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A Fuzzy Inference System Approach for Greenhouse Climate Control

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Abstract. Nowadays computerized control is very essential for the greenhouse climate control. Many conventional methods for controlling greenhouse climate are not effective since they are either based on on-off control methods or proportional control methods. This results in a loss of energy, labor, and productivity. To maintain a steady climate, a more sophisticated system must be used. In this paper, a greenhouse climate controller (GHCC) is designed using a Fuzzy Logic programming. Here, the developed Fuzzy Logic Controller (FLC) prototype is based on a Mamdani controller and it is built on the MATLAB software. The developed Fuzzy Logic Controller effectively controls the factors affecting the climate of greenhouse by controlling the thermal system and the ventilation - humidification system. Besides, thermal shading, CO_2 generation, forced ventilation and performance of system are also controlled. The 95 rules considered by our controller predict the output of the controller accurately. An interactive graphical user interface it is also developed in order to test the controller performance manually. The result from the interface shows that the proposed Fuzzy Logic Controller is very user friendly, easy to design, highly adaptable, quick to perform, and takes low memory space.

Keywords: Fuzzy Logic, Fuzzy Inference System, Greenhouse Climate Control.

1. Introduction

The main purpose of a greenhouse is to improve the environmental conditions in which plants are grown. In greenhouses provided with the appropriate equipment these conditions can be further improved by means of climate control [6]. Modern greenhouse and computerized climate control modules have become inseparable nowadays. Computerized climate control is an intrinsic part of present day modern greenhouse [7]. The functions of the computerized climate control can be summarized as follows: (a) It takes care of maintaining a protected environment despite fluctuations of external climate; (b) It acts as a program memory, which can be operated by the growers as a tool to control their crops [4]. The main advantages of using computerized climate control are as follows: (1) Energy Conservation [15]; (2) Better Productivity of Plants [17]; (3) Reduced Human Intervention [5]. The main environmental factors affecting the greenhouse climate control are as follows: Temperature [22], & Relative Humidity [11], of the inside Air; Vapor pressure Deficit [3]; Transpiration [9, 10, 20] Sunlight; CO_2 Generation [23] & Wind speed [11]; and Lighting [22]. Actuators responsible for the climate variations are: *Heating System:* Six types of heating systems are normally used, they are: Heat exchangers in the soil; Heat exchangers laid directly on the ground; Aerial pipes near the ground or benches; Fan heater units; Roof heating systems, and a combination of two of these [21]. *Cooling System:* There are three basic methods of greenhouse cooling: Natural ventilation; Mechanical fan; Pad cooling; Fog cooling; Thermal shade or nets. [8, 15, 17, 18]. *Lighting System* [22]. *CO_2 Generator:* Natural gas or propane burners hooked up to sensors can be used to generate CO_2, or flue gases from a hot water boiler burning natural gas can be captured and re-circulated. The most expensive, but safest option in terms of possible air pollution is compressed CO_2, which is unlikely to contain combustion gases as contaminants [23].

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2. Fuzzy Design vs. Conventional Design

Figure 1 and 2 illustrate a sequence of design steps required to develop a controller using a conventional and a Fuzzy approach. Using the conventional approach the first step is to understand the physical system and its control requirements. Based on this understanding, the second step is to develop a model, which includes the plant, sensors and actuators. The third step is to use linear control theory in order to determine a simplified version of the controller, such as the parameters of a PID controller. The fourth step is to develop an algorithm for the simplified controller. The last step is to simulate the design including the effects of non-linearity, noise, and parameter variations. If the performance is not satisfactory then the system must be re-modeled, the controller must be re-designed, the algorithm must be re-written and re-try. With Fuzzy Logic the first step is to understand and characterize the system behaviour by using knowledge and experience. The second step is to directly design the control algorithm using fuzzy rules, which describe the principles of the controller's regulation in terms of the relationship between its inputs and outputs. The last step is to simulate and debug the design. If the performance is not satisfactory we only need to modify some fuzzy rules and re-try. Although the two design methodologies are similar, the fuzzy-based methodology substantially simplifies the design loop. This leads to the following significant advantages: Simplified design complexity; Reduced design development cycle; Reduced hardware costs; Simplified implementation; Improved time to market; Better alternative solution to Non-Linear Control; Improved control performance [16].

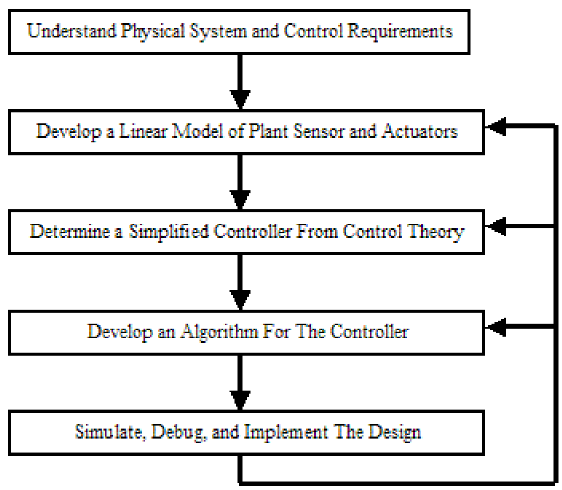

Figure 1 Conventional design

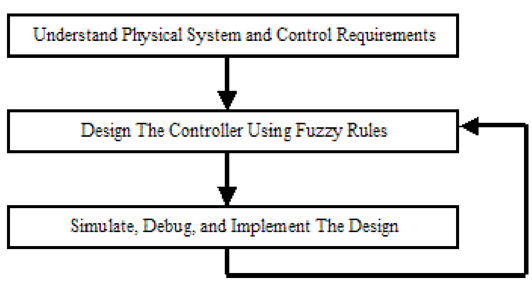

Figure 2 Fuzzy logic design

3. Main Idea of Fuzzy Logic Control Theory

This section presents the main ideas underlying our proposed Fuzzy Logic Controller (FLC). To highlight the issues involved, Figure 3 shows the basic configuration of an FLC. It comprises four principle components: a fuzzification interface, a knowledge base, decision-making logic, and a defuzzification inference. ***The Fuzzification***

Interface involves the following functions: Measure the values of input variables; Perform a scale mapping that transfers the range of values of input variables into corresponding universes of discourse; Perform the function of fuzzification that converts input data into suitable linguistic values, which may be viewed as labels of fuzzy sets. ***The Knowledge Database*** comprises knowledge of the application domain and the attendant control goals. It consists of a "database" and a "linguistic (fuzzy) control rule base". The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data manipulation in an FLC; The rule base characterizes the control goals and control policy of the domain experts by means of a set of linguistic control rules. ***The Decision-Making Logic*** is the kernel of an FLC. It has the capability of simulating human decision-making based on fuzzy concepts, implication and the rules of inference in Fuzzy Logic. ***The Defuzzification Inference*** performs the following functions: Scale mapping, which converts the range of values of output variables into the corresponding universe of discourse; Defuzzification, which yields a non-fuzzy control action from an inferred control action; A defuzzifier converts an inferred fuzzy control action into a crisp one [24].

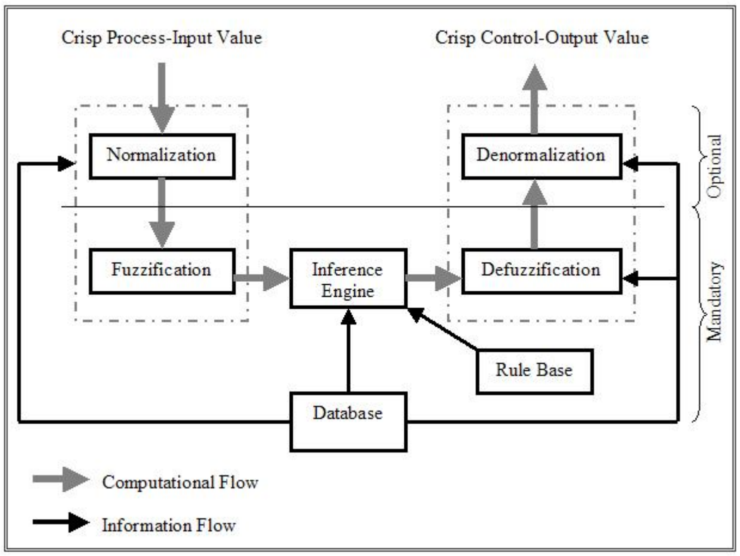

Figure 3 Basic configuration of FLC

4. Description of Greenhouse Climate Control System

To control the climate in the greenhouse, the greenhouse must be designed in such a way that it will incorporate the sensors measuring the factors affecting the outer and inner climate and the responsible actuators controlling these factors directly. The model designed by Arbel [2] examines the factors that influence the level of the climatic conditions obtained and their degree of uniformity, in a greenhouse equipped with a system of fogging and forced ventilation based on uniform roof openings and two side openings (east and west), fans at both ends of the greenhouse (north and south) placed at ground level, and uniformly distributed fogging nozzles installed at the top of the greenhouse. A similar model of greenhouse is taken into consideration with additional sensors and actuators. The model proposed below focuses on the sensors and actuators rather than the geometric values, since the programming of controller is given more importance in our project. The proposed model in block diagram form is shown in figure 4. The sensors and actuators used in the block diagram are as follows:

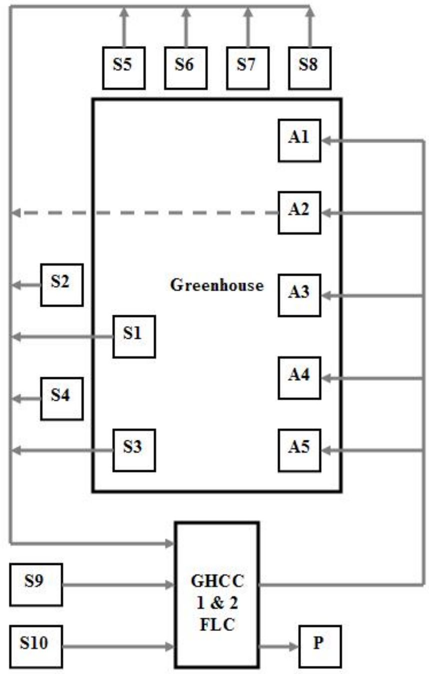

Figure 4 FLC block diagram

S1: Sensor recognizing the difference between, existing inside temperature of greenhouse & optimum temperature that must be maintained in greenhouse [ºC]
S2: Sensor recognizing the difference between, existing outside temperature of greenhouse & optimum temperature that must be maintained in greenhouse [ºC]
S3: Sensor recognizing the difference between, existing inside R-Humidity of greenhouse & optimum R-Humidity that must be maintained in greenhouse [%]
S4: Sensor recognizing the difference between, existing outside R-Humidity of greenhouse & optimum R-Humidity that must be maintained in greenhouse [%]
S5: Sensor sensing the sunlight incident on the greenhouse roof [W/m^2]
S6: Seasonal Cloudiness which reduces the sun's radiation [%]
S7: Wind speed [mph]
S8: Wind direction with respect to the direction of the ventilation system of the greenhouse
S9: Measurement error of the sensing system
S10: Change in Error of the measurement of the sensing system
A1: Actuator system for thermal system
A2: Actuator system for ventilation & humidification system
A3: Actuator system for Thermal shade system
A4: Actuator system for CO_2 generation system
A5: Actuator system for forced ventilation system
P: Performance of the system

5. Function of Greenhouse Climate Controller

The model designed by Pasgianos [14] relies on a model-based on feedback-feed forward compensation of external disturbances (loads) on the basis of input – output system linearization and decoupling; the transformation of user-defined settings for desired temperature and humidity into feasible controller set points, taking into account the constraints imposed by the capacities of the actuators and the psychrometric laws; and additional PI outer loops to compensate for model uncertainties and deviations from expected disturbances (weather). A similar model for the function of the greenhouse climate control (GHCC) is considered for our proposed system and shown as a functional block diagram in the Figure 5.

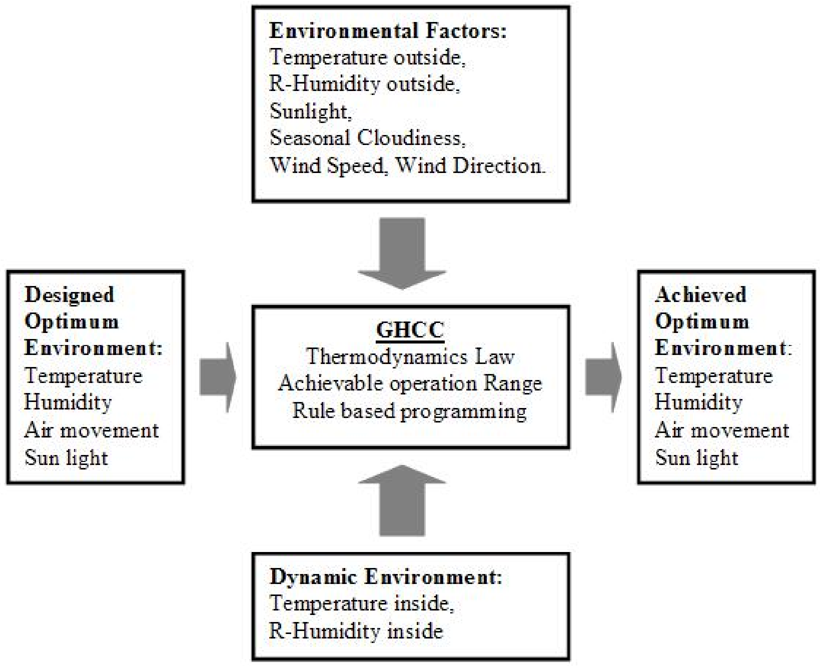

Figure 5 A functional block diagram - GHCC

6. Role of Fuzzy Logic Programming (FLP) in the Controller

The intelligent control technique proposed by Morimoto & Hashimoto [13] is useful for controlling agricultural systems, characterized by complexity and uncertainty, in an elaborate and sophisticated manner. It consists of a fuzzy controller and two optimizers and was applied to the control of the relative humidity in the storage house, which can be applied for greenhouse humidity control. A similar approach is proposed for the greenhouse climate controller, which consists of two Fuzzy Logic programming modules, where an output from the first FLP module is given as an input for the second FLP module. The role of Fuzzy Logic programming in the greenhouse climate controller is described in Figure 6.

7. Development of the proposed FLC

Here, the Fuzzy Logic rules are formulated using MATLAB® version 6.0 and the Fuzzy Logic Tool Box, as a simple Mamdani system. Membership functions and rules for our proposed Fuzzy Inference System as an FLC are developed by collective knowledge from several books and journals. A block diagram describing the Fuzzy Inference System is shown in Figure 7. It includes: Fuzzification; 95 Rule Base; Rule Evaluation and Aggregation System (Maximum Method) and Defuzzification System (Mean of Maximum Method)

7.1. Inputs, Outputs and Membership Functions of Fuzzy Logic Controller

The number, limits and shape of membership functions are adjusted using the interactive graphics tools provided by the MATLAB Fuzzy Toolbox-Fuzzy Inference Editor. The first step in designing the FLC is to identify the fuzzy input and output variables with range (universe of discourse). The ten inputs with the range (universe of discourse) are the:

1. Difference in temperature between inside greenhouse & optimum that must be maintained in greenhouse [-10 to +10 ºC].
2. Difference in temperature between outside greenhouse & optimum that must be maintained in greenhouse [-20 to +20 ºC].
3. Difference in R-Humidity between inside greenhouse & optimum that must be maintained in greenhouse [0 to 100 %].

4. Difference in R-Humidity between outside greenhouse & optimum that must be maintained in greenhouse [0 to 100 %].
5. Sunlight incident on the greenhouse roof [0 to 20 W/m^2].
6. Seasonal Cloudiness, which reduces the sun's radiation [0 to 100 %].
7. Wind speed [0 to 100 mph].
8. Wind direction with respect to the direction of the ventilation system of the greenhouse.
9. Measurement error of the sensing system (-4 to 4).
10. Change in Error of the measurement of the sensing system (-1 to 1).

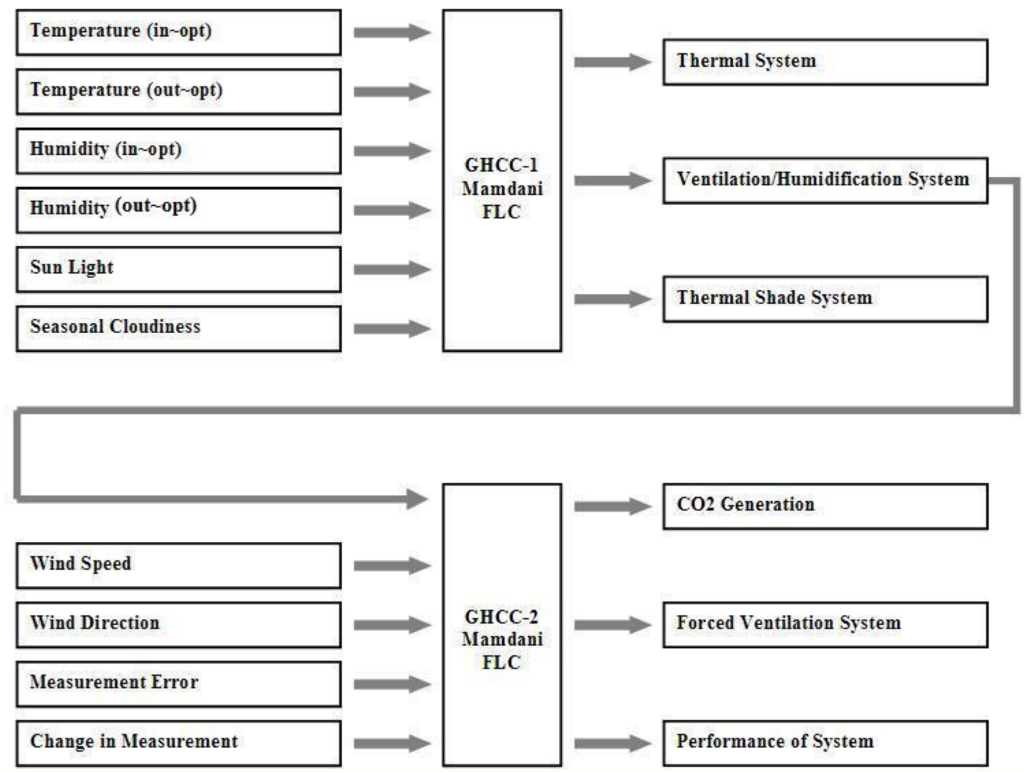

Figure 6 Role of FLP in GHCC

The six outputs with range (universe of discourse) are

1. Thermal system (0 to 100 %).
2. Ventilation & humidification system (0 to 100 %).
3. Thermal shade system (0 to 100 %).
4. CO_2 generation system (0 to 100 %).
5. Forced ventilation system (0 to 100 %).
6. Performance of the system (0 to 100 %).

In many fuzzy applications, the membership functions (MF) are arbitrarily selected as trapezoidal, triangular, or Gaussian depending upon the ranges selected [16]. In the proposed model, the Gaussian membership function type is used to define the input and output variables, since it is a smooth curve with a concise notation advantage. The membership functions for the input and output variable are discussed in Appendix A in [19].

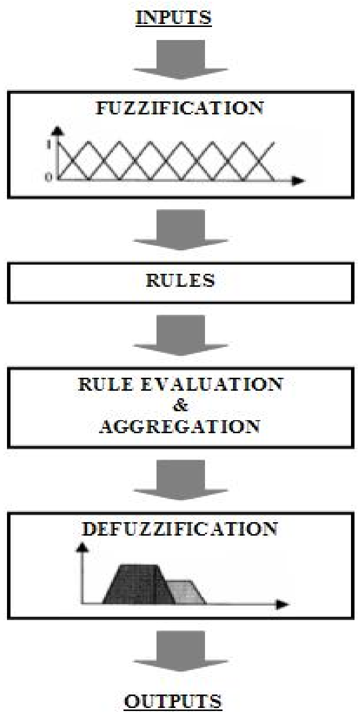

Figure 7 Steps in the FLC

7.2. Fuzzification

The Figure 7 shows measured input values that were transformed into FL values. As an example, consider the input measurements 6.5°C from the sensor S1 (senses the difference between inside and optimum temperature). The value 6.5°C intersect at the Positive and Positive High of the Temperature (in~opt) membership set, with a 20% grade in Positive set and 80% grade in Positive High set. Similarly, consider the input measurement 12.5°C from sensor S2 (senses the difference between outside and optimum temperature). The value 12.5°C intersect at the Positive and Positive High of the Temperature (out~opt) membership set, with a 20% grade in Positive set and 80% grade in Positive High set. While the Temperature (in~opt) and Temperature (out~opt) fuzzy set were intersected, the value of the Thermal system has a full 100% grade in the High Cooling set and 0% membership in rest of the set. Figure 8 shows the fuzzification process for the above-mentioned example.

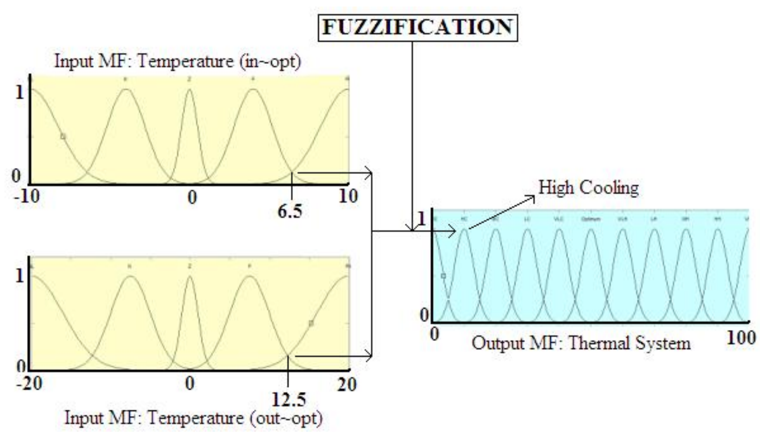

Figure 8 Example of fuzzification process.

7.3. Fuzzy Rules

Instead of using crisp sets, such as actual numbers, FLP permits the use of strings for writing rules. There are five variables used in Temperature (in~opt) and five variables in Temperature (out~opt), which results in fifty rules with 11 output variables of Thermal System. The rules for the input and output of the FLC are discussed in Appendix B in [19]. Each rule consists of two antecedents connected by 'AND' operator, and a conclusion consisting of a single consequence of Thermal System. The antecedent expressions are replaced by membership grades (μ) through the fuzzification process. Since each input membership function is restricted to only two values (μ), a maximum combination of five rules could fire at a time.

7.4. Rule Evaluations and Aggregation

The MIN-MAX inference method was used to determine output values from rules satisfied during the evaluation process. The consequent fuzzy union is restricted to the minimum of the predicate truth, while the output fuzzy region is updated by taking the maximum of the minimized fuzzy sets. The minimum operator limits certainty of the overall condition to the least certain input observation. The final output membership function was obtained using the MAX composition procedure.

7.5. Defuzzification

The Mean of Maximum (MOM) defuzzification method is used and it takes the mean value of the set with maximum membership grade, given as:

$$MOM = \bar{y} = \frac{\sum_{j=1}^{n} y_j}{n}$$

8. Interface for GHCC

Computerized greenhouse climate control is employed in places where the climate is extremely difficult to control manually, especially in the northern hemisphere. These systems must be judged on the basis of its ability to infer, from a set of given inputs, with that of an expert in greenhouse management area. Using this concept the system must be tested for reliability for several values of inputs. An interface is built using MATLAB GUI software tool. The interface frame is shown in Figure 9.

With this interface the user can vary the value of one or more input variable simultaneously and can see the effect of the inputs on the outputs. With the model defined, the final stage is to implement the interface and evaluate the results. A specific value for each input can be given, for which the rules are already defined and the values are already set.

9. Results

Every input variable is tested thoroughly by increasing and decreasing to its maximum and minimum position respectively to understand how the GHCC works. The following simulation results deal with different input values, and the results obtained from the system are presented in Figures 10 - 13.

10. Conclusions

The proposed Fuzzy Logic Control technique prototype for the greenhouse climate controller has the following advantages:

- In the GUI, the user can simply vary the climate change (input) to see the immediate effect (output) of the control of the greenhouse climate control system. The results show that the proposed Fuzzy Logic Controller performs quickly to control the greenhouse climate control system.
- The controller program is based on Fuzzy Logic programming with rule base; therefore it is simple to design the control program for any kind of greenhouse climate.
- The controller program can be modified and applied for any existing greenhouse application, as the design is very simple and the program is highly adaptable for any platform of operating system.

The program takes only few KB of memory space. Hence this has a high advantage over other programs that take a large amount of memory space.

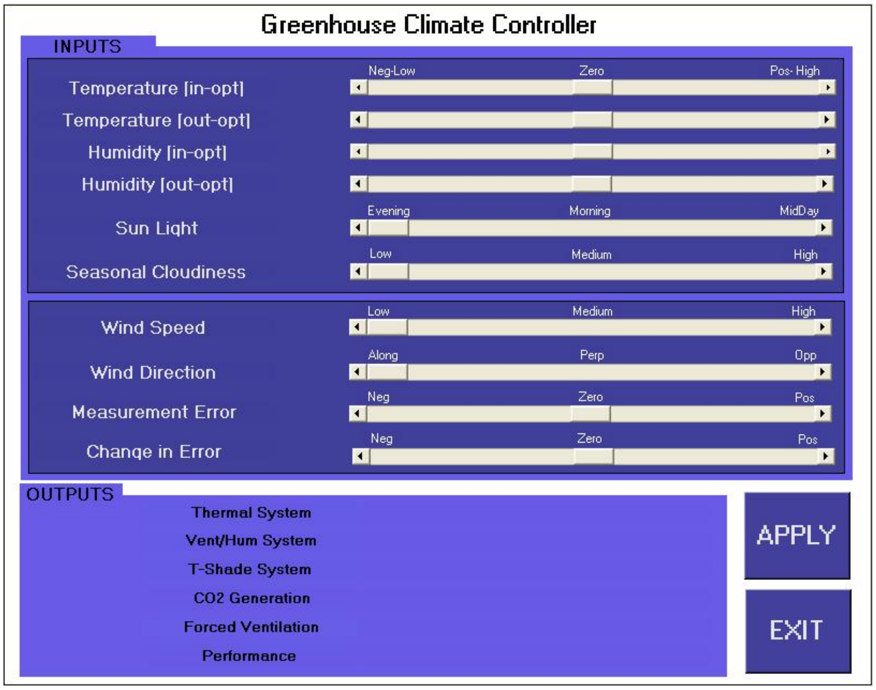

Figure 9 Interface for GHCC

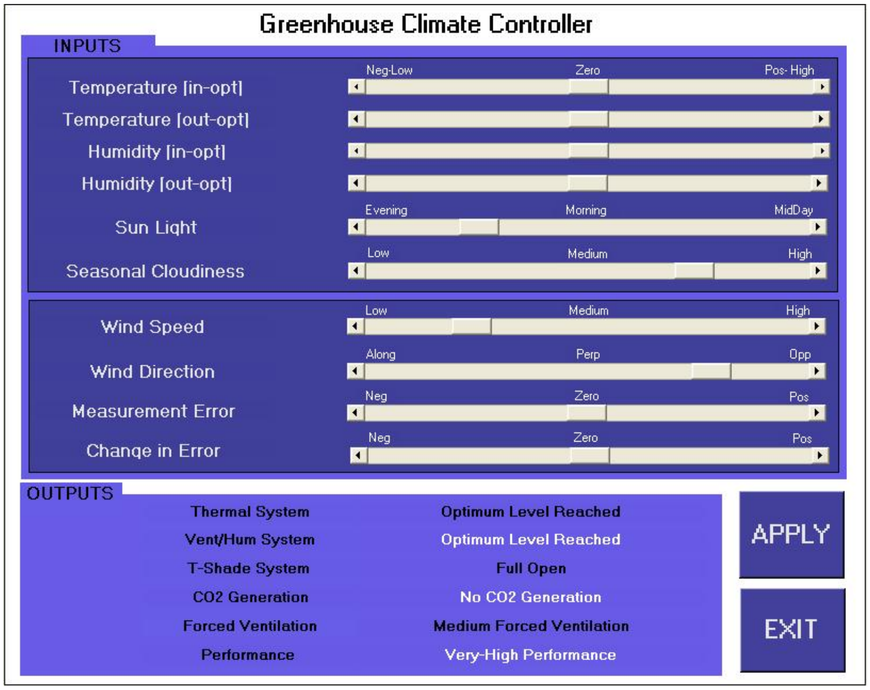

Figure 10 Result 1

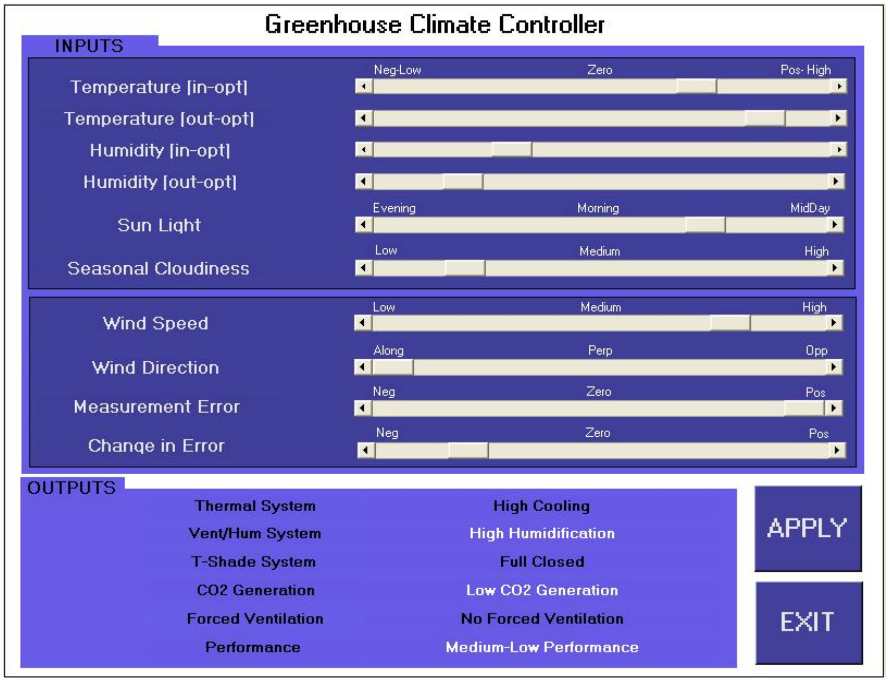

Figure 11 Result 2

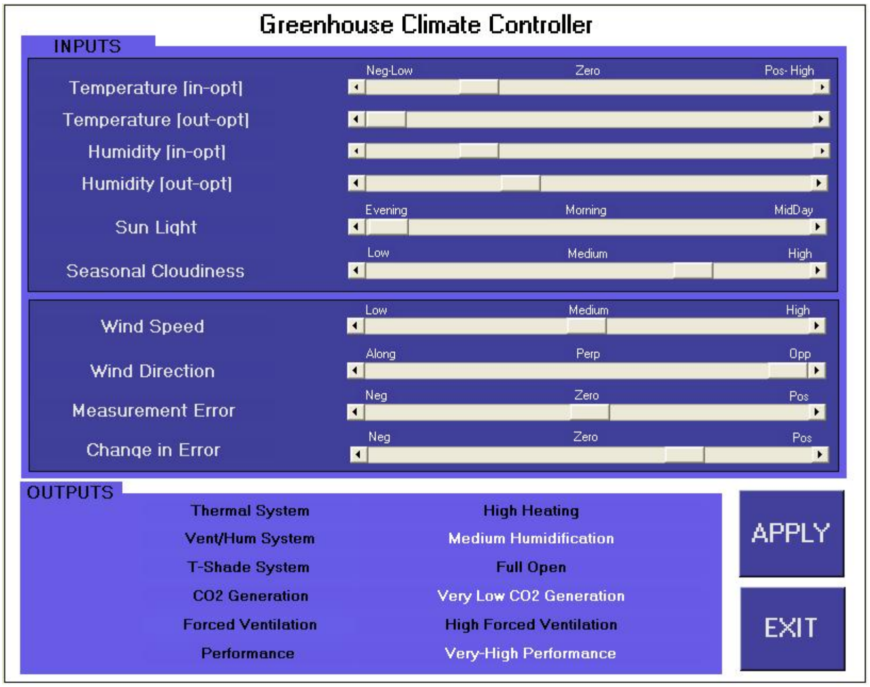

Figure 12 Result 3

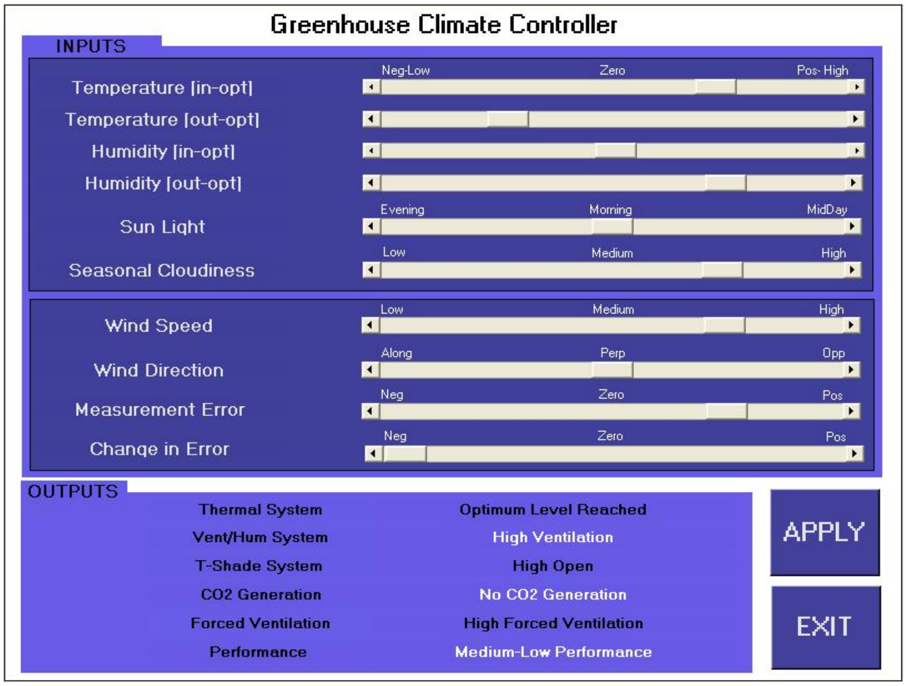

Figure 13 Result 4

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