Automation of microclimate in greenhouses

Marina Ganzhur[1,*], *Alexey* Ganzhur[1], *Andrey* Kobylko1, and *Denis* Fathi[1]

[1]Don State Technical University, 344003, 1, Gagarin sq., Rostov on Don, Russia

Abstract. An agricultural greenhouse is a complex system with many input features. Taking these features into consideration creates favorable conditions for the production of plants. The parameters are temperature and internal humidity, which have a significant impact on the yield. The aim of this study was to propose a dynamic simulation model in the MATLAB/Simulink environment for experimental validation. In addition, a fuzzy controller for the indoor climate of the greenhouse with an asynchronous motor for ventilation, heating, humidification, etc. has been designed. The model includes an intelligent control system for these drives in order to ensure optimal indoor climate. The dynamic model was validated by comparing simulation results with experimental measurement data. These results showed the effectiveness of the control strategy in regulating the greenhouse indoor climate.

1 Introduction

The greenhouse is a solution for protecting vegetation from diseases and bad weather, being a complex system. Its main function is maintaining the internal climate, which is influenced by many factors such as wind speed, solar radiation, external temperature and humidity. Two main problems have limited the expansion of greenhouse agricultural production.

First, the method of controlling and adjusting the air temperature inside the greenhouse to the needed value is fuzzy logic control. In this work, the Arvanitis 1999 model was taken as a basis for a dynamic model of an experimentally validated agricultural greenhouse, in order to create a suitable microclimate with appropriate drives installed in the greenhouse. Temperature is the main climatic variable affecting yield, therefore it is traditionally controlled in greenhouses. Based on the energy balance of the elementary volume of greenhouse air, the ratio can be calculated using the equation:

$$QH = (\ \ /dt) - (K\text{out,air}[T\text{out}-TG]) \tag{1}$$

Where TG is temperature in the greenhouse, Cq is heat capacity of the greenhouse, Kout,air is greenhouse heat loss rate, Tout is outside temperature and QH is heating power. Thus, the difference in temperature and humidity is an important feature when simulating a greenhouse installation.

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[*] Corresponding author: mganzhur@yandex.ru

Second, the use of multiple controlled drives such as ventilation, heating and humidification/dehumidification systems makes the greenhouse an energy-intensive consumer. Therefore, efficient energy systems should be used in order to reduce operating costs.

A greenhouse is a system that can promote plant growth as it guarantees suitable microclimatic conditions for fixed cultivation. In fact, a greenhouse is a heat storage system that converts incident solar radiation into heat dissipation. This physical process is based on conduction, heat accumulation and convection. The internal microclimate control can be automated (e.g. using a fuzzy controller) only if a physical model of the greenhouse is available. This model should be able to anticipate changes in the internal environment parameters, which are based on several boundary conditions. This work provides a model of a greenhouse using fuzzy logic. The proposed greenhouse model is based on four basic layers being involved in thermodynamic exchanges: the technical structure itself, the air inside the greenhouse, plants and soil. The role of each layer is as follows: the greenhouse retains heat (the cover is usually made of plastic film or glass); the indoor air is indoor climate that is controlled by temperature and humidity; plants play a strategic role in water and heat balance due to the evaporation process; soil is characterized by absorption and diffusion of thermal radiation.

The proposed system was tested in the MATLAB/Simulink environment using a meteorological database of real measurements. This included measurements of solar radiation, wind speed, temperature, and relative humidity. It also contained thermal properties of the greenhouse response to external solar radiation.

In theoretical simulating, temperature and humidity were compared with experimental measurements. The values are correlated and subject to the normal law, distributed both by hours and over a year. The simulation of temperature and humidity in the greenhouse was carried out using differential equations, the experimental external values were measured using the RTU5023 sensor. (Fig.1).

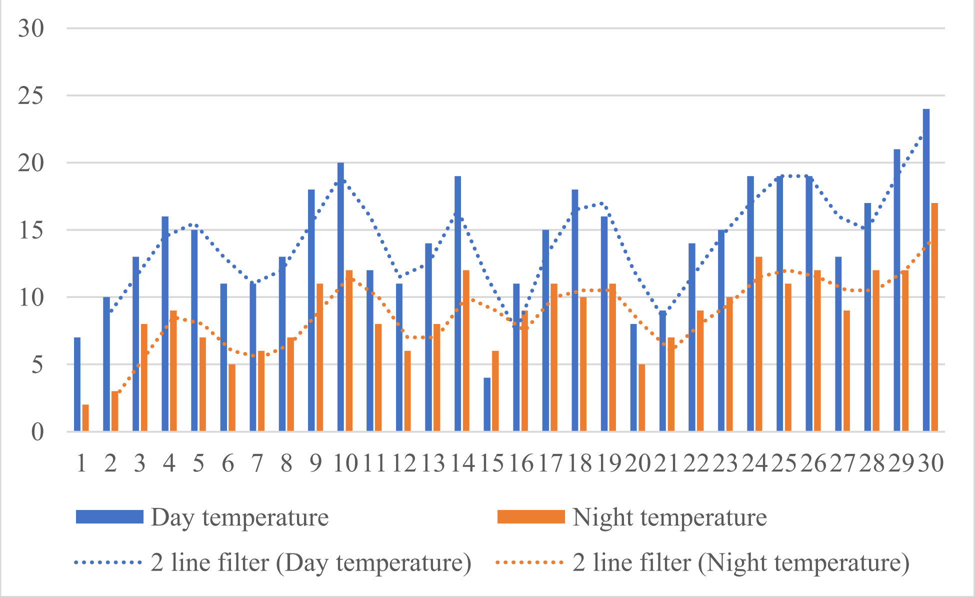


Fig. 1. Temperature change, April 2020

The solar radiation data are presented from the ones of the average statistics for the city of Rostov-on-Don (47.8132, 41.6217). The average annual value is close to 4 kW*h/m2 (Fig. 2).

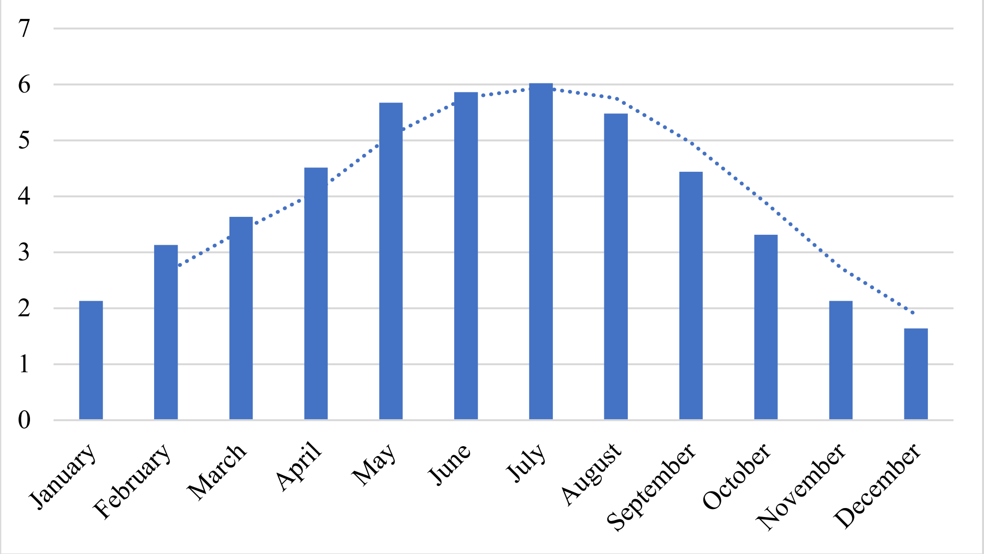
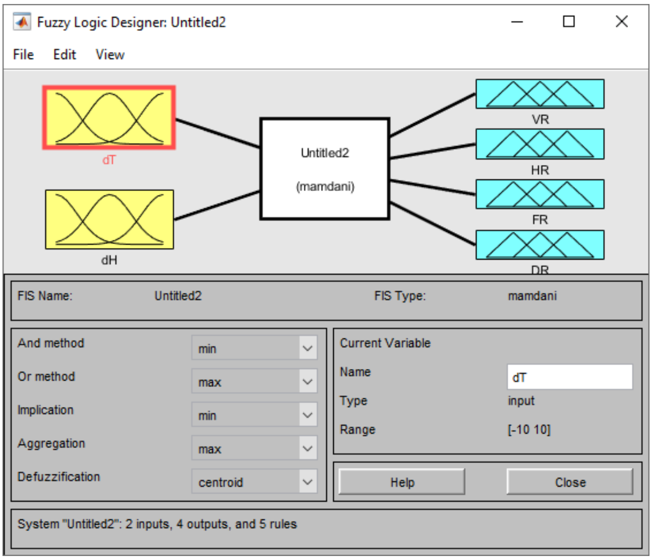


Fig. 2. Solar radiation, kW*h/m2

2 Fuzzy logic controller for the greenhouse

The work of the investigated system is as follows: comparison of temperature (T_{in}) and humidity (H_{in}) with the specified characteristics. The difference gives ΔT and ΔH errors for the regulation of internal factors of the greenhouse, controlled by the actuators for ventilation, heating, etc. When the actuators are active, the heat flow supplied by the heating system and the air flow from the ventilation system will be part of the thermodynamic model. Therefore, the temperature and humidity inside the greenhouse are controlled using appropriate equations.

Let us build a fuzzy system in MATLAB, Figure 3. The fuzzy controller is based on a fuzzy inference engine, which consists of three main processing subsystems. The first interface converts input linguistic variables to numeric values at Fig. 4. The database unit includes fuzzy rules. Transformation processor, clear control rules at output for specific actuators.



FIS Name: Untitled2
FIS Type: mamdani

And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid

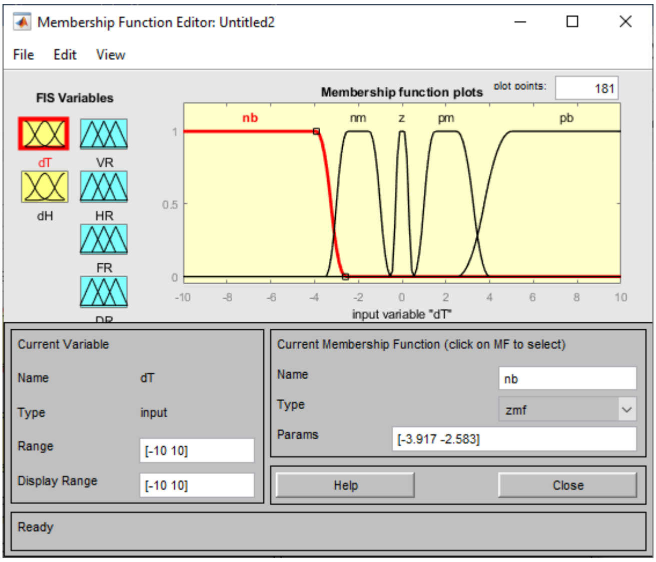
Current Variable
Name: dT
Type: input
Range: [-10 10]

System "Untitled2": 2 inputs, 4 outputs, and 5 rules

Fig. 3. Simulating fuzzy inference in the MATLAB environment

The input state variable of the fuzzy temperature controller is ΔT, where $\Delta T = T - T_{in} \in (NB, NM, Z, PM, PB)$ (Fig. 4).

The membership functions of the input temperature error are shown in, where NB is negative large, NM is negative mean, Z is zero, PM is positive mean, and PB is positive large.



plot points: 181

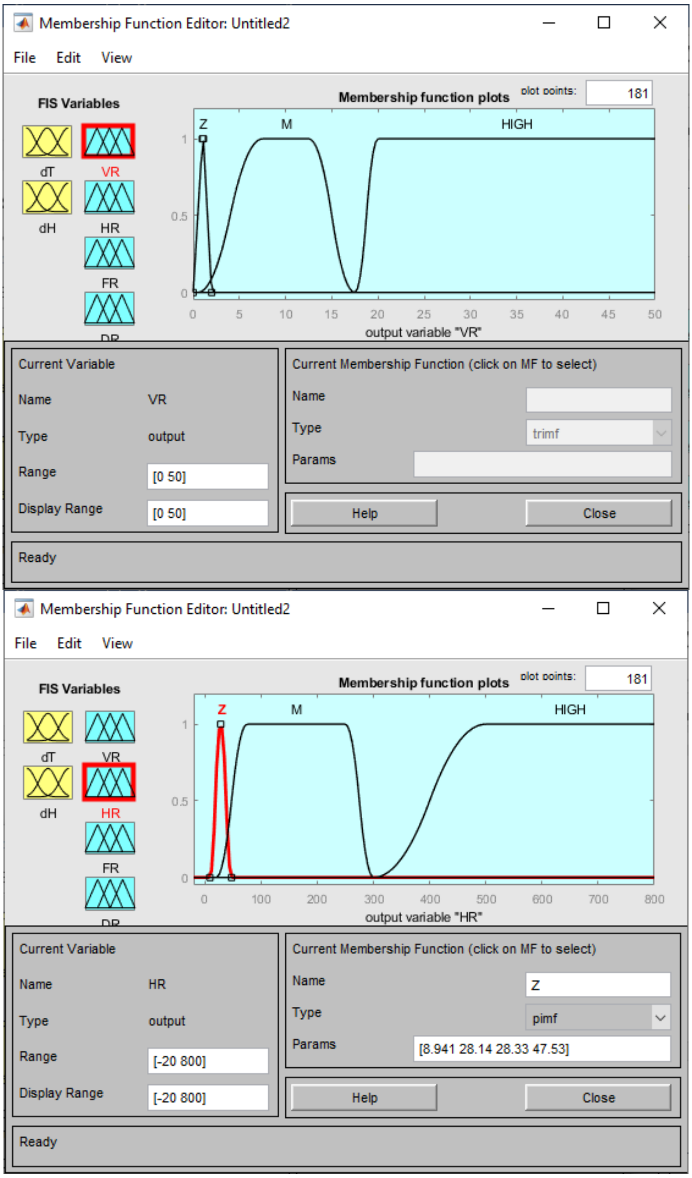
Current Variable
Name: dT
Type: input
Range: [-10 10]
Display Range: [-10 10]

Current Membership Function (click on MF to select)
Name: nb
Type: zmf
Params: [-3.917 -2.583]

Ready

Fig. 4. Simulating the temperature environment in a greenhouse installation

The output variables are ventilation speed (*Vr*) and heating rate (*Hr*), besides, *Vr* ϵ (Z, M, H) and *Hr* ϵ (Z, M, H) (Z = zero, M = medium and H = high). Figure 5 shows the membership functions of the output variables *Vr* and *Hr*.



plot points: 181

Current Variable
Name VR
Type output
Range [0 50]
Display Range [0 50]

Current Membership Function (click on MF to select)
Name
Type trimf
Params

Ready

plot points: 181

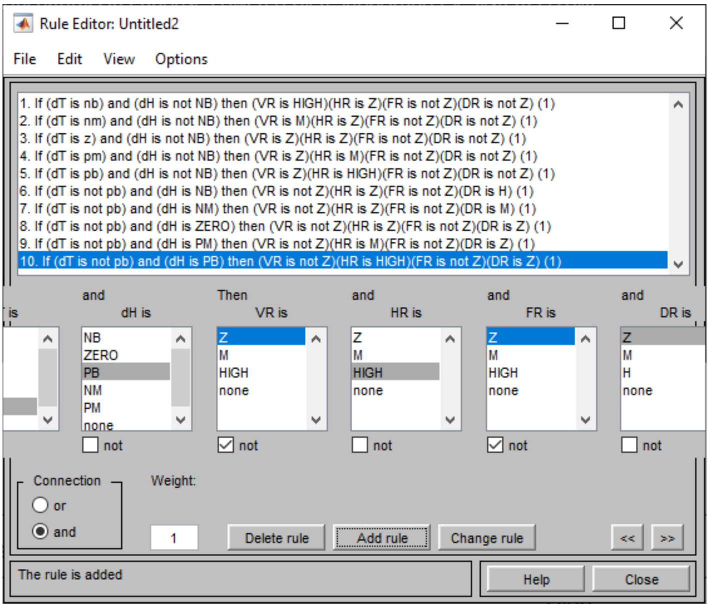
Current Variable
Name HR
Type output
Range [-20 800]
Display Range [-20 800]

Current Membership Function (click on MF to select)
Name Z
Type pimf
Params [8.941 28.14 28.33 47.53]

Ready

Fig. 5. Regulation of the ventilation rate and the heating rate of the greenhouse

The air humidity system is constructed in a similar way. Further, the rules of Figure 6 are used.

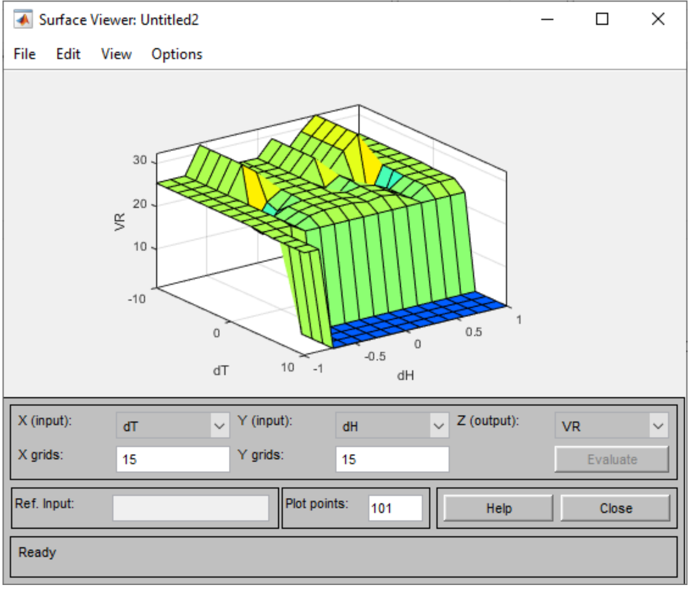


1. If (dT is nb) and (dH is not NB) then (VR is HIGH)(HR is Z)(FR is not Z)(DR is not Z) (1)
2. If (dT is nm) and (dH is not NB) then (VR is M)(HR is Z)(FR is not Z)(DR is not Z) (1)
3. If (dT is z) and (dH is not NB) then (VR is Z)(HR is Z)(FR is not Z)(DR is not Z) (1)
4. If (dT is pm) and (dH is not NB) then (VR is Z)(HR is M)(FR is not Z)(DR is not Z) (1)
5. If (dT is pb) and (dH is not NB) then (VR is Z)(HR is HIGH)(FR is not Z)(DR is not Z) (1)
6. If (dT is not pb) and (dH is NB) then (VR is not Z)(HR is Z)(FR is not Z)(DR is H) (1)
7. If (dT is not pb) and (dH is NM) then (VR is not Z)(HR is Z)(FR is not Z)(DR is M) (1)
8. If (dT is not pb) and (dH is ZERO) then (VR is not Z)(HR is Z)(FR is not Z)(DR is Z) (1)
9. If (dT is not pb) and (dH is PM) then (VR is not Z)(HR is M)(FR is not Z)(DR is Z) (1)
10. If (dT is not pb) and (dH is PB) then (VR is not Z)(HR is HIGH)(FR is not Z)(DR is Z) (1)

The rule is added

Fig. 6. Fuzzy inference rules

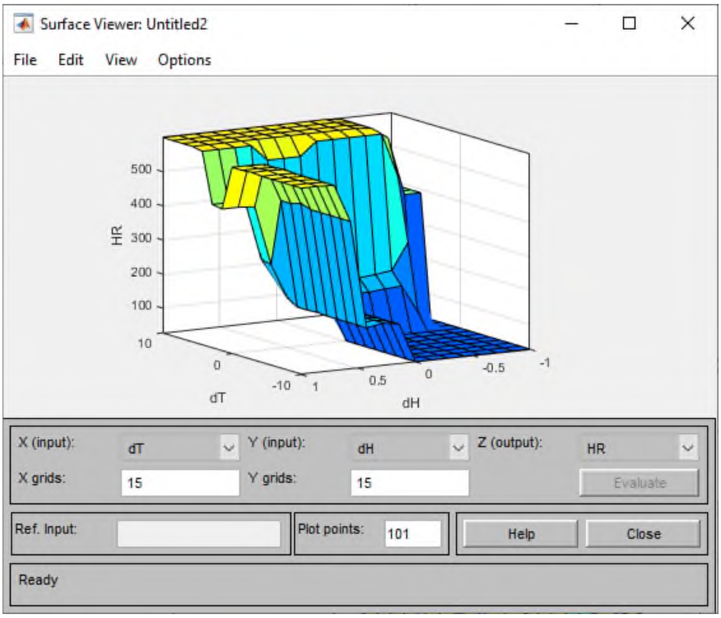
The simulation result can be demonstrated as follows - Figure 7-10.



X (input): dT
Y (input): dH
Z (output): VR
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101

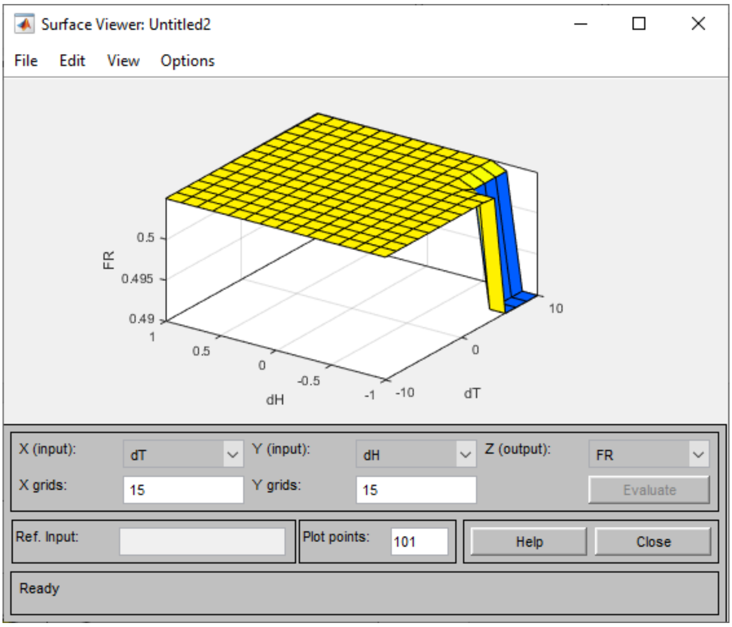
Ready

Fig. 7. Simulating the ventilation rate in a greenhouse installation



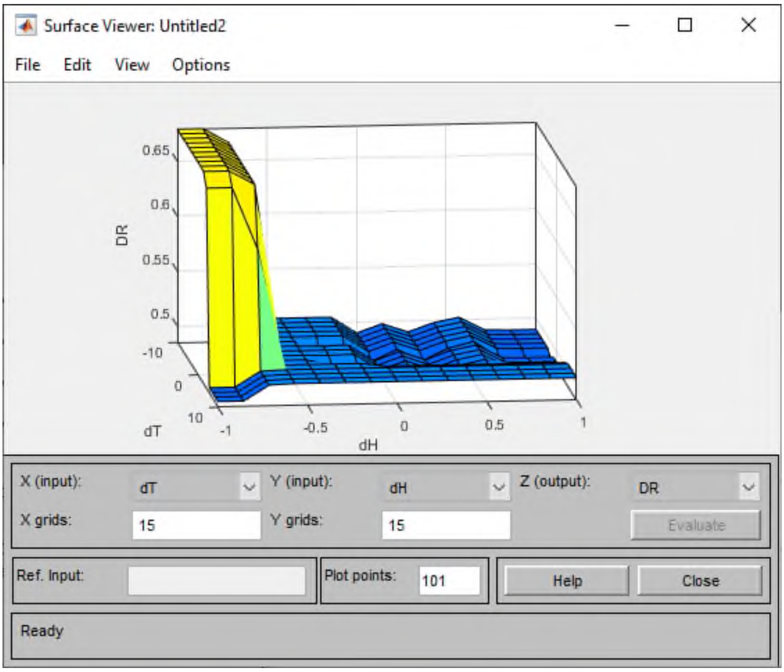
X (input): dT
Y (input): dH
Z (output): HR
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Fig. 8. Simulating the heating rate in a greenhouse installation



X (input): dT
Y (input): dH
Z (output): FR
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Fig. 9. Simulating the air humidification rate in a greenhouse installation



X (input): dT
Y (input): dH
Z (output): DR
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Fig. 9 - Simulating the air dehumidification rate in a greenhouse installation

3 Conclusion

After simulating the settings and sensor readings, it can be concluded that the system can work stably until a critical value appears, as a result of which the installation adjusts to system changes and stabilizes the microclimate values after automatic changes in the system.

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