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Resource Allocation and Scheduling Smart Home through Optimizing HVAC System Design Using PSO Algorithm to Reduce the Required Energy

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Abstract: *The proper performance of a system has a great significance in its traditional concept. Additionally, it is important in energy saving viewpoint. Particle Swarm Optimization (PSO) is a modern evolutionary algorithm which retains a better convergence rate and computational accuracy, comparing to other evolutionary algorithms. This study investigates the optimal design for HVAC system in apartments using PSO algorithm and examines the capabilities of energy consumption in HVAC designed system. Also, the resource allocation and scheduling the chores in smart home is modeled using PSO algorithm. Using scheduling algorithms, the execution time for energy resources allocation can be decreased in the buildings and as a result, the energy consumption can be decreased.*

Keywords: *PSO, HVAC, optimization, particle swarm optimization, saving energy*

INTRODUCTION

Modern human uses many machines and devices which facilitate their life and provide comfort and satisfaction for them. According to conducted studies, on average, any individual spends one hour of his time carrying out his regular daily activities. Home automation system leads to saving time and prevents wasting it. (Fomin S.P.A. et al., 2015)

Modern buildings allow monitoring and controlling building automation and electronic systems under normal conditions called "building management system". (Jan Vanus et al., 2015). Smart home technology is an example of limited life technology guidance, which is applied in order to assist the house residents with their daily activities and as a result to have a better life quality while preserving their privacy. Smart home system is generally a set of software and hardware which is used to monitor the living space and it is equipped with controlling the movement path and behavior of the residents and understanding their activities. Through this, the system reports the dangerous situations and carry out measures on the behavior of residents to satisfy them. Smart home technology is considered as a solution for the individuals who need care in order to decrease living and caring costs and improve the life quality and it has led to data collection from the house and its residents through image monitoring, ringing, smart programing, calendar reminders, etc. equipped with sensors, disks and ultimately cameras, for various applications such as saving energy, safety and security, collapse track, light management, fire detection, etc. (Mohsen Amiribesheli et al.,2015)

Smart building is a building equipped with a strong communication infrastructure which continuously reacts to the various conditions of the environment and adapts itself with them and also allows the residents to use the available resources more effectively and increases their security and comfort. (Leandro Y. et al., 2016)

Consumed energy in the buildings is generally in the form of lighting, thermal and cryogenic. In order to save energy, exceedingly consumed energies should be controlled and also wasted energies during the hours which the building is empty should be omitted. (Bin Zhou et al., 2016)

Due to the requirement to decrease consumption and expenses in long-term through warning on the waste of energy and the requirement to prevent its waste in smart homes and also the optimal use of heating and cooling systems so that energy can be saved more desirably, and this can be achieved through using an efficient algorithm called PSO. In this study, the resource allocation and scheduling tasks in smart homes are modeled using PSO algorithm. Using these scheduling algorithms can help to decrease the resource allocation time in building and as a result saving energy. The second chapter of this study reviews the literature on required energy in HVAC systems. In the third chapter, the methodology is introduced. The fourth chapter explains the consumed energy by HVAC system. The fifth chapter explains the resource allocation in the proposed method. The sixth chapter discusses the energy challenge and the seventh chapter is the conclusion.

1. Review of Literature

The energy consumption has been widely studied in HVAC systems. Many researchers have focused on mathematical models and simulation methods.(Anderw Kusiak et al., 2011)

used mathematical programming method to design environmental cooling absorption system. By merging Energy Plus building simulator software and GenOpt genetic optimization software, (Andrew Kusiak et al., 2011)created a model for optimizing effective parameters on energy, comfort temperature and investment amount. HVAC systems are complex, nonlinear and large-scale systems which have numerous limitations. Hence, many researches have studied the sue of data mining methods to form predicting models. .(Anderw Kusiak et al., 2011) used fuzzy logic and neural system for approximation of indoor comfort temperature and energy optimization. (Anderw Kusiak et al., 2011)introduced data mining method for optimization of HVAC system.

During the past three decades, many researchers have conducted thermal simulation of building using energy modeling. Among these researchers (Ardeshir Moftakhari et al., 2016) could be referred to. Additionally, to analyze the building energy calculation modeling is used which is in accordance with the studies published by (Ardeshir Moftakhari et al., 2016) . In (Concetta Marino et al.,2015), all energy analyses are carried out using simulating dynamic buildings software based on EnergyPlus. Reimbursement intervals and CO_2 emission are assessed. (Xiaofei He et al., 2014) formulated and codified global energy optimization model for HVAC system for integration of mathematical models of the main components. (Xiaofei He et al., 2014) studied optimal control of ventilation system using physics model. (Xi He et al.,2015) applied the concept of integration method for urban energy planning based on dynamic and local distribution.

(Zheng Yang et al.,2014) presented a set of various points for uninhibited and inhibited areas. Using HVAC software, residents of Switzerland saved energy by 34% in a regular summer day, while (Zheng Yang et al.,2014) residents of countries in southeast U.S. saved energy by 37. (Yaohui Zeng et al., 2015) optimized HVAC processes using data mining approach and executed the real online time for validating the feasibility and its effectiveness. (Fan Tang et al.,2014) applied neural systems for predicting energy consumption rate in commercial buildings. In this research, chromosome programming and modeling of HVAC systems are studied by (Jaghoo Seo et al., 2014). Genetic algorithm method and its changes are widely used in optimization of system control and in mechanical parts and systems design. (Ramiro H.Bravo et al.,) and (Zhangjun and Zhang Kanyu, 2012) present the room temperature change process from initial temperature of 30 °C using modified PID algorithm based on PSO. In (S.Sofana Reka and V. Ramesh, 2016) the direct load control system is optimized and simulated using PSO method.

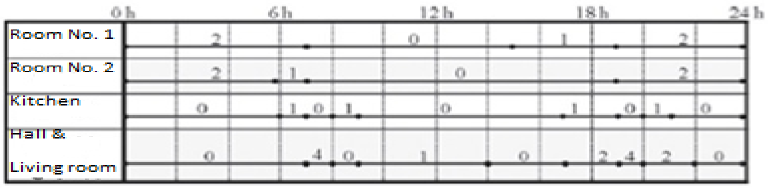
Energy consumption for HVAC systems is widely studied. Many of the researchers have focused on mathematical and simulation methods. (Anderw Kusiak et al., 2011) proposed supervisory control method to optimize local loop controller set points used in multi-part HVAC system. (Anderw Kusiak et al.,2011) created a model to optimize the effective parameters on energy, comfort temperature and investment amount. (Anderw Kusiak et al.,2011) proposed creating a dynamic model of HAVC system to control analysis. (Yanyu Zhang et al., 2014) proposes the optimal multipurpose controlling algorithm for HVAC which optimizes electricity cost index and comfort level index, simultaneously.

2. Methodology

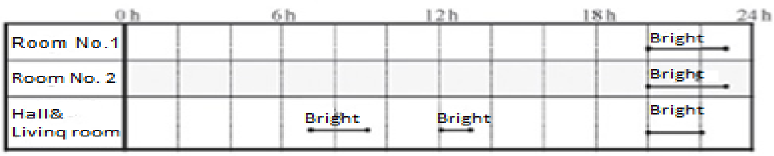
The target is to provide an optimal design for HVAC system in apartment using PSO algorithm and studying the capabilities of energy consumption in designed HVAC system. Designing HVAC system was carried out by considering the initial costs, execution costs, CO_2 emission, etc. On energy issues, considering measures on effective energy consumption and developing substitute energies are necessary, and also the risks which natural resources might encounter due to the execution. Optimization-simulation method is used as an effective energy management method and has developed in recent decades. In this study, the optimal design is proposed for HVAC systems in apartment buildings using PSO algorithm. The type and number of equipment and the capacity size are considered in order to decrease the energy consumption in execution of HVAC systems. The house includes two bedrooms, a living room, a kitchen, a bathroom and a hall. The family includes a father, a mother and two children. The heating and cooling systems were executed through a constant program.

The optimization of HVAC controlling systems is carried out through using particle swarm optimization algorithm and evolutionary strategy based on high convergence frequency and short calculation time. Since metaheuristic PSO algorithm solves the problem through sharing the least data and experiences through linking with other particles, HVAC problem is solved through a flow of information and a set of self-organizing rules. Short-term modeling and prediction of energy consumption in HVAC systems play a significant role in security and profitable economy of operations and management of energy consumption and air quality. PSO algorithm is suitable for the best condition predicting heating power consumption and also decreasing the predicted errors and computational costs. Air temperature set point (DAT-SP), the supply air static pressure set point (SP-SP) and humidity are the operational parameters in HVAC systems, which should be optimized. The execution process with PSO algorithm is carried out by MATLAB software. The experimental data are extracted from [8] for testing the algorithm which is presented in table 1 in the form of a (for the residents), b (for heating and cooling systems) and c (for light and heat discharge from the electrical devices).

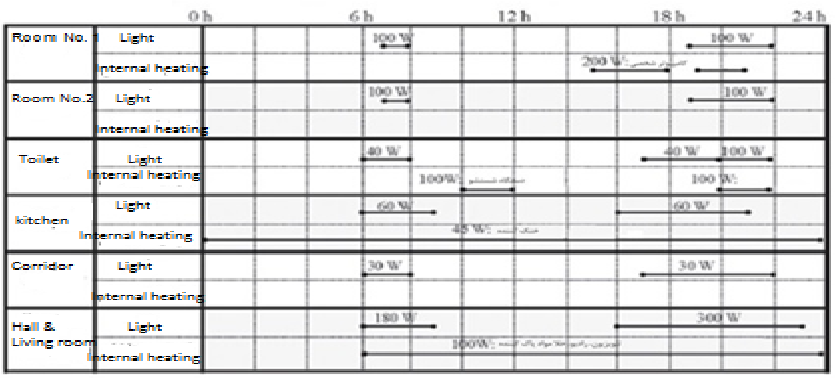
Table 1. related to the Experimental Data



a) Residents



b) Cooling and Heating Systems



c) Exit light and heating of the electronic device

Figure 1 presents the plan of a simple home which uses no sensor for its heating and cooling and the sensor is set manually. However, Figure 2 presents a semi-smart home whose heating and cooling systems are activated by setting motion and sensory sensors manually. Figure 3 is a smart home whose heating and cooling systems are activated by setting motion and sensory sensors automatically.

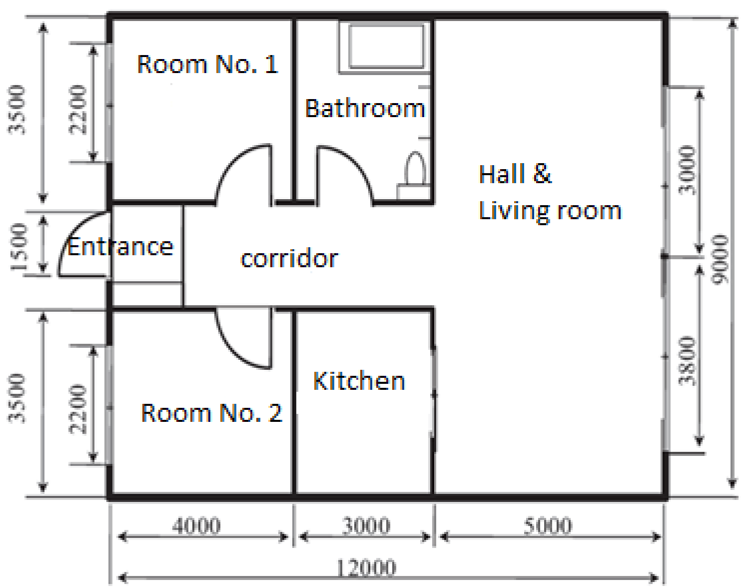


Figure 1. Simple Home

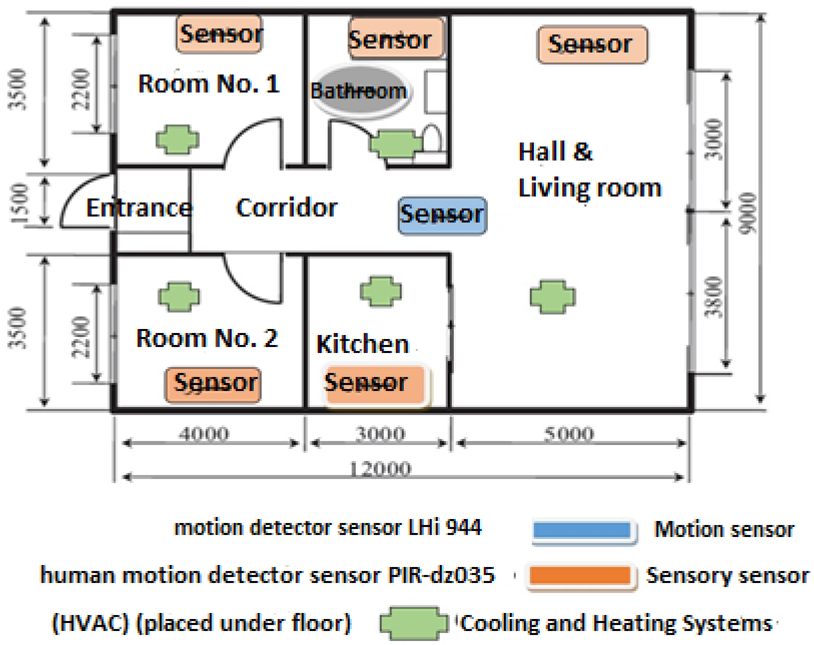


Figure 2. Semi-Smart Home (Manual Setting) [8]

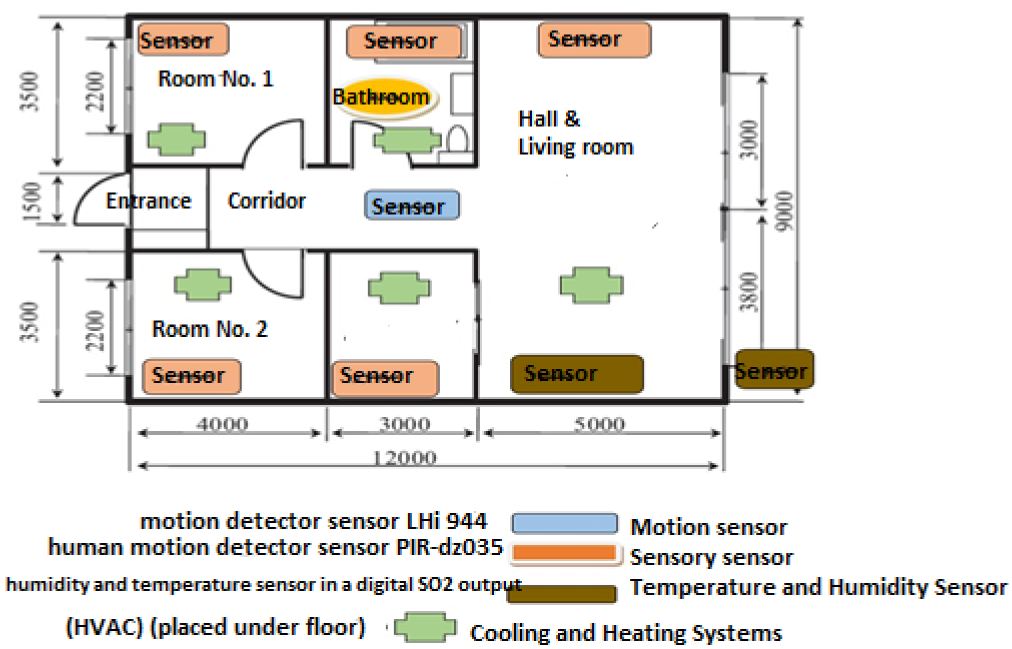


Figure 3. Smart Home (Manual Setting) [8]

In Figure 3, the sensors' location is varied based on monitor parameters. For instance, the temperature sensor is installed on the ceiling or the walls. The sensor of climate record is installed outdoors.

When it is measured by thermometer and psychrometer outdoor of smart home and is based on the temperature changes during the day, various seasons lead to formation of a predictable planning system that heating and cooling system automatically changes. And there is no need to turn these systems on and off. It is carried out through an accurate coding by regulating temperature, humidity and pressure of the outdoor, the temperature and humidity of the indoor changes according to the human desired condition. Of course, heating and cooling systems are applied under the floor due to the medical and other reasons, which are effective both in saving energy and fulfilling the human needs and issues related to the diseases. Regarding the annually temperature rise and the weather getting cool and unpredictable climate changes, controlling the temperature inside the house is carried out though sharing the data and experiences through exchanging data and simple laws (PSO algorithm) that helps to solve the cooling and heating problems.

3. HVAC System Energy Consumption

The energy consumed in HVAC system installed in the building includes two main parts: the energy consumption of one air handling unit (EAHU)(AHU) and the reheating energy of variable air volume box (EVAV) (VAV) which is presented in Equation 1. The energy consumed by air handling unit (EAHU) including coolers energy (ECHL), fan supply energy consumption and fan output (Efan), and water pumps energy consumption (Epump) is presented on Equation 2.

1.$E_{Total} = E_{AHU} + E_{VAV}$

2. $E_{AHU} = E_{CHL} + E_{Fan} + E_{Pump}$

The energy consumed by the boilers and the lighting are not inserted in the model due to the various controlling parts. The energy consumed by the coolers, the fan supply and fan return and water pumps could be calibrated by the measuring instruments installed in the system. Since AUH energy includes a large portion of the energy consumed by the HVAC system, the EAHU energy is considered in this part.

y1, y2 and y3 functions present the energy room temperature and room humidity which are used in Equation 3:

3. $y_1(t) = f_1([(y_1(t-d)]_{d\epsilon D_y}, [x(t-d)]_{d\epsilon D_x}, [v(t-d)]_{d\epsilon D_v})$

$y_2(t) = f_2([(y_2(t-d)]_{d\epsilon D_y}, [x(t-d)]_{d\epsilon D_x}, [v(t-d)]_{d\epsilon D_v})$

$y_3(t) = f_3([(y_3(t-d)]_{d\epsilon D_y}, [x(t-d)]_{d\epsilon D_x}, [v(t-d)]_{d\epsilon D_v})$

Where XXX includes the previous conditions of $y_1(t)$. For instance, $y_1(t-1)$ and $y_1(t-2)$; XXX is the optimized vector k at t and the previous conditions. For instance, x_1 is the supply parameter of temperature set point at t and x(t-1) is the same parameter at t-1. XXX is the controllable and uncontrollable parameter of vector m. For instance, $v_1(t-0)$ is the parameter of the output temperature at t and $v_1(t-2)$ is at (t-2); D_y, D_x and D_v are sets including parameter values for three functions available in Equation 3. For instance, D_{x1}={0.1} shows that the three functions include two measured values for x1, x1(t-0) and x1(t-1) at the present and t-1, respectively. Any function considers the $y_1=f_1()$, $y_2=f_2()$ and $y_3=f_3()$ defined in completely equal controllable and uncontrollable parameters. Since parameters depend on the goal functions, this impacts the accuracy of predicting model. Hence, in this research, the parameter selection algorithm chooses the most significant uncontrollable parameters for each function.

The model which minimizes the energy consumption is presented in Equation 4.

4. $min y_1(t)$

$y_1(t) = f_1([(y_1(t-d)]_{d\epsilon D1_y}, [x(t-d)]_{d\epsilon D_x}, [v1(t-d)]_{d\epsilon D1_v})$

$$y_2(t) = f_2([(y_2(t-d)]_{d\epsilon D2_y}, [x(t-d)]_{d\epsilon D_x}, [v2(t-d)]_{d\epsilon D2_v})$$

$$y_3(t) = f_3\left([(y_3(t-d)]_{d\epsilon D3_y}, [x(t-d)]_{d\epsilon D_x}, [v(t-d)]_{d\epsilon D3_v}\right)$$

In Equation 4, XXX, i is the number of solution vectors. XXX , y_1 refers to the AHU energy consumption. And y_2 is the room humidity and y_3 is the temperature. D_iy, D_{ix} and D_{iv} are sets including time function parameters corresponding to XXX. For instance, parameter $D2_{v2}$={0.1} shows that in function y_2 parameter of v2 includes two values of v2(t) and v2(t-1). It should be considered that vector XXX includes optimized parameters (set points) in three functions presented in Equation 4.

4. Resource Allocation in Proposed Method

Since resource allocation problem has a discrete space, its discrete algorithm modeling should be used or the problem space should be modelled in a way that they can be used in constant algorithms. In this paper, the constant algorithm of particle swarm is used. As a result, the first step is to find a suitable representation in which the particles can run an operational permutation and the modeling of the problem is carried out by permutation and random key methods.

Figure 4 presents the results of resource allocation in smart home and it is observed that for a three-bedroom apartment, how much time is required based on the number of carried out tasks and it is observed that the tasks finished in 99 minutes and this is the result of proposed algorithm. However, in Figure5, due to the low convergence in various spans, the algorithm is not able to gain better results for optimal answers or better allocation of the resources in smart home. This indicates that the algorithm is trapped in local optimization traps in some spans. In Figure 4, the resource allocation is finished up to 95 of fitness function, while in Figure 5, this has reached to 99 and this suggests that the proposed algorithm is a better method for allocating resources, but in Figure 5, due to being trapped in local optimization trap, an optimal answer cannot be achieved. Hence, the proposed algorithm is able to escape the local optimization trap due to a proper global search and the solution is discovered easily. Particle swarm algorithm is able to escape the local optimization trap through using the speed function in global search phase and this shows that the particle swarm algorithm functions well.

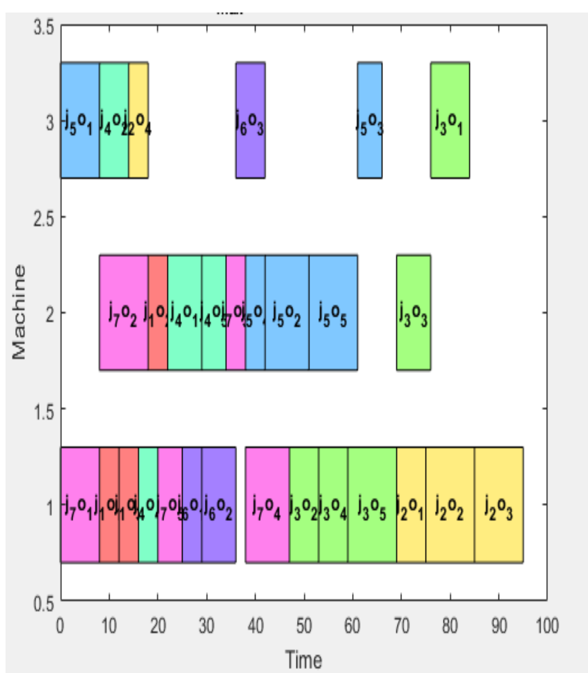


Figure 4. Resource Allocation in Smart Home (j=job and o=operation)

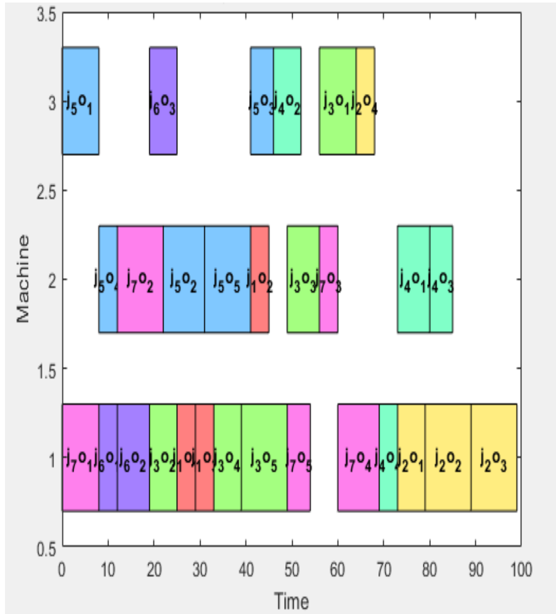


Figure 5. Resources Allocation in Scheduling System of Smart Home (j=job and o=operation)

For modeling the available resources and allocating the energy resources, b and P are considered as the consuming resource such as rooms and salons and electrical devices in house so that the estimation of energy consumption time for each house is determined before. Any of the strings including allocating energy resources to the devices inside the house is called a job. For instance, if three energy resources and 4 types of devices are in the house, one of the energy resources allocation matrices is presented as in Figure 6.

	resource1	resource2	Resource3
Job1	168	144	192
Job2	24	1248	96
Job3	144	240	288
Job4	384	216	336

Figure 6. Sample of Allocating 12 Devices in House to three Energy Resources

If any estimation of allocation time is shown by O ($O_{1,1}$=168), each set of allocating appliances to the energy resource of b can be shown as a string like J1O1, J1O2, J1O3,…, J1Ob and this trend is carried out for all jobs.

4.1. Mathematical Model of Scheduling Problem

The set of jobs which should be scheduled are as the Equation 5.

5. $job = [job_1, job_2, job_3, \dots, job_n]$

In which, these sets are defined as a job that include n members. Each member of this set is divided into subsets which include m members and defined as Equation 6.

6. $job_i tasks = [jtask_{i1}, jtask_{i2}, jtask_{i3}, \ldots, jtask_{im}]$

Moreover, this subset is allocated to the m of data center in cloud computing data. Each data center can carry out a subset of discrete data of the parsed tasks. For the referred tasks, DC_j of the executed jobs are as Equation 7.

7. $DC_j task = [jtask_{aj}, jtask_{bj}, \ldots, jtask_{rj}]$

The combination of these discrete subsets is all the jobs; that is, the combination of all subsets results in the job set. Hence, the total time of execution of job operations (r operation) referred to DC_j is as Equation 8.

8. $makespan(DC_j tasks) = max(jtask_{kj}.starttime + jtask_{kj}.exetime)$

jtask.starttime is the execution time of task beginning k which is executed in DC_j data center, jtaskkj.exetime is the execution time of jtaskkj in DC_j. Accordingly, the task scheduling problem in cloud computation is defined as Equations 9 and 10.

9. $DCtasks = \{DC_1 tasks, DC_2 tasks, \ldots, DC_m tasks\}$

10. $DC_j tasks = \{jtasks_{aj}, jtasks_{bj}, \ldots, jtasks_{rj}\}$

where decreases the makespan(DCjtaskes).

In order to assess the quality of the requested solution (DCtasks), the fitness function is defined as Equations 11 and 12.

11. $fitness(DCtasks) = \sum(fitness(jtask_{ij}, DC_j))$ where $(1 \leq j \leq m)$

12. $fitness(jtaskij, DC_j) = jtask_{ij.}TimeToExe$

jtask.TimeToExe the operation execution time of task i which requires DC_j for execution.

5. Discussion on Energy Challenge

Currently, there are many algorithms presented in various references including optimized algorithms which minimize the cost of electricity consumption, while the room temperature is kept at a predefined range. These algorithms do not qualitatively consider the user comfort temperature during HVAC operations. In this research, a considerable time enhancement is achieved for executing the energy resources allocation to the rooms using scheduling algorithms. The proposed algorithm is able to have a suitable global search through using the speed in executing the particles swarm algorithm. And as a result, with a proper leap it is able to escape from the local optimization trap and provide a desirable result for minimizing the resources allocation time and as a result a decrease in the costs and an increase in the users' comfort level.

(ON-OFF) × Energy Consumption Rate = job

OFF is the end time and ON is the start time. Energy consumption rate is in Kj. These jobs are executed in an arbitrary order.

7. implementation

This dataset includes the data collected at the workplace from www.CASCAS.Wsu.Smathome. The students collected data set for four months and presented their normal work routine in the environment. Sensors were divided into three categories: motion sensors, door sensor, and light control

Sensor's activities are divided into 8 categories which are for 40 users, that are presented in Table 2.

Table 2. Sensors Activities

M01..M51	motion sensors
I01..I08	item sensors
D01..D12	cabinet sensor
AD1-A	water sensor
AD1-B	water sensor
AD1-C	burner sensor
P01	phone sensor (start/top is start/stop of phone call)
T01..T03	temperature sensors

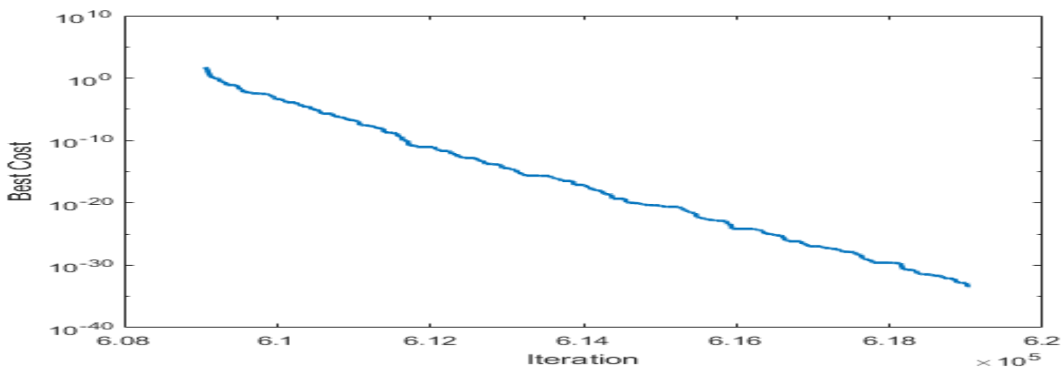
Table 3. Proposed Data Sample in the Dataset

Date	Time	Activity	Activity Type	Activity Number
2008-11-10	14:28:17, 986759	M22	ON	2 2
2008-11-10	14:28:18, 78605	M19	ON	1 1
2008-11-10	14:28:19, 551189	M23	ON	2 2
2008-11-10	14:28:20, 048559	M18	ON	1 1
2008-11-10	14:28:20, 615459	M01	ON	2 2
2008-11-10	14:28:21, 00566	M17	ON	1 1
2008-11-10	14:28:22, 025769	D07	OPEN	1 1
2008-11-10	14:28:22, 23544	M19	OFF	1 1
2008-11-10	14:28:22, 48164	M23	OFF	2 2
2008-11-10	14:28:22, 81818	M21	OFF	2 2
2008-11-10	14:28:23, 050209	M22	OFF	2 2
2008-11-10	14:28:23, 678289	M01	OFF	2 2
2008-11-10	14:28:23, 940809	M03	ON	2 2
2008-11-10	14:28:24, 28638	M18	OFF	1 1
2008-11-10	14:28:26, 409889	M17	OFF	1 1
2008-11-10	14:28:26, 71141	M03	OFF	2 2
2008-11-10	14:28:30, 07605	M03	ON	2 2
2008-11-10	14:28:32, 473779	I04	ABSENT	1 1
2008-11-10	14:28:33, 0757	M01	ON	2 2
2008-11-10	14:28:33, 714829	M23	ON	2 2
2008-11-10	14:28:34, 015579	M03	OFF	2 2
2008-11-10	14:28:34, 89439	D12	OPEN	2 2
2008-11-10	14:28:36, 62255	I06	ABSENT	1 1
2008-11-10	14:28:37, 072679	M01	OFF	2 2

The first column shows the date, the second column shows the time, and the third column shows the activity. The fourth column is the activity type carried out on the sensors. The fifth column is either 1 or 2 indicates which user has carried out this activity, since the sensors record two users' activities. The fifth column includes the activity in details.

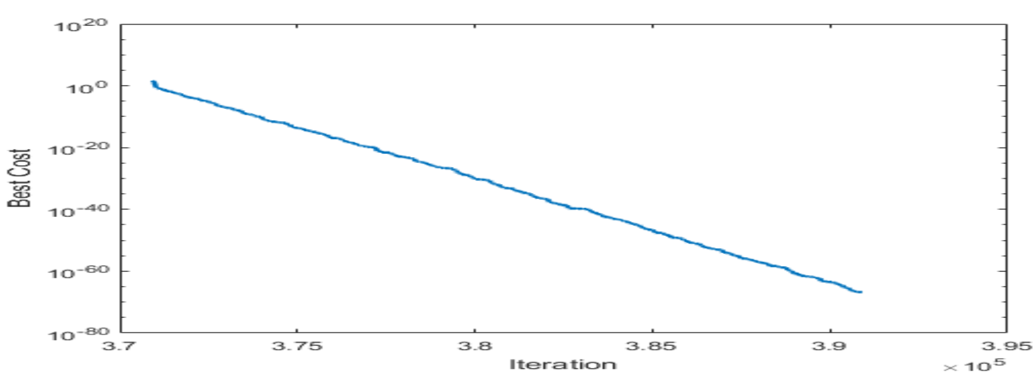
Figure 7 presents the convergence of particles swarm algorithm in 500 rounds of the algorithm and as it can be observed, it is moving towards the least answer and the fact is that the convergence is linear which implies to the well-performed movement and speed of the PSA. Since the algorithm has a proper speed and movement in various rounds, the best answer and minimal answer are achieved.

Figure 7. Diagram for 5,000 Repetitions and Reaching the Optimal Point (Zero)



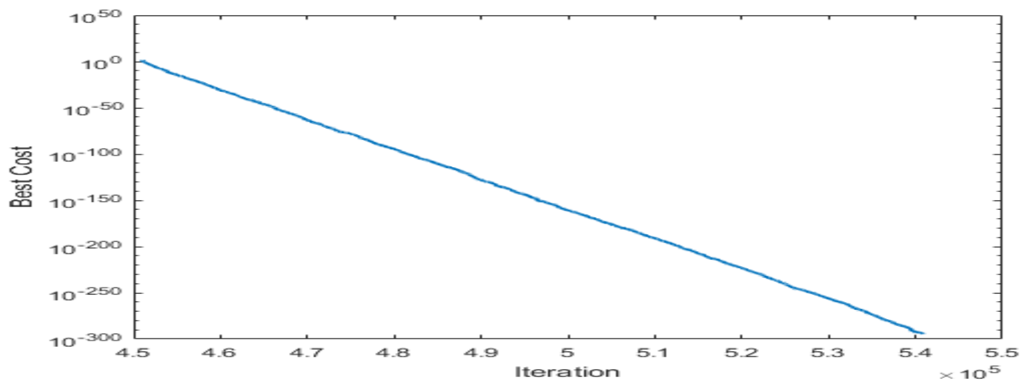
The convergence rate of the algorithm in 1,000 rounds is determined and the proposed algorithm has reached the minimal answer at the minimal value of 10^{-70}. Considering this minimal value and the linear behavior of the algorithm, it can be said that the PSA is converged towards the response and has a proper minimal point, which is shown in Figure 8.

Figure 8. Semi-Logarithmic Diagram for 1,000 Repetitions



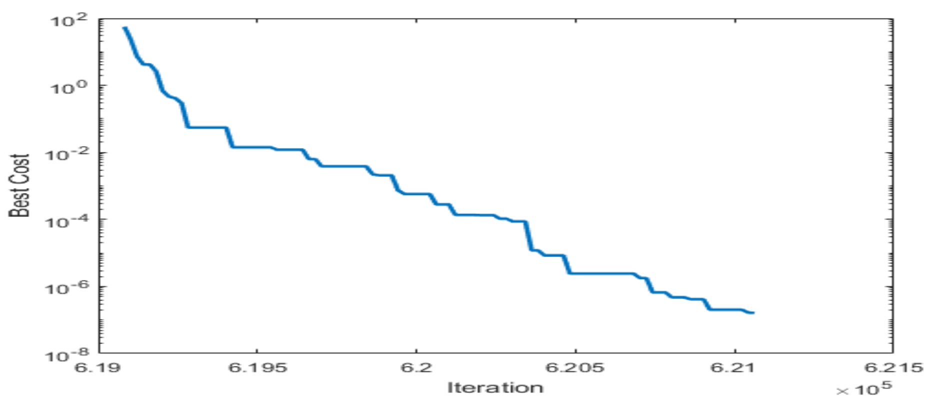
In higher numbers of the algorithm implementations, the proposed algorithm achieved a highly minimal answer, linearly, which shows that the proposed algorithm has had a better trend for gaining the answer and it has achieved to more minimal answers in various rounds, considering the movement and speed of the particles, that is presented in Figure 9.

Figure 9. For 4,000 Repetitions



As it is presented in Figure 10, the proposed algorithm is converged to the answer, since it has reached the answer in more minimal point of the algorithm.

Figure 10. Diagram for 20 Particles and 100 Repetitions



6. Conclusion

In this research, a considerable time enhancement was shown for executing the energy resources allocation using scheduling algorithms. The proposed algorithm (PSO) was able to have a suitable global search through using the speed in executing the particles swarm algorithm. And as a result, with a proper leap it was able to escape from the local optimization trap and provide a desirable result for minimizing the resources allocation time and as a result a decrease in the costs and an increase in the users' comfort level.

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