A Case Study On The Effectiveness Of Commercial Low-Power Household Energy Saving Device: Does It Perform As Advertised?

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Abstract – *In recent years, low-power domestic Energy Saving Devices (ESD) have been entering the mass consumer market to reduce consumers' electricity bills by plugging them in the power outlets. The product is simple to set up and use. The supplier claims that it "guarantees" a substantial amount of electricity bill cost savings (15 % to 40% savings) by improving power factor, increases power quality by stabilizing voltage, and reduces the impact of electrical surges. However, the problem is, there is no qualitative evidence on how ESD operates and whether it can reduce electricity bills for different types and numbers of household appliances. Typically, the promoter will only show a simple setup to demonstrate the electricity cost saving without credible evidence to ascertain whether the device can perform as it claims. This study aims to determine the true effectiveness of these devices by using an experimental approach to examine whether there is a substantial reduction in the cost of electricity after ESD is applied at an actual domestic electrical appliance's setup. The voltage, current, real power, apparent power, reactive power, and power factor are recorded before and after ESD is switched ON. In this study, the percentage of reduction of electricity costs of the house is only 3.23% or RM5.27 per month. The experimental data shows that the use of ESD has slightly caused a slight improvement to the power factor. Still, calculations show that, based on the experiment setup, the energy consumption did not reduce as much as what is advertised by the ESD supplier.*

Keywords: *domestic/household energy-saving device, low power electricity saving device, power factor correction*

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I. Introduction

Due to the rapid increase in population, modernization, industrialization, and economic growth, electricity demand has increased at an unprecedented rate. In Malaysia, from 1999 to 2009, the electricity peak demand has increased 66%, from 9,690 MW to 16,132MW, and is projected to grow at 3.5% over the next ten years [1] - [2].

Typically, consumers are unaware of how much electricity they have used until they receive the monthly bill. Those with high electricity bills are undoubtedly inclined to react towards a quick fix or solution on reducing electricity bills without the hassle of lowering their existing energy usage behavior or buying more energy-efficient appliances. This situation creates a market need where there has been a penetration of many low-power domestic "Energy Saving Devices" (ESD) offered to the consumer, which claims to help consumers significantly reduce their electricity bills. The product usually is easy to install and operate, i.e., just "plug-and-play" to any power outlet socket in the premise. Most of the catalog or product description and the promoter indicate that their products control or stabilize the voltage and decrease the fluctuations in voltages, causing high electricity bills.

Fig. 1 shows some examples of different make and brand of ESD in the market. Some supplier claims that their devices increase power quality by stabilizing the voltage, improving power factor, and reducing electrical surges. Some advertisements claim that their ESD could provide from 15% up to 40% of the energy and prolong 40% service life of electrical equipment.

Fig. 1. Examples of different brand and manufacturers of low power domestic ESD in the market

However, some studies and reports reported that these devices are a scam and are not reliable. In 2019, the Malaysian Energy Commission had tested several ESD and found them to be "ineffective" [3], even though some manufacturer claim that their device has been tested by Productivity and Standards Board of Singapore (PSB) , Standards and Industrial Research Institute of Malaysia (SIRIM) as well as the Conformité Européenne (CE) of Europe. However, the actual certificates are not available and hence, cannot to be verified. Although several news and websites also reported similar opinions with valid theoretical explanations, none of the reports have provided any empirical and experimental evidence to support that these devices are ineffective [4].

This project aims to perform a case study based on simulation and experiment to determine how effectively these commercial low power household ESD devices are. Specifically, this study seeks to determine whether there is an actual and quantifiable reduction in the cost of electricity after the actual installation of the ESD. The characteristics and performance of ESD on different types, sizes, and numbers of loads also will be studied and verify whether it can effectively reduce electricity bills on a typical household appliances setup.

II. Operations of the low power ESD

Based on observation, most ESD in the market advertised that their product saves power and energy by stabilizing the voltage, improving power factor, and reducing electrical surges' impact. In basic principle, this device utilizes the principle of voltage control and power factor correction, which means it must include capacitive-based equipment as its main component. Besides power factor correction, when configured correctly, introducing a capacitor in a circuit (e.g., in a rectifier circuit) could also be used for voltage smoothing. The smoothing works because the capacitor charges up when the voltage from the rectifier rises above that of the capacitor. Then as the rectifier voltage falls, the capacitor provides the required current from its stored charge.

The effectiveness of the ESD is related to how this device can improve power factor and stabilize the input power on different load usage. The relationship of power factor and how it can be corrected and the assessment method for power factor correction is described in the following sections.

A. Power Factor,Power Factor Correction and energy saving

In many households' electrical systems, magnetizing current (kVAR) and actual power (kW) are required, depending on the appliance type. For example, besides kW, air conditioner also requires kVAR to operate its motor, whereas heating devices such as space heaters and cloth iron only require kW. Apparent power is the sum of real power and reactive power. To reduce the apparent power required for any electrical load, the line that represents the kVAR must be reduced.

Power factor is a parameter that relates the current (amperes) and voltage (volts) of the electrical system. Power factor (PF) is the ratio between real power (P) and apparent power (S), and it represents the efficiency of the electrical system. A circuit can operate in 100% efficiency, which means the power factor is exactly 1.0. When the power factor drops below 1.0, the power utility provider must generate more than its minimum power supply to the circuit [5].

To perform power factor correction, the power factor must be measured or calculated using the following equations [6] :

$$PF = \frac{P}{|S|} = \cos\theta \tag{1}$$

$$P = |V||I| \cos\theta \tag{2}$$

$$S = VI \tag{3}$$

where, V is voltage (volt), I is current (ampere), and θ is the angle between apparent power and a real power. The real power (P) with the unit in kilowatts (kW) is electrical energy that is consumed and not stored in a magnetic or electric field. Meanwhile, the apparent power (S) with the unit in kilowatt amperes (kVA), is the total reactive and real power.

In Malaysia, generally, all consumers are encouraged to consistently maintain a high Power Factor index (above 0.85 or 0.90)[7]. However, for commercial and industrial customers, a power factor surcharge is imposed when the power factor is less than 0.90 (electricity supply 132kV and above) or less than 0.85 (electricity supply below 132 kV)[8]. However, such impose is not applicable for domestic customers.

For the same amount of useful (real) power transferred in an electric power system, a load with a low power factor draws more current than a load with a high power factor.

The low power factor may make the current have the same value of active power, then the power usage increases. The higher current could cause significant power loss and reduce the life of the insulation. Other than that, the low power factor can reduce the effective capacity of the electrical supply and make the electricity costs consumption becomes expensive.

The low power factor is basically influenced by the reactive load. Load contains the elements of inductive or capacitive in the circuit, such as motors and lighting. Low power factor is also caused by harmonic currents, this type of current is present in the load system and reflected into the system, but not in voltage. This harmonic current does not affect the power supply system, but it will lower the power factor. Only load that is purely resistive will not introduce harmonic currents such as heater and incandescent lamps. By reducing the effects of reactive power, the power factor will be closer to unity.

Power factor can also be improved by installing capacitors (KVAR generators), that is capacitor, corrector, synchronous generators or synchronous motors [9]. Also, it can be minimized by minimizing operations of idling or lightly loaded motors, avoid operating equipment above its rated voltage and replace standard motors with energy efficient motors [8].

Power factor correction aims to achieve a value of apparent power (S) close to the real power (P) so that the excess current drawn from the supply can be reduced. This can be done by placing reactance of opposite type in parallel to the load so that the positive reactive power (Q) can be canceled by the negative reactive power (Q) and vice versa [5]. The reactive power (Q) is energy in the system that is stored in the magnetic fields and its unit kilo volt-ampere reactive (kVAR). The injection of Qc (reactive power supplied by the capacitor) causes the inductive reactive power (Q_{old}) to be reduced to a new level (Q_{new}); hence the power factor is then increased [10]

III. Methodology

This paper aims to study on the effectiveness of ESD when installed in a typical household setup. To study the components and operations of ESD, a sample off-the-shelf ESD has been chosen as shown in Fig. 2.[11]. The cost of the device is priced between RM200 to RM300. For this particular model, the supplier recommendation usage for 1 unit is suitable for household with average consumption between 350kWh to 1000 kWh (for single phase premise) and between 750kWh to 2000 kWh (for three phase premise). For single phase client, this is equivalent to between RM100 to RM500 of electricity costs, based on the Malaysian domestic tariff. The installation instruction is just it can be plugged in any of the premise's wall power socket (13A). The manufacturer also claims that this energy saver stabilize the supply voltage, improve energy efficiency and power factor and save electricity up to 30% electrical consumption each month[11]

Fig. 2: The ESD under study when plugged in to a wall power socket

Most of the companies that make ESD sales conceal all of their design circuits and components in the documentation or advertisement. Upon opening the cover of the ESD, this model contains capacitor as a main component (see Fig. 3), as well as some resistors. It was also found that, almost all ESD in the market use the same component as this model, and the difference is just on the value of the capacitor. Based on physical inspection, it was found out that the device only consists of a single capacitor and some resistors. For comparison, another ESD was inspected, and it also contains a capacitor, but with different specifications (see Fig. 4). The specification of the capacitor under study is shown in Table I.

Fig. 3. Component inside the ESD under study

Fig. 4. Capacitor in another brand of ESD

TABLE I
THE DESCRIPTION OF CAPACITOR USED IN ESD SAMPLE UNDER STUDY

Application	AC / Motor
Package Type	Surface Mount
Capacitance	25 uF
Rated Voltage	450 V
Operating Temperature	-40 ~ +85 °C
Colour	White
Capacitance Range	4 uF ~ 100 uF
Capacitance Tolerance	±5%

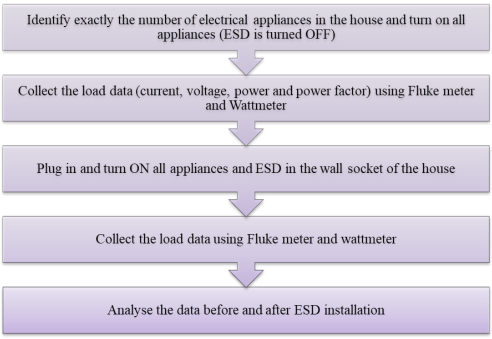

Fig. 5. Procedure for finding the effect of load parameters before and after installation of ESD using actual appliances

Fig. 8 shows the overall procedure to study the effectiveness of ESD in the electrical system in an actual typical household setup. Before installation and operation of ESD, some step and precautions must be followed to avoid any accident during data collection, as follows:

1. Plug in ESD direct with wall power socket (13A). The manufacturer advised not to plug the ESD into an extension or multiple sockets.
2. Avoid poor attachment of plug in the wall power socket when the power is on.
3. When switching off the ESD, wait for 10 seconds to store the initial electrical charge.

The data is analyzed by comparing the data of electrical appliances before and after the ESD is switched ON. As shown in Table II, a specific type and quantity of electrical appliances in the house have been chosen for the experimental setup.

TABLE II
LIST OF HOUSEHOLD APPLIANCES TO BE USED IN THE EXPERIMENT

No.	Electrical Appliances	Quantity	Power Rating (W)	Duration (hours)
1	Television	1	130	4
2	Personal Computer	2	65	8
3	Air-conditioner	1	750	8
4	Water heater	1	1500	2
5	Refrigerator	1	300	24
6	Fluorescent lamp	7	36	10
7	Fans	3	55	8
8	Washing machine	1	300	1

Table III and IV show the load data before and after the ESD is switched ON into the system. The data of currents, voltages, apparent, real and reactive power and power factor for each of the electrical appliances are measured using wattmeter WF-D02A and Fluke Multimeter before and after switching ON the ESD. Other than Fluke meter, the wattmeter also used to collect the data. The wattmeter used called as wattmeter WF-D02A (Taiwan). Wattmeter WF-D02A is the device that commonly used to measure the power consumption of the electrical appliances. The general steps for the measurement are as follows:

1. Plug in the wattmeter that called as wattmeter WF-D02A into the extension (Fig. 6)
2. Plug in the appliance to the wattmeter.
3. Plug in the ESD to wall power socket 13A.
4. Clamped the Fluke meter to the live wire connecting the appliances.
5. Data is then recorded from the wattmeter and Fluke Meter (Fig. 7).

Due to cost limitation to purchase multiple wattmeter and access of Fluke Meter to measure all device at once, the measurement is taken one device at a time. In this study, several assumptions need to be made regarding the load behavior for some appliances. Television, personal computer, tankless water heater, fans and fluorescent lamp typically have constant load when switched ON. However, for washing machine, it is assumed that the motor runs for the entire 1 hour duration (which includes washing and rinsing). For the air-conditioner, it is assumed that the compressor is running for the entire 8 hours and has reached the desired temperature setting.

TABLE III
LOAD DATA BEFORE INSTALLATION OF ESD

No.	Electrical Appliances	Voltage (V)	Current (A)	Power			Power factor
				Real power (W)	Apparent power (VA)	Reactive power (VAR)	
1	Television	224.3	0.63	96.4	141.31	103.61	0.68
2	Personal computer	223.0	0.47	63.1	104.81	83.68	0.60
3	Air-conditioner	237.0	4.30	743.8	1019.10	696.70	0.72
4	Water heater	236.1	7.31	1660.0	1725.89	472.33	0.96
5	Refrigerator	226.0	0.76	115.1	171.76	127.48	0.67
6	Fluorescent lamp	222.4	0.36	34.0	80.06	72.48	0.42
7	Fans	234.7	0.22	48.1	56.63	18.98	0.93
8	Washing machine	226.4	0.54	101.9	122.26	68.21	0.83

TABLE IV
LOAD DATA AFTER INSTALLATION OF ESD

No.	Electrical Appliances	Voltage (V)	Current (A)	Power			Power factor
				Real power (W)	Apparent power (VA)	Reactive power (VAR)	
1	Television	222.7	0.61	95.2	135.85	97.01	0.70
2	Personal computer	237.0	0.30	50.4	71.10	50.06	0.71
3	Air-conditioner	236.7	4.20	743.0	994.14	660.50	0.74
4	Water heater	230.0	7.27	1668.0	1672.10	235.87	0.99
5	Refrigerator	218.9	0.69	112.0	151.04	101.59	0.74
6	Fluorescent lamp	223.0	0.30	33.0	66.90	58.31	0.49
7	Fans	233.1	0.21	47.5	48.95	11.83	0.97
8	Washing machine	226.0	0.47	100.9	106.22	33.19	0.94

Fig. 6. Watt Meter WF-D02A plugged in socket between appliances

Fig. 7. Recording of data using Fluke Meter

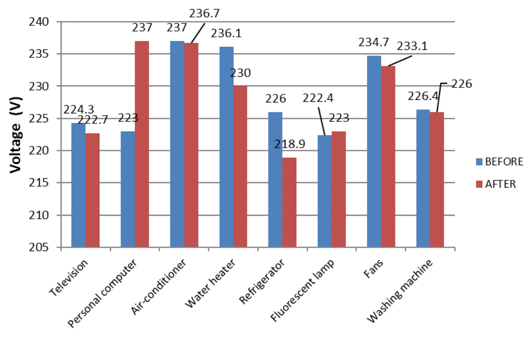

Fig. 8. Voltage versus Different Electrical Appliances

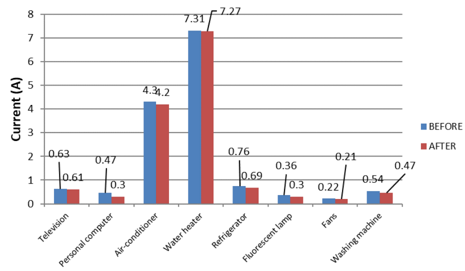

Fig. 9. Current versus Different Electrical Appliances

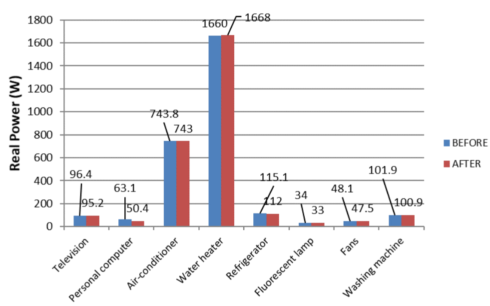

Fig. 10. Real Power versus Different Electrical Appliances

IV. Results and Discussion

In this part, the actual physical ESD under study will be tested based on the procedure as discussed previously.

The data comparison before and after ESD installation has been made and represented in Fig. 8 to Fig. 13. The following figures show the charts for voltages, currents, real powers, apparent powers, reactive powers, and power factors with different electrical appliances before and after the ESD (plugged in the wall power socket) is switched ON.

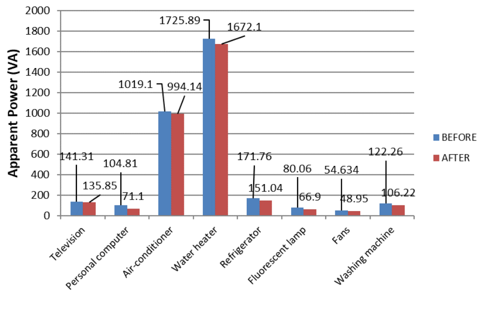

Fig. 11. Apparent Power for Different Electrical Appliances

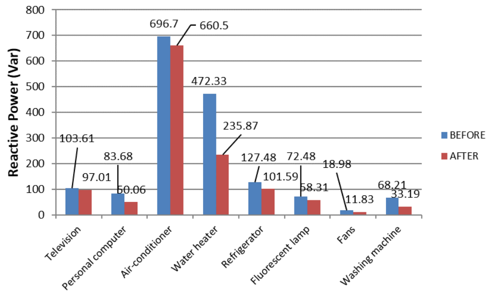

Fig. 12. Reactive Power versus Different Electrical Appliances

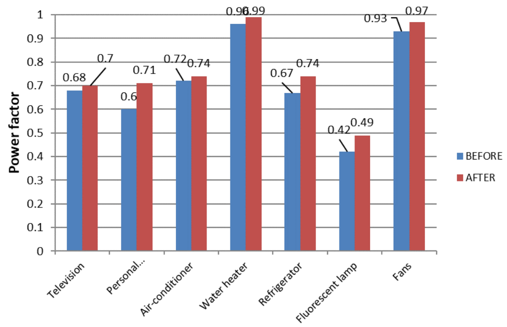

Fig. 13. Power Factor versus Different Electrical Appliances

Fig. 8 shows the voltages for each electrical appliance. The voltages for television, air conditioner, fluorescent lamp, fans, and washing machine are almost the same before and after ESD is switched ON. Meanwhile, the personal computer, water heater, and refrigerator presented more significant different values of voltages. This situation happens because the system is a single-phase system power supply. According to the Malaysian power utility (Tenaga Nasional Berhad) system, they are supplied 230V with tolerance +10% and -6%, which means the voltages are between 216.2V to 253V, so all appliances operate with voltage in the standard tolerable range set by TNB.

Based on Fig. 9, the most considerable value of current is the personal computer, which reduced about 0.17A. The second higher is the washing machine and air conditioner with 0.10A, followed by the refrigerator with a different value of 0.07A. Other than that, the current reduces by 0.10A for fluorescent lamps, refrigerators, water heaters, and fans.

Fig. 10 shows the comparison of real power before and after installation of ESD for each electrical appliance. The water heater recorded the highest value of real power for before and after installation ESD, and the value is almost the same. Water heaters are classified as purely resistive loads, and they require significantly high power to heat up the water in a short time. However, the real power value for water before is slightly lower than after installation ESD, that is, 1660W and 1668W before and after installation, respectively. The air conditioner is contributing second-highest power used.

The value before and after ESD is switched ON is 743.8W and 743W respectively, which mean there is too little reduction of real power, but air conditioner contributes highest overall power consumption per month, this because higher utilization period. For other loads like refrigerator, fans, television, personal computer, fluorescent lamp, and the washing machine recorded reading below 200W, the value for before and after installation ESD does not show significant reduction of real power and energy saving.

Fig. 11 shows the apparent power for every electrical appliance before and after the installation of ESD. The chart reveals no significant differences in apparent power before and after the ESD is turned ON. The higher value of apparent power recorded was water heater with 1725VA before and 1672VA after installation ESD, followed by air conditioner reading before installation is 1019.71VA and 994.14 VA after installation of ESD. The rest of the electrical appliances give measurement values below 200VA.

Fig. 12 shows the reactive power for each different electrical appliance. The results show that the air conditioner is recorded as the highest reactive power with 696.7Var and 660.5Var before and after installation ESD, respectively. The air conditioner consumes large reactive power as it requires an electrical motor to drive its compressor. The water heater also consumes some reactive power before ESD installation due to the water pump operation. However, after ESD is switched ON, almost half of the reactive power has been reduced. The other load such refrigerator, television, personal computer and washing machine present value less than 100Var before and after installation of ESD. The lowest value of reactive power is fans which is 18.98Var and 11.53Var before and after installation, respectively.

Finally, Fig. 13 shows the chart of power factor for all electrical appliances. The chart shows that fluorescent lamps have a significantly lower value of power factor. This is because the fluorescent lamp consists of magnetic ballast. For other electrical appliances, fans recorded as a high power factor value for before installation is 0.93 and after installation is 0.97. The other load, such as the water heater, shows a high value of power factor, reading before is 0.96 and 0.99 after installation of ESD. The rest of the electrical appliances shows power factor reading of between 0.6 to 0.7 before and after ESD is switched ON.

V. Estimation of electricity costs before and after installation of ESD

To identify whether there are significant reduction of costs after ESD installation, electricity costs of electrical energy consumption before and after the installation of ESD are calculated. In this study, the annual cost to run an appliance is calculated. The costs have been calculated by using the Malaysian electricity tariff. Table V shows the calculation of energy consumption for all appliances in a month before switching ON the ESD.

TABLE V
ENERGY CONSUMPTION FOR APPLIANCES BEFORE SWITCHING ON ESD (PER MONTH)

Electrical Appliances	Quantity	Duration (hours)	Power (W)	Energy consumption (kWh)
Television	1	4	96.4	11.67
Personal Computer	2	8	63.1	30.29
Air-conditioner	1	8	743.8	178.50
Water heater	1	2	1660.0	99.60
Refrigerator	1	24	115.1	82.80
Fluorescent lamp	7	10	34.0	71.40
Fans	3	8	48.1	34.63
Washing machine	1	1	101.9	3.06
		Total (kWh/month)		**513.85**

Based on Table V, the projected energy calculation for 1 month is calculated by referring to the Malaysian electricity tariff. The calculations of electricity costs are shown in Table VI.

The estimated electricity costs for the house in the month for the electrical appliances is RM162.96 without switching ON the ESD. The calculation of power consumption of electrical appliances after the ESD is switched ON is shown in Table VII.

TABLE VI
COST OF ELECTRICITY FOR APPLIANCES BEFORE SWITCHING ON ESD (PER MONTH)

Domestic Tariff Block (kWh)	Consumption	Tariff Rate (cents/kWh)	Cost of Electricity (RM)
First 200	200	21.8	43.60
Next 100	100	33.4	33.40
Next 100	100	40.0	40.00
Next 100	100	40.2	40.20
Next 100	13.85	41.6	5.76
Total	**513.85**		**162.96**

TABLE VII
ENERGY CONSUMPTION FOR APPLIANCES AFTER SWITCHING ON ESD (PER MONTH)

Electrical Appliances	Quantity	Duration (hours)	Power (W)	Energy consumption (kWh)
Television	1	4	95.2	11.42
Personal Computer	2	8	50.4	24.19
Air-conditioner	1	8	743.0	178.32
Water heater	1	2	1668.0	100.08
Refrigerator	1	24	112.0	80.64
Fluorescent lamp	7	10	33.0	69.30
Fans	3	8	47.5	34.20
Washing machine	1	1	100.9	3.03
		Total (kWh/month)		**501.18**

Based on Table VII, the estimated electricity costs have been made. The calculation for every kilowatt per month is calculated by referring to the tariff. The calculations of electricity costs are shown in Table VIII.

TABLE VIII
COST OF ELECTRICITY FOR APPLIANCES AFTER SWITCHING ON ESD (PER MONTH)

Domestic Tariff Block (kWh)	Consumption	Tariff Rate (cents/kWh)	Cost of Electricity (RM)
First 200	200	21.8	43.60
Next 100	100	33.4	33.40
Next 100	100	40.0	40.00
Next 100	100	40.2	40.20
Next 100	1.18	41.6	0.49
Total	**513.85**		**157.69**

Therefore, the estimated electricity costs for the house for the electrical appliances is RM162.96 per month if there is no installation of ESD. Meanwhile, the estimated electricity costs after the installation are 157.69 per month. The reduction of electricity cost is as shown in Table IX.

TABLE IX
ENERGY REDUCTION FOR BEFORE AND AFTER SWITCHING ON ESD (PER MONTH)

Before ESD Installation	After ESD Installation	Percentage Energy Reduction (%)
RM 162.96	RM 157.69	3.23%

The percentage of reduction of electricity costs of the house is 3.23% or RM5.27 per month. In a year, the consumer can have RM63.24 of benefits with the installation of ESD. Based on this result, the reduction percentage of electricity cost is not even close to what was advertised by the seller of the ESD under study (which is 25% for every month). However, despite the small savings, in the long run, this device might have the potential for return on investment. Thus, at a cost of RM250 (average), assuming that the same monthly usage and savings, it would take approximately 3 to 4 years for gaining its return of investment (ROI).

VI. Conclusion

Most household ESD claim and promotes that the customer can enjoy an immediate and significant amount of energy saving (up to 40%) just by plugging it into any wall power socket or near the energy meter. However, despite ambiguity on the reliability of these claims, the market demand for such devices still exists today. This study aims to experiment on a sample of ESD from a market to study and analyze the effectiveness.

From the investigation and analysis in this study, the ESD under study does not significantly reduce total energy consumption and cost of electricity under the above experimental setup. However, this cannot be generalized to all type, make and brand of other ESD in the market as each maker might have different settings and configuration and enhancements made to their devices. In this case, for a sample of ESD under study only uses a simple capacitor. A capacitor is used only to improve the power factor, but increasing the power factor alone might not produce a desirable effect on all types of electrical appliances. Power factor correction devices improve power quality but do not generally improve energy efficiency due to several reasons.

One of the reasons is that the only true power savings would occur if the product was only used near a reactive load (such as a motor) when the motor was operating, and then removed when the motor was not running. However, because there are multiple motors in a normal home that can turn on at any moment, this is unrealistic, but the ESD itself is recommended to be installed permanently to the wall power socket, as specified by the manufacturer.

Furthermore, the ESD's reactive power must be precisely sized in order to balance the inductive loads. Because inductive loads are not always switched on (for example, an air conditioner is rarely operated on 24 hours a day in a typical home), it is impossible to size them effectively unless the ESD is equipped with a system that monitors the household's load and controls the ESD's operating timing.

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