# Optimizing Energy Consumption using Fuzzy Logic for HEMS in a Smart Grid

Qurat-ul-Ain[1] Sohail Iqbal[2] Nadeem Javaid[3]

## Abstract

Energy consumption minimization and user comfort enhancement in Home Energy Management System (HEMS) are the major challenges in a smart grid. In HEMS, appliances of Heating, Ventilation, and Air Conditioning (HVAC) have a large impact on the energy consumption. For user comfort, one needs to take into account different environmental factors among which humidity plays an important role in determining the suitable temperature for optimal user comfort. In order to minimize energy consumption without compromising user comfort, fuzzy logic techniques are widely used without considering humidity. In this paper, we tune the Fuzzy Inference System (FIS) by including humidity as well as we propose a method for the automatic rule generation for FIS. Automatic rule generation is devised using combinatorics. The proposed system is evaluated by the membership functions of the input parameters and the results are compared using Mamdani FIS and Sugeno FIS. Indoor temperature, outdoor temperature, occupancy, price, initialized set points of thermostat, and humidity are the input parameters of the system. Performance metrics used for the evaluation are energy consumption, Peak-to-Average Ratio (PAR), cost, and efficiency gain. Simulation of one month energy consumption with proposed technique is performed in MATLAB®. Simulation results validate the proposed technique and show that despite all the energy savings, the proposed technique manages to be in the user comfort zone while achieving electricity cost reduction up to 24%. Moreover, optimization using FIS provides the reduced energy consumption up to 28%. The proposed technique seems to have a potential for improved demand-side energy management in a smart grid.

**Keyword:** Smart Grid, Fuzzy Logic, Energy Management, User Comfort

## 1 Introduction

Demand Response (DR) plays an important role in energy consumption minimization for the smart grid environment. HEMS is a demand response tool which is an important part of the smart grid that enables the residential users to create optimal energy consumption by considering many objectives such as energy cost, load profiles, and consumer comfort. The worldwide fossil fuel resources are declining at an escalated pace which signifies the need of energy management and minimization [1].Heating, Ventilation, and Air Conditioning (HVAC)

*[1]SEECS, National University of Sciences and Technology (NUST), Islamabad*
*[2]SEECS, National University of Sciences and Technology (NUST), Islamabad*
*[3]COMSATS Institute of Information Technology, Islamabad*
**Corresponding author: sohail.iqbal@seecs.nust.edu.pk*

appliances contribute the major part of total energy consumption worldwide in the current scenario. HVAC also shows great effects on peak load management during peak demand hours especially during summer days. Therefore, different techniques are used to schedule the HVAC to reduce peak load. Different pricing mechanisms or tariffs such as Real Time Pricing (RTP), Time of Use (TOU) [2] and critical peak pricing [3] are used to encourage the electricity user for reducing load demand during peak hours. Electricity cost is determined by the utility at different times of day based on TOU rates for the High Peak (HP), Mid Peak (MP), and Off Peak (OP). Based on these values, load control in HEMS is either shifted or curtailed especially for the HVAC.

A wind driven optimization based energy scheduling technique [4] is used to reduce the energy cost and PAR by shifting the load during peak hours to off peak hours. PAR is a useful measure which describes how peak electricity consumption affects the system. It is often seen that users find it difficult to remember that they need to update their thermostat particularly during critical situations. In [5] programmable communicating thermostat incorporated model which helps to reduce the PAR along with energy consumption.

Occupancy and user participation are the factors that directly affect the functionality of thermostats resulting in more optimal energy consumption and bill savings. Occupant's activities and presence have been observed in [6] to evaluate the energy savings. The user negligence while using thermostat effects the energy consumption in many cases where customers forget or neglect to participate in DR during peak prices [7].

Previous research shows that evaluation of energy consumption for HVAC by varying different parameters is performed. Energy evaluation is performed using different DR techniques day-ahead electricity prices, TOU rates, real time pricing is used to reduce energy consumption and electricity bills for residential consumers by shifting home appliance from high peak hours to off peak hours [8],[9]. Challenges that are often faced during the use of programmable thermostat (PT) is user's lack of communication with new technologies such as smart meters [10]. PTs are improved into Programmable Communicating Thermostat (PCT) [11] with the advancement in communication benefitting users to participate in DR program promulgated by the utility. Currently, types of thermostat that are being used to participate in DR are: 1) programmable communicating thermostat, 2) price responsive thermostats, and 3) occupancy responsive thermostat to reduce the residential HVAC energy consumption. Price responsive thermostat uses price signals from smart grid and change the thermostat set points to the values already defined by the residential users. Occupancy based thermostats sense the occupancy of the user and modifies the building or room set points. During these studies, it is observed that user comfort is heavily sacrificed while participating in the demand response programs[11].PCT is used because of its feature of communicating with the smart meter in order to read the price signals that are decided by the utility on interval basis. PCTs allows user to participate in DR programs where user can vary the thermostat set points according to the TOUs tariffs using the intervals of off peak, mid peak, and high peak. However, the constant interaction of the user with thermostat often irritates the residential users making the behavior of PCT as programmable thermostat (PT).

Keshtkar et al. [12] evaluate the load reduction in HVAC system using fuzzy logic model. Outdoor temperature, price, occupancy, and initialized set points are the input parameters of that system. However, the proposed system lacks adaptability in thermostat. The system in [13] is the extension of [12] where authors introduced the adaptive autonomous thermostat. In [13], system is made adaptive using fuzzy logic approach by training the thermostat on initialized set points. It considers the three consecutive changes of same set points for the same day of the week and then modifies the thermostat set point to the optimized set point. Although, this technique is good it is limited to cold regions of the world i.e. Canada in this case. And the results are reliable only for the country based research.

Extending the idea of [13], a model of worldwide adaptive thermostat is proposed by Javaid el al. [14]. The proposed technique uses Fuzzy Logic Controllers (FLC) to set the thermostat set points. Input parameters of this system are outdoor temperature, price, occupancy, and initialized set points for hot and cold cities. Their system is evaluated using Mamdani and Sugeno FIS. Although this technique showed good results in energy consumption minimization there are multiple parameters that can be considered for the improvement of results.

This limitation lead us to extend the existing study for further improvement in the energy consumption minimization using thermostat set points optimization.

The organization of paper is as follows: in Section II, problem considered is elaborated while the problem formulation is described in Section III. Proposed system is presented in IV and simulations along with the result analysis are discussed in Section V. The paper is concluded in Section VI.

## 2 Problem Statement

Residential HVAC systems contribute to a significant part of world's energy consumption. These devices are the primary electrical load during peak hours which often leads to peak load blackouts. As the energy prices increases during the peak hours such as TOU, the household electricity bill is strongly dependent on the HVAC system. Thermostat is widely used in order to save energy as well as to maintain the temperature of residential building in user desired range. PT is the kind of thermostat used in HEMS where users maintain the set point temperature on interval basis for a day which depicts their schedule and user preferences [13].

Many fuzzy logic techniques have been developed that targets to save energy without compromising the user comfort. It is observed that different factors play a significant role in determining the thermostat set points which in result affect the energy consumption. Some of them have been considered in previous research work but many of them are still missing. Humidity is an important factor that determines the way a user sets the set points. There is a need to design a model that incorporates the humidity to show the effect of humidity while setting the thermostat set points in order to reduce energy consumption without much compromising on the user comfort.

It is known that generating and writing the rules for the FIS is a very tedious and time consuming task. Measuring the effect of different parameters on the energy consumption is a beneficial methodology that will help us in setting the thermostat set points in a way that not only minimizes the energy consumption but the temperature will also remain within the user comfort range. But increase in the number of input parameters increases total numbers of rules to be defined hence increasing the complexity of defining the rules for the FIS. Defining an automatic way to set the rule base is an important task.

## 3 Problem Formulation

This section discuss the details of the formulation of proposed scheme, energy consumption, cost, PAR for HEMS. The proposed system is developed using fuzzy logic rules and evaluated using FIS. Fuzzy logic technique has a major advantage as compared to ON-OFF control as controlled variables used in this study varies continuously during a period of time [15]. FLC responds very well to these changes. The input and output of FLC are real variables which are connected through IF-THEN rules to achieve the desired output. The major advantage of FLC as compared to other controllers is its requirement of little mathematical modeling. Another reason for using the FLC is that the rules defined are purely on human intuition which is effective and more expressive. Mamdani and Sugeno are among the types of FIS that are most commonly used for evaluation. The input parameters used in this study are directly related to energy management and user comfort in residential buildings. Energy consumption is evaluated with the help of fuzzy rules. In this paper, energy consumption is calculated by considering with humidity and without humidity.

### *A. Mamdani and Sugeno FIS*

FIS takes the crisp inputs, fuzzifies it, applies fuzzy operators on premise (antecedent), performs implication from premise to conclusion (consequent), aggregate conclusion across fuzzy rules to generate fuzzy output and defuzifies it to get a crisp output. The model proposed is evaluated and tested using the Mamdani and Sugeno FIS.

Mamdani FIS uses linguistic variables for the rules and its premise and conclusion are both linguistic variable. Fuzzyrules are generated using the linguistic variables. e.g.

$$IF\ \text{Outdoor-}Temp\ is\ "Normal"\ AND\ \text{Indoor-}Temp\ is\ "Normal"\ AND\ \text{Rate}\ is\ "High\ Peak"\ AND\ Occpancy\ is\ "Absent"\ AND\ ISP\ is\ "Low"\ AND\ Humidity\ is\ "Low",\ THEN\ energyconsumption\ is\ "Low"$$

Defuzzification method used in Mamdani FIS is centroid which is calculated using the formula [16]:

$$z = \frac{\int \mu_C(z)\ .\ zdz}{\int \mu_C(z)dz} \qquad (1)$$

Sugeno FIS takes the premise part as a linguistic variables, however, its conclusion part is function which can be zero order (constant) or first order. Fuzzy rules are generated using the function which is efficient, for example:

*IF* Outdoor-*Temp is "Normal" AND* Indoor-*Temp is "Normal" AND Rates is "High Peak" AND Occpancy is "Absent" AND ISP is "Low" AND Humidity is "Low", THEN energyconsumption = energyconsumption* $(temp_{in}, temp_{out}, price, occupancy, ISP, humidity)$

Defuzzification method used in Sugeno FIS is weighted average which is calculated using the formula:

$$z = \frac{\sum \mu_C \bar{z} \cdot \bar{z}}{\sum \mu_C \bar{z}} \tag{2}$$

To conclude, Mamdani is intuition based that is well suited for the human input whereas Sugeno is computationally efficient method and well suited for the mathematical analysis [17].

In order to calculate the total cost following formula is used:

$$Cost(h) = EC(h) * Rates(h) \tag{3}$$

Here, Cost (h) is the hourly cost whereas EC (h) is the electricity consumption on hourly basis and Rates (h) are the hourly pricing tariffs based on TOU.

PAR is calculated using the formula as follows:

$$PAR(a_n) = \frac{P_{max}}{P_{avg}} = \frac{\max\limits_{0 \le n \le N-1} (a_n)}{\frac{1}{N} \sum\limits_{n=0}^{N-1} a_n} \tag{4}$$

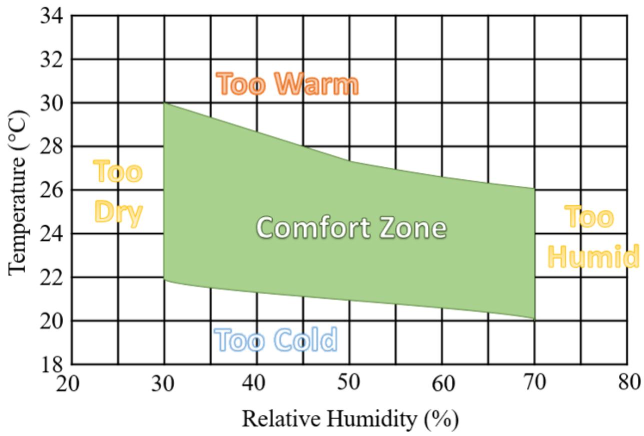


**Figure 1: Comfort Zone using Psychrometric Graph [20]**

## 4 System Model

In this manuscript, an extension to the adaptive fuzzy learning model [13] and worldwide adaptive thermostat model [14] is developed. Proposed technique introduces humidity along with the existing input parameters like outdoor temperature, indoor temperature, prices, occupancy, and set points of thermostat in hot and cold cities for energy consumption minimization without disturbing the user comfort.

The two cities considered for analyzing the cooling and heating power consumption in any residential building around the world are the WadiHalfa in Sudan and Yakutsk from Russia. WadiHalfa is one of the hottest cities in the world and Yakutsk is the coldest city in the world. Then, we have selected one of the hottest and coldest day from the respective cities. Highest temperature in WadiHalfa has been recorded during the month of June. Whereas, coldest weather in Yakutsk has been observed during January. Outdoor temperature for WadiHalfa and Yakutsk is taken form weather forecasting website [18] and [19] respectively. The initialized set points are used for controlling the indoor temperature for both cold and hot cities are defined using the psychrometric chart mentioned in [20]. Comfort zone defined in Fig. 1 shows the temperature range that can be used as thermostat set point with respect to a particular relative humidity value which results in little disturbance on user comfort. Values for occupancy and TOU pricing tariff are taken form [13].

In Fig. 2, computation model used in this system is depicted. Input parameters provided to the FIS are measured by deploying sensors. This system works for the cold and hot cities along with their thermostat heating and cooling points. The price is communicated to the user by utility using the smart meters of the residential buildings. These values are used to set thermostat set points.

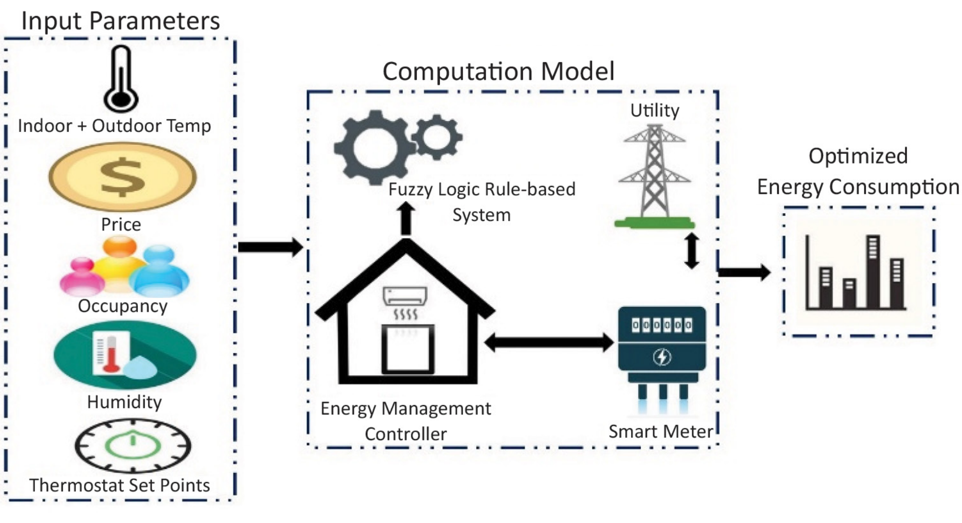


**Figure 2: HVAC Control System in HEMS**

Inputs of the system are indoor temperature, outdoor temperature, price, occupancy, thermostat set points, and humidity. Membership functions defined for the indoor temperature ($Temp_{indoor}$) and outdoor temperature ($Temp_{outdoor}$) are: 1) Very Cold (VC), 2) Cold (C), and 3) Normal (N) for cold cities whereas for hot cities the membership functions are 1) Normal (N), 2) Hot (H), and 3) Very Hot (VH). The user occupancy ($O$) has two membership functions: 1) Absent (A) and 2) Present (P). Price ($P_{rates}$) is defined on the basis of TOU tariff according to which membership functions are defined as: 1) Off Peak (OP), 2) Mid Peak (MP), and 3) High Peak (HP). The membership function used for thermostat set points ($ISP_s$) and humidity ($Humidity_{rel}$) are: 1) Low (L), 2) Medium (M), and 3) High (H). Output parameter of this system is energy consumption (EC). The output membership functions are 1) Very Low (VL), 2) Low (L), 3) Medium (M), 4) High (H), and 5) Very High (VH).Figs.3-5 shows the membership functions of some parameters used in this system as well as the defined ranges:

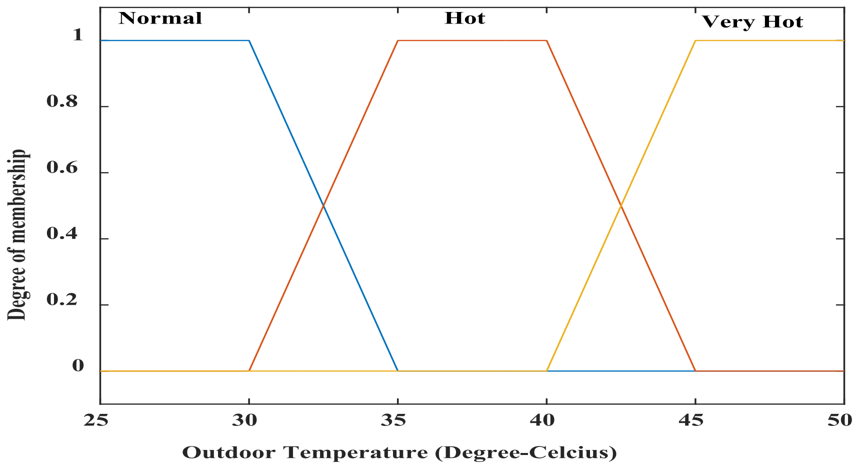


**Figure 3: Outdoor Temperature for Hot Cities**

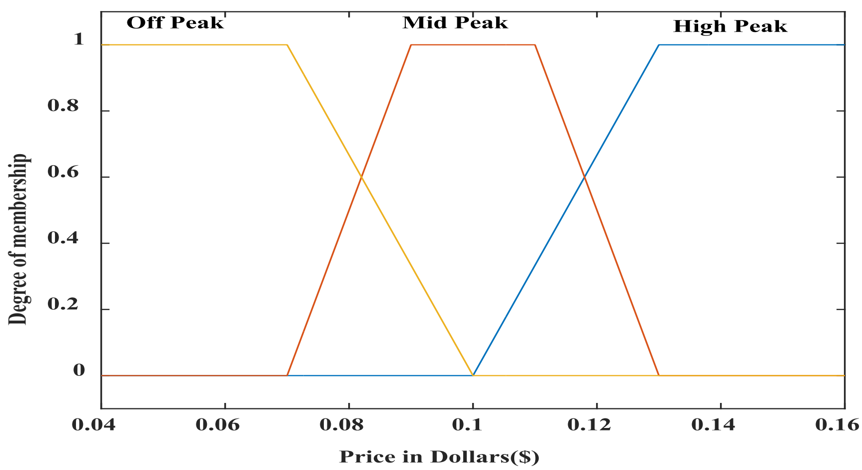


**Figure 4: TOU Price Rates**

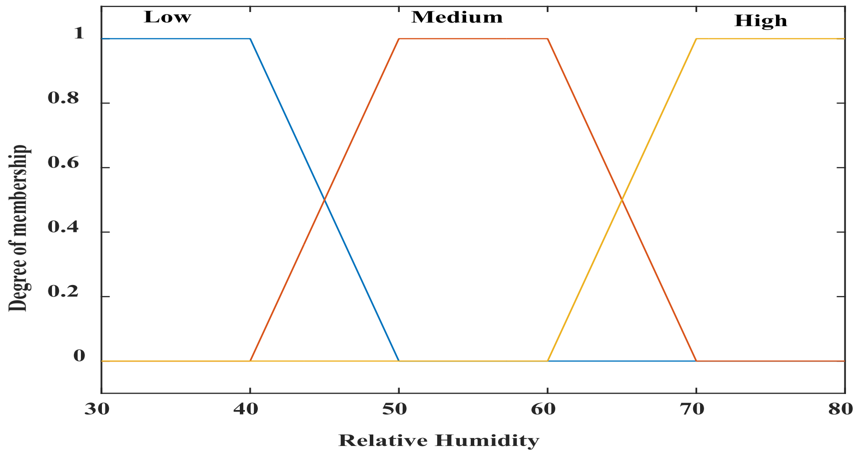


**Figure 5: Relative humidity**

Working of Fuzzy Logic System is heavily dependent on the selection of the membership function for the input and output parameters. When selecting a membership function for a parameter, consider the shapes that best represent the human knowledge. There has been a number of membership functions with well-known forms like triangular, left-shoulder, right-shoulder and trapezoidal.

The membership functions of input and output parameters used in this system are defined as trapezoidal which has a flat top or it can be said it is a truncated triangular membership function. Although the triangular membership function is simple to use the parameters used in this study are best defined using trapezoidal membership function since the temperature, set points, price and humidity do not suddenly drops their value and maintain the same value for a length of time. So, these flat line membership functions have the advantage of simplicity [21].

The system is evaluated with the help of fuzzy rules in order to determine the energy consumption. When FIS is defined without incorporating humidity, there are 4 variables with 3 values and fifth variable with 2 values. In this case, total number of rules defined in the rule base for both Mamdani and Sugeno FIS are 162. In the second scenario, FIS considering humidity has 5 variables with 3 values and sixth variable with 2 values resulting in total 486 rules in the rule base. Some of the fuzzy rules defined for FIS decisions making are shown in the Table 1.

**Table 1: Sample Fuzzy Rules for Energy Consumption Optimization**

| # *Rule* | $T_{in}$ | $T_{out}$ | *Rate* | *Occupant* | *ISP* | *Humidity* | *EC* |
|---|---|---|---|---|---|---|---|
| 1 | L | L | HP | A | L | L | VL |
| 2 | L | M | OP | P | L | L | M |
| 3 | L | H | MP | P | H | H | M |
| 4 | M | H | OP | A | M | H | H |
| 5 | M | L | MP | P | H | M | M |
| 6 | H | M | OP | A | L | M | M |
| 7 | H | H | OP | P | H | H | VH |

### *A. Automatic FIS rule base Generation*

It is observed that defining rule for the rule base of FIS is a very lengthy and tedious process. Developing an automatic FIS rule generation process using combinatorics method is also proposed in this paper.

**Algorithm 1** Automatic Rule Generator

```
Temp_outdoor ← {L,M,H}
Temp_indoor ← {L,M,H}
P_rates ← {OP,MP,HP}
O ← {A,P}
ISP_s ← {L,M,H}
for Temp_outdoor[1] to Temp_outdoor[n] do
    for Temp_indoor[1] to Temp_indoor[n] do
        for P_rates[1] to P_rates[n] do
            for O[1] to O[n] do
                for ISP_s[1] to ISP_s[n] do
                    Compute Score                          ▷ Defined in Eq.5
                    if Score = 0 or Score = 1 then
                        EC = VL
                    else if Score = 2 or Score = 3 then
                        EC = L
                    else if Score = 4 or Score = 5 then
                        EC = M
                    else if Score = 6 or Score = 7 then
                        EC = H
                    else
                        EC = VH
                    end if
                end for
            end for
        end for
    end for
end for
```

The major steps of FLC are as follows:

- First step is the fuzzification process in which all the membership functions of the system parameters are initialize and define.
- Second step is defining the rules in the rule base by giving weightage to membership functions of input parameters and then assigning the suitable output fuzzy value.
- Third step uses the Mamdani and Sugeno FIS to evaluate the energy consumption.
- After rule evaluation, defuzzification is performed to get the crisp value for the energy consumption. Calculation of remaining performance measures is performed.

Formula to compute the Score used in the Algorithm 1 is as follows:

$$Score = \sum_{i=0}^{n-1} Temp_{outdoor}[i] + \sum_{i=0}^{n-1} Temp_{indoor}[i] + \sum_{i=0}^{n-1} P_{rates}[i] + \sum_{i=0}^{n-1} O[i] + \sum_{i=0}^{n-1} ISP_{s}[i] \quad (5)$$

## 5 System Model

In this section, the results of the proposed FLC in HEMS are discussed. The proposed controller works for both cold and hot cities using the inputs: 1) Temp_outdoor, 2) Temp_indoor, 3) P_rates, 4) O, 5) ISP_s and 6) Humidity_rel. We have simulated the effect of these parameters for four scenarios: a) energy consumption in hot cities without humidity, b) energy consumption in hot cities considering humidity, c) energy consumption in cold cities without humidity, and d) energy consumption in cold cities using humidity. Furthermore, all these scenarios are evaluated for following performance measures: energy consumption, cost, PAR and efficiency gain.

### *A. Energy Consumption in Hot Cities*

Energy consumption computation based on outdoor temperature and humidity variations during the 24 hours for one of the hottest city in the world and on one of its hottest day is performed and the hourly energy consumption is presented in Fig. 6. Maximum hourly energy consumption of Mamdani without humidity, Sugeno without humidity, Mamdani with humidity, and Sugeno with humidity is 5.7kWh, 5.5kWh, 4.5kWh, and 4.5kWh respectively. Our proposed FLC improves the energy consumption by effectively maintaining the user comfort up to 21% for both techniques.

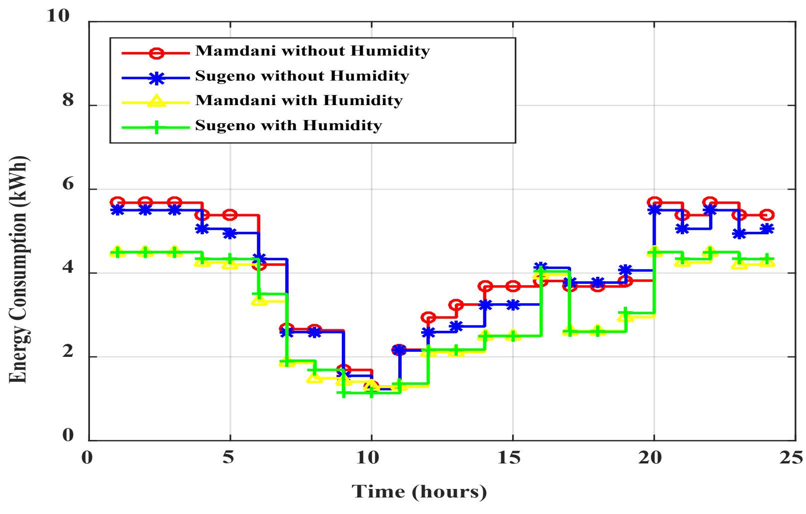


**Figure 6: Energy Consumption over a day for Hot Cities**

Fig. 7 shows the monthly energy consumption of our designed FLC using both FIS with and without considering humidity. Energy consumption shown is calculated by evaluating and analyzing the fuzzy rule base. In our study, the energy consumption is low when the initialized set points are high.

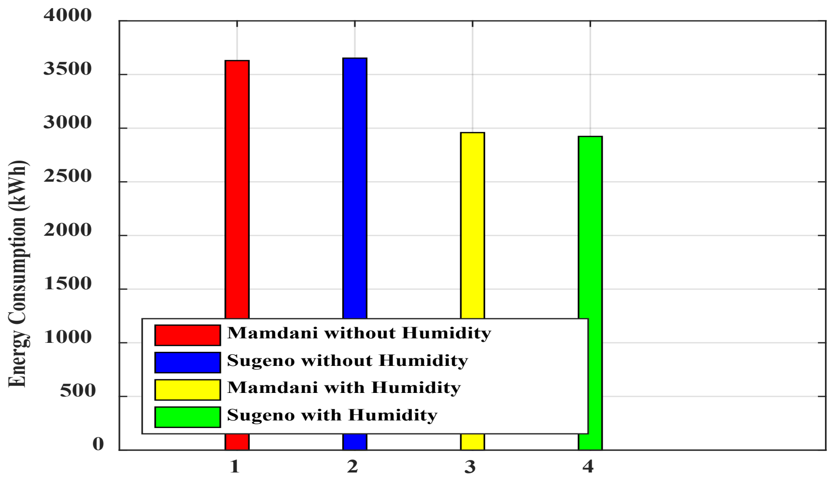


**Figure 7: One month simulation of energy consumption for Hot Cities**

We have run this simulation for one month. The energy consumption of FLC using Mamdani without humidity is 2954kWh, Sugeno without humidity consumes 2837kWh, Mamdani with humidity shows 2270kWh energy consumption and Sugeno with humidity consumes 2295kWh energy. Mamdani with humidity improves 23% energy consumption while Sugeno with humidity is improving 22% energy consumption as compared to the energy consumed using Mamdani without humidity.

The Mamdani FIS performs better than Sugeno FIS because it is simple in nature and have more energy efficiency. As the demand of HVAC varies on hourly basis in a residential building, the set points are modified by using temperature and humidity information. Thermostat set points are used according to Fig. 1, where it shows the range temperature that lies in the user comfort zone for a particular relative humidity value.

### *B. Energy Consumption in Cold Cities*

Now, we are going to discuss energy management in a residential building using proposed FLC in the cold cities. Input for the occupancy, TOU prices remains same during evaluation. Outdoor temperature, relative humidity, thermostat set points, and indoor temperature are used accordingly to cold cities weather. The effect of these input parameters using cold cities is shown in the Fig. 8.

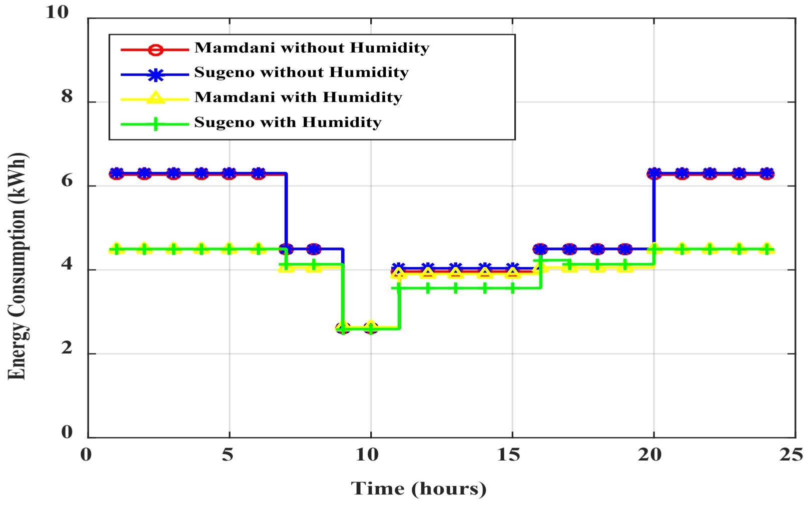


**Figure 8: Energy Consumption over a day for Cold Cities**

In Fig. 8, energy consumption of the techniques proposed and existing technique for comparison is presented. The maximum energy consumption in cold cities is 6.26kWh, 6.30kWh, 4.5kWh, and 4.5kWh using FIS Mamdani without humidity, Sugeno without humidity, Mamdani with humidity, and Sugeno with humidity where both proposed FIS show28% efficiency in energy consumption then existing FIS without humidity.

Fig. 9 shows the energy consumption of cold cities run for one month simulation using Mamdani and Sugeno while considering and leaving the humidity parameter. The behavior of energy consumption is maintained at a desired comfort level using ISPs. Although the energy consumption for cold cities is greater as compared to hot cities, our proposed system succeed in energy consumption minimization which shows the efficiency of proposed scheme to the earlier schemes.

The monthly energy consumption of Mamdani without humidity is 3630kWh, Sugeno without humidity is 3653kWh, Mamdani with humidity uses 2959kWh, and Sugeno with humidity consume 2922kWh of energy. Efficiency in energy consumption for Mamdani with humidity is 19% whereas in Sugeno with Humidity is 20% as compared to FIS without Humidity.

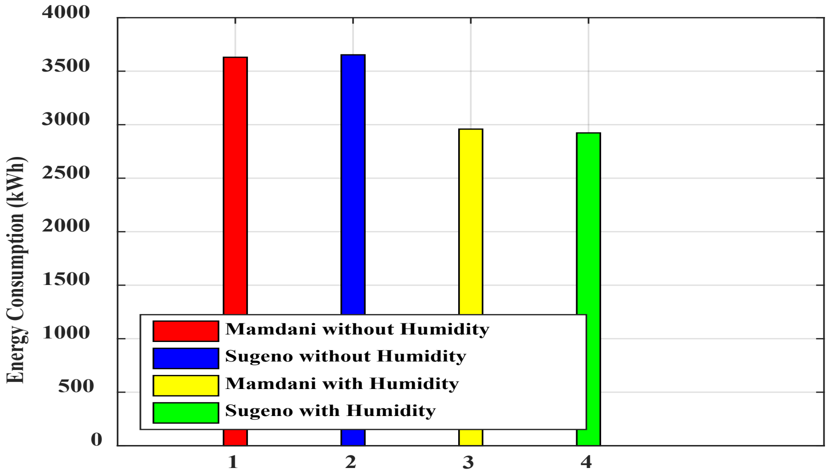


**Figure 9: One month simulation of energy consumption for Cold Cities**

### *C. PAR*

PAR of the cold cities is shown in Fig. 10, which shows Mamdani with humidity achieved 12% efficiency as compared to the Mamdani without humidity whereas efficiency of Sugeno with humidity is 10%. However, if the simulations are run for the hot cities no prominent efficiency gain is observed. This is mainly because the proposed system is mainly focused on the energy consumption minimization. Improvement in the PAR efficiency for the hot cities can be regarded as the byproduct of the proposed scheme.

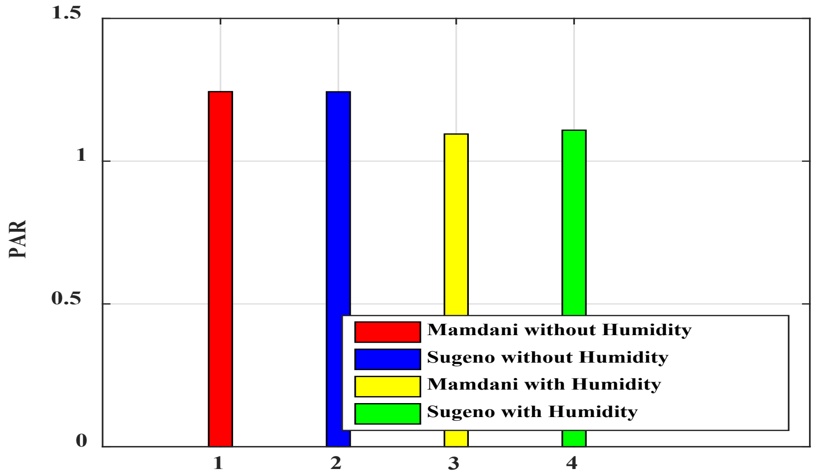


**Figure 10: PAR for Cold Cities**

### *D. User Comfort*

User comfort is mostly sacrificed in previous techniques. In this scheme we initialized the thermostat according to Fig. 1, which allows setting high set points for hot cities and low set points for cold cities considering a particular relative humidity values. Therefore, values for ISPs are selected that not only reduces the energy consumption but also keeps the residential environment in user comfort zone.

### *E. Cost in Hot Cities*

Cost reduction is an inevitable consequent of energy consumption minimization. Cost is computed using the Eq. (3) and proposed system performs best among all approaches. Using technique of Mamdani without humidity, cost is nearly8.92$, Sugeno without humidity costs 8.6 $, Mamdani with humidity approach cost 6.79 $, and Sugeno with humidity FIS costs 6.86 dollar per day as shown in the Fig. 11. Approach using Mamdani with humidity reduces the cost by 23.87% as compared to Mamdani FIS without humidity and Sugeno with humidity to 23.09% as compared to the method using Sugeno without humidity. Mamdani outperforms here because of its simple nature and so having energy efficiency.

### *F. Cost in Cold Cities*

Cost is computed using the Eq. (3) which was also used in the cost calculation for hot cities. As shown in Fig. 12. Scheme using Mamdani FIS without humidity costs 11.19 $, Sugeno without humidity costs 11.25$, Mamdani with humidity costs 9.4 $, and Sugeno with humidity costs 9.3 $ for energy consumption in a day.

Moreover, Mamdani with humidity shows efficiency of 16.44% in cost reduction and 17.33% efficiency of Sugeno with humidity as compared to the Mamdani and Sugeno without humidity.

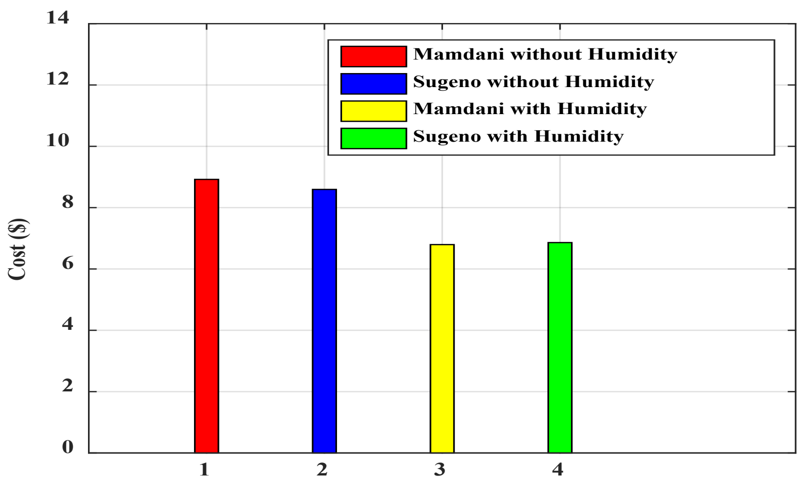


**Figure 11: Cost of energy consumption in a day for Hot Cities**

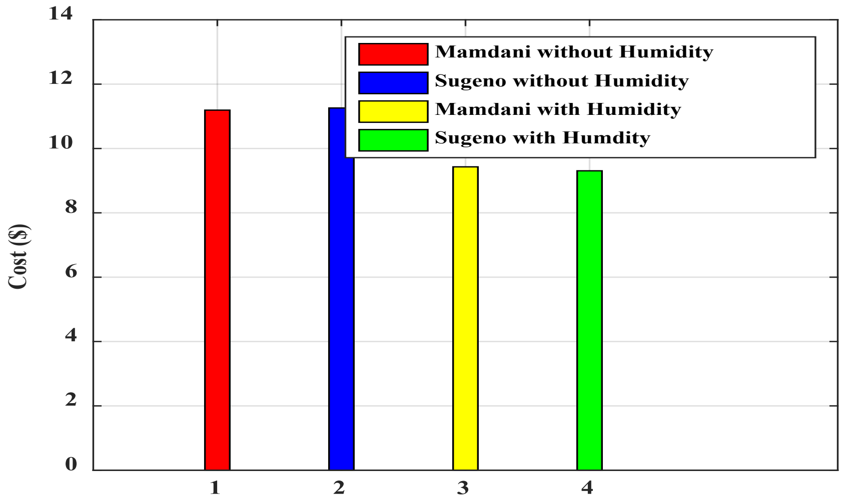


**Figure 12: Cost of energy consumption in a day for Cold Cities**

### *G. Result Analysis*

Effect of humidity on energy consumption minimization and cost reduction is studied in this paper. It is observed that considering humidity while setting thermostat set points plays an important role in achieving the defined objectives. It can be concluded that information of humidity values helps user to set the ISP_s in such a way that not only reduces energy consumption but also guarantee little disturbance in user comfort. Mamdani and Sugeno, both FIS give the reasonable results and show improvement in comparison of previous techniques. However the competition between the proposed Mamdani FIS and Sugeno FIS is very close, but it can be seen that Mamdani FIS performs better in hot cities whereas Sugeno FIS outperforms in cold cities.

Following points are concluded by analyzing the performance of Mamdani and Sugeno FIS used for both hot and cold cities:

i. In order to maintain the residential building temperature as close to user comfort zone, cold regions require more energy consumption as compared to hot regions because appliances for heating requires more energy than the appliances used for cooling purpose.

ii. Reason behind the slightly better performance of Mamdani in hot cities is the simplest nature of the rules defined through Mamdani FIS.

Although the variations in outdoor temperature influence the temperature range of user comfort, proposed scheme is minimizing energy consumption without disturbing user comfort.

## 6 Conclusion

In this paper, we extended the worldwide adaptive thermostat model to include the parameter of humidity and observed the effect it does on the energy consumption. An algorithm for the automatic generation of the fuzzy rules and their initialization in rule base is also proposed. Automatic generation of rules avoids the time consuming process of fuzzy rules initialization. Proposed scheme of work tracked the energy consumption of the HVAC in residential buildings throughout the world along with cost and PAR Simulation results show that proposed methodology significantly reduced the energy consumption and cost while maintaining the user comfort. Efficiency gain in energy consumption using Mamdani and Sugeno is 23% and 22% whereas cost obtained using Mamdani and Sugeno is 23.87% and 23.09% efficient when dealing with hot cities. In cold cities efficiency gain in energy consumption using Mamdani and Sugeno both is up to 28% whereas cost obtained using Mamdani and Sugeno is 16.44% and 17.33% efficient.

In future, more parameters that effect the user's decision of setting the thermostat set points should be considered along with the closed control loop. It can be extended for using more pricing schemes in order to observe the real time effect of dynamic pricing.

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