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Optimum energy management strategy with enhanced time of use tariff for campus building using particle swarm optimization

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ABSTRACT

Enhanced time of use (ETOU) tariff was introduced by Tenaga Nasional Berhad (TNB) in 2016 to promote demand response for commercial and industrial consumers. The ETOU tariff scheme offers different tariff rates at different times of the day. However, increment of electricity expenses might occur if consumers fail to optimally shift their consumption to lower rate hours and causing higher usage during peak hours. Furthermore, the time-based pricing tariff is still new to Malaysian consumers, thus consumers have lack of knowledge to perform demand response. Therefore, this research proposes an optimum load management strategy under the ETOU tariff for a commercial building using particle swarm optimization (PSO). The model was applied for Universiti Teknologi MARA (UiTM) Complex Engineering Shah Alam. Load profile of five different buildings in the complex were used as inputs for the study. The analyses were carried out at different controlled loads weightage factors ranged from 10-40% for load shifting strategy to determine the optimal solution. Results show the electricity cost decreases in all the controlled load weightage factors tested on the buildings after applying the load management strategy. The weightage factor of 40% provides the best solution for all buildings, saving 1-4% on the monthly bills.

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1. INTRODUCTION

Electricity plays a crucial role in our daily life [1]. The evolution and the production of electricity changes human life significantly spanning domestic, commercial and industrial sectors [2]. For domestic usage, the electricity is important for daily activity such as cleaning, cooking and family entertainment. While, the commercial and industrial sectors use the most electricity to run their daily business operations [3]. It was reported that the consumption of electricity in Malaysia are increasing every year. In 2017, the electricity consumption was 12,607 ktoe which is equivalent to 146,520 GWh. While in 2018, the electricity consumption increased 4.32% to 13,152 ktoe that equivalent to 152,865 GWh [4]. The industrial, residential and commercial sector are among the sectors with significant energy consumption that contributed to 28%, 5.2%, and 7.3% of the final energy consumption by sector, respectively [4]. Education buildings are categorised under the commercial sector. The Malaysia's Ministry of Higher Education aims to increase 53% of student enrolment by 2025 [5]. As such, more education buildings will be developed, thus increase the energy use of commercial sector from its current share. In campus buildings, the dynamic consumption pattern and lack of usage control in classrooms and laboratory often result in significant waste of energy [6].

In order to reduce electricity consumption and promote consumer's demand response, Tenaga Nasional Berhad (TNB) has established a time-based electricity tariff called enhanced time-of-use tariff (ETOU) for commercial and industrial consumers [7]. The ETOU is formed as part of initiatives for demand side management (DSM) approach. To control the amount of power consumed in Malaysia, the DSM unit was established by energy commission since efficient management of electrical energy regulation (EMEER) 2008 was gazetted. The main objective of ETOU is to motivate the consumers to use less energy during peak hours, hence reducing their electricity charge [8]. By reducing the peak demand would also help power utility to save their investment on power system infrastructures to meet the peak demand that occur less hour in a year. In order to get the maximum benefits of ETOU scheme, consumers should analyses and manage their electricity consumption optimally [9].

Many researchers have proposed various methods for load management techniques such as load shifting, valley filling and peak clipping. For example, a study on ETOU load management stratergy for an office building in Putrajaya, Malaysia have been conducted in [10]. In this paper, an optimization technique using mathematical formulation has been used to find the minimum value of peak load shifting. The result shows a remarkable cost reduction of the consumer's electricity bill. A review on the ETOU tariff rates has been conducted in [11] for industrial and commercial consumers. It was found that under the ETOU tariff rates, the electricity cost increased by 0.5%-12% without proper implementation of load management strategies. Particle swarm optimization (PSO) has been proposed in this paper for load management to solve the problem. In addition, a study in [12] applies ant colony optimization (ACO) for the similar purposes. The paper in [13] proposed optimization of the TOU tariff rates for the electric vehicle (EV) with the application of peak clipping and valley filling. Sulaima *et al.* [14] present a study on ETOU tariff rates for manufacturing sector. The study focuses on the implementation of PSO and ACO for reducing the consumer's energy cost. In order to improve energy efficiency in industrial sector, a study in [15] implements artificial neural network (ANN) and DSM strategies. Sulaima *et al.* [16] proposed optimum load profile forecasting model using ANN for industrial sector, where the load shifting strategy has also been applied to reduce the electricity cost under the ETOU tariff. From the literature review conducted, there is a lack of study on ETOU load management strategy for educational campus buildings.

Therefore, this research would enhance the efforts by proposing an optimum load management strategy under the ETOU tariff for campus building in Malaysia using PSO. The model has been tested on Universiti Teknologi MARA (UiTM) Complex Engineering Shah Alam. A load profile of different buildings in the Engineering Complex were used as inputs for the study.

a) Demand side management (DSM)

DSM involves a systematic approach and technology that enable users to use less energy [17]. There are several DSM strategies such as valley filing, load shifting, peak clipping, load building and energy conservation [18]. The valley filling aims in increasing demand during off-peak hours while maintaining peak load as shown in Figure 1. Low demand hours are met by constructing off-peak capacity, which improves the system load factor by increasing load during off-peak hours [19].

While on the other hand, the load shifting is the best solution from the point of view of utility companies, whereby with the implementation of the load shifting technique, the demand during the peak hours are shifted to off-peak hours as shown in Figure 2 [20]. The peak clipping is to reduce the demand during the peak load periods [21], whereby the high demand periods are being 'clipped' off resulting to a decrease on the load profile during the peak hours. This strategy focuses on reducing the highest demand as shown in Figure 3 [22]. Moreover, these loads are not able to be shifted to the off peak periods which is due to lack of installed capacity during these periods [23]. The load building is being used to increase the energy consumption over the course of the day [18] as shown in Figure 4. Finally, the energy conservation is being used to reduce the energy consumption throughout the day [18] as shown in Figure 5.

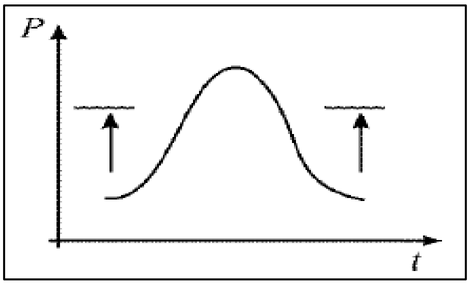

Figure 1. Valley filling technique

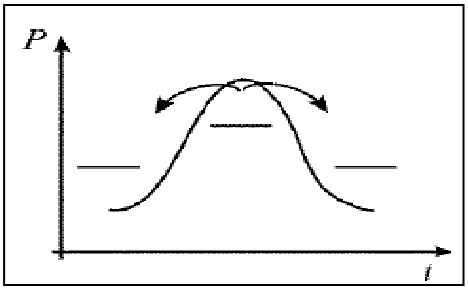

Figure 2. Load shifting technique

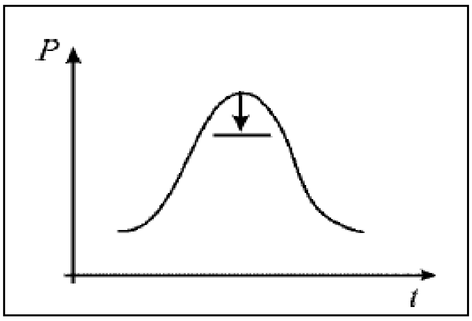

Figure 3. Peak clipping technique

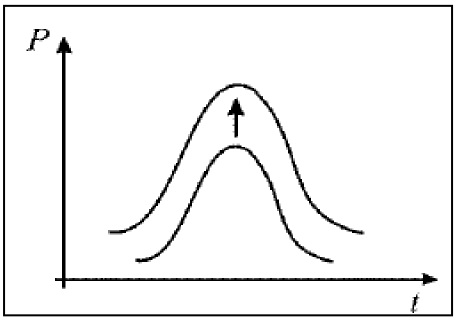

Figure 4. Load building technique

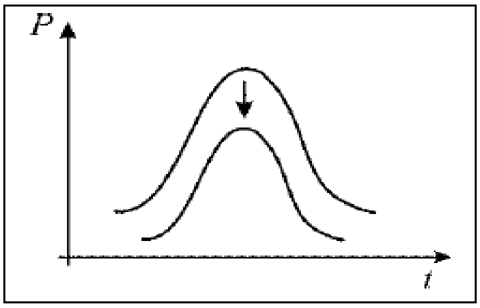

Figure 5. Energy conservation technique

b) ETOU in Malaysia

ETOU scheme in Malaysia offers three-time zones for energy charge which consists of off-peak period, Mid-Peak period and Peak period rates. The tariffs rate for off-peak period is less than Mid-Peak period and Mid-Peak period is less than Peak period rates. Meanwhile, the Maximum Demand charge has two different time zones which are the Mid-Peak and Peak period rates [8]. The scheme is shown in Table 1 while the ETOU time zones are classified as in Table 2.

Table 1. The ETOU scheme offers by TNB

Day	Type Of Charge	Time Zones and Rates
Monday to Friday	Energy Charge	➢ Peak period rates ➢ Mid-Peak period rates ➢ Off-Peak period rates
	Maximum Demand Charge	➢ Peak period rates ➢ Mid-Peak period rates
Weekends and Public Holiday	Energy Charge	➢ Off-Peak period rates
	Maximum Demand Charge	waived during Saturday, Sunday, and Public Holidays

Table 2. The ETOU time zones

Time Zone	Hours
Mid-Peak	08:00 – 11:00 hours
Peak	11:00 – 12.00 hours
Mid-Peak	12:00 – 14:00 hours
Peak	14:00 – 17:00 hours
Mid-Peak	17:00 – 22:00 hours
Off-Peak	22:00 – 08:00 hours

From the Table 2, it can be concluded that the Peak period is from 11:00–12:00 and 14:00–17:00 hours, while the Mid-Peak period is from 08:00–11:00, 12:00–14:00 and 17:00–22:00 hours. Lastly, the off-peak period is from 22:00–08:00 hours. These time zones apply for weekdays, while weekends and public holidays will be defined as off-peak period for the whole 24 hours. The ETOU tariff scheme is offered to low voltage (LV), medium voltage (MV), and high voltage (HV) customers under the tariff category of commercial consumer (Tariff C1, C2) and industrial consumer (Tariff D, Ds, E1, E1s, E2, E2s, E3, and E3s). The ETOU rates are shown in Table 3. The tariff rates are different for each period depending on the electricity demand at that time, whereby during the Peak hours, the electricity demand is high, therefore higher cost of generation will be incurred by the utility company to generate electricity [22].

Table 3. ETOU rates

Tariff Category	Demand Charge (RM/kWh/Month)		Energy Charge (cent/kWh)		
	Peak	Mid-Peak	Peak	Mid-Peak	Off-Peak
Commercial C1 MV ETOU	34.00	28.80	58.40	35.70	28.10
Commercial C2 MV ETOU	48.40	42.60	63.60	33.90	22.40
Industrial D LV ETOU	42.10	37.20	48.40	32.70	24.90
Industrial E1 MV ETOU	35.50	29.60	56.60	33.30	22.50
Industrial E2 MV ETOU	40.00	36.00	59.20	33.20	21.90
Industrial E3 HV ETOU	38.30	35.00	57.60	32.70	20.20

2. RESEARCH METHODS

The project involves data collection of load profiles that gathered from the Complex Engineering buildings in UiTM Shah Alam, formulation of the electricity cost optimization algorithm under the ETOU, development of the PSO optimization and analysis of the simulation. The analyses were carried out using different values of the weightage factors of the load shifting based on controlled load at $W = 10\%,\ W = 20\%,\ W = 30\%,\ and\ W = 40\%$.

2.1. Problem formulation

This optimization formulation to determine the electricity cost in enhanced time of use (ETOU) is presented in this section. The formulation is presented in (1).

$$ETOU_{cost} = [(\sum_{t=1}^{7} L(t) + \sum_{t=22}^{24} L(t)) \times T\_op] + (\sum_{t=8}^{10} L(t) \times T\_mp) + (\sum_{t=11} L\ (t) \times T\_p) + (\sum_{t=12}^{13}\ L(t) \times T\_mp) + (\sum_{t=14}^{16} L(t) \times T\_p) + (\sum_{t=17}^{21} L(t) \times T\_mp) \quad (1)$$

where $ETOU_{cost}$ is the total electricity cost based on ETOU tariff rates while L is an array of load profile for 24 hours retrieved from the commercial building, while t is the time in hours for every load in load profile. The time segmentation is divided into 6 segments based on the ETOU tariff zone consists of peak, mid-peak and off-peak hours as in Table 2. T_op stands for the tariff rate during off-peak hours, T_mp is the tariff rate during mid-peak hours and T_p is the tariff rate during peak hours based on Table 3 for C1 commercial consumer.

$$ETOU_{cost(min)} = \left[\left((\sum_{t=1}^{7} L(t) + \sum_{t=22}^{24} L(t)) - (P\_op \times W)\right) \times T\_op\right] + \left((\sum_{t=8}^{10} L(t) - (P\_mp1 \times W)) \times T\_mp\right) + \left((\sum_{t=11} L\ (t) - (P\_p1 \times W)) \times T\_p\right) + \left((\sum_{t=12}^{13}\ L(t) - (P\_mp2 \times W)) \times T\_mp\right) + \left((\sum_{t=14}^{16} L(t) - (P\_p2 \times W)) \times T\_p\right) + \left((\sum_{t=17}^{21} L(t) - (P\_mp3 \times W)) \times T\_mp\right) \quad (2)$$

where $ETOU_{cost(min)}$ is the minimisation of the electricity cost based on the optimal load after implementing PSO under ETOU tariff rates. P_op is the total desired off-peak power after optimization for segment 1,while P_mp1 represents mid-peak power after optimization for segment 2, P_p1 represents peak power after optimization for segment 3, P_mp2 represents mid-peak power after optimization for segment 4, P_p2 represents peak power after optimization for segment 5 and P_mp3 represents mid-peak power after optimization for segment 6. In this study, W is the weightage factor for load shifting.

In this paper, the total energy of the six segments shall not be more and less than 5% before and after the optimization as presented below:

$$\sum(E1' + E2' + E3' + E4' + E5' + E6') - \sum(E1 + E2 + E3 + E4 + E5 + E6) = \pm 5\% \quad (3)$$

2.2. Particle swarm optimization (PSO)

PSO is a swarm intelligence-based metaheuristic algorithm capable of tackling difficult mathematical problems in engineering [24]. It was proposed originally by Kennedy and Eberhart and was inspired by the concept of swarm intelligence, which is widespread in animal groups such as flocks and shoals [25]. Figure 6 shows the overall flowchart of PSO. The method begins by initialising the PSO parameters and randomly initialising particle location and velocity. Second, the fitness function for each particle is assessed for the local and optimal solution. In this study, the input system data for the starting variable is an average of 24 hours' load profile power consumption from commercial buildings. The fitness function value is then computed for each particle. The fitness function in this project is the user's desire to reduce the cost of his or her power bill. Following that, each particle's location and velocity are updated. Finally, if the halting requirements are met, the algorithm will terminate. Otherwise, the stages from creating the global random are repeated until the halting requirement is fulfilled [26].

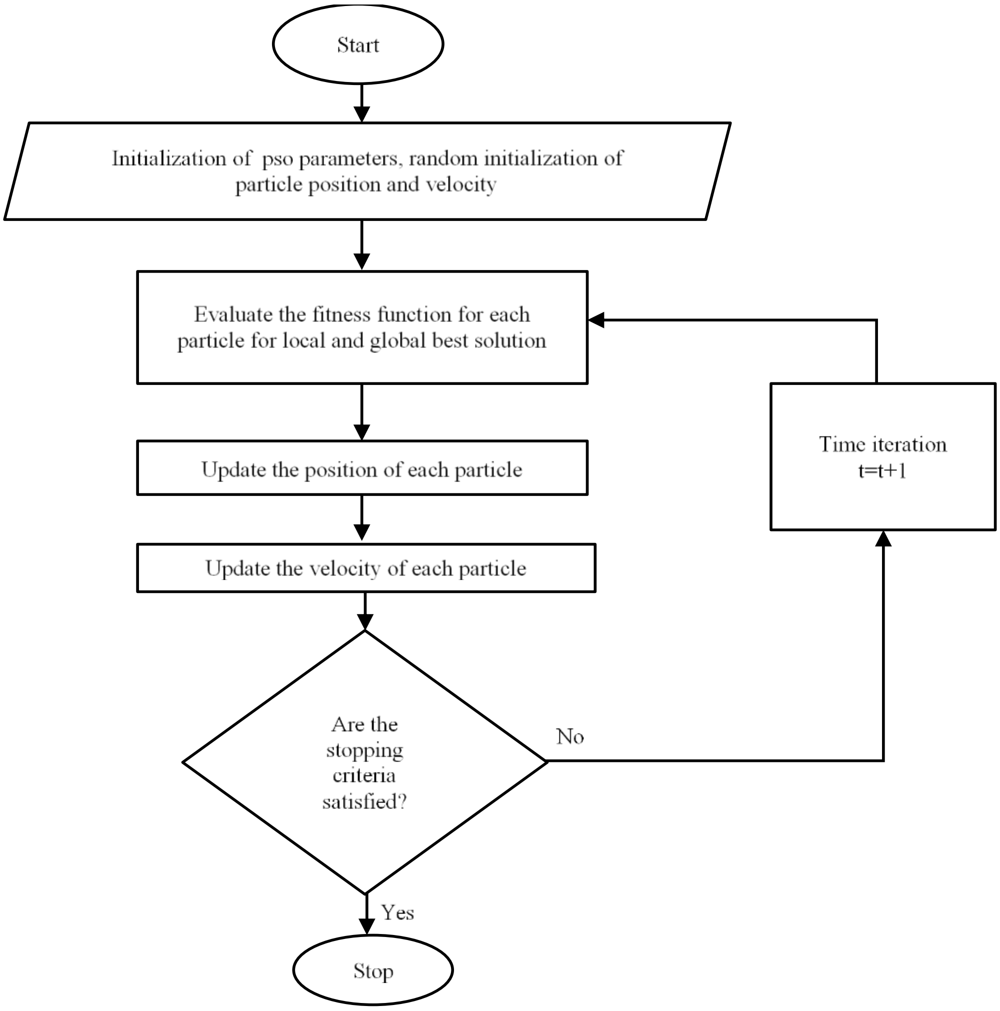

Figure 6. Flowchart of particle swarm optimization (PSO)

2.3. Load profiles

Figures 7-11 show the 24-hours electrical load profiles of several buildings in UiTM Complex Engineering Shah Alam gathered in January 2020, denoted as SNTW1, SNTW2, SNT3, SNT4 and SNT5. From the load profile shown below, the demand varied hourly and reached its peak during the daytime. The load patterns show that the building reached its maximum demand at 11.00 a.m for SNTW1 and SNT5, 3.00 p.m for SNTW2 and SNT4 and, 12.00 p.m for SNT3. On the other hand, the electricity consumption was the lowest at 3.00 a.m for SNTW1, SNTW2, and SNT3, 1.00 a.m for SNT4 and 12.00 a.m for SNT5.

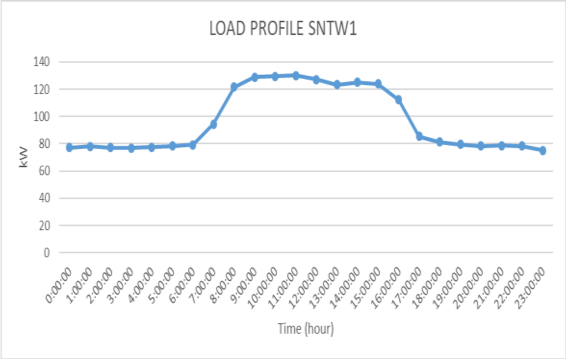

Figure 7. Load profile for commercial building SNTW1

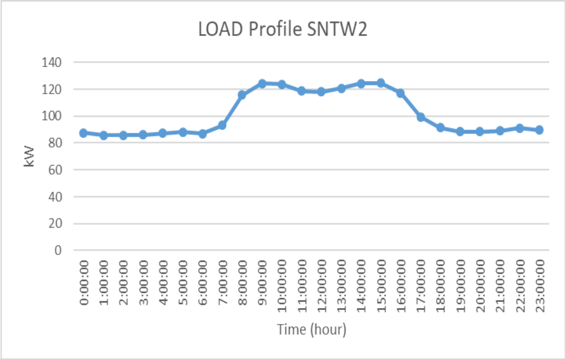

Figure 8. Load profile for commercial building SNTW2

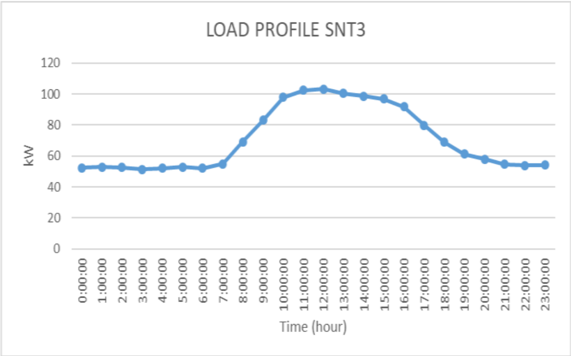

Figure 9. Load profile for commercial building SNT3

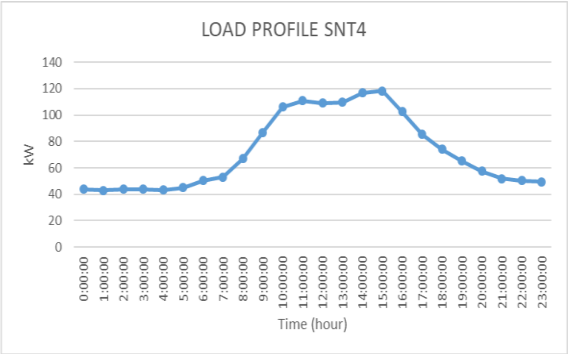

Figure 10. Load profile for commercial building SNT4

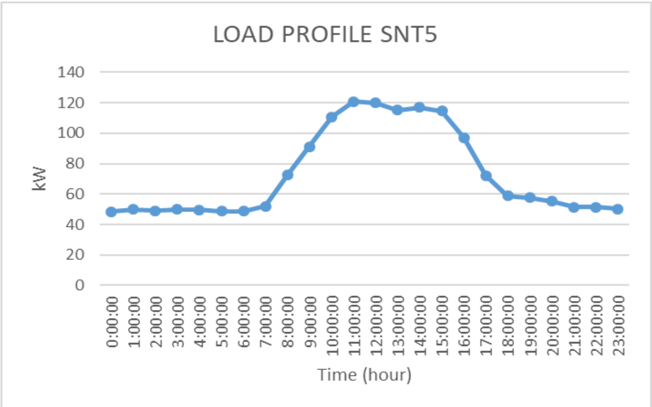

Figure 11. Load Profile for commercial building SNT5

3. RESULTS AND DISCUSSION

This section presents the findings and analyses of the load profile before and after PSO implementation, and the cost reduction under the ETOU after optimization. The weightage factors for load shifting of $W = 10\,\%$, $W = 20\,\%$, $W = 30\,\%$, $and\ W = 40\,\%$ based on controlled were used to determine the optimal solution.

3.1. Optimum load profile

Based on the weightage factors mentioned above, the optimum load profile is selected from the highest saving. Table 4 shows the total energy of the buildings before and after optimization at different weightage factors. According to the findings, the load profile with $W = 40\%$ is the optimum since it would save more energy and cost than the other weightage factors. This is followed by the weightage factors at $W =$ 30%, 20% and 10%. This result shows that the higher the weightage of load that can be controlled, the lower the energy consumption can be reduced in the buildings. Figures 12-16 show the optimum load profiles at 40% weightage factor as compared to the load profile before optimum load shifting has been applied for SNTW1, SNTW2, SNT3, SNT4, and SNT5, respectively. The blue line stands for the load profile before optimization, while the red line stands for the load profile after optimization.

Table 4. Total energy results

Location	Case (%)	Total Energy (kWh) Before Optimization	Total Energy (kWh) After Optimization	Different Total Energy Percentage (%)
	W=10	2318	2294	1.04
SNTW1	W=20	2318	2252	2.85
	W=30	2318	2229	3.84
	W=40	2318	2222	4.14
	W=10	2426	2397	1.20
SNTW2	W=20	2426	2375	2.10
	W=30	2426	2374	2.14
	W=40	2426	2347	3.25
	W=10	1697	1675	1.30
SNT3	W=20	1697	1663	2.00
	W=30	1697	1646	3.01
	W=40	1697	1628	4.07
	W=10	1730	1709	1.21
SNT4	W=20	1730	1699	1.79
	W=30	1730	1690	2.31
	W=40	1730	1655	4.34
	W=10	1754	1734	1.14
SNT5	W=20	1754	1727	1.54
	W=30	1754	1703	2.91
	W=40	1754	1691	3.59

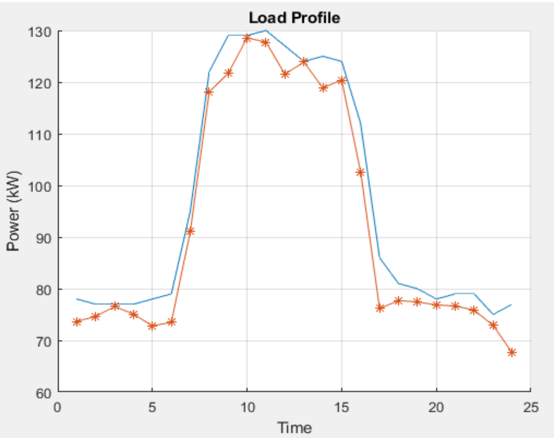

Figure 12. Load profile before (blue) and after (red) optimization for SNTW1

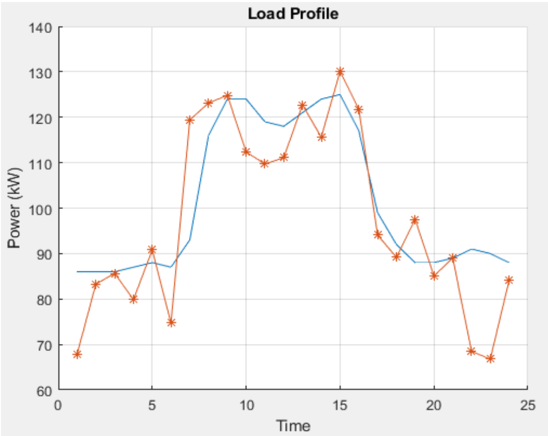

Figure 13. Load profile before (blue) and after (red) optimization for SNTW2

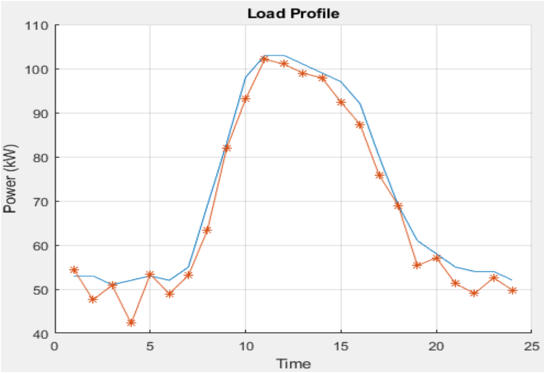

Figure 14. Load profile before (blue) and after (red) optimization for SNT3

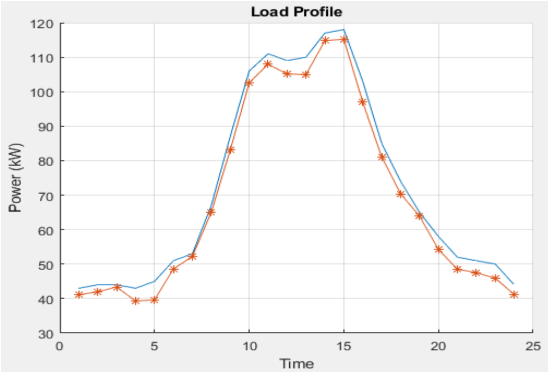

Figure 15. Load profile before (blue) and after (red) optimization for SNT4

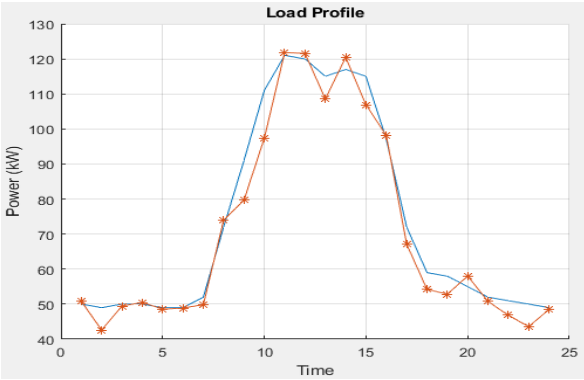

Figure 16. Load profile before (blue) and after (red) optimization for SNT5

3.2. ETOU cost results

Table 5 shows the total electricity cost before and after load optimization was applied under the ETOU tariff rates. The Table 5shows that after optimising the load profile, the electricity cost decreases between 1- 4% in all the buildings depending on the weightage factor. In comparison among the weightage factor cases, it can be concluded that the load profile at $W = 40\%$ provides the lowest electricity cost under the ETOU tariff for all the buildings tested with SNTW1 benefited the most.

Table 5. Total electricity cost results

Location	Case (%)	Total Cost (RM)		Saving Percentage (%)
		Before Optimization	After Optimization	
SNTW1	W=10	879	870	1.02
	W=20	879	854	2.84
	W=30	879	852	3.07
	W=40	879	843	4.10
SNTW2	W=10	909	899	1.10
	W=20	909	886	2.53
	W=30	909	891	1.98
	W=40	909	884	2.75
SNT3	W=10	654	647	1.07
	W=20	654	642	1.83
	W=30	654	635	2.91
	W=40	654	629	3.82
SNT4	W=10	683	677	0.88
	W=20	683	673	1.46
	W=30	683	669	2.05
	W=40	683	656	3.95
SNT5	W=10	690	683	1.01
	W=20	690	681	1.30
	W=30	690	673	2.46
	W=40	690	669	3.04

4. CONCLUSION

This study proposes PSO algorithm for determining an optimal load management strategy for campus buildings under the ETOU tariff rates. The findings demonstrate that the proposed technique can optimise the load profile and therefore lowering the total cost of energy in the buildings. By applying the optimum load management strategy in the building cases at load shifting weightage factor of 40%, the consumers would save electricity bills between 3-4%. This approach will benefit other commercial consumers to implement load management strategies under the ETOU tariff to reduce their electricity bills.

For future recommendation, this research can be improved by employing various load management techniques such as valley filling, peak clipping and energy conservation to determine the optimal strategy for gaining maximum benefit of ETOU tariff. In addition, implementing other optimization techniques than presented in this paper would help in achieving accurate optimum load profiles.

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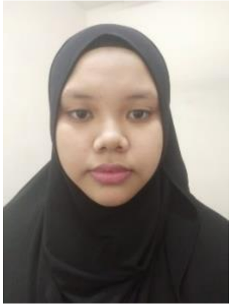

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