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Improvement of Parameters of Microclimate of Underground Thermos Greenhouses

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Abstract

The main reason for applying microclimate control in greenhouses is to achieve optimal growing environment. Because of its complexity, excessive control in greenhouses can adversely affect the cultivation of crops. Moreover, we have optimum control to achieve these challenging goals, including lower emissions and reduced production costs. The most important stage in the research of algorithms of management of technological objects is to develop a model of the object, which reflects the processes occurring in the object. Typical solutions for managing objects are based on simple models, operating with abstract parameters. Such models, in connection with the abstract nature of the parameters do not allow in-depth study and changes in the characteristics of the object. For more in-depth research and synthesis of automatic control systems of interest are models that reveal the physical basis of operation of the facility. This article describes a practical approach about greenhouse control system

Keywords: parameters of microclimate, thermos greenhouse, optimal environment

INTRODUCTION

The world population is expected to grow by one more billion people within the next 13 years. Conventional agricultural methods show obvious limitations and are not efficient enough to produce sufficient food for everyone. Land that is unprofitable for traditional farming contributes to shortages, by urban conditions that prevent self-sufficiency. Drought conditions and the lack of access to certain resources exist all over the world and are the most important cause of food insecurity on the continent. There is, however, enough sun light and water to sustainably feed the world population.

Poverty and food insecurity are closely linked. There is, therefore, also a need to empower people financially through providing appropriate and sustainable agricultural technologies that are proven to be useful, to increase agricultural productivity. Recent research work done on boosting smallholder production for food security indicated that food insecurity is linked to strong institutional support and external environment and that certain policies and strategies, developed to increase agricultural productivity, can have a substantial contribution towards reducing the general food insecurity status of the country. One of the proven agricultural technologies for growing farm product in controlled conditions is use of greenhouses. Due to the aridity of the land, water scarcity and declining soil health in Kazakhstan, the popularity of greenhouse crop production is expected to increase. Greenhouse production can contribute in achieving the strategic objectives of the plan for Kazakhstan's agriculture related to:

- An increased creation of wealth in agriculture and rural areas,
- increased sustainable employment,
- increased incomes and increased foreign exchange earnings,
- reduced poverty and inequalities in land and enterprise ownership,
- improved farming efficiency,
- improved national and household food security, and stable and safe rural communities, reduced levels of crime and violence and sustained rural development.

Development of small-scale and even large-scale greenhouses all over Kazakhstan can have a significant impact on food security, malnutrition and economic development in Kazakhstan. The national government of Kazakhstan is in support of projects like these and it is critical to ensure that the outcome is successful and sustainable. Several different types of greenhouse structures are available in Kazakhstan. However, there is limited sufficient scientific information available on the performance of different types of greenhouses, cooling systems, heating systems and climate control installations. Since the typical climate of Kazakhstan generally causes supra-optimum temperatures in greenhouses, the focus of studies should be on comparing the performance of different cooling systems in the country. Similarly, there are no comprehensive studies aimed at screening and analyzing the low-cost greenhouses concerning the sustainability of producing food crops, with less intensive climate control. Typical cooling systems installed in Kazakhstan include evaporative cooling (fogging, pad and fan) and natural ventilation (roof/side or roof and side ventilation or the use of shade netting). Based on the above analysis, a study on the engineering of sustainable and appropriate greenhouse technologies in Kazakhstan needs to be undertaken, in order to identify or develop the best greenhouse technologies that can be the best-fitted to the different agro-climatic conditions in the country.

Experimental studies were carried out in Zhetysu State University named after Ilyas Zhansugurov in Taldykorgan. The average maximum air temperatures vary between 20.6 and 27.8˚C and the average minimum temperatures vary between-6 and 7.4˚C. Solar radiation varies between 15.1-27.8

MJ.m-in two days and the daily average RH ranges between 61.1-75.3%.

Materials and Methods

To solve these tasks is used the conservation of energy, the theory of mathematical modeling, automatic control theory, the theory of identification; programming theory. The following describes the way research greenhouses and various materials and procedures are used.

SUBSTANTIATION OF PARAMETERS OF MICROCLIMATE IN GREENHOUSES

Greenhouse climate parameters

Plants require specific factors that enhance growth resulting from photosynthesis. Physiological fluxes are optimized by limiting plant stress caused by unfavourable climate parameters. These parameters, namely, temperature, relative humidity, light and carbon dioxide, are given in the sections below.

Temperature

Temperature has a direct impact on the physiological development phases (flowering, germination, development) of the plant, controls the transpiration rate and, in turn, controls the plant water status through stomatal control during the photosynthesis. Temperature requirements in a greenhouse depend largely on the type of crop to be grown.

Each crop and its development process responds differently to temperature. High temperatures generally cause an escalation in plant growth rates, with an increase in leaf area. It then stimulates a greater transpiration rate in the plants, which try to cool down, and this can result in water loss and an imbalance of the distribution of photosynthesis. This can, in turn, cause physical disorders and restrict the reproductive development of plants.

The difference between day and night temperatures, as well as the average 24-hour temperatures can also affect plant growth. Low temperatures can have a significant effect on growth rates and can influence fruit and seed production. As further described in Section 6, Kazakhstan is characterized by several different climatic conditions. Temperature of climate area plays a large role in greenhouse design. When it comes to greenhouse production, Kazakhstan generally has very high temperatures that can limit the success of all-year-round greenhouse crop production. This will be carefully considered when designing structures and control systems.

Relative Humidity

It is critical that the correct balance of temperature and humidity kept in the greenhouse. Humidity control remains a challenge and high or low humidity levels affect plant development. Vapour pressure deficit (VPD) is the difference between the air’s moisture content and the amount of moisture air can hold when it is saturated. High VPD usually caused by high temperatures and low humidity and affects plant growth by causing high stomatal resistance and plant water stress and the plant transpires more water than it can absorb. Low VPD, in turn, caused low plant transpiration and associated physical disorders.

The main challenge with humidity control is the interaction with temperature. Many greenhouse operations are moving towards controlling the greenhouse according to VPD or moisture deficit, which measure the combined effect, rather than controlling only the relative air humidity (RH). Areas specifically on the Kazakhstan’s line have very high humidity and the effect of such external conditions can have detrimental implications on greenhouse crops. Designs and control systems have thus to be adjusted for these specific conditions. Moreover, the effectiveness of different greenhouse designs and control systems in terms of maintaining the optimum inside relative air humidity needs are understood.

Light Intensity

The growth of plants is controlled by three light (photo) processes, namely photosynthesis, photomorphogenesis and photoperiodism. Every variation in light has a direct effect on these processes. Light is part of the photosynthesis process, by converting carbon dioxide into organic material and then releasing oxygen in the presence of light. Photomorphogenesis is the way of plants developing under the influence of different types of light and photoperiodism is how the plant reacts to different day-lengths and whether it will seed or flower. The most important process is photosynthesis and light is the primary energy source to enable this process. In Kazakhstan, light levels are generally sufficient for effective plant production and artificial lighting is only for crops that need longer day lengths.

Carbon Dioxide

Carbon dioxide (CO2) is the primary substrate for the creation of photosynthates during photosynthesis. It accelerates plant growth by increasing net photosynthesis in plants. A well-ventilated greenhouse in Kazakhstan with healthy gas exchange rates and air circulation should ultimately have CO2 levels of approximately 300ppm. Increasing CO2 levels from the natural level to a concentration of between 700 and 900 µ11-1 enhances plant growth. Recent studies have shown that plants do not really benefit much from dosing when CO2 levels exceed 1000 µ11-1. CO2 is absorbed via stomata in the plant and effective absorption of CO2 in a greenhouse is, therefore, strongly dependent on other climate factors affecting the stomata openings in the plant.

Climate control installations

Cooling Systems

A big challenge of greenhouse growing and greenhouse production is cooling of the internal climate. High summer temperatures directly influence the success of year-round greenhouse crop production. Greenhouse designers should consider the economic viability of a cooling system that successfully controls the microclimate of the greenhouse in relation to external climatic conditions. A brief description of the different technologies and challenges are provided in the subsections below.

Greenhouse ventilation systems

The greenhouse structure will be specifically designed to the choice of ventilation and cooling. Net solar radiation in a greenhouse can reach values ranging between 500 and 600

W.m-2. To maintain the inside temperatures of the greenhouse close to the outside temperatures, about 200-250 W.m-2 of sensible heat will be removed.

Ventilation will provide temperature control to prevent the extreme build-up of heat during the summer months, to control excessive humidity in the greenhouse and to ensure sufficient air exchanges size outside and inside of a greenhouse (to manage carbon dioxide and oxygen levels in the greenhouse).

Natural ventilation is the result of pressure differences created by wind and temperature gradients between the inside and outside of a greenhouse. It occurs through openings in the greenhouse structure. It controls humidity and temperature build-up within the greenhouse and can ensure sufficient air exchange. It requires less energy, in some cases no energy (fixed ventilation openings), and is, therefore, the cheapest method for cooling greenhouses. Natural ventilation works better than other cooling technologies for greenhouses, especially in humid, tropical and subtropical regions. Ventilation openings will be optimized in order to attempt to cool of the greenhouse, even in low wind speed conditions. Ventilation areas should at least be 25-30% of the greenhouse floor area for most of our local Kazakhstan regions. However, limited data is available in Kazakhstan on which designs and ventilation systems are scientifically proven the most effective, with specific outside conditions.

Forced ambient air ventilation will be also implemented by installing exhaust fans and blowers. Forced ventilation can reduce the internal air temperature of the greenhouse and improve greenhouse conditions. Certain experiments, however, have shown that forced ventilation without evaporative cooling pads might actually increase internal greenhouse temperatures with outside conditions of low humidity and high temperatures.

In several regions of Kazakhstan, closed greenhouses have been built, where forced ventilation is used, but because of rising electricity costs in the country, developers are moving away from this concept. The cost-effectiveness and performance of certain designs will be, therefore, be evaluated in detail, prior to deciding on a system. Scientific empirical data and accurate modelling are required to property evaluate this.

Shading

Direct solar radiation is the primary source of heat gain in greenhouses. This should be controlled by shading or reflection. Shading will be done using several different approaches, such as internal and external shade screens, paints and nets. Shading might negatively influence plant development and photosynthesis because of the reduction of light and the possible effect on ventilation rates/gas exchanging. Hence, care will be taken, when deciding on the type of shading and associated control strategies. Partially reflected internal shade screens will be installed and have been proven to reduce the greenhouse air temperature by 6˚C, compared to ambient temperatures. The screens contain highly reflective aluminized materials, usually woven with plastic thread. The screens reflect the unwanted solar radiation from the greenhouse roof, while still allowing some light transmittance.

Many producers use paint/whitening on the roofs of the greenhouse for the cooling effect. It is an inexpensive method, has proven to effectively reduce the VPD, air temperature and canopy-to-air temperature, and has a positive effect on the microclimate of the greenhouse. Whitening also transforms a large part of the direct radiation into diffused radiation, which will been proven to increase the absorbed radiation by the crop. Another benefit of this cooling method is that it does not influence the ventilation rate of the greenhouse.

External mobile shade clothes are also used for shading and have been proven to reduce crop transpiration and internal VPD. They are preferable because it prevents the heat input in the greenhouse. External screens have to withstand all atmospheric conditions and are therefore expensive to install. Internal shade screens are often used in Kazakhstan’s greenhouses, but they also have a negative effect on light and ventilation rates, as described above.

Evaporative cooling

Evaporative cooling does not only decrease the air temperature in greenhouses, but also increases the absolute internal humidity and is therefore often more desirable in certain regions than the other cooling technologies. Fan-pad systems, fogging systems and roof evaporative cooling systems are generally the most common and effective evaporative cooling installations for greenhouses. Its suitability is restricted to certain regions due to limited evaporation in most humid regions and it seldom suits tropical and subtropical climate regions. With evaporative cooling, water evaporates and absorbs the heat from the air and, in turn reduces the air temperature. It is as the most effective way to control temperature and humidity inside a greenhouse.

The fan-pad system consists of a fan on one gable end and a wet pad on the opposite end. A small stream of water runs over the pad continuously and air is drawn through the pad by the fans, absorbing heat and water vapour in the greenhouse. It also increases the humidity of the internal air. This installation has shown a reduction in air temperature of up to 12˚C, even under very high ambient temperatures. The length of the greenhouse will be considered, as the efficiency might decrease and large temperature gradients can be expected across greenhouses of longer lengths. Other disadvantages are that it is an expensive installation with high operation costs, namely, freshwater supply, electricity and the maintenance costs.

Fogging installations are used to increase relative humidity and cooling inside of greenhouse. Water is pumped through high pressure nozzles and sprayed as extremely fine droplets into the air. The decrease in droplet size increases the surface area per unit mass of water, which increases the heat and mass exchange between water and air and, in turn, increases the evaporation rate. The evaporation effect causes cooling, as well as humidification. Nozzles are usually installed just below gutter height and can be distributed throughout the greenhouse to ensure a uniform effect, which has proven more effective than the fan-pad system in terms of variations in temperature and humidity across the greenhouse.

Roof evaporative cooling includes spraying water onto the external surface of a roof and this creates a thin water layer on the surface. This decreases the solar radiation transmissivity to the greenhouse and increases the evaporation rate, which consequently decreases the water temperature and closely surrounding air. Again, this system will work most effectively in hot, dry climate regions. Literature shows that evaporative cooling (fogging, and pad and fan) has potential for controlled farming under the arid and semi-arid conditions of Africa, as well as Kazakhstan.

Solar radiation filtration

Global solar radiation enters a greenhouse as three different types of radiation, namely, ultraviolet radiation (UV), photosynthetic active radiation (PAR) and near infrared radiation (NIR). Most of the UV radiation is absorbed by the Earth's atmosphere. The extreme exposure of plants to UV can result in the degradation of the photosynthetic process. PAR is absorbed by the plant and is important for photosynthesis and plant growth. NIR is less absorbed by the plant and more by the greenhouse structure and equipment, causing the increase in ambient temperature in the greenhouse. Cooling of greenhouse is by modifying covering materials has been investigated and implemented for many years. NIR-filtering is also done by using specific plastic cellophanes, glass for greenhouses, moveable screens or NIR filtering shading paint.

Internal Air Circulation System

Internal air velocities of a greenhouse are recommended to be between 0.5 to 0.7 m.s-1 for optimal plant growth, by facilitating gas exchange (CO2 and water vapour). To ensure this, fans are often installed above the crop. The number of fans that have installed in the greenhouse calculated to ensure 0.01m3.s-1 per m^2 and have installed in the direction of the ridge. Distances between the fans should not exceed 30 times the diameter of the fans.

Air Humidification

Other than using fogging installations for cooling and humidity control, the following systems are also generally used for humidification only:

a) Steam,
b) High pressure humidifiers, and
c) Pulsators.

Steam boilers are often used in colder countries to supply heat or for humidity control in greenhouses. Heaters will be used to create saturated vapour that is then pumped into the greenhouse.

For high pressure humidifiers, compressed air is used to split water into tiny droplets and then propel through the greenhouse in an air stream. Pulsators are generally used for irrigation, but are often used for overhead irrigation and then also serve for humidification of the greenhouse. Pulsator drops are thus much larger than high pressure humidifiers, but will still be successful.

Carbon Dioxide Control

As previously described, carbon dioxide (CO2) enrichment systems have shown positive effects on plant growth for many years. CO2 enrichment is usually a source of fuel combustion. A brief description of some CO2 enrichment systems that are available are given below:

- Liquid CO2: Pure CO2 pumping from containers to the greenhouse is the purest type of CO2 enrichment. Like many other systems, it does not have the greenhouse heating effect. The disadvantage of this system is the high cost of transporting gas containers.
- Fuel combustion: Burning liquid kerosene, propane-butane gas or natural gas produces CO2 as part of the gas emissions through the burners. Heat is also produced by this type of operation and is often the primary reason for the installation. The constraint of these systems is that CO2 can only be dosed when heat is also required in the greenhouse. The choice of the type of fuel is general based on availability and cost per unit and the purity of the gas emissions.

Dosing will be specifically controlled according to light levels, temperature and ventilation in greenhouses, to ensure the efficiencies are optimized.

CLASSIFICATION AND DESIGN OF GREENHOUSES

Existing greenhouses of industrial type can be classified by a number of operational and construction features: by seasons, growing technology, the type of material of the frame and translucent fencing, spacebar heating and ventilation.

The purpose of the greenhouse is divided into vegetable and seedling, and a seedling greenhouse for growing seedlings for open and protected ground differs in technological equipment and design of ventilation systems.

Duration: all year (winter) and seasonal (operated in spring, summer and autumn). As a rule, the greenhouse frame is installed in a permanent place with the exception of mobile greenhouses, widely spread in some North-Western regions for growing seedlings and early greens of perennial vegetable crops.

By cultivation distinguish rack, soil and hydroponic greenhouses. In turn, the hydroponic greenhouses can be fitted with different equipment in accordance with the method of growing. There are greenhouses with traditional, classical way of supplying the nutrient solution by the method of flooding in which plants are grown in concrete sealed trays or racks filled with granite gravel or expanded clay.

In recent times the wide spread of various methods of small-scale culture of growing plants are used in peat-based substrate with the use of drip irrigation systems, running water and aerovega culture, aeroponic culture, etc.

As the material of the frame in greenhouses galvanized steel and aluminum profiles, wooden laminated elements are used.

By appearance of translucent fencing greenhouses are divided into glass and cellophane greenhouses with a coating of hard polymer materials. Cellophane covers are used in this situation. To save energy, special dual-layer rigid polymer materials apply with an air gap between the layers 5-25 mm.

By design and planning solutions greenhouses can be divided into agrarian and block, according to the sectional profile to lean with equal and unequal slopes, with flat, cylindrical and hyperbolic rays.

The greenhouse is the most advanced type of cultivation constructions. Significant difference of greenhouses from other types of plants in protected ground is the ability to create favorable conditions not only for growing plants, but also for staff and technological equipment. As a result, greenhouses increase the productivity of labor and production culture, the seasonal nature of agricultural work disappears. In a greenhouse than in contrast to the small shelters and greenhouses can without changing the integrity of the fencing all agricultural activities, as well as widely used various mechanisms to care for the plants.

One of the first types of greenhouses is “Klin” greenhouse. It had a blank north wall and south facing with glass roof. This design provided a good thermal insulation and lighting in the winter months. Greenhouses of similar design currently are widely accepted and recommended for construction on private land. One of the options (shed buried in the ground of the greenhouse) is given in (figure 1).

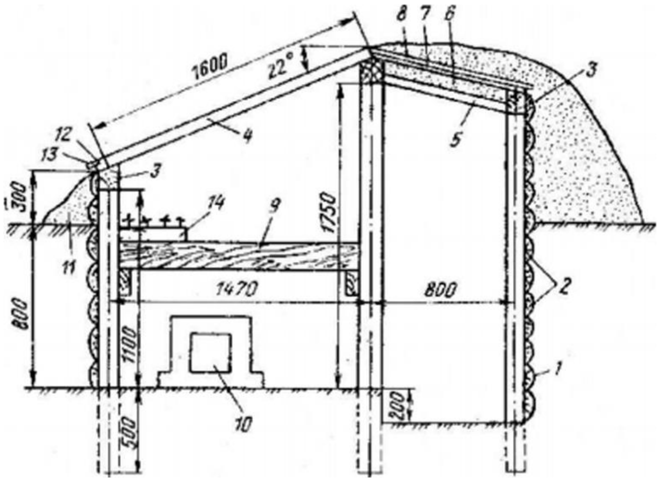

Figure 1: Winter lean-to greenhouse. 1-pillars; 2-cladding of the slab; 3-rail; 4-greenhouse frame; 5-facilities; 6-saw; 7-roofing; 8-earth backfilling; 9-rack; 10 duct; 11-slope; 12-resistant Board; 13-low tide; 14-a box of seedlings.

Today, when we increase the area of greenhouses lean-two greenhouses gave way to the hangar greenhouses. They do not have any internal supports. A typical example of such greenhouses to individual owners is a winter greenhouse with a gable roof of the greenhouse frames (figure 2).

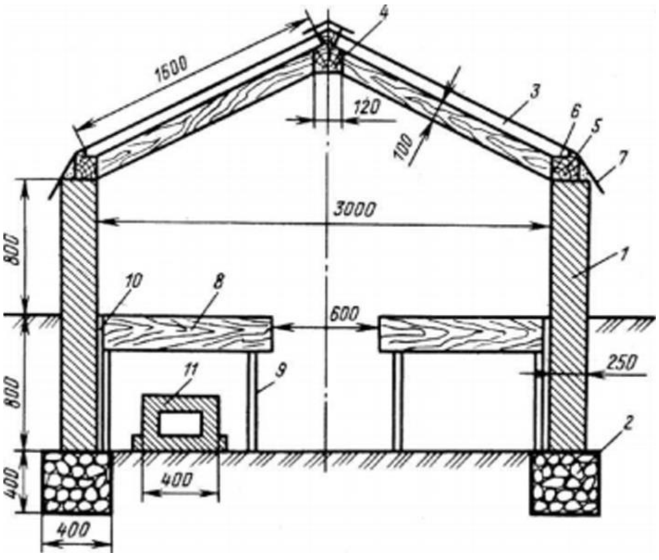

Figure 2: Winter gable greenhouse. 1-wall; 2-foundation; 3-rafters; 4-ridge bar; 5-wrap timber; 6-groove for the stop frame; 7-low tide; 8-rack; 9-rack; 10-the gap between the wall and the rack; 11-chimney

Along with gable hangar greenhouses with flat slopes are widespread, the sectional profile of which is close to the arc of a circle or is a broken line (polygonal profile). As a rule, these greenhouses are covered with a cellophane of polymeric material (figure 3).

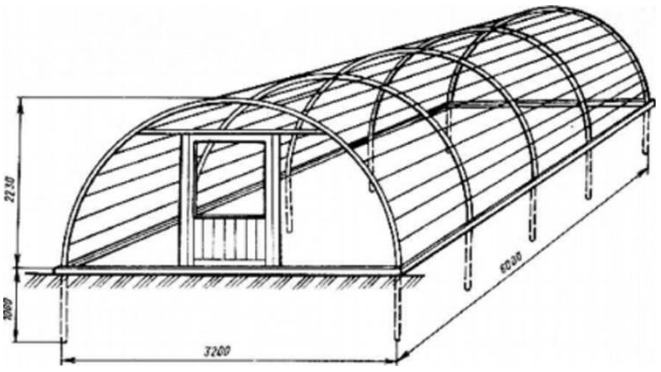

Figure 3: Arched greenhouse for personal use

However, the cylindrical shape is of the possible collection of water and snow in the upper area of the roof, the formation of "bags" and as a result it brings shading of plants and the destruction of the coating. Therefore, a more preferred is hyperbolic or arrow-shaped form of the roof (figure 4).

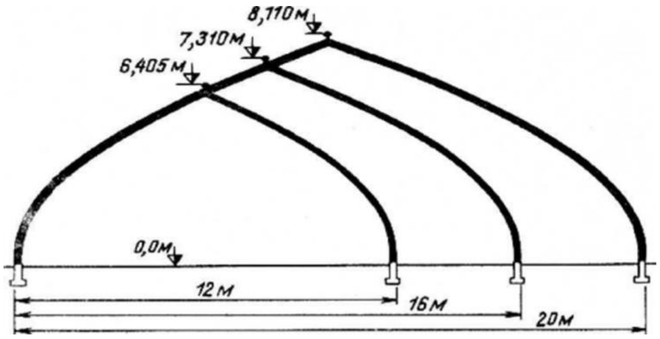

Figure 4: Modification of the frames of the Finnish greenhouses

Block greenhouses include an arbitrary amount of hangar. The walls between adjacent greenhouses will be take away and the supporting stands will be leave. Change of the size of the greenhouse is possible by increasing the number of sections and their length. This feature is widely used in practice, when based on a standardized kit of parts to create the greenhouse area of 50-6,000 m^2.

We offer the model of underground thermos-greenhouse

Underground thermos-greenhouse has been installed in the training and production phase of Zhetysu state University named after I. Zhansugurov, Almaty region, Taldykorgan. (Fig. 5).

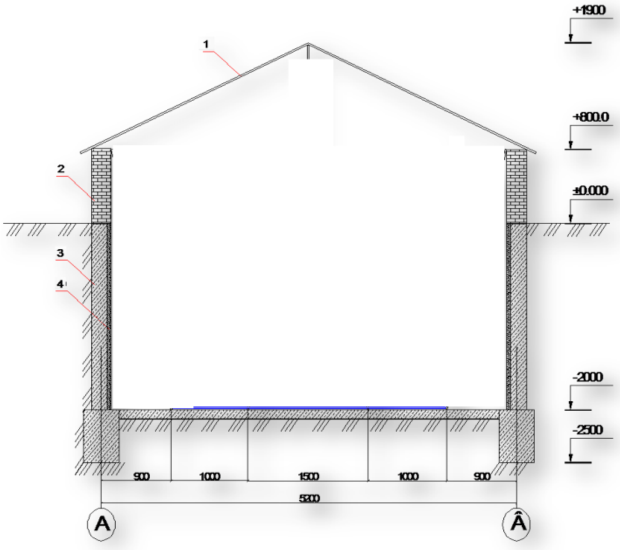

Figure 5: Underground greenhouse-thermos. 1-polycarbonate, 2-brick, 3-reinforced concrete wall, 4-light reflective material.

The main feature of this greenhouse is economical in its using of energy for heating. Of course greater efficiency savings depends on how this greenhouse is buried in the ground.

Although the greenhouse-thermos can build on the ground, but the best effect to retain heat in the greenhouse is achieved if the greenhouse is partially or completely embedded in soil. From this stems the second feature is the greenhouses' construction.

The third feature is reflective wall, which is supported by high light in the greenhouse. In cloudy weather, this greenhouse is lighter respectively two times higher than in open areas. This gives an advantage over other greenhouses in the winter period, as in sunny weather the heat inside will be by solar energy.

Due to the bright lighting and constant temperature we can achieve the high of harvest of more than to 30%.

When we use energy-saving technologies, we can decrease costs by 45%, which contributes to a rapid payback in 2-3 years.

The measures and techniques for installation and fastening of sheets from polycarbonate, ensure sufficient tightness of connections and eliminate the possibility of heat loss.

Recommendations for the care of the soil in the greenhouse and lighting parameters.

The use of solar energy for energy supply will help to replace from 20 to 60% of the thermal load on the objects of agriculture, depending on climatic location, to exclude the cost of shipping fossil fuels (important for remote users), to prevent pollution of the environment and agricultural products.

MICROCLIMATE CONTROL IN GREENHOUSES

The main reason for applying microclimate control in greenhouses is to achieve optimal growing environment. Because of its complexity, excessive control in greenhouses can adversely affect the growing crops. Moreover, we need an optimal ambiental control to accomplish these complicated objectives, including low emissions and reduced production costs. This paper describes one practical approach to the real-time control system in a greenhouse. Control system considers internal and external ambient factors related to the regulation process. Control system cyclically reads the data from the sensors and implements appropriate response on the actuator, based on required greenhouse conditions. Most challenging was the design of the control algorithm for this kind of process, due to the complexity of influential greenhouse variables.

In order to achieve optimal plant growth and maximize the yield, microclimate in greenhouses should be closely monitored by advanced mechatronic systems. According to the intrinsic greenhouse features, the setting and tuning of greenhouse climate controllers is by no means an easy or a standard procedure. A large number of greenhouse controller settings makes it difficult to foresee its influence on the results and the costs involved. One uses an optimal control to reach the resulting complex production system [1]**.** The dynamic behavior of the greenhouse microclimate is a combination of physical processes involving energy transfer (radiation and heat) and mass balance (water vapor fluctuation and CO2 concentration). These processes depend on the environmental conditions, structure of the greenhouse, type and state of the crop, and on the effect of the control actuators [2].

The main reason for microclimate control in greenhouses is to achieve maximum plant growth and yield. Automatic control system monitors:

- inside the greenhouse (soil and air temperature, relative humidity, carbon dioxide concentrations, electrical conductivity and soil moisture)
- outside the greenhouse (temperature, relative humidity, solar radiation, wind speed, wind direction and rainfall rate)
- equipment (pipe temperature, vents and curtains position)

Each microclimate parameter should be maintained at optimal level, which is determined by the type and state of the crop [3]. Location and sensor numbers depend on the structure and dimensions of the greenhouse. The sensors will be placeby the high of plants in the greenhouse. Climate in the greenhouse is controlled by:

- heating system
- ventilation and fogging system
- lighting and shading system
- fertigation system
- CO2 injection system

Operating principle

Numerous applications of a control system have significantly increased through the development of new materials for highly efficient actuation and sensing, thereby reducing energy losses and environmental impacts [4]. An automatic control system includes sensors, PLC and actuators. The algorithm for automatic control of the greenhouse microclimate includes several steps:

1. The sensor detects the level of climate parameter and sends a signal to the PLC.
2. The PLC checks whether it is in the range or not (above or below).
3. When the measured value is above the maximal or below the minimal preset value the PLC performs action. It runs the actuators until the climatic parameter is brought back to its optimum.

Heating system

Heating water system could be based upon the perimetric pipelines, under benches, or by overhead fan radiators [5]. A hot water heating system is the best way to provide uniform temperature distribution in the greenhouse [6]. The hot water heating system includes:

- boiler with a burner
- main heating loop
- secondary heating loops

The burner heats the water in the boiler, which then flows through the main heating loop. The hot water is pumped through the secondary heating loops and tubing system which is located between plants, along the side walls and under the roof.

A thermohygrometer placed in the greenhouse detects ambient temperature. It also sends a signal to the PLC. The PLC then calculates the necessary hot water temperature in the boiler and pipe system, based on the difference between the detected and desired (set) optimal temperature [7].

The temperature on the pipeline surface is measured within 1-1.5 m after mixing valve [8]. The water temperature in the system is controlled to maintain the desired greenhouse temperature, by using three-way mixing valves and mixing hot and cold water at a constant flow rate. The open and close cycles of the valve operating controls by PLC. The PLC does not measure deflector position in the valve (no position feedback). Water pumps (high flow rate /low pressure) are also controlled by the PLC. The main circulation pump runs constantly (high/low/off), maintaining more uniform temperature field. The (on/off) circulation pumps are applied in the secondary heating sections in order to reduce energy consumption.

Ventilation and fogging system

Greenhouse ventilation is most important for controlling the temperature, relative humidity and CO2 level. Good ventilation in the greenhouse can be achieved with a combination of a roof vent, front doors and fans [9]. Plants grow under the influence of the PAR radiation (diurnal conditions), performing the photosynthesis process. Furthermore, temperature influences the speed of sugar production by photosynthesis, and thus radiation and temperature have to be in balance in the way that a higher radiation level corresponds to a higher temperature [10]. In the case of high temperature and relative humidity (thermohygrometer) or CO2 concentration (carbon dioxide sensor) in the greenhouse, the PLC activates the electric motors and roof vent opens for 10 %. The best is to use butterfly roof vent where one of each side can be automatically opened, depending on the wind direction [11].

Based on the difference rate between detected and preset temperature, as well as relative humidity and CO2 level, the PLC calculates optimal roof vent position. Just a while after (usually 3 min.), the PLC performs check-up and if the control parameter hasn’t been brought back to its optimal level, the roof vent keeps opening for another 10 %.

This process continues until the parameter does not drop below the maximum allowable value.

If the weather station detects rainfall or high wind, the PLC closes the roof vent and runs the fans or fogging system. The role of the fans is to maintain the uniform temperature and humidity field. The fresh air enters at one side and replaces hot stale air that moves out at the opposite side of the greenhouse. The fans induce the air flow and raise the hot air up. The operating principle is the same, the PLC calculates the time needed for fans to run and activates its electric motor.

Fogging system consists of a set of micro sprinklers that release water under high pressure and create a fine spray, which increases ambient humidity and lowers the temperature. Mist flow is varied by solenoid valves which are controlled by the PLC. High pressure pumps driven by single-phase motors run continually (on/off), also controlled by the PLC [12].

The lighting system

Light intensity significantly influences other climate parameters in the greenhouse. Artificial illumination is applied in the absence of natural light, or when overshaded.

The shading system is installed mostly to prevent heat transfer from excessive light (blocking the direct sun rays). Shade curtains also help to reduce thermal losses at night. If the weather station detects high solar radiation, the PLC activates the electric motors (roll-up system) and curtains move horizontally.

The difference between the detected and desired solar radiation initiates the PLC to calculate the necessary change of the curtain position. Special lamps are used to provide enough light for normal crops growth (during winter and cloudy days). The lack of natural light directs the PLC to turn the lights on [13]. The PLC can calculate the required illuminating time based on the growing season of crop, in order to determine the amount of light needed for the process of photosynthesis [14].

Irrigation and nutrition system

To ensure rational use of water and fertilizer it's best to use a fertigation system (drip irrigation), which involves pumps, filters, control panel, EC and pH sensor [15]. This system provides the required mixture based on the current needs of the crops. The EC sensor measures water conductivity and checks the concentration of respective mixture components. The PLC receives a signal from the WET sensor which detects three soil parameters: water content (soil moisture), electrical conductivity and temperature.

Based on the quoted information and considering solar radiation and growing crops season, the PLC calculates the required amount of water and fertilizer. Fertilizer is injected and dosed directly into the water by a piston pump. That mixture flows through pipelines propelled by the circulation pumps. The mixture flow can be modified by solenoid valves governed by the PLC.

CO2 injection system

CO2 is added to the room to improve the process of photosynthesis. Since this paper reviews hot water heating system, assuming that the water will be heated using natural gas, it would be the best to extract CO2 from combustion byproducts (CO2 and steam). A special fan pushes CO2 from the vent, forcing it to mix with outside air in order to cool down (from 200 °C), to the ambient temperature or below it (30 °C) [16]. Gas condenser collects the steam in the gas pipeline and separates it. A certain portion of the condensing heat can additionally warm up the soil.

A better CO2 distribution within the greenhouse can be accomplished with a pipeline network, similar to the irrigation/fertigation system. Special gauges for CO2 concentration measurement are set on the distribution pipes, in order to detect possible gases hazard. If the carbon dioxide concentration is below the recommended value, PLC opens solenoid valves which are responsible for spreading gas. After a while the gas check-up is performed in order to prevent rapid increasing in CO2 concentration [17].

DEVELOPMENT OF A MATHEMATICAL MODEL OF THE GREENHOUSE MICROCLIMATE

The most important stage of technological objects of control algorithms research is to develop an object model that reflects the processes taking place in the facility. Typical solutions for the management objects are based on the simplest models, operating parameters of the abstract. Such models, due to the abstract nature of the parameters do not allow a deep study and modify the characteristics of the object. For more deep research and synthesis of automatic control systems by introducing the interest of modelopens the physical basis of the object.

We classify existing greenhouse climate models into two types:

1. The principal models using data on the physical processes of heat and mass transfer taking place in a greenhouse. The processes are described by differential equations with parameters having a physical interpretation.
2. Cybernetic when the greenhouse microclimate is seen as a "black box", and examined the relationship of input and output values. The parameters of these models are determined experimental by identification method.

Today, there are many works devoted to models of greenhouse microclimate. All these models are taken as the basis of vegetation during photosynthesis.

Climate model proposed in [18], serves as a basis for developing climate models in thermos greenhouses. In this paper the principal model will be use in continuous time.

The model was developed based on the following simplifying assumptions:

1. The model interprets the greenhouse as a specified volume of air bounded by walls, roof and foundation. The spatial distribution of variables describing climate, is not considered.
2. Changing the fruiting bodies of biomass plants in the process of development is not taken into account. The biomass of the fruiting bodies of fungi is a constant value.
3. Control object is regarded as quasi-stationary.

The equation of the heat balance of energy, affecting the temperature change inside the greenhouse has the form:

$$\rho \cdot V \cdot C \cdot \frac{dT\,(t)}{dt} = Q_{proc}\text{-}\left(\sum Q_{fenc} + Q_{fresh}\right) \tag{5.1}$$

where

ρ-air density ($kg/\text{м}^3$);

V-air volume (м^3);

C-specific heat of air($J/deg \cdot \text{kg}$);

$T\ (t)$-temperature inside the greenhouse (deg);

Q_{proc}-heat proceeds from the heating system (W);

$\sum Q_{fenc}$-heat loss through the building envelope (W);

Q_{fresh}-heat loss for heating of fresh air (W);

Opening the terms of equation (5.1).

Thermal receipts from the heating system at [20]

$$Q_{proc} = G_{heat} \cdot C_{heat}\left(T_{initial} - T_{final}\right) \tag{5.2}$$

Where

G_{heat}-coolant flow (kg/s);

C_{heat}-specific thermal capacity of the heat-carrier $(J/deg\cdot \mathrm{kg})$;

$\mathrm{T}_{initial}, \mathrm{T}_{final}$-temperature of the heat-carrier on an input and an output exchanger (deg).

Heat loss through the building envelope [20, p.47]:

$$Q_{fenc} = \sum k\cdot F\cdot (T_{Int} - \mathrm{T}_{out}) \tag{5.3}$$

where

k-heat transfer coefficient of building envelope$\left(J/(\text{м}^2\cdot \text{с}\cdot {^\circ}\text{C})\right)$;

F-fencing area (m^2);

T_{in}-air temperature inside the building (deg);

T_{out}-outdoor air temperature (deg);

T_{in}-T_{out}= ΔT-temperature difference (deg);

heat loss for heating fresh air [20]:

$$Q_{fresh} = G_{fresh}\cdot \mathrm{C}_{air}(\mathrm{T}_{in} - \mathrm{T}_{out}) \tag{5.4}$$

where

G_{fresh}-fresh air for ventilation premises (kg/s);

C_{air}-specific thermal capacity of air (J/kgdeg);

T_{in}-air temperature inside the building (deg);

T_{out}-outdoor air temperature (deg);

The equation (5.1) is completely substituting the disclosed members (5.2), (5.3) and (5.4):

$$\begin{aligned}\rho\ \cdot\ \mathrm{V}\ \cdot\ \mathrm{C}\ \cdot \frac{dT\ (t)}{dt} &= \\ = G_{heat}\cdot \mathrm{C}_{heat} & \\ -\sum (k\cdot F)\cdot (T_{Int} - \mathrm{T}_{out})\cdot G_{fresh} & \\ \cdot \mathrm{C}_{air}(\mathrm{T}_{Int}\cdot \mathrm{T}_{out}) &\end{aligned} \tag{5.5}$$

The equation of mass balance of water in the atmosphere of the greenhouse will have an appearance:

$$\rho\cdot V\cdot \frac{dX(t)}{dt} = G_{fresh}\cdot \mathrm{X}_{fresh} - G_{outg}\cdot \mathrm{X}_{outg} + \ G_{vapour} \tag{5.6}$$

Where

ρ-density of air $(kg/\text{м}^3)$;

V-air volume (м^3);

X(t)-absolute humidity in the greenhouse atmosphere (kg_{water}/kg_{air});

G_{fresh}-fresh air flow (kg/s);

X_{fresh}-absolute humidity of fresh air (kg_{water}/kg_{air});

G_{outg}-vapour consumption (kg/s);

X_{outg}-absolute humidity of the outgoing air (kg_{water}/kg_{air});

G_{vapour}-vapour consumption (kg/s);

mass balance equation [19, p.81] of carbon dioxide in the atmosphere is determined by the greenhouse balance of carbon dioxide mass in the following way:

$$\begin{aligned}\rho\cdot V\cdot \frac{d\mathrm{M}_{\mathrm{CO}_2}(t)}{dt} &\\ = G_{fresh}\cdot \mathrm{M}_{\mathrm{CO}_2\,fresh} - G_{outg} &\\ \cdot \mathrm{M}_{\mathrm{CO}_2 outg} + \ \mathrm{oxi}\ (\mathrm{t},\mathrm{m}) &\end{aligned} \tag{5.7}$$

$\mathrm{M}_{\mathrm{CO}_2}(t)$-absolute CO_2 content in the atmosphere of greenhouse $(kg_{\mathrm{CO}_2}/kg_{air})$;

$\mathrm{M}_{\mathrm{CO}_2\,fresh}$-absolute CO2 content in the atmosphere $(kg_{\mathrm{CO}_2}/kg_{air})$;

$\mathrm{M}_{\mathrm{CO}_2 outg}$-absolute CO2 content in the outgoing air from the greenhouse $(kg_{\mathrm{CO}_2}/\text{с})$;

$\mathrm{oxi}\ (\mathrm{t},\mathrm{m})$-air oxidation process, followed by the release of CO2 into the air greenhouses.

For values of temperature, humidity and carbon dioxide content developed on the basis of these equations we express the values of the differential equations. We write the equation of the temperature differential in the form of (5.5):

$$\rho\ \cdot\ \mathrm{V}\ \cdot\ \mathrm{C}\ \cdot \frac{dT\ (t)}{dt} = G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial} - \mathrm{T}_{final}\right) - -\sum k\cdot F\cdot (T_{Int} - \mathrm{T}_{out}) - G_{fresh}\cdot \mathrm{C}_{air}(\mathrm{T}_{Int}\cdot \mathrm{T}_{out})$$

$$\frac{dT(t)}{dt} = \frac{1}{\rho VC}\left[\begin{matrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial} - \mathrm{T}_{final}\right) - \\ -\sum k\cdot F\cdot (T_{Int}\cdot \mathrm{T}_{out}) - G_{fresh}\cdot \mathrm{C}_{air}(\mathrm{T}_{Int}\cdot \mathrm{T}_{out}) \end{matrix}\right] \tag{5.8}$$

Assume the outgoing air temperature at the air temperature inside the space (5.8). Then the equation becomes:

$$\frac{dT(t)}{dt} = \frac{1}{\rho VC}\left[\begin{matrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial} - \mathrm{T}_{final}\right) - \\ -\sum k\cdot F\cdot (\mathrm{T}(t)\cdot \mathrm{T}_{out}) - G_{fresh}\cdot \mathrm{C}_{air}(\mathrm{T}(t)\cdot \mathrm{T}_{out}) \end{matrix}\right] \tag{5.9}$$

We got an inhomogeneous linear differential equation of the first order. Express it:

$$\frac{dT(t)}{dt} + \frac{(\sum k\cdot F + G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}\ \mathrm{T}(t) = \frac{1}{\rho VC}\left[\begin{matrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial} - \mathrm{T}_{final}\right) + \\ +\mathrm{T}_{\text{н}}\sum k\cdot F + G_{fresh}\cdot \mathrm{C}_{air}) \end{matrix}\right] \tag{5.10}$$

We define an auxiliary function μ (t):

$$\mu(t) = e^{\int \frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}dt}$$

We take $\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{\text{в}air})}{\rho VC}$ =const. then:

$$\mu(t) = e^{\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}t} \tag{5.11}$$

Multiply the original equation (5.10) to (5.11):

$$\frac{dT(t)}{dt}\cdot \mu(t)+\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}\,\mathrm{T}(t)\cdot \mu(t)=\frac{1}{\rho VC}\begin{bmatrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{out}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\end{bmatrix}\cdot \mu(t)$$

$$\frac{d(T(t)\cdot \mu(t)}{dt}=\frac{1}{\rho VC}\begin{bmatrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{out}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\end{bmatrix}\cdot \mu(t) \tag{5.12}$$

Integrating equation (5.12):

$$T(t)\cdot \mu(t)=\int\frac{1}{\rho VC}\begin{bmatrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{out}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{out})\end{bmatrix}\cdot \mu(t)\,dt \tag{5.13}$$

Let us assume for the constant factor $\frac{1}{\rho VC}\begin{bmatrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{\text{н}}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{\text{возд}})\end{bmatrix}$ and take out it outside the integral sign, and then multiply both sides by $\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air}$

$$T(t)\cdot \mu(t)\cdot (\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})=\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}\cdot\begin{bmatrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{\text{н}}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\end{bmatrix}\cdot\int\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}dt \tag{5.14}$$

Consider the integral:

$$T(t)\cdot \mu(t)\cdot (\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})=\begin{bmatrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{out}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\end{bmatrix}\cdot e^{\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}t}+\mathrm{const} \tag{5.15}$$

We express T (t)by substituting T_0 Instead Const.:

$$T(t)=\frac{\begin{bmatrix} G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{out}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\end{bmatrix}\cdot e^{\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}t}+T_0}{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\cdot e^{\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}t}} \tag{5.16}$$

Where T_0-the initial temperature

We get the value of absolute humidity. We write humidity equation in differential form (5.6):

$$\rho\cdot V\cdot\frac{dX(t)}{dt}=G_{fresh}\cdot \mathrm{X}_{fresh}-G_{outg}\cdot \mathrm{X}_{outg}+G_{vapour}$$

Let us take the humidity of the outgoing air of humidity indoors (Xoutg $=$ X). Then the equation becomes:

$$\rho\cdot V\cdot\frac{dX(t)}{dt}=G_{fresh}\cdot \mathrm{X}_{fresh}-G_{outg}\cdot \mathrm{X}+G_{vapour} \tag{5.17}$$

Received first order differential equation is expressible in canonical form:

$$\rho\cdot V\cdot\frac{dX(t)}{dt}=G_{outg}\cdot \mathrm{X}=G_{fresh}\cdot \mathrm{X}_{fresh}+G_{vapour}$$

$$\frac{dX(t)}{dt}+\frac{G_{outg}}{\rho\cdot V}\cdot X=\frac{G_{fresh}\cdot \mathrm{X}_{fresh}+G_{vapour}}{\rho\cdot V} \tag{5.18}$$

We define an auxiliary function $\mu(t)$:

$$\mu(t)=e^{\int\frac{G_{outg}}{\rho\cdot V}dt}$$

Assume $\frac{G_{outg}}{\rho\cdot V}=const$, then:

$$\mu(t)=e^{\frac{G_{outg}}{\rho\cdot V}t} \tag{5.19}$$

Multiply the original equation (5.18) to (5.19):

$$\frac{dX(t)}{dt}\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}+\frac{G_{outg}}{\rho\cdot V}\cdot X(t)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}=\frac{G_{fresh}\cdot \mathrm{X}_{fresh}+G_{vapour}}{\rho\cdot V}\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}$$

transform:

$$\frac{d\left(X(t)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}\right)}{dt}=\frac{G_{fresh}\cdot \mathrm{X}_{fresh}+G_{vapour}}{\rho\cdot V}\cdot e^{\frac{G_{outg}}{\rho\cdot V}t} \tag{5.20}$$

Taking $\frac{G_{fresh}\cdot \mathrm{X}_{fresh}+G_{vapour}}{\rho\cdot V}=const$ we integrate equation (5.20) for t:

$$X(t)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}=\frac{G_{fresh}\cdot \mathrm{X}_{fresh}+G_{vapour}}{\rho\cdot V}\int e^{\frac{G_{outg}}{\rho\cdot V}}dt \tag{5.21}$$

We multiply both sides by G_{outg} and take the integral:

$$X(t)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}\cdot G_{outg}=\left(G_{fresh}\cdot \mathrm{X}_{fresh}+G_{vapour}\right)e^{\frac{G_{outg}}{\rho\cdot V}t}+const(\qquad 5.22)$$

We express *x(t)*, by substituting x_0 instead of *const.*:

$$X(t)=\frac{(G_{fresh}\cdot \mathrm{X}_{fresh}+\ G_{vapour})\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}+\mathrm{X}_0}{e^{\frac{G_{outg}}{\rho\cdot V}t}\cdot\ G_{outg}} \tag{5.23}$$

Where X_0-initial moisture content.

Let us find the value of CO$_2$. The equation of mass balance of carbon dioxide in the atmosphere of greenhouse in differential form (7):

$$\rho\cdot V\cdot\frac{d\mathrm{M}_{\mathrm{CO_2}}(t)}{dt}=G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}-G_{outg}\cdot \mathrm{M}_{\mathrm{CO_2}outg}+\ \mathrm{oxi}\ (\mathrm{t,m})$$

Let us take the CO$_2$ content of the outgoing air for the content of CO$_2$ indoor air ($\mathrm{M}_{\mathrm{CO_2}outg}=\mathrm{M}_{\mathrm{CO_2}}$). The equation becomes:

$$\rho\cdot V\cdot\frac{d\mathrm{M}_{\mathrm{CO_2}}(t)}{dt}=G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}-G_{outg}\cdot \mathrm{M}_{\mathrm{CO_2}}(t)+\ \mathrm{oxi}\ (\mathrm{t,m}) \tag{5.24}$$

We express the resulting first order differential equation

$$\frac{d\mathrm{M}_{\mathrm{CO_2}}(t)}{dt}+\frac{G_{outg}}{\rho\cdot V}\cdot \mathrm{M}_{\mathrm{CO_2}}(t)=\frac{G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}+\ \mathrm{oxi}\ (\mathrm{t,m})}{\rho\cdot V} \tag{5.25}$$

We define an auxiliary function $\mu(t)$:

$$\mu(t)=e^{\int\frac{G_{outg}}{\rho\cdot V}dt}$$

Assume $\frac{G_{outg}}{\rho\cdot V}=const$:

$$\mu(t)=e^{\frac{G_{outg}}{\rho\cdot V}t} \tag{5.26}$$

Multiply the original equation (5.25) to (5.26):

$$\frac{d\mathrm{M}_{\mathrm{CO_2}}(t)}{dt}e^{\frac{G_{outg}}{\rho\cdot V}t}+\frac{G_{outg}}{\rho\cdot V}\cdot \mathrm{M}_{\mathrm{CO_2}}(t)\ \cdot\ e^{\frac{G_{outg}}{\rho\cdot V}t}=\frac{G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}+\ \mathrm{oxi}\ (\mathrm{t,m})}{\rho\cdot V}\ \cdot\ e^{\frac{G_{outg}}{\rho\cdot V}t}$$

Transform:

$$\frac{d\left(\mathrm{M}_{\mathrm{CO_2}}(t)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}\right)}{dt}=\frac{G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}+\ \mathrm{oxi}\ (\mathrm{t,m})}{\rho\cdot V}\cdot e^{\frac{G_{outg}}{\rho\cdot V}t} \tag{5.27}$$

Assume $\frac{G_{fresh}\cdot\mathrm{M}_{\mathrm{CO_2}\,fresh}+\mathrm{oxi}\ (\mathrm{t,m})}{\rho\cdot V}=const$and integrate equation:

$$\mathrm{M}_{\mathrm{CO_2}}(t)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}=\frac{G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}+\ \mathrm{oxi}\ (\mathrm{t,m})}{\rho\cdot V}\int e^{\frac{G_{outg}}{\rho\cdot V}dt} \tag{5.28}$$

Multiply both sides of the equationG_{outg} on and take the integral:

$$\mathrm{M}_{\mathrm{CO_2}}(t)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}\cdot G_{outg}=\left(G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}+\mathrm{oxi}\ (\mathrm{t,m})\right)\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}+\mathrm{const} \tag{5.29}$$

We express $\mathrm{M}_{\mathrm{CO_2}(t)}$, $\mathrm{M}_{\mathrm{CO_2}}$ substituting instead of *Const* .:

$$\mathrm{M}_{\mathrm{CO_2}(t)}=\frac{\left(G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}+\ \mathrm{oxi}\ (\mathrm{t,m})\right)\ \cdot e^{\frac{G_{outg}}{\rho\cdot V}t}+\ \mathrm{M}_{\mathrm{CO_2}\,0}}{e^{\frac{G_{outg}}{\rho\cdot V}t}\cdot G_{outg}\ \cdot} \tag{5.30}$$

Where$\mathrm{M}_{\mathrm{CO_2}\,0}$-the initial concentration of carbon dioxide.

Thus, the system of equations (5.31), approximately describing climate greenhouses, has the form:

$$\begin{cases} T(t)=\dfrac{\begin{bmatrix}G_{heat}\cdot \mathrm{C}_{heat}\left(T_{initial}-\mathrm{T}_{final}\right)+\\ +\mathrm{T}_{out}(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\end{bmatrix}\cdot\ e^{\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}t}+T_0}{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})\ \cdot\ e^{\frac{(\sum k\cdot F+G_{fresh}\cdot \mathrm{C}_{air})}{\rho VC}t}} \\ X(t)=\dfrac{(G_{fresh}\cdot \mathrm{X}_{fresh}+\ G_{vapour})\cdot e^{\frac{G_{outg}}{\rho\cdot V}t}+\mathrm{X}_0}{e^{\frac{G_{outg}}{\rho\cdot V}t}\cdot\ G_{outg}} \\ \mathrm{M}_{\mathrm{CO_2}(t)}=\dfrac{\left(G_{fresh}\cdot \mathrm{M}_{\mathrm{CO_2}\,fresh}+\ \mathrm{oxi}\ (\mathrm{t,m})\right)\ \cdot e^{\frac{G_{outg}}{\rho\cdot V}t}+\ \mathrm{M}_{\mathrm{CO_2}\,0}}{e^{\frac{G_{outg}}{\rho\cdot V}t}\cdot G_{outg}\ \cdot} \end{cases} \tag{5.31}$$

The information contained in this work, the model (5.31) approximately describes the greenhouse microclimate, which is permissible for the analysis and synthesis of control algorithms. The model does not take into account the distribution of climate parameters in size and height of the greenhouse facilities.

DISCUSSION AND CONCLUSION.

Microclimate conditions that have to be controlled to optimize crop growth include temperature, RH, solar radiation, CO2 and internal air velocity. Light intensity (solar radiation) and CO2 are the primary factors that enhance photosynthesis and plant growth. Temperature and RH are the critical factors to control, to optimize plant photosynthesis under optimal light and CO2 conditions, but are also the most difficult factors to successfully control in greenhouses, especially in Kazakhstan, where extremely high temperatures are experienced at certain times of the year and therefore greenhouse cooling remains a challenge.

Greenhouse structures are designed to control and optimize the internal micro-climate inside the structure. Some have evaluated types of greenhouse structures and the performance in terms of internal temperature and ventilation rates. Different shapes, sizes, orientations and greenhouse covers are used in combination with cooling systems, to support the optimal control of the internal climate. Various cooling systems across the globe and their performance in controlling these factors have been reviewed and compared by several researchers. Experimental and numerical studies have been done, as described in the literature, on the performance of different cooling systems under specific conditions. Natural ventilation, pad fan evaporative cooling, screening and fogging systems are commonly used cooling systems in Kazakhstan. Each system will perform differently, depending on the area. Limited literature is available for cooling system performance for the variable agro-climatic conditions in Kazakhstan.

Implementation of such an effective mechatronic system could be affordable only with large greenhouses. Its profitability rises with the growing size of the land covered. Even smaller greenhouses can absorb such a sophisticated system if the monitoring concept is based on the centralized main unit and distributed local boxes and sensoring in the neighboring assets. Each separate greenhouse is covered with itselves PLC, and then the set of PLCs constitutes a distributed monitoring system with a single governing main unit. This way, a set of different plants can be grown in separate sections and yet a micro-climate would be uniquely managed.

The model allows calculation of the parameters defining the impacts of climate greenhouses, to predict the impact of each of the values of the microclimate on the other, makes it possible to calculate the quality of control indicators.

In conclusion, there is a large knowledge gap in data and literature availability, to sufficiently assist local Kazakhstan investors/farmers to select the optimum greenhouse design and the associated systems. There is limited peer-reviewed literature available in Kazakhstan that compares the performance of different natural and evaporative cooling systems. To be able to develop models for predicting this performance for different designs and climatic conditions, the calibration and optimization of models are required. The selection of greenhouses cannot be done without taking into account capital expenditure and operating and maintenance costs. This research project will, thus, also look at these aspects for the greenhouse selection process.

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