Evaluation and Generalization to Predict Lowest Temperature of an Earth Air Heat Exchanger: Case Arid Zones

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Abstract

Due to the economic and environmental risks posed by fossil fuels, the use of renewable energies has become necessary. Geothermal energy, which extracts heat from the ground to heat or cool buildings, has not taken its place in Algeria as our economic and management reality. According to the importance of this study and to attract researchers to use this new technique in arid areas. Optimization methods are the most favorable, economical and less expensive to give a valid estimate of the results among these methods is fuzzy logic. This paper present numerical optimization of air temperature for diameter, flow and length by using fuzzy logic. For this propose, the experimental findings used to predict the reason of air temperature in buried pipe in arid zone. The accuracy it's about 99.3%. The extended model and the experimental findings were determined to be in good agreement using the fuzzy logic technique.

Keywords: Fuzzy logic, Prediction, Earth Air Heat Exchanger (EAHE), Desert zones.

1. INTRODUCTION

Because of soil temperature in certain depth, some researchers create new technologies to produce thermal comfort and electricity from the air velocity for a comfortable life for human beings, one of those technologies is an earth air heat exchanger, a renewable method based on geothermal energy which is used in arid and desert regions and is considered as an essential component of conventional and vernacular architecture.

Earth air heat exchangers are recognized as a possible solution for building both cooling and heating systems. This consists of plastic, metallic, or concrete pipes buried underground at a specific depth. With the assistance of a blower, new atmospheric air is transported via pipes. Heat transmission between earth and air in pipes occurs based on the temperature differential. To achieve optimal performance, the system must be designed efficiently.

Leyla Ozgener analyzed an experimental EAHE system and validate the results mathematically for obtain a different categories of EAHE [1]. Michel et al. investigate a numerical model of EAHE by applying the constructer design to achieve the greatest thermal potential(heat/cooling) [2]. Joaquim Vaz et al. in Brazil, studied experimentally EAHE systems in different buried ducts (1,60 m; 0,60 m and 0,50 m) during the year. The results of this study showed the typical months for heating and cooling the air [3]. Trikor Singh et al. applied this method in the Indian zones with a depth 1,5 to 2 m [3, 4]. Dong Yang et al. evaluated the importance length of the buried pipe to reduce the air temperature, as a result they found a decrease of air temperature by 7 °C [5, 6]. A numerical transient analysis of an earth pipe air heat exchanger was validated experimentally by Bansal et al. the model was created using FLUENT. The author concluded that for a 23 m long and 0.15 m diameter exchange, the temperature drops by about (10 to 12) °C [6]. The importance of this method was more defining from N.Rosa et al [7]. G.N. Tiwari et al. validate the numerical results from the experimental during the year, this validation was made for finding the correlation coefficient and root mean square percentage deviation for each month. As a results for January the values are 0,99% and 4,24% respectively, on the other hand, the maximum value of heating potential is 11,55 Mj and cooling potential is 18,87 Mj , for a typical day in the months of January and June, off sunlight hours of 8 p.m.-8 a.m. and peak sunshine hours of 8 a.m.-8 p.m[8]. For energy conservation, M. Santamouris et al. treated the effect pipe length, pipe diameter and air velocity [9]. N.M. Thanu et al. studied this method in a real condition at a farmhouse for using a simple pass mode to condition threes bedroom (living room, a dining room and a kitchen). The results show the different temperature and humidity in the different season of the year (summer, winter and autumn). The cooling/heating potential was found to be 7,9; 2,1 and 1,9 respectively [10].

W.R. Sissoko Adol et al. Created an experimental design to validate the results with the analytical one from the injection of the ambient air (with a temperature) through ducts buried in soil with a depth of 2,5 m. The results show the influence of low velocity on heat transfer coefficient with an increase 2,997 $W.m^{-2}.k^{-1}$ per unit velocity [11]. A.Trombe et al. [12] created a computational model to assess the efficiency of this system when connected with a single home; the findings were compared to an experimental model. This system could be used to save 10% of home energy use by preheating fresh air in the winter in order to improve the comfort conditions in the summer. An experimental investigation was undertaken by employing low-cost construction materials such as bamboo (Bambuseae) and hydraform (cement and soil plaster) was conducted by T.Choudhury et al [13]. In this type of EAHE, the difference between inlet and outlet air temperature was recorded from 42 °C to 26 °C. J. Pfafferott [14] The thermal performance of three EAHEs for mid-European office buildings in service was examinated, and the ratio of thermal energy provided to mechanical dissipation energy was determined to establish and optimize an EAHE's energy efficiency by minimizing pressure drop. Ghosal M.K et al [15] mentioned the effect of pipe depth, length, and air flow rate on thermal performance of EAHE system, they estimated an increasing pipe length, both decreasing pipe diameter and mass flow rate of flowing air inside buried pipe, and increasing ground depth up to 4 m rises the ambient temperatures of the house in the winter and reduces it in the summer. M. Bojic et al [16] provided technological and financial assessments of an EAHE connected to a building's heating or cooling system. Viorel Badescu and Stephane Thiers [17, 18] examined passive buildings and used various sources of renewable energies, such as solar and wind energy, to reduce operational energy usage. The new model was integrated into the current theoretical approach and applied in the computer code used to simulate the functioning of the heating system in a passive apartment. Mihalakakou et al. examinated the variation of velocity, soil depth and the radius for an EAHE[19]. P. Hollmuller treated the exchange with a solid medium of diffusive nature, taking into account the often difficult to characterize temperature depreciation when using the EAHE for heating/cooling buildings. The heat exchange was addressed with a diffusive solid medium, taking temperature depreciation into account, which is often difficult to describe. As a result, it was determined that a systematic study of the connection between an exchanging air/ground building and a technical system was critical [20]. To investigate the effect of exchanger settings on thermo-hydraulic performance, the thermal efficiency was calculated De Paepe et al. with the pressure drop of the air inside the tube. Longer tubes resulted in a decrease in efficiency and a high drop pressure, whereas smaller diameter tubes provide good efficacy but also raise drop pressure[21]. D. Bartolomeu et al conducted research on the performance testing of an air/ground type heat exchanger. They tested system consists of a network of 36 tubes 16 cm in diameter and 25 cm in length, positioned at depths ranging from 2 m to 2.5 m and 3 m. The study was conducted with the goal of determining the appropriate system dimensions required to maximize its performance [22]. The following investigations indicate that the EAHE system's performance is impacted by its design. Experimental data were used to verify the computational fluid dynamics model's (CFD) predictions, and they showed that the optimal EAHE tube diameter for overall performance is 152.4 mm, while the best diameter for thermal performance is 50.[23]A study on 3D modeling The effects of humid air on a multiple-tubular EAHE system were investigated using CFD. It demonstrated the impact of condensation on the even distribution of airflow inside the EAHE tube. Condensation decreased the EAHE's thermal output by 7.9%. The EAHE multi-tube system was built around the shape of the U, Z, and L tubes. The L construction allows the greatest heat transfer and lowest pressure drop, which makes it suitable [24].

In Bologna, Italy, the shallow soil temperature is 16 °C. Mahdavi et al. explain using 39 m for their system, that the energy and exergy efficiency depend on the length of the EAHE pipes. Temperature differences at 1m of depth range from 22 to 28 °C, where the pipes are situated. A horizontal serpentine EAHE system is employed; it has a bigger footprint[25]. Barbaresi et al. built 12 EAHE systems were in a vertical spiral configuration (total length: 60 m; depth of installation: 2 m), serving as a backup for the principal GH heating system (24 8 12.7 m^3) throughout the winter. The vertical spiral design gives up less space. They estimate that the EAHE contributes to a 10 to 30% reduction in energy use. Furthermore, they think their system could decrease gas emissions by 8 to 28%. However, they point out that there is not a lot of study on how much energy GHs use [26]. In order to prevent the loss of heat, a thick layer of insulated foam was put around the EAHE soil. In Loughborough, England, they used this system to heat and cool a 142.87 m3 greenhouse. According to measurements, COP cooling ranged within 1.20 and 3.45 and COP heating ranged between 1.48 and 2.97 [27]. Even over longer periods of time, the EAHE system maintains an excellent outlet air temperature [28]. For identifying the impact of operating factors on the performances of the EAHE, a transient one-dimensional heat transfer model was developed [29]. In Portugal, Samia Hamdane et al. developed an experimental device for assessing the environmental impact and thermal performance of agricultural greenhouses using an earth air heat exchanger system. Their findings indicate that in addition to reducing CO emissions, EAHE systems also reduced energy consumption [30]. The main objective of the present study is to develop a new model using fuzzy logic which not applicated previously in earth air heat exchanger systems, and to verify and validate experimental data that shows how accurate the fuzzy logic system is in solving various problems. That is the reason why this new technology is being used to maintain track of time, money, and a variety of components.

2. METHOD AND EXPERIMENTAL

2.1. Site and description of the experimental device

The experimental test bench is installed at the University of Biskra. It is composed of a network of four 50 m long high pressure PVC pipe sections. The tube has an internal diameter of 110 mm. The entire is positioned 3 meters below a 2% slope. This depth (3 m) for the Biskra site was predetermined through a study done in accordance with the site's local data. A concrete reception pit is constructed at the interchange's exit and the tubes are arranged and spaced apart with a 2 m center distance. An air extractor with variable flow is positioned at the exchanger's input in addition to a series of probe heaters were installed, running the length of the heat exchanger from the input to the output. Thermal probes were added along the heat exchanger figures 1 and 2 [31].

Fig. 1. Trenches for installation of the buried air / ground heat exchanger [23]

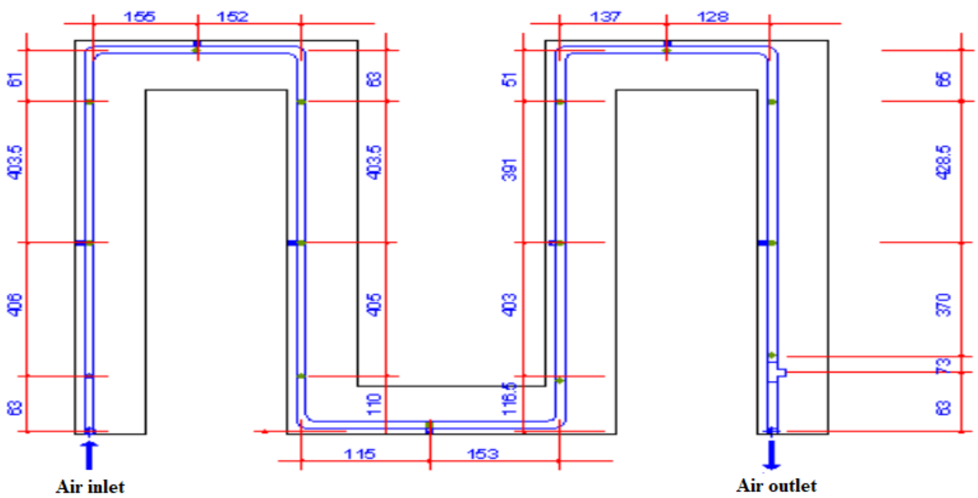

Fig. 2. Arrangement of probes along the exchanger [23]

2.2.Mathematical modeling

2.2.1. Soil temperature modeling

The concept of heat conduction applied to a semi-infinite homogenous solid serves as a basis for the mathematical model of soil temperature. Derbal et al. presents details about soil heat conduction [32].

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{\alpha} \times \frac{\partial T}{\partial t} = 0 \quad (1)$$

$$T(0,t) = T_{mean} + A_s \times \cos(\omega(t - t_0)) \quad (2)$$

$$T(\infty,t) = T_{mean} \quad (3)$$

where the soil thermal diffusivity is given by: $\alpha = \frac{\lambda}{\rho.Cp}$

$$\text{T(z.t)=T}_{\text{mean}}\text{+A}_{\text{s}}\text{(exp-(z)} \times \sqrt{\frac{\tau}{365 \times \alpha}}) \times \cos\left[\frac{2\tau}{365}(t - t_0) - (\frac{z}{2}) \times \sqrt{\frac{365}{\alpha\tau}}\right] \quad (4)$$

2.2.2. EAHE Modeling

A straight pipe of 50 meters in length serves as the model for the earth air heat exchanger. It is assumed that the air flow has a greater impact on soil temperature and that this variation only follows Equation (4). Ref [33]. gives an equation for the convective heat transfer coefficient in a tube.

$$h_{convection} = \frac{Nu \times \lambda}{D} \quad (5)$$

The following correlation was used to obtain the Nusselt number:

$$\text{Nu} = 0.0214.(\text{Re}^{0.8} - 100).\ \text{Pr}^{0.4} \quad (6)$$

Inside the pipe, the Reynolds number and Prandtl number are determined by:

$$\text{Re} = \frac{V_{air} \times D_i}{\upsilon} \quad (7)$$

$$\text{Pr} = \frac{V \times \rho \times Cp}{\lambda} \quad (8)$$

We can express the heat that was transmitted along the underground pipe as next [32]:

$$\phi = \dot{m} \times Cp \times dT(x) = \frac{dx}{R_{convection} + R_{pipe} + R_{soil}} \times (T(z,t) - T(x)) \quad (9)$$

The pipe's thermal resistance can be expressed as:

$$\text{R}_{\text{pipe}} = \frac{1}{\lambda pipe.2.\pi} . \ln(re|ri) \quad (10)$$

Between the inside surface of the pipe and the air inside the pipe, the convective thermal resistance is:

$$R_{conv} = \frac{1}{ri.hconv.2.\pi} \quad (11)$$

The thermal resistance of the soil can be expressed as:

$$R_{soil} = \frac{1}{2.\pi.\lambda}.\ln(R(z,t)|re) \quad (12)$$

The total thermal conductance of the EAHE is then given by:

$$C_{tot} = \frac{1}{(Rconv+Rpipe+Rsoil)} \quad (13)$$

Combining Equations (9) and (13), the energy balance can expressed as follows :

$$\frac{dT(x)}{T(z,t)-T(x)} = \frac{Ctot}{\dot{m}.Cp}.dx \quad (14)$$

The integral of Equation (14) :

$$-\ln(T(z,t) - T(x)) = \frac{Ctot}{\dot{m}.Cp}.\ x + cte \quad (15)$$

The ground's surface's boundary equation [5]:

$$T(0) = T_{amb} \quad (16)$$

Equation (15)'s (Cte) can be replaced with its expression taken from Equation (16)'s boundary condition to obtain.:

$$\ln(T(x) - T(z,t)/(Tamb - T(z,t))) = \frac{-Ctot}{\dot{m}.Cp}.\ x \quad (17)$$

At x = L, the air outlet temperature is as follows:

$$T_s = T_{amb} + (T(z,t) - T_{amb})\ .\ (1 - e^{\frac{-Ctot}{\dot{m}.Cp}.x}) \quad (18)$$

The following expression gives the air mass flow rate:

$$\dot{m} = \rho_a.V_a.\ \pi.D_i^2/4 \quad (19)$$

The Fourier series is able to be utilized to illustrate the hourly change in the ambient temperature [34]:

$$T_{amb} = \frac{Tmax+Tmin}{2} + \frac{Tmax-Tmin}{2}\ \cos\left(\frac{\pi}{12}(t - 14)\right) \quad (20)$$

2.3. Method

2.3.1. Fuzzy logic

Lotfi Zadeh developed fuzzy logic as an evolution of Boolean logic [35]. As an extension of conventional theory of sets, the concept of fuzzy sets was developed in mathematics in 1965. Fuzzy logic provides a lot of variety in the argument for application by introducing the idea of an amount of condition verification, which results in a condition of being in a state other than true or false, allowing errors and uncertainties to be taken into consideration. As a result, the fuzzy logic principle has been applied to a variety of production processes in which tests and human understanding are critical [35, 36].

2.3.2. Fuzzy system

The figure below illustrates the main steps of fuzzy model
First step: fuzzification, Second step: inference, Third step: Defuzzification.

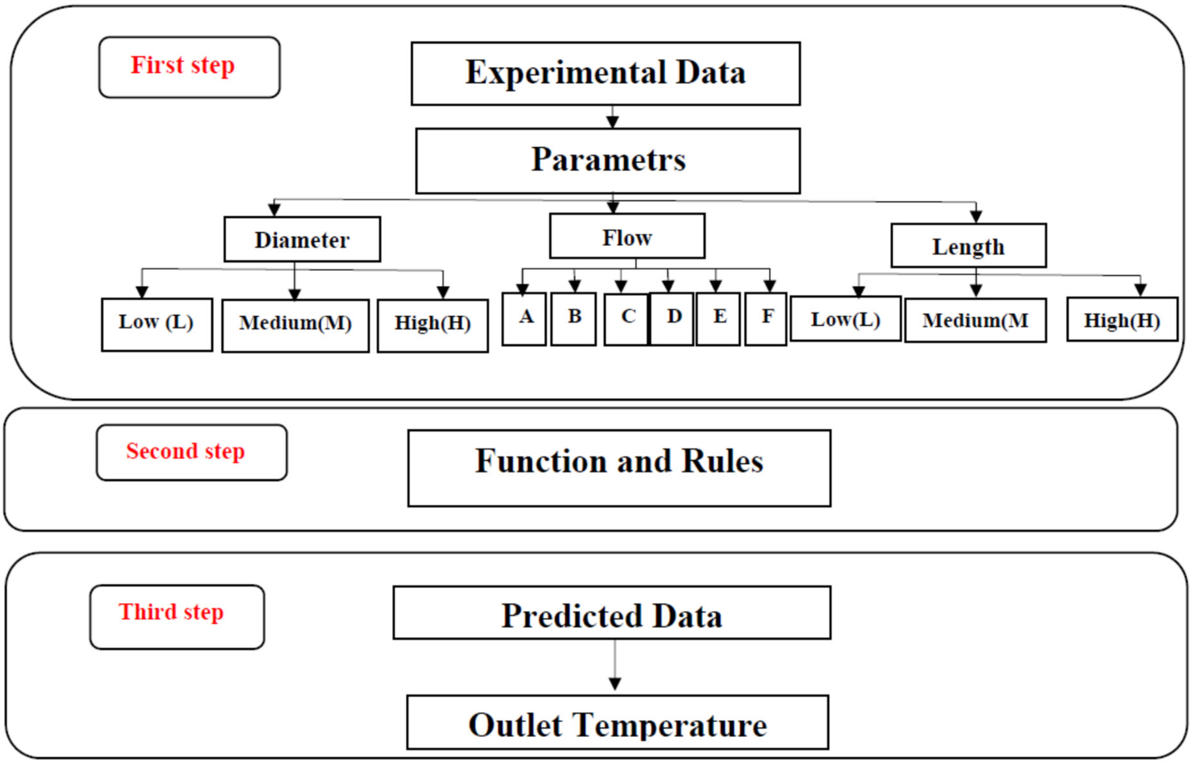

Fig. 2. Flowchart of Fuzzy logic steps

We choose the following for this fuzzy system inference:

- The input consists of three variables (Diameter, Flow and length).
- One variable output (we have air temperature).

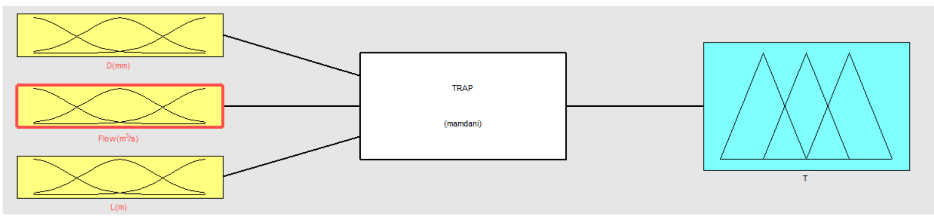

Fig. 3. The fuzzy system variables (Input, Output)

Table 1. Input parameters for membership function

Factor	Symbol	Unit	Levels 1					
			Low (L)		Medium (M)		High (H)	
Diameter	D	mm	110		200		250	
Flow	Qv	m^3/s	100		150		200	
			Levels 2					
			A	B	C	D	E	F
Length	L	m	0	10	17	23	34	45

Table 2. Output parameters for membership function

Factor	Symbol	Unit	Levels						
			A	B	C	D	E	F	G
Temperature	T	C°	30,5	31,5	32,5	33	34,5	35	36,5

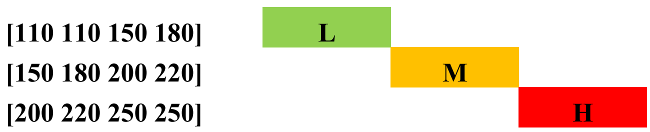

Fig. 4. Linguistic variables for Diameter (D)

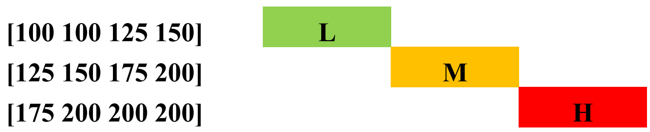

Fig. 5. Linguistic variables for Flow (Qv)

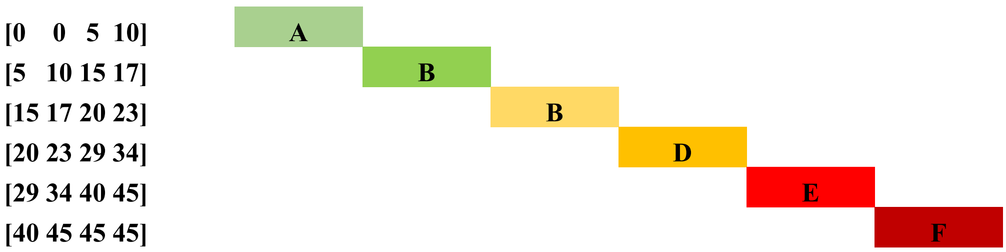

Fig. 6. Linguistic variables for Length (L)

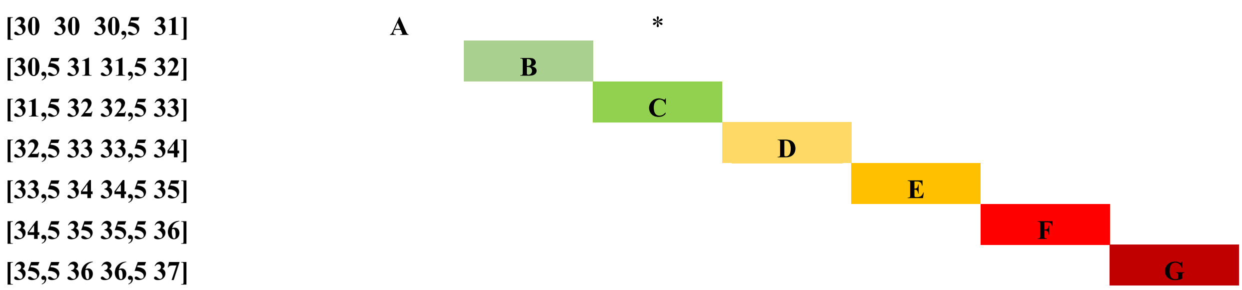

Fig. 7. Linguistic variables for Temperature (T)

Some membership functions are shown (figures 4, 5, 6, and 7). Tables 1 and 2 in this study discuss trapezoidal membership functions for the input variables (figures 8, 9, 10, and 11).

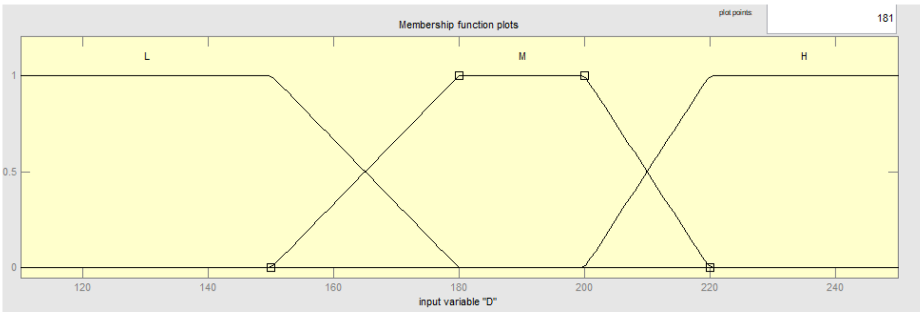

Fig. 8. Fuzzy system for Diameter (D)

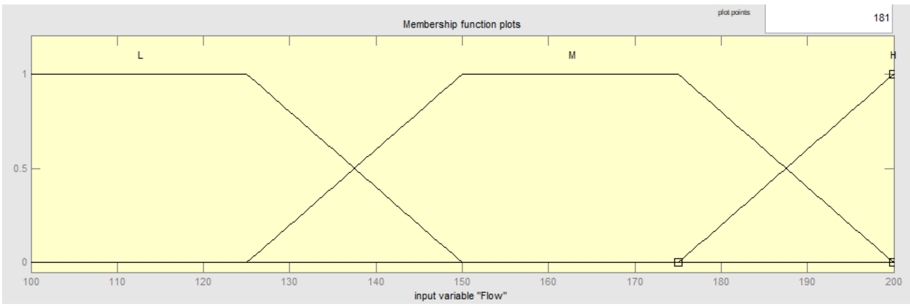

Fig. 9. Fuzzy system for Flow (Qv)

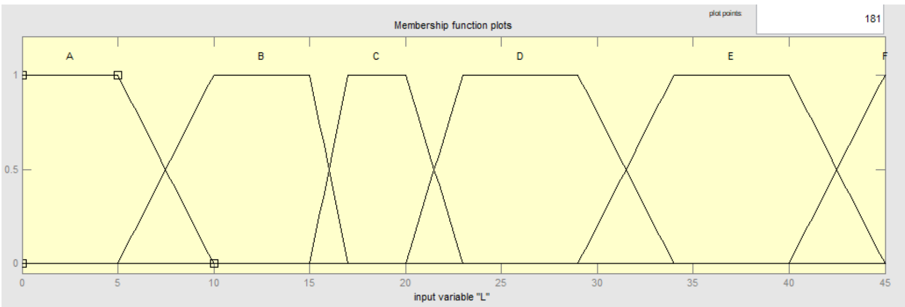

Fig. 10. Fuzzy system for Length (L)

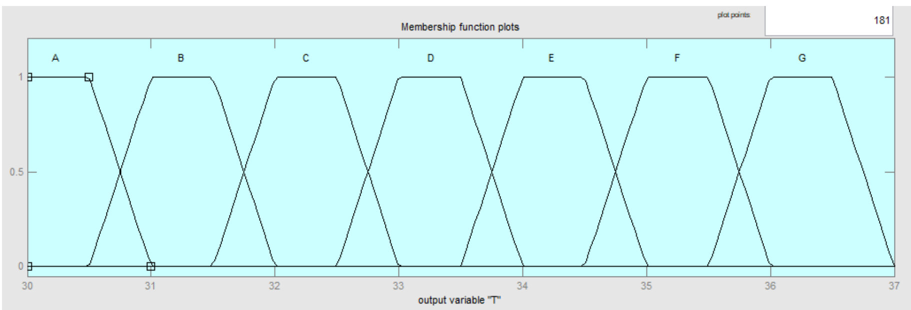

Fig. 11. Fuzzy system for Temperature (T)

2.3.2 Fuzzy rules

The calculation rules are displayed in Table 3.
If a Diameter is.. and Flow is.. and Length is.. so Temperature is…

Table 3. Fuzzy rules.

Test	D(mm)	Flow (m^3/s)	L(m)	Tair (°c)
1	L	L	A	G
2	L	L	B	E
3	L	L	C	D
4	L	L	D	D
5	L	L	E	B
6	L	L	F	A
7	M	L	A	G
8	M	L	B	F
9	M	L	C	E
10	M	L	D	D
11	M	L	E	C
12	M	L	F	C
13	H	L	A	G
14	H	L	B	F
15	H	L	C	E
16	H	L	D	E
17	H	L	E	D
18	H	L	F	C
19	L	M	A	G
20	L	M	B	E
21	L	M	C	D
22	L	M	D	C
23	L	M	E	B
24	L	M	F	A
25	M	M	A	G
26	M	M	B	F
27	M	M	C	E
28	M	M	D	D
29	M	M	E	C
30	M	M	F	B
31	H	M	A	G
32	H	M	B	F
33	H	M	C	E
34	H	M	D	E
35	H	M	E	C
36	H	M	F	C
37	L	H	A	G
38	L	H	B	E
39	L	H	C	D
40	L	H	D	C

41	L	H	E	A
42	L	H	F	A
43	M	H	A	G
44	M	H	B	E
45	M	H	C	D
46	M	H	D	D
47	M	H	E	B
48	M	H	F	A
49	H	H	A	G
50	H	H	B	F
51	H	H	C	E
52	H	H	D	D
53	H	H	E	C
54	H	H	F	B

3. RESULTS AND DISCUSSION

3.1. Deffazifuction

The table below show the temperature values of the experimental study comparing with the simulation.

Table 4. Comparison between experimental temperature values and simulation

Test	T(experimental)	T(simulation)
1	36,5	36,2
2	34,5	34,3
3	33,5	33,2
4	33	33,2
5	31,5	31,3
6	30,5	30,4
7	36,5	36,2
8	35	35,3
9	34,5	34,3
10	33,5	33,2
11	32,5	32,2
12	32	32,2
13	36,5	36,2
14	35,5	35,3
15	34,5	34,3
16	34	34,3
17	33	33,2
18	32,5	32,2
19	36,5	36,2
20	34,5	34,3

21	33,5	33,2
22	32,5	32,2
23	31,5	31,3
24	30,5	30,4
25	36,5	36,2
26	35	35,3
27	34,5	34,3
28	33,5	33,2
29	32,5	32,2
30	31,5	31,3
31	36,5	36,2
32	35	35,3
33	34,5	34,3
34	34	34,3
35	32,5	32,2
36	32	32,2
37	36,5	36,2
38	34	34,3
39	33	33,2
40	32	32,2
41	30,5	30,4
42	30	30,4
43	36,5	36,2
44	34,5	34,3
45	33,5	33,2
46	33	33,2
47	31,5	31,3
48	30,5	30,4
49	36,5	36,2
50	35	35,3
51	34	34,3
52	33,5	33,2
53	32	33,2
54	31	31,3

In the present study, we found that the values in 54 test of those temperature are too close and the figure 12 illustre it more.

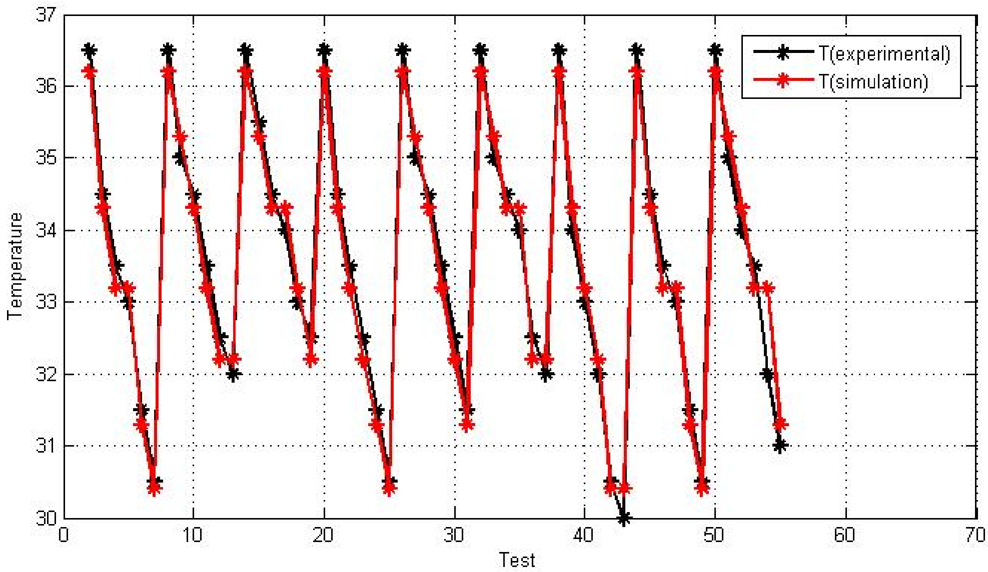

Fig. 12. Experimental and simulation temperature curves

To examine that this model is valid for all arid zones, we chose the fuzzy loigic for a validation of the experimental results with the others of simulation. To obtain a good result from this study, it is necessary to add different values of parameters diameter, flow and length which did not exist before in the experimental values. the method consists of changing one of these parameters and fixing the others the table 5 explain this method of validation.

Table 5. Validation method

Test	Diameter	Flow	Length	T(experimental)	T(simulation)
1	110	150	7	35,1	35,4
2	110	150	12,5	32,2	32,2
3	110	150	29	34,1	34,3
4	200	100	2,5	36,15	36,2
5	200	100	15	32,48	32,2
6	200	100	35	32,8	32,2
7	250	200	2,5	36,1	36,2
8	250	200	25	33,25	33,2
9	250	200	41	31,7	32,2

3.2.Validation of results

The error was applied to calculate the difference between the observed and predicted values; the steps are shown in equation (21) below. The percentage of individual error was divided in order to reduce the overall difference in measurement value.

$$ei = \left(1 - \frac{|Texp - Tpr|}{Texp}\right) * 100\% \tag{21}$$

The precision is calculated by applying the predicted value technique to the observed value. In the second equation (22), P represents the model's consistency, N represents the total number of examined data sets. The model's accuracy is close to the average individual precision.

$$P = \frac{1}{N}\sum \left(1 - \frac{|Texp - Tpr|}{Texp}\right) * 100\% \tag{22}$$

Table 6. Fuzzy logic results to calculate the error (ei%) and the precision (P%)

TEST	T(EXPERIMENTAL)	T(SIMULATION)	ERROR	ERROR %
1	35,1	35,4	0,00855	99,14529915
2	32,2	32,2	0	100
3	34,1	34,3	0,00587	99,41348974
4	36,15	36,2	0,00138	99,86168741
5	32,48	32,2	0,00862	99,13793103
6	32,8	32,2	0,01829	98,17073171
7	36,1	36,2	0,00277	99,72299169
8	33,25	33,2	0,0015	99,84962406
9	31,7	32,2	0,01577	98,42271293
				Precision = 99,3027 %

The graph below compares the values predicted by our fuzzy logic model to the values measured experimentally.

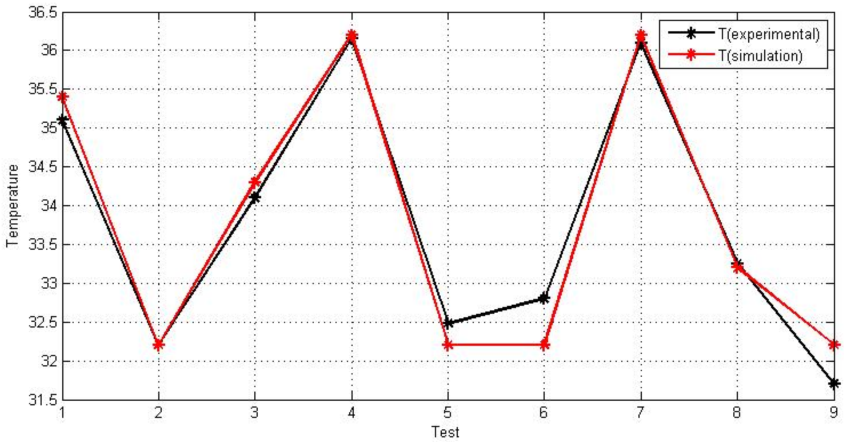

Fig. 13. Comparison between experimental and simulation results (validation curves)

After obtaining validation curves figure 13, it is observed that the two temperature curves are very proximity in the test 1, 3, 5 and .7 and they are identical in the trials 2.4 and 8. On the other hand in the tests 6 and 9 the curves are far from each other because one of the obstacles for example: the air velocity, climate change of the day, error in the measuring device. As a consequence, our fuzzy logic-based prediction model operates well and accurately, and it may be utilized to solve problems.

4. CONCLUSIONS

In this work based on an experimental data which carry out in university Biskra with a specific parameters to evaluate and generalize the finding to all similar systems using a new technology called fuzzy logic which not be used previuosly in this field of research. It can be conclude, according to this experimental study found that:

- The existence of some parameters influence on the performance and efficiency of this system by length, depth, type, diameter of pipe and inlet velocity of air.
- To several reasons, including confirmation of the experimental results, it requires the use of another method of optimization, which validates this work. In this case, the fuzzy logic system is the most reliable method among the other optimization methods.
- The maximum air temperature values are found for maximum values of Diameter, Flow, and Length.
- This program can provide a good results , maintain the time of the different studies, and the most important is its precision, the accuracy of this system in our work is 99.3%. So, it can be validated that fuzzy logic is valid for all the systems in this way with instalrations and different equipment.
- Fuzzy logic provides good agreement between experimental results in a certain optimized and economical time.

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