Fuzzy Logic System Report: IMAT3406

Adam Hai

Project Supervisor: Dr Archie Singh

January 26, 2017

Contents

1. Introduction

An identified requirement for this project was to develop a fuzzy inference system of personal choice, which contains at least 3 inputs variables and 1 output variable. The system chosen was an automated room heating system that assists in the control of the rooms temperature. The fuzzy inference system that will be implemented will determine what the temperature setting should be within a room, this is done using multiple inputs. These inputs include the amount of sunlight currently in the room (lux), what season it is using (day of year), the time of the day, and the temperature outside (°C). These four variables are then sent to the fuzzy inference system that then calculates an output and the heating of the room is adjusted.

The first model used for the proposed fuzzy inference system is the Mamdani. A collection of fuzzy 'if-then' rules are then used and will control how the system operates based on the current time in the year. For instance, during the summer the heating levels will be considerably lower than during winter. Then the 'if-then' rules are used specifically to retrieve the membership levels each individual input has to a specific fuzzy set. An example of this is see how 'cloudy' an input luminosity of 350 lux is, (in this case there is no level of membership as 350 lux is not considered 'cloudy', and is instead considered 'clear' or 'pitch black'). This method is viewed as the Mamdani fuzzy inference method.

With the option to create and implement multiple fuzzy inference systems for comparison, the Sugeno model is also implemented. The Sugeno model can produce an output which is linear or constant weighted mathematical expression, whereas, the Mamdani model produces an output that is a membership level of a fuzzy set. Therefore, with the fuzzy models defined, a rulebase is created based on the various inputs of the system, and the systems are then tested using specific data to identify and justify the final configurations that are decided upon.

2. Literature Review

Once the decision of the fuzzy system to be undertaken was made, research was done into existing systems. This would assist in the project being a success and help support any decisions needed for both the design and implementation of the system. Moreover, the initial inputs and outputs are incredibly important therefore need to be assessed to see if they would be suitable for the system being undertaken otherwise changes would have to be made.

Singhala, Shah, and Patel had created a a fuzzy inference system in order to control the temperature so that they could heat up a system component. The specific system they came up with was considerably similar to the one I was deciding to create, and one of the inputs they used was the current temperature of the machine (Singhala, Shah, and Patel, 2014) this maps directly onto how the temperature of the room will be measured in the proposed system and will assist in how to control certain aspects of the room temperature.

Mahajan had developed a lighting system for a university using sensors to detect if people enter the room which enabled the control of energy consumption (Mahajan, 2015). Although this system is rather different the idea that light sensors could be used with the system being developed to gather information based on the intensity of the light entering the room, thus would support the idea of a luminosity input to determine if the lighting in the room is going to affect the temperature before it actually begins to change.

Another system which is similar to the one proposed would be that of Isizoh et al (Isizoh et al., 2015). The system which they decided to create was a temperature control system. This system uses a micro-controller to implement the fuzzy logic model and contains one very specific input variable called temperature which ranges from cold to hot (Isizoh et al., 2015). However, the lack of inputs can slightly affect the rule base and cause the system to be less accurate, but this still strengthens the choice that the temperature input in our system is incredibly important.

A lot of the systems reviewed in the literature review had a wide range of similarities to this project and were all existing systems. Some of these similarities included the temperature and luminosity variable inputs. Firstly, a system was reviewed based on being able to alter the temperature of an actual physical machine. This presented many differences but also similarities to the current project such as how the membership function was defined for the temperature control, therefore it was important to choose a suitable approach similar to the one that was shown as it was proven to be fairly successful.

The next system reviewed was the least similar out of the three but provided key insight into a specific part of what I wanted to include, this was the luminosity. The system which was used was to control the lighting in the room based on an output of intensity. This attracted possible additions to the project as an input variable of luminosity could provide key information about how warm the sun is making the home as a whole, and adjust the temperature accordingly.

Finally, the last system which was reviewed had many similarities to the first one. Nonetheless it also provided a very important insight into how to actually control the energy usage in an environment using a heater or a fan, as well as providing a unique insight into how the membership functions were utilised. This proved to be vital in the development of the projects system.

Overall the literature review proved to be a key element in assisting with any design decisions that were to be undertaken for the system. The existing systems that were researched provided a lot of information regarding the variable inputs and outputs and greatly supported certain aspects of the system. However as a lot of the systems I managed to find were quite basic, I still believe key inputs regarding the day of the year and the luminosity provide many benefits to the proposed system and will help in determining the correct output needed to make the system.

In the end the literature review was primarily used to make sure that the inputs and outputs for the proposed system were relevant. However, the system which is proposed does not in anyway reflect any of the systems which were researched and will not copy or be built of any of the work that they had conducted.

3. The System

3.1 Proposed System

The system that is proposed is a room temperature system and was developed both as a Sugeno and Mandami inference system. This then allows a comparison to view which one is the best at following the rule base and producing the desired outputs required to make the system a success.

3.2 Variable inputs

Fuzzy inference system contain a great amount of inputs, this is mentioned in the introduction, these inputs provide important information in order for the system to function correctly and allow the

3.2.1 Luminosity

The first input that was identified was luminosity in the room this was decided upon based on how extra light coming through windows may provide a temperature increase in the room. In order to measure luminosity the 'lux' unit of measurement may be used. Microsoft, have a wide range of values that categorises based on if it is pitch black there will be 0 lux or if there is direct sunlight it will be at its maximum. (Microsoft, 2015). Trapezoidal membership functions proved to be the most effective for luminosity, as for simplicity, multiple categories defined by Microsoft were collated together in order to simplify the amount of categories needed. Therefore, the trapezoidal seemed perfect to cover a greater range of lux values.

Pitch Black: This starts at the value of 0 lux and then continues onto 350 and then finally moves onto 400 lux.

Clear: This starts at 350 lux, which then gradually increases to 400 lux and then continuing onto 5000 and 5100 lux.

Overcast: This starts at 4900 before making a steady increase onto 5100 lux and then reaches 30000 and 30100 lux.

Direct Sunglight: This starts at 30000 lux and then moves onto 31000 lux before finally reaching 100000 lux.

3.2.2 Temperature outdoors

In order to provide an accurate system, measuring the temperature outdoors is incredibly important as is probably the most important input as it provides the fuzzy inference system with information regarding how acceptable the temperature should be in the room relative to outside. The temperatures are recorded in degrees Celsius and are fuzzified to use the values between -25(°C) and 45(°C). Due to the temperatures needed to be covered by a rigid amount of categories using the trapezoidal membership functions would enable the system to cover specific temperature levels which are highly important for a room temperature system.

Very Cold: Begins at -25(°C) before reaching -10(°C) and then leading up to 0(°C)

Cold: Begins at -10(°C) moving up onto 0(°C) and 3(°C) and then leads up to 10(°C)

Mild: Begins at 3(°C) moving up onto 10(°C) and 15(°C) and then leads up to to 23(°C)

Warm: Begins at 15(°C) moving up onto 23(°C) and 26(°C) and then leads up to 28(°C)

Hot: Begins at 26(°C) moving up onto 28(°C) and 30(°C) and then onto 32(°C)

Very Hot Begins at 30(°C) moving up onto 33(°C) and 45(°C) and finishes at 45(°C)

3.2.3 Time of day

The time of day is an incredibly important input for the fuzzy inference system as during the early hours of the morning and the late evening when the sun goes down, there are significant temperature differences that should be addressed when making an automated system. The input variable will be using an integer from 0 to 1440 using minutes this will be used to find the membership of the current time of day has to the actual category. This is implemented using the Gaussian function which allows the categories to flow relatively smoothly between each specific time.

Midnight Begins: Reaches peaks of 12am.

Dawn: Reaches peaks of 5am.

Morning: Reaches peaks of 9am.

Afternoon: Reaches peaks of 12pm.

Evening: Reaches peaks of 5pm.

Night: Reaches peaks of 9pm.

Midnight Ending: Reaches peaks of 12am.

3.2.4 Seasons

The seasons are another important input as naturally it is understood that during the Summer and the Spring months it gets rather warm and during the Winter and the Autumn months the weather gets increasingly more cold. Thus, this input provides many benefits in controlling the temperature within the room. The seasons will be given to the fuzzy inference system using the integers 1 - 365 and the fuzzy inference system will determine what season it is. As there is not significant changes to outdoor temperature during season changes, the Gaussian function seemed to be most appropriate in order to allow a smooth transition between seasons as the ending of a season has a relatively similar temperature of the beginning of another.

Winter Start: The beginning of winter in the new year is the 1st of January.

Spring: The highest point of the season is April 1st.

Summer: The highest point of the season is July 2nd.

Autumn: The highest point of the season is October 1st.

Winter End: The highest point of the season is December 31st.

3.3 Variable output:

In order to have a successful fuzzy inference system the output for the heating control should be relatively straightforward. Therefore a percentage was chosen to be used as the unit and as the output requires a clean switch from one heating option to another using both the trapezoidal and triangular functions seemed the most plausible to use thus making sure there are no significant increases or decreases happening instantly during use of the system.

Off: Percentage set at - 0%

Low: Percentage set at - 25%

Med: Percentage set at 50%

High: Percentage set at 75%

Max: Percentage set at 100%

4. Defined rules

The input data needs to be fuzzified so that it will belong in the correct set. This is achieved using the if-then fuzzy rules that the Mandami system and Sugeno both implement.

In Appendix A there is the list of rules used so that the system can select the most suitable output from all the inputs provided. The fuzzy inference system provides us with unique logic in which we can use specific information to determine the output. For example when it is a very hot day the heating will be turned off as it is highly likely that the room temperature would increase significantly.

Core Rules: The core rules will contain when it is a very hot and also when it is very cold. Therefore, the temperature in the system will be adjusted to either Max or be turned Off.

Seasonal Rules: For the multiple seasons each one will have their own specific rules. During Winter the specific rules will usually be setting the heating quite high due to it being generally cold this will be done by checking the outdoors temperature. During the Spring season and the Autumn system the rules will be similar as the Autumn will be generally a colder version of the mild Spring temperatures. Finally, the Summer temperatures are generally higher and may present some similarity to the winter ones. The temperatures will be adjusted depending the specifically on the outdoor temperatures but will also be influenced by the other input variables.

Energy Saving Rules: These rules have mainly been created to save energy as it could reduces costs and also benefit the planet in the long run. Certain aspects to the rules are that during midnight the temperature lowers as if it is a bedroom and people are going to sleep it will lower the temperature unless requested not to and when its the morning the gradual temperature shall be increased in order for people to enter into a warm room. The weighting of the rules were taken into consideration when creating the rules therefore it is lower than any of the previously mentioned rules, as energy saving shouldn't take precedence over a very cold day.

5. Experimental Design & Evaluation

5.1 Undertaken tests

In order to fully make sure that the system is working as best as possible a wide range of input data is used. This data is stored in a Microsoft Excel spreadsheet file which the system will be able to interpret to produce an output. This is done using the largest of maximum defuzzification method that comes provided in MATLAB.

5.2 Test performance

5.2.1 Mandami

Firstly, the Mandami fuzzy inference system was tested, this contained very specific data in order to test how robust and effective the system is, some of this data can be found in Table 5.1. Firstly, the core rules were tested to make sure that they would produce the correct output, these turned out to work perfectly and the output was reflecting the correct temperature settings. The next was to test the seasonal rules for the vast majority of the rules the output displayed was incorrect, such as a medium/high setting on a mild spring morning. Nonetheless, the rules were firring for the test data which was presented and managed to show the system was still working as intended overall even with certain rules taking more precedence.

Table 5.1: Mandami Test Data

Input 1	Input 2	Input 3	Input 4	Output	Expected Output	Rule
0	-20	1100	1	100%	100%	Very Cold Rule
3500	34	1300	200	-5%	0%	Very Hot Rule
0	0	0	83	-5%	50%	Spring midnight start
3500	5	540	83	45.4%	15%	Spring morning mild
3500	15	15	720	48.55%	5%	Spring afternoon mild

Full test data for the Mandami system can be found in the Appendix B Figure B.1.

5.2.2 Sugeno

Secondly, the Sugeno fuzzy inference system was also tested. The same data used for the previous system was also used in order to provide a fair representation on how the system operates. The Sugeno fuzzy inference system produced a wide range of outputs and a selection of the tests can be found in Table 5.2. Looking at the outputs generated by the data, it is clear to see that the system does sometimes take an extreme approach such as the 200% output on a very cold day. Nonetheless, the data can be rounded or limited if implemented fully into a system therefore all the data produced reflects the rules created for the system accurately and the Sugeno model is ideal for a room temperature system.

Table 5.2: Sugeno Test Data

Input 1	Input 2	Input 3	Input 4	Output	Expected Output	Rule
0	-20	1100	1	200%	100%	Very Cold Rule
3500	34	1300	200	1.27e-012	0%	Very Hot Rule
0	0	0	83	50.4%	50%	Spring midnight start
3500	5	540	83	14.7%	15%	Spring morning mild
3500	15	15	720	3.23%	5%	Spring afternoon mild

5.3 Critical Reflection

The Mandami fuzzy inference system overall seemed to perform well, it was straightforward to implement and allowed all the desired inputs and outputs to be implemented. The rules implemented seemed to work for most occasions however, there were instances where an undesired output was given. Looking at the Sugeno fuzzy inference system it was also rather straightforward to develop and was easy to replicate the inputs and output of the Mandami system as well as adding the rules.

Once the data was inputted manually the Sugeno system produced a different output the the Mandami system. Almost all these outputs did appear to follow the stated rules, however, there were occasions when the data produced was not ideal. Nonetheless, I do believe that the Sugeno fuzzy inference system seemed to be the most effective out of both, in producing a reliable output to set the correct heating temperature of the room where as the Mandami proved to have more inconsitent outputs.

6. Conclusion

In conclusion based on the specifications that were given, the fuzzy inference systems seemed to perform considerably well with not major issues. The literature reviewed provided great insight into how similar systems were created. This assisted in allowing the right choices to be made for the development of the system enabling a high quality product which examines multiple avenues in order to be unique and efficient.

The inputs chosen allowed the systems to explore different paths that generic temperature systems take. Thus, providing a more refined system which allows it to adjust the temperature of the room with greater detail. Specific membership functions were chosen in order to allow the systems to produce a much more consistent set of outputs. The fuzzy inference systems also were designed to take a simplistic approach, to enable sufficient execution allowing a complex inputs with a specific amount of rules which are a good representation of the performance of the system.

Overall both the Mandami and Sugeno models were explored, and both fuzzy inference systems managed to perform the task required in altering the room temperature. This was done based on various conditions in the ruleset using various inputs and membership function. Looking at this we are able to say that the development of both systems were a success however the Sugeno model seemed to be more suitable.

Bibliography

[1] Singhala, P., Shah, D. and Patel, B. (2014) Temperature Control using Fuzzy Logic, Temperature Control using Fuzzy Logic, .

[2] Mahajan, R. (2015) Application of fuzzy logic in automated lighting system in a university: A case study, International Journal of Engineering and Manufacturing, 5(3), pp. 1119. doi: 10.5815/ijem.2015.03.02.

[3] Isizoh, A., O, O.S., E, A.A. and D, O.C. (2015) Temperature control system using fuzzy logic technique, International Journal of Advanced Research in Artificial Intelligence (IJARAI), 1(3). doi: 10.14569/IJARAI.2012.010305.

[4] Microsoft (2015). Understanding and Interpreting Lux Values. https://msdn.microsoft.com/en-us/library/windows/desktop/dd319008(v=vs.85).aspx.

A. Defined rules

```
% --- ALL RULES ---  Sunlight/Temp/Time/Year/Output/Weight/(AND/OR)

% Core Rules
verycold_rule = [ 0 1 0 0 5 1 0 ]; % Whenever it is Very Cold, the heater should be turned Off
veryhot_rule = [ 0 6 0 0 1 1 0 ]; % Whenever it is Very Hot, the heater should be turned onto Max

% Energy Saving Rules
midnight_start_energy_rule = [ 0 0 1 0 1 0.8 1 ]; % Heating temperature should be lowered when midnight start appraoches
midnight_end_energy_rule = [ 0 0 7 0 1 0.8 1 ]; % Heating temperature should be lowered when midnight end approaches
dawn_energy_rule = [ 0 0 2 0 1 0.8 1 ]; % When dawn approaches heating should be gradually increased
evening_energy_rule = [ 0 0 5 0 1 0.8 1 ]; % When evening aproaches heating should be gradually decreased

% --- Season Rules ---

% Spring
spring_morning_mild = [ 2 3 3 2 3 1 1 ]; % The outdoor temperature is mild, and it is clear, therfore the output is Medium
spring_afternoon_warm = [ 2 4 4 2 2 1 1 ]; % The outdoor temperature is mild, and it is clear, therfore the output is Low
spring_evening_mild = [ 2 3 5 2 3 1 1 ] % The outdoor temperature is mild, and it is clear, therfore the output is Medium
spring_midnight_end = [ 1 2 1 2 4 1 1 ]; % The outdoor temperature is cold, and there is no light, therfore the output is High
spring_midnight_start = [ 1 2 7 2 4 1 1 ];; % The outdoor temperature is cold, and there is no light, therfore the output is High

% Summer
summer_hot = [ 0 5 0 3 1 1 2 ]; % In Summer, it is a very hot day, so the output is Off
summer_warm = [ 0 4 4 3 2 1 1 ]; % In Summer, it is a warm day, set the output to Low

% Autumn
autumn_morning_mild = [ 2 3 3 4 3 1 1]; % Heating temperature is set to Medium during a mild Autumn morning
autumn_afternoon_warm = [ 2 4 4 4 2 1 1]; % Heating temperature is set to Low during a warm Autumn afternoon
autumn_evening_mild = [ 2 3 5 4 3 1 1 ]; % Heating temperature is set to Medium during a mid Autumn evening
autumn_midnight_start = [ 1 2 7 4 4 1 1 ]; % Heating temperature is set to High during the Autumn midnight start
autumn_midnight_end = [ 1 2 1 4 4 1 1]; % Heating temperature is set to High during the Autumn midnight end

% Winter
winter_start_freezing = [ 0 1 0 1 5 1 2 ]; Heating temperature is set to Max when winter starts and it is freezing
winter_end_freezing = [ 0 4 4 3 5 1 1 ]; Heating temperature is set to Nax when the winter is ending and it is freezing
```

Figure A.1: Rules used for both Mandami and Sugeno systems

B. Test data

```
1) In(1): 0.00, In(2) -20.00, In(3) 1100.00 In(4) 1.00 => Out: 100.00

2) In(1): 3500.00, In(2) 34.00, In(3) 1300.00 In(4) 200.00 => Out: -5.00

3) In(1): 0.00, In(2) 0.00, In(3) 0.00 In(4) 83.00 => Out: -5.00

4) In(1): 0.00, In(2) 0.00, In(3) 1440.00 In(4) 83.00 => Out: -5.00

5) In(1): 3500.00, In(2) 5.00, In(3) 540.00 In(4) 83.00 => Out: 45.40

6) In(1): 3500.00, In(2) 15.00, In(3) 720.00 In(4) 83.00 => Out: 48.55

7) In(1): 3500.00, In(2) 5.00, In(3) 1020.00 In(4) 83.00 => Out: -5.00

8) In(1): 3500.00, In(2) 29.00, In(3) 1300.00 In(4) 200.00 => Out: -5.00

9) In(1): 3500.00, In(2) 25.00, In(3) 1300.00 In(4) 200.00 => Out: -5.00

10) In(1): 0.00, In(2) 0.00, In(3) 0.00 In(4) 270.00 => Out: -5.00

11) In(1): 0.00, In(2) 0.00, In(3) 1440.00 In(4) 270.00 => Out: -5.00

12) In(1): 3500.00, In(2) 5.00, In(3) 540.00 In(4) 270.00 => Out: 45.40

13) In(1): 3500.00, In(2) 15.00, In(3) 720.00 In(4) 270.00 => Out: 48.55

14) In(1): 3500.00, In(2) 5.00, In(3) 1020.00 In(4) 270.00 => Out: -5.00

15) In(1): 0.00, In(2) -25.00, In(3) 1200.00 In(4) 365.00 => Out: 100.00

16) In(1): 3500.00, In(2) -25.00, In(3) 1200.00 In(4) 365.00 => Out: 100.00
```

Figure B.1: Test data used in the fuzzy inference systems with Mandami output

C. Mandami fuzzy set

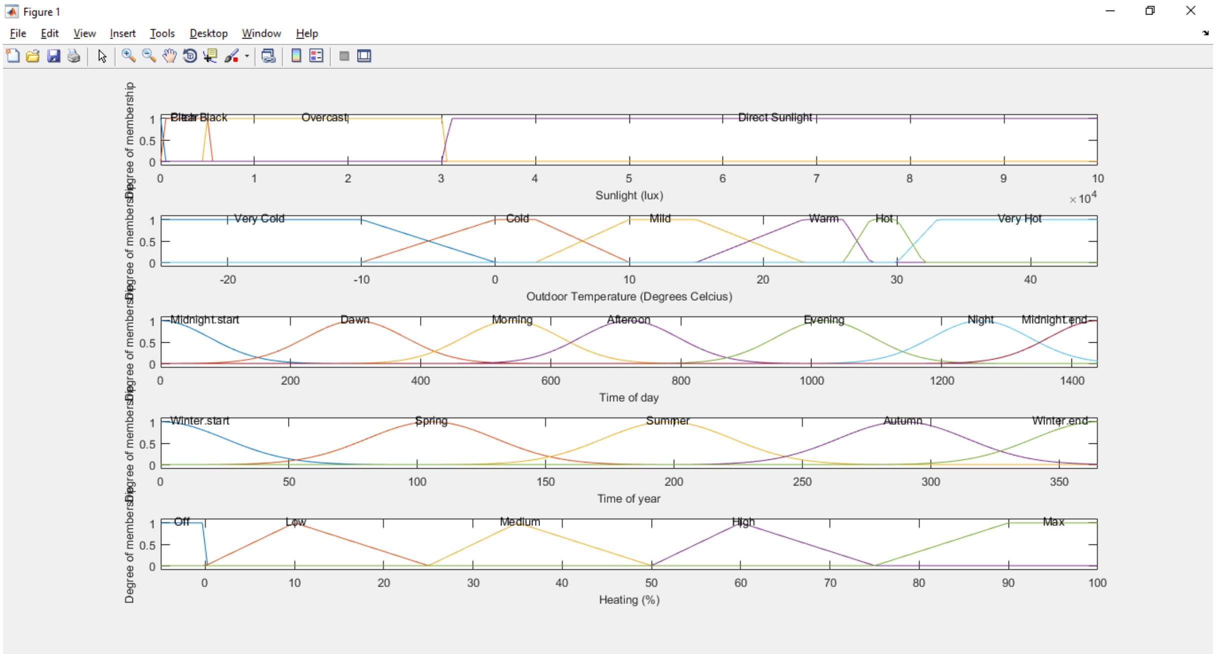

Figure C.1: Mandami fuzzy inference system

D. Sugeno fuzzy set

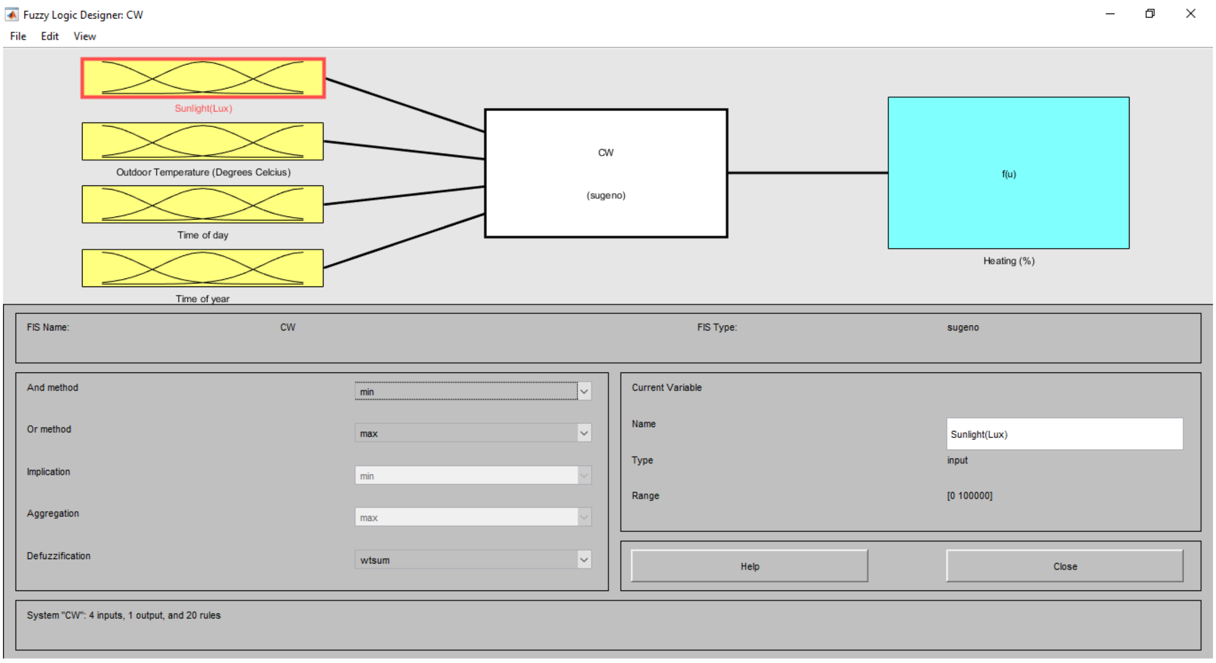

Figure D.1: Sugeno fuzzy inference system

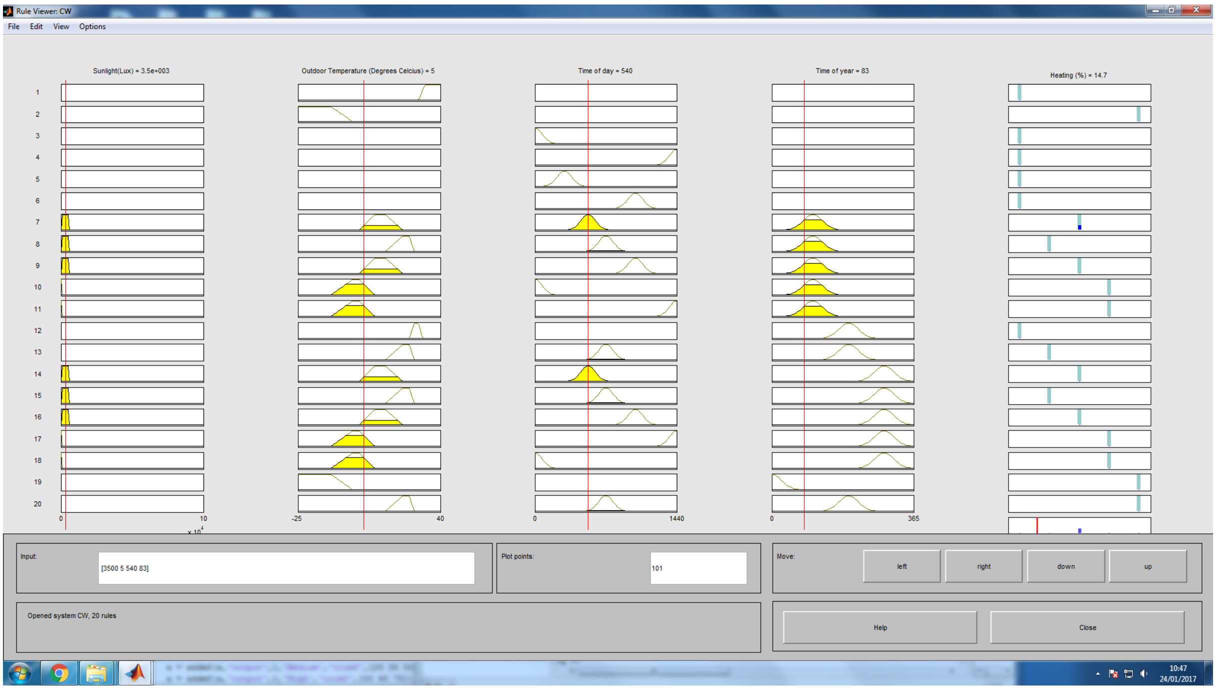

Figure D.2: Sugeno rule viewer