

## METHODICAL ASPECTS OF MODELING TECHNOLOGICAL PROCESSES IN SELECTED AGRICULTURAL FACILITIES

### Summary

The purpose of the work was to present the methodology of modeling technological processes taking place in specialized agricultural facilities (greenhouses, mushroom farms, storage rooms) for the purpose of controlling the microclimate in these buildings. In the work, the author wanted to share her experience of many years in the field of process modeling and microclimate control, pointing out the difficulties and problems that must be overcome while formulating models and presenting recommendations to overcome these difficulties. In addition, the work discusses the possibilities of using the developed models during the design of microclimate control systems and during the control of thermal and humidity parameters. **Key words:** specialized agricultural buildings, modeling of technological processes, energy-saving microclimate control

## METODYCZNE ASPEKTY MODELOWANIA PROCESÓW TECHNOLOGICZNYCH W WYBRANYCH OBIEKTACH ROLNICZYCH

### Streszczenie

Celem pracy było przedstawienie metodyki modelowania procesów technologicznych zachodzących w specjalistycznych obiektach rolniczych (szklarniach, pieczarkarniach, przechowalniach) dla potrzeb sterowania mikroklimatem w tych budynkach. W pracy autorka chciała podzielić się swoimi wieloletnimi doświadczeniami z zakresu modelowania procesów i sterowania mikroklimatem, wskazując na trudności i problemy, które należy pokonać podczas formułowania modeli oraz przedstawiając zalecenia odnośnie sposobów pokonania tych trudności. Ponadto w pracy omówiono możliwości wykorzystania opracowanych modeli podczas projektowania systemów sterowania mikroklimatem i podczas sterowania parametrami termiczno-wilgotnościowymi.

**Słowa kluczowe:** specjalistyczne budynki rolnicze, modelowanie procesów technologicznych, energooszczędne sterowanie mikroklimatem

### 1. Symbols

- a** – surface area,  $m^2/m^3$ ,
- $c_{zi}$**  – specific heat of potato,  $J/kg \cdot ^\circ C$ ,
- e** – control error,  $^\circ C$ ,
- $q_{res}$**  – respiration heat of potatoes,  $kJ/kg$ ,
- r** – heat of vaporization of water,  $J/kg_{H_2O}$ ,
- t** – time, h,
- $t_{zi}$**  – potato average temperature,  $^\circ C$ ,
- $t_{pw}$**  – the air average temperature,  $^\circ C$ ,
- u** – control signal,
- $u_{zi}$**  – average water content of the potato,  $kg_{H_2O}/kg$ ,
- $\alpha$**  – heat transfer coefficient,  $J/m^2 \cdot h \cdot ^\circ C$ ,
- $\beta$**  – mass transfer coefficient, m/h,
- $\rho_{zi}$**  – density of potato,  $kg/m^3$ ,

### 2. Introduction

As is known, the fulfilment of technological requirements strictly defined by technologists, relating to microclimatic conditions and the composition of the atmosphere, is a guarantee of obtaining:

- high and good quality harvest of fungi grown in a mushroom farm or vegetable crops grown in a greenhouse,
- low losses and good quality potatoes, vegetables or fruit after storage in storage rooms.

Currently two-position or continuous (PID) control systems are used to control the microclimate and the composition of the atmosphere. Control algorithms of these systems have serious disadvantages. The disadvantages will be discussed below.

A characteristic feature of the two-position control algorithms, which are the most commonly used in the potato and vegetable storage systems, is that the courses of regulated technological parameters (i.e. temperature of potatoes or vegetables and relative humidity of air inside the storage room) have a saw tooth shape. This entails significant, higher than acceptable, deviations of the values of regulated parameters from the values required by technologists. This is also due to the fact that the potato and vegetable storages are equipped only with ventilation devices which often cannot be switched on due to the meteorological conditions unfavourable for ventilation. This is especially the case in winter or late spring. The effect of such a disadvantageous operation of the control system implementing the two-position algorithm is the increase in technological losses and the deterioration of the quality of stored potatoes or vegetables.

Continuous control systems are used in: greenhouses, mushroom-growing cellars or fruit storages. During continuous control using the PID algorithm (proportional P, integral I, derivative D), the regulator's settings, guaranteeing the exact regulation of technological parameters, are selected at the stage of design of the control system. It is assumed then that the dynamic properties of the technological process are unchanged during system operation. However, during cultivation mushrooms or vegetables, as well as during the storage of agricultural produce, their weight changes. Thus, the dynamic properties of processes occurring in the aforementioned agricultural objects change. This entails little adjustment, and thus: increased technological losses and deterioration in the quality of stored fruit cause

lower harvests and lower quality of mushrooms in a mushroom farm or crop of vegetables in a greenhouse.

The results of simulation tests have shown that it is possible to eliminate these shortcomings through application of modern control algorithms. These algorithms enable the implementation of energy-saving microclimate control or precise control of thermal and moisture parameters. The condition for using these algorithms is knowing the models of technological processes taking place in specialist agricultural facilities.

The purpose of this work was:

- presenting the modelling methodology of technological processes taking place in specialized agricultural facilities, such as: greenhouses, mushroom-growing cellars or storehouses of crops in which the microclimate is controlled. In the description of the modelling methodology, the scope of necessary work was presented and the problems that need to be solved were given. There are also recommendations for solving these problems;
- discussion of the possibility of using formulated technological processes models during design of microclimate control systems, deprived of the above-mentioned disadvantages, or during the control of thermal-moisture parameters.

### 3. Modelling methodology of technological processes taking place in selected agricultural facilities

Technological processes occurring in specialist agricultural facilities during microclimate control include heat and mass exchange processes. These processes differ from industrial processes. This specificity consists in the fact that:

- we are dealing with living organisms (mushrooms, plants, agricultural crops);
- the course of life processes taking place in these organisms may depend on random factors, such as, for example, meteorological conditions prevailing during the vegetation of potatoes in the field or fruit in the orchard. In such cases, there is no repeatability of the qualitative and quantitative process of life, e.g. breathing, in subsequent seasons of storage;
- processes occurring inside buildings are quick-changing processes, while processes occurring in living organisms are slow-changing processes;
- living organisms can change their chemical composition (their dynamic properties) during the implementation of the technological process.

This specificity should be taken into account when creating a model of technological processes taking place in greenhouses, mushroom farms or storage rooms.

During the formulation of the technological process model, I propose to distinguish eight stages. The stages will be discussed below.

**Stage 1. Getting to know the modelled object.** If possible, it would be recommended:

- conducting preliminary research on the technological process taking place in the specialized agricultural building that interests us. These tests would consist in an experimental determination of thermal-to-humidity parameters of the technological process;
- registration of temperature and relative humidity of air outside the building during the microclimate tests in the building.

**Stage 2. Determination of the purpose and scope of the analysis.** Process models can be formulated for various purposes. A model created during a modern microclimate control system design, can be used:

- in the applied control algorithm (e.g. predictive or adaptive),
- during the selection of the variant of the designed control system due to the used control algorithm, which guarantees compliance with the assumptions adopted during the design,
- during optimization or polyoptimization of microclimate control.

At this stage, the scope of the process analysis is also determined. For example, decisions are made whether the entire storage process will be modelled or only one selected stage, whether the model covers all phases of plant development in the greenhouse or only the selected phase, etc. You need to get acquainted with the environment that affects the technological process. Find answers to the questions: in what climate zone is the specialized agricultural building we are interested in, what are the average daily, monthly and annual temperatures and relative humidity of the atmospheric air.

**Stage 3. Creating a physical model.** When formulating a physical model, the components of the technological process model should be separated. For example, the model of the plant growing process in a greenhouse is composed of: soil model, plant model, internal air model and greenhouse building model.

Then, a 'stocktaking' of the constituent processes, mechanisms of heat transfer, mass, energy, etc. taking place in each of the above-mentioned 'submodels' should be made. For each of them should be specified: fixed parameters, input and output variables of the test object and disturbances.

In order to organize the knowledge of the modeled process at this stage, it is recommended to create a drawing on which a block diagram of the technological process model will be presented, taking into account all the above mentioned elements of the physical model.

**Stage 4. Adoption of assumptions and simplifications of the model.** Assumptions are conditions that determine the scope of the model's validity, reducing the scope of its generality. Simplifications are conditions that degrade the accuracy of the model by omitting specific phenomena in the physical model, which we think are not significantly influencing the accuracy of the original model reproduction by its model. Simplifications result from the adopted assumptions, and their admissibility is determined by the desired accuracy of the model [2].

**Stage 5. Formulating the technological process model.** During this modeling stage, it is necessary to perform a number of works, such as:

- Description of the components, phenomena or mechanisms of heat transfer, mass or energy of the modeled system with laws and claims of scientific knowledge;
- Creation of model equations, which are most often equations of heat and mass balances. Such a model in the methodology of empirical sciences is called the abstract model structurally similar [1]. An example of an equation describing the heat exchange in potatoes during storage is shown below.

$$\rho_{zi} \cdot c_{zi} \cdot \frac{dt_{zi}}{dt} = \rho_{zi} \cdot \frac{dq_{res}}{dt} - r\rho_{zi} \cdot \frac{du_{zi}}{dt} - \alpha\alpha(t_{zi} - t_{pw}) \quad (1)$$

*enthalpy change in potatoes*     *tuber breathing*     *evaporation of water from tubers*     *penetrations of heat*

- Formulating auxiliary information models. During biological processes modeling, we may have to deal with a situation where a biological or biochemical process taking place in a specialized farm building is not described by the law of scientific knowledge but only as a chemical reaction. For example, such a process is the process of potato's respiration during storage in a storage room (see formula 1). In this case, it is necessary to conduct experimental tests of the breathing process. During the tests, the relationship between the respiration intensity  $\frac{dq_{res}}{dt}$  and the temperature of

the potatoes and the storage time should be determined. Based on the results of these tests, mathematical formalism should be created (called information model in methodology [1]), which then will replace the chemical formula describing the respiration of agricultural products in the heat balance equation.

The professional experience of the author shows that the mathematical formalism describing the process of potato respiration based on the results of experimental tests of the breathing process carried out in one storage season was not precise enough for the needs of control. It resulted from the fact that there is no quantitative and qualitative repeatability of this process in subsequent years of storage. The required accuracy of the potato storage process model was only obtained after formulating the breathing model on the basis of the averaged results of breathing tests of 28 varieties of tubers during 12 storage seasons.

It should be remembered that the scope of the technological process model is the same as the scope of experimental research necessary to create an information model.

- Linearization of non-linear expressions in equations. The equations describing the heat and mass exchange in the buildings we are interested in are non-linear equations. If we wanted to solve them analytically, the non-linear expressions found in the equations should be linearized.

- Searching for the value of equation coefficients. In order to be able to solve the heat and mass exchange equations being a model of the technological process, it is necessary to know the value of the equation coefficients. Finding them is not always easy. It is recommended to use during modeling the values determined experimentally. You can try to look for interesting values of coefficients in Ginzburg's work [3].

The author's experience shows that the considered models of technological processes are very sensitive to the values of heat transfer coefficients  $\alpha$  and penetration of the mass coefficients  $\beta$ .

- Supplementing the equations with initial and boundary conditions.

**Step 6. Solution of model equations.** Before solving the equations that constitute the process model, the method of solving the equations should be selected. It is necessary to decide whether it will be an analytical method or a numerical method and what software will be used then.

If the analytical method is chosen, should be taken into account facts that:

- model equations are non-linear partial differential equations,

- non-linear expressions occurring in model equations require linearization,
- these equations do not have exact, but only approximate solutions.

The author's experience shows that the method that allows you to get an approximate solution of equations is, known in the chemical engineering, method of frequency characteristics.

It is more beneficial to use the numerical methods for solving model's equations, e.g. the MATLAB programming environment. It is then necessary to build a computer model of the process in the Matlab Simulink toolbox. Fig. 1 shows, for example, a computer model of the potato layer, built in Simulink [4].

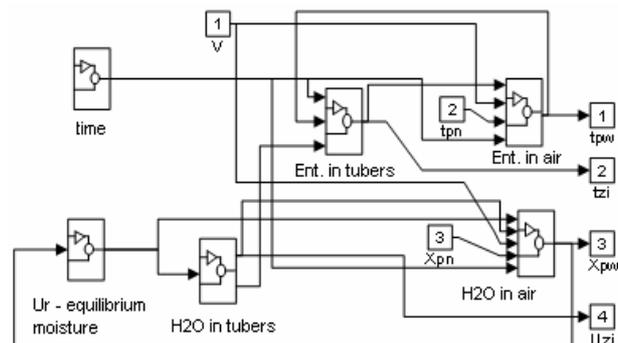


Fig. 1. Computer model of the potato layer, built in Matlab Simulink toolbox [4]

Rys. 1. Komputerowy model warstwy ziemniaków, zbudowany w przyborniku Simulink programu Matlab [4]

The next step is to determine the simulation research plan and the way of presenting the results of these tests.

**Stage 7. Model validation.** The aim of validation is to confirm in a documented manner that the formulated model, according to the assumptions, allows to obtain the planned results. During validation, a logical and empirical verification of the results of technological parameters calculation is carried out, using the model. Empirical verification consists in comparing the results of calculations with the results of experimental research of technological parameters. Here the results of preliminary research of the technological process received in the first modeling stage are useful. Then, determine the model's errors and determine its accuracy. The author's experience shows that the accuracy of the model, satisfactory for the needs of the control, is  $\pm 5\%$ .

**Stage 8. Implementation of the modeling analysis purpose specified in the second stage of modeling.** The possibilities of using formulated technological process model for the needs of microclimate control will be discussed in more detail below.

#### 4. Possibilities of using the technological process model while designing a modern microclimate control system

In the second stage of modeling of the technological process, three possibilities of using the formulated model of the technological process in a selected, specialized agricultural building were indicated. These applications concern the control of ventilation and air-conditioning equipment as well as the design of a modern microclimate control system and include:

- development of an energy-saving microclimate control algorithm, whose part is technological process model,

- selection of the variant of the designed control system with different control algorithms, guaranteeing precise control or the lowest energy consumption,
- optimization or poly-optimization of microclimate control.

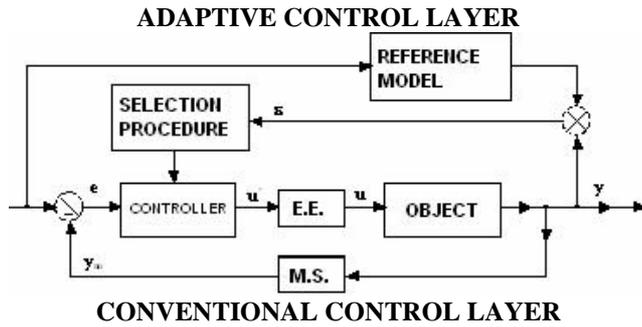


Fig. 2. Construction of an adaptive control system for technological parameters of greenhouse. Signs: E.E. - executive elements, M.S. - measuring sensors,  $e$  - regulation error,  $u$  - control signals,  $y$  - regulated variable,  $y_m$  - measured regulated variable,  $\varepsilon$  - error [6]

Rys. 2. Budowa adaptacyjnego systemu sterowania parametrami technologicznymi szklarni. Oznaczenia: E.E.- element wykonawczy, M.S. - czujnik pomiarowy,  $e$  - uchyb regulacji,  $u$  - sygnał sterujący,  $y$  - wielkość regulowana,  $y_m$  - wielkość regulowana, zmierzona przez czujnik pomiarowy,  $\varepsilon$  - błąd [6]

As confirmed by simulation studies, modern, energy-saving control algorithms that can be successfully used to control the microclimate in specialized farm buildings are a predictive control algorithm or an adaptive control algorithm [6]. The block diagram of the control system implementing the adaptive algorithm is shown, for example, in Fig. 2. As can be seen

in the figure, the component of the algorithm is a model of a technological process, called here a reference model.

The construction and functioning of microclimate control systems with predictive algorithm and adaptive algorithm are discussed in detail in [6].

The developed model of the technological process can also be used during the design of the microclimate control system. We can choose the best, due to the adopted design assumptions, variant of the system with different control algorithms. For example, we can compare the operation of conventional, currently used, microclimate control algorithms with the proposed predictive control algorithm. In order for the technical implementation of this task to be possible, the developed model of the technological process should be additionally expanded with the model of the applied control system for ventilation and air conditioning devices along with the adopted control algorithm.

Fig. 3 shows, for example, computer models:

- technological process (marked with icons of cultivation hall and ground),
- outside air,
- control system for ventilation and air-conditioning equipment in the mushroom-growing cellar.

The model was implemented in the MATLAB programming environment.

With the model shown in Fig. 3, simulation tests of the functioning microclimate control system can be carried out. Fig. 4 and 5 show examples of simulation results in the form of:

- the course of the internal air temperature in the mushroom-growing cellar (Fig. 4),
- sample waveforms of the control signal for the air humidifier in the mushroom-growing cellar (Fig. 5).

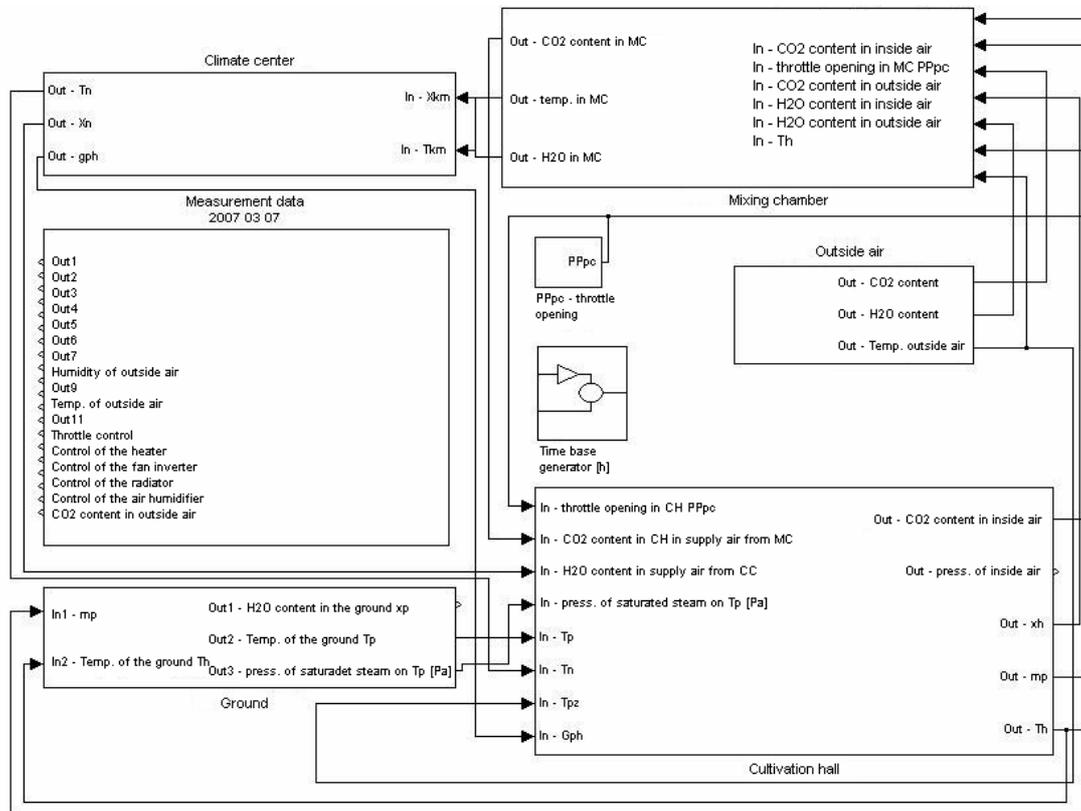
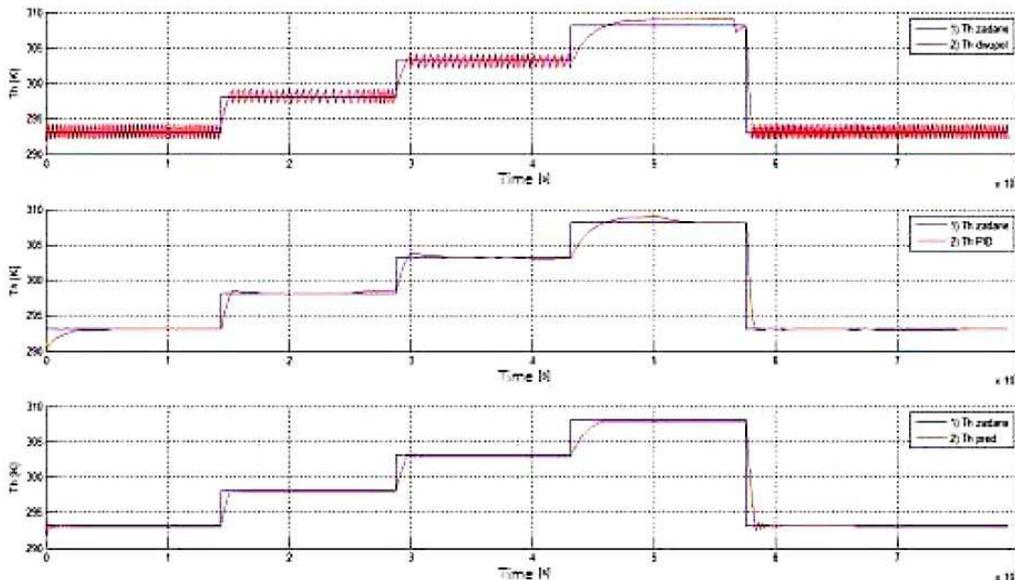


Fig. 3. Computer model of the technological process (marked with the icons: cultivation hall and ground) with the external air model and the model of the control system for ventilation and air conditioning devices in the mushroom-growing cellar [5]

Rys. 3. Komputerowy model: procesu technologicznego (oznaczonego ikonami: hala uprawy i podłoże), powietrza zewnętrznego oraz systemu sterowania urządzeniami wentylacji i klimatyzacji w pieczarkarni [5]



Control algorithm:

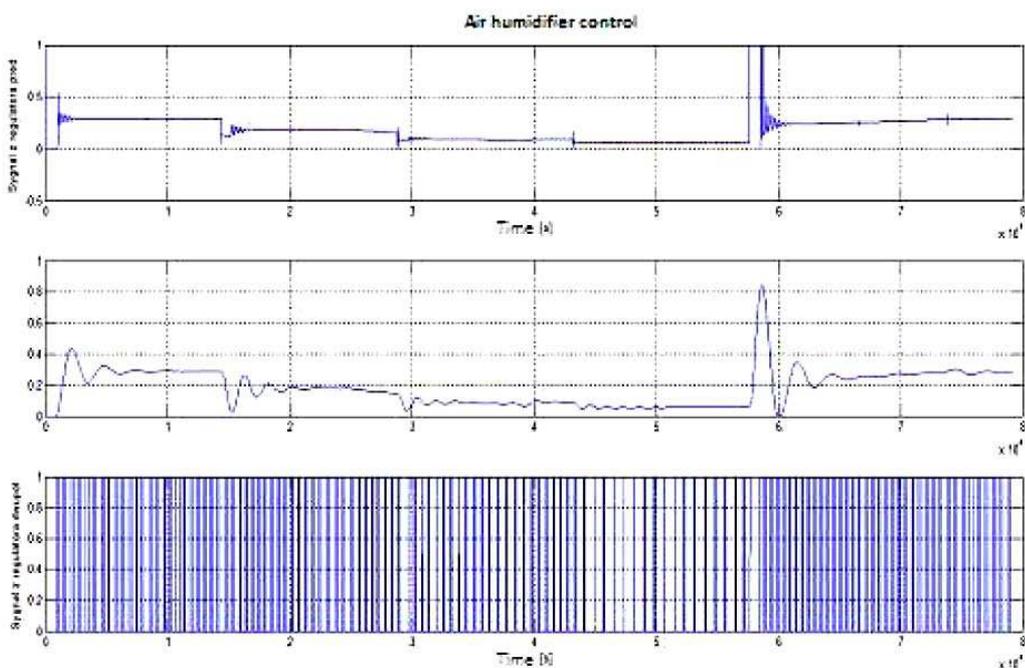
two-position

PID

predictive

Fig. 4. Sample patterns of indoor air temperature in a mushroom farm, obtained by using various control algorithms. Signs: the course of the set value - blue, the course of the controlled variable - red [8]

Rys. 4. Przykładowe przebiegi temperatury powietrza wewnątrz pieczarekarni uzyskane w wyniku badań symulacyjnych z wykorzystaniem różnych algorytmów sterowania. Oznaczenia: kolor niebieski - wielkość zadana, kolor czerwony - wielkość regulowana [8]



Control algorithm:

two-position

PID

predictive

Fig. 5. Exemplary sequences of the signal controlling the air humidifier obtained as a results of simulation tests by using three control algorithms [8]

Rys. 5. Przykładowe przebiegi sygnału sterującego wilgotnością względną powietrza wewnętrznego otrzymane w wyniku symulacji z wykorzystaniem trzech algorytmów sterowania [8]

These trends were obtained using three different microclimate control algorithms: two previously used algorithms (two-position and PID) and a modern, energy-saving prediction algorithm.

The results of simulation tests can be used during optimization of microclimate control in specialist agricultural facilities. The application of control optimization allows for:

- ensuring the best quality of control, and thus the highest, good quality harvest of mushrooms in a mushroom-

growing cellar or vegetable yield in a greenhouse, or the lowest technological losses in storage rooms. As an indicator of the quality of regulation it was assumed here a minimum of the integral from the square of the control error  $e$  (formula 2):

$$\min I_{JR} = \int_{t_0}^{t_k} e^2(\tau) d\tau. \quad (2)$$

The control error  $e$  is the difference between the desired, set value of the tested technological parameter and its controlled value, obtained during the microclimate control with the use of given algorithm. During the implementation of this optimization, we use the results of simulation tests in the form of runs of technological parameters while microclimate control (example - Fig. 4);

- ensuring minimal energy consumption. As an indicator of energy consumption, a minimum square of the control signal  $u$  for individual ventilation and air conditioning devices was adopted:

$$\min I_E = \int_{t_0}^{t_k} u^2(\tau) d\tau \quad (3)$$

When designing energy-saving microclimate control in a mushroom farm, simulation tests should be carried out, during which signals controlling ventilation and air-conditioning equipment are determined (Fig. 5);

- to carry out poly-optimization, consisting in finding during control a compromise between two mutually exclusive postulates of agricultural products producers, i.e. minimization of regulatory error and minimization of energy consumption.

The use of optimization during microclimate control in specialist farm buildings is described in more detail in [7, 8].

## 5. Summary

The methodology of formulating technological process models presented in the work is addressed primarily to young researchers dealing with agricultural engineering

processes. The author of the work hopes that this work and the recommendations contained therein will help in overcoming the difficulties associated with modeling technological processes and designing modern, energy-saving control systems for agriculture.

## 6. References

- [1] Pabis S.: *Metodologia Nauk Empirycznych. 15 wykładów.* Koszalin: Wyd. Uczelniane Politechniki Koszalińskiej, 2009. ISBN 978-83-7365-180-7.
- [2] Tarnowski W.: *Projektowanie układów regulacji automatycznej ciągłych z liniowymi korektorami ze wspomaganiami za pomocą MATLAB'a.* Koszalin: Wyd. Uczelniane Politechniki Koszalińskiej, 2008. ISSN 0239-7129.
- [3] Ginzburg A.C.: *Теплофизические характеристики картофеля, овощей и плодов.* BO Agroproizdat. Moskva 1987. IB 4872.
- [4] Wachowicz E.: *Modelowanie w układach sterowania procesami technologicznymi.* Inżynieria Rolnicza, 2003, 13(55), 7-19.
- [5] Wachowicz E., Woroncow L.: *Comprehensive Model of Processes Proceeding AT a Mushroom-Growing Cellar.* Technical Sciences, 2010, 13, 30-39.
- [6] Wachowicz E.: *Nowoczesne algorytmy sterowania mikroklimatem w przechowalniach.* Acta Agrophisica, 2011, Vol. 17(2), 395-404.
- [7] Wachowicz E., Raczek A.: *Temperature Control of Potatoes in the Storage Using DMC Control Algorithm.* Journal of Research and Applications in Agricultural Engineering, 2015, Vol. 60(1), 112-115.
- [8] Wachowicz E., Raczek A., Woroncow L.: *The Use of Optimization of Energy-saving Microclimate Control In Selected Agriculture Engineering Objects.* Journal of Research and Applications in Agricultural Engineering, 2016, Vol. 61(1), 119-123.