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Fuzzy Logic Derivation and Simulation of a Three-Variable Solar Water Heater Using Matlab Fuzzy Logic Toolbox

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Abstract: In this study, the proponent makes use of the concepts of fuzzy logic in classifying the solar water heater as Very Hot, Hot, Lukewarm and Cold. The input parameters include cloudiness, amount of sunlight and seasonal differences. The parameters in the model are acquired through the use of sample raw data of the standard values and the relative levels from the weather forecast of Philippine Atmospheric and Astronomical Services Administration (PAGASA). The goal of the study is to describe the fuzziness in solar water heater, design a fuzzy-based system and simulate and verify the effectiveness of the results. The proponent preferred to use the triangular membership functions and Sugeno-style of inference systems. The results obtained using Matlab Fuzzy Logic Toolbox was compared with the results obtained using Microsoft Excel. The comparison between these two methods for obtained solar water heat is tabulated. It was realized that there was a perfect correlation between the crisp outputs obtained for both methods. This means that there is perfect relationship between variables being compared, regardless of the input range. In general, Microsoft Excel and Matlab Fuzzy Logic Toolbox, of different programming platforms and of different methodologies, are correlated with each other and can both be powerfully used in solar water heater classification. The study showed that the fuzzy-based system for solar water heater is simple, available, stable and effective. This paper presents a cheaper approach to the classification of solar water heater, which will also apply most likely to the classification of any other solar and conservation energy metrologies.

Key Words: solar water heater; fuzzy logic; PAGASA; Matlab toolbox; Sugeno-style

1. INTRODUCTION

Several innovations and matured renewable energy technologies have been well established for many years to apply the solar water heating (SWH) or solar hot water (SHW) systems. SWH systems are designed to deliver hot water for different purposes. Accordingly, SWH has been widely used in different countries such as Australia, Austria, China, Cyprus, Greece, India, Israel, Japan and Turkey (Web-1). In the Philippines, considering that it is a tropical country, the concepts and applications of SHW is rarely adopted.

The wet and dry are two seasons in the Philippines, which is based upon the amount of rainfall. Based on temperature, the seven warmest months of the year are from March to October; the winter monsoon brings cooler air from November to February. May is the warmest month, and January, the coolest. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) monitor and manage the weather in the Philippines (Web-2).

Hot water heated by the sun is used in many ways. Perhaps, the best known usage is in the residential setting to provide domestic hot water. In addition, solar hot water is needed in industrial applications, this includes, but not limited to, the generation of electricity (Web-1). In a solar water heater, water passes through a collector, usually on a roof, where it is heated by the sun. In order to attain the highest temperature possible, the collector is painted black and insulated. Solar collectors can also be used to heat homes and buildings, and power industrial processes (Union of Concerned Scientists, 2013).

In this study, the proponent will use the concepts and principles of fuzzy logic in simulation of a three-variable solar water heater. The factors to be considered for classifying solar water heater includes the amount of sunlight, cloudiness, angle of sun, seasonal differences and location. In this study, the proponent will consider the three critical parameters used in measuring the heat of solar water: cloudiness (okta), amount of sunlight (hours/day) and seasonal differences (T °C).The parameters will be categorized as Very Good, Good, Fair, Poor and Very Poor. The solar water heater classifies the output as Very Hot, Hot, Lukewarm and Cold. The proponent will use triangular membership functions for its input and output parameters and it would employ the Sugeno style of fuzzy inference system. The proponent would verify the results using Matlab Fuzzy Logic Toolbox and it will be compared to derived formulas in Excel. This study will be simulated purely mathematical. It excludes building of a thermosiphoning water heater, modeled after home solar water heaters.

1.1 Objectives of the Study

The prime objective of this study is to classify the solar water heater using fuzzy logic applications. Specifically, this study aims to: a) describe the fuzziness in solar water heater, b) design a fuzzy-based system for solar water heater, and c) simulate and verify the performance of the fuzzy system.

2. METHODOLOGY

2.1 Fuzzy Logic System

Lotfi Zadeh, a professor at the University of California at Berkeley, conceived and introduced the concept of Fuzzy Logic (FL). It is described as a problem-solving control system methodology that lends itself to implementation of different systems, which can be implemented in hardware, software, or a combination of both. FL's approach to control problem imitates how a person would make decisions, only much faster (Web-3).

As illustrated in *Figure 2.1*, Fuzzy Logic requires Fuzzy Rules and Inference to transform fuzzy input sets to crisp outputs. The transformation process incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically (Web-3).

Fuzzy Associative Memory Matrix (FAM) is a technique used to store and represent fuzzy rules. The weight values of FAM Matrix entries will be computed based on minimum membership functions obtained with respect to its x and y coordinates. The last phase of Fuzzy Logic System operation is to defuzzify the fuzzy output sets by determining a value from membership function and compute for the crisp output. The most popular method of deffuzification is the center-of-gravity method.

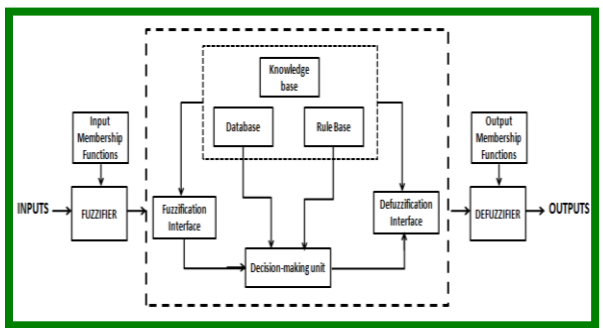

Fig. 2.1. Configuration of Fuzzy Inference System

In this research, the proponent makes use of experimental study. It is a type of evaluation, which is used to determine whether an intervention had the intended causal effect on program participants (Web-4). The proponent gathered a minimum of 30 raw data to categorize the input parameters into "very good", "good", "fair", "poor" and "very poor". The proponent identified PAGASA as its experts to help them categorizing the ranges observed. Through the use of brainstorming and focus discussion, the perception of experts about the linguistic description of solar water heater is obtained. The method used for such data qualification is averaging technique and trial and error method. The proponent makes use of the Sugeno style of inference system to illustrate the Fuzzy Associative Memory (FAM) matrix. The Matlab Fuzzy Logic will be used for this propose and the results will be compared using Excel results.

In constructing the membership functions for the identified critical input parameters, the proponent makes use of the definition and description of weather forecast terminologies used and adopted by PAGASA. Figure 2.2 is the cloud description and Figure 2.3 shows the sample weather averages (annually) obtained from PAGASA.

Sky Condition	Definition/Description
Clear or Sunny Skies	• State of the sky when it is cloudless, totally clear or with a few small light clouds visible. • Has a total cloud cover of less than one okta.
Partly Cloudy	• State of the sky is within 2-5 oktas total cloud cover or has between 30% to 70% cover of the celestial dome.
Partly Cloudy to at Times Cloudy	• Mostly partly cloudy but there are times when more than 70% of the celestial dome is covered with clouds.
Mostly or Mainly Cloudy	• The sky is mostly covered with clouds but with possible brief periods of sunshine. • The total cloud cover is between 6 to 8 oktas.
Cloudy	• The sky is covered with clouds between 6 to 8 oktas or has more than 70% cloud cover. • Predominantly more clouds than clear sky. • For a longer period during the day, the sun is obscured by clouds.
Overcast	• The sky is totally or completely covered with thick and opaque clouds, 8 oktas or around 100% cloud cover.

Fig. 2.2. Cloud Description from PAGASA

MONTH	Average Sunlight (hours/day)	Average Minimum Temperatures	Average Maximum Temperatures
Jan	5.7	22	30
Feb	7	22	30
Mar	7.3	24	32
Apr	8.6	25	33
May	7.2	26	34
Jun	5.4	25	32
Jul	4.3	25	31
Aug	4.3	25	31
Sep	4.4	24	31
Oct	5.1	24	31
Nov	5.1	24	31
Dec	4.9	23	30
AVE	5.775	24.08333333	31.33333333
MAX	8.6	26	34
MIN	4.3	22	30

Fig. 2.3. Weather Averages (Annually) from PAGASA

For solar water heater classification purposes, hierarchical structure is constructed (*Figure 2.4*). The input parameters includes the cloudiness, amount of sunlight and seasonal differences, which will be categorized as very good, good, fair, poor and very poor. The last hierarchical level classifies the solar water heater as very hot, hot, lukewarm and cold. The following are the sample rules stored at two different hierarchical levels of structure (Web-4):

If *Cloudiness* is <very good> and *Amount of Sunlight* is <very good> and *Seasonal differences* is <Very good>
Then solar water heater is classified as < Very Hot>
If *Cloudiness* is <very good> and *Amount of Sunlight* is <good> and *Seasonal differences* is <good>
Then solar water heater is classified as < Very Hot>
If *Cloudiness* is <very good> and *Amount of Sunlight* is <good> and *Seasonal differences* is <good>
Then solar water heater is classified as < Very Hot>

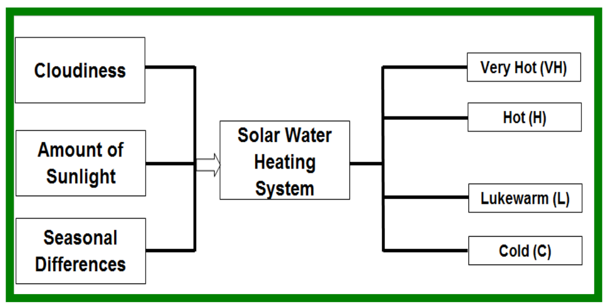

Fig. 2.4. Hierarchical Structure for Solar Water Heating System

3. DESIGN CONSIDERATIONS

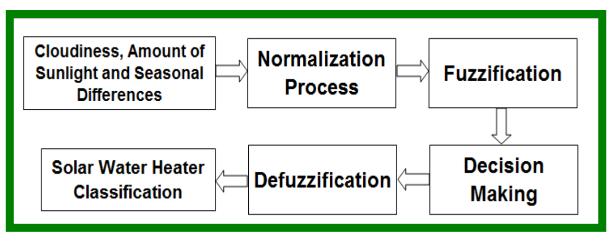

Fig. 3.1. Block Diagram of Solar Water Heating Fuzzy System

Figure 3.1 is the block diagram of the solar water heating fuzzy system. The system requires three (3) inputs from the user. The cloudiness is measured in okta, the amount of sunlight is in hrs/day and the seasonal differences are measured in temperature. The inputs of the user will be normalized to fit the fuzzy scale of 0 to 1. Traditionally, to normalize the data means to fit the data within unity (1), so all the data values will take on a value of 0 to 1 (Web-5). The normalized inputs will be fuzzified. Using FAM matrix, the rules will trigger the outputs and it will be defuzzified using centroid of area for Sugeno style of inference system. After obtaining the crisp output, the proponent will now be able classify the solar water heating system as very hot, hot, lukewarm or cold.

3.1 Matlab Fuzzy Logic Toolbox

In Fuzzy logic system, the linguistic variables are used instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number or fuzzy variable) is called fuzzification. The control rules that relate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behavior, also the perception and experience (Caldo, 2012). In this study, the proponent makes use of the averaging technique in deriving its membership functions. However, some of the control rules are developed using "trial and error" method.

The triangular shapes of the membership function of this arrangement presume that for any particular input there is only one dominant fuzzy subset. From the combination of cloudiness, amount of sunlight and seasonal differences, a total of 125 fuzzy rule bases are formulated. The reverse process of fuzzification is called defuzzification. The linguistic variables are converted into a numerical variable. As the weighted sum method is considered to be the best well-known defuzzification method, it is utilized in the present model. The defuzzified output is the solar water heat.

There are five primary graphical user interface (GUI) tools for building, editing and observing fuzzy inference systems in the toolbox. This includes Fuzzy Inference System (FIS) Editor, Membership Function Editor, Rule Editor, Rule Viewer and Surface Viewer. These GUIs are dynamically linked with each other, and if changes were made to the FIS of one of the toolbox, the effect can be seen in other GUIs.

Sugeno, or Takagi-Sugeno-Kang is a method of fuzzy inference used in this study for Matlab Fuzzy Logic Toolbox simulation. It is introduced in 1985 and it is similar to the Mamdani method in many respects. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant. In this paper, the proponent considered the use of constants as output membership functions (Web-6).

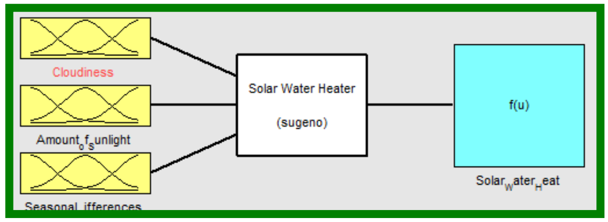

Figure 3.2. FIS Editor for Solar Water Heater

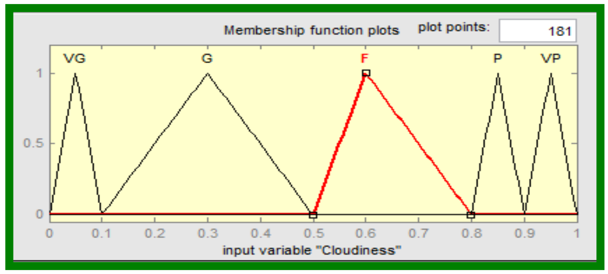

Figure 3.3. Cloudiness (input)

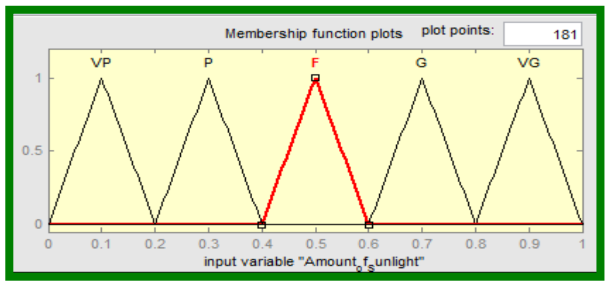

Figure 3.4. Amount of Sunlight (input)

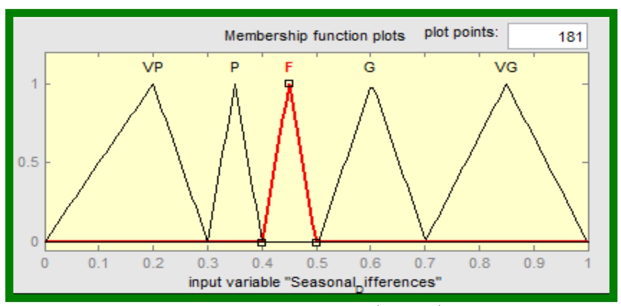

Figure 3.5. Seasonal Differences (input)

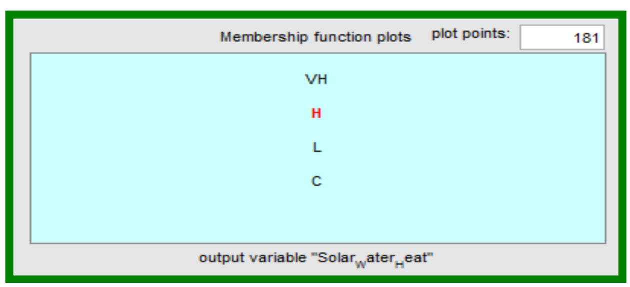

Figure 3.6. Solar Water Heat (crisp output)

Figures 3.7 and 3.8 show the rule editor and viewer for fuzzy-based solar water heating system, it is where the FAM matrix of 125 rules is plugged in. On the other hand, the graphical illustration of the rules for solar water heater simulation purposes is elicited in *Figures 3.9 and 3.10*.

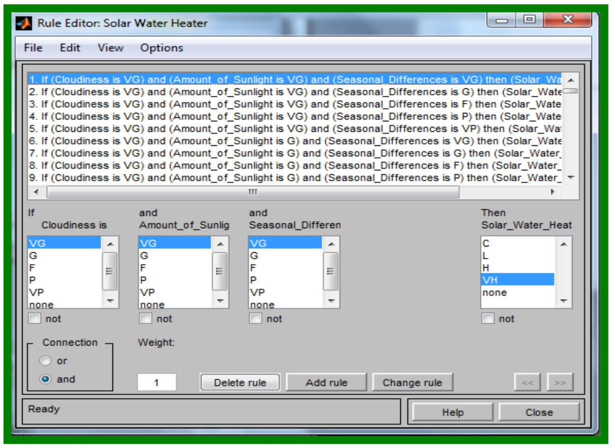

Figure 3.7. Rule Editor for Solar Water Heater

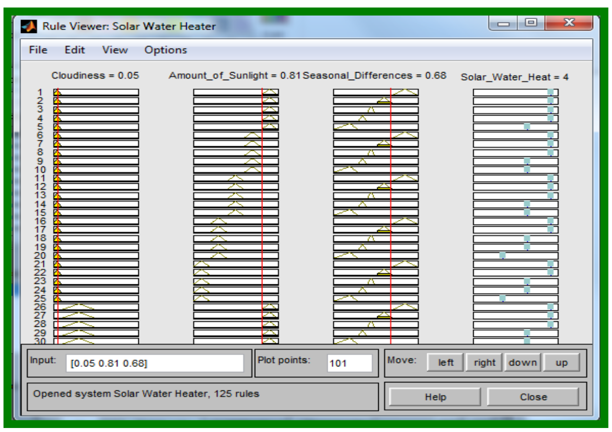

Figure 3.8. Rule Viewer for Solar Water Heater

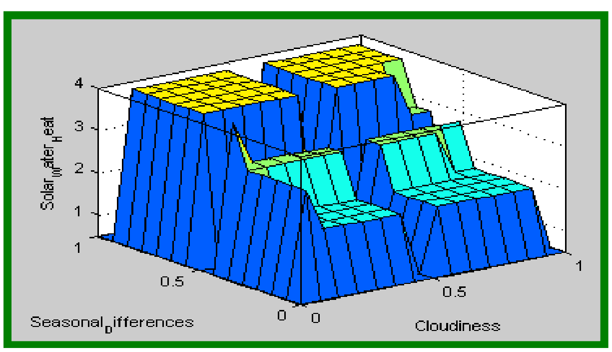

Figure 3.9. Surface Viewer for Solar Water Heater (Cloudiness and seasonal differences as x & y-inputs, solar water heater as z-output)

4. EXPERIMENTS AND ANALYSIS OF RESULTS

In order to come up with a tangible monitoring of fuzzy-based solar water heating system, the proponent derived the Sugeno style of fuzzy inference system for simulation purposes using Microsoft Excel.

In simulating the fuzzy-based solar water heating system, the proponent conducted several tests for different values of input ranges. This simulation is made for two different metrologies: Fuzzy Logic Matlab Toolbox and Excel Fuzzy Derivation, the results of which are shown in Table 4.1.

Table 4.1. Measure of Correlation Between Matlab Fuzzy Logic Toolbox and Excel Derivation of Solar Water Heater Classification

Trials	Solar Water Input Parameters	Input Values (Normalized)	Crisp Output (Matlab Fuzzy Logic Toolbox)	Crisp Output (Excel Derivation)	Linguistic Classification	True Error	% Relative Approximate Error
1	Cloudiness	0.05	4	4	Very Hot	0	0
	Amount of Sunlight	0.81					
	Seasonal Differences	0.68					
2	Cloudiness	0.04	4	4	Very Hot	0	0
	Amount of Sunlight	0.85					
	Seasonal Differences	0.72					
3	Cloudiness	0.35	4	4	Very Hot	0	0
	Amount of Sunlight	0.71					
	Seasonal Differences	0.74					
4	Cloudiness	0.61	4	4	Very Hot	0	0
	Amount of Sunlight	0.73					
	Seasonal Differences	0.77					
5	Cloudiness	0.07	3	3	Hot	0	0
	Amount of Sunlight	0.22					
	Seasonal Differences	0.42					
6	Cloudiness	0.31	3	3	Hot	0	0
	Amount of Sunlight	0.92					
	Seasonal Differences	0.37					
7	Cloudiness	0.08	2	2	Lukewarm	0	0
	Amount of Sunlight	0.32					
	Seasonal Differences	0.25					
8	Cloudiness	0.92	2	2	Lukewarm	0	0
	Amount of Sunlight	0.11					
	Seasonal Differences	0.42					
9	Cloudiness	0.91	1	1	Cold	0	0
	Amount of Sunlight	0.19					
	Seasonal Differences	0.1					
10	Cloudiness	0.96	1	1	Cold	0	0
	Amount of Sunlight	0.1					
	Seasonal Differences	0.2					

The results obtained using Matlab Fuzzy Logic Toolbox was compared with the results obtained using Microsoft Excel. The comparison between these two methods for obtained solar water heat is tabulated. It was realized that there was a perfect correlation between the crisp outputs obtained for both methods. This means that there is perfect correlation of the variables being compared, regardless of input range. In general, Microsoft Excel and Matlab Fuzzy Logic Toolbox, of different programming platforms and of different methodologies, are correlated with each other and can both be powerfully used in solar water heater classification.

5. CONCLUSION

In this paper, the proponent makes use of fuzzy logic in classifying solar water heater. The study showed that the fuzzy-based system for solar water heater is simple, available, stable and effective. The result proponent got is credible. The classification is reliable due to very high to perfect correlation obtained between Matlab Fuzzy Logic Toolbox and Membership Function Template.

The paper presents a technique employing fuzzy logic for automatic classifying of solar water heating system. The paper is relevant and important as per the needs of the developing world. Also, it presents a cheaper approach to the classification of solar water heater, which will also apply most likely to the classification of any other solar and conservation energy.

6. ACKNOWLEDGMENTS

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