# Reduce Energy Consumption by Optimizing Temperature and Enforcing Smart Rules in Residential Buildings

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**Abstract**–In this article, to reduce energy consumption and manage its consumption in smart residential buildings, considering the convenience of people, a set of rules for determining intelligent temperature has been selected. For this purpose, expert rules and questionnaires have been prepared and used to make the indoor temperature intelligent based on individuals' emotional components, including clothing, outdoor temperature, age, body mass index, humidity, and the number of inhabitants. For this purpose, the ideal temperature under normal conditions of 22 degrees Celsius is considered by existing standards. The standard for determining the thermal indexes of PMV and PPD is used to validate the rules, and the result is acceptable compliance of these rules with the existing standard. According to the intervals set for the characteristics used, 1215 rules are defined for this system. A dashboard has been prepared in Excel software to adjust the temperature according to the existing rules, which is displayed as output by entering each available data based on qualitative and quantitative amounts of appropriate temperature. To evaluate the energy consumption, the two modes of temperature regulation with intelligent systems and manual temperature regulation have been compared. Results. For example, manually adjusting the temperature in 12 to 18 hours is a constant consumption pattern. By adjusting the temperature of the expert system per second, the consumption pattern changes based on residents' satisfy.

**Keywords**: Energy consumption, intelligent temperature regulation, intelligent rules, energy optimization.

## 1. Introduction

Zekic-Susac et al. (2020), in an article entitled "Energy efficiency management with machine system as an approach in the public sectors of smart cities," discussed how to integrate the Big Data operating system and machine system in an intelligent system to manage energy efficiency in The public sector was integrated as part of the smart city concept. This paper also uses the technological requirements to create such a platform that can be used by the public sector to plan the reconstruction of public buildings, reduce energy consumption costs, as well as connect such buildings as part of smart cities [1]. Harkouss et al. (2018), in an article entitled Multi-objective optimization method for buildings with clean and effective energy, found that in designing a building with clean energy, finding the best combination of design strategies is the most critical challenge that faces energy performance problems of a particular building. . In this paper, a method for multi-criteria optimization based on the simulation of the above way is presented. It consists of four stages: building simulation, optimization process, multi-criteria decision making, and the proposed solution's strength. The analysis results clearly show that, regardless of the weather, to design this method in a residential home, it is necessary to minimize the minimum heat load of the environment through passive strategies that are achieved with confidence [2]. Lorena Tuballa and Lochinvar Abundo (2016), in an article entitled "Review of the Development of Smart Grid Technologies," reviewed the smart grid with its general features, functions, and specifications, which provided a basic technology related to Smart Grid and research activities, challenges and Have identified issues. This shows how these technologies have shaped the modern power grid and have continued to evolve and strengthen their role in better aligning energy supply and demand [3]. Mogles et al. (2018), in an article entitled Behavioral Interaction Design of Energy Changes for a Computational Model, examined the creation of a structure to fit different types of models and the use of a simulation model as a tool for evaluation, which influences consumption decisions.

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According to the results, the proposed model can predict energy-saving behavior much better than existing random models and accurately estimate the effect of accepted technologies. Also, the analytical model can be turned into a decision-making system adapted to changing energy behavior [4]. Mohammadi et al. (2018), in an article entitled Integration of smart energy hubs in distribution networks considering the concept of demand response and uncertainty to a new optimization framework based on the information gap decision theory approach and a combined scenario to investigate and The study of the optimal performance of smart energy hobbies concerning economic priorities, technical limitations of the distribution network and the presence of uncertainties. Considering energy hubs equipped with innovative installations, demand-side management programs, including price response and load response services, have been made available to motivate consumers to renew consumption patterns and meet the energy hub's economic priorities.Using the hybrid uncertainty modeling approach results, the intelligent energy hub operator can adopt risk-taking and risk-avoidance strategies against uncertainties [5]. Haider et al. (2017), in an article entitled "Responding to the demand response of the smart residential network," examined the response to the demand to manage the need to adapt to existing energy sources without adding new production capacity. The results show that most demand response schemes arise from an external problem that includes the effectof the high level ofel consumption of subscribers on the price rate of other subscribers, especially in the peak consumption period—presented[6].Joo and Chol (2017), in a paper entitled Energy Management of Multiple Smart Homes with Distributed Energy Sources Based on Divided Optimization Standard, present a distributed optimization algorithm for scheduling the energy consumption of multiple smart homes with shared energy resources (separation of devices). This study demonstrates the simulation of a proposed distributed algorithm in terms of power cost and consumer convenience level based on the performance of the centralized algorithm. This paper also analyzes the effect of different grid topologies on the proposed algorithm. As a result, a model for selecting the optimal grid configuration concerning cost savings is presented [7].

## 2. Research method and field

This article intends to model the energy consumption behaviors of individuals with the help of the presented expert system. In this article, energy consumption behavior is studied, and its statistical population is selected from people of different genders and ages in different environments. The tool used is based on Excel software. According to the purpose of this article, the factors affecting the energy consumption behavior of people in the environment should be identified first. Then the existing laws should be extracted and validated by examining the observations. Therefore, the factors affecting consumption are identified. Considering that the primary purpose of the research is to present a model of rules with the help of a set theory of questions, a summary of the set theory of these questions and the basic concepts related to it are described. Then, with the modeling process of the existing idea, it continues with the help of data on the behavior of people in selected environments. Finally, the outputs of implementing different models are presented using the software. Finally, a comparison between the results of the models in terms of temperature determination and energy consumption and optimization is performed.

### 2.1 Smart temperature validation

To validate this article, the standard for determining the thermal indices of PMD and PPD and local thermal comfort criteria have been used. For this purpose, several validation rules have been validated. This validation is acceptable compliance with the mentioned standard [8].

### 2.2 Predicting average thermal votes

PMV is an index used to predict individuals' average temperature based on a seven-point scale for thermal sensation (Table 1). The PMV index is based on the thermal balance of the human body [8].

**Table 1.**The seven-point scale brackets heat sensation [7].

| Thermal index | temperature (degrees Celsius) |
|---|---|
| Hot | +2 |
| A little hot | +1 |
| Neutral | 0.0 |
| a bit cold | -1 |
| Cold | -2 |
| Very Cold | -3 |

The PMV index can be calculated from Equation (1).

$$PMV = (0.303e^{-0.036M} + 0.028)\Big\{(M-W) - 3.05 \times 10^{-3}[5733 - 6.99(M-W) - Pa\,] - 0.42[(M-W) - 58.15] - 1.7 \times 10^{-5}M(5867 - Pa\,) - 0.0014M(34 - ta\,) - 3.96 \times 10^{-8} fcl\,\Big[(tcl + 273)^4 - \big((tr\,) + 273\big)^4\Big] - fcl\, h_c(tcl - ta\,)\Big\} \quad (1)$$

In this regard, M is the metabolic rate in terms of (W/m$^2$), W is the adequate mechanical power in terms of (W/m$^2$), $I_{C1}$ is the insulation of clothing in terms of (m$^2$.K/W), $f_{C1}$ is the surface area factor of clothing, $t_a$ is the air temperature. (°C), $t_r$ average radiant temperature in (°C), var relative air velocity in (m/s), $P_a$ partial vapor pressure in (pa), $h_c$ heat transfer coefficient in (w/ (m2.k)), $t_{c1}$ with the surface temperature of the garment in terms of (°C) [8].

### 2.3 Quantitative prediction of individuals

PPD is an indicator for quantitatively predicting the percentage of people dissatisfied with feeling cold or hot. According to international standards, thermal dissatisfaction includes handling very hot, warm, cold and very cold. If the PMV value is known, the PPD index can be estimated from Equation (2) [8].

$$PPD = 100 - 95\exp(-0.03353PMV^4 - 0.2179PMV^2) \quad (2)$$

Figure (1) shows the relationship between these two thermal indicators. PPD can estimate the number of people who feel dissatisfied with heat. The rest of the people feel relatively good. The distribution of individual heat sensation is shown in Table (1).

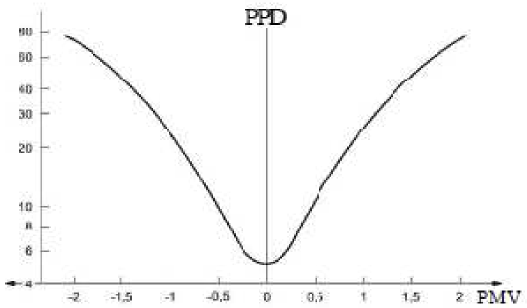


**Fig. 1.**PPD is a function of PMV [7].

### 2.4 Smart temperature validation

For example, in this section, three items of rules are given, and according to the relationships and tables in the standard, the amount of PMV and PPD is determined, and according to the standard, PMV values are between -0.5 to +0.5, equivalent to 90% of residents' satisfaction with the temperature situation. Is the environment [8].

**Rule 1:** If the age is old and there is little cover, and the percentage of humidity is high, the outside temperature is cold, and the number of entries is medium, and the body mass index is low, set the temperature at 23.5 degrees.

**Rule 2:** If the age is old and has medium coverage and the percentage of humidity is low, and the outside temperature is moderate, and the number of entries is low, and the body mass index is standard, set the temperature at 24 degrees.

**Rule 3:** If the age is young and has medium coverage and the humidity is high, and the outside temperature is warm, and the number of entries is high, and the body mass index is high, set the temperature at 17 degrees.

### 2.5Validation result

According to the above information, the amount of PMV and PPD for each of the rules and the ideal temperature in these rules according to the satisfaction of individuals are given in Table (2).

As can be seen in the table, there is only a difference of 0.5 degrees between the existing rules in the second rule, and the results, given that the PMV value is in the range of 0.5 to -0.5, indicate that the expert system and the determination temperature Operated properly by this system.

**Table 2.**Determine the appropriate PMV and PPD based on the ideal temperature

| Rules | Certified temperature | Ideal temperature (C °) | PMV | PPD (%) |
|---|---|---|---|---|
| Law 1 | 23.5 | 23.5 | -0.02 | 5.006 |
| Law 2 | 24 | 23.5 | -0.13 | 5.352 |
| Law 3 | 17 | 17 | -0.001 | 5.001 |

### 2.6 Rules if- then

The if-then rules are presented in the model and are the knowledge base, which is designed according to the questionnaire and consultation with experts. Given the existence of six factors, there will be 1215 rules. Due to the constraints ahead, a more limited number of regulations are analyzed, for example: "Set the temperature to 24 degrees."

### 2.7 Trapezoidal membership function

In this paper, the fuzzy membership function is used for the intervals of each of the six effective parameters. A fuzzy number like $\tilde{A}$ is actually a standard, convex fuzzy set in R (the reference set of real numbers).

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-a}{b-a} & if \quad a \le x \le b \\ 1 & fined \ if \quad b \le x \le c \\ \frac{d-x}{d-c} & if \quad c \le x \le d \\ 0 & otherwise \end{cases} \qquad (3)$$

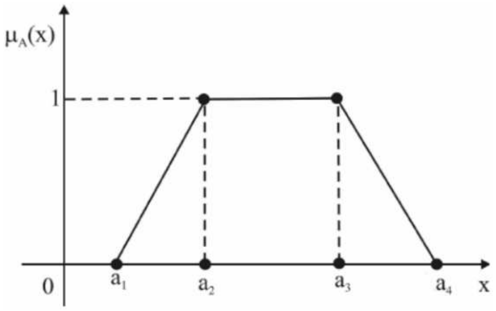


**Fig. 2.**Fuzzy trapezoidal numbers

### 2.8De-fuzzy

Fuzzg can be calculated by the undefined mean method according to Equation (4).

$$\begin{aligned} A_{max}^{(1)} &= \frac{a_1 + a_M + a_2}{3} \\ A_{max}^{(2)} &= \frac{a_1 + 2a_M + a_2}{4} \\ A_{max}^{(3)} &= \frac{a_1 + 4a_M + a_2}{6} \\ Z^* &= \left\{A_{max}^{(1)} + A_{max}^{(2)} + A_{max}^{(3)}\right\} \end{aligned} \qquad (4)$$

In fuzzy logic, fuzzy sets define linguistic concepts, and membership functions represent the correct value of such linguistic expressions. The degree of membership of an object in a fuzzy set sets its value between 0 and 1. One means being a group member, zero means not entirely in the background, and other values mean that it is partially in the environment. Are located. The degree of membership of an object in a fuzzy set is defined as a function in which the subject matter is the same range and distance [0,1] as the same range.

### 2.9Statistical Society

The statistical population of this article is the residents of small-scale residential buildings and experts in construction and housing, whose number is limited and less than 450 people, so according to previous research, the Delphi questionnaire has been used in this article.

## 3. Modeling and design of the fuzzy expert system

Considering that this research aims to design an expert system and present a model, a design method for measuring people's satisfaction with the optimal temperature is given according to six factors, an expert system used in all residential buildings.

Model inputs are the same six factors determining residents' emotional characteristics (age, body mass index, coverage, humidity, outdoor temperature, and number of users).

**Table 3.** Comparison of the methods used in the research.

| Title | Range of values | Question |
|---|---|---|
| Age | {Young, middle-aged, old} | How old are the people in your house? |
| Body Mass Index (BMI) | {Low, medium, high} | What is the ratio of weight to height squared in the household? |
| The amount of coverage | {Too low, low, medium, high, very high} | What is your usual coverage at home? |
| Humidity | {Low, medium, high} | What is the average humidity in your city? |
| Outdoor air temperature | {Cold, temperate, warm} | What is the approximate temperature outside your home? |

### 3.1 Membership function used for coverage

The first input is the coverage of different people, divided into five groups (very low, low, medium, high, and very high). Its trapezoidal membership function is symbolically shown in Figure (3).

### 3.2Membership function used for age

The second input is the age of different people, divided into three age groups (young, middle-aged, old), and symbolically, its trapezoidal membership function is shown in Figure (4).

### 3.3Membership function used for outdoor temperature

The third input is the age of outdoor temperature in different people, divided into three temperature groups (cold, temperate, hot), and its trapezoidal membership function is symbolically shown in Figure (5).

### 3.4Membership function used for body mass index

The fourth input is the body mass index in different people, divided into three proportional groups (low, medium, high), and its trapezoidal membership function is symbolically shown in Figure (6).

### 3.5Membership function used for air humidity percentage

The fifth input is the percentage of humidity outside the house in different people, divided into three percentage groups (low, high). Its trapezoidal membership function is symbolically shown in Figure (7).

### 3.6Membership function used for several people

The sixth input is the number of people inside the house, divided into three groups of numbers (low, medium, high), and its trapezoidal membership function is symbolically shown in Figure (8).

### 3.7Rule output

According to the membership functions and based on the questionnaire and the expert system, the internal temperature of the house is obtained as an output. Table (4) gives a number of rules as an example and the output temperature is determined.

**Table 4.**Sample output temperatures based on six inputs

| Row | Rules | Inside Temp (°C) | Rules | Range of values | Question |
|---|---|---|---|---|---|
| 1 | If Clo Very Low And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | 26 | If Clo Very Low And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | {Young, middle-aged, old} | How old are the people in your house? |
| 2 | If Clo Low And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | 25.5 | If Clo Low And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | {Low, medium, high} | What is the ratio of weight to height squared in the household? |
| 3 | If Clo Medium And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | 25 | If Clo Medium And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | {Too low, low, medium, high, very high} | What is your usual coverage at home? |
| 4 | If Clo High And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | 24.5 | If Clo High And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | {Low, medium, high} | What is the average humidity in your city? |
| 5 | If Clo Very High And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | 24 | If Clo Very High And Out Temp Cool And Age Young And BMI Thin And Humidity Percentage Low And User Low | {Cold, temperate, warm} | What is the approximate temperature outside your home? |
| 6 | If Clo Very Low And Out Temp Moderate And Age Young And BMI Thin And Humidity Percentage | 25 | | | |

| | | | |
|---|---|---|---|
| | Low And User Low | | |
| 7 | If Clo Low And Out Temp Moderate And Age Young And BMI Thin And Humidity Percentage Low And User Low | 24 | |
| 8 | If Clo Medium And Out Temp Moderate And Age Young And BMI Thin And Humidity Percentage Low And User Low | 24 | |

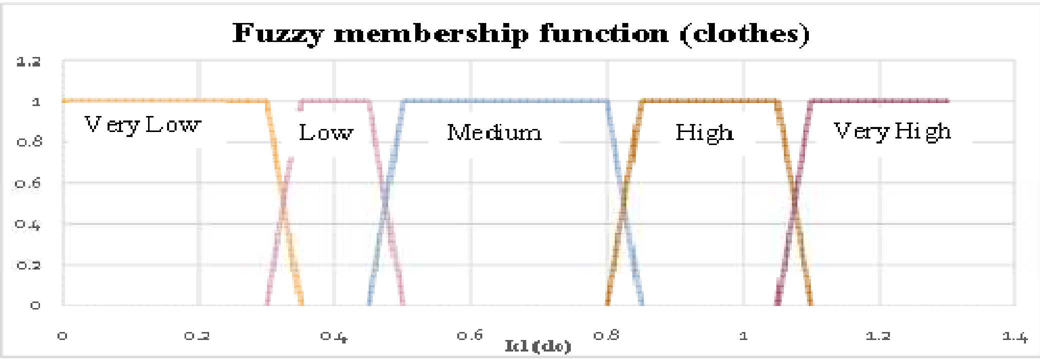


**Fig. 3 -** Trapezoidal membership function of coverage

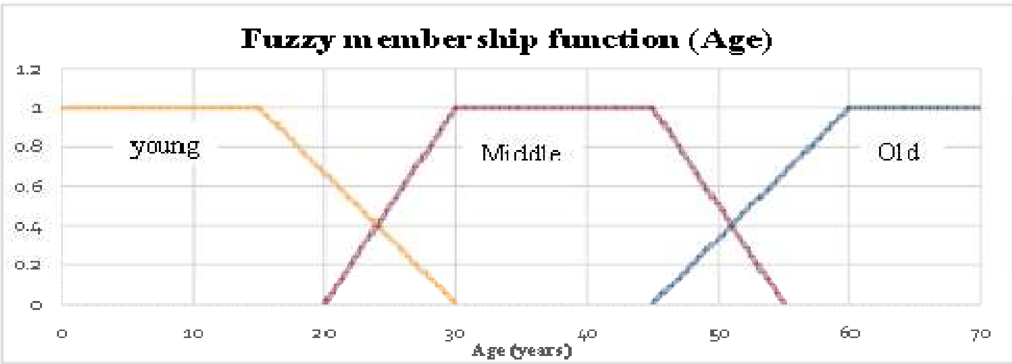


**Fig. 4 -** Age Trapezoid Membership Function

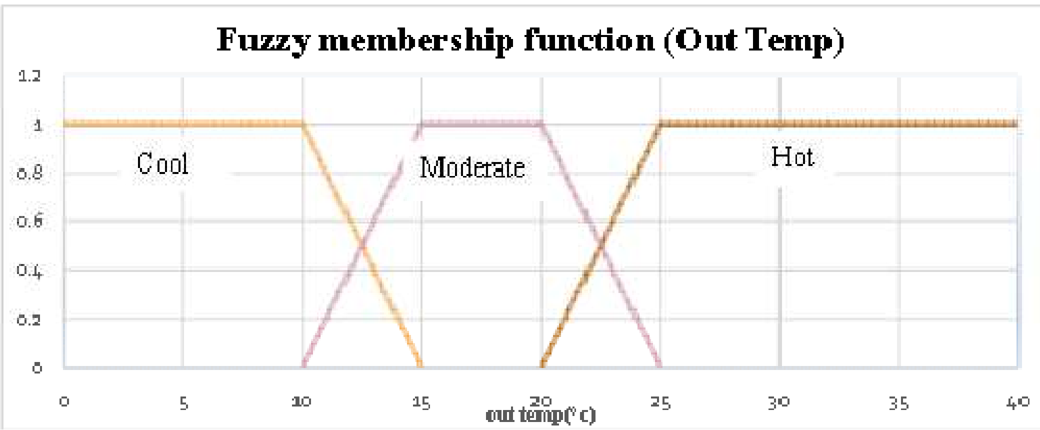


**Fig. 5 -** Outdoor air temperature trapezoidal membership function

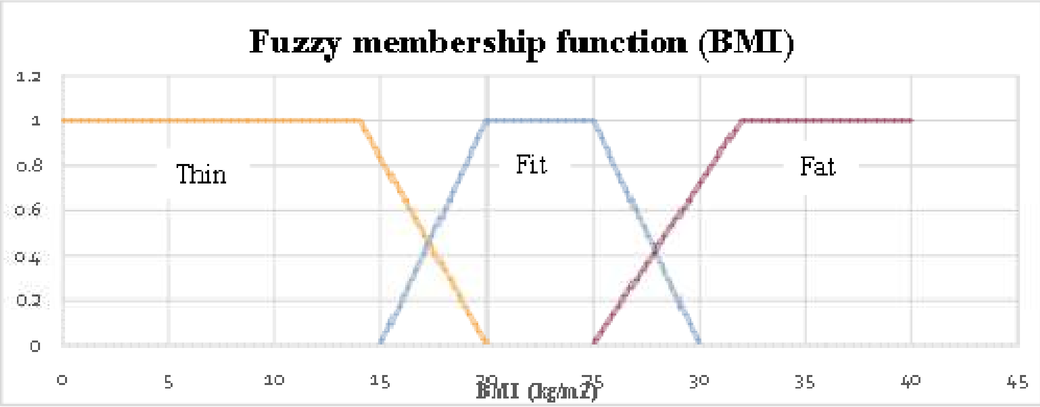


**Fig.6 -** Body mass index trapezoidal membership function

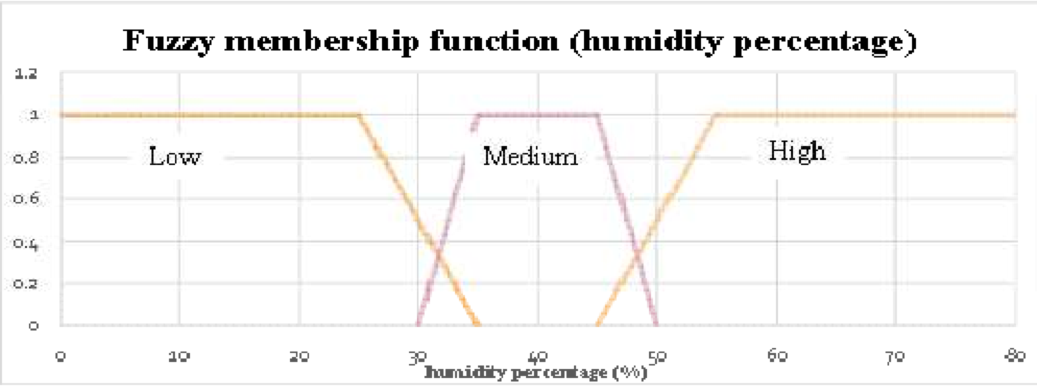


**Fig. 7 -** Air humidity trapezoidal membership function

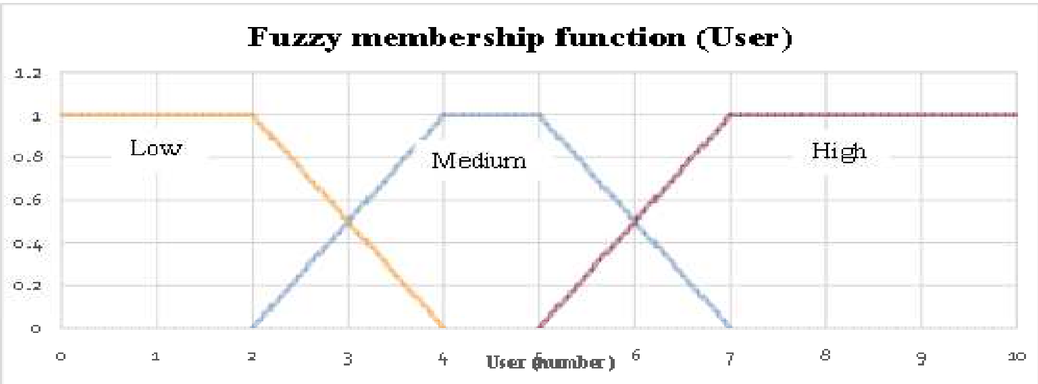


**Fig. 8 -** Trapezoidal membership function of the number of people

## 4. Interpretation of results and outputs

According to the expert system designed and written using the rules, some of which are given in Table (4), an intelligent output temperature determination system is written in Excel, based on six inputs' quantitative and qualitative values. According to the rules, it determines the output temperature. Figure (9) shows a view of the dashboard designed in Excel.

### 4.1 the amount of energy consumption

According to case studies, a gas cooler with a cooling and heating capacity of 50,000 BUT / h is generally required for a house with an area of 200 square meters. Because the scale discussion between the expert system design and the traditional temperature control system is discussed here, the high or low consumption of the air conditioner does not make a difference in this study. Therefore, according to the power consumption and thermostat in the air conditioner, a graph can be used for the consumption of air conditioners during a day based on the amount of consumption and according to the power consumption of the air conditioner and its specifications provided by the manufacturer in hot and cold days in Figure 10. Drew.

Figure 10 shows the amount of energy consumption in a consumer based on the manual temperature setting of 23 degrees Celsius on the hot day of the year and 28 degrees Celsius on the cold day of the year. Using the expert system and intelligent temperature adjustment based on it, the energy consumption can be shown in Figure (11). As can be seen in the diagram, the temperature changes according to the expert system every hour of the day and night according to the current conditions (six components of coverage, age, outside temperature, body mass index, humidity percentage and number of people entering). The opinion also changes the amount of consumption. In this diagram, considering that the temperature is likely to change every few minutes, the consumption rate has been obtained experimentally by measuring the power consumption (ampere meter) and has become the desired unit, i.e., the kilowatt-hour.

### 4.2 Compare charts

For better comparison and more detailed review of the results, the previous two graphs, namely the amount of consumption in the temperature setting mode manually Figure (10) and the amount of consumption based on the temperature setting in an intelligent way using the expert system and dashboard designed Figure (11) Are shown in Figure (12) for the hot day and in Figure (13) for the cold day.

## 5. Analysis of results and conclusion

According to the obtained diagrams and the designed intelligent system, the energy consumption per hour and night is significantly reduced. As can be seen, the energy consumption of the air conditioner on hot days of the year and the amount of heating energy consumption on cold days of the year using an expert temperature system has decreased by about 10% compared to traditional temperature regulation. According to the results, it can be said that using this system in the building can significantly optimize the amount of energy consumption and, at a low cost, reduce the amount of energy bill to an acceptable level within 24 hours. For future research, it is suggested that other emotional characteristics be considered to create the model. According to the obtained diagrams, it can be concluded that using this intelligent system designed while reducing energy consumption, the comfort of residents also increases, which can be seen exclusively in Figures 12 and 13.

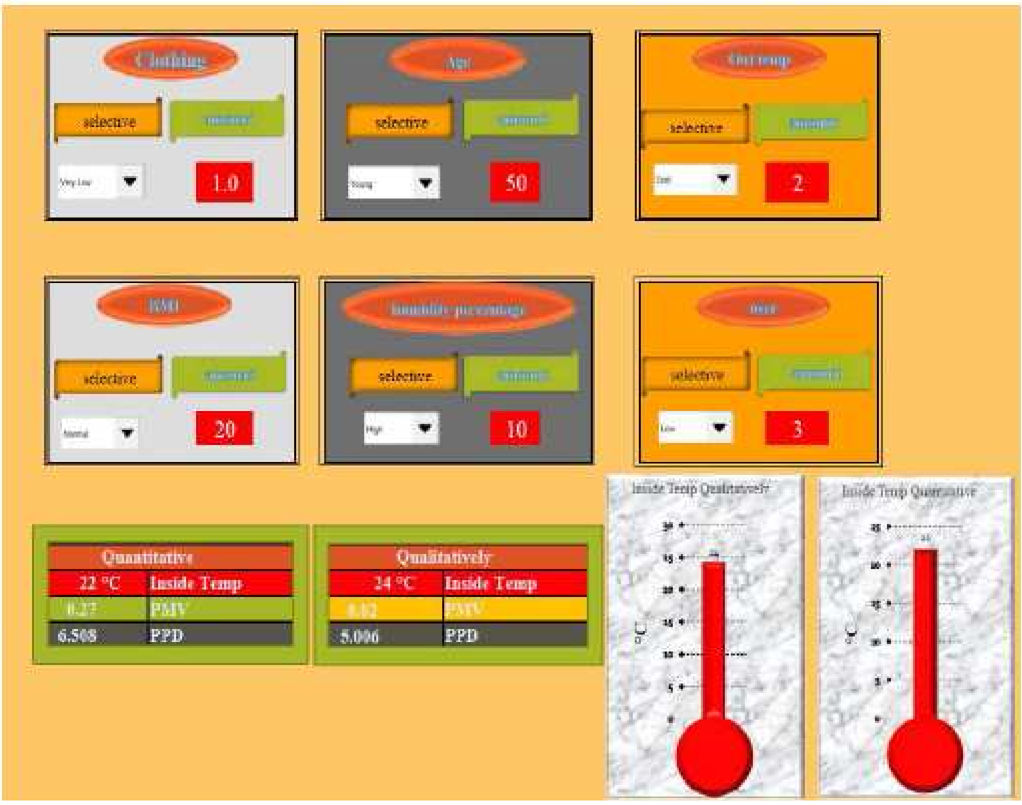


**Fig.9 -** Dashboard Determining the output temperature in Excel

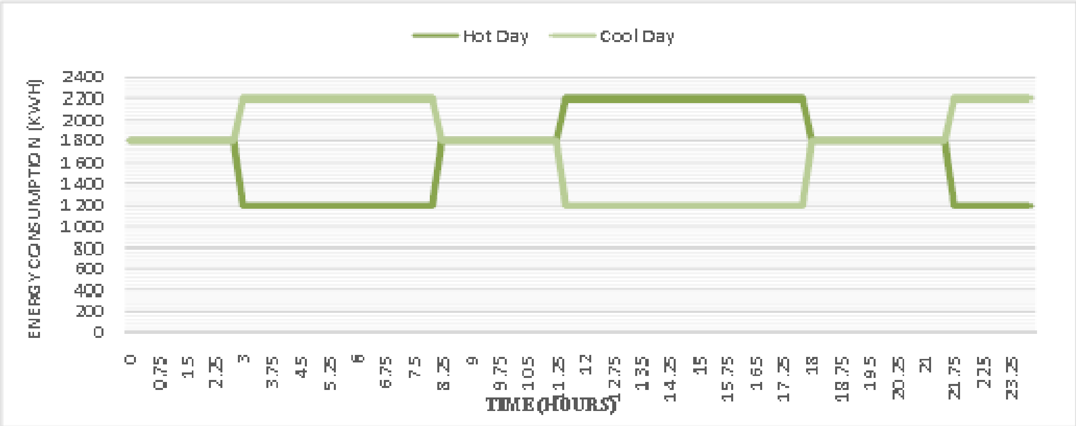


**Fig. 10 -** Cooling and heating energy consumption chart based on manual temperature adjustment

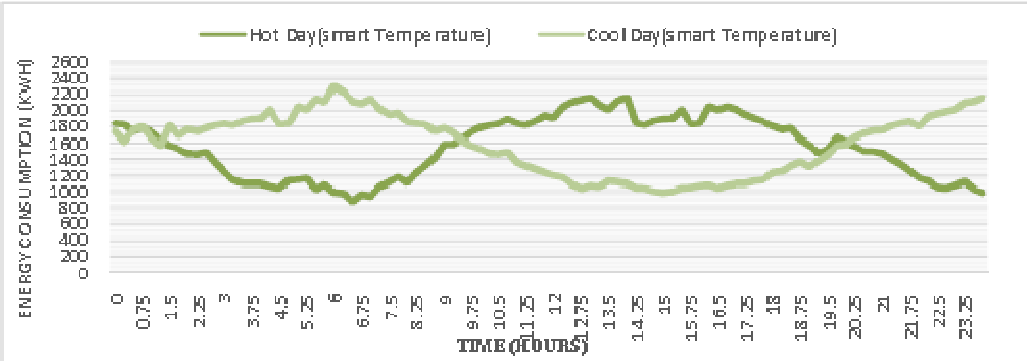


**Fig.11 -** Hairy cooling and heating energy consumption based on intelligent temperature regulation

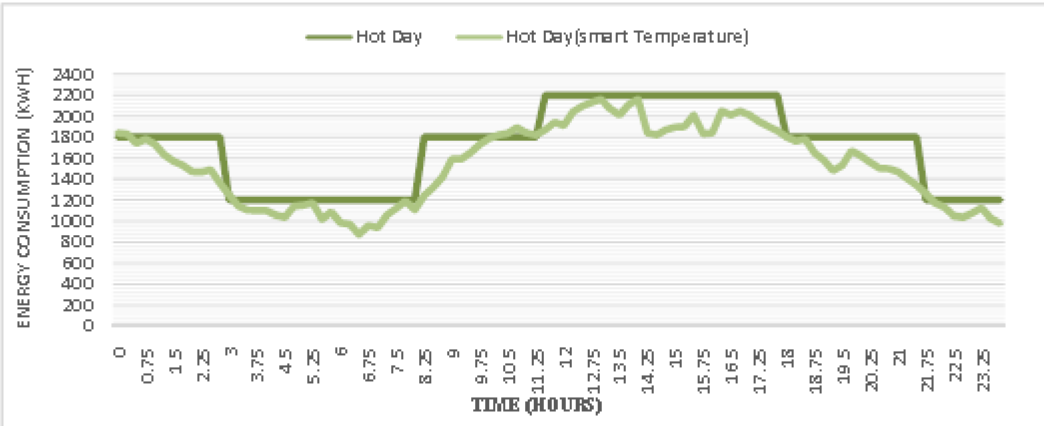


**Fig.12 -** Comparison of cooling energy consumption charts based on intelligent and manual temperature adjustment

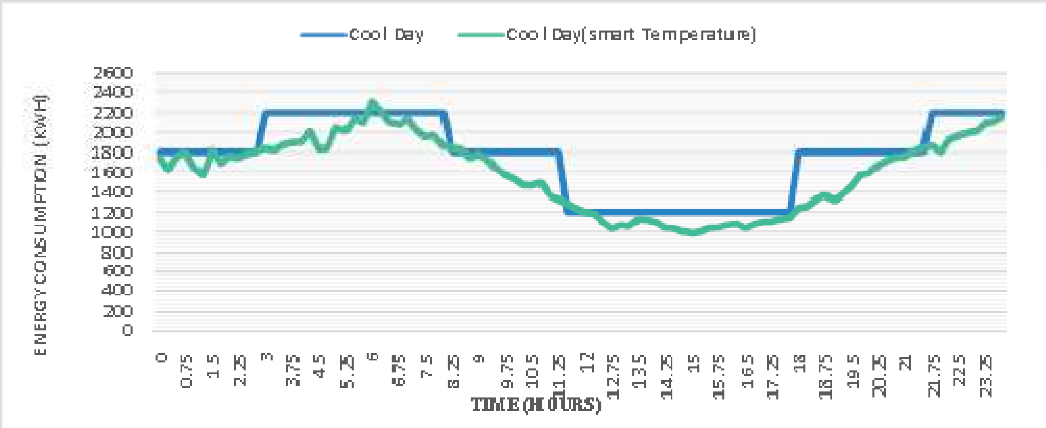


**Fig.13 -** Comparison of heating energy consumption charts based on intelligent and manual temperature adjustment

According to Figures 12 and 13, it is observed that in the time period of 12 to 18 hours, there is a fixed consumption pattern for manually adjusting the temperature, while by adjusting the temperature of the expert system per second, the consumption pattern changes based on residents' satisfaction and energy consumption decreases. Is. This problem can also be seen in the time range of 3 to 8 in the morning when the pattern of manual consumption is fixed, but energy consumption with an expert system reduces energy consumption based on people's comfort. According to the diagram of Figure 11, it can be seen that with the use of an intelligent and expert temperature regulation system, the temperature for the environment changes according to 6 inputs at any time, which makes the person always in the environment according to temperature conditions uniformity compared to temperature regulation. Experience a hand that is not subject to change with input changes.

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