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COMPREHENSIVE MODEL OF PROCESSES PROCEEDING AT A MUSHROOM-GROWING CELLAR

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Key words: mushroom-growing cellar, modeling, simulation.

Abstract

A comprehensive, mathematical and a computer model of a mushroom-growing cellar was presented in this paper. This model includes models of a manufacturing processes occurring in a mushroom, models of air conditioning and ventilation systems, and also a control system model. The results of simulation tests on a mushroom-growing cellar carried out with the MATLAB software environment were presented in a subsequent part of the paper.

KOMPLEKSOWY MODEL PROCESÓW WYSTĘPUJĄCYCH W PIECZARKARNI

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Słowa kluczowe: pieczarkarnia, modelowanie, symulacja.

Abstrakt

W pracy omówiono kompleksowy, matematyczny i komputerowy model pieczarkarni. W jego skład wchodzą modele procesów technologicznych występujących w pieczarkarniach, a także modele układów wentylacji i klimatyzacji oraz model systemu sterowania. Przedstawiono wyniki badań symulacyjnych pieczarkarni, przeprowadzonych z wykorzystaniem środowiska programowego MATLAB.

List of symbols and signs

G – mass rate of air flow, kg s^{-1},
H – mass flux density, kg s^{-1} m^{-2},
M – mass, kg,

PP – air throttle loading, absolute,
T – temperature, K,
w – carbon dioxide content in air, kg kg^{-1},
x – water content in air, kg kg^{-1},

Indices:
ch – cooler,
CO_2 – CO_2 system,
h – cellar,
km – mixing chamber,
n – air humidifier,
na – heater,
p – cultivated soil,
pc – air supplied a cellar to a mixing chamber,
ph – air supplied to a cellar,
pw – air exhausted from a cellar to the environment,
pz – outside air,
s – cultivated soil sprinkler,
skr – condenser.

Introduction

Strong market competition forces owners of mushroom-growing cellars to produce cheap, high quality mushrooms. Hence, expectations of the owners of mushroom-growing cellars directed at automation specialists include:

1. Assurance inside the cultivation halls the required runs or values of technological parameters in the form of: temperature and relative humidity of indoor air, temperature and moisture content in the cultivated soil, as well as carbon dioxide in the air inside the mushroom-growing cellars. This makes it possible to obtain high and good quality crop of mushrooms (SZUDYGA 1995). This condition is possible to meet when the mushroom-growing cellar will be equipped with air conditioning and ventilation equipment and control system for these devices.

2. Energy-efficient control of technological parameters, thereby reducing operating costs of a mushroom-growing cellar, and hence will reduce the price of mushrooms.

The above-mentioned demands are mutually incompatible. It is not the cheapest possible (i.e. without switching on the energy-consuming air conditioning and ventilation equipment), the growing of mushrooms of good quality. Therefore, in the Department of Automation at Technical University of

Koszalin the work is underway, which aims to reach a compromise between the expectations of the owners of mushroom-growing cellars. This work consists in searching for energy-saving algorithms to control the technological parameters of a mushroom-growing cellar, while ensuring the best possible quality control.

It is common knowledge that testing of new, untested proposals of mushroom-growing cellar control algorithms is associated with the possibility of the creation of material losses incurred by an owner of the mushroom-growing cellar. Therefore there was developed a comprehensive model a of mushroom-growing cellar, which allows the validation and assessment of the operation control system of ventilation and air conditioning equipment, equipped with a variety of energy-efficient control algorithms. Evaluation of algorithm control proposals will based on the results of simulation tests, carried out using a complex model a of mushroom-growing cellar.

The aim of this work was:

– formulate a comprehensive mathematical and computer model of a mushroom-growing cellar containing models of the processes of heat and transfer taking place in the hall of mushroom cultivation, models of air conditioning and ventilation equipment and a model of a control system,

– carry out simulation tests using the developed model and model validation.

Simulation model of a mushroom-growing cellar

Figure 1 illustrates a block diagram of a simulation, comprehensive model of a mushroom-growing cellar.

A simulation, comprehensive model of a mushroom-growing cellar contains the following models:

1. Control object in the form of technological processes occurring in the inside air at the hall and cultivated soil,

2. ambient or outside air,

3. processes during the operation of ventilation and air conditioning equipment, i.e. a mixing chamber, cooler, condenser, heater, humidifier, sprinkler and CO_2 system.

In addition, a model comprising the control system model for air conditioning and ventilation devices, currently implementing the control algorithm applied to the a mushroom-growing cellar in Wersk.

Comprehensive computer model of the mushroom-growing cellar is presented in Figure 2.

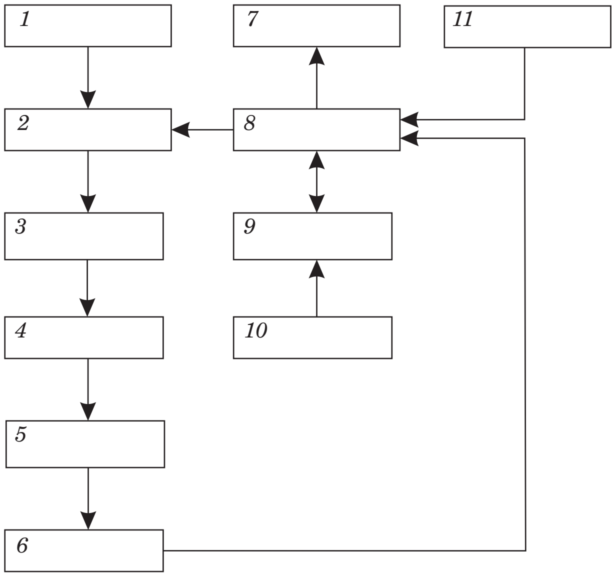

Fig. 1. Block diagram of a comprehensive model of a mushroom-growing cellar: *1* -atmospheric air, *2* – mixing chamber, *3* – cooler, *4* – condenser, *5* – heater, *6* – humidifier, *7* – outside air, *8* – inside air, *9* – cultivated soil, *10* – sprinkler, *11* – CO_2 system

Source: Own study.

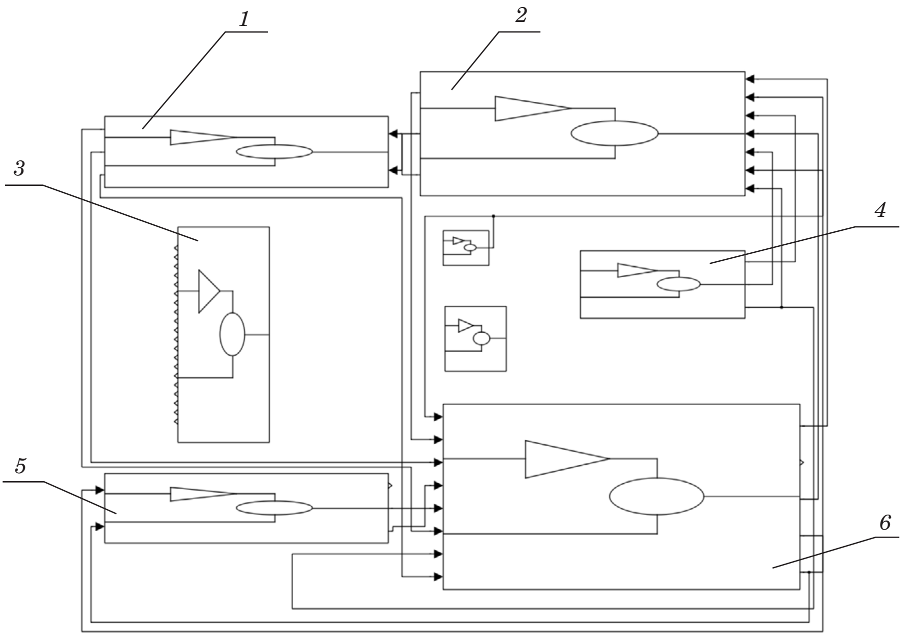

Fig. 2. Comprehensive computer model of the mushroom-growing cellar: *1* – climate control panel, *2* – mixing chamber, *3* – experimental data, *4* – outside air, *5* – cultivated soil, *6* – cultivation hall

Source: Own study.

Simulation model of processes proceeding in the mushroom-growing cellar was received after it was implemented in the MATLAB software environment Simulink toolbox (TARNOWSKI 2004) of differential equations providing a mathematical model of the heat and mass transfer processes occurring in the inside air and cultivated soil of mushrooms.

Mathematical model of processes proceeding in the mushroom-growing cellar

The mathematical model of processes proceeding in air and in cultivated soil of a mushroom-growing cellar assumes the form of a heat and mass balance equation (Equations 1–5). These equations describe changes as a function of time in:
– enthalpy of air in a plant house (Equation 1),
– water content in air in a plant house (Equation 2),
– heat of cultivated soil in a plant house (Equation 3),
– water content in a cultivated soil in a plant house (Equation 4)
– carbon dioxide content in air inside a plant house (Equation 5).

$$\underbrace{M_h \cdot c \cdot \frac{dT_h}{dt}}_{\substack{\text{Change}\\ \text{in air enthalpy}\\ \text{in a plant house}}} = c \cdot (\underbrace{G_{ph} \cdot T_{na} \cdot K_{na}}_{\substack{\text{Heat flux}\\ \text{from a heater}}} - \underbrace{G_{ph} \cdot T_{ch} \cdot K_{ch}}_{\substack{\text{Coolness flux}\\ \text{from a cooler}}} - \underbrace{G_{pw} \cdot T_h}_{\substack{\text{Heat flux}\\ \text{carried off}\\ \text{with exhausted air}}} + \underbrace{G_{ph} \cdot T_{km}}_{\substack{\text{Heat flux}\\ \text{supplied}\\ \text{to a plant house}\\ \text{with blown-in air}}} - \underbrace{G_{pc} \cdot T_h}_{\substack{\text{Heat flux}\\ \text{supplied to}\\ \text{a mixing chamber}}}) + \underbrace{\alpha \cdot S_p \cdot (T_h - T_p)}_{\substack{\text{Heat flux}\\ \text{from cultivated soil}}} \tag{1}$$

$$\underbrace{M_h \cdot \frac{dx_h}{dt}}_{\substack{\text{Change}\\ \text{of water content}\\ \text{in inside air}}} = \underbrace{x_{pz} \cdot G_{pz}}_{\substack{\text{Woter stream}\\ \text{in atmospheric air}}} - \underbrace{x_h \cdot G_{pw}}_{\substack{\text{Woter stream}\\ \text{in exhausted air}}} - \underbrace{x_h \cdot G_{pc}}_{\substack{\text{Woter stream}\\ \text{supplied to}\\ \text{a mixing chamber}}} - \underbrace{H_{skr}}_{\substack{\text{Woter stream}\\ \text{collected}\\ \text{in a condenser}}} + \underbrace{H_N}_{\substack{\text{Woter stream}\\ \text{absorbed by}\\ \text{air from}\\ \text{a humidifer}}} + \underbrace{\alpha_p \cdot S_p \cdot (x - x_{pm})}_{\substack{\text{Woter stream}\\ \text{evaprated by soil}}} \tag{2}$$

$$\underbrace{M_p \cdot c_p \cdot \frac{dT_p}{dt}}_{\substack{\text{Change of heat}\\ \text{in cultivated soil}}} = \underbrace{\alpha \cdot S_p \cdot (T_h - T_p)}_{\text{Heat flux given up to air}} - \underbrace{r_{pw} \cdot \alpha_p \cdot S_p \cdot (x - x_{pm})}_{\substack{\text{Heat flux used for evaporation}\\ \text{of water from soil}}} \tag{3}$$

$$\underbrace{M_p \cdot \frac{dx_p}{dt}}_{\substack{\text{Change of woter}\\ \text{content in}\\ \text{cultivated soil}}} = \underbrace{H_S}_{\substack{\text{Stream of woter}\\ \text{obtained from}\\ \text{a sprinkler}}} - \underbrace{\alpha_p \cdot S_p \cdot (x - x_{pm})}_{\substack{\text{Stream of water evaporated}\\ \text{by cultivated soil}}} \tag{4}$$

$$\underbrace{M_h \cdot \frac{dw_h}{dt}}_{\substack{\text{Change of } CO_2\\ \text{content in inside air}}} = \underbrace{G_{ph} \cdot w_{km}}_{\substack{\text{Stream of } CO_2\\ \text{in air supplied}\\ \text{to a plant house}}} + \underbrace{G_{CO_2} \cdot w_{CO_2}}_{\substack{\text{Stream of } CO_2\\ \text{supplied}\\ \text{from a } CO_2 \text{ system}}} - \underbrace{G_{pw} \cdot w_h}_{\substack{\text{Stream of } CO_2\\ \text{removed from a plant}\\ \text{house with exhaused air}}} - \underbrace{G_{pc} \cdot w_h}_{\substack{\text{Stream of } CO_2\\ \text{in air supplied}\\ \text{to a fixing chamber}}} \tag{5}$$

An example of a simulation model of the heat exchange process in the air inside a mushroom-growing cellar is presented in Figure 3. This model constitutes the implemented MATLAB software environment, Equation 1.

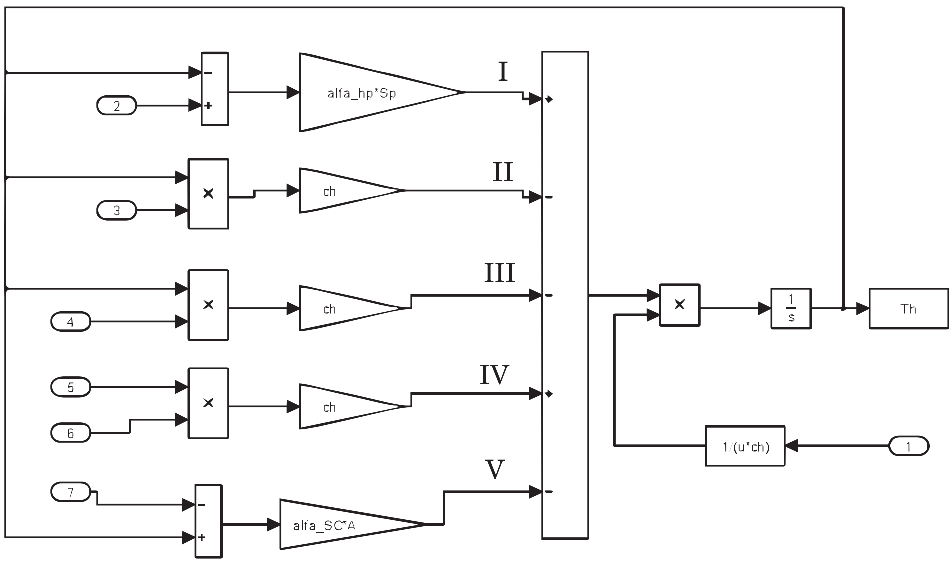

Fig. 3. Implementation of equation (1) in the MATLAB software environment forming a mathematical model of heat exchange in the air inside a mushroom-growing cellar: 1–7 – data input, I – heat flux from cultivated soil, II – heat flux removal to a mixing chamber, III – heat flux removal along with air blown out, IV – heat flux supplied to a hall along with air from a climate control panel, V – heat flux removal to environment

Source: Own study.

Mathematical models and simulation of processes proceeding during the operation of air conditioning and ventilation equipment

The processes shown in Figure 1 proceeding during the operation of air conditioning and ventilation equipment are described mathematically, using the textbook according to (MALICKI 1977). Then the equations were implemented in the MATLAB software environment. The following examples disclose equations (6 – 15), which form a mathematical model of the mixing chamber.

$$G_{ph} = G_{pz} + G_{pc} \tag{6}$$

$$G_{pz} = PP_{pz} + G_{ph} \tag{7}$$

$$G_{pc} = PP_{pc} + G_{ph} \tag{8}$$

$$PP_{pz} = 1 - PP_{pc} \tag{9}$$

$$G_{pz} = (1 - PP_{pc}) \cdot G_{ph} \tag{10}$$

$$G_{ph} \cdot w_{km} = G_{pz} \cdot w_{pz} + G_{pc} \cdot w_h \tag{11}$$

$$G_{ph} \cdot w_{km} = PP_{pz} \cdot G_{ph} \cdot w_{pz} + PP_{pc} \cdot G_{ph} \cdot w_h \tag{12}$$

$$w_{km} = PP_{pz} \cdot w_{pz} + PP_{pz} \cdot w_h \tag{13}$$

$$x_{km} = (1 - PP_{pc}) \cdot w_{pz} + PP_{pc} \cdot x_h,\ x_{km}(\max) = f(T_{km}) \tag{14}$$

$$T_{km} = (1 - PP_{pc}) \cdot T_{pz} + PP_{pc} \cdot T_h \tag{15}$$

A computer model of the processes proceeding in the mixing chamber, obtained after implementing the above equations in the MATLAB software environment is presented in Figure 4.

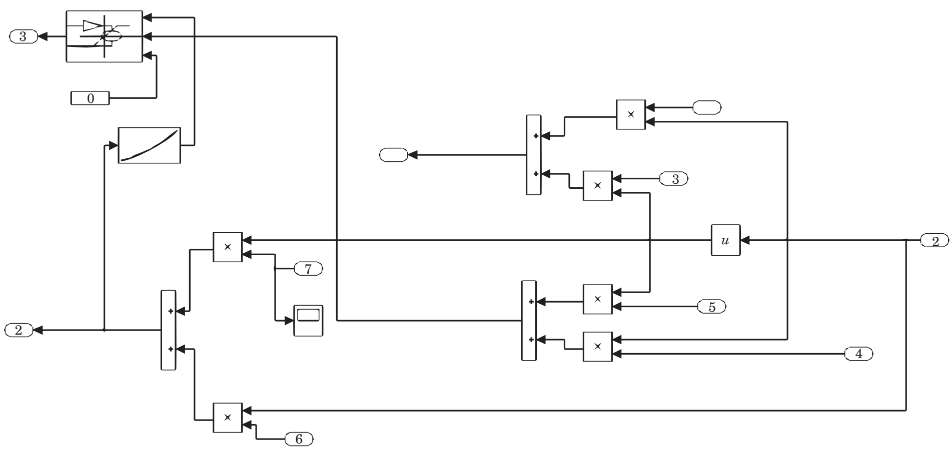

Fig. 4. Implementation of Equation (1–10), forming a mathematical model of the mixing chamber, in the MATLAB software environment: 1–6 – data ports
Source: Own study.

Sample results of simulation processes proceeding at a mushroom-growing cellar

At a mushroom-growing cellar in Wersk near Czluchow experimental investigations were conducted, during which runs of the technological parameters of a mushroom-growing cellar and operating conditions of ventilation and air conditioning equipment were simultaneously recorded. It was assumed during the simulation tests carried out based on the knowledge of a comprehensive, computer model of a mushroom-growing cellar that ventilation and air conditioning equipment was working, such as at the mushroom-growing cellar in Wersk, and then runs of the technological parameters were determined. In order to verify the correctness of a comprehensive model of a mushroom-growing cellar, it has undergone operational validation.

It was that the simulation results were compared with measurements carried out at a real mushroom-growing cellar. Simulation tests and measurements were carried out while maintaining the same reference conditions (operating conditions of ventilation and air conditioning equipment).

Figure 5 shows the examples of:

– calculated and recorded in Wersk runs of indoor air temperature obtained during the operation of an air heater (Fig. 5a),

– operating conditions of the mixing chamber, where due to the possibility of controlling the degree of throttle opening, the respective proportions of outside air were mixed with the internal (Fig. 5b). (The figure below shows the percentage of outside air in the mixed air). Moreover, the calculated and measured runs of air temperature at the outlet from the mixing chamber corresponding to the operating conditions are also presented in Figure 5b.

Analysis of the simulation test results revealed that the model was formulated properly and that it properly reflects the runs of processes proceeding at a mushroom-growing cellar.

Summary

The results of work on the development of a comprehensive model of a mushroom-growing cellar were presented in the paper. In effect, the mathematical and computer models were produced: the processes of heat and mass transfer occurring at a mushroom-growing cellar, a model of the environment, as well as models of the processes proceeding in the ventilation and air conditioning equipment and the controls. Logical and empirical analysis of the simulation test results confirmed that models were performed correctly. The comprehensive model of a mushroom-growing cellar proposed in the paper will

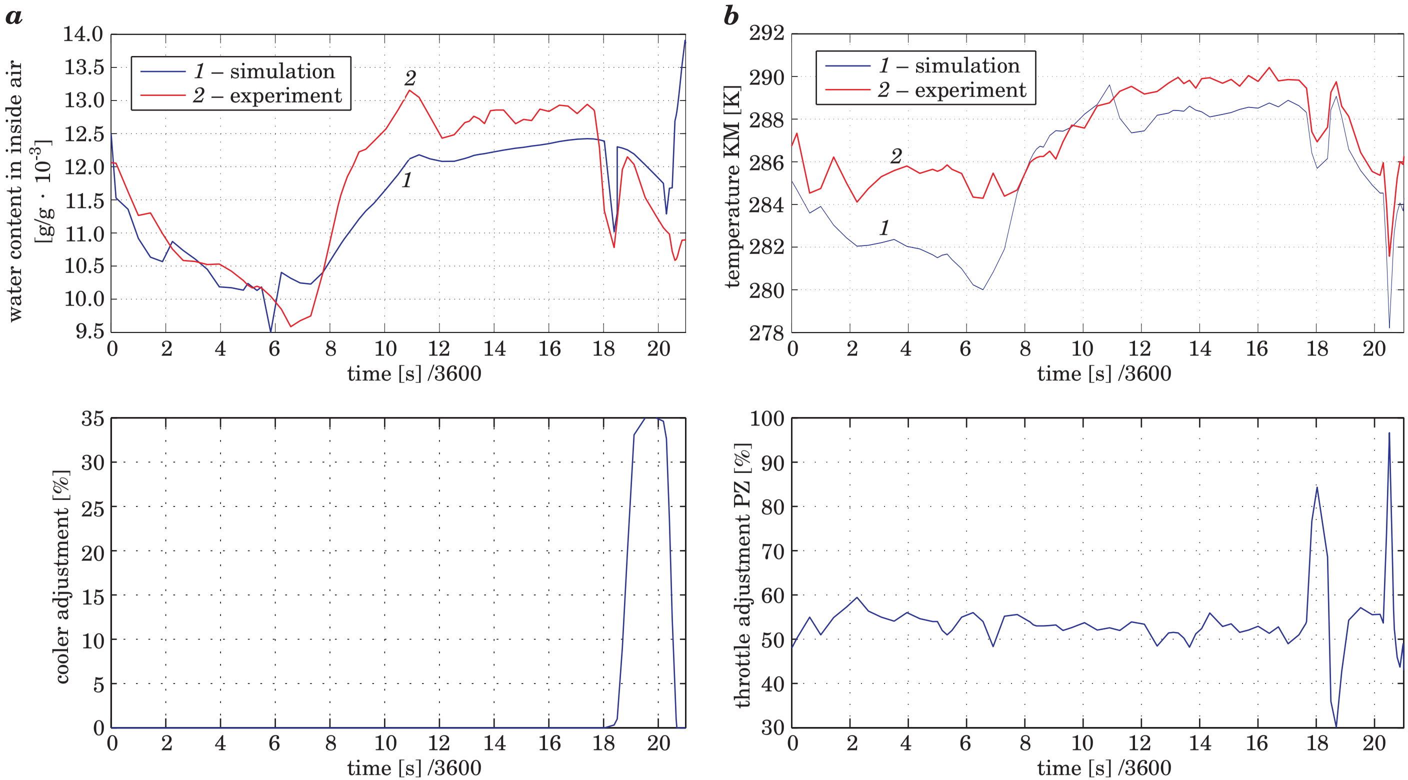

Fig. 5. Sample runs: *a* – the indoor air temperature and operating conditions of the air heater, *b* – the mixed air temperature at the outlet of the mixing chamber and the degree of opening of the outside air throttle

Source: Own study.

have application in the development and while testing the algorithms for efficient ventilation and air conditioning equipment in the building of a mushroom-growing cellar.

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