Controlling Mass/Heat Transfer and Optimizing the use of Thermal Energy to Ensure Lighting in the Greenhouse using Artificial Intelligence

Moustafa Sahnoune Chaouche[1], Faouzi Didi[1], Malika Amari[1], Ameur Guezmir[2], Kamel Belhenniche[4], Abdelhamid Chellali [3]

[1]LERM - Renewable Energy and Materials Laboratory. Department of Common-Core, Faculty of Technology. University of Médéa , 26.000, Algeria

[2] Laboratory of Magnetic materials (LMM), University of Djillali Liabes , Sidi-Bel Abbes BP 89, 22000.

[3]Laboratory of Biomaterials and Transport Phenomena (LBMPT).

[4]Faculty of Technology, Department of Common-Core Technology, University of Médéa , 26.000, Algeria.

Received : 11-09-2022 **Accepted** : 29-12-2022 **Published** : 26-02-2023

Abstract- Greenhouse cultivation has been undergoing significant development for several years in order to cope with an increasingly competitive market conditioned by stringent quality standards. Greenhouse production systems become considerably sophisticated and therefore disproportionately expensive. That is why, the greenhouses who want to remain competitive, must optimize their investment by a greater control of the conditions of production. In order to make full use of the increased possibilities for crops, it is necessary to adjust the state of the system automatically. Better management of climatic parameters under glass makes today a major challenge on a global level. This is particularly true in the field of agriculture. Greenhouse systems need to be modernized and more oriented towards the use of new cropping techniques and appropriate automatic devices. To improve profitability, crops must be grown in optimal environments. It is therefore important to control air temperature, humidity, CO_2 content ... etc. All these factors must be considered in the energy balance, since each of them can influence others. Advances in computing, including the ever-increasing capabilities of computers, have contributed significantly to the automatic control of climate processes. Computer-aided management has become an indispensable tool in the study of climate in greenhouses. It contributes to improving the climatic conditions for greenhouse cultivation. But above all, it is the only rational way to predict climate change under glass. The improvement of the latter concerns the structure of the greenhouse, the choice of cover, the choice of the site and the bioclimatic stage. The growth of the sheltered plant depends on the temperature of the indoor air in the greenhouse maintained in the shelter. Among the means of controlling the climate in the summer, the ventilation of greenhouses plays a key role in reducing the temperature of the greenhouse and in winter, heating of greenhouses is also important, The temperature inside the greenhouse. The thermal performance of the greenhouse is also to be taken into account, the insulation, thermal storage and heating equipment can be of interest to implement. The present study in this article is part of a contribution to the development of serri-culture and aims to develop new strategies for controlling climatic parameters of greenhouse and our work aims to control the Light using artificial intelligence by modeling a fuzzy Mamdani method controller using MATLAB Simulink software.

Keywords: Thermal transfer, Thermal / mass balance , Optimization, Modelling, Simulation, , Lighting, Control, Greenhouse.

Tob Regul Sci. ™ 2023;9(1): 785-796
DOI: doi.org/10.18001/TRS.9.1.56

Introduction

When choosing a type of greenhouse and the equipment it requires, it is essential to consider the local climate. Before starting a greenhouse project, it is necessary to carefully consider the climate and the effects of climate on the growth of the crops you intend to plant.

Greatly the amount of sun that the culture receives per day. For this, the duration of sunshine is a good reference. Many crops react to shorter or longer days (the said photo periodicity of crops). This is why it is important to know the length of the day throughout the year. You can extend the day by using artificial light or shorten it by using blinds (eg a black plastic film). This is mostly practiced in tropical countries to allow crops to pass the development stage. You need to know the length of day to allow you to choose the crop you want to plant. The total amount of sunlight determines the rate of growth and the level of production. The variation in the duration of sunshine is strongly related to the differences in the duration of daylight.

The way in which crops can be protected to promote growth and improve the growth period can vary between simple and inexpensive methods and complicated methods that require a lot of capital. There are different types of structures and coating material. We will limit ourselves to constructions suitable for the covering of plastic film and shading materials. We will also need to take into account the height of the crop as well as the requirements of the crop.

Within a greenhouse, climate is regulated by ventilation, heating and cooling, as well as by using shading systems. When you try to solve one of the factors, it usually affects other climate factors. To give an example, increasing the temperature causes the relative humidity to drop. Ventilation affects the temperature as well as the humidity of the air, while the shade affects the transmission of light (assimilation level) as well as the temperature. Climate control is most difficult when the weather is dry and sunny, especially in the immediate post-transplant period, when only part of the land is covered by the plants. The transpiration of plants has an important effect on the stability of the climate inside the greenhouse. High perspiration demands a lot of energy and thus ensures that the air temperature does not rise too high, which increases the humidity of the air.

When it comes to greenhouses, all lighting systems are not equal, according to Xiuming Hao (Ph.D.), a researcher with Agriculture and Agri-Food Canada (AAFC). Dr. Hao is studying how quality lighting can improve the growth and nutritional value of plants at the Harrow Research and Development Center[8-10].

Greenhouses with supplemental energy-efficient lighting systems enable Canadian growers to grow high-quality fruit and vegetables year-round. It also helps them maintain their market share and allows Canada to compete in domestic and international markets. However, since Canada has low daylight throughout the year, the lack of ambient lighting affects greenhouse production, especially during the winter months. The solution is to use artificial lighting, but crops grow and grow differently when exposed to alternative light sources. In addition, not all artificial lighting systems are equal.

"The quality of lighting is related to the actual distribution of the light spectrum, a factor that greatly influences plant growth, fruit yield, fruit quality and the production of health benefits," explains M Hao. The way in which the spectral distribution of light improves plant growth, fruit yield and fruit quality has not been thoroughly studied. " [9-11]

This area of research remains largely unexplored because there is no alternative to conventional light sources in greenhouses, high pressure sodium (HPS) lamps. HPS lamps emit broad spectrum light which makes it difficult to obtain accurate spectral distribution profiles for research purposes. However, it is now possible to achieve this through the modeling of intelligent controllers and above all by fuzzy logic to optimize the management of light in agricultural greenhouses.

Modeling of the Greenhouse

Our model is parameterized (state variables), meaning that spatial heterogeneity is ignored and that the internal content of flows at the boundary of the system boundary is uniformly distributed [1].

The model consists of a set of differential equations formulated as follows [4]:

$$cap * \frac{\partial T}{\partial t} = \sum(puissance_{in} - puissance_{out}) \text{ [W]} \quad (1)$$

Where :

T : Is the temperature of the element under consideration (C °).

cap (J K^{-1}) : Is its thermal capacity and the incoming and outgoing thermal power are expressed in watts.

A. Modeling of light

Two light sources are treated in agricultural greenhouse:

- Natural light

Hour after hour, the software follows the position of the sun. The solar radiation can be stopped by the far horizon or attenuated by the sunscreens as well as by the windows of the greenhouse.

- Artificial light

Artificial light is generated by lamps placed above the crops. Nothing filters or attenuates this light. The efficiency of the lamps is considered. All the electrical energy consumed contributes to increase the temperature of the greenhouse.

In our work we have based on the model of (Jamisson M.Hill, 2006, Didi Faouzi 2016) [3-7].

B. Modeling of the fuzzy controller

The fuzzy logic control (FLC) is very robust, it is a flexible method that can be easily modified, and can use several inputs and outputs. It is much simpler than its predecessors (linear algebraic equations), and still very fast And less costly to implement. Then the controllers by fuzzy logic are very simple and easy to use. This method basically consists of three parts: an input, a processing part and an output part [2]:

1) The first part is an input: Indeed, it is represented in the membership functions.

2) The second part is a part of treatment, so-called rules of decisions.

3) The third and final part, is the exit step. The controller converts the results into specific values, which can be managed by another system.

One of the first questions to ask when designing a Fuzzy Logic Controller (FLC) is: What are my inputs and outputs? Once this issue is resolved, the next item to deal with is the range of inputs and outputs. When we speak of fuzzy sets, this range is called universal space [4].

An output value controlled by the fuzzy logic theoretical (FLC) is developed using the MATLAB Simulink software.

FLC is widely used when modeling the system implies that information is scarce and inaccurate[13-15], or when the system is described by a complex mathematical model. An example of this type of structure is the agricultural greenhouse and its variables such as the internal temperature. This state variable influences and activates the dynamic behavior of the greenhouse, it is non-linear. The internal temperature is one of the important and even main variables in the control and modeling of greenhouses.

In addition, a FLC is efficient to deal with continuous functions using the membership function (MF) and the IF-THEN rules. In general, a FLC contains four parts: fuzzifier, rules of decisions, Fuzzy inference engine and defuzzify [12-14].

First, a set of input data is gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms, and membership functions. This step is known as Fuzzification. Then, an inference is made on the basis of a set of rules. Finally, the resulting fuzzy output is matched to a net output using the MF (membership functions) in the defuzzification step.

Mamdani is method of fuzzy inference. Is the method we used and applied in our work to optimize the management of the microclimate of our agricultural greenhouse model. This method has fuzzy rules of form (IF-THEN) that have been used to implement the Modeling of the fuzzy controller (FLC).

In many fuzzy applications, membership functions (MF) have been arbitrarily chosen as trapezoidal, triangular or Gaussian curves depending on the selected ranges.

In our model, the sigmoid membership function is considered to define the input and triangular variables for the output variables (Figure 2).

All membership functions are defined on the normalized domain [-1, 1] in the discourse universe. With eight linguistic values, as shown in Figure 1,

This figure illustrates the fuzzy sets of membership functions that contain seven fuzzy sets. The linguistic values of the fuzzy sets used are:

Very cold (TVCOLD), COLD (TCOLD), Uncooked (TCOOL), OK (TGOOD), Low warm (TSH), Warm (TH), Very hot (HST) Designed on the basis of expert knowledge and in specialized literature.

We added to our model of the greenhouse an intelligent regulator using the fuzzy logic and we chose the Mamdani method with a single input, we started by first defining the input data and the outputs, and by The following has been attempted to link the membership functions in a logical manner in order to respond to the following steps:

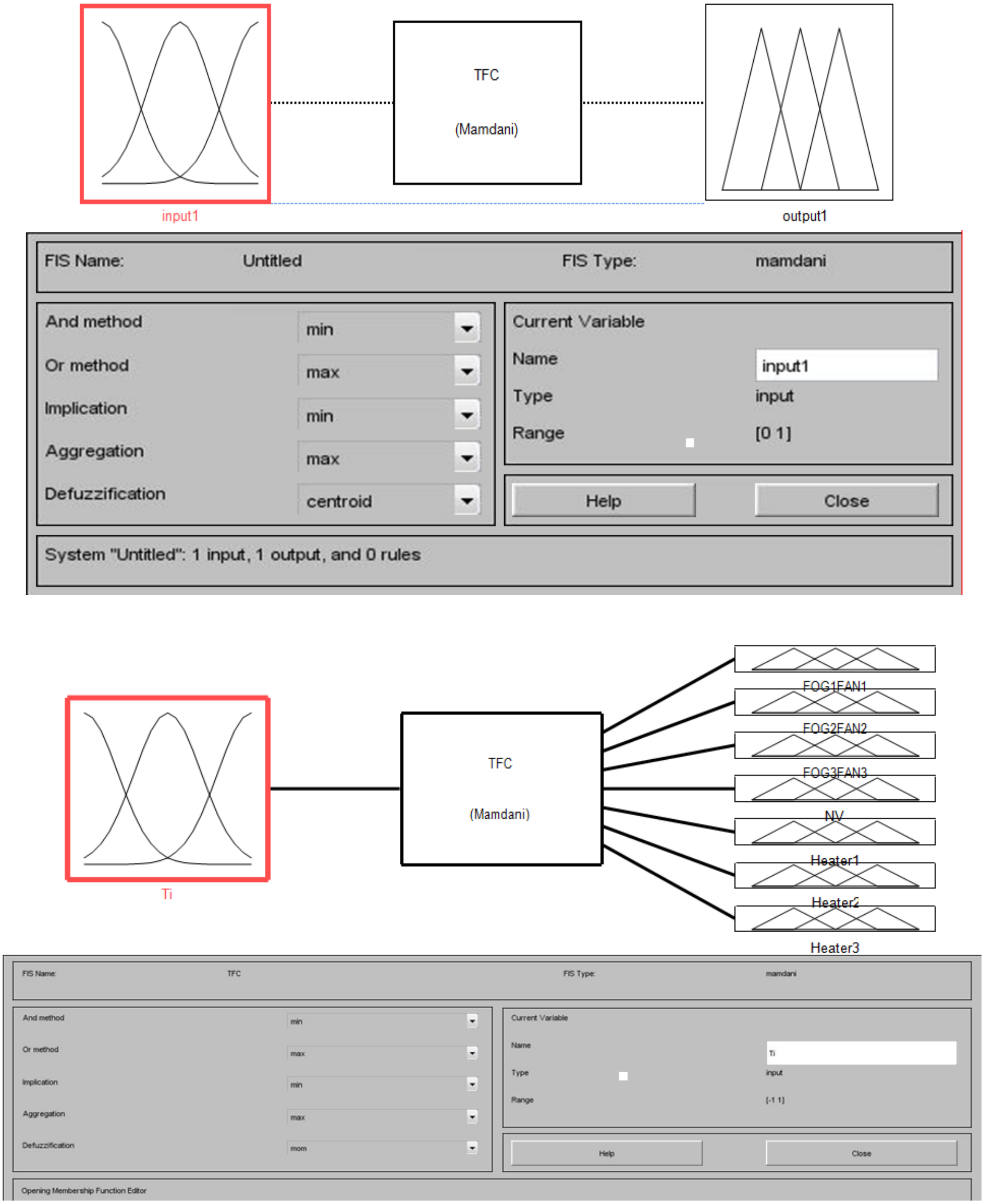


Figure 1. Creating Input and Output

Then the range of variations (the fuzzy sets) and the membership functions for the input and the output were defined, and each part of the membership function was called by a significant name.

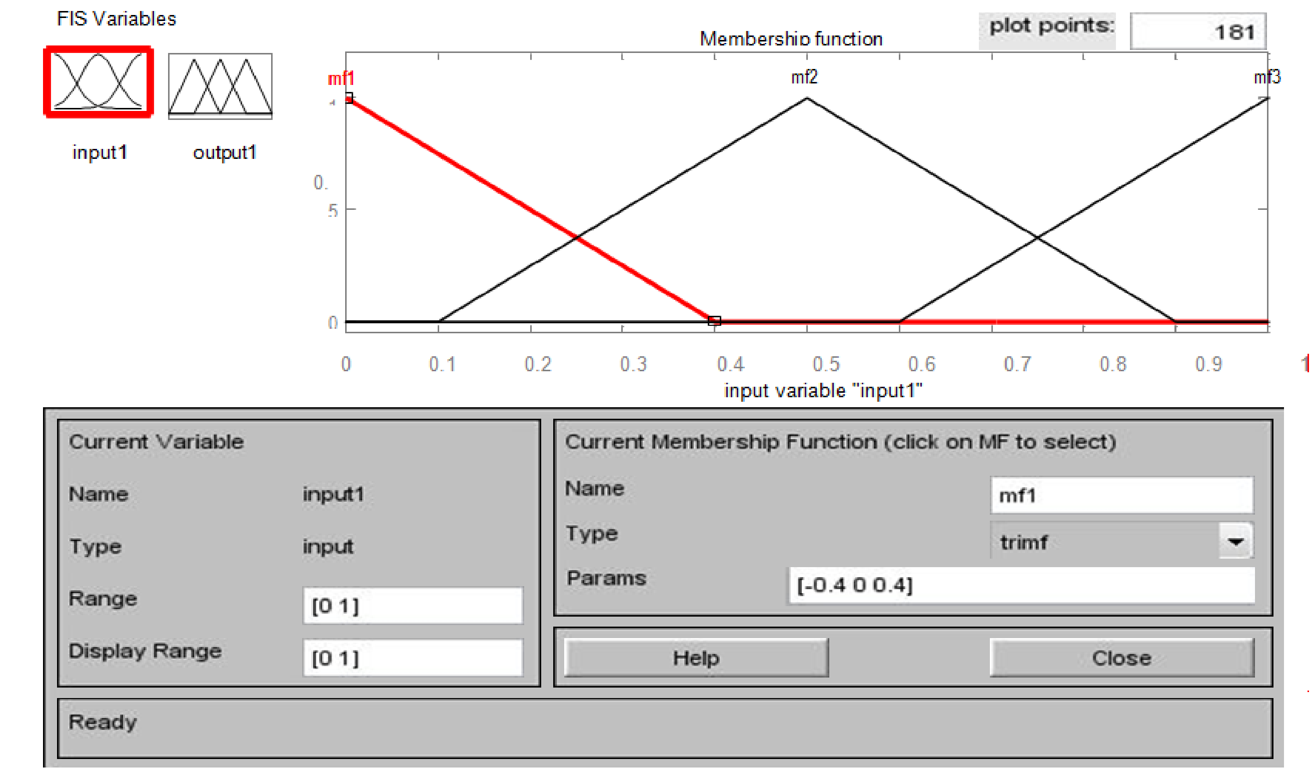


Figure 2. Membership function of the command

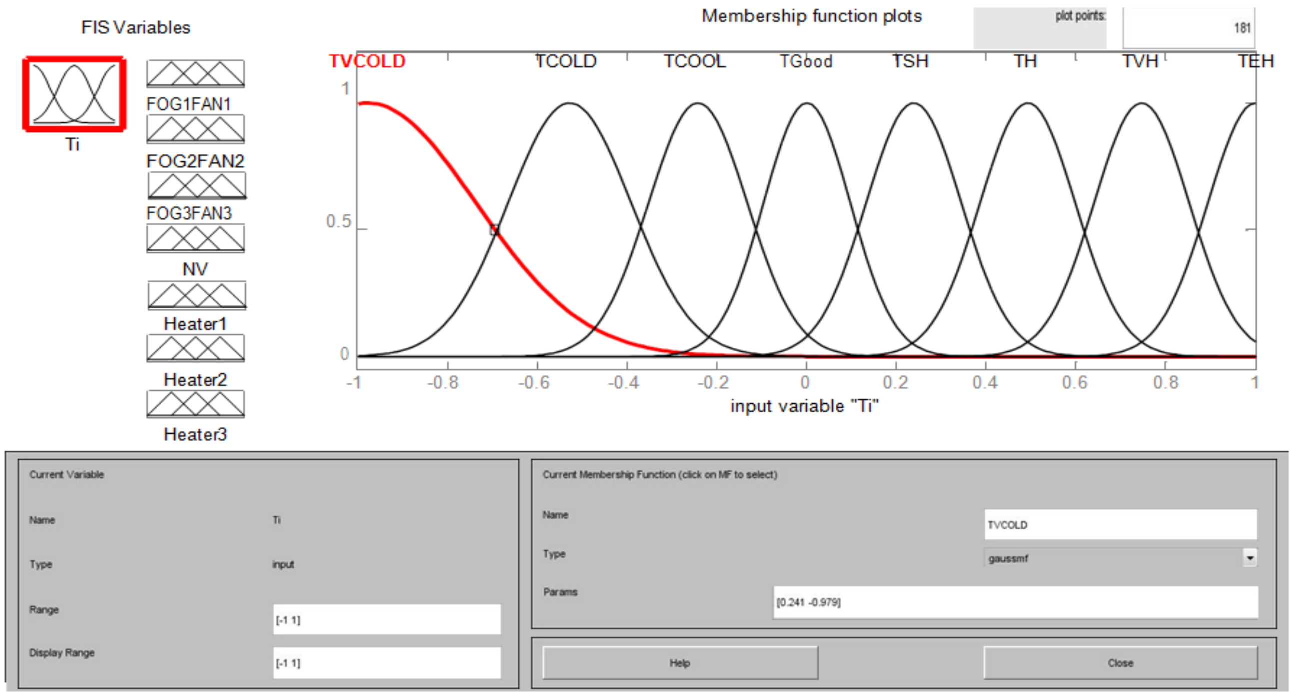


Figure 3. Membership functions for input and output variables

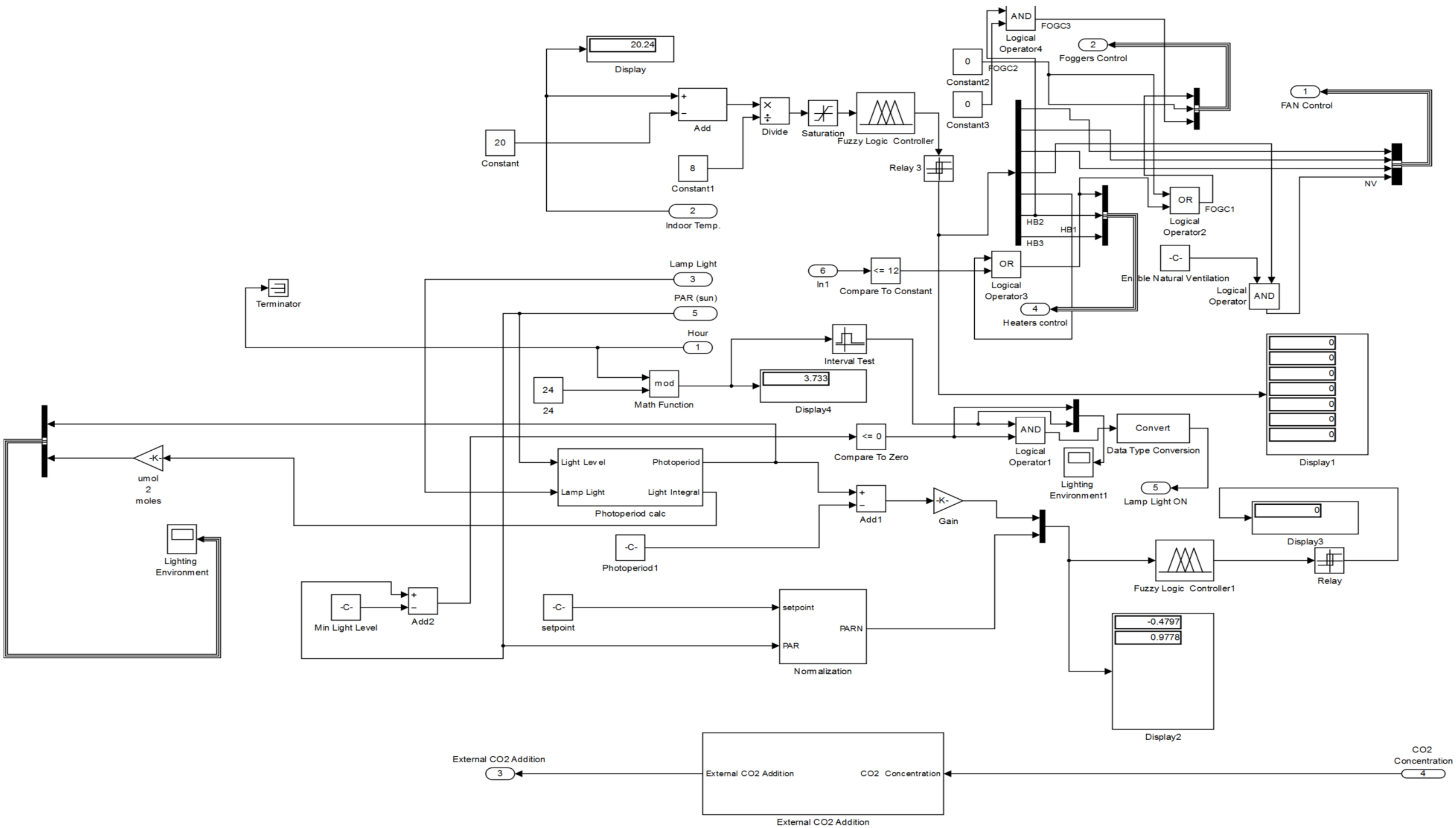
After defining the membership functions, the inference rules have been implemented in such a way as to achieve optimum control as desired, for example if the climate inside the greenhouse becomes lime the regulator will automatically Lowering the temperature by closing a heating system or opening a cooling system or by any other means and in order to keep the required instruction which will be translated by the following command [5]:

- 1.If (Ti is TVCOLD) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is ON)(Heater2 is ON)(Heater3 is ON) (1)
- 2. If (Ti is TCOLD) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is ON)(Heater2 is ON)(Heater3 is OFF) (1)
- 3. If (Ti is TCOOL) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is ON)(Heater2 is OFF)(Heater3 is OFF) (1)
- 4. If (Ti is TGood) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)
- 5. If (Ti is TSH) then (FOG1FAN1 is OFF)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is ON)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)
- 6. If (Ti is TH) then (FOG1FAN1 is ON)(FOG2FAN2 is OFF)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)
- 7. If (Ti is TVH) then (FOG1FAN1 is ON)(FOG2FAN2 is ON)(FOG3FAN3 is OFF)(NV is OFF)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)
- 8. If (Ti is TEH) then (FOG1FAN1 is ON)(FOG2FAN2 is ON)(FOG3FAN3 is ON)(NV is OFF)(Heater1 is OFF)(Heater2 is OFF)(Heater3 is OFF) (1)

We save the file (.fis) to load it into the workspace and retrieve it in the Simulink Fuzzy block under the same name of the saved file.

The simulation of our system was done by MATLAB SIMULINK. The results of the MATLAB / SIMULINK software indicate the high capacity of the proposed technique to control the internal temperature of the greenhouse even in the event of a rapid change of atmospheric conditions. The modeling of the system Is defined in the form of this block diagram introduced in our Simulink shown in Figure (4 and 5). Its goal is to achieve the set temperature of 20 ° C required by the internal environment of our greenhouse. Indeed, by varying the ranges of inferences, the efficiency of the regulator has been increased around this set point. It would also be possible to modify the inference rules or the forms of the membership functions used.

Figure 4. Schéma Simulink représente notre contrôleur flou



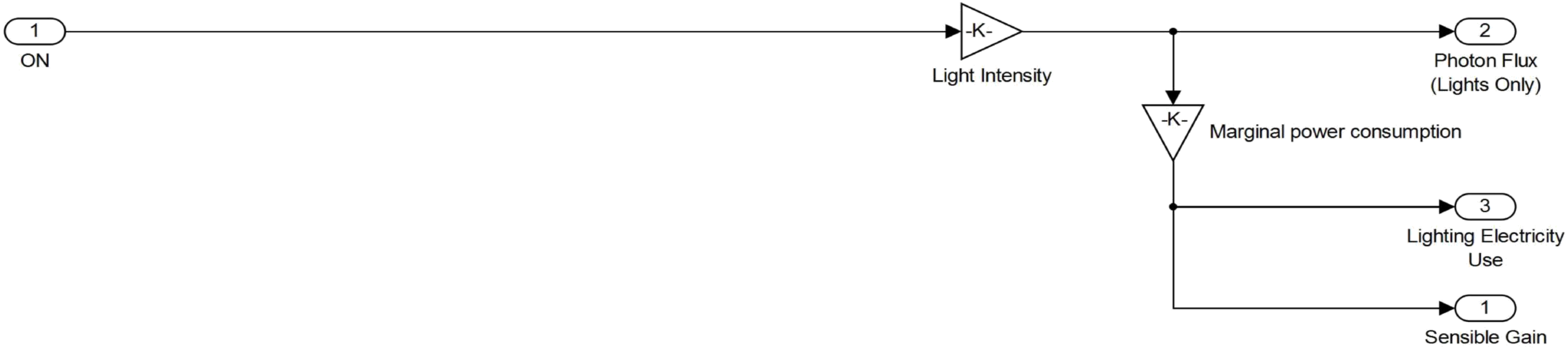


Figure 5. Schéma Simulink de la lumière

Simulation And Results

The results of the MATLAB / SIMULINK software indicate the high capacity of the proposed technique for controlling the climate inside the greenhouse (light) even in the event of rapid changes in atmospheric conditions.

The results of the simulation clearly show the real thermo-energetic behavior of the agricultural greenhouse, in a wet zone for Dar El-Beida Alger This enabled us to know the capacities and the performances of our fuzzy controller.

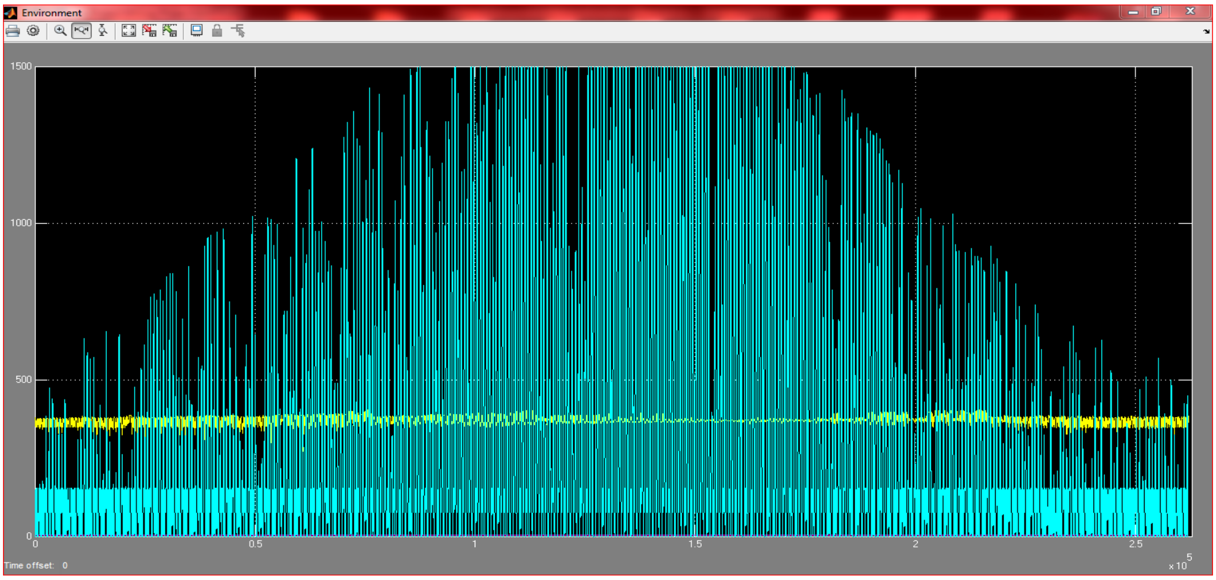


Figure 6. Assessment of the intensity of light in a year

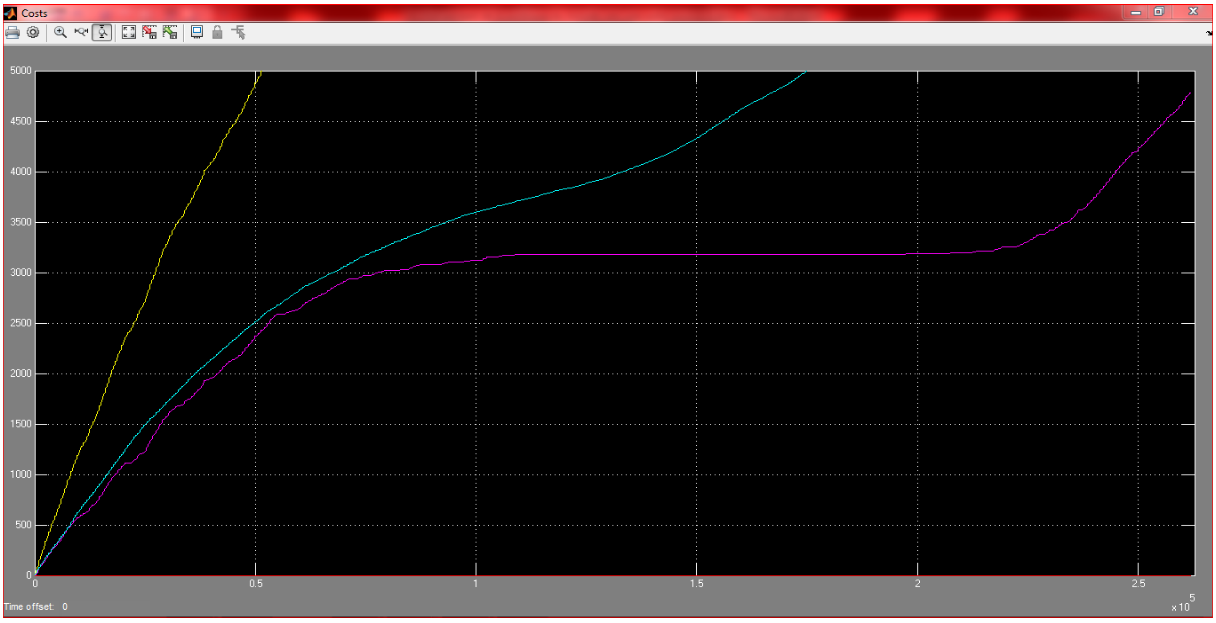


Figure 7. Evaluation of the cost of light in a year

A. Discussions on Figures

It can be seen in the two figures above that the consumption of energy (electricity, water) to ensure the lighting (light) inside the greenhouse for the operation of photo synthesis (respiration) of the plant Is low despite the intelligent control that has been applied to optimize the cost. And this forces us to look for another free source to lighten the environment of the plant in the greenhouse with a minimum of cost eg the use of geothermal energy by the modeling of a heat exchanger for the purpose of cooling , Heat and clear the greenhouse free of charge with good food production.

Conclusion

The aim of this project is to optimize energy consumption for lighting in the horticultural greenhouse (the relationship between construction and operating costs and productivity) through minimal use and Judicious use of all energy resources: heating energy, lighting. It is therefore not the aim of this work to aim at the optimization of cultural practices, but rather to optimize the construction, equipment and economic management of the physical environment of greenhouses.

To do this, the project proposes to develop a computer tool for the planning and management of a greenhouse sheltering a greenhouse culture with the modeling of an intelligent controller. And after the results obtained we will try to optimize the cost in the next job by using free energy (geothermal).

References

[1] Didi Faouzi , N. Bibi Triki and A. Chermitti, 2016. Optimizing the greenhouse micro-climate management by the introduction of artificial intelligence using fuzzy logic. Int. J. Computer Eng. Technology, 7: 78-92 , Volume 7, Issue 3, May-June 2016, pp. 78–92, Article ID: IJCET_07_03_007.

[2] Didi Faouzi , N. Bibi-Triki , B. Draoui , A. Abène, 2016 , Modeling, Simulation and Optimization of- agricultural greenhouse microclimate by the application of-artificial intelligence and/or fuzzy logic, International journal of scientific & engineering research, volume 7, issue 8, august-2016 issn 2229-5518.

[3] Didi Faouzi , N. Bibi-Triki , B. Draoui , A. Abène, 2016 Comparison of modeling and simulation results management micro climate of the greenhouse by fuzzy logic between a wetland and arid region, International Journal of Multidisciplinary Research and Modern Education (IJMRME) ISSN (Online): 2454 - 6119, Volume II, Issue II, 2016 .

[4] Didi Faouzi , N. Bibi-Triki , B. Draoui , A. Abène, 2016 , Modeling and Simulation of Fuzzy Logic Controller for the purpose of Optimizing the Management Micro Climate of the Agricultural Greenhouse, MAYFEB Journal of Agricultural Science Vol 2 (2016).

[5] Didi Faouzi , N. Bibi-Triki , B. Draoui , A. Abène, 2017, Greenhouse Environmental Control Using Optimized, Modeled and Simulated Fuzzy Logic Controller Technique in MATLAB SIMULINK, Computer Technology and Application 7 (2016) 273-286, doi: 10.17265/1934-7332/2016.06.002.

[6] Didi Faouzi , N. Bibi-Triki , B. Draoui , A. Abène. Dated 10th March 2017, The Optimal Management of the Micro Climate of the Agricultural Greenhouse through the Modeling of a Fuzzy Logic Controller, International Knowledge Press, Journal of Global Agriculture and Ecology (JOGAE), 7(1): 1-15, 2017, ISSN: 2454-4205, Ref. No. IKP/JOGAE/17/0102.

[7] Jamisson M.Hill, dynamic modeling of tree growth and energy use in a nursery greenhouse using MTLAB and Simulink , Cornell University , 7/31/2006.

[8] Taylor, C.J., Leigh P., Price L., Young P.C., Vranken, E. and Berckmans, D. (2004). Proportional-integral-plus (PIP) control of ventilation rate in agricultural buildings. Control Engineering Practice, vol. 12, pp. 225–233.

[9] Zilouchian, A., & Jamshidi, M. (2001). Intelligent control systems using soft computing methodologies: CRC Press, Inc.

[10] Liu, D., & Wang, F.-Y. (2006). Advances in computational intelligence. New Jersey: World Scientific.

[11] Ruano, A. (2005). Intelligent control systems using computational intelligence techniques. London: Institution of Electrical Engineers.

[12] Pan Lanfang, Wang Wanliang, Wu Qidi, " Application of Adaptive Fuzzy Logic System to Model for Greenhouse Climate", Proceedings of the 3rd World Congress on Intelligent Control and Automation June 28-July 2, 2000, Hefei, P.R. China, pp. 1687-1691.

[13] M. Guerbaoui, A. Ed-dahhak, Y. ElAfou1, A. Lachhab, L. Belkoura. Bouchikhi, "Implementation of Direct Fuzzy Controller in Greenhouse Based on Labview", International Journal of Electrical and Electronics Engineering Studies, Vol.1, No.1, pp. 1-13, 2013.

[14] P. A. Saudagar, D. S. Dhote, D. R. Solanke, "Microcontroller based Intelligent Temperature Controller for Greenhouse", International Journal of Engineering and Science, Vol. 1, Issue 11, PP 40-44, 2012.

[15] Tilley, D., D. Ogle, and L. St. John. 2010. Plant guide for Doulas' dusty maiden (Chaenactis douglasii). USDA-Natural Resources Conservation Service, Idaho Plant Materials Center. Aberdeen, ID. 83210.