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Application of adaptive fuzzy decision-making system for managing water consumption at smart house

Reza Mohammadi Jahan[1], Mohsen Daryani[1], Mehdi Azarafza*[2]

[1]*Department of Electrical Engineering, Faculty of Engineering, Maragheh Branch, Islamic Azad University, Maragheh, Iran*
[2]*Department of Computer Engineering, Faculty of Electrical & Computer Engineering, University of Tabriz, Tabriz, Iran*

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ABSTRACT

The purpose of this study is application of fuzzy-based decision-making system (FMCDM) method and a device for monitoring and controlling water consumption in a smart house used for water supply management (WSM) based on intelligent water management system (IWMS). This paper presents an algorithm applied for water demand consumption (WDC) optimization in regular household and its capability to evaluate the WDC range and decision and controlled WSM in critical circumstances. For this purpose, the heuristic decision-making method are used to monitor and control the WCM as effective IWMS methods based on artificial intelligence technology (AIT) and smart-learning multi-sensor. To program the device software, the MATLAB fuzzy logic programming software has been used. In order to assess the device's capability to respond to real conditions, a device is run to study sample-data for 24 hours a day for a month. In this study, four locations (kitchen, restroom, bathroom and garden balcony) are considered as the main WDC locations, then FMCDM algorithm are applied on these targets by main device. The results indicate that the first place (kitchen) has the greatest impact on WDC. However, the fourth place (garden balcony) has the lowest impact on WDC as well water consumption volume (WCV). Moreover, for analysis justification, the expert system (ES) is conducted as a comparison that shows the appropriate agreement with the FMCDM results.

1. Introduction

Most cities' water departments extricate water from sources where withdrawal surpasses energizing which is off-chance that our general public keeps on pulling back water at such an unsustainable rate. Absence of sterile frameworks to expel human water-waste from thickly populated territories causes genuine well-being concerns including loose bowels and intestinal worms, then poor water quantity/quality increases water scarcity worldwide risks (WHO, 2002; 2012). These issues have very unfortunate results which can be controlled by integrated management and sustainable development planning. Water demand in many countries around the world, especially in Iran is exponentially increasing due to the intrusion of many industries, lifestyle, health, hygienic cultures, etc. In order to respond to these waste water reasons, conservative planning is necessary to balance, control and manage demand-supply relation whereas demands increase day by day and supplying sources are thrown down. To this end, various researcher have presented diverse methods and equipment such as sea-water purification techniques (Nishida et al., 2017), water recovery and re-using (Vatankhah et al., 2018), wastewater treatment (Erkanlı et al., 2017) and water consumption control (Schultz et al., 2014). On the one hand, by developing artificial intelligence technology (AIT), refined analysis has expanded with high accuracy in various applied sciences and engineering fields induced many achievements and better results where one of these achievements is regarded in urban planning and resources management affected by an increase in urban population. As a result of this population growth, the

*** Corresponding author.**
E-mail address: azarafza.mehdi@gmail.com
M.Sc., Research Assistant.

balance between resources and consumption in urban areas will decrease (UNDESA, 2010). It affects the management of urban resources directly and supplies resources in different countries, especially in the developing and undeveloped countries which in turn increases demand for residential supplies, especially supply of drinking water (Kenny et al., 2009). Steady increase in demand for fresh water supplies by thousands of people in cities will put meaningful pressure on urban management in terms of economic, social, and public services (McDonald et al., 2011). On the other hand, shortage of water resources, water-quality, recycling technology and lack of experts take the city into the crisis. An intelligent water management system (IWMS) is recommended as the most effective method which provides an opportunity to promote traditional water management methods focused on application of optimal decision-based water consumption management (WCM) by utilizing renewable supplies, water-saving technologies, revised economic/political laws, appropriate national/local regulations as alternative strategies to manage residential water demands (Gleick et al., 2003). Various IWMS strategies have recently been applied to improve the state of the city's technologies offering promising results (Jorgensen et al., 2009). In fact, smart house projects utilize ubiquitous intelligence computation to control monitored home environments which is capable of momentary decisions, pattern recognition, and alarm systems, services using the remote-technology (Alam et al., 2012) to consume or save water in homes. These smart environments help local management of water consumption. The first idea of smart homes includes an incorporating smartness of comfort, healthcare, safety, security, and energy conservation (Lutolf, 1992). As mentioned, the concept of smart home is the integrating various services in a home using a common communication system which ensures economy, secure, comfort and energy conservation, including intelligent functional and flexible systems. According to Berlo et al. (1999) smart home is defined as an intelligent place with high technology that allows devices to be automatically controlled and provides appropriate services to the owner / users (Winkler, 2002). Briere and Hurley defined the smart home as harmonic, conglomerate, and capable based on controllable intelligent network (Briere and Hurley, 2007). Smart home's elaborated definition was illustrated in 2003 by Intertek as a dwelling incorporating of communication network that connects key electrical appliances and services and allows them to be remotely controlled, monitored, or accessed' (Alam et al., 2012). The ability to monitor and control smart home is WCM's potential strategy which is an appropriate alternative for IWMS application. The combination of the IWMS optimal decision making system with monitoring-based conservational technology of smart home can develop a heuristic decision-making operator to improve the WCM in a standard house. In smart homes, wireless technology is used to monitor and control home environment which could be modified for standard house and a smart system is implemented for the monitoring-based conservation such as saving energy (Keshtkar and Arzanpour, 2016) and water consumption (Gurung et al., 2015) which can be used for optimized decision-making to economic providence of resource consumption. In this study, we tried to propose a heuristic decision-making method based on artificial intelligence technology for WCM management to improve the existing traditional used in a standard house which applied smart-learning multi-sensor devices for monitoring and controlling the WCM as effective IWMS methods.

2. Intelligence decision-making system

Having presented the fuzzy set theory in 1965 by Zadeh (Zadeh, 1965), application of fuzzy logic has been extending rapidly in various sciences and many helpful contributions of this logical inference system in various fields such as linguistics (Bodenhofer et al., 2003), decision-making (Abdullah, 2013), and clustering (Li and Lewis, 2016. from mathematical aspect, the fuzzy sets are introduced in contrast to definitive sets (crisp sets) or classical set theory were fuzzy sets capability to get numbers/values set instead of a specific number/value where it can cover various uncertainties in analysis (known as uncertain sets). In the fuzzy set theory, all sets (M) consist of a main value (A) and the membership function (μ_A) is evaluated in the real unit interval [0,1] which can be used in a wide range of ambiguous information, imprecise data and intuitive assessment (Kahraman, 2008). If N is the crisp set with the n number of elements (N= {1, 2, 3, …., n}), M is fuzzified set form N when the universal set ($U=\{u_1, u_2, u_3, ..., u_n\}$) where μ is the applied membership function form of all elements of the standard set (Zadeh, 1965):

$$N=\{A_1, A_2, A_3, \ldots, A_n\} \quad (1)$$

$$\mu=\{\mu_1, \mu_2, \mu_3, \ldots, \mu_n\} \quad (2)$$

$$M=\{(A_1, \mu_1), (A_2, \mu_2), (A_3, \mu_3), \ldots, (A_n, \mu_n)\} \quad (3)$$

This ability to cover the uncertainties and ambiguous information in fuzzy logical inference system (FLIS) is the main idea in developing strategies to prefer optimal decisions from multi-groups and many alternatives used in this study to take appropriate decisions in order to achieve monitoring-based conservational IWMS results in smart houses. For this purpose, it is necessary to make a choice between several criteria in pairs or groups of uncertainty alternatives assessed as imprecise data from WCM in daily period. Multi-criteria decision-making (MCDM) is one of the well-known decision making subjects are highly flexible to the imprecise data solving where merged by FIS (Abdullah, 2013). Multiple-attribute decision-making (MADM) and multiple-objective decision-making (MODM) are two fundamental processes of MCDM involving the best alternative based on considering an interacting design constraint set which is able to consider the elements in a set ordered as weighted alternative correspondent of element's importance, sensitivity, effectiveness and solidarity. In weighed MCDM, the alternative score is associated with each attribute and assigned by a pair or group of comparisons based on expert system assessment (Wang et al., 2005). Bellman and Zadah (1970) take account of the main idea of fuzzy set theory for solving decision making-based problems as (Kahraman, 2008):

$$A'_f=B'_f \cap C'_f \quad (4)$$

Where A'_f is fuzzy decision, B'_f is fuzzy goal and C'_f is the fuzzy constraints. The membership functions can be defined as (Kahraman, 2008):

$$\mu_{A'fmax} = \mathrm{Max}\ [\mu_{B'f}, \mu_{C'f}] \quad (5)$$

$$\mu_{A'fmin} = \mathrm{Min}\ [\mu_{B'f}, \mu_{C'f}] \quad (6)$$

If we have i fuzzy goals and j fuzzy constraints then the fuzzy decision is defined as (Kahraman, 2008):

$$A'_f = B'_1 \cap B'_2 \cap B'_3 \cap \cdots \cap B'_i \cap C'_1 \cap C'_2 \cap C'_3 \cap \cdots \cap C'_j \quad (7)$$

$$\mu_{A'f max/min} = Max/Min\ [(\mu_{B1'f}, \mu_{B2'f}, \mu_{B3'f}, \ldots, \mu_{Bi'f}), (\mu_{C1'f}, \mu_{C2'f}, \mu_{C3'f}, \ldots, \mu_{Cj'f}) \quad (8)$$

In fuzzy multi-criteria decision-making (FMCDM), membership function is related to the fuzziness existing and is described based on expert system assessment. Expert system is an intelligent programming system includes inference engine module (IEM), knowledge-base module (KBM) and user-interface module (UIM) and is able to present the quantitative conclusion, recommendation or advice from some things or some functions based on qualitative factors (Rasmy et al., 2002). Fig. 1 shows the integration between AIT techniques and FMCDM. The expert system is used to solve different applications that can be modeled in MCDM and can provide expert view from any expertise to related works and taking the optimized decision to regional/local planning based on discrete alternative selection. This capability can be used comprehensively in IWMS implementations in smart houses to achieve optimal appropriate decisions to reduce requirement consumption in WCM.

3. Material and Methods

The study prepares adapted smart environment as simulated regular condition for water demand consumption (WDC) which is tried to apply of IWMS water-conservation implement and control mechanism for WDC in smart house capable to use as alarm system of excessive consumption or water waste detector. In order to achieve these aims, a multi-sensor based on FMCDM is prepared for these circumstances and devices considered as an intelligent agent, which monitored perceived and controlled the main WDC location in smart house using sensors and involved consequently controlling mechanism. To collect data, 4 spots of home are selected as WDC spots and monitored 24 hours a day (total time is 1 month) to evaluate the peaks of WDC in the house. The result of this evaluation is shown in Fig. 2. As shown in figure 2, WDC peaks are between 7:30 to 11:30 AM and 15:30 to 19:30 PM. considering these points as regular WDC in the house and any tolerance from this range, it then indicates shortcomings or excessive consumption. The FMCDM is applied for the WDC decision in a smart house where hardware framework for assessment is prepared as Fig. 3. Using a multi-sensor device for collecting data and monitoring WDC in the environment which provides interface encapsulation of FMCDM subsystem. To code the device, it is implemented under MATLAB fuzzy logic software (Godfrey, 2016). The FMCDM flowchart utilized in this study is presented in the Fig. 4. The user is able to interact with system and supervise in different applications and levels. Also, as shown in Fig. 3, the multi-sensor device is used as a mechanical concept of the FMCDM and utilized for WDC monitoring as well it controls building up a cover for water consumption at home. According to the FMCDM algorithm, water consumption limitations indicate the daily, weekly and monthly consumption continuously measured overnight. Any changes in this procedure demonstrate a water waste occurrence where the device acts as a warning agent. Figure 4 shows the approaches which the device is applied to analyze processing core in alarm system.

4. FMCDM to monitoring-controlling the WDC

Regarding Fig. 5, the most important water treatment centers at home are classified in kitchen, restroom, bathroom and garden balcony which are considered in this study as potential locations of WDC in standard houses. In fuzzy analysis, each of these locations is presented as a 'ZONE' for WDC. In IWMS water-conservation strategies, optimizing daily consumption and reducing consumption are essential parts. On the other hand, identifying and tracking excessive consumption (for whatever reason) are also necessary factors for saving resources. In developing countries such as Iran, the per capita consumption of resources is not clarified and managed as traditional way which evaluates descriptiveness and linguisticness (vague). Thus, all data collecting are conducted manually from each smart house where the data is imported into the assessment based on imprecise information. One of the most important benefits of FMCDM application is algorithm flexibility for responding the ambiguous values. Therefore, the algorithm can be implemented with a good accuracy. In order to utilize algorithm correctly, some assumptions must be considered as following characteristics:

- Whole shifting in WDC is concentrated in the specified areas (zones),
- Other house areas are deprived of water consumption directly,
- Depreciation of water in the outside pipes of houses is not intended and water transmissions in the pipes of these areas are monitored,
- The daily per capita consumption of the house is considered as same as the average monthly consumption of house,
- Rise in the middle level of WDC is introduced as the problem cause,
- Each zone is considered independently in WDC.

4.1. FMCDM-based algorithm inputs

The FMCDM does not require much ground data and information of restriction, and the range of changes in WDC values are considered as the input parameters accomplished for daily modification in terms of monthly average per capita consumption. Moreover, the house's WDC peaks are intended to accurate computational errors.

4.2. FMCDM-based algorithm outputs

Outputs of algorithm are recognized as a specified classification related to ambiguous information used as input data. This classification is shown in Fig. 5. Based on this figure, the 'Low consumption' is good stats and 'High consumption' is critical of WDC as IWMS identification. These features are considered as fuzzy simulation output and decision-making for each zone in a house. Therefore, each zone is independently affected by water consumption measured from entire system.

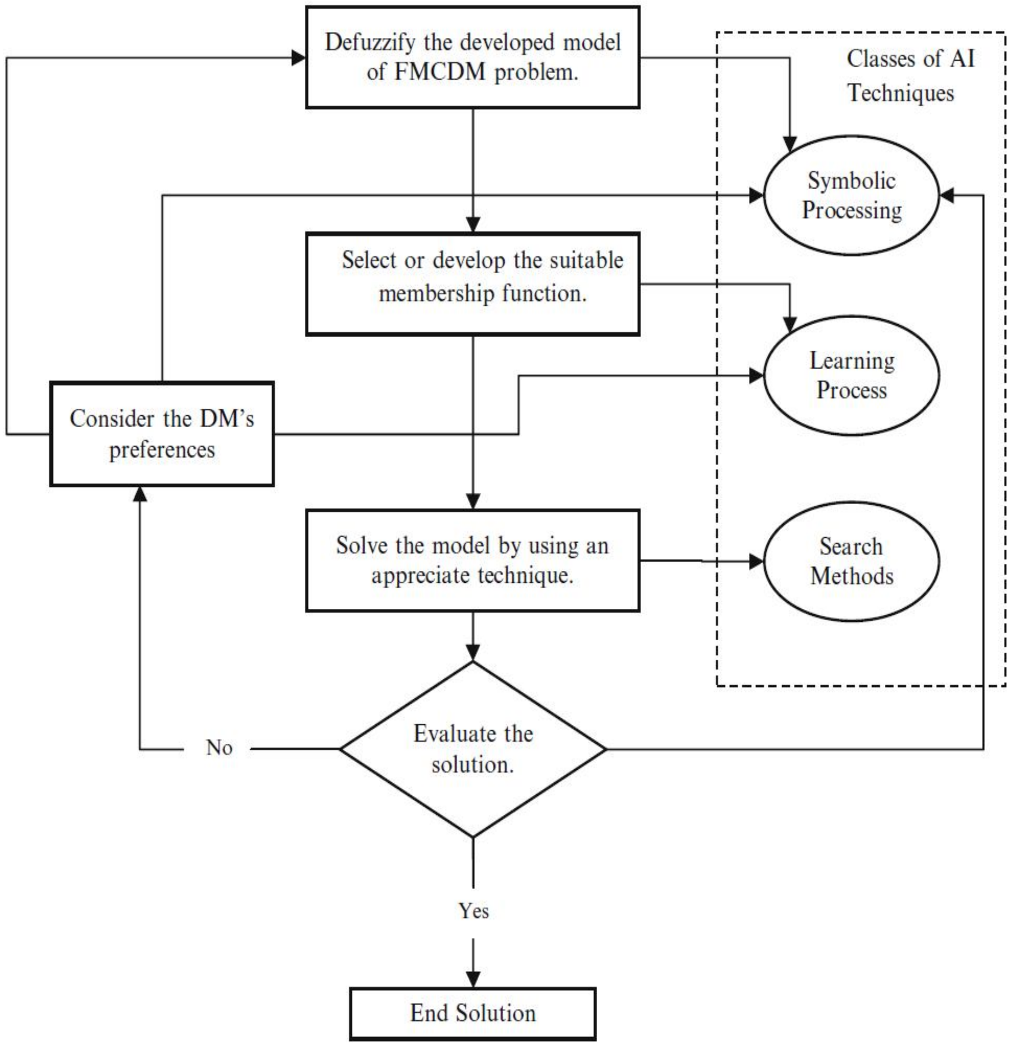

Figure 1. The FMCDM and AIT coalition (Kahraman, 2008)

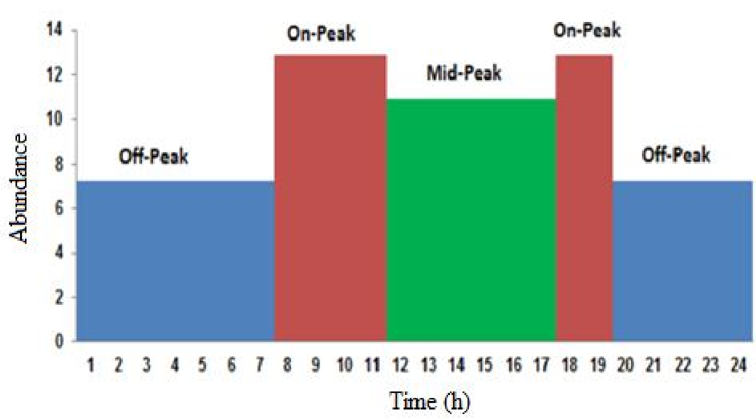

Figure 2. Results of data collecting from WDC in smart house (this study)

Figure 3. A view of the used device

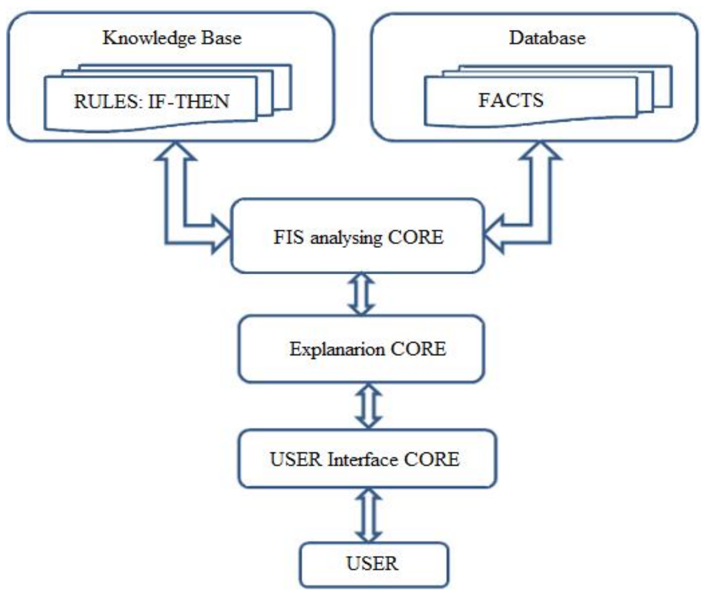

Figure 4. The processing flowchart in this study

For the final decision, each zone is defined by different rules applied for measured water consumption data. The results are estimated independently relative of time and average information obtained from monitoring for each zone. At the end, decision of the entire system is utilized in device calculation procedure for critical conditions. If the results increase on high consumption category of the zone after removal of noise (system tolerance due to the probability of mixing the related criteria with each other) and estimation of waste-water of WDC, the resources of that zone are discontinued.

Figure 5. Definition of output considered in FMCDM decision

5. The algorithm application

According to the above statements, it has been attempted to simulate WDC based on FMCDM of water consumption from different zones in the smart house. The membership function plots of these zones are presented in Figs. 6 to 10 which are representations of graphical status of each zone for daily per capita consumption in an independent and time-depended way. According to these figures, the zones affect differently on entire system evaluated results. However, in general, the trend for system assessment and zone 1 (kitchen) have the greatest and zone 4 (garden balcony) has the lowest impact on WDC. These results are confirmed the measured data from the real condition of device monitoring.

6. Evaluation Cases

In order to assess the device ability to respond to real conditions, the algorithm is run to study sample-data. For this end, the smart home is prepared and the equipment is connected to the house monitored for a month 24 hours a day and collected data to achieve average WDC in house. The data are gathered over 7 different periods and each period is took a week of continuous water meter dataset from pipelines indicating water consumption volume (WCV). Moreover, the time is recorded to evaluate the time-dependency of WCV. The results of monitoring from zones are shown in Fig. 11.

Regarding Fig. 10, controlling limits for WDC were prepared from the IWMS, the results of the controlling mechanism for WDC from house is illustrated in Table 1. According to the results of Table 1, zone 1 has the highest effect and zone 4 has the lowest effect on WDC from smart house which was in an appropriate confirmation with the FMCDM results. Furthermore, for justification of final results, the expert system is conducted as the specialist controlling assignments. The results of the expert analysis also provide good results compared with final results, which emphasizes on success of device and the proposed algorithm. These tips show good accuracy and performance of algorithm and prove that devices were capable to be used for smart or regular houses.

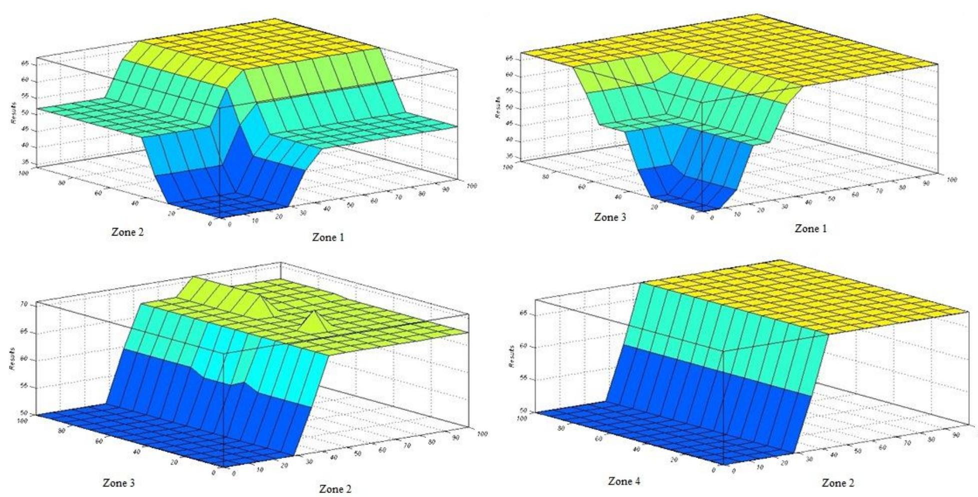

Figure 6. Graphical status zones variation in smart home

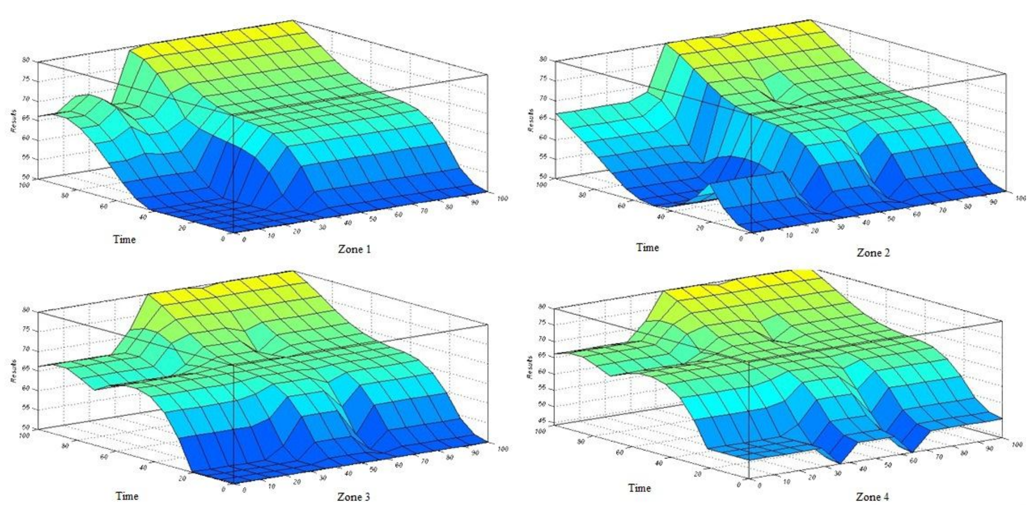

Figure 7. Per capita water change for zones during the daily period

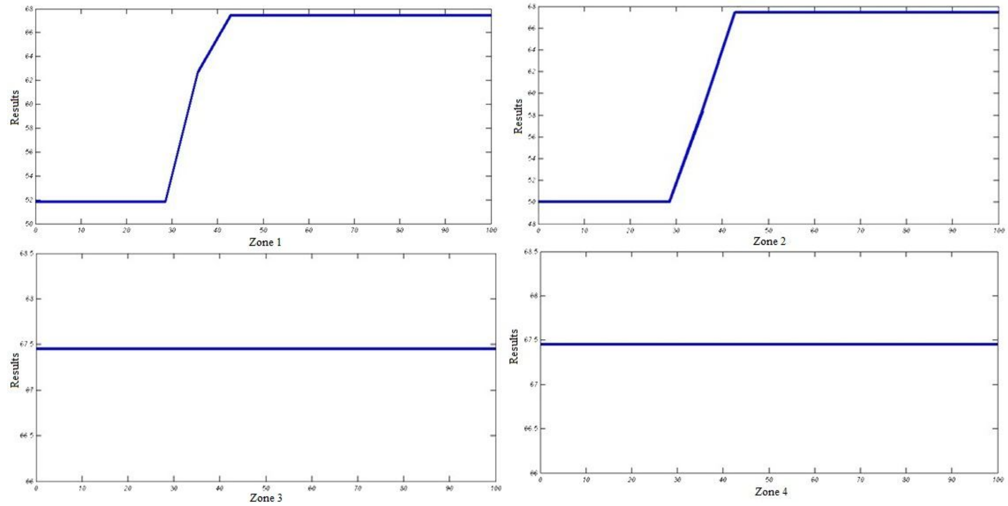

Figure 8. Per capita water consumption zones per day

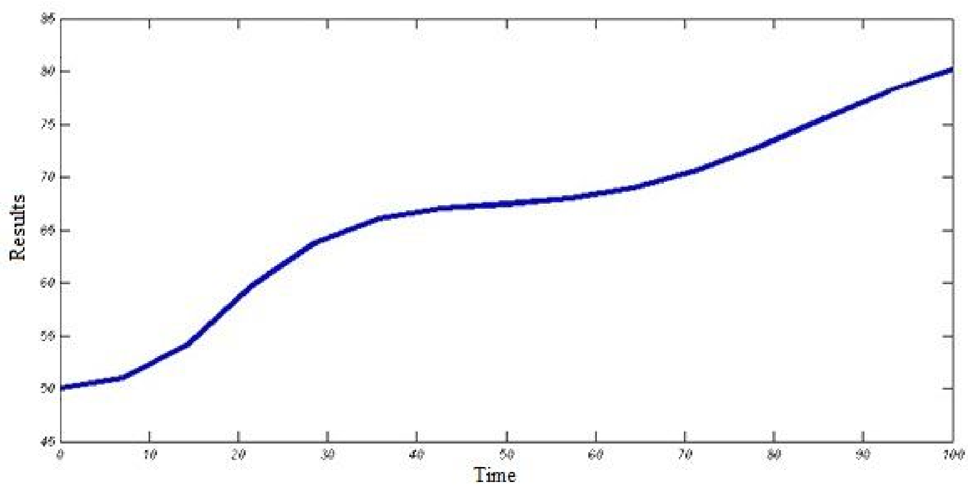

Figure 9. Influence of WDC in water management at home

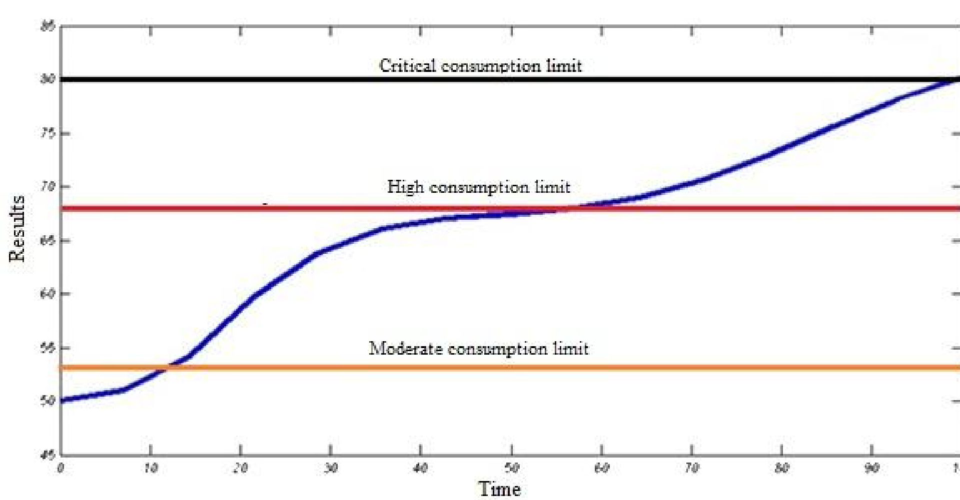

Figure 10. The results of device for WDC based on IWMS in smart home

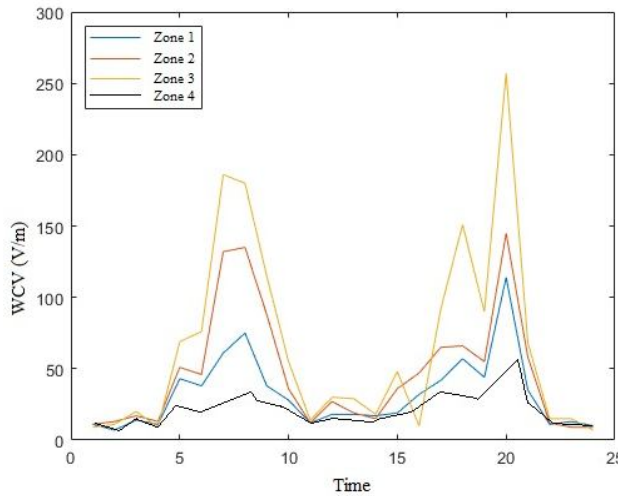

Figure 11. The results from device monitoring of WCV in smart home

Table 1 Results of study cases from smart home (ave.)

Time	WCV	FMCDM	ES	Time	WCV	FMCDM	ES
1	20	Low	Low	13	27	Low	Low
2	18	Low	Low	14	18	Low	Low
3	25	Low	Low	15	51	High	High
4	15	Low	Low	16	44	Moderate	Moderate
5	33	Moderate	Moderate	17	65	High	High
6	51	Moderate	Moderate	18	110	High	High
7	48	Moderate	Moderate	19	132	High	High
8	53	Moderate	Moderate	20	200	High	High
9	180	High	High	21	67	High	High
10	57	Moderate	Moderate	22	46	Moderate	Moderate
11	35	Moderate	Moderate	23	18	Low	Low
12	42	Moderate	Moderate	24	11	Low	Low

7. Conclusion

Nowadays, concerns about over excessive water consumption in urban communities are growing rapidly. This fact has led to the consideration of managing water resource approaches focused on water consumption management and engineering. Using smart houses and systematically using water management are the most effective ways to reduce water loss and drinking water management. FMCDM-based strategy is used to monitor and control the WDC at smart home regarding developing heuristic decision-making method based on AIT and smart-learning multi-sensor devices as one of the effective IWMS methods. For this purpose, the algorithm is implemented by MATLAB fuzzy logic software, and it is tested in real conditions. The regular house is transformed into smart homes by installing equipments. Steps of monitoring and controlling are applied to recognize the WDC pattern in house. During monitoring stage, the time-based WCV is recorded to evaluate the average WDC monthly from 24 hours a day. At the controlling stage, according to the IWMS familiar with pattern, three restrictions are defined to restrict the WDC. Then make sure that the machine crosses any of the limits and announces it to the users (these restrictions could be redefined or changed). In critical situations, depicting wasting water or lost water, the machine is involved and it disables the accessible area immediately. The results of real condition test are justified to assessment of accuracy and performance by expert system which has appropriate agreement with the FMCDM results. According to the results, in 9 A.M., 3 P.M., 5- 9 P.M. are considered as the most possible occurrence of WCV in which zone 1 has the highest and zone 4 has the lowest effect on WDC.

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