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ENERGY CONSERVATION AND COMFORT MANAGEMENT IN BUILDING ENVIRONMENT

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Abstract. *Today energy conservation in building sector is a major subject of interest to the research community. A number of applications proposed and exist in the literature, but the trade-off between users comfort index and energy consumption is still a major challenge to the researchers. In this paper we propose energy conservations and comfort management model in building environment using Multi-Island Genetic Algorithm (MIGA) and Genetic Algorithm (GA). The focus of our paper is to increase occupants comfort index and minimize energy consumption simultaneously. The input of the fuzzy logic is the error difference between real environment and user set parameters. To minimize the required output power of the fuzzy, we need to minimize the error difference. To do this, the input parameters of the fuzzy are optimized using MIGA/GA. After optimization, the error difference between MIGA/GA optimal parameters and environmental parameters becomes small as compare with the error difference between without-MIGA/GA parameters (without optimization) and environmental parameters. This small error consequently minimizes the required power with respect to the occupant's comfort index and available power. The results show the effectiveness of the proposed model in increasing the occupant's comfort index and minimizing energy consumption.*

Keywords: Energy management in buildings, Comfort index, Multi-Island Genetic Algorithm, Genetic Algorithms, Energy saving, Fuzzy logic

1. **Introduction.** Energy conservations and occupant's comfort index are two important design objectives in future building environment. Reason is that, in energy consumption sectors most of the energy is consumed in building environment. The energy consumption increases day by day and its sources of generations are less and expensive as well. On the other side occupants of the building want to consume less energy without compromising the comfort index. This requirement of minimum energy consumption without compromising users comfort index is a challenging problem to the research community. The problem leads to the trade-off between energy consumption and occupants comfort index [1]. To address this trade-off a control system is much needed to maintain both energy conservation and occupant's comfort index simultaneously.

The fundamental three parameters which determine occupant's quality of lives in a building environment are thermal comfort, visual comfort and air quality [2]. Temperature indicates the thermal comfort of the occupant's in a building environment. The auxiliary heating or cooling system is applied to preserve the temperature in a comfortable area of the building. The illumination level is used to indicate the visual comfort of the occupants in building environment [3]. The electrical lighting system is used to manage the visual comfort. CO2 concentration is used as an index to measure the air quality in the building environment. Ventilation system is utilized to keep low CO2 concentration

[4]. So the combination of these three parameters can serve as an occupant's comfort index in buildings. We will consider these three parameters to evaluate the occupant's comfort index in building environment.

In the literature many works have been presented in the area of energy savings and some valuable energy conservation systems have been proposed. Approaches based on conventional control systems have been introduced in the previous works: Designers used Proportional Integral Derivative (PID) controllers in order to overcome the overshoot of the temperature [5]. Other conventional controllers proposed in the literature included optimal control [6] and adaptive control [7]. These conventional controllers have some disadvantages. They need a model of the building, they are not user friendly and there are many difficulties in monitoring and controlling the parameters caused by nonlinear features. An optimized fuzzy controller applied for the control of environmental parameters at the building zone level has been proposed in [8]. In this method the occupants' preferences are monitored via a smart card unit.

Other proposals in this connection are predictive control approaches [9,10], where weather predictions have been applied to heating, ventilating and air conditioning system. A multi-agent control system with information fusion has been devised in [11]. They proposed a building indoor energy and comfort management model based on information fusion using ordered weighted averaging (OWA) aggregation. They achieve a high level of comfort with minimum power consumption. The perceived comfort in office buildings is strongly influenced by several personal, social and building factors. The relationship between these factors are complex, so to get a better understanding of the relationships between these factors a proposal has been presented in [12]. A method presented in [13] proposed a comfort classification indexes suitable for both single environment and whole buildings. The methodology allows evaluation of both energy consumption and polluting impacts and takes into account comfort conditions of indoor environment and outdoor climate.

GA (Genetic Algorithm) has been applied for energy management in many ways, like GA adopted for heating, ventilation and air-conditioning (HVAC) control problems [14]. This method also is applied to the control problems of energy systems consisting of fuel cells, thermal storage, and heat pumps [15]. Another author applied GA to investigate multi-objective (building energy cost and occupant thermal discomfort) problems to identify the optimal pay-off characteristics [16]. One of the authors applied GA to mixed integer and nonlinear programming problems in an energy plant in Beijing and made a detailed economic investigation by changing the economic and environmental legislative contexts [17]. Application of GA for the optimization of the control parameters in parallel to hybrid electric vehicles (HEV) was described in [18]. The optimization problem was formulated for an electric assistant control strategy (EACS) in order to meet the minimum fuel consumption and emissions while maintaining the vehicle performance requirements. Another work proposed integrated algorithm based on GA, simulated-based GA, time series and DOE (ANOVA and DMLT) to forecast electricity energy consumption [19]. A method which demonstrated the application of GP to learn occupancy behavioral rules that predict the presence and absence of an occupant in a single-person office was proposed in [20]. An optimum scheduling strategy of cold water supply system in an intelligent building has been proposed in [21]. An integrated GA and artificial neural network (ANN) to estimate and predict electricity demand using stochastic procedures has been proposed in [22]. Optimal control strategies of variable air volume and air conditioning system were proposed in [23]. The control strategies included a base control strategy of fixed temperature set point and two advanced strategies for insuring comfort and indoor air quality (IAQ). The optimization problem for each control strategy was formulated

based on the cost of energy consumption and constrained by system and thermal space transient models. Supervisory control for hybrid solar vehicles proposed in [24], and some beginning tests have been performed on the road. An optimal design method for energy system of single building has been developed for the first time by establishing optimal design method for distributed energy system [25].

In this work, we proposed an optimized model for users comfort index and energy saving using fuzzy logic, coordinator agent and MIGA/GA. Our proposed technique addressed both energy savings and occupants comfort index simultaneously. MIGA/GA integrates in its fitness function the indoor occupants' comfort index and the corresponding energy consumption. MIGA/GA targets to satisfy the occupant's requirements along with minimal energy consumption. A range of user set parameters (temperature, illumination, airquality) which constitute occupants' comfort index in building [2] are selected and then optimized using MIGA/GA according to the user's comfort index. The error difference of optimal parameters and real environmental parameters is then input to the fuzzy controller. The output of the fuzzy controller is the minimum required power according to the user's comfort index. Coordinator agent takes required power (fuzzy controller output) and optimal parameters from the MIGA/GA as input. The coordinator agent adjusts the input power of the building on the basis of available power, required power and user comfort index. The adjusted power is compared with the required power to get the actual consume power. The actual consume power is input to the actuators to be consumed. All the work discussed above except [11] either addressed users comfort index in the building or consumed minimum energy, but not both. In [11], a multi-agent control system is proposed with information fusion. It addressed both occupant's comfort index and energy consumption simultaneously. The system they proposed is based on multiple agents and information fusion as compared with our proposed single agent based system. They used two optimizers, one for optimizing user's set points and the other for determination of degree of BUM function as opposed to our proposed model in which we used only one optimizer which is based on MIGA/GA and which optimizes user's set points according to the environmental parameters and user's comfort index. Our proposed model is simple and maintains the user's comfort index with minimum energy consumption similar to that of [11].

The organization of this paper is as follows: Section 2 describes GA and MIGA. In Section 3, we present optimization model using GA and MIGA to increase occupant's comfort index and save energy simultaneously. In Section 4, we show simulation results and discussion. The concluding remarks are given in Section 5.

2. **Genetic Algorithm.**

GA is evolutionary, search and optimization algorithm based on the principles of natural selection and genetics. The principals of GA technique are given by [26]. GA has been deployed to solve wide range of optimization problems where search space is too much large. GA evolves a population of initial individuals to a population of high quality individuals where each individual represents a solution of the problem to be solved. Each individual is called chromosome and is composed of a predetermined number of genes. The quality of fitness of each chromosome is measured by a fitness function as the quantitative representation of each chromosome's adaptation to a certain environment.

Determination of the following factors has the crucial impact on the efficiency of the algorithm and depends on the application: selection of fitness function, representation of individuals and the values of GA parameters (crossover and mutation rate, size of population, threshold of fitness value).

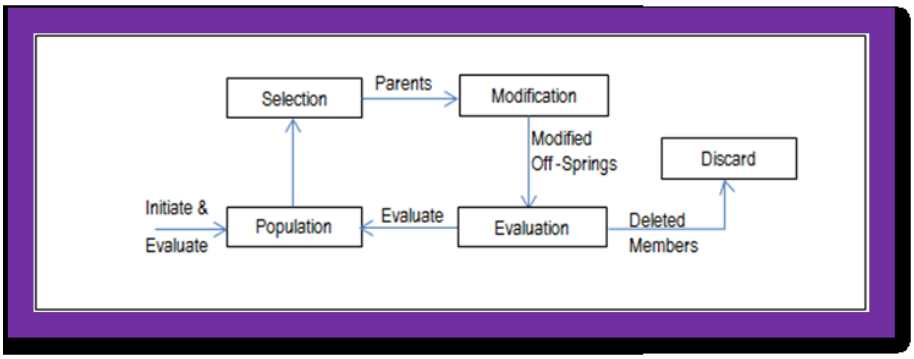

FIGURE 1. Genetic algorithm flow cycle

Figure 1 shows the flow cycle of the GA. First of all, initial population of chromosome is created. Then it is evaluated by using some fitness function, in our case we used Equation (3.1) for evaluation of chromosomes. Then selection of parent candidates is carried out for modification (crossover). In our case we used rank based selection to select parent candidates. Then after modification of parent chromosomes we got new chromosomes as modified off-springs, also called child chromosomes.

After getting child chromosomes we evaluate them against the fitness function that is Equation (3.1). Then after evaluation of child chromosomes some best chromosomes are selected for next generation and remaining weak chromosomes are deleted. The modification process also involved another method called "mutation". After some fixed iterations the algorithm performs mutation in which case the genes of the chromosomes are randomly perturbed. This enables GA to avoid getting stuck in local optima. Hence, GA searches for the best solution in multiple directions. This process of modification using "crossover" and "mutation" is continuing until the GA algorithm converged to the optimal solution or number of desired iterations completed.

Multi-Island Genetic Algorithm (MIGA)

MIGA is a distributed variant of GA. The outstanding feature of this method is that the population in one generation is divided into several sub-populations called "Islands", and the genetic operations are performed independently on each sub-population. This independency enables the calculation to avoid converging partial optimal solutions. An exchange of individual information, termed "migration", is carried out periodically between sub-populations. Figure 2 shows idealized diagram of the MIGA description.

3. Proposed Energy Conservations and Comfort Management Model.

3.1. Conceptual configuration. Figure 3 shows the conceptual configuration of the proposed energy conservation and comfort management model where comfort index of the user increases and consumed power decreases. Although there is a trade-off between comfort index and energy conservation, but using MIGA/GA we maintain both the parameters at the same time. Temperature which indicates thermal comfort inside the building is calculated by the sensor device. Similarly, illumination is the visual display (subjective) and Air Quality is the CO2 emission inside the building and can be calculated by the sensor devices. CO2 concentration is used as an index to measure the air quality in the building environment.

3.2. Block diagram of the proposed model. Figure 4 shows the block diagram of the proposed building energy management model. Environmental parameters (Temperature, Illumination and Air Quality) are input to the MIGA/GA for optimization, and then

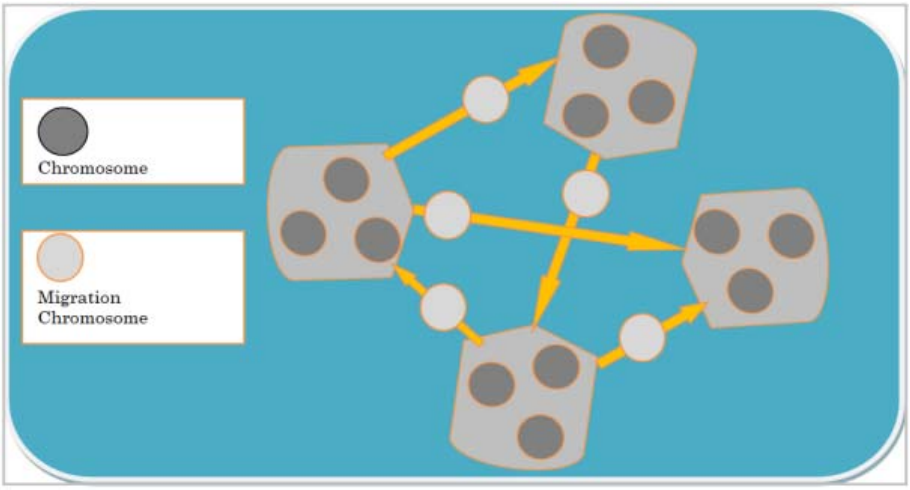

FIGURE 2. Operational diagram of MIGA

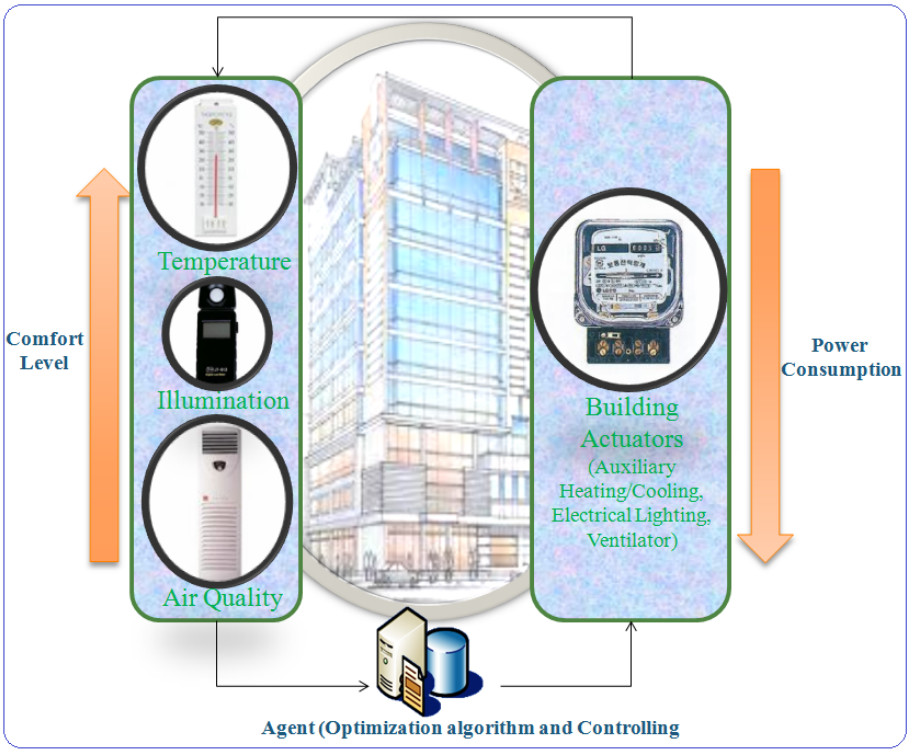

FIGURE 3. Conceptual configuration of building energy management system

optimized parameters are used as user comfort to calculate the occupant's comfort index. Coordinator Agent adjusts the power according to the user comfort index and available source power from grid source or local energy sources. Three fuzzy controllers' temperature controller, illumination controller and airquality controller control the temperature, illumination and air quality inside the building. Actuators utilize the output power from fuzzy controller. Coordinator agent perform the function of coordination between fuzzy controllers, user set parameters and optimized parameters of MIGA/GA. It also provide comfort index according to the user requirements and keeps energy consumption as minimum as possible.

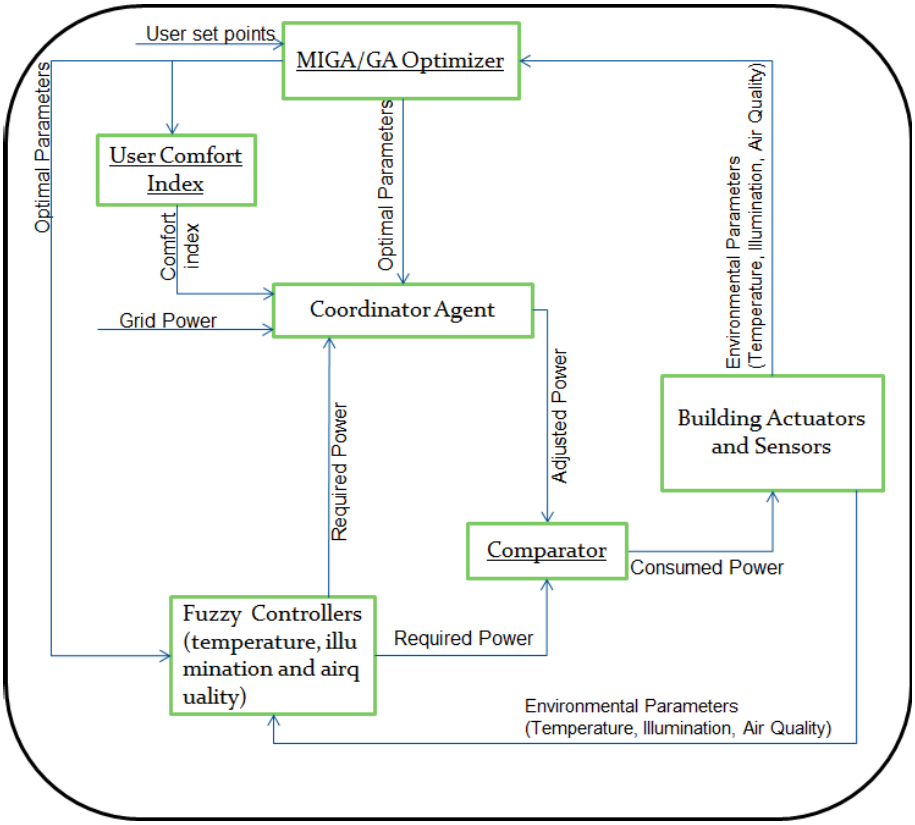

FIGURE 4. Block diagram of the proposed model

3.2.1. *Optimization algorithm using GA.* GA steps for parameters optimizations and comfort calculations are:

(1) Initial random population.
(2) Calculate fitness function for user comfort using Equation (3.1).
(3) Select best individuals using any of three selection criteria (Rank, Roulette wheel or Tournament selection), we used rank based selection.
(4) Perform 'one point' crossover of the selected individuals.
(5) After crossover, we get off-springs.
(6) Now calculate comfort for the off-springs.
(7) Combining populations of steps (3) and (5) and then perform step (3).
(8) If mutation criteria meet, then perform mutation.
(9) Repeat above eight steps until required number of iterations.
(10) Then after arrival of termination criteria select best fitted chromosome.

The GA algorithm run for ($\alpha = 300$) generations, and following parameters of GA were considered: 100 initial population, "one-point" crossover with the probability of 0.9% and mutation rate as 0.1%. When GA evaluation process finished, best fitted chromosome was selected to get optimal parameters and comfort index. The GA algorithm stops either when α is met or no significant change is observed in the fitness for γ (few successive) generations. The experimentations are performed using Latitude D620 laptop of 2.00GHz with 2GB RAM. The C # 2008 is used for the simulation. The algorithm took 30 minutes to produce the optimal results.

3.2.2. *Optimization algorithm using MIGA.*

(1) Initial random population.
(2) Divide Initial population into multiple Islands.

(3) Perform step (4) to step (10) for each of the Island.
(4) Calculate fitness function for user comfort using Equation (3.1).
(5) Select best individuals using any of three selection criteria (Rank, Roulette wheel or Tournament selection), we used rank based selection.
(6) Perform 'one point' crossover of the selected individuals.
(7) After crossover, we get off-springs.
(8) Now calculate comfort for the off-springs.
(9) Combining populations of steps (5) and (7).
(10) If mutation criteria meet, then perform mutation.
(11) If migration criteria meet, then perform migration.
(12) Repeat above eight steps until required number of iterations.
(13) Select best chromosome for each island when the termination criteria satisfied.

The MIGA algorithm stops either when the maximum number of generations ($\alpha = 300$) met, or no significant change is observed in the fitness for γ (few successive) generations. The population size and number of island were set to 100 and 2 respectively. The conventional single point crossover is performed with the probability of 0.9%, migration rate of chromosomes as 0.5% and mutation rate as 0.1%. The experimentations are performed on the same notebook used for GA. The algorithm took 40 minutes to produce the optimal results. When MIGA evaluation process finished, best fitted chromosomes were selected from each island to get optimal parameters and comfort index.

3.2.3. *Comfort index.* The comfort index can be calculated by using Equation (3.1) [3].

$$Comfort = \alpha_1 \left[1 - (e_T/T_{user\_set})^2\right] + \alpha_2 \left[1 - (e_L/L_{user\_set})^2\right] + \alpha_3 \left[1 - (e_A/A_{user\_set})^2\right] \quad (3.1)$$

where *Comfort*, is the overall comfort level of the user and its value is in between $[0, 1]$, β_1, β_2, β_3 are the user defined factors which solve the any possible conflict between the three comfort factors (temperature, illumination and air-quality). The values for these parameters are between 0 and 1. $\beta_1 + \beta_2 + \beta_3 = 1$, which means that at any time addition of these values should not exceeds "1", so that value of comfort is scale down in between $[0, 1]$. e_{Temp}, is the error difference between optimal parameter (temperature) of MIGA/GA and actual sensor temperature. e_{Ill}, is the error difference between optimal parameter (illumination) of MIGA/GA and actual sensor illumination. e_{Air}, is the error difference between optimal parameter (air quality) of MIGA/GA and actual sensor air quality. T_{set}, L_{set}, A_{set} are the user set parameters of temperature, illumination and air-quality.

3.2.4. *Fuzzy controller.* The error difference between real environmental parameters and optimal parameters of MIGA/GA along with rate-of-change in the error is input to the fuzzy controller. The fuzzy controller produces the results based on the membership function. The output of the fuzzy controller is the required power for temperature, illumination and air-quality control in the building environment. This required power is input to the coordinator agent.

In Equations (3.2), (3.3), and (3.4), μ_{Temp}, μ_{Ill}, μ_{Air} are the temperature, illumination and air quality increment relationship with consumed power P in time K respectively. x is the basic operation power for air quality.

$$\mu_{Temp} = 0.05^* P_{Temp}{}^* k \quad (3.2)$$

$$\mu_{Ill} = 20^* P_{Ill} \quad (3.3)$$

$$\mu_{Air} = 3^* P_{Air} - x/2 \quad (3.4)$$

When the consumed power P_{Temp} increases, the increment in temperature μ_{Temp} also increases with a proportion of 0.05. If value of the constant 0.05 increased, then μ_{Temp} increases from the required comfort level of temperature. If consumed power P_{Ill} increases, the increment in illumination μ_{Ill} also increases with a proportion of 20. If the constant 20 increased, then μ_{Ill} increases from the required comfort level of illumination. If consumed power P_{Air} increases, the increment in airquality also increases with a proportion of 3. If the constant 3 increased, then μ_{Air} increases from the required comfort level of airquality. "x" is the basic operation power of ventilator.

3.2.5. *Coordinator agent.* Coordinator agent uses required power from fuzzy controller, user set parameters and optimal parameters from the MIGA/GA. It then adjusts the power on basis of the available power, required power and user comfort index. The adjusted power is then compare with the required power to get the actual consume power. The actual consume power is given to the actuators to be used. The actual consume power is the minimum power to be consume in the building.

In Equations (3.5)-(3.9), the parameters $U1$, $U2$ and $U3$ are the small values between $[0, 1]$ for compensating the power losses in distribution. $P(k)$, is the required power, which is the sum of power demands from temperature, illumination and air quality. $P_{available}(k)$, is the total energy source (outside grid-power or internal local power source). $P_{\max\_input}$, is the maximum input power either from the power grid or from the local micro sources to the building and k is the time variable.

$$P_{Temp}(k+1) = P_{Air}(k) + U1 \tag{3.5}$$

$$P_{Ill}(k+1) = P_{Air}(k) + U2 \tag{3.6}$$

$$P_{Air}(k+1) = P_{Air}(k) + U3 \tag{3.7}$$

$$P_{Temp}(k) + P_{Ill}(k) + P_{Air}(k) = P_{available}(k) \tag{3.8}$$

$$P_{total}(k) <= P_{\max\_input}(k) \tag{3.9}$$

3.2.6. *Building actuators.* Building actuators are the devices which actually use the energy inside the building. That is AC (cooling), heater (heating), refrigerator (cooling) and oven (heating). Sensors devices are used to get updated environmental information's regarding temperature, illumination and airquality level.

3.3. **Fuzzy logic.** The concept of Fuzzy Logic (FL) was introduced in [27], by a professor L. A. Zadeh at the University of California at Berkley.

TABLE 1. Fuzzy controller rules for temperature controller

Required Power		e_{Temp}						
		NB	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
ce_{Temp}	*NB*	*NB*	*NS*	*PS*	*PB*	*PB*	*PB*	*PB*
	NM	*NB*	*NM*	*ZE*	*PM*	*PM*	*PB*	*PB*
	NS	*NB*	*NM*	*NS*	*PS*	*PM*	*PB*	*PB*
	ZE	*NB*	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
	PS	*NB*	*NB*	*NM*	*NS*	*PS*	*PM*	*PB*
	PM	*NB*	*NB*	*NM*	*NM*	*ZE*	*PM*	*PB*
	PB	*NB*	*NB*	*NB*	*NB*	*NS*	*PS*	*PB*

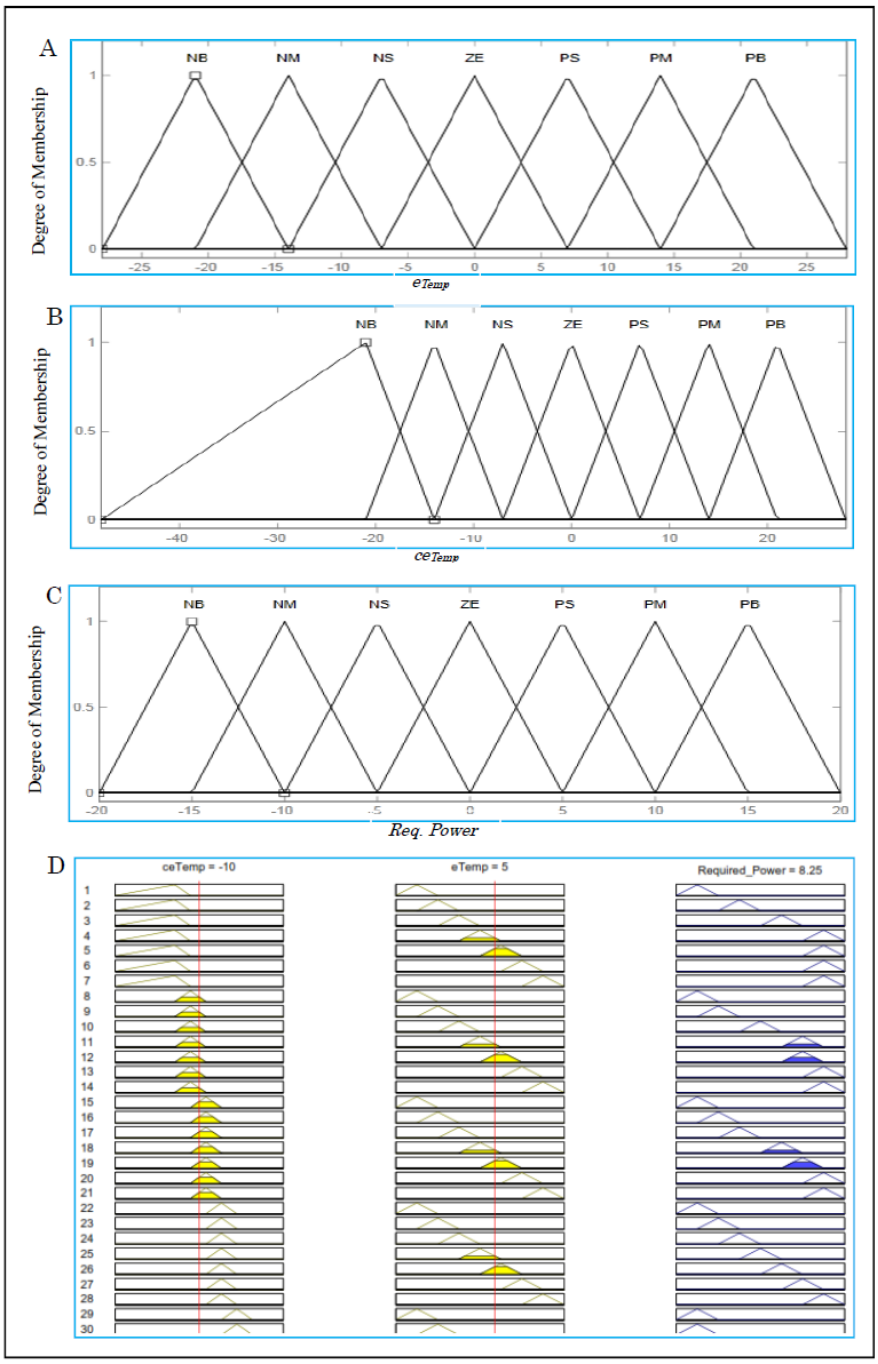

FIGURE 5. The input and output membership functions with example of rules for temperature: A, input membership function of e_{Temp}, B, input membership function of ce_{Temp}, C, output membership function, D, example of rules.

3.3.1. *Fuzzy controller for temperature.* The input to the fuzzy controller for temperature is the error difference between optimal parameters of MIGA/GA and real environmental parameters. For efficient controlling, both error difference e_{Temp} and change in error ce_{Temp} (difference between current and previous error) are used. The input/output membership functions and rule example are shown in Figure 5.

Table 1 shows the fuzzy controller rules for temperature control. It is a 7×7 matrix. Each entry in the table is the error difference e_{Temp} and change in error ce_{Temp}. The

required power is the power to fulfill the user requirements inside the building. In Table 1 "NB" means Negative Big, "NM" means Negative Medium, "NS" means Negative Small, "ZE" means Zero, "PS" means Positive Small, "PM" means Positive Medium, "PB" means Positive Big.

3.3.2. *Fuzzy controller for illumination.* The input to the fuzzy controller for illumination is the error difference between optimized illumination parameter and real environment illumination parameter. The input membership/output membership functions and example of rules for illumination are shown in Figure 6. The input membership function is for the error e_{Ill}, which is the only input error.

Table 2 shows fuzzy controller rules for illumination control. When the input error is "Small" the required output power will "OSmall". For error "SS" (Simple Small) the

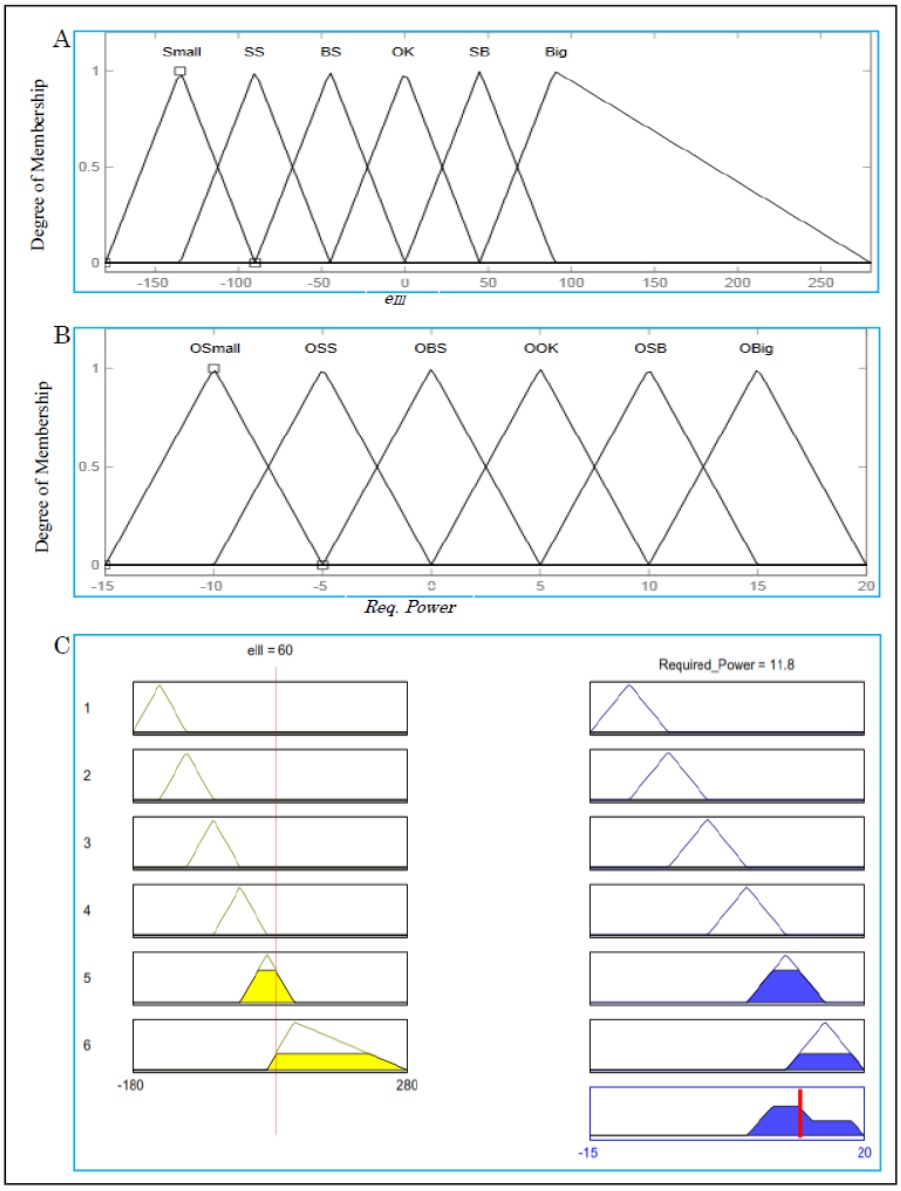

FIGURE 6. The input/output membership functions with example of rules, for illumination: A, input membership function of e_{Ill}, B, output membership function C, an example of rules

output power will be "OSS", for "BS" (Big Small) the required power will be "OBS" and so on.

3.3.3. *Fuzzy controller for air quality.* The input to the fuzzy controller for Air-Quality is the error between optimized Air-Quality parameter and real environmental Air-Quality parameter. The input/output membership functions and example of rules for Air-Quality are shown in Figure 7. The input membership function is for the error e_{Air} which is the only input to the air quality fuzzy controller. Table 3 shows the fuzzy controller rules for air-quality control. If the input error is "Low" the required output power will be "OFF". For "OK" the output power will be "ON' and so on.

TABLE 2. Fuzzy controller rules for illumination control

Error	*Small*	*SS*	*BS*	*OK*	*SB*	*Big*
Required Power	*OSmall*	*OSS*	*OBS*	*OOK*	*OSB*	*OBig*

TABLE 3. Fuzzy controller rules for air quality control

Error	*Low*	*OK*	*SH*	*LH*	*HIGH*
Required Power	*OFF*	*ON*	*SL*	*OSH*	*OHIGH*

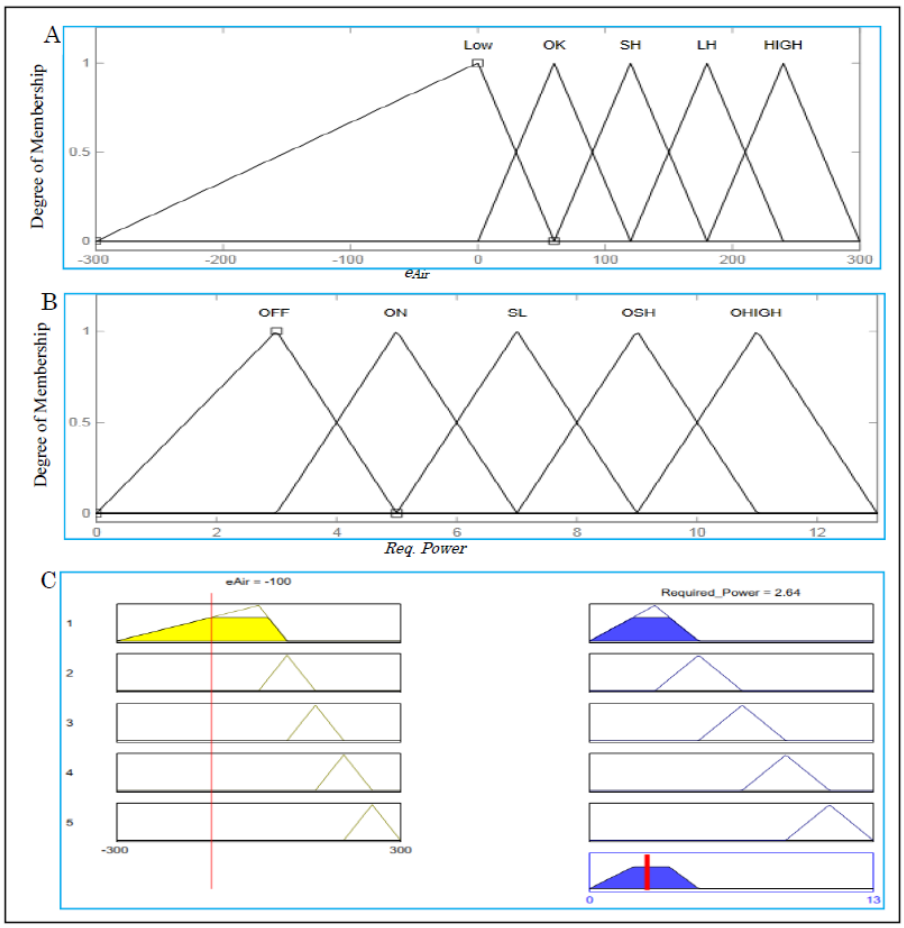

FIGURE 7. Input and output membership functions with example of rules, for air quality: A, input membership function of e_{Air}, B, output membership function C, an example of rules

4. **Main Results and Discussion.** Matlab is used for input and output membership functions construction. While actual simulation carried out in C# 2008. User preference set parameters range is $T_{set} = [66, 78]$ (k), $L_{set} = [720, 880]$ (lux) and $A_{set} = [700, 880]$ (ppm).

The environmental data (sensor data) of 250 seconds is supposed. The environment in this data is disturb five times and every time the temperature goes down to 50 (K), illumination level goes down to 600 (lux) and airquality goes down to 700 (ppm) respectively.

Figure 8 shows the comparisons of user set parameters, environmental parameters and optimal parameters of MIGA and GA. Environmental disturbance occurs' several of time

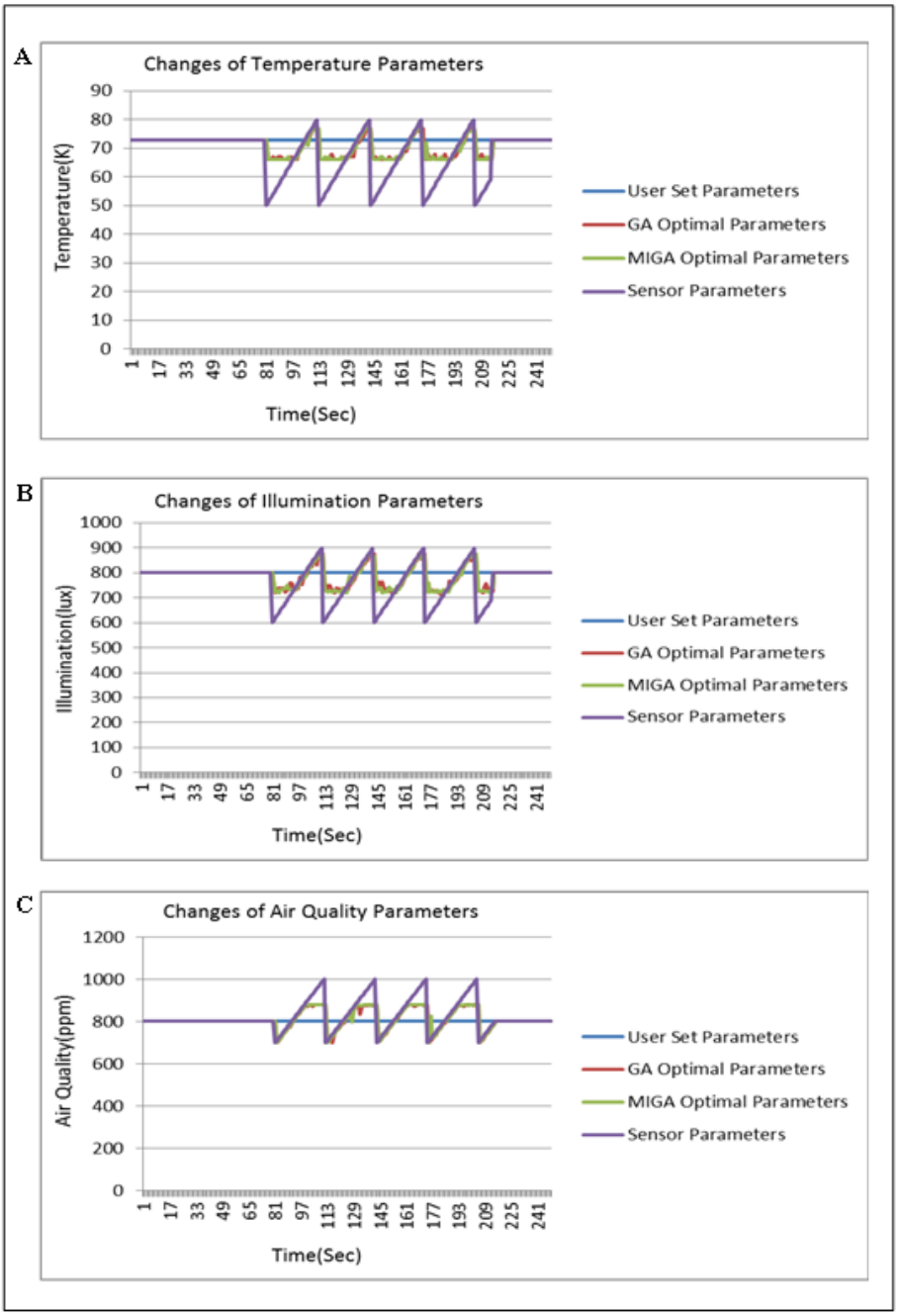

FIGURE 8. Changes of optimized parameters and user set parameters: A, Temperature, B, Illumination, C, Air Quality

from 82s to 215s. MIGA and GA optimize the user set parameters during this time. The errors difference between the optimal parameters of MIGA/GA and the measured environmental parameters become smaller as compared with the error difference between without-MIGA/GA parameters (without optimization) and measured environmental parameters. Although the extents of result improvement due to MIGA and GA somehow vary in each simulation run, the errors difference are consistently shown to be smaller than that of without-MIGA/GA.

In case of temperature controller Figure 8(A), the user parameters are optimized by MIGA and GA. This can be particularly seen in environmental disturbance time. The errors difference between optimal parameters of MIGA/GA and measured environmental

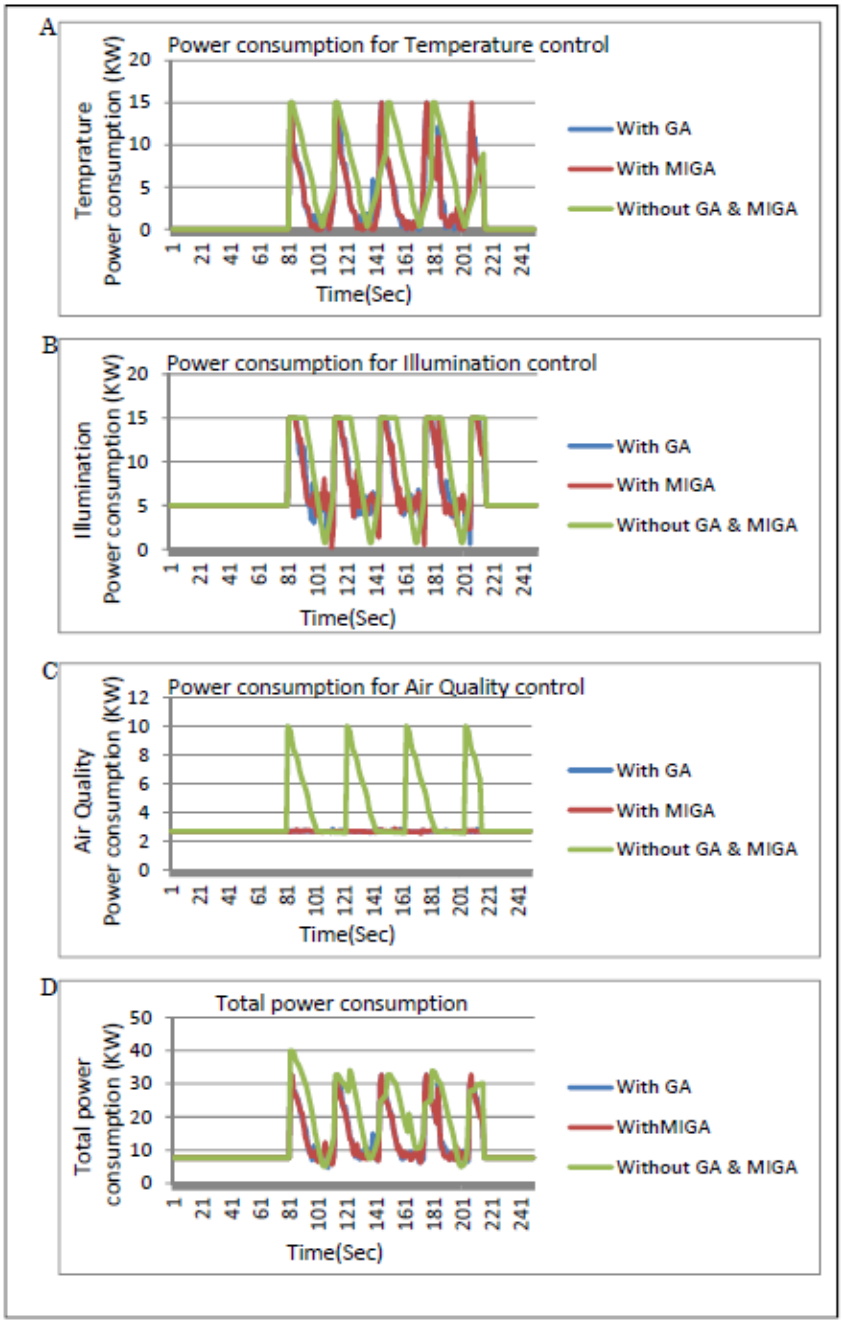

FIGURE 9. Comparison of power consumption: A, Temperature, B, Illumination, C, Air Quality, D, Total power consumption

parameters are small as compared with the errors difference between without-MIGA/GA parameters and measure environmental parameters. In case of illumination controller Figure 8(B), MIGA and GA are able to optimize the user set parameters. So when disturbance occur in environment, then that time MIGA and GA optimal parameters have smaller error as compared to that of without-MIGA/GA parameters. In case of Air Quality controller Figure 8(C), MIGA and GA both are able to optimize most of the user set parameters. When disturbance occur in environment, then MIGA and GA optimal parameters have smaller errors as compared with that of without-MIGA/GA parameters.

Figure 9 shows the comparisons of power consumption. If we see the results in Figure 9(A) then it can be determine clearly, that in case of power consumption for temperature, most of the time less power consumed by MIGA/GA as compared to power consumption without-MIGA/GA. This is due to the fact that MIGA/GA optimizes the user set temperature parameters during environmental disturbance. Similarly in case of illumination Figure 9(B), less power consumed by MIGA/GA based systems as compared with without-MIGA/GA system. The fact behind this is the optimization of the user set illumination parameters.

Similarly if we see the results in Figure 9(C), then it can be seen that in case of power consumption for air quality, less power consumed by MIGA/GA based optimized system as compared to power consumption without-MIGA/GA. Similarly if we see the results in Figure 9(D) then it can be seen that total power consumed by MIGA and GA based systems are much less than without-MIGA/GA systems.

So in all cases of power consumptions i-e temperature, illumination, air quality and total power, MIGA and GA consume much less power than that of its counterpart without-MIGA/GA.

Figure 10 shows the results of user comfort index in case of MIGA based system, GA based system and without-MIGA/GA (without optimization). In case of MIGA and GA, user comfort index is high as compare with the user comfort index without-MIGA/GA. When environmental disturbance occurs in the building, MIGA and GA provides better comfort index as compare with without-MIGA/GA. Both GA and MIGA recover from environmental disturbance very quickly as compare with without-MIGA/GA. GA itself, recover more quickly than MIGA. First time power disturbance occurs at time 82sec. At this time comfort level of MIGA goes down to about 0.97, GA goes down to about 0.96 and comfort level without-MIGA/GA goes down to about 0.92. MIGA and GA recover soon

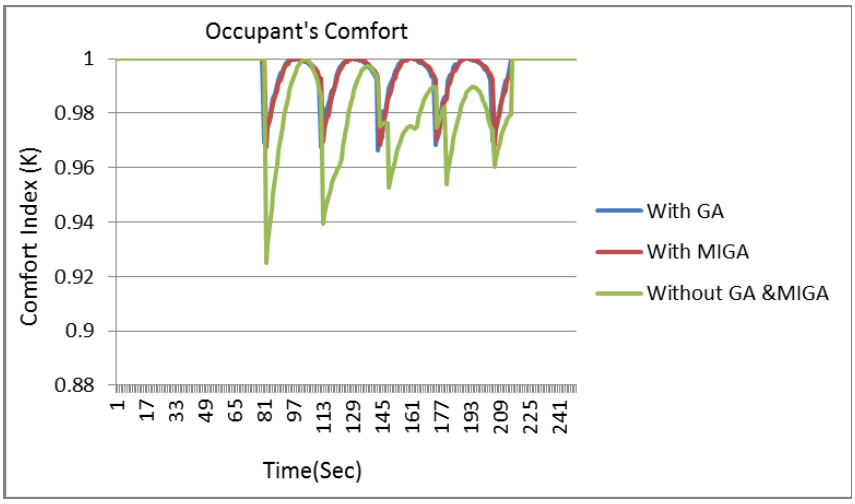

FIGURE 10. Comparison of comfort index with MIGA, GA and without-MIGA/GA

and immediately provide maximum comfort level as compare with without-MIGA/GA. When we compared MIGA and GA, then GA recover quickly than MIGA. In all cases of environmental disturbance that we have shown in Figure 8, MIGA and GA recovers the environment immediately and more quickly as compare to without-MIGA/GA. The recovery point is the one when comfort index reaches 0.99 or 1.

In Figure 10, if we see the comfort degradedness when environmental disturbance occurs, MIGA and GA's comfort level goes down slowly as compared with without-MIGA/GA. So in this case again MIGA and GA provide better comfort level as compare to without-MIGA/GA. So we can say that MIGA and GA both are able to provide optimal comfort index without compromising the energy savings. MIGA and GA both are able to balance the power consumption and occupants comfort level.

Overall, the comfort indices provided by MIGA and GA outperform without-MIGA/GA comfort index. Comfort index of GA recover soon as compare with MIGA. Total power consume by MIGA is either less or equal to that of GA. Also GA runs quickly as compare with MIGA.

5. **Conclusions.** In this paper an optimization based model for comfortable and energy saving using MIGA/GA in building environment is presented. We address both energy efficiency and user comfort index simultaneously. Users set parameters are also considered in deciding the comfort index.

To minimize the required output power of the fuzzy, we minimize the error difference by optimizing the input parameters of the fuzzy using MIGA/GA. After optimization, the error difference between MIGA/GA optimal parameters and real environmental parameters becomes small as compare with its counterpart without-MIGA/GA parameters (without optimization). As a result this small error minimizes the required power with respect to the occupant's comfort index and available power. The results show the effectiveness of the proposed model in increasing the occupant's comfort index and minimizing energy consumption. Our results show that MIGA/GA provides better comfort index as compare to without-MIGA/GA comfort index. The proposed MIGA and GA based optimize model produces over all much better comfort index as compared to without-MIGA/GA. Both GA and MIGA recover from environmental disturbance very quickly as compare to its counterpart without-MIGA/GA. GA recovers more quickly than that of MIGA. Using MIGA and GA, the building environment can be made user friendly. Our proposed MIGA and GA based model can be incorporated with SCADA software of buildings for practical applications.

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REFERENCES

[1] Z. Wang, R. Yang and L. Wang, Multi-agent control system with intelligent optimization for smart and energy-efficient buildings, *Proc. of the 36th Annual Conference of the IEEE Industrial Electronics Society*, Phoenix, AZ, USA, pp.1144-1149, 2010.

[2] A. I. Dounis and C. Caraiscos, Advanced control systems engineering for energy and comfort management in a building environment – A review, *Renewable and Sustainable Energy Reviews*, vol.13, no.6-7, pp.1246-1261, 2009.

[3] Z. Wang, R. Yang and L. Wang, Multi-agent intelligent controller designs for smart and sustainable buildings, *Proc. of IEEE International Systems Conference*, San Diego, pp.277-282, 2010.

[4] S. J. Emmerich and A. K. Persily, State-of-the-art review of CO2 demand controlled ventilation technology and application, *National Institute of Standards and Technology, Technology Administration, Department of Commerce*, USA, pp.1-43, 2001.

[5] G. J. Levermore, *Building Energy Management Systems, An Application to Heating, Natural Ventilation, Lighting and Occupant Satisfaction*, E & FN SPON, London, 1992.

[6] C. Bernard, B. Guerrier and M. M. Rasset-Louerant, Optimal building energy management, *Part II: Control, ASME Journal of Solar Energy Engineering*, vol.114, no.1, pp.13-22, 1982.

[7] P. S. Curtis, G. Shavit and K. Kreider, Neural networks applied to buildings, *A Tutorial and Case Studies in Prediction and Adaptive Control, ASHRAE Transactions*, vol.102, no.1, pp.732-737, 1996.

[8] D. Kolokotsa, G. S. Stavrakakis, K. Kalaitzakis and D. Agoris, Genetic algorithms optimized fuzzy controller for the indoor environmental management in buildings implemented using PLC and local operating networks, *Engineering Application of Artificial Intelligence*, vol.15, pp.417-428, 2002.

[9] A. Kusiak, M. Li and Z. Zhang, A data-driven approach for steam load prediction in buildings, *Applied Energy*, vol.87, pp.925-33, 2010.

[10] J. Siroky, F. Oldewurtel, J. Cigler and S. Privara, Experimental analysis of model predictive control for an energy efficient building heating system, *Applied Energy*, vol.88, pp.3079-87, 2011.

[11] Z. Wang, L. Wang, A. I. Dounis and R. Yang, Multi-agent control system with information fusion based control model for smart buildings, *Applied Energy*, http://dx.doi.org.10.1016.j.apenergy.2012.05.020, 2012.

[12] P. M. Bluyssen, M. Aries and P. V. Dommelen, Comfort of workers in office buildings: The European HOPE project, *Building and Environment*, vol.46, pp.280-288, 2011.

[13] C. Marino, A. Nucara and M. Pietrafesa, Proposal of comfort classification indexes suitable for both single environments and whole buildings, *Building and Environment*, vol.57, pp.58-67, 2012.

[14] W. Huang and H. N. Lam, Using genetic algorithms to optimize controller parameters for HVAC systems, *Energy and Buildings*, vol.26, pp.277-282, 1997.

[15] S. Obara and K. Kudo, Multiple-purpose operational planning of fuel cell and heat pump compound system using genetic algorithm, *Transaction of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan*, vol.91, pp.65-75, 2003.

[16] J. I. Wright, H. A. Loosemore and R. Farmani, Optimization of building thermal design and control by multi-criterion genetic algorithm, *Energy and Buildings*, vol.34, pp.959-972, 2002.

[17] H. Li, R. Nalimi and P. A. Haldi, Thermal-economic optimization of a distributed multi-generation energy system, *A Case Study of Beijing: Applied Thermal Engineering*, vol.26, pp.709-719, 2006.

[18] M. Montazeri-Gh, A. Poursamad and B. Ghalichi, Application of genetic algorithm for optimization of control strategy in parallel hybrid electric vehicles, *Journal of the Franklin Institute*, vol.343, pp.420-435, 2006.

[19] A. Azadeh and S. Tarverdian, Integration of genetic algorithm, computer simulation and design of experiments for forecasting electrical energy consumption, *Energy Policy*, vol.35, pp.5229-5241, 2007.

[20] T. Yu, Modeling occupancy behavior for the energy efficiency and occupants comfort management in intelligent buildings, *Proc. of Machine Learning and Applications (ICMLA), Ninth International Conference*, pp.12-14, 2010.

[21] M. Li and Q. Ren, Optimization for the chilled water system of HVAC systems in an intelligent building, *Proc. of Computational and Information Sciences (ICCIS), International Conference*, pp.17-19, 2010.

[22] A. Azadeh, S. F. Ghaderi, S. Tarverdian and M. Saberi, Integration of artificial neural networks and genetic algorithm tp predict electrical energy consumption, *Applied Mathematics and Computation*, vol.186, pp.1731-1741, 2007.

[23] M. Mossolly, K. Ghali and N. Ghaddar, Optimal control strategy for a multi-zone air conditioning system using a genetic algorithm, *Energy*, vol.34, pp.58-66, 2009.

[24] M. Sorrentino, I. Arsie, R. Di-Martino and G. Rizzo, On the use of genetic algorithm to optimize the on-board energy management of a hybrid solar vehicle, *Proc. of IFP International Conference – Advances in Hybrid Powertrains*, 2010.

[25] G. Kayo and R. Ooka, Application multi-objective genetic algorithm for optimal design method of distributed energy system, *Proc. of the 11th International IBPSA Conference Glasgow*, Scotland, 2009.

[26] J. H. Holland, *Adaptation in Natural and Artificial Systems*, The University of Michigan Press, Ann Arbor, MI, USA, 1975.

[27] L. A. Zadeh, Fuzzy algorithms, *Information and Control*, vol.12, pp.94-102, 1968.