JAISCR, 2023, Vol. 13, No. 1, pp. 19 – 35
10.2478/jaiscr-2023-0002

# INFORMATION TECHNOLOGY FOR COMPREHENSIVE MONITORING AND CONTROL OF THE MICROCLIMATE IN INDUSTRIAL GREENHOUSES BASED ON FUZZY LOGIC

Ivan Laktionov[1,*], Oleksandr Vovna[2], Maryna Kabanets[3]

[1] *Department of Software of Computer Systems, Dnipro University of Technology,*
*av. Dmytra Yavornytskoho, 19, Dnipro, UA49005, Ukraine*

[2] *Department of Electronic Engineering, SHEI 'Donetsk National Technical University'*
*of the Ministry of Education and Science of Ukraine,*
*Sofii Kovalevskoi st., 29, Lutsk, UA43024, Ukraine*

[3] *Language Training Department, SHEI 'Donetsk National Technical University'*
*of the Ministry of Education and Science of Ukraine,*
*Sofii Kovalevskoi st., 29, Lutsk, UA43024, Ukraine*

[*] *E-mail: laktionov.i.s@nmu.one*

*Submitted: 27th June 2022; Accepted: 19th October 2022*

### Abstract

Nowadays, applied computer-oriented and information digitalization technologies are developing very dynamically and are widely used in various industries. One of the highest priority sectors of the economy of Ukraine and other countries around the world, the needs of which require intensive implementation of high-performance information technologies, is agriculture. The purpose of the article is to synthesise scientific and practical provisions to improve the information technology of the comprehensive monitoring and control of microclimate in industrial greenhouses. The object of research is non-stationary processes of aggregation and transformation of measurement data on soil and climatic conditions of the greenhouse microclimate. The subject of research is methods and models of computer-oriented analysis of measurement data on the soil and climatic state of the greenhouse microclimate. The main scientific and practical effect of the article is the development of the theory of intelligent information technologies for monitoring and control of greenhouse microclimate through the development of methods and models of distributed aggregation and intellectualised transformation of measurement data based on fuzzy logic.

**Keywords:** monitoring, control, information technology, greenhouse, fuzzy logic.

## 1 Introduction

### 1.1 Relevance of the topic

Nowadays, computer and information technology for the digitalisation of various industries is developing very dynamically and is consequently being used in more and more applications. This fact necessitates the continuous development of scientific aspects of modernization of such applied information technology. One of the main sectors of the national economy of Ukraine, which needs urgent and rapid modernization through the development and implementation of high-performance information technology, is agriculture. In turn, an important area of sustainable agricultural development, which plays a crucial role in ensuring food security in many countries around the world, taking into account climatic zones, is vegetable growing in greenhouses. This fact is confirmed by the statistics of the annual increase in the total area of greenhouses around the world.

According to the latest FAO data, this figure has increased by about 25 % in the last ten years and is estimated to be about 500,000 ha in 2021 [1]. Besides the fact that modern greenhouse complexes are popular agrotechnical objects, they are still quite knowledge-intensive productions, and, therefore, should be considered as technical objects of continuous action with a certain working space, on which soil and climatic factors and the characteristics of the irrigation solution have the integral effect. The term “integral state” in this article refers to complex measurement information processed by intellectualised methods on the set of physical and chemical parameters of the aerogas medium, soil and irrigation solution. Thus, the topic of the article is relevant and the importance of the expected scientific and applied result from solving the problem consists in improving the software and hardware base of agricultural greenhouses, which stimulates the positive dynamics of food security in the world by providing all-the-year-round production of high-quality agricultural production in necessary volumes at a satisfactory pace.

The main social and economic effect of software and hardware re-equipment of agricultural enterprises consists in providing high values of indicative indicators of long-term sustainability, competitiveness and investment attractiveness of the agricultural segment of the national economy of many countries of the world.

## 1.2 Review, critical analysis and systematization of modern literature sources

As a result of the analysis of current internationally recognized regulations ASABE and FAO [2, 3] on ensuring compliance with the requirements of complexity and consistency of functional transformations of measurement data by means of information and communication technologies in greenhouse conditions, it was found that temporal instability and spatial heterogeneity of processes, the need to take into account the relationship of a significant number of physical and chemical soil and climatic parameters, as well as the scale of adaptation of information and measurement procedures to different types and periods of vegetation, have not allowed developing a theory of integrated monitoring and adaptive hardware and software control of agrotechnical processes. A review of current trends in the development of instrumental information and computer-oriented technologies has allowed us to identify a set of those that can be used as a basis for increasing the level of intellectualization and digitalization of agricultural procedures [4, 5]: artificial neural networks (ANN); evolutionary computing and genetic algorithms (ECGA); fuzzy logic (FL); evolutionary robotics (ER); the Internet of Things (IoT); wireless sensor networks (WSN).

Currently, there are a significant number of high-quality research results and practical developments on designing computer-oriented and infocommunication technologies for monitoring and control of greenhouse microclimate, the main ones of which are presented in Table 1.

It should be noted that the research results given in Table 1 are not exhaustive. The above-mentioned scientific works provide general science-based approaches and modern tested directions of using methods and tools of intellectualization and digitalization of information technologies of monitoring and management of agricultural processes in greenhouse conditions. Also, as a result of data systematisation of the critical analysis data (see Table 1), it was found that the algorithmic base of fuzzy logic theory is universal and effective in solving the problem of data transformation [6] in terms of information and measurement procedures of non-destructive monitoring and automatic control.

In scientific papers [7–10], the authors of this article substantiated the need and proved the possibility to develop applied information technologies for agricultural use based on serial budget sensor and microprocessor components and unified standardised software packages for measurement information interpretation.

Based on the logical generalisation of the above analysis of the existing greenhouse climate monitoring and control technologies, it should be noted that a significant range of research is devoted to the development of hardware and software solutions of functional devices for monitoring specific parameters and/or control of individual agrotechnical procedures. Considering the qualitative solution of certain problems of software and hardware development of information technologies, the theory of comprehensive monitoring and control of the integral climatic state of the analysed physical environments is in its infancy. The main issues requiring additional development on the basis of known theories are: accounting for the principles of systematic and comprehensive collection and processing of distributed measurement information and accounting for the interrelations of measured parameters when interpreting the physical media integral state.

### 1.3 Purpose, object, subject and structure of the research

The main purpose of the article is to synthesise the scientific and practical provisions for improving the information technology for complex monitoring and control of microclimate of industrial greenhouses by substantiating computer-oriented method of integrated aggregation and transformation of measurement data on soil and climatic parameters based on the fuzzy logic theory. The research object is non-stationary processes of aggregation and transformation of measurement data regarding the complex soil and climatic state of industrial greenhouses. The research subject is methods and models of computer-oriented analysis of measurement information on the integral state of microclimate of greenhouses. The structure of the article: Section 1 contains information on the relevance of the research topic, research fields, the current state of the subject area and scientific and practical novelty of the obtained results; Section 2 contains information on the materials used and research methods; Section 3 contains the main quantitative and qualitative research results; Section 4 contains information on promising areas for further research; Chapter 5 provides conclusions.

### 1.4 Scientific and practical significance of the obtained results

Scientific and practical novelty and significance of the results of the article lies in the synthesis of computer-oriented method of integrated monitoring and automatic control of greenhouse microclimate based on the results of non-destructive measurements of distributed physical and chemical parameters and information transformation algorithms based on fuzzy logic, which allows setting online indicators of compliance between the current and recommended state of the microclimate and generating signals of adjustment of agro-procedures, taking into account the plant types and periods of vegetation.

## 2 General approaches, materials and research methods

### 2.1 Approaches to the research

Theoretical and methodological basis to achieve the main aim is a comprehensive approach through the use of the following world-proven scientific methods: analysis and systematisation of the known scientific and practical results; information and computer modelling; synthesis of structural and algorithmic organisation of information monitoring and control systems; the fuzzy logic theory. The main research results were obtained as a result of a computer experiment with the certified and licensed software Matlab & Simulink in profile laboratories of SHEI “DonNTU” (Pokrovsk).

### 2.2 The structure of information technology

Justification of functioning modes of information technology of comprehensive monitoring and control of microclimate in industrial greenhouses in conditions of uncertainty and scale of measurements is connected with solving the problem of formalised description of the investigated technology. Thus, in accordance with the principles of conceptual modelling, a general structural and algorithmic diagram of measurement information transformation has been developed (see Figure 1).

The following symbols are used in Figure 1: $T_{air\ in}$ – air temperature in the growing area; $T_{air\ out}$ – ambient air temperature; $T_{water}$ – irrigation solu-

**Table 1**. Systematisation of known research results and development of information technology for greenhouse climate monitoring and control

| **Research object** | **Measured parameters** | **Technologies used** | **Literature source** |
|---|---|---|---|
| Functional characteristics of intelligent monitoring systems | Humidity and temperature of air and soil; light intensity | IoT, WSN | [11] |
| Network protocols and algorithms for greenhouse automation systems | Air temperature and humidity | IoT | [12] |
| Methods and means of cloud analysis of multilevel irrigation system data | Humidity and temperature of air and soil; light intensity | IoT | [13] |
| Robotic system for monitoring agricultural procedures | Air temperature and humidity | ER | [14] |
| Methods for optimisation of greenhouse cultivation processes | Air humidity and temperature; lighting; $_2$ concentration | ECGA | [15] |
| Approaches to the construction of virtual sensors for temperature monitoring | Air temperature | WSN, FL | [16] |
| Decision making algorithms for greenhouse irrigation system | Humidity and air temperature; air flow velocity | ANN | [17] |
| Tools for remote monitoring of microclimate parameters | Humidity and temperature of air and soil | IoT, WSN | [18] |
| Methods and tools for intellectualization of the control systems of greenhouse parameters | Air humidity and temperature; light intensity | WSN, FL, ANN | [19] |
| Methods of forecasting greenhouse measurement information | Air humidity and temperature; light intensity; air flow velocity | ECGA | [20] |
| Regression models of information processing on microclimate parameters | Air humidity and temperature | ANN | [21] |
| Methods and tools for developing microclimate monitoring systems | Air humidity and temperature; nitrogen concentration | ANN, ECGA | [22] |
| Functional characteristics of drip irrigation system | Air humidity and temperature; light intensity | FL | [23] |
| Tools for remote monitoring of greenhouse microclimate parameters | Air humidity and temperature | WSN, FL | [24] |

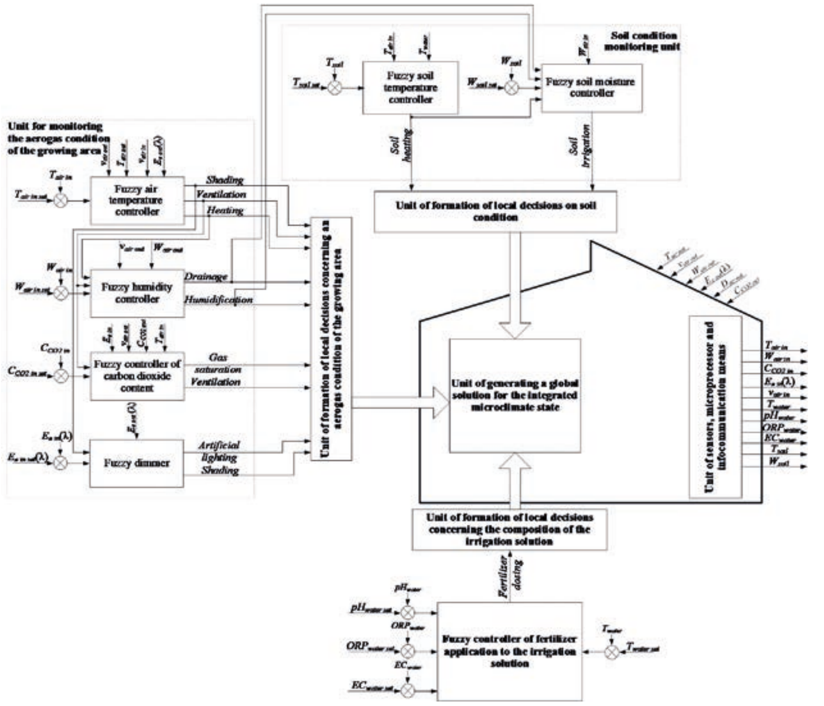


**Figure 1**. Structural and algorithmic diagram of measurement information transformation

tion temperature; $T_{soil}$ – soil temperature; $W_{air\ in}$ – air humidity in the growing area; $W_{air\ out}$ – ambient air humidity; $W_{soil}$ – soil humidity; $\nu_{air\ in}$ – air velocity in the growing area; $\nu_{air\ out}$ — ambient air velocity; $E_{e\ in}(\lambda)$ – energy lighting of the growing area; $E_{e\ out}(\lambda)$ – ambient energy lighting; $C_{CO2\ in}$ – carbon dioxide concentration in the growing area; $C_{CO2\ out}$ – ambient carbon dioxide concentration; $D_{air\ out}$ – ambient wind direction; $pH_{water}$ – acidity of the irrigation solution; $OPR_{water}$ – redox potential (OPR) of the irrigation solution; $EC_{water}$ – electrical conductivity of the solution; index *set* – recommended value of the measured value.

Thus, the diagram of transformation of measuring information in relation to the integral condition of the microclimate in greenhouses, given in Figure 1, from the point of view of computer monitoring and automatic control technology is a complex and multifaceted object that requires special intellectual algorithms for aggregation and analysis of measuring data during the technological processes of cultivation. Thus, it is possible to draw a conclusion about the feasibility and prospects of using fuzzy intelligent algorithms for aggregation and transformation of measurement data on the integrated state of the greenhouse microclimate, taking into account types and vegetation periods of cultivated crops.

### 2.3 Algorithm of fuzzy information technology development

Given the characteristics of the task of computerised non-destructive monitoring and automatic situation control and the analysis of the world experience in developing applied information systems based on fuzzy logic [19, 25, 26], the Mamdani algorithm was selected as the basic algorithm.

The first step in developing the fuzzy information technology was to define the input variables and turn them into a linguistic appearance. As input variables, the following physical and chemical quantities were chosen in their respective operating ranges: air temperature in the growing area ($T_{air\ in}$ – from 15 °C to 30 °), relative humidity in the growing area ($W_{air\ in}$ – from 55 % to 95 %), carbon dioxide concentration in the growing area ($C_{CO2\ in}$ – from 0.05 % to 0.2 %), air flow rate in the growing area ($\nu_{air\ in}$ – from 0.2 $m \cdot s^{-1}$ to 0,6 $m \cdot s^{-1}$), energy lighting of the growing area ($E_{e\ in}$ – from 60 $W \cdot m^{-2}$ to 110 $W \cdot m^{-2}$), soil temperature ($T_{soil}$ – from 16 °C to 26 °C), soil relative humidity ($W_{soil}$ – from 50 % to 95 %), temperature of the irrigation solution ($T_{water}$ – from 18 °C to 27 °C), acidity of the irrigation solution ($pH_{water}$ – from 5.0 to 7.5 un.), redox potential of the irrigation solution ($OPR_{water}$ – from -400 mV to 300 mV), electrical conductivity of the irrigation solution ($EC_{water}$ – from 1.8 mS·m$^{-1}$ to 3.0 mS·m$^{-1}$), ambient air temperature ($T_{air\ out}$ – from -20 °C to 45 °C), relative humidity of ambient air ($W_{air\ out}$ – from 10 % to 100 %), ambient energy lighting ($E_{e\ out}$ – from 20 W·m$^{-2}$ to 300 W·m$^{-2}$), ambient air velocity ($\nu_{air\ out}$ – 0.5 m·s$^{-1}$ to 5.0 m·s$^{-1}$) [2, 3, 27]. The main crop types studied were tomatoes and cucumbers, respectively, at two characteristic ripening periods, before and after vegetation season.

All the above linguistic variables regarding the microclimate internal state (characteristics of air in the growing zone, soil and irrigation solution) were fuzzified using piecewise linear membership functions (triangular and trapezoidal), satisfying the condition "located in the interval" by the following terms: significantly below normal (VL), below normal (L), normal (N), above normal (H), significantly above normal (VH). External climatic parameters were fuzzified by the following terms: below the established in the growing zone (L), equal to the established in the growing zone (N), above the established in the growing zone (H).

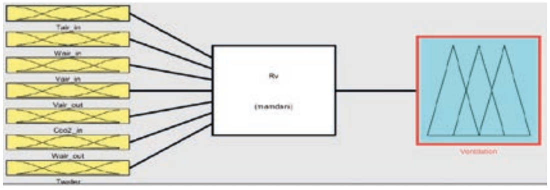
The output signals of the information technology were fuzzified into the input variables in a similar way in the second stage of the algorithm. The main difference lies in the type of membership functions. Gaussian functions were chosen for fuzzification of the output variables to prevent the occurrence of abrupt switching of control signals. As output variables the following values were used: the current values of control voltage (reduced to a unified form in the range from 0 V to 5 V) in pulse-width modulated (PWM) format, previously reduced to a unified form in the range from 0 V to 5 V and afterwards fed to drive and / or power mechanisms of automatic control systems for technological processes of greenhouse crops growing. This approach was chosen based on the possibility of further implementation of fuzzy laws of program control in the microcontroller unit of the information technology under study. The initial variables include: percentage of opening of the ventilation system mechanisms ($r_v$ with the term set $M_1$={"minimum (MIN)", "small (S)", "average (Norm)", "high (H)", "maximum (MAX)"}); the opening angle of the shading system mechanisms ($\alpha_{open}$ with the term set $M_2$={"MIN", "Norm", "MAX"}); electric power of the air heating system ($P_{el\ soil}$ with the term set $M_3$= {"MIN", "Norm", "MAX"}); electric power of the ground heating system ($P_{el\ soil}$ with the term set $M_4$= {"MIN", "Norm", "MAX"}); electric power of the irrigation solution heating system ($P_{el\ water}$ with the term set $M_5$={"MIN", "Norm", "MAX"}); flow rate of the irrigation solution ($CON_{wate}$ with the term set $M_6$={"MIN", "S", "Norm", "H", "MAX"}); flow rate of the humidifying air fluid ($CON_{steam}$ with the term set $M_7$={"MIN", "Norm", "MAX")}; carbon dioxide flow rate ($CON_{O2}$ with the term set $M_8$={"MIN", "Norm", "MAX"}); electric power of artificial lighting system ($P_{light}$ with the term set $M_9$={"MIN", "Norm", "MAX"}); fertilizer dosage applied to the irrigation solution ($CON_{fert}$ with the term set $M_{10}$={"MIN", "Norm", "MAX"}); water addition to the irrigation solution ($CON_{dist}$ with the term set $M_{11}$={"MIN", "Norm", "MAX"}).

Therefore, as can be seen from the analysis of the information above, local solutions (for regulators of each technological process separately) of information technology are divided into three or five terms of trapezoidal functions, due to the principle of PWM control of drive and / or power units technological processes of growing crops. The global solution concerning the integral condition of microclimate is provided on the principle of hierarchical grouping: the local ones are united separately from the blocks of soil sensors, aerogas composition of the growing zone and parameters of the irrigation solution; the formation of the global solution is performed by combining solutions from three local subsystems. The Global Solution (IMC) is fuzzified with five possible states (terms): well below the norm (GVL), below the norm (GL), norm (GN), above the norm (GH), well above the norm (GVH). To implement the fuzzy inference and defuzzification steps, the maximum algorithm and centre of gravity method were used, respectively. The development of the fuzzy database is based on a logical synthesis of experts' experiences of indoor vegetable production [2, 3, 28].

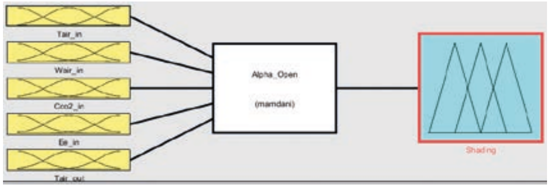
# 3 Research results

## 3.1 Monitoring and control subsystem models in Simulink

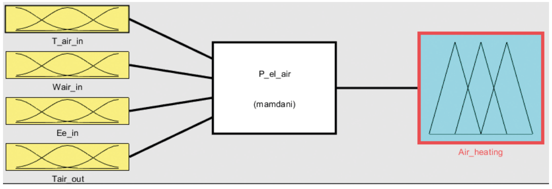
Based on the principle of the research problem decomposition, when developing a computer model of information technology for climate monitoring and control, local decision-making structures were synthesised for all of the above-mentioned controllers of agricultural processes (see Figure 2). For the fertiliser dosing and irrigation water addition systems, the model structures are identical, i.e. the qualitatively relevant input variables ($CON_{fer}$ and $CON_{dist}$) depend on the same set of irrigation solution characteristics ($pH_{water}$, $EC_{water}$ and $OPR_{water}$). The difference between these models lies in the fuzzification of the input parameters and the rule databases, as will be discussed later in the research results.



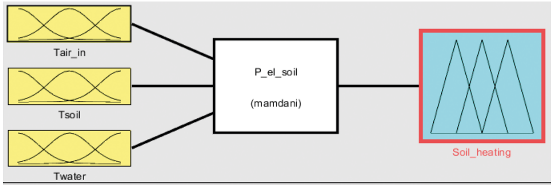
a) Ventilation system controller software unit



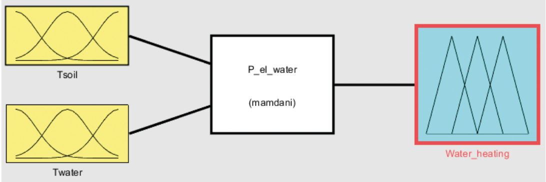
b) Shading system controller software unit



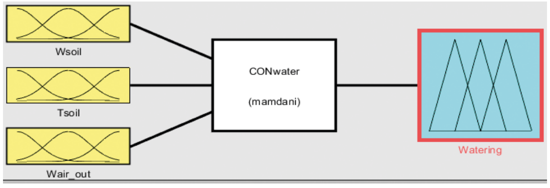
c) Software unit of the air heating controller



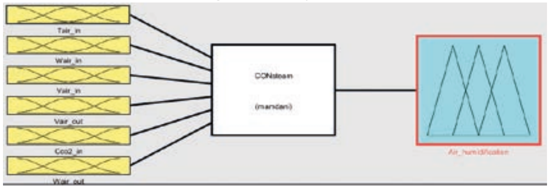
d) Soil heating system controller software unit



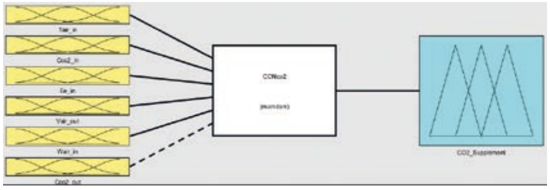
e) Software unit of the controller of the irrigation solution heating system



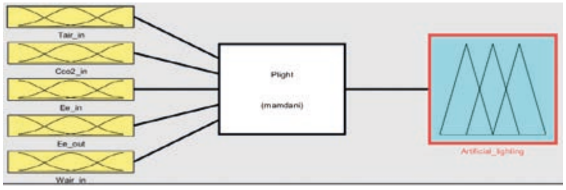
f) Software unit of the controller of the soil irrigation system



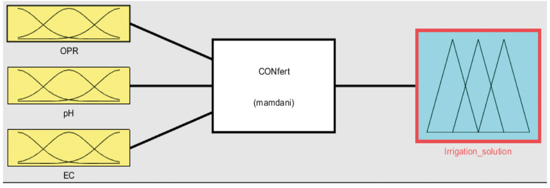
g) Software unit of the humidification system controller



h) Software unit of the controller of the carbon dioxide supply system



i) Software unit of the controller of the artificial lighting system



j) Software unit of the controller of the fertiliser dosing system and water addition to the irrigation solution

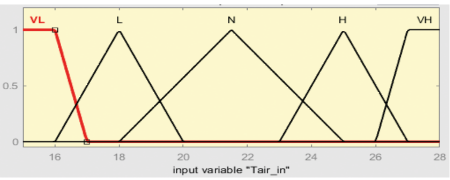
**Figure 2**. Structural organisation of computer models of the information technology local controllers for microclimate monitoring and control

The global solution concerning the integral condition of microclimate is provided on the principle of hierarchical grouping of local solutions from distributed regulating systems of agrotechnical processes as by means of structural organisation by taking into account functional connections of all measured parameters of air in the growing area, soil and irrigation solution, which is shown in Figure 3.

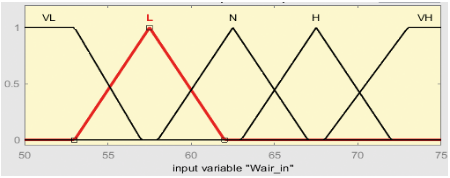
The obtained computer models (see Figures 2 and 3) are structural and functional basis for further research into information technology synthesis.

## 3.2 Fuzzification of input and output variables

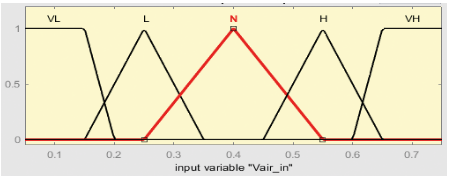
The procedure of fuzzification of input and output variables is implemented in the Fuzzy Logic Designer environment of Matlab & Simulink application software package by the procedure described in Section 2.3 “Algorithm of development of fuzzy model of information technology”. The results of fuzzification input variables, characterising internal soil and climatic state of greenhouse microclimate and irrigation solution parameters, by the example of tomatoes to fructification are shown in Figure 4. The term structure and the fuzzification approaches for other crop types, taking into account the possible growing seasons, are identical to those shown in Figure 4, the adaptation being done by changing the numerical values of the boundaries of the respective terms.



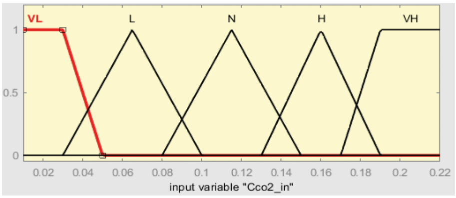
a) air temperature ($T_{air\ in}$)



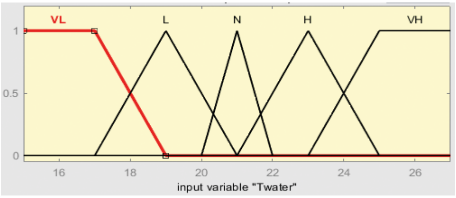
b) relative humidity ($W_{air\ in}$)



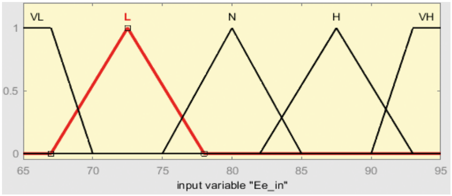
c) air velocity ($\nu_{air\ in}$)



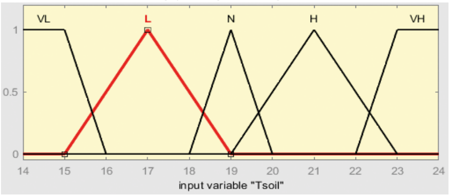
d) carbon dioxide concentration ($C_{CO2\ in}$)



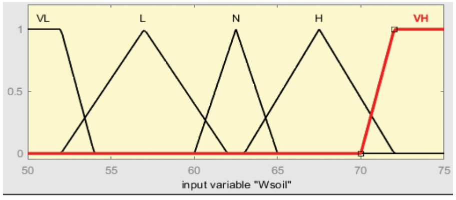
e) irrigation solution temperature ($T_{water}$)



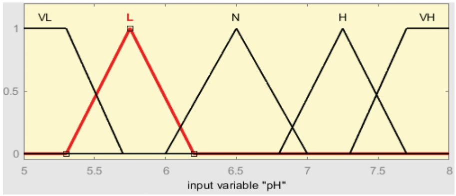
f) energy lighting ($E_{e\ in}$)



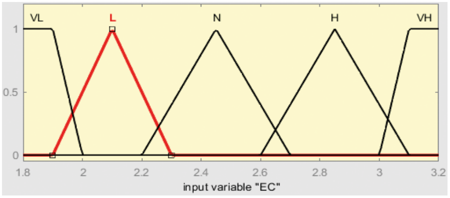
g) soil temperature ($T_{soil}$)



h) soil moisture ($W_{soil}$)



i) irrigation solution acidity ($pH_{water}$)



j) electrical conductivity ($EC_{water}$)

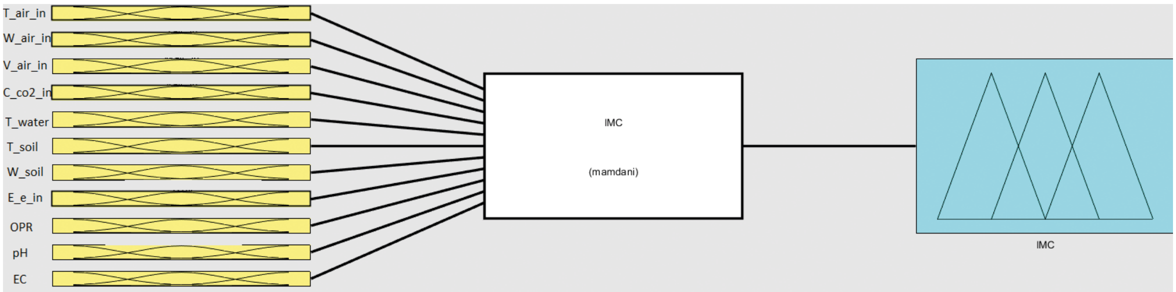
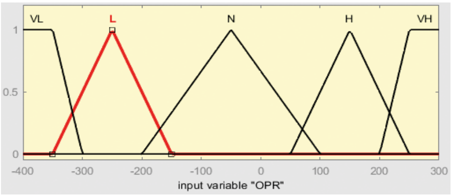


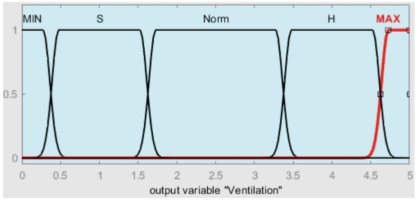
**Figure 3**. Structural organisation of a computer model for generating a global decision on greenhouse climate



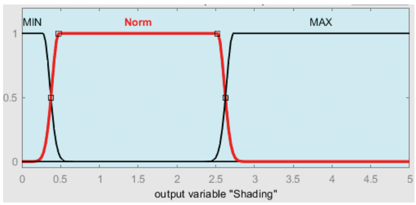
k) ORP of the irrigation solution ($OPR_{water}$)

**Figure 4**. Results of fuzzification the information technology input variables

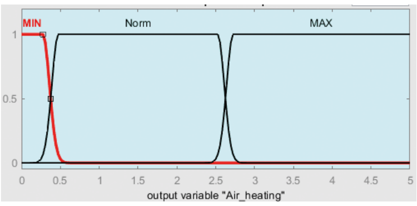
The approaches to fuzzification the physical and chemical environmental parameters are similar to those shown in Figure 4. Only the numerical values of the corresponding terms of the linguistic variables undergo changes in accordance with the data given in Section 2.3. The results of fuzzification the initial variables for local and global solutions of the information technology under study are shown in Figure 5.



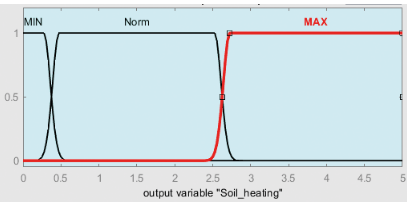
a) Ventilation ($r_v$)



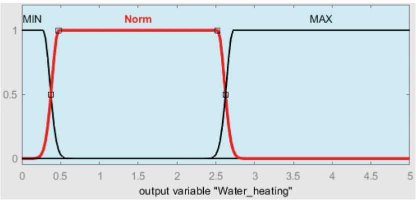
b) Shading ($\alpha_{open}$)



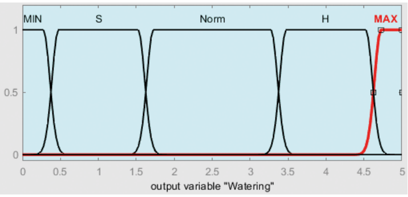
c) Air heating ($P_{el\ air}$)



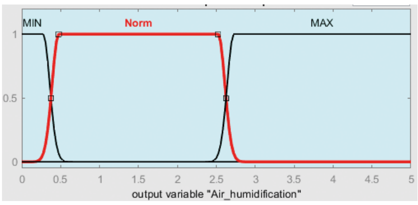
d) Soil heating ($P_{el\ soil}$)



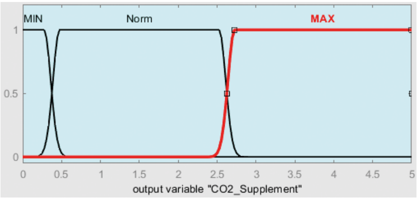
e) Water heating ($P_{el\ water}$)



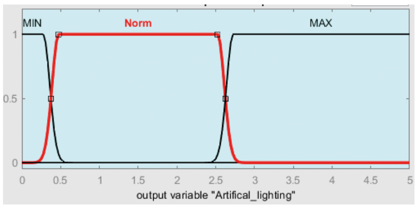
f) Watering ($CON_{water}$)



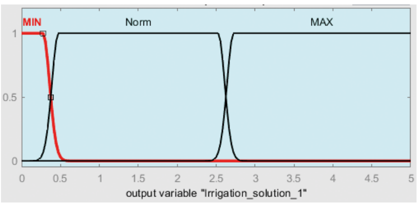
g) Air humidification ($CON_{steam}$)



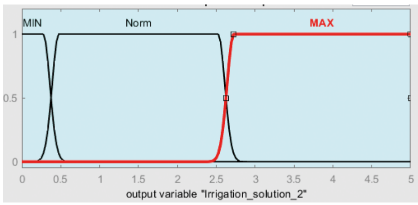
h) $CO_2$ Supplement ($CON_{CO2}$)



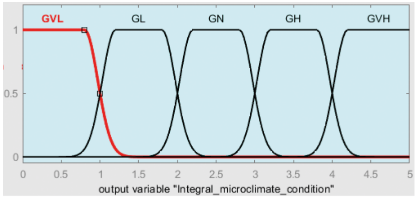
i) Artificial lighting ($P_{light}$)



j) Irrigation solution 1 ($CON_{fert}$)



k) Irrigation solution 2 ($CON_{dist}$)



l) Integral microclimate condition ($IMC$)

**Figure 5**. Results of fuzzification the information technology input variables

The obtained fuzzification results (see Figures 4 and 5) are the algorithmic basis for further research on the synthesis and testing of information technology.

### 3.3 Fuzzy control rule database

The proposed database of fuzzy rules taking into account preliminary results of fuzzification the input and output variables of information technology of comprehensive monitoring and control of microclimate of industrial greenhouses is given below. Also, during the development of the appropriate fuzzy rule base for each technical subsystem (local regulators) and for the global solution generation unit of the integral microclimate state, the possibility of identifying pre-emergency situations was considered and provided for. In each group of fuzzy control rules, the functions were formed with a possible state of input and output variables as "None", which corresponds to the absence of data from sensors of physical and chemical parameters or feedback from control units of the technological processes. Thus, the output linguistic variable takes the value "None" if at least one of the input linguistic variables is characterised by the corresponding value "None". This approach makes it possible to increase the practical use efficiency of the developed information technology. Based on the decomposition principle of the research task, all rules have been divided into two categories. The first category of rules refers to the local regulators of soil and climate conditions and the characteristics of the irrigation solution:

- IF $T_{air\ in}$=VL and $T_{air\ out}$=L, THEN $P_{el\ air}$=MAX and $_{open}$=MAX;
- IF $T_{air\ in}$=L, THEN $P_{el\ air}$=Norm and $_{open}$=MAX;
- IF $T_{air\ in}$=N and $T_{air\ out}$=N, THEN $P_{el\ air}$=MIN and $_{open}$=Norm;
- IF $T_{air\ in}$=H and $W_{air\ in}$=N and $E_{e\ in}$=L, THEN $P_{el\ air}$=MIN and $_{open}$=Norm and $P_{light}$=Norm;
- IF $T_{air\ in}$=H and $W_{air\ in}$=N and $E_{e\ in}$=VL, THEN $P_{el\ air}$=MIN and $_{open}$=MAX and $P_{light}$=MAX;
- IF $T_{air\ in}$=VH and $W_{air\ in}$=N and ($E_{e\ in}$=L or $E_{e\ in}$=VL), THEN $P_{el\ air}$=MIN and $_{open}$=MIN and $P_{light}$=MAX;
- IF $W_{air\ in}$=VL and $T_{air\ in}$=N, THEN $CON_{steam}$=MAX and $r_v$=MIN;
- IF $W_{air\ in}$=L and $T_{air\ in}$=N, THEN $CON_{steam}$=Norm and $r_v$=MIN;
- IF $W_{air\ in}$=N and $T_{air\ in}$=N, THEN $CON_{steam}$=MIN and $r_v$=MIN;

- IF $W_{air\ in}$=H and ($v_{air\ in}$=N or $v_{air\ out}$=L) and ($v_{air\ out}$=N or $v_{air\ out}$=L) and ($T_{air\ in}$=H or $T_{air\ in}$=VH) and ($C_{CO2\ in}$=H or $C_{CO2\ in}$=VH), THEN $CON_{steam}$=MIN and $r_v$=Norm;
- IF $W_{air\ in}$=VH and ($v_{air\ in}$=N or $v_{air\ out}$=L) and ($v_{air\ out}$=N or $v_{air\ out}$=L) and ($T_{air\ in}$=H or $T_{air\ in}$=VH) and $C_{CO2\ in}$=VH and ($W_{air\ out}$=N or $W_{air\ out}$=H), THEN $CON_{steam}$=MIN and $r_v$=MAX;
- IF $W_{air\ in}$=VH and ($v_{air\ in}$=N or $v_{air\ out}$=L) and ($v_{air\ out}$=N or $v_{air\ out}$=L) and ($T_{air\ in}$=H or $T_{air\ in}$=VH) and $C_{CO2\ in}$=H and $W_{air\ out}$=L, THEN $CON_{steam}$=MIN and $r_v$=MAX;
- IF $T_{soil}$=VL and $T_{air\ in}$=VL, THEN $P_{el\ soil}$=MAX;
- IF $T_{soil}$=L and $T_{air\ in}$=L, THEN $P_{el\ soil}$=Norm;
- IF $T_{soil}$=N or $T_{soil}$=H or $T_{soil}$=VH, THEN $P_{el\ soil}$=MIN;
- IF $T_{water}$=VL, THEN $P_{el\ water}$=MAX;
- IF $T_{water}$=L, THEN $P_{el\ water}$=Norm;
- IF $T_{water}$=N and $T_{soil}$=N, THEN $P_{el\ water}$=MIN;
- IF $T_{water}$=H, THEN $P_{el\ water}$=MIN;
- IF $T_{water}$=VH, THEN $P_{el\ water}$=MIN and $P_{el\ soil}$=MIN and $r_v$=S;
- IF $W_{soil}$=VL and $T_{soil}$=VH, THEN $CON_{water}$=MAX;
- IF ($W_{soil}$=VL and $T_{soil}$=H) or ($W_{soil}$=L and $T_{soil}$=VH), THEN $CON_{water}$=H;
- IF ($W_{soil}$=VL and ($T_{soil}$=N or $T_{soil}$=L or $T_{soil}$=VL)) or ($W_{soil}$=L and ($T_{soil}$=H or $T_{soil}$=VH)), THEN $CON_{water}$=Norm;
- IF $W_{soil}$=L and ($T_{soil}$=N or $T_{soil}$=L or $T_{soil}$=VL), THEN $CON_{water}$=S;
- IF ($W_{soil}$=H or $W_{soil}$=VH) and ($W_{air\ out}$=N or $W_{air\ out}$=L) and $T_{soil}$=N, THEN $CON_{water}$=MIN;
- IF $E_{e\ in}$=VL and $E_{e\ out}$=L and ($C_{CO2\ in}$=N or $C_{CO2\ in}$=H or $C_{CO2\ in}$=VH), THEN $P_{light}$=MAX;
- IF $W_{soil}$=N, THEN $CON_{water}$=MIN;
- IF $E_{e\ in}$=L and ($E_{e\ out}$=L or $E_{e\ out}$=N) and ($C_{CO2\ in}$=N or $C_{CO2\ in}$=H or $C_{CO2\ in}$=VH), THEN $P_{light}$=Norm;
- IF $E_{e\ in}$=N or ($E_{e\ in}$=L and $E_{e\ out}$=H), THEN $P_{light}$=MIN;
- IF $C_{CO2\ in}$=VL and ($E_{e\ in}$=N or $E_{e\ in}$=H or $E_{e\ in}$=VH) and $T_{air\ in}$=N, THEN $CON_{CO2}$=MAX;
- IF $C_{CO2\ in}$=L and ($E_{e\ in}$=N or $E_{e\ in}$=H or $E_{e\ in}$=VH) and $T_{air\ in}$=N and $C_{CO2\ out}$=N, THEN $CON_{CO2}$=Norm;
- IF $C_{CO2\ in}$=N and ($E_{e\ in}$=N or $E_{e\ in}$=H or $E_{e\ in}$=VH) and $T_{air\ in}$=N, THEN $CON_{CO2}$=MIN;
- IF $C_{CO2\ in}$=H and ($T_{air\ in}$=H or $T_{air\ in}$=VH) and ($W_{air\ in}$=H or $W_{air\ in}$=VH), THEN $CON_{CO2}$=MIN and $_{open}$=Norm;
- IF $C_{CO2\ in}$=VH and $T_{air\ in}$=VH and $W_{air\ in}$=VH and ($v_{air\ out}$=N or $v_{air\ out}$=L), THEN $CON_{CO2}$=MIN;
- IF $OPR_{water}$=VL or $pH_{water}$=VL or $EC_{water}$=VL, THEN $CON_{fert}$=MAX and $CON_{dist}$=MIN;
- IF $OPR_{water}$=L or $pH_{water}$=L or $EC_{water}$=L, THEN $CON_{fert}$=Norm and $CON_{dist}$=MIN;
- IF $OPR_{water}$=N or $pH_{water}$=N or $EC_{water}$=N, THEN $CON_{fert}$=MIN and $CON_{dist}$=MIN;
- IF $OPR_{water}$=H or $pH_{water}$=H or $EC_{water}$=H, THEN $CON_{fert}$=MIN and $CON_{dist}$=Norm;
- IF $OPR_{water}$=VH or $pH_{water}$=VH or $pH_{water}$=VH, THEN $CON_{fert}$=MIN and $CON_{dist}$=MAX;
- IF $T_{air\ in}$=None or $W_{air\ in}$=None or $v_{air\ in}$=None or $v_{air\ out}$=None or $C_{CO2\ in}$=None or $W_{air\ out}$=None or $T_{water}$=None, THEN $r_v$=None;
- IF $T_{air\ in}$=None or $W_{air\ in}$=None or $C_{CO2\ in}$=None or $E_{e\ in}$=None or $T_{air\ out}$=None, THEN $_{open}$=None;
- IF $T_{air\ in}$=None or $W_{air\ in}$=None or $E_{e\ in}$=None or $T_{air\ out}$=None, THEN $P_{el\ air}$=None;
- IF $T_{air\ in}$=None or $T_{soil}$=None or $T_{air\ in}$=None, THEN $P_{el\ soil}$=None;

- IF $T_{soil}$=None or $T_{air\ in}$=None, THEN $P_{el\ water}$=None;
- IF $W_{soil}$=None or $T_{soil}$=None or $W_{air\ out}$=None, THEN $CON_{water}$=None;
- IF $T_{air\ in}$=None or $W_{air\ in}$=None or $v_{air\ in}$=None or $v_{air\ out}$=None or $C_{CO2\ in}$=None or $W_{air\ out}$=None, THEN $CON_{steam}$=None;
- IF $T_{air\ in}$=None or $C_{CO2\ in}$=None or $E_{e\ in}$=None or $v_{air\ out}$=None or $W_{air\ in}$=None, THEN $CON_{CO2}$=None;
- IF $T_{air\ in}$=None or $C_{CO2\ in}$=None or $E_{e\ in}$=None or $E_{e\ out}$=None or $W_{air\ in}$=None, THEN $P_{light}$=None;
- IF $OPR_{water}$=None or $pH_{water}$=None or $pH_{water}$=None, THEN $CON_{fert}$=None and $CON_{dist}$=None.

The second category relates to the procedure of generating the global solution:

- IF ($T_{air\ in}$=N and $T_{water}$=N and $T_{soil}$=N and $W_{air\ in}$=N and $W_{soil}$=N and $_{air\ in}$=N and $E_{e\ in}$=N and $C_{CO2\ in}$=N and $pH_{water}$=N and $OPR_{water}$=N and $EC_{water}$=N), THEN IMC=GN;
- IF ($T_{air\ in}$=L or $T_{water}$=L or $T_{soil}$=L or $W_{air\ in}$=L or $W_{soil}$=L or $_{air\ in}$=L or $E_{e\ in}$=L or $C_{CO2\ in}$=L or $pH_{water}$=L or $OPR_{water}$=L or $EC_{water}$=L), THEN IMC=GL;
- IF ($T_{air\ in}$=VL or $T_{water}$=VL or $T_{soil}$=VL or $W_{air\ in}$=VL or $W_{soil}$=VL or $_{air\ in}$=VL or $E_{e\ in}$=VL or $C_{CO2\ in}$=VL or $pH_{water}$=VL or $OPR_{water}$=VL or $EC_{water}$=VL), THEN IMC=GVL;
- IF ($T_{air\ in}$=H or $T_{water}$=H or $T_{soil}$=H or $W_{air\ in}$=H or $W_{soil}$=H or $_{air\ in}$=H or $E_{e\ in}$=H or $C_{CO2\ in}$=H or $pH_{water}$=H or $OPR_{water}$=H or $EC_{water}$=H), THEN IMC=GH;
- IF ($T_{air\ in}$=VH or $T_{water}$=VH or $T_{soil}$=VH or $W_{air\ in}$=VH or $W_{soil}$=VH or $_{air\ in}$=VH or $E_{e\ in}$=VH or $C_{CO2\ in}$=VH or $pH_{water}$=VH or $OPR_{water}$=VH or $EC_{water}$=VH), THEN IMC=GVH;
- IF ($T_{air\ in}$=None or $T_{water}$=None or $T_{soil}$=None or $W_{air\ in}$=None or $W_{soil}$=None or $_{air\ in}$=None or $E_{e\ in}$=None or $C_{CO2\ in}$=None or $pH_{water}$=None or $OPR_{water}$=None or $EC_{water}$=None or $T_{air\ out}$=None or $W_{air\ out}$=None or $v_{air\ out}$=None or $E_{e\ out}$=None or $C_{CO2\ out}$=None), THEN IMC=None.

The above database of rules is the algorithmic basis of the software component during the implementation of the laws of microprocessor control of agricultural processes.

### 3.4 Fuzzy aggregation and output methodology

The implemented fuzzy aggregation and output methodology for local controllers of the system, taking into account the complex influence of internal and external factors based on the maximin method is the following:

$$\mu_{res}(r_v) = \max\left\{\min\begin{bmatrix} T_{air\,\mathrm{in}}, W_{air\,\mathrm{in}}, \\ v_{air\,\mathrm{in}}, v_{air\,\mathrm{out}}, C_{CO2\,\mathrm{in}}, \\ W_{air\,\mathrm{out}}, T_{water} \end{bmatrix}\right\};$$

$$\mu_{res}(\alpha_{open}) = \max\left\{\min\begin{bmatrix} T_{air\,\mathrm{in}}, W_{air\,\mathrm{in}}, \\ T_{air\,\mathrm{out}}, E_{e\,\mathrm{in}}, \\ C_{CO2\,\mathrm{in}}, v_{air\,\mathrm{out}} \end{bmatrix}\right\};$$

$$\mu_{res}(P_{el\,\mathrm{air}}) = \max\left\{\min\begin{bmatrix} T_{air\,\mathrm{in}}, W_{air\,\mathrm{in}}, \\ T_{air\,\mathrm{out}}, E_{e\,\mathrm{in}} \end{bmatrix}\right\};$$

$$\mu_{res}(P_{el\,\mathrm{soil}}) = \max\left\{\min\begin{bmatrix} T_{soil}, T_{air\,\mathrm{in}}, \\ T_{water} \end{bmatrix}\right\};$$

$$\mu_{res}(P_{el\,\mathrm{water}}) = \max\left\{\min\left[T_{soil}, T_{water}\right]\right\};$$

$$\mu_{res}(CON_{water}) = \max\left\{\min\begin{bmatrix} T_{soil}, W_{soil}, \\ W_{air\,\mathrm{out}} \end{bmatrix}\right\};$$

$$\mu_{res}(CON_{steam}) = \max\left\{\min\begin{bmatrix} W_{air\,\mathrm{in}}, T_{air\,\mathrm{in}}, \\ v_{air\,\mathrm{in}}, v_{air\,\mathrm{out}}, \\ C_{CO2\,\mathrm{in}}, W_{air\,\mathrm{out}} \end{bmatrix}\right\};$$

$$\mu_{res}(CON_{CO2}) = \max\left\{\min\begin{bmatrix} T_{air\,\mathrm{in}}, v_{air\,\mathrm{out}}, \\ C_{CO2\,\mathrm{in}}, C_{CO2\,\mathrm{out}}, \\ E_{e\,\mathrm{in}} \end{bmatrix}\right\};$$

$$\mu_{res}(P_{light}) = \max\left\{\min\begin{bmatrix} W_{air\,\mathrm{in}}, T_{air\,\mathrm{in}}, \\ E_{e\,\mathrm{in}}, E_{e\,\mathrm{out}}, C_{CO2\,\mathrm{in}} \end{bmatrix}\right\};$$

$$\mu_{res}(CON_{dist}) = \max\left\{\min\begin{bmatrix} OPR_{water}, pH_{water}, \\ EC_{water}, T_{water} \end{bmatrix}\right\};$$

$$\mu_{res}(CON_{fert}) = \max\left\{\min\begin{bmatrix} OPR_{water}, pH_{water}, \\ EC_{water}, T_{water} \end{bmatrix}\right\},$$

where $\mu_{res}$ – the resulting identity function of the controlling linguistic variable influence; $T_{air\ in}$ – air temperature in the growing area; $T_{air\ out}$ – ambient air temperature; $T_{water}$ – irrigation solution temperature; $T_{soil}$ – soil temperature; $W_{air\ in}$ – air humidity in the growing area; $W_{air\ out}$ – ambient air humidity; $W_{soil}$ – soil humidity; $\nu_{air\ in}$ – air flow velocity in the growing area; $\nu_{air\ out}$ – ambient air flow velocity; $E_{e\ in}$ – energy lighting of the growing area; $E_{e\ out}$ – ambient energy lighting; $C_{CO2\ in}$ – carbon dioxide concentration in the growing area; $C_{CO2\ out}$ – ambient carbon dioxide concentration; $pH_{water}$ – irrigation solution acidity; $OPR_{water}$ – ORP of the irrigation solution; $EC_{water}$ – electrical conductivity of the irrigation solution; $r_v$ – percentage of opening mechanisms of the ventilation system; $\alpha_{open}$ – opening angle of shading mechanisms; $P_{el\ air}$ – capacity of the air heating system; $P_{el\ soil}$ – capacity of the soil heating system; $P_{el\ water}$ – capacity of the irrigation solution heating system; $CON_{water}$ – irrigation solution consumption; $CON_{steam}$ – air humidification liquid consumption; $CON_{O2}$ – $_2$ consumption; $P_{light}$ – capacity of the artificial lighting system; $CON_{dist}$ – water addition to the irrigation solution; $CON_{fert}$ – dosage of fertilisers added to the irrigation solution.

## 3.5 Structure of fuzzy data transformation

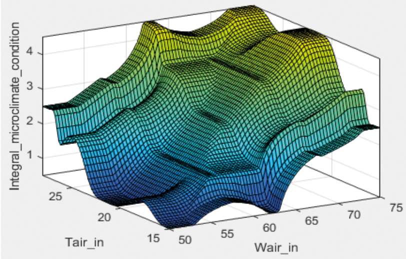
The implemented structure of the complex fuzzy data transformation process for control and monitoring of the integral state of the greenhouse microclimate is shown in Figure 6, which includes the following functional units:

- a fuzzification unit performing the function of aggregation and fuzzy transformation of measurement information from sensors of physical and chemical quantities;
- a fuzzy output unit, which performs the function of algorithmization of obtaining information of the influences' affiliation functions on certain control channels;
- a rule database unit, containing a set of rules defined above, reproducing the algorithm of the software component of information technology;
- a defuzzification unit, designed for conversion of functions on each control channel into the output PWM control signals.

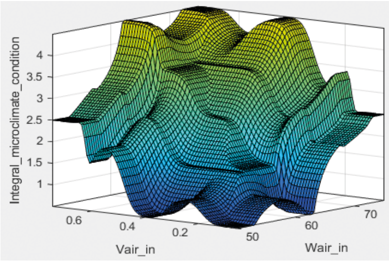
The developed structural diagram of the process of complex fuzzy transformation of data on a greenhouse microclimate state (see Figure 6) considers time dynamics (t) of informative physical and chemical values and is adaptive to crop types and vegetation periods by changing numerical values in terms of linguistic variables.

## 3.6 Results of the computer experiment

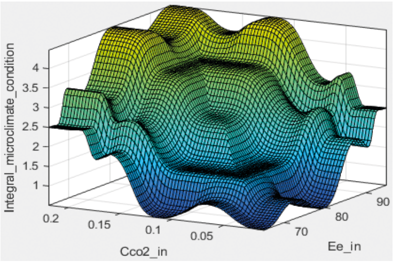
As a result of systematisation of the results obtained in Sections 3.1 – 3.5 of the research of information technology for monitoring and control of microclimate in greenhouses based on fuzzy logic, a series of computer simulation tests in Fuzzy Logic Designer environment of Matlab & Simulink application software package was performed. The results of these tests were 3D graphs of microclimate state dependence (IMC) on a set of measured parameters, as shown in Figures 7 – 9.



a) *IMC* dependence on $T_{air\ in}$ and $W_{air\ in}$



b) *IMC* dependence on $v_{air\ in}$ and $W_{air\ in}$



c) *IMC* dependence on $E_{e\ in}$ and $C_{CO2\ in}$

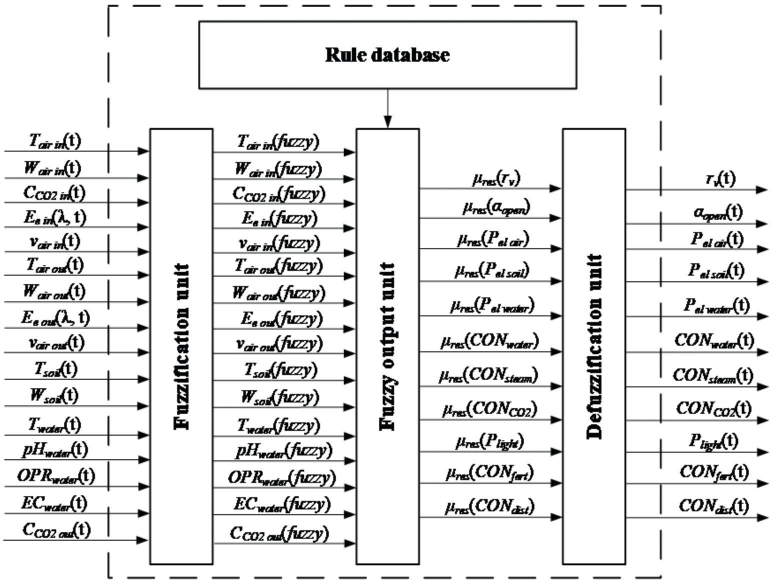
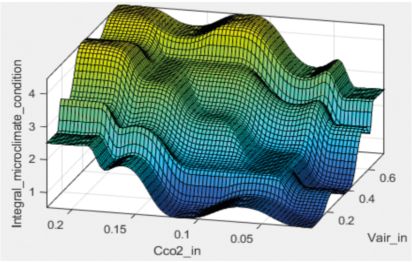


**Figure 6**. Structural diagram of the complex fuzzy data transformation process



d) *IMC* dependence on $v_{air\ in}$ and $C_{CO2\ in}$

**Figure 7**. Dependence of the integrated state of the greenhouse microclimate on physical parameters of the aerogas environment of the growing area

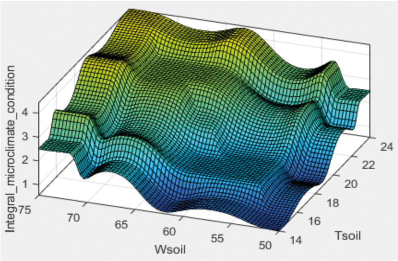
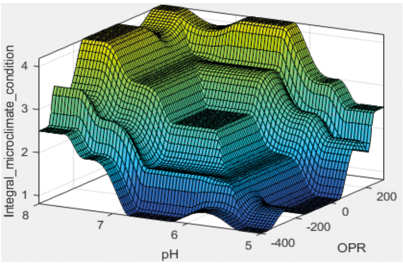
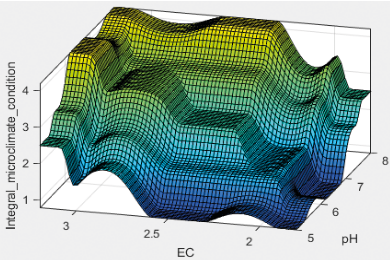


**Figure 8**. Dependence of the state of the microclimate on the soil parameters

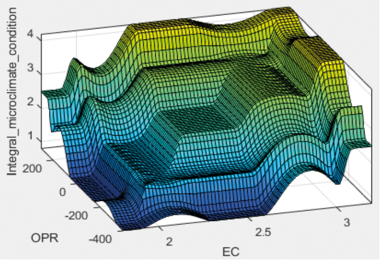
The obtained results of the computer experiment (see Figures 7 – 9) prove the feasibility and prospects of using fuzzy logic methods in information technology of comprehensive monitoring and control of agricultural processes in industrial greenhouses. This development allows software implementation of intelligent algorithms for greenhouse microclimate control taking into account a significant number of functional interrelationships of soil and climatic factors and characteristics of irrigation solution of a wide range of growing crops during different periods of their vegetation. This, in turn, makes it possible to integrate complex intelligent computational algorithms into the microprocessor-based processing of measurement data, which leads to the positive effect of reducing hardware redundancy of applied information technologies for agricultural purposes and the possibility of their rapid reconfiguration based on expert data update.



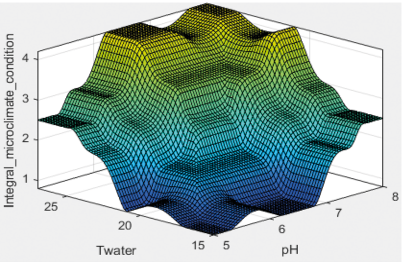
a) *IMC* dependence on $OPR_{water}$ and $pH_{water}$



b) *IMC* dependence on $EC_{water}$ and $pH_{water}$



c) *IMC* dependence on $EC_{water}$ and $OPR_{water}$



d) *IMC* dependence on $T_{water}$ and $pH_{water}$

**Figure 9**. Dependence of the integrated state of the greenhouse microclimate on the physical and chemical parameters of the irrigation solution

## 4 Discussion and suggestions for future investigations

The main scientific and practical effect of the research results consists in development of a theory of developing intellectual information technologies for control and monitoring of microclimate of industrial greenhouses through the development of methods and models of distributed aggregation and microprocessor-based transformation of measurement data on the basis of fuzzy logic. Promising priority areas for further research of this information technology are: software integration of the developed models into industrial logic controllers for agricultural purposes; long-term experimental tests in real operating conditions in different climatic zones; comprehensive technical and economic evaluation of investment attractiveness of implementation of the obtained solutions.

## 5 Conclusions

The article solves an important problem of developing scientific-applied provisions of modernization of software and hardware base of industrial greenhouses through the development of information technology of comprehensive control and monitoring of microclimate conditions in industrial greenhouses on the basis of the fuzzy logic theory.

The main results of the article are: review, critical analysis and systematisation of the literature sources in the field of applied intelligent computer-oriented information technology for agricultural applications; synthesis of the structural and algorithmic organisation of information technology of complex monitoring and control of the integral condition of greenhouse microclimate; developing and testing the computer model of the process of complex aggregation and transformation of informative parameters of greenhouse microclimate; establishing the evidence base for the feasibility of using the fuzzy logic theory in computer-oriented monitoring and control of agrotechnical processes in industrial greenhouses; substantiation of priority promising areas for further research on digitalization of agricultural enterprises of greenhouse vegetable production.

## 6 Acknowledgements

The authors would like to thank the Cabinet of Ministers of Ukraine, the Verkhovna Rada of Ukraine and the Committee of State Prizes of Ukraine in Science and Technology for the financial support of scientific research that they provided to the research team through the Verkhovna Rada Award and the Cabinet of Ministers Scholarship.

## 7 List of abbreviations

| | |
|---|---|
| FAO | – the Food and Agriculture Organisation; |
| ASABE | – the American Society of Agricultural and Biological Engineers; |
| ANN | – artificial neural networks; |
| ECGA | – evolutionary calculations and genetic algorithms; |
| FL | – fuzzy logic; |
| ER | – evolutionary robotics; |
| IoT | – Internet of Things; |
| WSN | – wireless sensor networks; |
| SHEI | – state higher educational institution; |
| ORP | – oxidation reduction potential (redox potential); |
| PWM | – pulse width modulation. |

# References

[1] FAOSTAT: Food and agriculture organization of the united nations. Available at: http://www.fao.org/faostat/en/#home [Accessed 25 May 2022].

[2] W. Baudoin, A. Nersisyan, A. Shamilov, A. Hodder, D. Gutierrez, Good Agricultural Practices for greenhouse vegetable production in the South East European countries, Food and Agriculture Organization of the United Nations, Rome 2017. URL: https://www.fao.org/documents/card/ru/c/22b737e1-488e-4993-86c9-13fd3fed122f/

[3] American Society of Agricultural and Biological Engineers: ANSI/ASAE EP406.4 JAN2003 (R2008) Heating, Ventilating and Cooling Greenhouses. Available at: http://materialstandard.com/wp-content/uploads/2019/07/ANSI-ASABE-EP406-4-JAN2003-R2008.pdf [Accessed 15 May 2022].

[4] A. Kamilaris, A Review on the Application of Natural Computing in Environmental Informatics, In: 32nd EnviroInfo, Munchen, Germany, 2018, pp. 1–11. https://doi.org/10.48550/arXiv.1808.00260.

[5] M. Erazo-Rodas, M. Sandoval-Moreno, S. Munoz-Romero, M. Huerta, D. Rivas-Lalaleo, C. Naranjo, J. Rojo-Alvarez, Multiparametric Monitoring in Equatorian Tomato Greenhouses (I): Wireless Sensor Network Benchmarking, Sensors, 18 (8), 2018, pp. 1–22. https://doi.org/10.3390/s18082555.

[6] J. Miliauskaite, D. Kalibatiene, Complexity in Data-Driven Fuzzy Inference Systems: Survey, Classification and Perspective, Baltic J. Modern Computing, 8 (4), 2020, pp. 572–596. https://doi.org/10.22364/bjmc.2020.8.4.08.

[7] I. Laktionov, O. Vovna, A. Zori, Copncept of low cost computerized measuring system for microclimate parameters of greenhouses, Bulg. Journal of Agric. Sc., 23 (4), 2017, pp. 668–673. URL: https://agrojournal.org/23/04-24.pdf.

[8] O. Vovna, I. Laktionov, S. Sukach, M. Kabanets, E. Cherevko. Method of adaptive control of effective energy lighting of greenhouses in the visible optical range. Bulg. Journal of Agric. Sc., 24 (2), 2018, pp. 335–340. URL: https://agrojournal.org/24/02-23.pdf.

[9] I.S. Laktionov, O.V. Vovna, Y.O. Bashkov, A.A. Zori, A.A., V.A. Lebediev, Improved Computer-Oriented Method for Processing of Measurement Information on Greenhouse Microclimate, Int. J. Bioautomation, 23 (1), 2019, pp. 71–86. https://doi.org/10.7546/ijba.2019.23.1.71-86.

[10] I.S. Laktionov, O.V. Vovna, M.M. Kabanets, H.O. Sheina, I.A. Getman, Information model of the computer-integrated technology for wireless monitoring of the state of microclimate of industrial agricultural greenhouses, Instrumentation Mesure Metrologie, 20 (6), 2021, pp. 289 – 300. https://doi.org/10.18280/i2m.200601.

[11] J. Arshad, S. Saleem, M. Sana Ullah Badar, S. Khalid, Z. Mumtaz, S. Ullah, Z. Illyas, H. Ahmad Madni, An intelligent monitoring and controlling of greenhouse: Deployment of wireless sensor networks and internet-of-things, Preprints MDPI, 2019, pp. 1–13. https://doi.org/10.20944/preprints201811.0215.v1.

[12] A. Touhami, B. Khelifa, L. Garcia, L. Parra, J. Lloret, B. Fateh, Sensor Network Proposal for Greenhouse Automation placed at the South of Algeria, Network Protocols and Algorithms, 10 (4), 2018, pp. 53–69. https://doi.org/10.20944/10.5296/npa.v10i4.14155.

[13] S. Salvi, S.A. Pramod Jain, H.A. Sanjay, T.K. Harshita, M. Farhana, J. Naveen, M.V. Suhas, Cloud Based Data Analysis and Monitoring of Smart Multi-level Irrigation System Using IoT, In: 2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), Palladam, India, 2017, pp. 752–757. https://doi.org/10.1109/I-SMAC.2017.8058279.

[14] F. Ouyang, H. Cheng, Y. Lan, Y. Zhang, X. Yin, J. Hu, X. Peng, G. Wang, S. Chen, Automatic delivery and recovery system of Wireless Sensor Networks (WSN) nodes based on UAV for agricultural applications, Computers and Electronics in Agriculture, 162, 2019, pp. 31–43. https://doi.org/10.1016/j.compag.2019.03.025.

[15] J.R. Llera, E.D. Goodman, E.S. Runkle, L. Xu, Improving greenhouse environmental control using crop-model-driven multi-objective optimization, In: Genetic and Evolutionary Computation Conference Companion (GECCO' 18), Kyoto, Japan, 2018, pp. 292 – 293. https://doi.org/10.1145/3205651.3205724.

[16] C.H. Guzman, J.L. Carrera, H.A. Duran, J. Berumen, A.A. Ortiz, O.A. Guirette, A. Arroyo, J.A. Brizuela, F. Gomez, A. Blanco, H.R. Azcaray, M. Hernandez, Implementation of Virtual Sensors for Monitoring Temperature in Greenhouses Using CFD and Control, Sensors, 19 (1), 2018, pp. 1–13. https://doi.org/10.3390/s19010060.

[17] H. Wang, J.A. Sanchez-Molina, M. Li, F.R. Diaz, Improving the Performance of Vegetable Leaf Wetness Duration Models in Greenhouses Using Decision Tree Learning, Water, 11 (1), 2019, pp. 1–19. https://doi.org/10.3390/w11010158.

[18] J. Agajo, J.G. Kolo, G. Jonas, A.R. Opeyemi, N.O. Chikeze, O.B. Chukwujekwu, A modified web-based agro-climatic remote monitoring system via wireless sensor network, In: 2017 IEEE 3rd Int. Conf. on Electro-Technology for National Development (NIGERCON), Owerri, Nigeria, 2018, pp. 258–270. https://doi.org/10.1109/NIGERCON.2017.8281898.

[19] M. Azaza, K. Echaieb, E. Fabrizio, A. Iqbal, A. Mami, An intelligent system for the climate control and energy savings in agricultural greenhouses, Energy Efficiency, 9 (6), 2016, pp. 1241–1255. https://doi.org/10.1007/s12053-015-9421-8.

[20] Zh. Xu, J. Chen, Switching Control Strategy for Greenhouse Temperature-Humidity System Based on Prediction Modeling: A Simulation Study, Journal of Engineering and Technological Sciences, 49 (5), 2017, pp. 689–703. https://doi.org/10.20944/preprints201611.0044.v1.

[21] M. Taki, Y. Ajabshirchi, S. Faramarz Ranjbar, M. Matloobi, Application of neural networks and multiple regression models in greenhouse climate estimation, AgricEngInt: CIGR Journal, 18 (3), 2016, pp. 29–43. URL: https://cigrjournal.org/index.php/Ejounral/article/view/3672/2414

[22] Y. Kaneda, H. Ibayashi, N. Oishi, H. Mineno, Greenhouse Environmental Control System Based on SW-SVR, Procedia Computer Science, 60 (1), 2015, pp. 860–869. https://doi.org/10.1016/j.procs.2015.08.249.

[23] T.A. Izzuddin, M.A. Johari, M.Z.A. Rashid, M.H. Jali, Smart irrigation using fuzzy logic method, ARPN Journal of Engineering and Applied Sciences, 13 (2), 2018, pp. 517–522. URL: http://www.arpnjournals.org/jeas/research_papers/rp_2018/jeas_0118_6698.pdf

[24] C. Algarin, J. Cabarcas, A. Llanos, Low-Cost Fuzzy Logic Control for Greenhouse Environments with Web Monitoring, Electronics, 6 (4), 2017, pp. 1–12. https://doi.org/10.3390/electronics6040071.

[25] R. Ben Ali, E. Aridhi, M. Abbes, A. Mami, Fuzzy logic controller of temperature and humidity inside an agricultural greenhouse, In: 7th International Renewable Energy Congress (IREC), Hammamet, Tunis, 2016, pp. 1–6. https://doi.org/10.1109/IREC.2016.7478929.

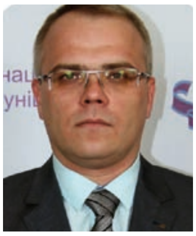
[26] O. Alpay, E. Erdem, The Control of Greenhouses Based on Fuzzy Logic Using Wireless Sensor Networks, Int. J. of Computational Intelligence Systems, 12 (1), 2019, pp. 190–203. https://doi.org/10.2991/ijcis.2018.125905641.

[27] A.J. Both, L. Benjamin, J. Franklin, G. Holroyd, L.D. Incoll, M.G. Lefsrud, G. Pitkin, Guidelines for measuring and reporting environmental parameters for experiments in greenhouses, Plant Methods, 11 (43), 2015, pp. 1–18. https://doi.org/10.1186/s13007-015-0083-5.

[28] W. Baudoin, Good agricultural practices for greenhouse vegetable crops: Principles for mediterranean climate areas, FAO of the United Nations, Rome 2013. URL: https://agris.fao.org/agris-search/search.do?recordID=XF2013001549

---

**Ivan S. Laktionov** is the Professor of the Department of Computer systems' software of Dnipro University of Technology (Dnipro, Ukraine). He received his Doctor of Science degree in 2021 majoring in computer systems and components. He specialises in advanced computer, sensor, infocommunication and microprocessor technologies of physical and chemical parameters monitoring and control systems. He is the author of more than 70 scientific works (paper, theses, monographs, tutorials and patents), including more than 20 articles in the world's authoritative publications Scopus and WoS.
https://orcid.org/0000-0001-7857-6382



**Oleksandr V. Vovna** is the Head of the Department of Electronic Engineering of SHEI "Donetsk National Technical University" (Lutsk, Ukraine). He received his Doctor of Science degree in 2015 majoring in computer systems and components. He specialises in development, simulation and research of computerized information-measuring systems for industrial applications. He is the author of more than 270 scientific works (paper, theses, monographs, tutorials and patents), including 29 articles in the world's authoritative publications Scopus and WoS.
https://orcid.org/0000-0003-4433-7097

**Maryna M. Kabanets** is the Head of the Language Training Department of SHEI "Donetsk National Technical University" (Lutsk, Ukraine). She received her Doctor of Science degree in 2019 majoring in general pedagogy and history of pedagogy and her full professorship in 2021. She specialises in vocational education, teacher training, gifted education, creativity development and theory and methodology of higher education. She is the author of more than 80 scientific works (articles, theses, monographs), including 5 articles in the world's authoritative publications Scopus and WoS.
https://orcid.org/0000-0002-7961-8350