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Fuzzy Based Temperature Control of Greenhouse

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Abstract: These Greenhouses should provide a controlled environment for plant production with sufficient sunlight, temperature and humidity. Better growing conditions are achieved in greenhouses mainly by maintaining a higher internal ambient as compared with external temperature. Thus the greenhouse heater requirements depend upon the amount of heat loss from the structure. The proposed scheme measures the on-line sequential data of temperature from the greenhouse and the heating power is recursively updated based on the energy balance of an elementary volume of greenhouse air by using intelligent controllers. Simulation results of the greenhouse dynamics illustrate the effectiveness of the proposed scheme without the exact mathematical model of the plant.

Keywords*:* Greenhouse, fuzzy logic controller, heat loss, temperature control, heating power, PSO.

1. INTRODUCTION

Greenhouse cultivation aims basically to protect the plantations from bad weather and becomes in recent years a mean to achieve controlled agricultural production. The control of the climatic environment in greenhouses has received considerable attention in these last years. The main reasons for this increasing interest are related to the following agronomic and financial objectives: (a) to extend the growing season and the potential yield; (b) to manage the climate in order to reach higher standards of quality; (c) to develop low-cost production systems, compatible with the scarcity of resources and the low investment capacity of growers. The main objective of the climate control problem is to maintain the temperature inside greenhouse environment within suitable ranges. The difficulty resides in the complexity of the phenomena which conditions the ideal environment, essentially dictated by the day/night cycle, the growth season, the local climate, and the nature of the culture. (Bakker J C et al.,1995).

2. HEATING

Many greenhouses must be heated for year-round crop production. A good heating system is one of the most important steps to successful plant production. Any heating system that provides uniform temperature control without releasing material harmful to the plants is acceptable. Suitable energy sources include natural gas, LP gas, fuel oil, wood and electricity. The cost and availability of these sources will vary somewhat from one area to another. Convenience, investment and operating costs are all further considerations. Savings in labour could justify a more expensive heating system with automatic controls. Greenhouse heating requirements depend upon the amount of heat loss from the structure. Heat loss from a greenhouse usually occurs by all three modes of heat transfer: conduction, convection and radiation. Usually many types of heat exchange occur simultaneously.

2.1 Conduction

Heat is conducted either through a substance or between objects by direct physical contact. The rate of conduction between two objects depends on the area, path length, temperature difference and physical properties of the substance(s) (such as density). Heat transfer by conduction is most easily reduced by replacing a material that conducts heat rapidly with a poor thermal conductor (insulator) or by placing an insulator in the heat flow path.

2.2 Convection

Convection heat transfer is the physical movement of a warm gas or liquid to a colder location. Heat losses by convection inside the greenhouse occur through ventilation and infiltration (fans and air leaks).

2.3 Radiation

Radiation heat transfer occurs between two bodies without direct contact or the need for a medium such as air. Like light, heat radiation follows a straight line and is either reflected, transmitted or absorbed upon striking an object. Radiant energy must be absorbed to be converted to heat. The rate of radiation heat transfer varies with the area of an object, and temperature and surface characteristics of the two bodies involved.

2.4 Factors Affecting Heating Loss

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Heat loss by air infiltration depends on the age, condition and type of greenhouse. Older greenhouses or those in poor condition generally have cracks around doors or holes in covering material through which large amounts of cold air may enter. Greenhouses covered with large sheets of glazing materials, large sheets of fibre glass or a single or double layer of rigid or flexible plastic have less infiltration (Fig. 1). Solar radiation enters a greenhouse and is absorbed by plants, soil and greenhouse fixtures. The warm objects then re-radiate this energy outward. The amount of radiant heat loss depends on the type of glazing, ambient temperature and amount of cloud cover. (Seginer,et al.; 1992)

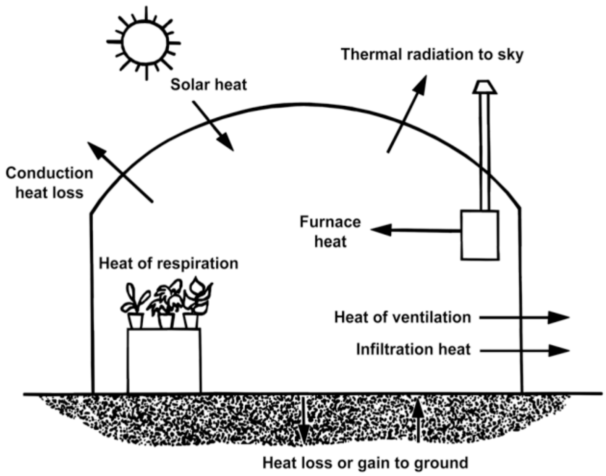

Fig. 1. Energy losses and gains in a greenhouse

3. CALCULATION OF MINIMUM DESIGN TEMPERATURES

A good outside temperature to use in heater design calculations (to select heater size) can be found by subtracting 15 degrees F from the average daily minimum temperature. Another requirement the heater must meet is to provide enough heat to prevent plants from freezing during periods of extremely low temperatures. (as cited in www.cps.gov.on.ca/english/plans/E6000/6701/M-6701L.pdf) For example consider the table 1.

Table 1.Climatic Conditions in Georgia (1948-2004)

Location	Minimum Temperature °F and (Year Occurring)	Average Daily Minimum January Temperatures (°F)
Atlanta	-8 (1985)	33.6
Athens	-4 (1985)	33.2
Augusta	-1 (1985)	33.6
Columbus	-2 (1985)	36.4
Macon	-6 (1985)	35.8
Rome	-9 (1985)	30.5
Savannah	3 (1985)	39.0
Tifton	0 (1985)	38.0
Valdosta	9 (1981)	38.6

At an Augusta location and an average daily minimum January temperature of 33.6 degrees F, the design temperature would be about 18.6 degrees F, so use 20 degrees F. This requires a 45-degree F rise above design temperature; and, with glass, the R-value will be 0.91.

Conduction Heat Loss, Q_C = Area x $\Delta T/R$ (1)
Air Infiltration Losses, Q_A= 0.02 x Volume x C x ΔT (2)
Perimeter Heat Loss, Q_P= P x L x (ΔT) (3)
Total Heat Loss, $Q_T = Q_C + Q_A + Q_P$ (4)
Where

Q = Heat loss, BTU/hr
A = Area of greenhouse surface, sq. ft
R = Resistance to heat flow (a characteristic of the material)
V = Greenhouse volume, cu. ft
C = Number of air exchanges per hour
P = Perimeter heat loss coefficient, BTU/ft °F hr
L = Distance around perimeter
The values are listed below in the table 2.

Table 2.Values used for the greenhouse considered

R(glass)	0.91
V	30,928 cu ft
C for new construction, glass or fiberglass	0.75 to 1
C for Old Construction glass, good maintenance	1 to 2
C for Old Construction glass, poor condition	2 to 4
Perimeter for Uninsulated P	0.8 BTU/ft °F hr
Perimeter for insulated P	0.4 BTU/ft °F hr

4. TEMPERATURE CONTROL

Temperature is the main climatic variable affecting the crop growth, and thus, this variable has been traditionally controlled in the greenhouses. Based on the energy balance of an elementary volume of greenhouse air, the relation can be given by eq. 5. (Arvanitis, 1999).

$$Q_H = C_q\left(\frac{dT_G}{dt}\right) - (K_{out,air}[T_{out} - T_G]) \quad (5)$$

Where T_G is the greenhouse temperature, C_q is the greenhouse thermal capacity, $K_{out,air}$ is the heat loss coefficient from greenhouse air to outside air, T_{out} is the outside temperature and Q_H is the heating power.

The scheme of temperature control inside the greenhouse is shown in (Fig. 2).

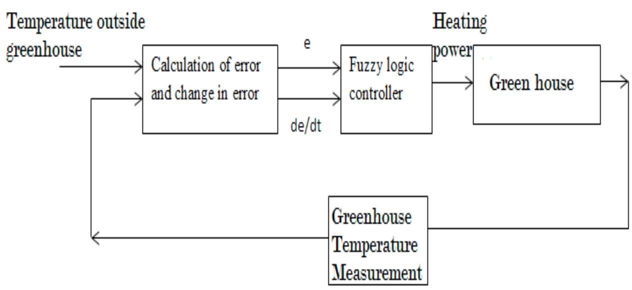

Fig. 2. Greenhouse heating system and control

The outside temperature and the present inside temperature of the greenhouse are the inputs from the sensor. The error and the change in error are computed which are the inputs to the fuzzy logic controller. The output is the heating power required to maintain the greenhouse at an optimum temperature.

5. FUZZY CONTROL

In the last decade, the fuzzy logic gained interest in the scientific community and fuzzy knowledge-based systems are one of the most successful applications of fuzzy sets and fuzzy logic methods. This is mainly due to the flexibility and simplicity by which knowledge can be expressed using fuzzy rules as well as to the theoretical developments in this field.

The aim advantage of fuzzy control is the possibility of implementing human expert knowledge in the form of linguistic if – then rules. The design of a fuzzy controller begins with the choice of linguistic variables, the process state, the input and the output variables. The next step is the choice of the set of linguistic rules and the kind of fuzzy reasoning process. Once the rules are setup, after the inference, the fuzzy set and the crisp output value have to be generated; a defuzzification strategy has to be established too. (Horiuchi J, 2002)

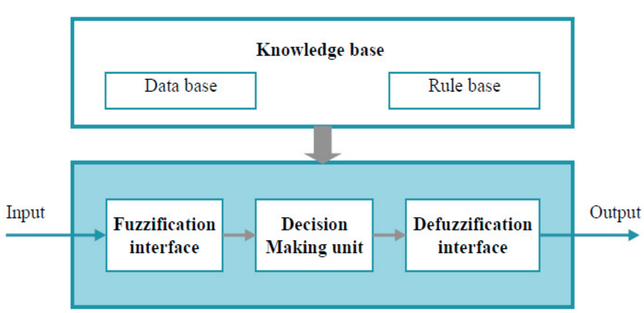

Fig. 3. Block diagram of a fuzzy controller

The block diagram of a fuzzy controller is shown in fig 3. It is composed of four principal modules: The fuzzification interface performs the transformation of crisp inputs into fuzzy sets. The knowledge base supplies the fuzzification module, the interface engine, and the defuzzification interface with necessary information for their proper functioning. The decision making unit or interface engine computes the meaning of the set linguistic rules. The defuzzification interface transforms the union of fuzzy sets (individual contributions of each rule in the rule base) into a crisp output. (Chuen-Lee, C., 1990)

5.1 Optimized fuzzy logic control using PSO

In order to increase the degree of automation of the fuzzy control system, a "near-optimal" controller synthesis strategy has been developed using PSO technique. An optimization method that finds the optimal solution using a population of particles is PSO algorithm. Each swarm of PSO is a solution in the solution space. The algorithm can be explained as follows. (Eberhart, R. 1995)(Lafont 2002).

- Each individual particle i has the following properties: A current position in search space X_{id}, a current velocity p_{id} and a personal best position in search space P_{id}.
- The personal best position p_{id} corresponds to the position in search space where particle i presents the smallest error as determined by the objective function f assuming a minimization task.
- The global best position marked by represents the position yielding the lowest error amongst all the p_{gd}.

During the iteration every particle in the swarm is updated using the following two equations:

$$V_{id}(t+1) = w.V_{id}(t) + c_1.r_1(P_{id} - X_{id}(t))c_2.r_2\left(P_{gd} - X_{id}(t)\right)$$
$$X_{id}(t+1) = X_{id}(t) + V_{id}(t+1) \quad (6)$$

Where $V_{id}(t+1)$ and $V_{id}(t)$ are the updated and current particles velocities, respectively, $X_{id}(t+1)$ and $X_{id}(t)$ are the updated and current particle position, respectively, c_1 and c_2 are two positive constants and r_1 and r_2 are normalized unit random numbers within the range [0, 1] and w is the inertia weight.

The approach of using a PSO for MF tuning in FLC is shown in (Fig. 4).

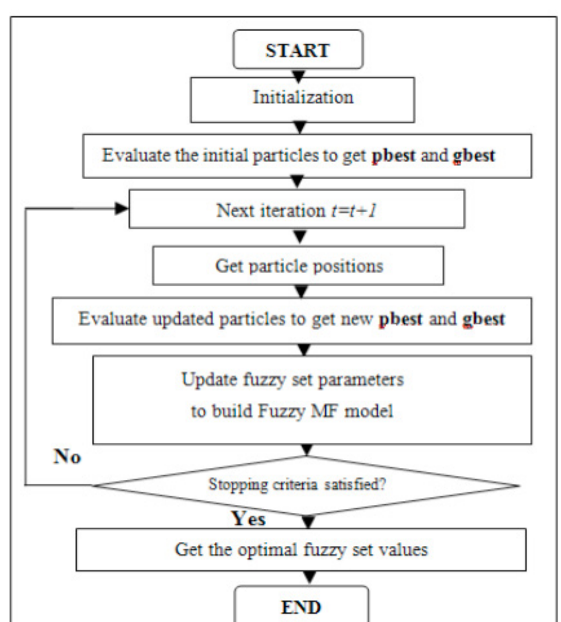

Fig. 4. Flowchart for Optimizing FLC using PSO

In this process, each particle is shaped to represent the MF parameters of the FLC's inputs and outputs. The cost function used here is root mean square error. The PSO parameters are listed below in the table 3.

Table 3. PSO parameters

PSO parameters	values
Population Size	25
Personal Learning Coefficient	1
Global Learning Coefficient	2
Inertia Weight	1
Maximum Number of Iterations	1000

6. SIMULATION

For the simulation purpose the weather data of Georgia is taken for the month of January 2015 and used as input external temperature outside the greenhouse.

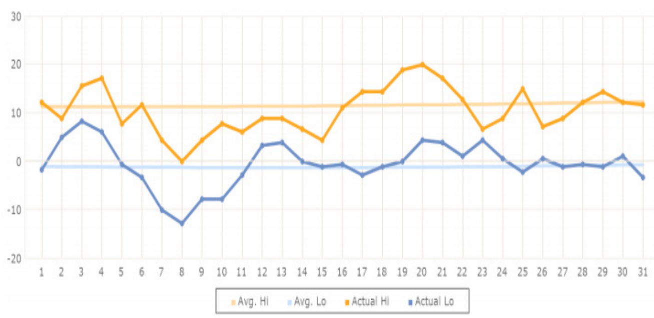

Fig. 5. Temperature Graph of Georgia (January 2015) (www.accuweather.com/en/us/ga/georgia.weather)

6.1 Linguistic variables, values and membership functions of basic fuzzy logic control

The linguistic variables are error e, change in error ce and the output u. The membership functions are shown in (fig 6, 7, 8). The labels used for linguistic variables 'e' are 'extreme –ve', 'too-ve', 'low-ve', 'small-ve', 'zero', 'small+ve' and '+ve'.

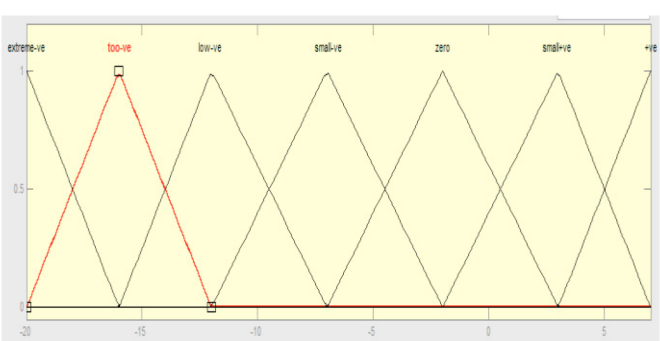

Fig. 6. Membership function for e

The labels used for linguistic variables 'ce' are 'low', 'med' and 'high'.

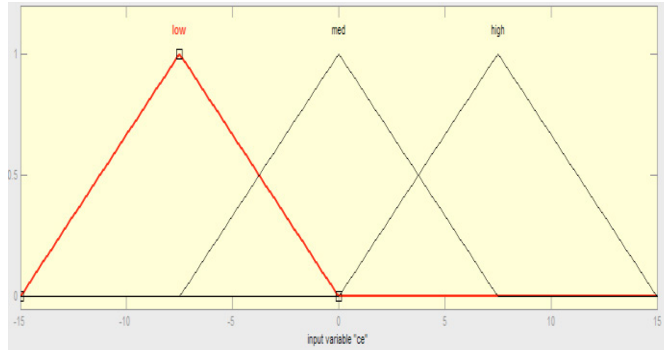

Fig. 7. Membership function for ce

The labels used for linguistic variables 'out' are 'range1', 'range2', 'range3', 'range4', 'range5', 'range6'. Triangular and trapezoidal membership functions are used.

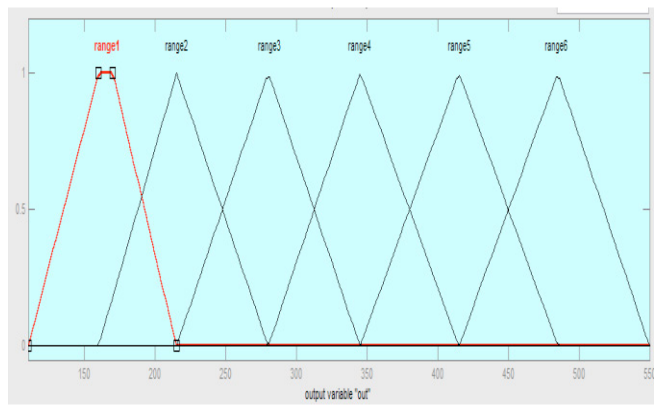

Fig. 8. Membership function for the output

The minimum temperature pattern recorded in Georgia in January 2015 is shown in (Fig. 9). It is compared with against the greenhouse temperature. The error and change in error are given as input to Fuzzy controller.

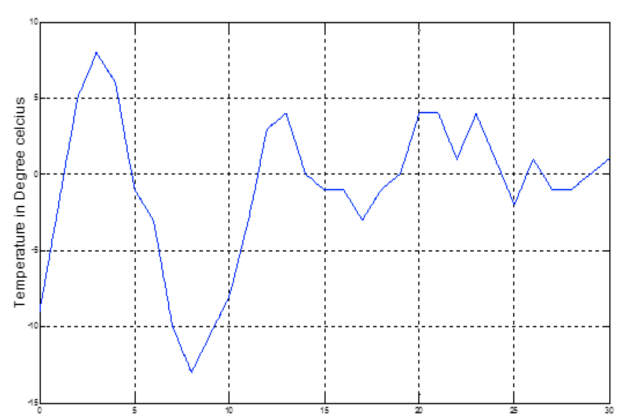

Fig. 9. Minimum temperature of Georgia in January 2015

Fuzzy controller evaluates the heating power that is to be applied to the greenhouse using 21 rules and it is listed in table. 4 and the pattern is shown in (Fig. 10). These rules are based on the knowledge of heating requirement of greenhouse mentioned in section 3 of the paper.

Table 4. Fuzzy rules

Ce/e	extreme –ve	too-ve	low-ve	small-ve’	zero	small+ve’	+ve
low	Range6	Range6	Range5	Range4	Range3	Range2	Range1
med	Range6	Range6	Range5	Range4	Range3	Range2	Range1
high	Range6	Range5	Range4	Range3	Range2	Range1	Range1

The output of a process can be logical union of two or more membership functions defined on the universe of discourse the output value. Centroid membership function is used for defuzzification process. The output variable is the heating temperature value applied to the greenhouse and it is shown in (fig. 10).

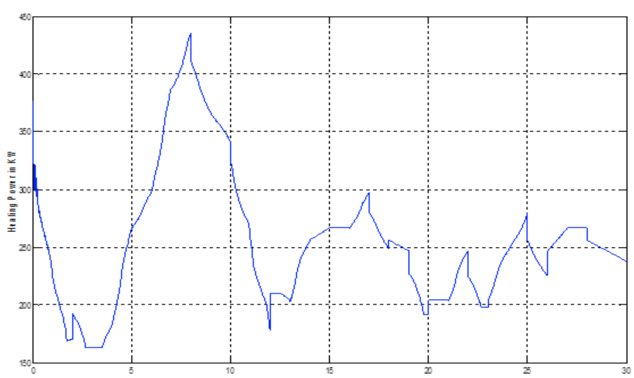

Fig. 10. Heating Power pattern applied to the greenhouse for January 2015.

(Fig. 11) shows the controlled temperature using basic FLC inside the greenhouse throughout the month of January 2015.

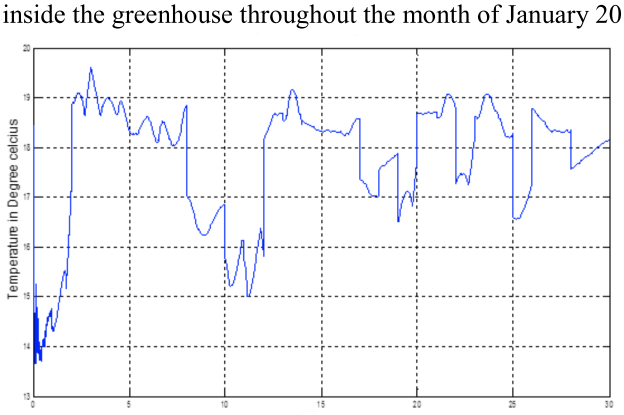

Fig. 11. FLC Controlled Temperature response inside glasshouse

6.2 Optimized membership functions of fuzzy logic control

During optimization, Gaussian membership functions instead of triangular have been adopted in order have membership functions which are smooth and non-zero at all points. The input membership functions error ‘e’ and change in error ‘ce’ are shown in (Fig. 12, 13).

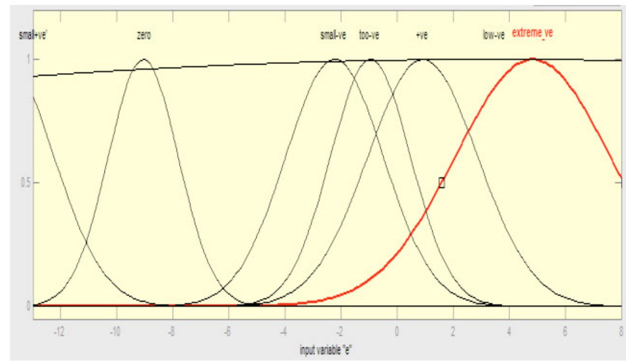

Fig. 12. Optimized membership function of e

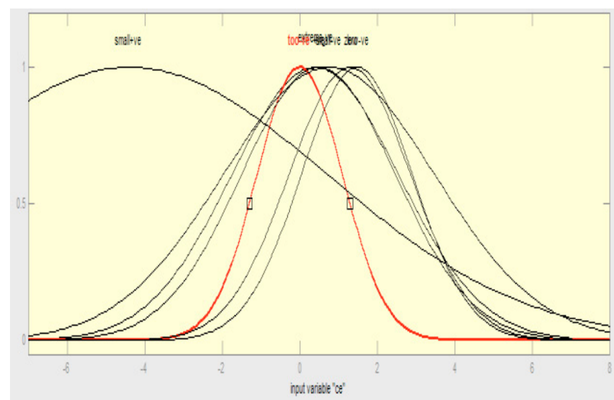

Fig. 13. Optimized membership function of ce

FIS is Takagi-Sugeno type fuzzy controller so the defuzzification membership functions are Singleton. Singleton membership functions are simple and use less computing resources. Also the using PSO, the rules are optimized and 7-rule FLC provide the control strategy.

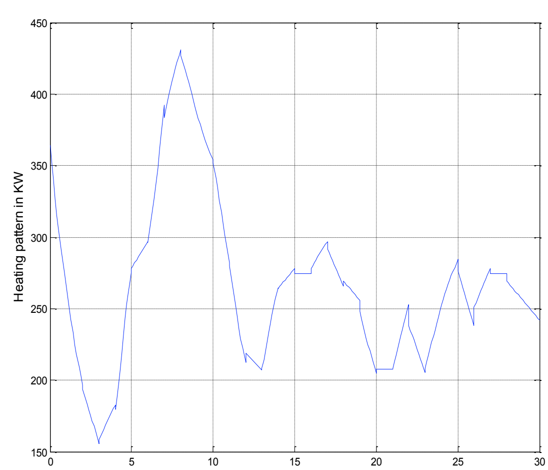

Fig. 14. Optimized Heating Power pattern applied to the greenhouse

The controller output is also optimized and also the computation memory required and associated time is also reduced.

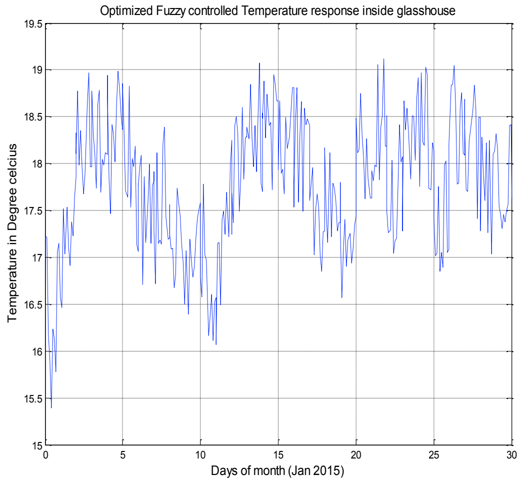

Fig. 15. Optimized FLC Controlled Temperature response inside glasshouse

From (Fig 10, 11, 14 and 15) it is inferred that better improvement in temperature inside greenhouse is achieved with similar input energy pattern. Also from the heating pattern of both basic fuzzy and optimised fuzzy control, it shows PSO-FLC has more acceptable desired results rather than conventional FLC in control of the greenhouse temperature. Also PSO-FLC controller gives robustness improvement and very good results in compare with the conventional FLC controller.

7. CONCLUSION

Due to the greenhouse complex dynamics of the envelopment physics, the fuzzy control represents a useful tool to be applied to this type of processes. In this paper, greenhouse temperature is controlled using basic fuzzy and optimized fuzzy through PSO. It is inferred that the optimized membership functions (MFs) provided better performance than a fuzzy model for the same system, when the MFs were heuristically defined. Thus throughout the month including severe weather conditions the intelligent controllers are able to maintain temperature between 15 and 20 degree Celsius without exact mathematical model of the greenhouse. Thereby damage of the crops and production losses are greatly reduced.

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