed for high snow and wind loads, which is due to the presence of reinforced farms, their large number and close location to each other (67cm) [2].

The most common types of greenhouses in Estonia are as follows:

1)Type: STANDARD

Polycarbonate cover - 4mm; wood (150mmX50mm)

2)Type: Premium

Polycarbonate cover - 6mm; metal

3)Type: Exclusive

Polycarbonate cover - 8mm; metal, antidust etc.

In this thesis, the object of research is the Dutch greenhouse complex, by technology of the fourth-generation type Venlo, in the Research Center greenhouse technology area of 2592 m^2 at the JSC “TEPLICHNIY, KOMBINAT”, Kiev’s region, Ukraine (Figure 17).

Figure 17. Research and Practical Center of greenhouse technology.

In greenhouses type Venlo, the frames are made of galvanized steel (Figure 18). [17]

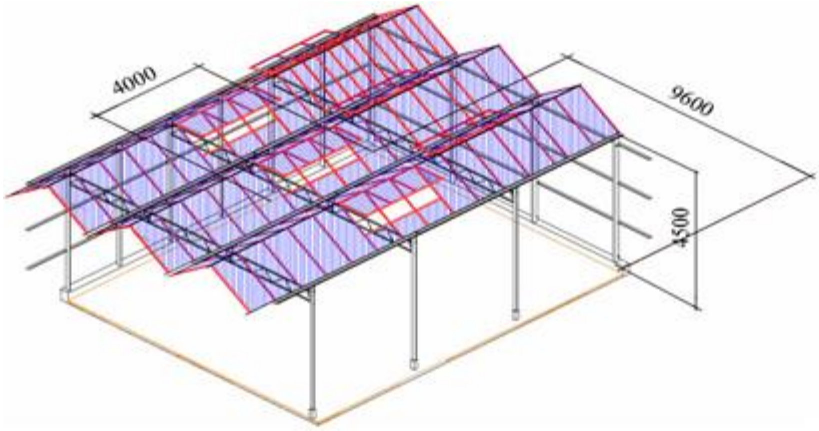


Figure 18. Example of the industrial greenhouses Venlo.

The metal construction cover is made of the hot dip galvanizing cover with a thickness of 200 microns [17].

Advantages of Venlo type greenhouses:

- design with maximum light transmission;
- aluminium gutters;
- modern energy-saving equipment;
- construction in according to European standards;
- capable for different climatic zones;
- effective and reliable ventilation system;
- innovative energy saving design of the greenhouse roof.

Steel structures are protected against corrosion by hot dip galvanizing coatings with a thickness of 200 microns. The outer envelope of greenhouse is translucent. Side protections implemented by filling an aluminum frame double glass with 4 mm thick. Construction is set on concrete foundation. Base is a monolithic reinforced concrete or precast reinforced concrete raft. The height of the metal structures of columns from the base to the tray can be from 4.5 m and more [17]. Figure 19 presents a plan of the research greenhouse complex.

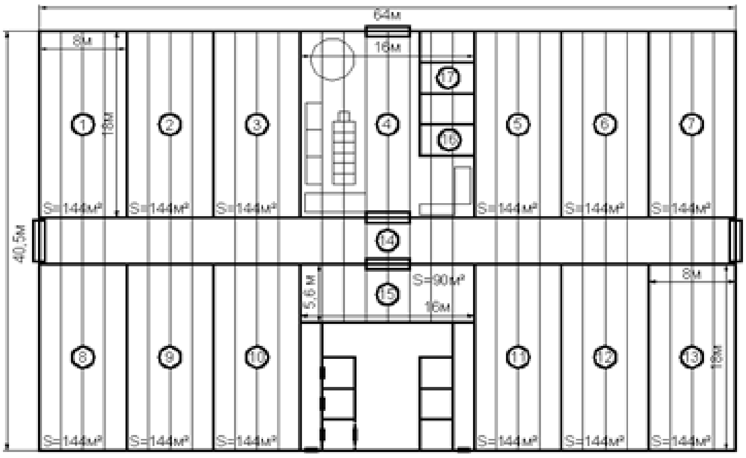


Figure 19. Plan scheme of the greenhouse complex area of 2592 m^2.

Technical parameters of the greenhouse complex are shown in Table 1.

Table 1. Parameters of the greenhouse complex

The total area of the complex	2592,00 m²
Length	64 m
Width	40,50 m
The height of the gables	4,5 m
The height of the groove	4,8 m from the ground (the ground level) to the bottom of the groove
The slope of the roof	23°
Size of glass	2140 x 1125 mm

The microclimate computer by company Hoogendoorn is used in the greenhouse, which is a computer-processor (Figure 20).

Figure 20. The microclimate computer by Hoogendoorn.

The computer controls the following processes: temperature, light, humidity, air circulation and CO^2.

To manage the process of microcomputer performs three tasks:

- measurement;
- calculation;
- control.

Microclimate computer consists of the different components that can be divided into hardware and software.

Hardware consists of visible parts: keyboard, printer, monitor, CPU, etc.

The software contains all the information stored in the computer: control program measurements, settings, etc. (Figure 21).

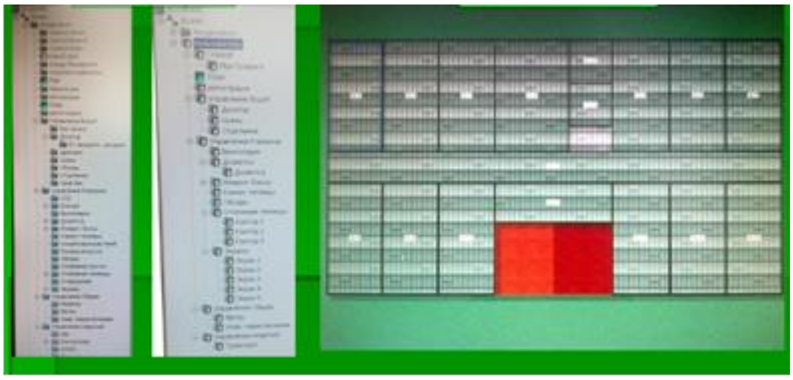


Figure 21. GUI of greenhouse software.

For plants lighting lamp brand GAN 6-750 AL Superagro is used (Figure 22).

Figure 22. Lamp

In the greenhouse, electrical control panel is shown on Figure 23 (a) and distribution panel on Figure 23 (b).

Figure 23. Electrical panels: a) control panel section; b) the distribution board.

Greenhouse has a modern system of irrigation by Dutch Technology (Figure 24).

Figure 24. The control system of irrigation.

Automated irrigation system allows to create an optimal climate for plant nutrition during their growing.

The Dutch modern heating system is used in the greenhouse (Figure 25).

Figure 25. Units of heating system.

The heating system is done by Tihelman method by which creates the same temperature at different points in the greenhouse.

3.2 Calculus of energy consumption for climate control in greenhouses

The temperature is the most significant factor influencing the level of energy consumption.

To predict the energy consumption for heating greenhouses in Estonia, here in this thesis, was applied the methodological approach which is used in JSC “TEPLICHNIY, KOMBINAT”, which was formed by results of long-term observations in the mentioned above greenhouse complex. There was set a linear dependence of energy consumption for heating greenhouses with the different constructions depending on the average temperature in their location. Hence the total consumption of energy for heating greenhouses (Y) can be determined by the formula (1):

$$Y = N \cdot S \cdot (t_1 \cdot (C_1 - k_1 \cdot X_1) + t_2 \cdot (C_2 - k_2 \cdot X_2) \qquad (1)$$

where: Y - energy consumption for heating of the greenhouses, Gcal / m^2; N - the period when natural gas was used, days; S - greenhouse area, m^2; t_1, t_2 - the time of heating during the day/night respectfully, h; C1, C2 - free variables of the equation of regression, according to the method [3] for the modern "Dutch" greenhouses are following - C_1 = 51,58; C2 = 52,75; k_1, k_2 – constants of the equation of regression, according to the method [3] are: k_1=0,91; k_2=1,93; X_1, X_2– temperature during the day and night, ºC.

According to the formula (2.1) the consumption of energy for heating in the coldest day of the year (January 3, 2016):

$$Y = 1 \cdot 2592 \cdot (12 \cdot (51.58 - 0.91 \cdot (-16)) + 12 \cdot (52.75 - 1.93 \cdot (-19)) = 4.8 Gcal = 558 \text{ kW}$$

Estimated consumption of energy for heating in coldest month (January) are presented in Table 2.

Table 2. Consumption of energy for heating in January

Day of month	Energy consumption (Y)*					
	Day		Night		Energy consumption (Y) Gcal	Energy consumption (Y) kW
	Avg. temperature X	Energy consumption (Y) Gcal	Avg. temperature X	Energy consumption (Y) Gcal		
1	-10	1,9	-14	2,5	4,4	512
2	-15	2	-18	2,8	4,8	558
3	-16	2,1	-19	2,7	4,8	558
4	-15	2	-20	2,9	4,9	570
5	-11	1,9	-13	2,4	4,3	500
6	-8	1,8	-11	2,3	4,1	477
7	-5	1,7	-7	2,1	3,8	442
8	-5	1,8	-5	1,9	3,7	430,3
9	0	1,6	-6	2	3,6	419
10	0	1,6	0	1,6	3,2	372
11	-3	1,7	-2	1,7	3,4	395,4
12	3	1,5	-2	1,8	3,3	384
13	0	1,6	3	1,5	3,1	360,5
14	-1	1,6	1	1,6	3,2	372
15	0	1,6	-3	1,8	3,4	395,4
16	1	1,6	-1	1,7	3,3	384
17	-8	1,8	-6	2	3,8	442
18	-8	1,8	-9	2,2	4	465
19	-5	1,7	-7	2,1	3,8	442
20	-7	1,8	-7	2,1	3,9	453,6
21	-7	1,8	-11	2,3	4,1	477
22	-9	1,9	-7	2	3,9	453,6
23	-9	1,9	-10	2,2	4,1	477
24	-12	1,9	-14	2,5	4,4	512
25	-5	1,7	-16	2,6	4,3	500
26	-5	1,7	-6	2	3,7	430,3
27	2	1,5	-2	1,6	3,3	384
28	4	1,5	2	1,5	3	349
29	3	1,5	4	1,4	2,9	337,3
30	5	1,5	0	1,6	3,1	360,5
31	2	1,5	2	1,6	3,1	360,5
Monthly	-4,6	53.9	-6,58	63.2	117,1	13620

Table 3. Consumption of energy for the heating season

Months	Energy consumption (Y)*				
	Day		Night		Energy consumption for a month (Y)* Gcal
	Avg. temperature X	Energy consumption (Y) Gcal	Avg. temperature X	Energy consumption (Y) Gcal	
October	10,6	40,5	4,2	40	80,5
November	5,8	43,3	3,2	40,2	83,5
December	2,7	48,1	1,4	44,9	93
January	-4,6	53,9	-6,6	63,2	117,1
February	4,7	41,3	-1	44,2	85,5
March	7,2	43,6	1	45,6	89,2
April	17,6	33,2	7,3	33,7	66,9
For season		303,9		311,8	615,7

From the data above, the heating energy consumption was calculated for the rest of the year and presented in the Table 3 above.
The consumption of energy for the heating season is 615,7 Gcal or 71608 kW.

3.3 The efficiency of using alternative energy sources in greenhouses

3.3.1 Types of alternative (renewable) energy sources

The main types of alternative energy sources are: wind energy, hydropower, solar energy, bioenergy and geothermal energy.
Hydropower is a type of renewable energy which uses the energy from water flow. The power plant, which through turbine converts the kinetic energy of water into electricity is called hydroelectric power plant (HPP).
The electricity generated by hydropower plants is in average 4 times cheaper than from regular power plants. Therefore, the use of hydropower resources is reasonable where the highly energy-consuming manufactures are situated. Avoiding usage of fuel and way easier power generation technology leads to the fact that labour costs in HPP is almost 10 times less than at power plants (including fuel extraction and transportation).
Wind energy - is one of the types of renewable energy, which specializes in using the kinetic energy of the wind. Nowadays, wind power of Denmark covers about 2% of the

country's electricity needs. In the US several stations employ about 17,000 wind turbines with total capacity of 1500 MW. In order to build wind farms proved economically efficient, it is necessary that the average wind speed in the area was at least 6 meters per second. In Ukraine, windmills can be built on the Black and Azov Seas, in the steppe regions and mountains of the Crimea and the Carpathians. As well as in Estonia there is a wind park built by Eesti Energia in 2002. By this it is assumable that wind turbines would be competitive in cost and can participate in meeting the energy needs of the country. There are also batteries required for reserve electricity for times when the wind is too weakened to produce energy.

Solar power - is one of the types of renewable energy, which converts solar energy into any other energy. This energy sector is one of the fastest growing, prompting experts to give it special attention. First, the solar energy is available in every corner of our planet. Second, solar energy is a clean source that can be used in an increasing scale without any negative impact on the environment. Solar energy is inexhaustible source of energy that will be available to mankind and through millions of years.

To the devices, with which the process of converting solar energy into other forms, refer the various solar panels (Figure 26).

Figure 26. Solar panel.

The advantages of solar energy:

- noiselessness of work;
- period of the solar cells is almost unlimited;
- conversion of solar energy is mainly due to the use of photovoltaic cells;
- can be used as an additional independent source of electricity even in private homes;
- the possibility of paying as per "green" tariff.

Disadvantages of solar energy:

- Dependence on climatic characteristics of the area;
- The need of placement in a large area.

Bioenergy - a direction of alternative energy where energy production is based on processing biological materials. There are some types of biological material: corn, engineering, oil crops, crop residues, animal husbandry, fisheries, organic industrial wastes etc. Bioenergy is obtained mostly by biogas plants (Figure 27).

Figure 27. Biogas plant.

With these biogas plants the energy can be easily produced from existing sewage waste, such as waste paper and pulp industry, sugar production, sewage, animal waste etc. These various sewages should be diluted in one substance and left for the fermentation process, in which methane gas is formed. This can be done by converting current sewage plants into biogas plants. After the biogas plant will release all possible methane gas, residual waste can be a good fertilizer than the original biomass.

Geothermal energy - an industrial energy from hot springs, thermal groundwater. The main source of energy is a constant flow of heat from the heated mineral resources directed to the ground of the Earth. The crust gets heat through friction cores, chemical reactions, radioactive decay of elements and gives the geothermal heat which is supplied by hot water and steam into underground reservoirs at shallow depths and geyser that reaches the surface.

The main indicator of suitability for use of geothermal sources is their natural temperature at which they are divided into low-thermality water with a temperature of 40-70 ° C, middle-thermality temperature 70-100 ° C, high-thermality water and steam with a temperature of 100-150 ° C and other fluids with temperature above 150 ° C.

3.3.2 Calculus of heat pumps

The calculations are conducted as per method taken from [4]. Average value of heat consumption in the coldest month (January) can be found by Formula (2):

$$Y_h = \frac{Y}{T} \tag{2}$$

where: Y - total consumption of thermal energy in the coldest month (January), Gcal; T – period, hours.

Then, by formula (2) we find the average of the consumption of heat for 1 hour (January):

$$Y_{год} = \frac{112}{744} = 0,15$$

Than define the required capacity heat pump for heating (Formula 3):

$$Pн = Y \cdot K \tag{3}$$

where, Y - the total consumption of thermal energy the coldest month; K - ratio Gcal to MW (K = 1,163).

Thus, the total power of heat pumps required for heating greenhouses area of 0.25 hectares, is determined by the Expression (3).

$$Pн = 0,15 \cdot 1,163 = 0,1744 \text{ MW}$$

Calculations were made by taking the data of geothermal heat pumps manufactured by NIBE output of 12 kW (F 1240).

Next, here us defined the required number of heat pumps for the needs of the greenhouse complex by the formula (4):

$$N = \frac{Pn}{P} \tag{4}$$

where: P – power of one heat pump [kW].

Hence, the number of heat pumps:

N=174,4/12=15 units

Table 4. Heat pump specification

Width	600 mm
Weight	625 мм
Voltage	400 V
Volume	160 l
Coolant	R407C
Power	12 kW
Coefficient of efficiency	4.8

3.3.3 Calculus of solar panels

Average annual total solar radiation that comes on 1 m^2 surface in Ukraine is in the range 1000 kWh / m^2 in the northern part. The average annual potential of solar energy in Ukraine 1235 kWh / m^2, which corresponds to the energy intensity of about 100 litters of diesel fuel or 100 m^3 of natural gas, and it is quite high, much higher than, for example, in Estonia approx. (1500 kWh / m^2) and Poland (1080 kWh / m^2).

To calculate the amount of monocrystalline solar panels type PLM-200M-72, which is required for the needs of the greenhouse complex, the method of overall power consumption is used [4]:

$$L = \frac{Te}{K \cdot Ke} \tag{5}$$

where: Te - the total consumption of thermal energy in the greenhouse area of 0.2592 hectares, Gcal; K - ratio Gcal to MW; Ke - coefficient of efficiency

The amount of power consumption is:

$$L = \frac{615,2}{1,163 \cdot 4,27} = 123,88$$

To determine the required number of solar panels, the formula is used:

$$N = \frac{L}{t \cdot P} \tag{6}$$

where, t - the number of sunny days per year (approx.); P - Power of monocrystalline solar panels, L - power consumption of heat pump, W per year.

$$N = \frac{12388000}{100 \cdot 200} = 619 \text{ solar panels}$$

3.3.4 Calculus of wind turbines

To calculate the characteristics of wind turbine, NEG Micon (Belgium) ones were used with a capacity of 1.5 MW. However, this is the maximum power that the generator can produce a wind speed of 15 m / s. For Kyiv region average level wind speed of only 3 m/s.

According to the method of calculation given in [4] the area of wind turbine can be found:

$$N = \frac{pSV^3}{2} \tag{7}$$

where: ρ – density of air under normal conditions; S – concentrated air area, m^2; V -avg. annually wind speed in the Kiev region:

Thus, the area of wind turbines is:

$$N == \frac{1,225 \cdot 150 \cdot 3^3}{2} = 2480,6\,\text{W}(0.0025\text{MW})$$

Thus, using wind turbines for lightning purposes is not profitable, as it would be needed to install 55 wind turbines with power of 1.5 MW to fulfil the needs of greenhouse.

3.3.5 Calculus of solar collectors

To find the absorptive surface area of collectors if backup heating source is present, by the formula (8), m^2:

$$A = \frac{Q}{\eta \cdot q_i} \tag{8}$$

where: Q - solar collectors heat flow in the heating system, W; q_i - the intensity of solar radiation on the plane collector, W / m^2; η – efficiency of solar collector

Solar collectors heat consumption for February is calculated by follows:

$$Q = F \cdot K \cdot (t_{\text{int}} \cdot t_{out}) \tag{9}$$

where: F - a greenhouse area, m^2; K - coefficient of losses of heat, W / m^2 · deg; t_{out} - the temperature outside of the greenhouse, C; t_{int} - internal temperature in the greenhouse.

$$Q = 2592 \cdot 4 \cdot (18 - (-2)) = 207360 \text{ kW}$$

The intensity of the incident solar radiation, W / m^2 per day of light determined by the formula (10):

$$q_i = P_s \cdot I_s + P_d \cdot I_d \tag{10}$$

where; P_s, P_d – factors of placing solar collector for direct and diffuse radiation and for direct radiation, coefficient is P_s = 1,1; I_s, I_d - the intensities of the coming solar radiation respectively on a horizontal surface which is I_s = 221 W / m^2, I_d = 639 W / m^2.

The coefficient of placing solar collector for diffuse radiation:

$$P_d = \cos^2 \frac{b}{2} \tag{11}$$

where: b - an inclined angle to the horizontal solar collector.

Average monthly values for solar collector P_s have different angles to the horizon, and is taken from tables. Here is taken the optimal angle b = 60ºC. Thus:

$$P_d = \cos^2 \frac{60}{2} = 0,15$$

The intensity of the incident (coming) solar radiation for each day is:

$q_i = 1{,}1 \cdot 221 + 0{,}15 \cdot 639 = 338.8$ W/m^2

The efficiency can be found as follows:

$$\eta = 0{,}8 \cdot \left[\theta - \frac{v \cdot \left(0{,}5 \cdot \left(t_1 + t_2\right) - t_3\right)}{q_i} \right] \qquad (12)$$

where: ν - overall coefficient of heat losses of solar collector which is 8 W / (m^2 · K); θ - overall optical characteristic of the collector, in particular collector θ = 0,73; t_3 - the average daily outdoor temperature, ° C. where t_3 = 2 °C.

$t_1 = t_3 + 5 = 7$

$t_2 = t_1 + 5 = 12$

$$\eta = 0{,}8 \cdot \left[0{,}73 - \frac{8 \cdot \left(0.5 \cdot \left(12 + 7\right) - 2\right)}{338.8} \right] = 0{,}42$$

Thus, the absorptive surface area of collectors (February) is:

$$A = \frac{207360}{0{,}42 \cdot 338.8} = 1360 \text{ m}^2$$

The avg. area of absorptive area of solar collectors is A=1360 m^2, therefore, by calculations, there is a need to choose 680 flat solar collectors ATMOSFERA F2M area of 2 m^2.

4 Simulation of solar collector and development the automatic climate control in greenhouses

4.1 Mathematical modelling of the climate control (heating) in greenhouse and analysis of control theory characteristics

4.1.1 Mathematical model of solar collector

To build the model of the solar heating system, there is a need to know the dynamic properties of collectors and water heating system using solar panels. Dynamic properties of collector defining standard EN-12975. Building a model allows to research and design the control system.

For designing was used the model of flat solar collector based on linear differential equations derived from the energy balance of the collector.

The equation of energy balance of collector is following:

$$\frac{dt_{k2}}{dt} = \frac{P - P_{tp}}{c_k} \tag{13}$$

where: t_{k2} - the output temperature of the collector, C; P - power consumption, W/m^2; P_{tp} - the value of heat flow and heat loss to the environment; C_k - effective heat capacity of the collector.

The total heat capacity of the collector for the flow of hot water and heat loss can be expressed by the Formula (14):

$$P_{ks} = m \cdot c_p \cdot (t_{k2} - t_{k1}) + U_K \cdot (t_{k1} - t_a) \tag{14}$$

The power, which is needed for the collector is expressed by the Formula (15):

$$P = q_v \cdot F_a \cdot k_t \tag{15}$$

where: q_v - the intensity of solar radiation; F_a - collector aperture area; k_t - heat transfer coefficient.

Combining dependencies (14) and (15) to dependence (13) we obtain the differential equation (16) that reflects the dynamic properties of flat solar collector:

$$\frac{c_k}{m \cdot c_p} \cdot \frac{t_{k2}}{dt} + t_{k2} = \frac{F_a \cdot k_t}{m \cdot c_p} \cdot [q_v - U_K (t_{k1} - t_a)] + t_{k1} \tag{16}$$

Equation (16) is a differential equation of the first order without delay, then the general form of the equation is as follows:

$$T_z \cdot \frac{dy}{dt} + y(t) = k \cdot u(t) \tag{17}$$

where:

k – coefficient of strengthening and $= \frac{F_a \cdot K}{m \cdot c_p}$ (18)

T_z - time constant and= $T_z \cdot \frac{dy}{dt} + y(t) = k \cdot u(t)$ (19)

u(t) = $q_v - U_k (t_{k1} - t_a)$ (20)

t_{k1} - input temperature;

y(t) – output signal=t_{k2} (21)

The equation (17) models the dynamic properties of the solar collector, which consists of three parts of inertial link of the first order. In order to determine the characteristics of bias, there is a need to convert equation (16) to a transfer function of the general form expressed by equation (22) using Laplace equation.

$$W(s) = \frac{k}{T_z \cdot S + 1} \tag{22}$$

The model of collector which is defined by equation (16) does not include transport delays associated with the flow of coolant between the input and output temperature which will not show real dynamic properties of the collector. Hence there is a need to model the collector in the way described by equation (16), adding transport delay and using high accuracy in equation (18) which is linking the physical properties of the working environment and mass flow rate.

$$\tau = \frac{l \cdot \rho \cdot \pi \cdot d^2}{4 \cdot Q_m} \tag{23}$$

where: τ - time delay, s; d - inside diameter, m; l - length of the collector; Q_m - mass flow, kg/strength.

Dynamic properties in complex form of the collector can be represented in the new transfer function of the equation (22) in equation (24):

$$W(s) = \frac{k}{T_z \cdot S + 1} \cdot e^{-s \cdot \tau} \tag{24}$$

An experimental model of the solar collector shown in Figure 28.

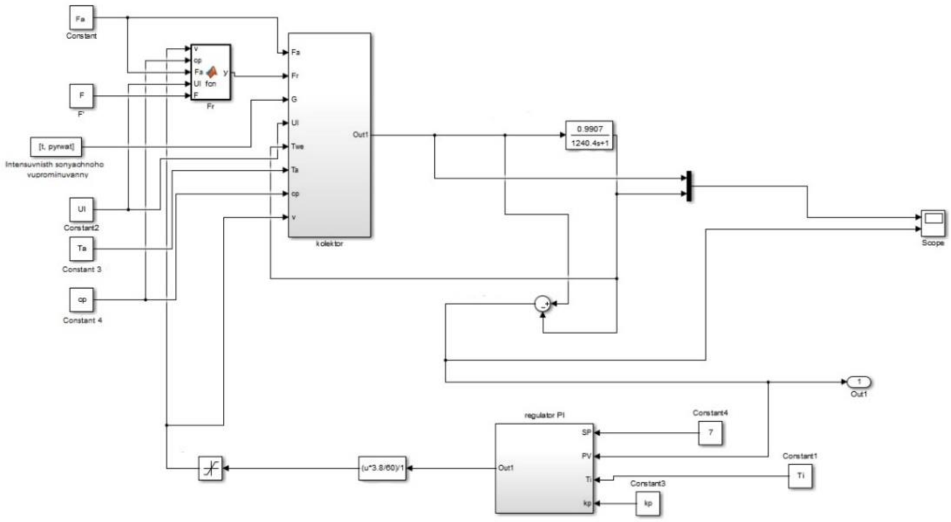


Figure 28 Experimental model of solar collector.

4.1.2 Analysis of dynamic characteristics in control theory

The dynamic characteristics of the solar collector allow determining dynamic properties of that collector. Determine the characteristics of the standard PN-EN 19275-2. This standard allows execution of the experiment in real and laboratory conditions. For the experiment the input and output temperature measurements and solar radiation pressure are taken. It also stated that the dynamic characteristic of collector is defined only for input temperature.

The Figure 29 shows the experimental dynamic characteristic of a flat solar collector.

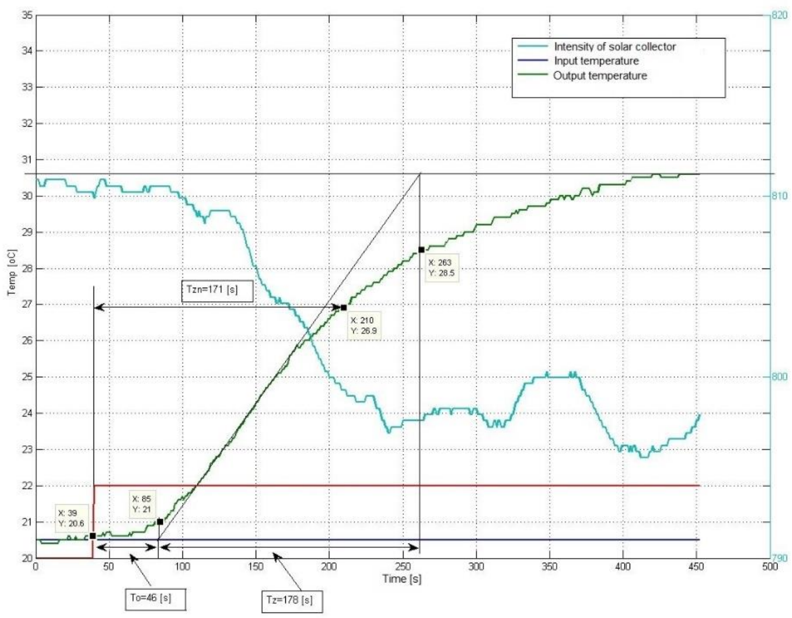


Figure 29. Dynamic characteristic of a flat solar collector

Based on the theory of automation there can be made the approximation of dynamic characteristics to the first order loop, in order to determine dynamic characteristics of the collector.

To test the model there was a comparison of simulative and dynamic characteristics using the Dependence (16). Analysing the real transition state with simulation (Figure 30) differences can be observed. The dynamic characteristic simulation and real transient temperature change on the output of the working environment shown in Figure 30.

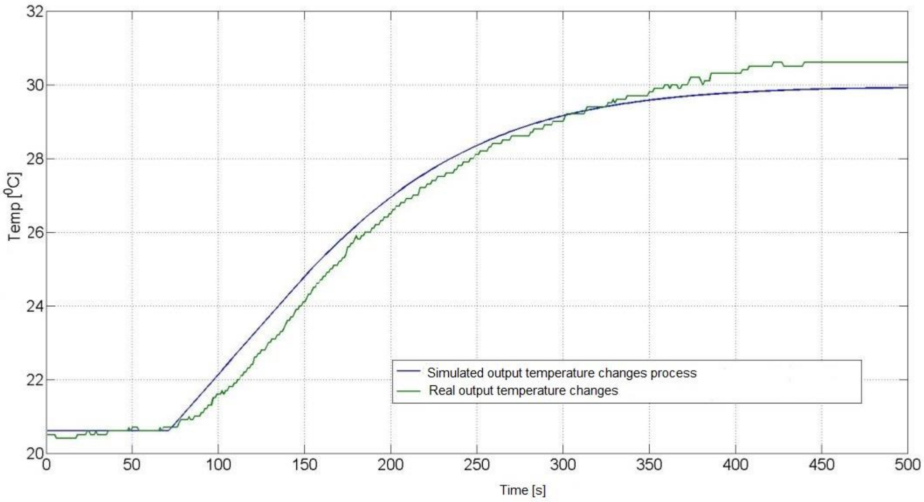


Figure 30. Dynamic characteristics of simulative and real transient temperature changes on the output of the working environment.

The model of solar radiation voltage is characterized by changes of radiation voltage over time (Figure 31).

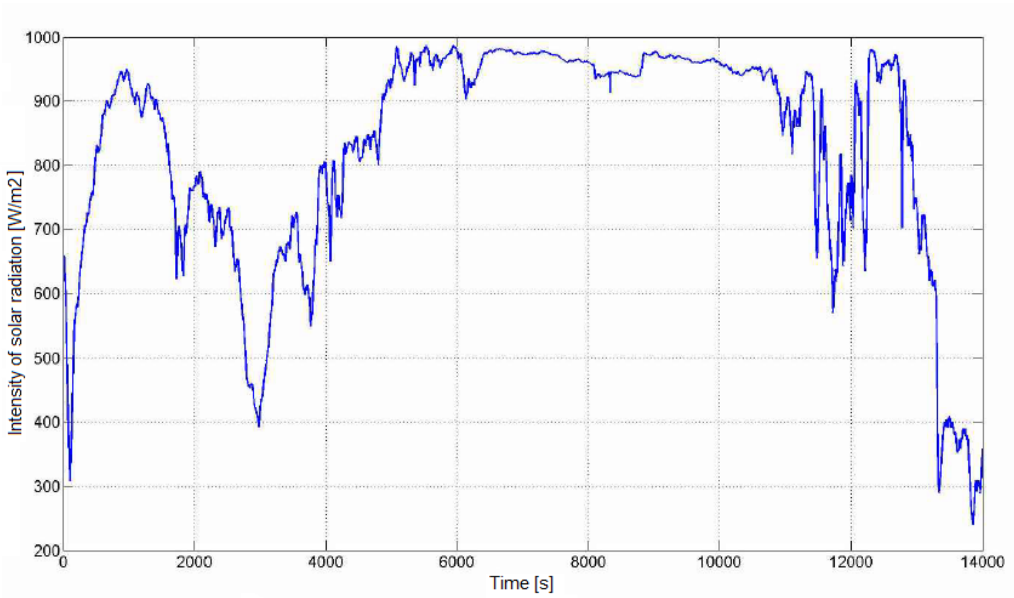


Figure 31. Dynamic voltage characteristics of solar radiation.

4.1.3 Mathematical modelling of heating process in greenhouse

Growing plants in the greenhouse requires the use of soil and air heating systems in a comfortable environment. Greenhouses are heated with water, steam and steam mixture [10].

Building the mathematical model of heating, the greenhouse is object with parameters. The air temperature in the greenhouse t_p is the same for the entire volume of the greenhouse but the temperature of the heating pipes t_v has an average value between the input temperature of hot water t_g and water temperature at the output of greenhouse t_y.

A static model of technological parameters by the channel temperature is shown below and split into two parts which accumulating energy: heated air and water which heats that air. (Figure 32). [10]

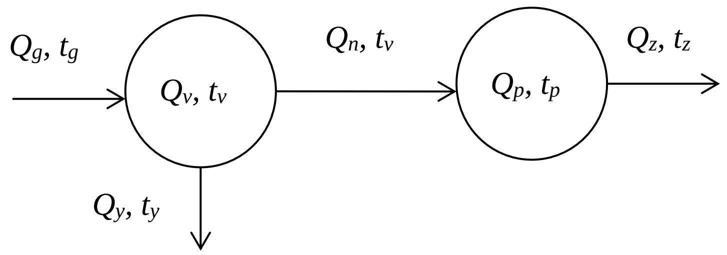


Figure 32. The scheme of a heat flow in the greenhouse.

In the static state, the value of heat of the water Q_v and air Q_p remains the same and can be expressed into two equations of thermal balance for water and air in the greenhouses [10].

For water: $Q_g - Q_y - Q_n = 0$, for air $Q_n - Q_z = 0$ (25)

where Q_g – heat which came with water; Q_y - heat which is taken with water; Q_n - heat transferred to the air; Q_z – lost heat.

The amount of heat that came in into the heating system of the greenhouse in 1 second and came out, depends on the heat capacity of water C_v, engine productivity G_n water density ρ_v and temperature of the water. The heat which is present in the heating system also depends on the volume of water V_v [10].

Thus:

$$Q_g = C_v G_n \rho_v t_g$$

$$Q_y = C_v G_n \rho_v t_y$$

$$Q_v = C_v V_v \rho_v t_v. \qquad (26)$$

The amount of heat which is present in a greenhouse depends on the heat capacity C_p of air, air density ρ_p, temperature t_p and volume of greenhouse V_p:

$$Q_p = C_p V_p \rho_p t_p \tag{27}$$

By Fourier law, here is calculated the heat, which is transferred from the water to the air through the pipe, and from the air to the outside air through the greenhouse glass [10]:

$$Q_n = k_1 F_t (t_v - t_p)$$

$$Q_z = k_2 F_c (t_p - t_z) \tag{28}$$

where k_1, k_2 - coefficients of heat transfer through the pipe and the glass of greenhouse; F_t, F_c – the surface of heating pipes and glazed surface of a greenhouse, t_z - ambient temperature. Heat transfer coefficients are calculated as follows:

$$k_1 = \frac{1}{\frac{1}{\alpha_{vt}} + \frac{\delta_t}{\lambda_t} + \frac{1}{\alpha_{tp}}};$$

$$k_2 = \frac{1}{\frac{1}{\alpha_{pc}} + \frac{\delta_c}{\lambda_c} + \frac{1}{\alpha_{cz}}}; \tag{29}$$

where: α_{vt}, α_{tp}, α_{pc}, α_{cz} - heat transfer coefficients from water to the pipe, from the pipe to the greenhouse air, from the greenhouse air to the glass walls of the greenhouse, from the glass to the outside air respectfully; λ_t, λ_c – coefficients of thermal conductivity respectfully of pipe's steel and wall's glass; δ_t, δ_c – thicknesses of pipe's wall and glass.

Here the static model turns to dynamic model. From the equations of statics and presented equations above, the differential equations of heating amount changes over time in water and air of the greenhouse were obtained. [10]

Taking in account the parameters that are the same: density and heat capacity of water and air, volume of environment, derivatives will be found by the water and air temperatures: t_v and t_p [10]:

$$C_v V_v \rho_v \frac{dt_v}{d\tau} = C_v G_n \rho_v t_g - C_v G_n \rho_v t_y - k_1 F_t (t_v - t_p)$$

$$C_p V_p \rho_p \frac{dt_p}{d\tau} = k_1 F_t (t_v - t_p) - k_2 F_c (t_p - t_z) \tag{30}$$

Assuming that $t_v = (t_g + t_y) / 2$, from the above presented equation, the definition of cooling water can be found and used in the equation (30). After simplification, the equation (31) is put to form of Cauchy equation [10]:

$$\frac{dt_v}{d\tau} = \frac{2G_n}{V_v}(t_g - t_v) - \frac{k_1 F_t (t_v - t_p)}{C_v V_v \rho_v}$$

$$\frac{dt_p}{d\tau} = \frac{k_1 F_t (t_v - t_p) - k_2 F_c (t_p - t_z)}{C_p V_p \rho_p} \qquad (31)$$

Thus, the system of equations is used to model the heating of greenhouse using Matlab Simulink.

The coefficients calculations of the equation system (31) are shown further. The heat transfer coefficients can be calculated as per formula (29):

$$k_1 = \frac{1}{\frac{1}{1070} + \frac{0.002}{50} + \frac{1}{16}} = 15{,}75 \text{ W/m deg,}$$

$$k_2 = \frac{1}{\frac{1}{14} + \frac{0.004}{0{,}74} + \frac{1}{18}} = 7{,}55 \text{ W/m deg.}$$

The length of pipes can be calculated as follows:

$$L = \frac{V_v}{\frac{\pi \cdot d_v^2}{4}} \qquad (32)$$

where: V_v – capacity (volume) of heating system, m^3; d_v - internal diameter of pipe, mm.

Thus:

$$L = \frac{82}{\frac{\pi \cdot 0{,}044^2}{4}} = 53928{,}5 \text{ m}$$

Heat exchange surface is:

$$F_t = L \cdot \pi \cdot 0{,}048 \qquad (33)$$

where: L – length of pipes, m.

$$F_t = 53928{,}5 \cdot \pi \cdot 0{,}048 = 8132{,}23 \text{ m}^2$$

The glazed surface of a greenhouse can be calculated as follows, assuming that the shape of greenhouse is rectangular:

$$F_c = 10000 + 500 \cdot 2 \cdot 3 + 20 \cdot 2 \cdot 3 = 13120 \text{ m}^2$$

The volume of air in the greenhouse:

$$V_p = 10000 \cdot 3 = 30000 \text{ m}^3$$

Time delay:

$$\tau_з = \frac{V_v}{4 \cdot \frac{G_n}{3600}} = 295{,}2 \qquad (34)$$

where: G_n – productivity of pump, m^3 / s; V_v - volume air in pump, m^3.

$$\tau_з = \frac{82}{4 \cdot \frac{250}{3600}} = 295{,}2 \text{ sec}$$

Additional coefficients for ease of forming simulation model of heating in the greenhouse can be calculated as follows:

$$a_1 = k_1 F_t \quad (3.23)$$

where: k_1 - coefficient of heat transfer; F_t - heat exchange surface, m^2.

$$a_1 = 11{,}837 \cdot 7933.9 = 93913.6$$

$$a_2 = k_2 F_c \qquad (35)$$

where: k_2 - coefficient of heat transfer; Fc - glazed surface of greenhouse, m^2.

$$a_2 = 4{,}189 \cdot 13120 = 54959.7$$

$$b1 = C_v \rho_v V_v \qquad (36)$$

where: C_v - water heat capacity, J / (kg·deg); ρ_v - the density of water, kg / m^3; V_v - the volume of heating system in greenhouse, m^3.

$$b_1 = 1005 \cdot 4174 \cdot 82 = 3.439 \cdot 10^8$$

$$b2 = C_p \rho_p V_p \qquad (37)$$

where: C_p – air heat capacity, J / (kg·deg); ρ_p - the density of air, kg / m^3; V_v - the volume of air, m^3.

$$b2 = 1005 \cdot 1{,}293 \cdot 30000 = 3.898 \cdot 10^7$$

From the above presented equation system, a model of heating in greenhouse was created using Simulink, which is shown on Figure 33.

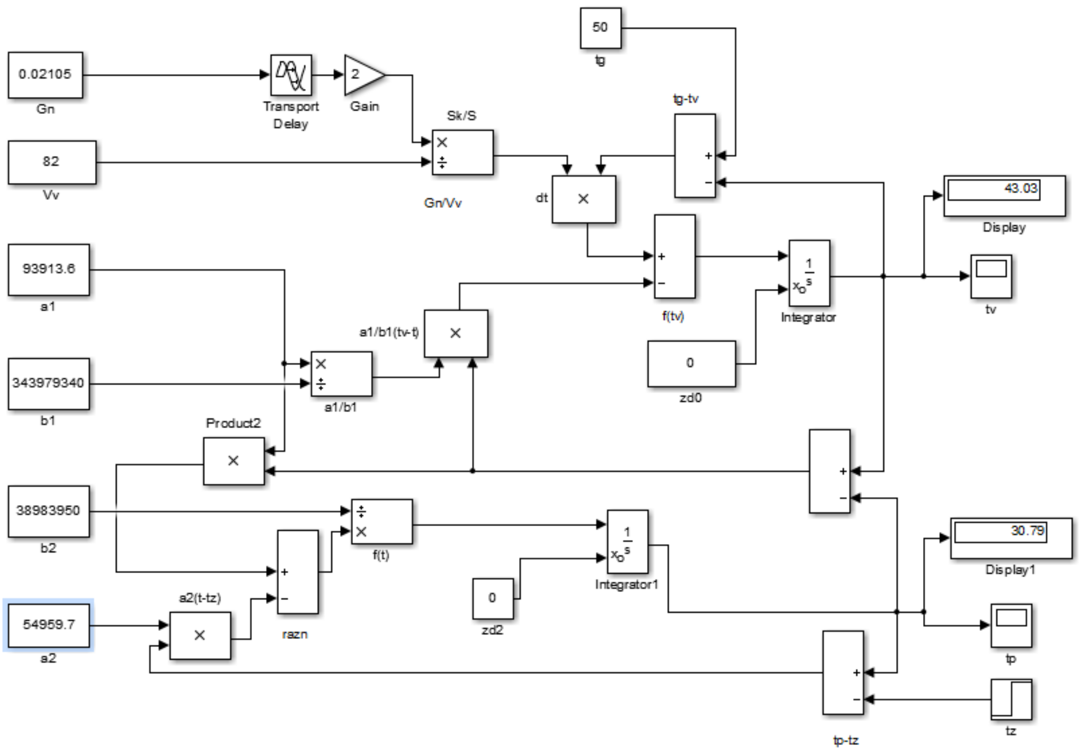
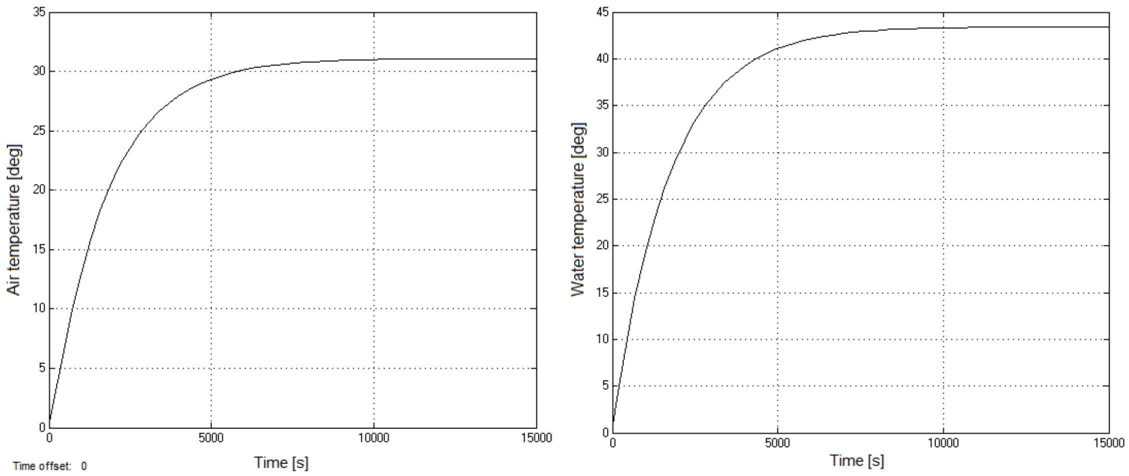


Figure 33. The model of heating system in greenhouse.

The changes in air temperature inside the greenhouses and water temperature for heating shown in Figure 34.



a) b)

Figure 34. a) changes of the air temperature in the greenhouse; b) changes of the water temperature for heating.

The same model can be used for greenhouses of smaller size by changing following parameters: volume, length, capacity, productivity.

4.1.4 Creating the simulation model of heating system in greenhouse

For creating the simulation model of heating system in the greenhouse with usage of solar collectors which heat the water, following diagram can be used (Figure 35):

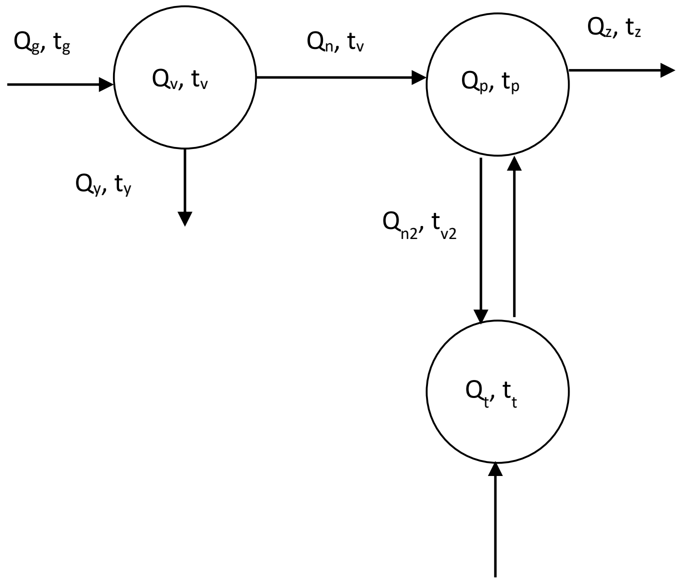


Figure 35. Hot air flow in greenhouse scheme with usage of solar collectors.

In the heating season, the greenhouse is fed with cold water. Therefore, to control the temperature of the water, the heating system can use solar collectors that heat water and storage that hot water in the tank.

In the scheme of heat flow the collector receives the heat from solar radiation and heat is returned with antifreeze that does not freeze with -30 ° C. In the system, during the heating season, water storage tank is used. The heat with antifreeze from the collector goes for heating water and greenhouse itself. The water goes through pipes in the greenhouse and heats it.

Hence, we can obtain the system of differential equations that takes into account changing amounts of heat of the air and water with antifreeze:

$$C_v \cdot V_v \cdot \rho_v \frac{dt_v}{d\tau} = C_v \cdot G_n \cdot \rho_v \cdot t_y - K_1 \cdot F_1 (t_v - t_p)$$

(38)

$$C_p \cdot V_p \cdot \rho_p \frac{dt_p}{d\tau} = K_1 \cdot F_t (t_v - t_p) - K_2 \cdot F_c (t_p - t_z) + K_3 \cdot F_t (t_{ts} - t_{vs})$$

Below presented the system of equations, which describe heat exchange with usage of solar collectors:

$$\frac{d(V_B \cdot \rho_v \cdot C_v \cdot t_{vs})}{d\tau} = F_t \cdot K_t (t_{ts} - t_{vs}) + \frac{G_v}{3600} \cdot \rho_v \cdot C_v \cdot t_v + \frac{G_v}{3600} \cdot \rho_v \cdot C_v \cdot t_{v2}$$

$$\frac{d(V_t \cdot \rho_t \cdot C_t \cdot t_{ts})}{d\tau} = V_{tk} + V_{tmm} + V_{tб} = F_k \cdot \eta \cdot S_q + G_t \cdot \rho_t \cdot C_t \cdot t_t - F_{tepl} \cdot K_{tepl} (t_{ts} - t_p)$$

$$d(V_{kol} \cdot \rho_{tos} \cdot (t_0 - t_{ts}) = F_{kol} \cdot \eta \cdot q + 2(t_{vs} + 5 - t_{ts}) G_t \cdot \rho_t \cdot C_t - F_{tepl} \cdot K_{tepl} \cdot 2(t_{ts} - t_{vs})$$

$$\frac{d(V_b \cdot \rho_b \cdot C_b \cdot t_{tvs})}{d\tau} = F_t \cdot K_t (t_{ts} - t_{vs})$$

$$\frac{d(V_b \cdot \rho_b \cdot t_b)}{d\tau} = G_n (2 \cdot t_v - t_b) \qquad (39)$$

Below the differential equations are put to form of Cauchy:

$$\frac{dt_{ts}}{d\tau} = \frac{F_{kol} \cdot \eta \cdot q + 2(t_{vs} + 5 - t_{ts}) \cdot G_t \cdot \rho_t \cdot C_t - F_{tepl} \cdot K_{tepl} (t_{ts} - t_{vs})}{F_{kol} \cdot \rho_t \cdot C_t}$$

$$\frac{dt_{vs}}{d\tau} = \frac{F_t \cdot K_t (t_{ts} - t_{vs}) - F_b - Q_3}{V_b \cdot \rho_t \cdot C_t}$$

$$\frac{dt_b}{d\tau} = \frac{G_n \cdot 2(t_v - t_b)}{V_b \cdot \rho_v} \qquad (40)$$

To define the volume of antifreeze in all collectors, the data from calculations in the section 3.3.5 can be taken and the following formula can be used:

$$V_k = 0.0018 \cdot n \qquad (41)$$

where: n – number of collectors

$$V_k = 0.0018 \cdot 680 = 1.2 \text{ m}^3$$

Average temperature in the tanks, C°

$$t_{vs} = \frac{t_{v1} + t_{v2}}{2} \qquad (42)$$

where: t_{v1} t_{v2}- temperature at the input and output of the tank, C°:

$$t_{vs} = \frac{11 + 16}{2} = 13.5^o C$$

The volume of antifreeze in the pipe which connects collectors and tank, m^3:

$$V_{t1} = \frac{\pi d^2}{4} \cdot l_{tp} \qquad (43)$$

where: l_{tp} - pipe length, m.

$$V_{t1} = \frac{0.03^2}{4} \cdot 220 = 0.05 m^3$$

The volume of the entire system where the antifreeze is present, m^3:

$$V_t = V_k + V_{t1} \quad (44)$$

where: V_k – volume of antifreeze in all collectors, m^3, V_{t1} - volume of antifreeze in the pipe which connects collectors and tank m^3.

$$V_t = 1.2 + 0.05 = 1.25 m^3$$

The value of the average temperature of antifreeze, C°:

$$t_{ts} = \frac{t_{t1} + t_{t2}}{2} \quad (45)$$

where: t_{t1} and t_{t2} - the temperature at the input and output of antifreeze, C°:

$$t_{ts} = \frac{10 + 20}{2} = 15^o C$$

The heat that is stored in antifreeze [W], can be found as per formula:

$$q_{tk} = V_t \cdot p_t \cdot C_t \cdot t_{ts} \quad (46)$$

where: V_t - volume of the entire system where the antifreeze is present m^3; t_{ts} – value of the average antifreeze temperature, C°; ρ_t – antifreeze density, kg / m^3; C_t – antifreeze heat capacity, J / kg·deg.

$$q_{tk} = 1.25 \cdot 1095 \cdot 2923 \cdot 15 = 60012843.75 \text{ W}$$

The heat that comes from the sun [W], can be found as per formula:

$$Q_s = A \cdot \eta \cdot q_i \quad (47)$$

where: A - absorptive surface area of collectors, m^2; q_i - the intensity of solar radiation which comes on the plane collector, W / m^2; η - efficiency of the solar collector.

$$Q_s = 1360 \cdot 0.45 \cdot 338.8 = 207345.6 \text{ W}$$

The heat which is transferred to water Q_{tv}, [W], can be found as per formula:

$$Q_{tv} = F_t \cdot k_t \cdot (t_{t2} - t_{vs}) \quad (48)$$

where: F_t - heat exchanger area, m^2; k_t – coefficient of the heat transfer, W / m^2·deg, t_{t2} - the temperature at the output of antifreeze, C°; t_{vs} - the average water temperature in the tank C°.

$$Q_{tv} = 1.5 \cdot 2923 \cdot (20 - 13.5) = 28499.2 \text{ W}$$

The heat of antifreeze which is returned to the tank from solar collector [W], can be found as per formula:

$$Q_{t1} = \frac{G_t}{3600} \cdot p_t \cdot C_t \cdot t_{t1} \quad (49)$$

where: G_t - pump productivity of processing antifreeze, m^3 / h; ρ_t – density of antifreeze, kg / m^3; C_t - antifreeze heat capacity, J / kg·deg; t_{t1} - the temperature at the input of antifreeze, C°.

$$Q_{t1} = \frac{1}{3600} \cdot 1095 \cdot 2923 \cdot 10 = 8890.8 \text{ W}$$

The heat that comes from the water into the tank, W:

$$q_v = V_b \cdot p_v \cdot C_v \cdot t_{vs} \quad (50)$$

where: V_b - the volume of the tank, m^3; ρ_v - the density of water, kg / m^3; C_v - water heat capacity, J / kg·deg; t_{vs} - the average water temperature, C°.

$$q_v = 200 \cdot 1000 \cdot 4180 \cdot 13 = 1086800000\,0 \text{ W}$$

The temperature of cooled antifreeze at the output of the tank is assumed higher than the temperature in the input, C°:

$$T_{t1} = t_{v1} + 5 \quad (51)$$

where: t_{v1} - water temperature at the input of the tank, C°.

T_{t1} = 11+5=16 °C

Pump productivity for antifreeze [m^3/h], can be found as per formula:

$$G_t = \frac{w}{\Delta t \cdot k_t} \quad (52)$$

where: w - collector power, W; Δt - temperature changes in pipes at the input and output, C°; k_t – coefficient of coolant.

$$Gt = \frac{16000}{10 \cdot 2923} = 0.54 \text{ m}^3\text{/h}$$

From these equations, the simulation model of solar collectors for heating greenhouses was created. The model shows the time which is needed to heat water and antifreeze in the collector. The created simulation system could be used for greenhouses with different parameters.

A simulation model for greenhouse with heating by collector shown in Figure 36.

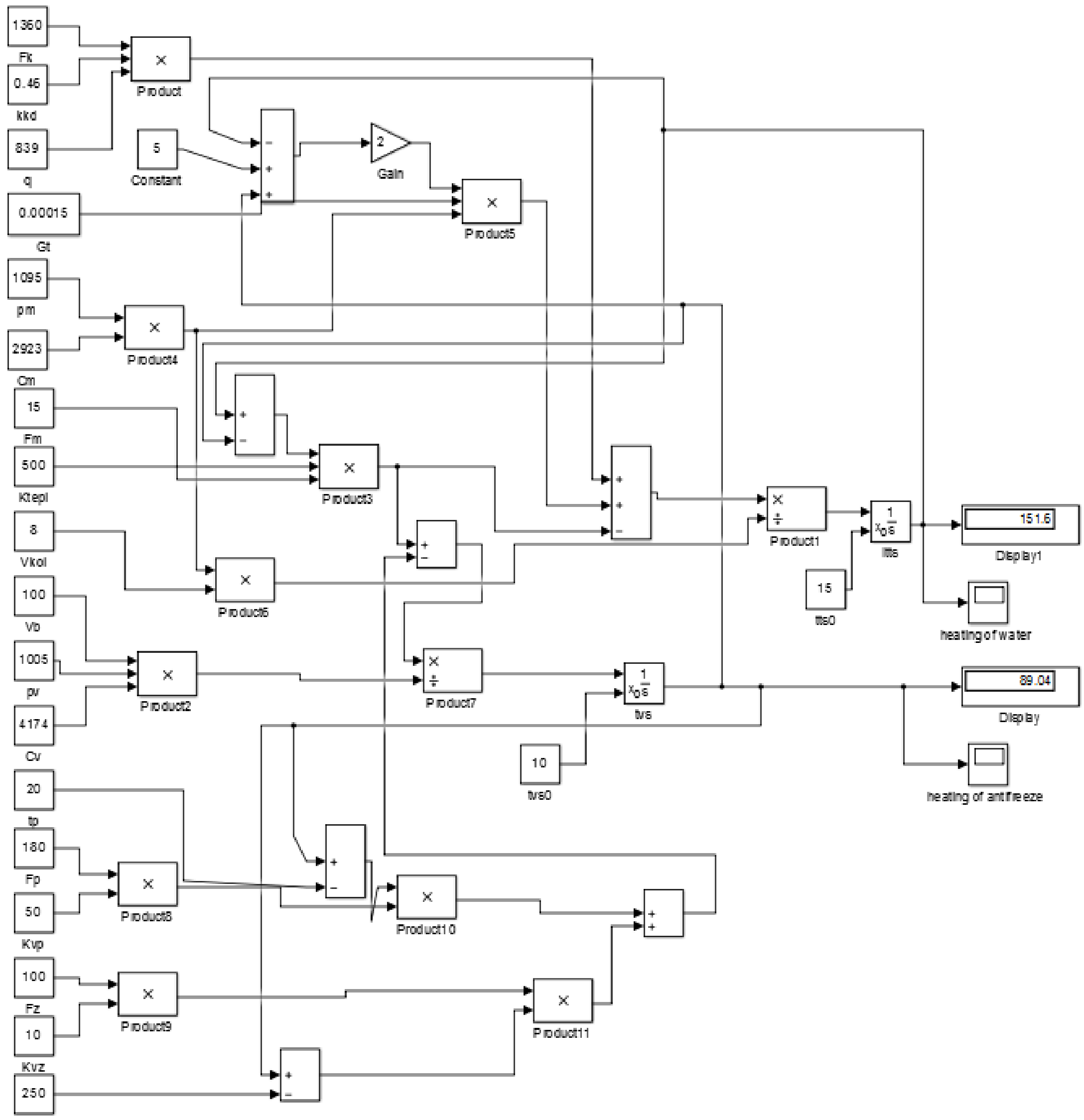
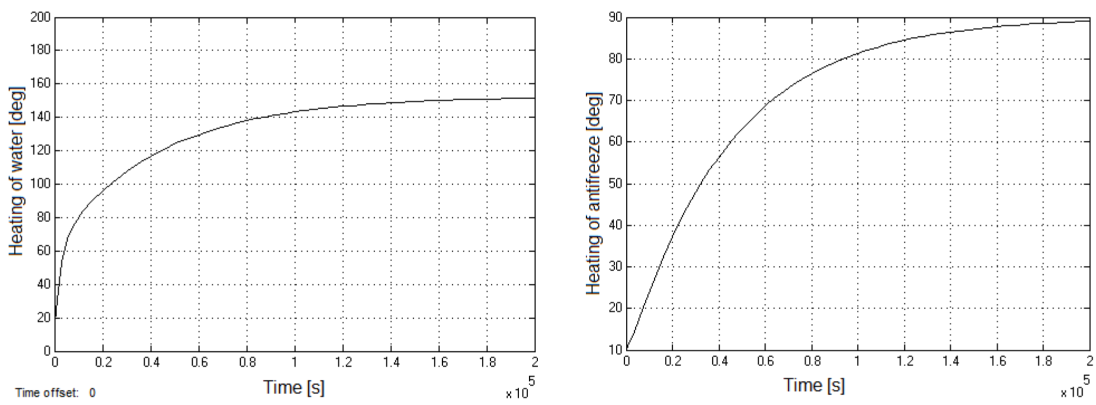


Figure 36. The simulation model of heating the greenhouse by solar collector.

Characteristics of heating water and antifreeze in the collector are shown in Figure 37.



a) b)

Figure 37. a) Heating of water b) heating of antifreeze

Further is presented a simulation model of heating a greenhouse, which shows temperature losses of water and air and the water temperature in the tank in time in dependence of time (Figure 38).

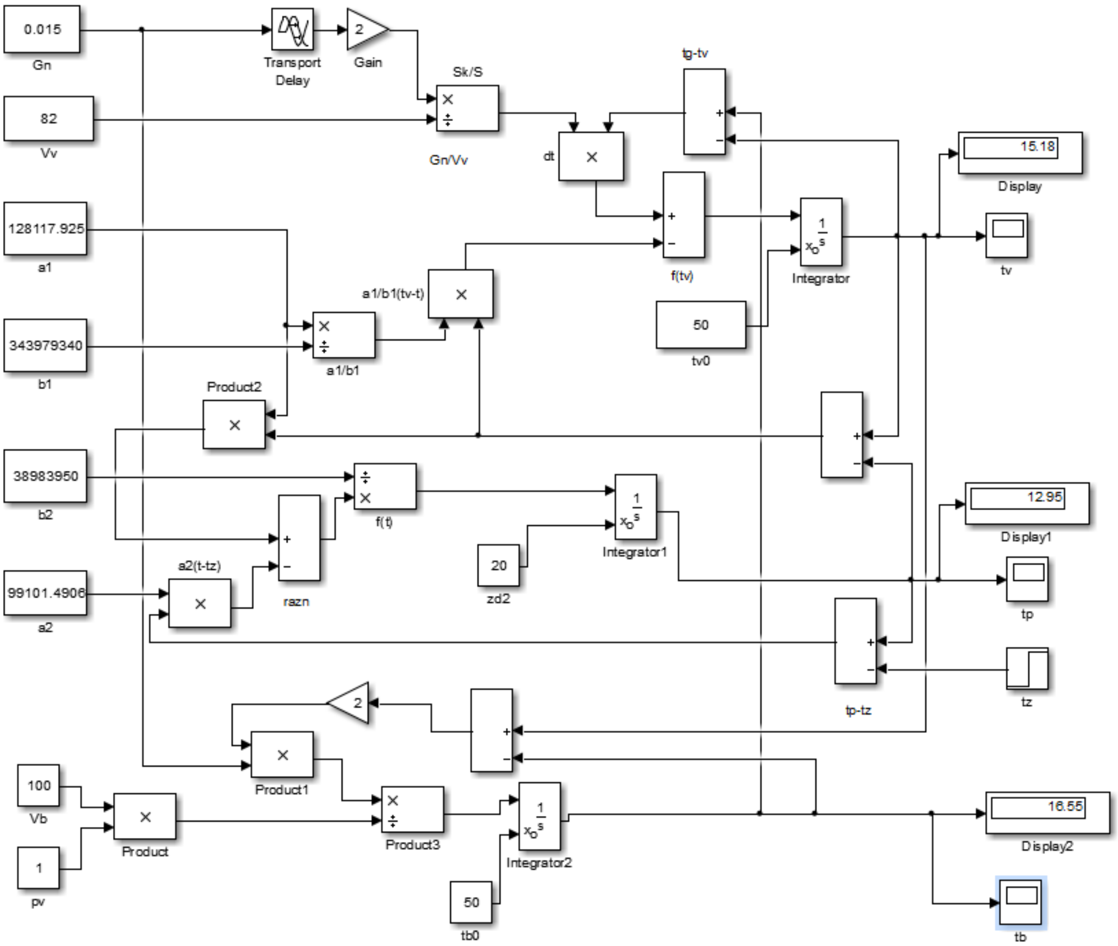
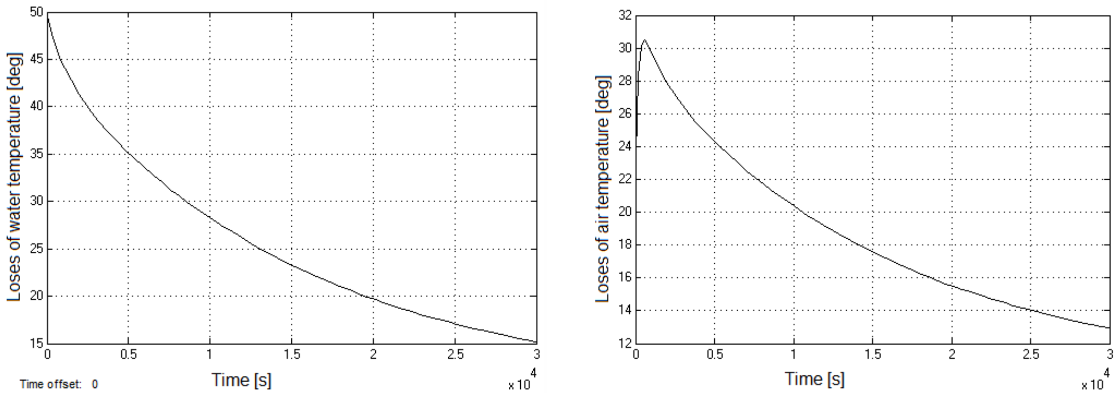


Figure 38. A simulation model of heating process in the greenhouse.

Characteristics of losses of water and air temperature in dependence of time are shown in Figure 39.



a) b)

Figure 39. Losses of temperature characteristics: a) water b) air

Loss of water temperature in the tank shown in Figure 40.

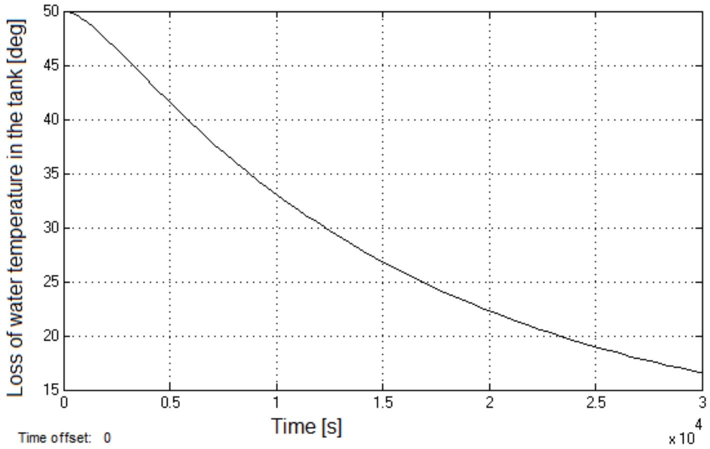


Figure 40. Loss of water temperature in the tank.

4.2 Analysis and selection of the automation hardware

4.2.1 Selection of control mechanism

The set of control system consists of a controller that implements one of the control algorithms and other devices by which measuring, monitoring and recording settings are possible.

To select the technical devices, the environmental parameters such as temperature, humidity, pressure, dust, vibration and so on availability are considered.

The hardware is selected for metrological parameters as well as:

- for accuracy class 0.1 and a standard width of 250 mm range of recording, for highly accurate processes
- for accuracy class 0.5 with a standard width of 160 mm are recording, for an average accuracy of measurement and recording.
- for accuracy class 1 with a standard width of 100 mm range recording, where high precision measurement is not needed.

Regulators are determined by 2 factors:

- bandwidth characteristics;
- consumer characteristics.

Choice of control mechanism depends on the dynamic properties of the object and control quality, which should be provided by technological requirements. The controller choosing is mainly detects by the time delay in dependence to the time constant of controlled object (Table 5).

Table 5. The value of time delay related to the time constant of object.

τ_o / T_o	Controller
less than 0,2	P
from 0,2 to 1,0	P, PI or PID
more 1,0	P, PI or PID

The agricultural production often uses continuous controllers that allow to realize: proportional (P), proportional-integral (PI), proportional-integral-differential (PID) control loop feedback mechanism (controller). The settings of controlled object (τ_o, T_o, K_o) are determined by the graphical method, shown in the section 4.1.2.

For the object, which is illustrated in this master thesis, the time delay is $\tau_o = 400$ sec. and time constant is $T_o = 2000$ sec.

The gain of the object can be found as per formula:

$$K_o = \frac{\Delta T_в}{\Delta \varphi_{кр}} \tag{53}$$

where: $\Delta T_в = t_{\max} - t_{\min}$ (54)

$$\Delta \varphi_{кр} = \Delta \varphi_{кр1} - \Delta \varphi_{кр2} \tag{55}$$

Then: $\Delta T_в = 19 - 13 = 6$ °C

$$\Delta \varphi_{кр} = 30 - 20 = 10$$

Thus, the gain of the object:

$$K_o = \frac{6}{10} = 0.6$$

To define the controller needed, the following calculation is used:

$$\frac{\tau_o}{T_o} = \frac{400}{2000} = 0{,}2$$

Based on the calculation, the PI controller with 20% of overshooting can be used here. Proportional-integral controller provides high accuracy control with significant changes in load. In reality the universal digital controller OBEH TPM-151 can be used which allows the temperature control for heating the greenhouse.

Transfer function of PI controller is following:

$$W_{KE}(s) = K_r\left(1 + \frac{1}{T_{iz} \cdot s}\right) \tag{56}$$

where: K - is the proportional gain, a tuning parameter, T_{iz} – constant of integration (integral action time).

The transfer function of control object is following:

$$W_{OK}(\mathrm{s}) = \frac{K_o}{\mathrm{T}_o \cdot \mathrm{s} + 1} \cdot e^{-\tau_0 \cdot s} \tag{57}$$

Using calculated parameters, the transfer function of controlled object is following:

$$W_{OK}(\mathrm{s}) = \frac{0{,}6 \cdot e^{-400 \cdot \mathrm{s}}}{2000 \cdot \mathrm{s} + 1}$$

OBEH TPM-151 functionality:

- One or two channels programmable control;
- Two built-in universal inputs and two outputs;
- controlled by different actuators:
    1) 2-position (heater motors);
    2) 3-position (valves, cranes);
    3) Auxiliary devices (dampers, shutters, steam generators, etc.).
- Auto-tuning PI controllers by modern efficient algorithms;
- Manual control of output power;
- The range of standard versions for the most common processes;
- Extensive configuration from the computer or from the front panel of the device (different levels of access for the operator, engineer and service engineer of the system);
- Quick start program is designed specifically for each modification;
- Quick access to the programming settings from the front panel;
- Two types alarm system;
- Built-in RS-485 interface.

PI - controller OBEH TPM-151 shown on Figure 41.

Figure 41. OBEH TPM-151.

PI - controller allows to control the load in two ways: digital(impulse) and analog.
TPM-151 controls the speed with which the value changes. If the maximum control action is not enough to keep the measured value, controller launches and an alarm.
While auto-tuning, the device calculates the best value for the PI parameters, digital filter time constant and the period following the control impulses.
The connection diagram of controller is shown on Figure 42.

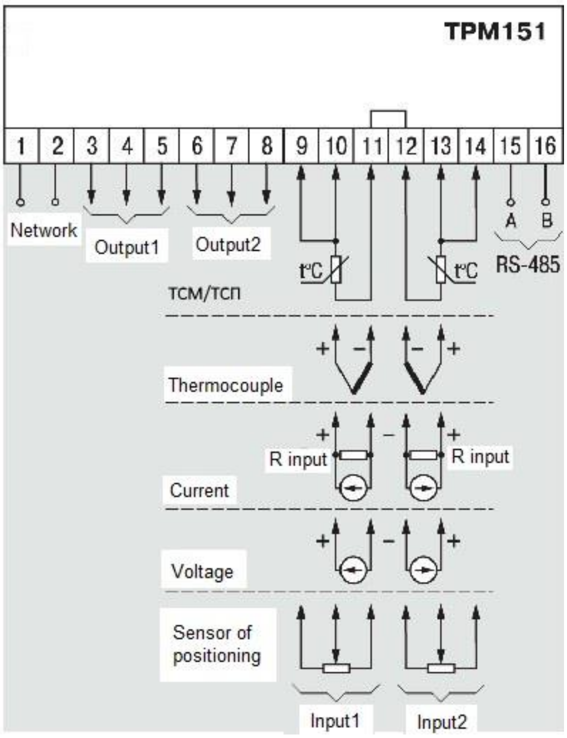


Figure 42. Connection diagram of controller OBEH TPM-151

To define optimal settings of controller for the steadyness of system (steady state), the following parameters (τ_o, T_o, K_o) are needed to be determined by the graphic method.
The settings of PI controller can be defined by 3 engineering methods:

- by oscillation frequency index;
- by amplitude stability;
- by root oscillation index.

For greenhouse heating purpose, the PI settings can be defined by the second method.

For open-loop system with PI controller is following:

$$W_{роз}(j\cdot\omega) = K_p[1-(j/T_i\cdot\omega)\cdot W_{ок}(j\cdot\omega)] = k_p\cdot W_{ок}(j\cdot\omega) - j\cdot[k_p\cdot W_{ок}(j\cdot\omega)]/(T_i\cdot\omega) \quad (58)$$

Thus, when turning on the PI controller, each vector of the object will increase in k_p times and the vector $[k_P W_{OY}(j\cdot\omega)]/T_i\cdot\omega$ will be added.

The parameters K_p and T_i, that provide the desired stability by amplitude C, can be found as per expressions:

$$\overline{OD} = W(j\cdot\omega_i) = \overline{OE_i} + \overline{ED_i} = k_P\cdot W_{OY}(j\cdot\omega) - \frac{k_P\cdot W_{OY}(j\cdot\omega)}{T_i\cdot\omega} = k_P\cdot\overline{OA_i} - j\cdot\frac{k_P\cdot\overline{OA_i}}{T_i\cdot\omega}. \quad (59)$$

and follows:

$$\overline{OE_i} = k_P\cdot\overline{OA_i},\ k_P = \frac{\overline{OE_i}}{\overline{OA_i}} \quad (60)$$

$$\overline{ED_i} = \frac{k_P\cdot W_{OY}(j\cdot\omega)}{T_i\cdot\omega_i} = \frac{\overline{OE_i}}{T_i\cdot\omega_i},\ T_i = \frac{\overline{OE_i}}{\omega_i\cdot\overline{ED_i}} \quad (61)$$

For specific frequencies, the above vector ratios are converted to scalar.

PI controller parameters by oscillation amplitude index C=0.7 can be calculated in Mathcad.

Further the Nyquist plot (or APFC amplitude-phase-frequency characteristic (Bode diagram)) with line segment OA on circles OE, ED is plotted (Figure 43):

$C := 0.7 \qquad \omega := 0, 0.0001 .. 0.2 \qquad i := 1 .. 12 \qquad j := \sqrt{-1}$

$r := \frac{1-C}{2} \qquad r = 0.15 \qquad d := 2\cdot r \qquad d = 0.3$

Transfer function OK

$x := 0, -0.001 .. -d \qquad W(\omega) := \frac{0.6\cdot e^{-400\cdot j\cdot\omega}}{(2000\cdot j\cdot\omega)+1} \qquad y(x) := \sqrt{r^2 - (x+r)^2}$

OE		ED		OA	
$ax_i :=$	$ay_i :=$	$bx_i :=$	$by_i :=$	$cx_i :=$	$cy_i :=$
0	0	−0.3	0	0	0
−0.09	−0.136	−0.09	−0.136	−0.0091	−0.0142
0	0	−0.3	0	0	0
−0.17	−0.148	−0.17	−0.148	−0.0091	−0.0116
0	0	−0.3	0	0	0
−0.23	−0.125	−0.23	−0.125	−0.0091	−0.0095
0	0	−0.3	0	0	0
−0.258	−0.103	−0.258	−0.103	−0.0084	−0.006
0	0	−0.3	0	0	0
−0.283	−0.0656	−0.283	−0.0656	−0.0077	−0.004
0	0	−0.3	0	0	0
−0.294	−0.046	−0.294	−0.046	−0.007	−0.0021

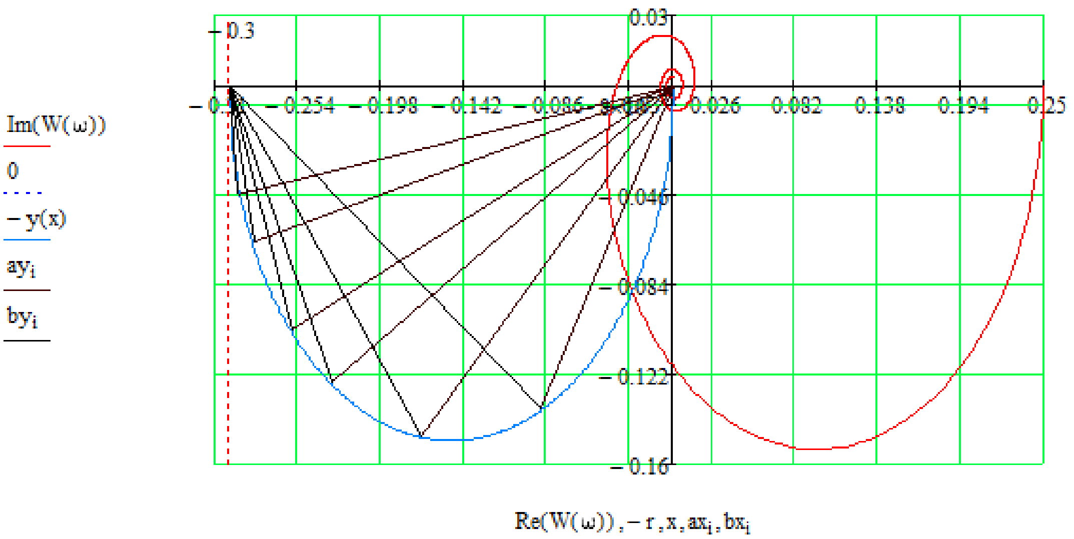


Figure 43. Calculation of PI parameters and Nyquist plotting.

To define the frequencies where Nyquist plot intersects with line segments (Figure 44).

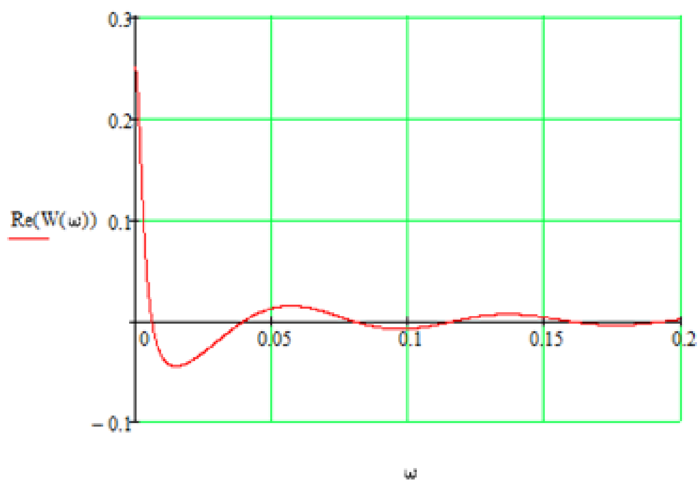


Figure 44. Defining the frequencies where Nyquist plot intersects with line segments.

To define the length of line segments OA, OE, ED, following calculations were used:

$$OA_i := \sqrt{(cx_i)^2 + (cy_i)^2} \qquad ED_i := \sqrt{d^2 - \left[(ax_i)^2 + (ay_i)^2\right]} \qquad OE_i := \sqrt{(ax_i)^2 + (ay_i)^2}$$

$OA_i =$	$ED_i =$	$OE_i =$	$\omega_i :=$
0	0.3	0	0.0042
0.017	0.252	0.163	0.0042
0	0.3	0	0.0042
0.015	0.198	0.225	0.0031
0	0.3	0	0.0028
0.013	0.147	0.262	0.0025
0	0.3	0	
0.01	0.113	0.278	
0	0.3	0	
0.009	0.075	0.291	
0	0.3	0	
0.007	0.038	0.298	

To define control parameters K_p and T_i, following calculations were used:

$i := 1..6$

$OA_i :=$	$ED_i :=$	$OE_i :=$	$\omega_i :=$
0.017	0.252	0.163	0.0042
0.015	0.198	0.225	0.0042
0.013	0.147	0.262	0.0042
0.01	0.113	0.278	0.0031
0.009	0.075	0.291	0.0028
0.007	0.038	0.298	0.0025

$$Kp := \frac{OE}{OA} \qquad Ti := \frac{OE}{\omega \cdot ED} \qquad \frac{Kp}{Ti} > max$$

$\frac{OE_i}{OA_i} =$	$\frac{OE_i}{\omega_i \cdot ED_i} =$	$\frac{\frac{OE_i}{OA_i}}{\frac{OE_i}{\omega_i \cdot ED_i}} =$
9.588	154.006	0.062
15	270.563	0.055
20.154	424.36	0.047
27.8	793.605	0.035
32.333	$1.386 \cdot 10^3$	0.023
42.571	$3.137 \cdot 10^3$	0.014

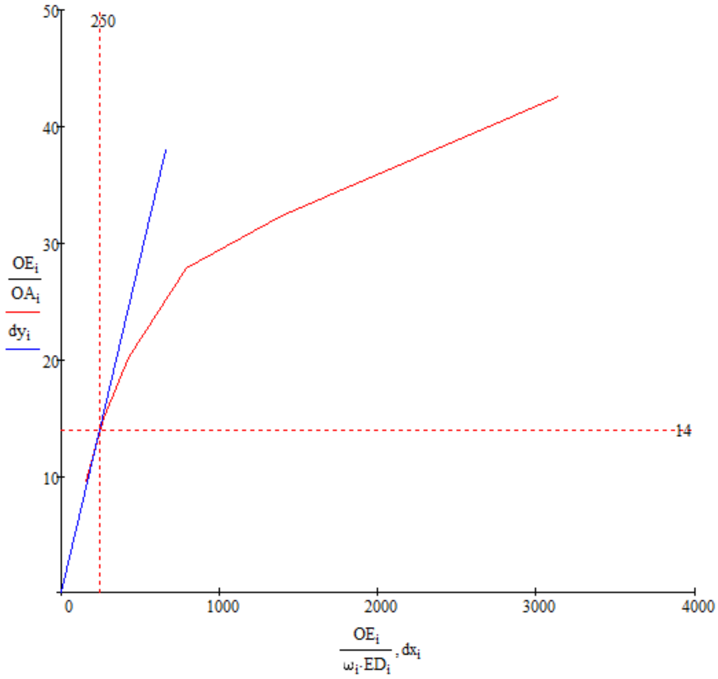


Figure 45. Defining the optimal control parameters.

Thus, Kp=14, Ti=250 sec. are optimal control parameters with transfer function:

$$W_{KE}(s) = 14 \cdot \left(1 + \frac{1}{250 \cdot s}\right)$$

4.2.2 Selection of sensor (transducer)

Perceiving element of greenhouse temperature control is temperature sensor.

Sensors must follow further requirements:

- High sensitivity;
- linearity and uniqueness of static characteristic (permissible non-linearity must not exceed 0,1-3%);
- stability characteristics over time;
- resistance to chemical influence and controlling environment;
- ease of maintenance and installation.

Sensors are selected in the way that the limit of measurement covers the range of value changes with overload handling ability of the sensor and the possibility of connecting to the selected control element.

In the greenhouse, the control temperature range is from 12 to 26 C°. Thus, there is a need to select the range of copper thermal converter type TCM-1088 (Figure 46), which has limits of the measurement range from -50 to 150 C°, and inertia is 20 seconds. Technical characteristics of the thermocouple is shown in Table 6.

Figure 46. Temperature transducer TCM-1088.

Table 6. Technical characteristics of TCM-1088.

Range of measuarable temperatures	-50 – 150°C
Inertia	20 sec
Pressure of the environment	0,4 MPa, 6,3 MPa, 10MPa
Length	120 – 3150 mm
Protection material	08X13
Class	A, B, C.
Nominal statical charachteristic	50M

Nominal static characteristic of TCM-1088 is shown on Figure 47.

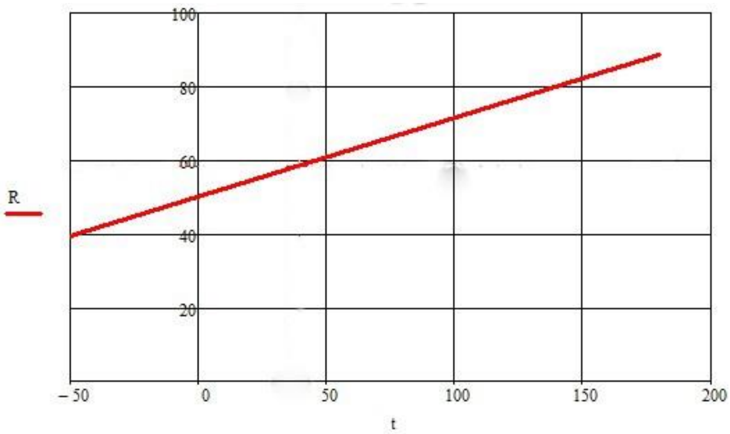


Figure 47. Nominal static characteristic of TCM-1088

Thermal convertors are inertial by their dynamical properties.

Transfer function of the sensor is following:

$$W(s) = \frac{k}{T \cdot s + 1} \tag{62}$$

where: k – is gain, and can be defined as per formula:

$$k = \frac{\Delta R}{\Delta T} \tag{63}$$

where: ΔT - the difference of temperature values (Fig. 3.20); ΔR - the difference of resistance values (Figure 47).

Then:

$$k = \frac{60-50}{50-0} = 0,2 \text{ Ohm/C°}$$

Time constant equals to the inertia value as per technical characteristics:

$T = 20$ sec

Thus, transfer function is following:

$$W(s) = \frac{0,2}{20 \cdot s + 1}$$

4.2.3 Selection of actuator

The executive mechanism is an automation device, which follows the commands from controller. Actuators designed for processing control signals and meant for working with the least error.

Actuators must meet the following requirements:

- the ability to have the necessary effort and adjustable time which is sufficient to reshuffle the control element of the object;
- ensure the possibility of adjusting the value of control element;
- to provide the necessary movement speed and acceleration of the control element.
- be robust and stable

Thus, there is a need to select an actuator engine type АИР 132S4. Technical characteristics of the engine are presented in section 5.1.

This actuator is an integrating element with transfer function as per expression:

$$W_{BM}(s) = \frac{k_{BM}}{T_{\mu} \cdot s} \tag{64}$$

where: $T_{\mu} = 2.8$ sec

$$k_{BM} = \frac{90}{220/50} = 20,45 \text{ deg/sec}$$

Thus, the actual transfer function is as follows:

$$W_{BM}(s) = \frac{20.45}{2.8 \cdot s}$$

4.2.4 Selection of control element (regulator)

Control elements (regulators) are designed to change the parameters for controlling the automation system

Regulator is the electric valve which controls and changes the water volume in accordance with the object needs. Regulating valves are used in the heating control and exchange systems based on hot water processing.

To select the regulator, the following data is needed:

$\gamma = 1$ g / cm^3 - total mass of water;

$\Delta P_c = 15$ kg / cm^2 - the absolute pressure in the heating system to regulator;

$\Delta P_{L\,max} = 4$ kg / cm^2 - maximum pressure drop in the line.

The maximum bandwidth of the regulator is as follows:

$$K_{\gamma\max} = Q_{\max} \cdot \sqrt{\frac{\gamma}{\Delta P_{\min}}} = Q_{\max} \cdot \sqrt{\frac{\gamma}{\Delta Pc - \Delta P_{L\max}}} \qquad (65)$$

where: Q_{max} - maximum volumetric flow of hot water, m^3 / h

$$K_{\gamma\max} = 150 \cdot \sqrt{\frac{1}{10-4}} = 61 \text{ m}^3/\text{h}$$

Thus, the regulator can be chosen as follows:

$$K_{\gamma} > 1{,}2 \cdot K_{\gamma\max} \qquad (66)$$

where: $K_{\gamma\,max}$ - maximum bandwidth (capacity)

Thus:

$$K_{\gamma} \geq 1{,}2 \cdot 61 = 73{,}2 \text{ m}^3/\text{h}$$

Hence there is a need to select the three-way control valve Honeywell V5328A (Figure 48) with a diameter of 75 mm and a bandwidth (capacity) of 75 m^3 / h.

Figure 48. Control element (regulator) Honeywell V5328A.

Transfer function of the regulator is as follows:

$$W_{PO}(s) = \frac{k_{PO}}{s} \qquad (67)$$

The adjustments of the viscosity index can be found per formula:

$$z = 420 \cdot \frac{Q_{\max}}{\nu \cdot \sqrt{K_{\gamma \max}}} \qquad (68)$$

Then:

$$z = 420 \cdot \frac{150}{0{,}2 \cdot \sqrt{61}} = 40384 > 1000$$

To define the working capacity of regulator, the following formula is used:

$$K_{\gamma L} = Q_{\max} \sqrt{\frac{\gamma}{\Delta P_{L\max}}} \qquad (69)$$

$$K_{\gamma L} = 150 \cdot \sqrt{\frac{1}{4}} = 75 \ \text{m}^3/\text{h}$$

The ratio of changes in pressure of regulator can be found as per formula:

$$n = \frac{K_{\gamma_{PO}}}{K_{\gamma_L}} \qquad (70)$$

where: $K_{\gamma L}$ - operating bandwidth of regulator m^3/h; $K_{\gamma PO}$ - nominal bandwidth regulator m^3 / h.

$$n = \frac{75}{75} = 1$$

To specify the pressure drop in the actuator, the following formula is used:

$$\Delta P_{AC} = \frac{\Delta P_C}{1 + n^2} \qquad (71)$$

$$\Delta P_{AC} = \frac{10}{1 + 1^2} = 5 \ \text{kg/cm}^2$$

To calculate the flow of fluid through actuator when the pressure drops on it, following formula is used:

$$Q_{AC} = K_{\gamma_{PO}} \sqrt{\frac{\Delta P_{AC}}{\gamma}} \qquad (72)$$

$$Q_{AC} = 75 \cdot \sqrt{\frac{5}{1}} = 167 \ \text{m}^3/\text{h}$$

To determine the relative maximum and minimum flow rate, the next formulas are used:

$$\mu_{\max} = \frac{Q_{\max}}{Q_{AC}}$$

$$\mu_{\min} = \frac{Q_{\min}}{Q_{AC}} \tag{73}$$

Thus:

$$\mu_{\max} = \frac{150}{167} = 0{,}9$$

$$\mu_{\min} = \frac{30}{167} = 0{,}18$$

$$k_{PO} = \frac{\Delta\mu}{\Delta l} = \frac{\mu_{\max} - \mu_{\min}}{l_{\max} - l_{\min}} \tag{74}$$

where: l_{min} = 0.3 i l_{max} = 0.52.

$$k_{PO} = \frac{0{,}9 - 0{,}18}{0{,}52 - 0{,}3} = 3.27$$

Thus, the transfer function is following:

$$W_{PO}(s) = \frac{3{,}27}{s}$$

4.3 Block diagrams of temperature control in greenhouse

Automatic control in greenhouses using alternative energy sources depends on the changes of the temperature.

The control object is a greenhouse. The temperature in the greenhouse is measured with a specified range by the heat Q, that comes from heating registers. Valve changes flow rate (hot water). Actuator move the valve on the value of φ (t). Perceiving element is the thermal converter (Sensor), which transforms the temperature Θ (t) into the voltage. Regulator controls the speed of change of the controlled parameter. The disturbance (F) is the temperature and humidity, precipitation, wind and so on. Functional-structural block diagram of temperature control in greenhouse is shown on the Figure 49.

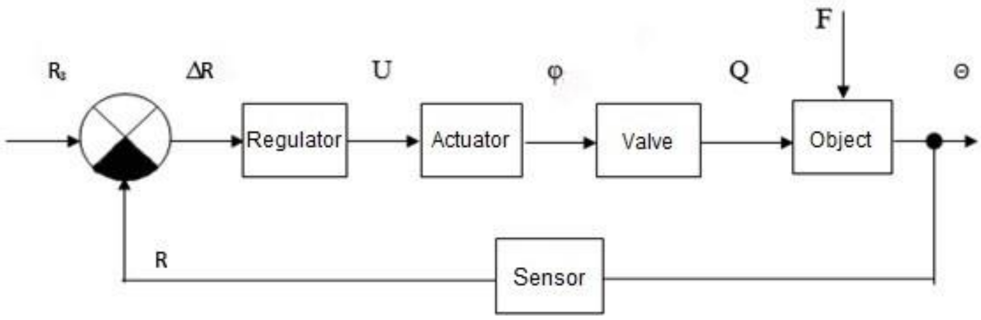


Figure 49. Functional-structural diagram of temperature control in greenhouse

where: Θ - the temperature in the greenhouse; R_S - setpoint value; ΔR - divergence signal; Q - heat flow; U - voltage; F - disturbance; φ - angle of valve rotation.

By this diagram, the structural and algorithmic diagram is presented (Figure 50). Here are instead of elements, shown theirs transfer functions. Structural and algorithmic diagram is a graphical representation of the functional elements of the system, which describes the mathematical model of control.

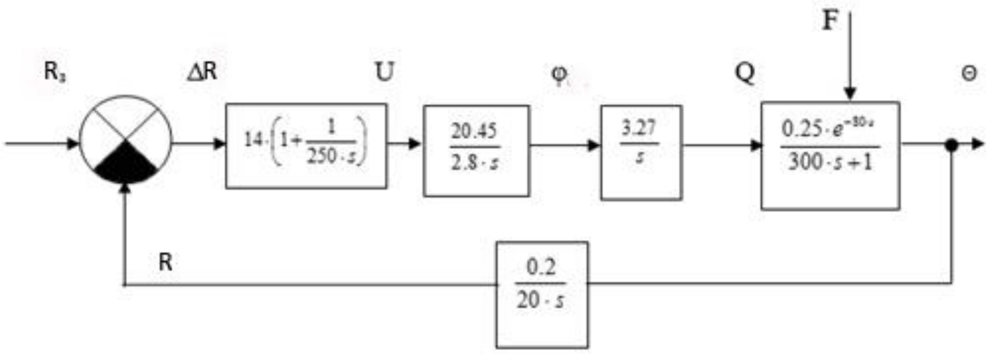


Figure 50. Structural-algorithmic diagram of temperature control in greenhouse

4.4 Stability criteria of temperature control in greenhouse

The evaluation criteria of stability is based on the use of the frequency characteristics. One of the criteria is sustainability Mikhailov criteria, which shows the stability of closed-loop control system by the performance of the vector in the complex plane.

For determining the stability of a closed-loop system, there is a need to define the characteristic equation:

$$C(s) = c_n \cdot s^n + c_{n-1} \cdot s^{n-1} + \ldots + c_1 \cdot s + c_0 = 0 \tag{75}$$

Swapping the imaginary parameter s to $j \cdot \omega$. Then the characteristic equation is:

$$C(s) = c_n \cdot (j \cdot \omega)^n + c_{n-1} \cdot (j \cdot \omega)^{n-1} + \ldots + c_1 \cdot (j \cdot \omega) + c_0 = X(\omega) + j \cdot Y(\omega) \tag{76}$$

The real and imaginary components of Mikhailov plot are as follows:

$$X(\omega) = c_0 - c_2 \cdot \omega^2 + c_4 \cdot \omega^4 - ... \quad (77)$$

$$Y(\omega) = c_1 \cdot \omega - c_3 \cdot \omega^3 + c_5 \cdot \omega^5 - ... \quad (78)$$

where: X(ω) – real component, Y(ω) – imaginary component.

The transfer function of open system is as follows:

$$W_{open}(s) = W_R(s) \cdot W_V(s) \cdot W_{AC}(s) \cdot W_O(s) \cdot W_S(s) \quad (79)$$

Thus:

$$W_{open}(s) = 14 \cdot \left(1 + \frac{1}{250 \cdot s}\right) \cdot \frac{3.27}{s} \cdot \frac{20.45}{2,8 \cdot s} \cdot \frac{0,25 \cdot e^{-80 \cdot s}}{300 \cdot s + 1} \cdot \frac{0,2}{20 \cdot s} =$$

$$= \frac{290 \cdot s \cdot e^{-80 \cdot s}}{s \cdot (250 \cdot s) \cdot (2.8 \cdot s) \cdot (20 \cdot s) \cdot (300 \cdot s + 1)}.$$

The transfer function of closed system is as follows:

$$W_{CLO}(s) = \frac{W_{open}(s)}{1 + W_{open}(s)} \quad (80)$$

$$W_{CLO}(s) = \frac{\dfrac{(290 \cdot s) \cdot e^{-80 \cdot s}}{s \cdot (250 \cdot s) \cdot (2.8 \cdot s) \cdot (20 \cdot s) \cdot (300 \cdot s + 1)}}{1 + \dfrac{(290 \cdot s) \cdot e^{-150 \cdot s}}{s \cdot (250 \cdot s) \cdot (2.8 \cdot s) \cdot (20 \cdot s) \cdot (300 \cdot s + 1)}}$$

$$W_{CLO}(s) = \frac{(290 \cdot s + 1,34) \cdot e^{-80 \cdot s}}{4200000 \cdot s^5 + 1500000 \cdot s^4 + 75000 \cdot s^3 + 250 \cdot s^2 + (290 \cdot s) \cdot e^{-80 \cdot s}}$$

Here we obtain the characteristic equation of the closed system of the 4th order:

$$C(s) = 4200000 \cdot s^5 + 1500000 \cdot s^4 + 75000 \cdot s^3 + 250 \cdot s^2 + (290 \cdot s) \cdot e^{-80 \cdot s}$$

$$e^{-80 \cdot s} = \cos 80\omega - j \cdot \sin 80\omega$$

$$C(j \cdot \omega) = 4200000 \cdot (j \cdot \omega)^5 \cdot 1500000 \cdot (j \cdot \omega)^4 + 75000 \cdot (j \cdot \omega)^3 + 250 \cdot (j \cdot \omega)^2 +$$
$$+ (290 \cdot (j \cdot \omega)) \cdot (\cos 80\omega - j \cdot \sin 80\omega).$$

From the above equations:

$$X(\omega) = 4200000 \cdot \omega^5 - 75000 \cdot \omega^3 + 290 \cdot \omega \cdot \sin 80\omega + \cos 80\omega$$

$$Y(\omega) = -150000 \cdot \omega^4 + 250 \cdot \omega^2 + 290 \cdot \omega \cdot \cos 80\omega - \sin 80\omega$$

The Mikhailov plot built in the Mathcad is shown on the Figure 51.

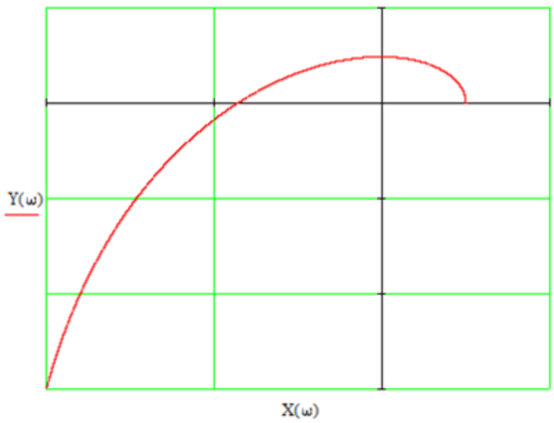


Figure 51 Mikhailov plot of the temperature control stability of greenhouse

Thus, as per Mikhailov plot, the system is stable.

4.5 Functional block diagram of temperature control in greenhouse

For the greenhouse complex of area 2592 m^2, is developed the functional block diagram of a climate control, using solar collectors and panels.

The main contours of greenhouse climate control are following:

Contour №1 - loop control of lower flow heating. Pipes of lower heating process are also used as a transport system for the movement of trucks to collect technological products (harvesting of crops).

Contour №2 - loop control of upper heating is designed to heat the upper zone of greenhouse. In the cold season with significant snow precipitation, the load on the glass covering significantly increases in the greenhouse which reduces the daylight entering the greenhouse. When that area greenhouses is heated, the snow on the actively roof melts and melted water flows down via special gutters to the catchment tank.

Contour №3 - loop control of vegetative heating to compensate heating loss in the lower area of the greenhouse and to maintain optimal temperature for plant roots.

Contours 1-3 are supplied with steel pipes of different diameters with hot water as a heating transporters. The temperature in the respective zone is converted by the relevant temperature sensors into an electrical signal, which is using the amplifier TT amplifies and goes to the automatic control device TIC. Automatic control device, depending on the temperature, creates the voltage to control the actuator that changes the flow of hot water through a 3-way valve of corresponding heating contour by changing the temperature in the respective zone of the greenhouse.

Contour №4 - loop control of lighting in greenhouses which is used for increasing amount of crops providing photosynthesis. This process is the result of absorption of light energy that is consumed mostly by leaves. Also photosynthesis releases oxygen into the atmosphere.

Contour №5 - energy saving loop control system of vertical curtaining (curtain screen). Using the curtain screens can significantly save energy because the main heat loss in greenhouses are made through overlapping. Thus, in the cold season, the heater temperature in heating system without curtain screens is 75-90 C°, and with the use of dual screen, the heater temperature in the pipes is 45-55 C°.

Contour №6 - loop control ventilation transoms in the greenhouse. It consists of a position sensor (opening) transoms GE and air velocity sensor which is a part of the climate station SE. If the temperature or humidity exceeds the set value, the automatic control device UAC creates control signal and actuator opens the transoms. If the air velocity exceeds the permissible value, to prevent the formation of "sailing" effect transoms are closed.

Contour №7 - control loop of solar collectors in the greenhouse. The collectors are used to heat water by using solar energy, which saves the energy, needed for heating greenhouses.

Contour №8 - control loop of solar panels. Through solar panel photovoltaic effect occurs transition from solar to electric energy. Battery is charged from the panel, which gives the voltage for lighting need.

The Figure 52 illustrates the main contours of temperature control in greenhouse by corresponding functional blocks.

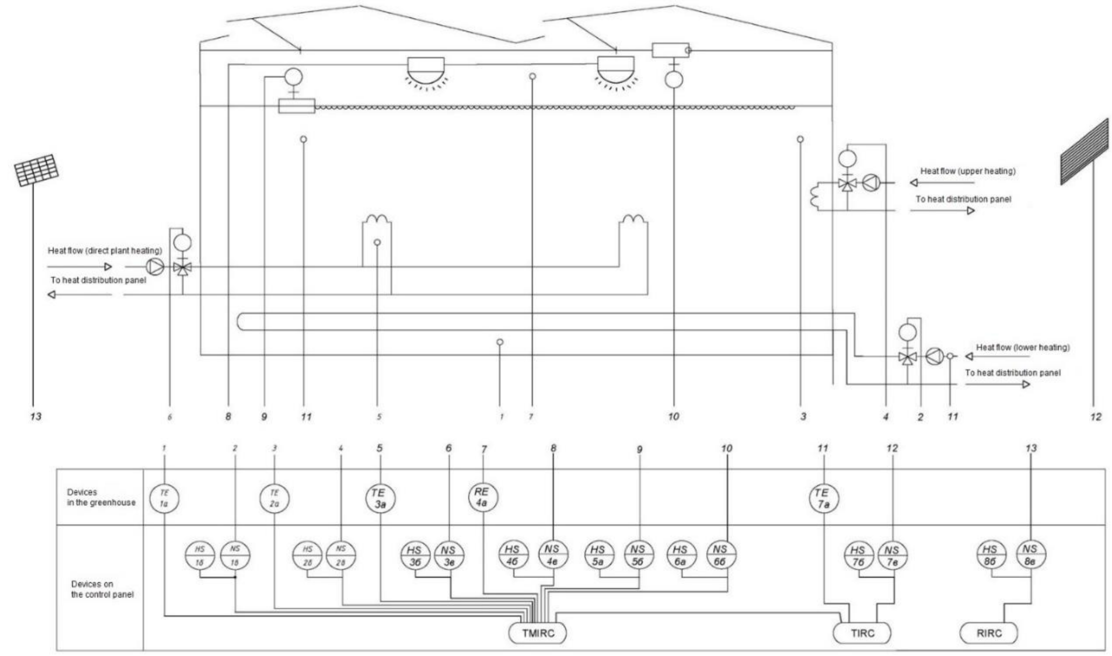


Figure 52. Functional block diagram of temperature control in greenhouse.

5 Technical implementation

5.1 Selection the actuator for water pumping

The actuator for the water pump must have productivity 3.33 m^3/sec, efficiency – 0.7, rpm 1400

Th calculate the power of pump, the following formula can be used:

$$P_H = \frac{Q \cdot \rho \cdot H \cdot g \cdot 10^{-3}}{\eta_н} \quad (81)$$

where: Q – pump productivity [m^3/sec], H - pump pressure, Pa η_H - pump efficiency, ρ - density of water, kg/m^3, g - gravity, g = 9.81 m/s^2.

$$P_H = \frac{3.33 \cdot 1000 \cdot 150 \cdot 9.81 \cdot 10^{-3}}{0.7 \cdot 3600} = 7\,\text{kW}$$

Pump loading diagram [12] is shown on Figure 53.

Figure 53. Pump loading diagram.

As an actuator to pump water, there is a need to choose a three-phase asynchronous motor series АИР 132S4 (Figure 54), whose characteristics are presented in Table 7.

Figure 54. Electrical motor АИР 132S4.

Table 7. Technical characteristics of the motor

Power	7.5ckW
Rotational speed	1460 rmp
Current at 380V	15,6 A
Power factor	0.84
Efficiency	86 %;
Mass	76 kg
Inertia	0.0227 kg·m^2
M_{min}	2.0
$\mu_{п}$	2.2
$\mu_{к}$	2.5
Frequency	50 Hz
Voltage	220/380 V

The electric motor is an actuator of a regulator. Electric motors are designed for long-term work in three-phase AC circuit with two ways of connection: triangle and star, depending on voltage 220/380 V. Engines are widely used in industrial and communal services, construction, compressors, mixers, shutter mechanisms, pumps, fans, conveyors and more.

Advantages of electric engine АИР 132S4:

- Energy saving;
- Low noise level;
- Increased multiplicity of starting points;
- High reliability of the engine;
- High speed;
- Long working hours;
- Ease of installation;
- Material of wires is copper;
- Reliable cooling system;
- Possible short-term overload;

- Ease of design;
- Robust bearings.

The selected motor satisfies the needs of the system and its transient response characteristics are shown on the Figure 55 [12].

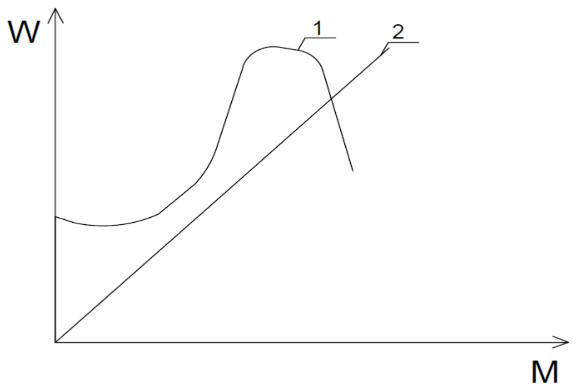


Figure 55. Transient response characteristics.

where: 1 - the acceleration time; 2 - characteristic of changes of the time when motor accelerates.

The most important is check the motor for the thermal conditions during launch (start), which can be done by the Formula (82):

$\tau_{all} \geq V_t \cdot t_s$; (82)

Where: τ_{all} - allowable temperature rise during cooling, Vt - speed of the winding during temperature rise at braked rotor, V_t = 8˚C/sec, t_s is time of start (0.06 sec)

τ_{all} = 70-40 = 30˚C;

30 °C ≥ 8·0,06 = 0,48 °C

Hence condition is satisfied, as the electric motor does not overheat during start.

The test on the motor's starting torque is not required, as momentum of start is not large.

The test on the motor overload capacity is not required, because the engine runs with a constant load.

5.2 Selection of the technical equipment (switch, magnetic starter, relay, circuit breaker)

Technical equipment is meant for safe start, control and stop of the system.

Electrical apparatus is selected by current, voltage, capacity, number of poles, electrical protection requirements from abnormality of work and depending on environmental conditions [6]. The electrical equipment must satisfy following requirements:

- Nominal voltage of network: $U_N \geq U_{N.Net}$
- Current of the network: $I_N \geq I_{N.cont}$, $I_{sw} \geq I_{N.cont}$

where: I_N – nominal current; I_{sw} – the largest switching current, $I_{N.cont}$ – continuous current of the circle

Packet switches are used for infrequent inclusions (up to 30 times per hour) and shutdowns circuits with a voltage of 380 V and 220 DC and are used to control (ON/OFF, signalling and recording) power and lighting equipment.

To select the packet switch, there is a need to consider the inequalities: $U_N \geq U_{N.Net}$, U_N=24 V;

where: U_N is the nominal voltage of the switch, $U_{N.Net}$ is the nominal voltage of network.

$I_{sw} \geq I_{short}$,

where: I_{sw} is the current of the switch, I_{short} – short circuit current

Thus, here is selected packet switch ПКП Е9 100А/3.833 for switching control circuits with voltage 24…500 V and current 10 A (Figure 56).

Figure 56. Packet switch ПКП Е9 100А/3.833.

Electromagnetic starters are key devices for automatic control equipment. They are designed for remote start by plugging directly into the network, stop and reverse-phase asynchronous motors with short circuit rotor. If the starters have a relay, they also protect motors from overload [6].

The started can be chosen by requiring following inequality: $U_{N.St} \geq U_{N.Net}$, $I_{St} \geq I_{N.cont}$

where: $U_{N.St}$ – nominal voltage of starter, I_{St} – current of the starter

The continuous current $I_{N.cont}$ is 5.6 A [6], thus we can select the starter ПМ 1-09-10 380В 9А, which requires the above mentioned requirements (Figure 57).

Figure 57. Magnetic switch ПМ 1-09-10 380В 9А with following characteristics: $U_{N.St}$ =380V, I_{St}=9A.

To select the relay the following requirements are needed to be followed: $I_N \geq I_{N.cont}$, ($I_{N.cont}$ = 5.6A). Thus the relay Eaton (Moeller) ZB12-10 with I_N=7A (Figure 58).

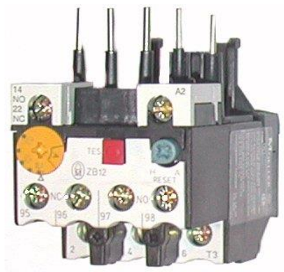


Figure 58. Relay Eaton (Moeller) ZB12-10.

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current, typically resulting from an overload or short circuit. Its basic function is to interrupt current flow after a fault is detected. To select the circuit breaker there are following requirements:

$U_A \geq U_M$ 380 V=380 V;

$I_A \geq I_H$ $25A > 5{,}6A$;

$I_{open} \geq I_H$ $25A > 5{,}6A$;

Thus, here is selected the circuit breaker E.Next s001010/25A which is shown on the Figure 59.

Figure 59. Circuit breaker E.Next s001010/25A

Mentioned above equipment can be used for implementing the system.

6 Summary

This master thesis analyses the alternative energy sources and the efficiency of their usage in greenhouses. The system of temperature control is shown where solar collectors are used to heat the water which is heating the greenhouse. This system uses data taken in Ukrainian industrial greenhouse and can be implemented in Estonia.

The results of the study in the master's work formed following conclusions:

1. Analysing the different technologies of renewable energy found that the most economical is to use a hybrid system using solar collectors to heat water for heating greenhouses and solar panels that generate electricity for lighting.
2. A simulation model of hybrid heating system in greenhouse using solar collectors which can provide information about temperature loss of water and air and water temperature in the tank with accordance to time.
3. The system automatically controls the temperature conditions using software controller. Selected control mechanism, actuator, sensor and other elements of the system. Built: functional, functional-structural and structural-algorithmic diagrams. Possible implementation is described by selection of hardware.

7 References

1. https://goo.gl/zCOKDb
2. https://goo.gl/y042eQ
3. Ефективність енергозберігаючих технології в овочівництві закритого грунту: дисертація / В.Ф, Іваненко – Київ: 2015 – 186 с.
4. Ефективність альтернативних джерел енергії у тепличному господарстві / Л,П, Червінська, В.Ф. Іваненко – Київ: 2013 – 10 с.
5. Розробка системи опалення та математичної моделі процесів тепло- і масопереносу в теплицях з використанням альтернативних джерел енергії / В. Г. Горобець, О. В. Яценко – Київ: НУБІП, 2014. – 13 с.
6. Мартиненко І.І., Лисенко В.П., Тищенко Л.П., Болбот І.М., Олійник П.В. Проектування систем електрифікації та автоматизації АПК Київ, Інтас. - 2008. – 305 с.
7. Електроенергетика та охорона навколишнього середовища. Функціонування енергетики в сучасному світі: науково-пізнавальне видання // С.Г.Плачкова, І.В. Плачков., Н.І. Дунаєвська – Режим доступу: energetika.in.ua/ua/books/book-5
8. Технічні засоби автоматики: Навчальне видання // Ю.А. Климентовський, А.М. Гладкий. – К.: Видавництво «КВІЦ», 2003. – 238с.
9. Теорія автоматичного управління: Навч. Посіб. // Б.Л. Головінський, Ю.В. Шуруб, В.П. Лисенко - К.: Вид. центр НУБІП України, 2012. – 240 с.
10. Типові технологічні процеси і об'єкти виробництв. Метод. вказівки для підготовки, виконання та самост. опрацювання лабор. Робіт / В. Решетюк, В. Мірошник. – К.: НУБІПУ, ПП «Універсіл», 2009. – 83 с.
11. Охорона праці в галузі (Електробезпека). Метод. вказівки до практичних занять / В.Г. Тракай - К.: Редакційно-видавничий відділ НУБІП України, 2016 – 68 с.
12. Методичні вказівки щодо виконання курсової роботи з дисциплін «Електропривод сільськогосподарських машин, агрегатів та потокових ліній»,

«Електропривод виробничих машин і агрегатів» / Ю.М. Лавріненко, О.Ю. Синявський, В.В. Савченко - К.: Видавничий центр НУБІП України, 2010 – 47 с.

13. Підручники – навчальні матеріали онлайн [Електронний ресурс] – Режим доступу до ресурсу: http://pidruchniki.com/13820328/ekologiya/alternativni_ dzherela_energiyi/

14. Офіційний сайт Української Асоціації відновлюваної енергетики [Електронний ресурс] – Режим доступу до ресурсу: http://uare.com.ua/.

15. Офіційний сайт сервісної компанії Ліміт [Електронний ресурс] – Режим доступу до ресурсу: http://www.limit.kiev.ua/uk/rizne/perevagi-gollandskih-tehnologiy-v-teplichnomu-budivnitstvi/

16. Перспективи використання енергії та палива в Україні з нетрадиційних та відновлюваних джерел // Дероган Д.В., Щокін А.Р..//Бюл. "Новітні технології в сфері нетрадиційних і відновлюваних джерел енергії", Київ: АТ "Укренергозбереження",1999.- №2, - С.30-38.

17. Офіційний сайт ТОВ «СВ АТС-Україна» [Електронний ресурс] – Режим доступу до ресурсу: http://www.agrotechnical.com.ua/RU/oborudovanie/kons trukcii-teplic/

18. Офіційний сайт «ЕКОЦЕНТР з впровадження альтернативних джерел енергії» [Електронний ресурс] – Режим доступу до ресурсу: http://www. eco svit.net/ua/sonyachni-kolektor