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Efficiency Saving Scheme for Energy Consumption Monitoring System

Dr. Richard M. Pabelona Jr.[1] Dr. John Gerald A. Pilar[2]

[1]*Associate Professor II,*
College of Industrial Technology,
Main Campus, 6115 Talisay City, Negros Occidental, Philippines.
[2]*Associate Professor V,*
College of Business Management and Accountancy,
Fortune Towne Campus, 6100 Bacolod City, Negros Occidental, Philippines.

ABSTRACT
This systems project involves developing an energy consumption monitoring system, which comprises two modules using an Arduino microcontroller. The main module uses a current transformer, while the sub-module uses a current sensor to accurately read the overall energy consumption of a household and individual appliances, respectively. An internet connection is needed for the main module to transmit data to the EMONCMS website. Meanwhile, the sub-module transfers data to the main module via Radio Frequency. All data collected are viewable online on any internet-connected device. A household's Energy consumption can easily be monitored through user-friendly graphs, thus becoming a basis for an efficient energy-saving scheme. The study results show that the device has reached a level of acceptability, making it a significant addition to households and capable of performing its intended task.

KEYWORDS: *Energy, consumption, monitoring, modules, microcontroller, sensor, frequency, and scheme.*

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I. INTRODUCTION

Electricity is highly considered one of life's most vital commodities. Everything would not be possible without it. People from different countries have their fair share of electricity-related issues, concerns, and demands that must be addressed clearly and concretely. Questions such as: "How much is my bill for this month?", "How much electricity was consumed?" "Why is this month's bill bigger than last?" are unanswered. According to the Japanese External Trade Organization (JETRO) survey of 2011, electric rates in Manila were higher than in Tokyo and Singapore.

According to the World Bank, the growing energy demand has inevitably tagged along with the Philippines' economic growth, which hit 6.6% in 2012. Supply can barely cope with the increasing demand, projected to grow by four percent annually from 2011 to 2015. For example, Bacolod City has 110 megawatts per day of energy consumption (CENECO, 2013); although it is highly urbanized, it still experiences power interruptions. Furthermore, it is usual to have a power shortage due to technical failures or, worse, a power supply deficiency (GBPC, 2013). With the advent of technology, energy consumption is affected due to the high demand for energy needed for appliances and media devices to operate. Commercial products for electricity consumption monitoring are available at the market but do not guarantee a reliable service due to a lack of support from their manufacturers. In addition, those commercial products are only available in some local stores here in the Philippines, making potential buyers go for online purchases with significantly higher prices and expensive shipment fees. In addition, upgrades are limited, service parts are unavailable, and technical support and maintenance need to be improved.

With all the facts cited, the researcher was challenged to develop an innovative device that could have great potential for the Philippine electronics industry and electrical companies and be globally competitive. On the other hand, the device has functions similar to those commercial products offered outside the country but with higher availability, better performance, and competitive market price. It conforms to the Philippine National Standards (PNS) for products and services. The device integrates various technologies that offer multiple features but with a price point consideration and practical approach, thus leading to affordable upgrades, maintenance, and feature additions. On the software side, an open-source content management system (CMS) is used for the device's front end for data storage. The openness of the device in its hardware and software aspects leads to more community involvement, which can contribute to the improvement of the system in the future. The device is not primarily designed to lower consumers' energy consumption but to give them more awareness and consciousness in a convenient manner of monitoring their daily, weekly, monthly, and yearly electricity usage, consequently leading them to a better energy-saving habit. The researcher also had first-hand experience in this conflict and is therefore aware of the said information that led him to create a device that can promote cost-effective saving techniques to help lower energy consumption in the future.

Objectives of the Study

This study aims to determine the acceptability and capability of the energy consumption monitoring system as the basis for an efficient saving scheme by utilizing a developed device.

II. Materials and Methods

The Research Design

Phase 1 used quantitative research methods that are not data-free, using all types of sampling techniques that aim for generalization and even infer the characteristics of the population (Adanza, 2009). The research design for the survey questionnaire is a schema that maps out the data sources, the type of data to be collected, how the data will be collected, and the methods to be used in data analysis (Edralin, 2002). Therefore, the researcher pointed out the relationships between the variables under study. This study investigated the acceptability and capability of the device for energy consumption monitoring systems.

The study was descriptive by nature, which was considered by the investigator as appropriate since this investigation attempted to describe and analyze the acceptability and capability of the device for energy consumption monitoring system as the basis for an efficient energy saving scheme.

Block Diagram

The project's block diagram (see Figure 1) includes an overview of the system's main components. There are two designs involved in the diagram. First is the primary controller, which consists of the sensor, main line, microcontroller, network, content management system, internal storage, and a 9 Volt DC and 9 Volt AC power supply. This part acts as the host of the data gathered from the sensors. Once data are present, processing takes place according to the formula contained in the firmware. The main module accepts data from the sub-module through its radio frequency receiver. Afterward, all the data goes through the network and off to be posted on the content management system. Upon network failure, the internal storage is used to store the data that was not uploaded, and later on, it will be re-uploaded when the connection is back.

The second part of Figure 1 is the client module, which is responsible for getting the amount of power an appliance or device consumes using a sensor and a microcontroller. The microcontroller transmits the processed data using the radio frequency transmitter to the main module.

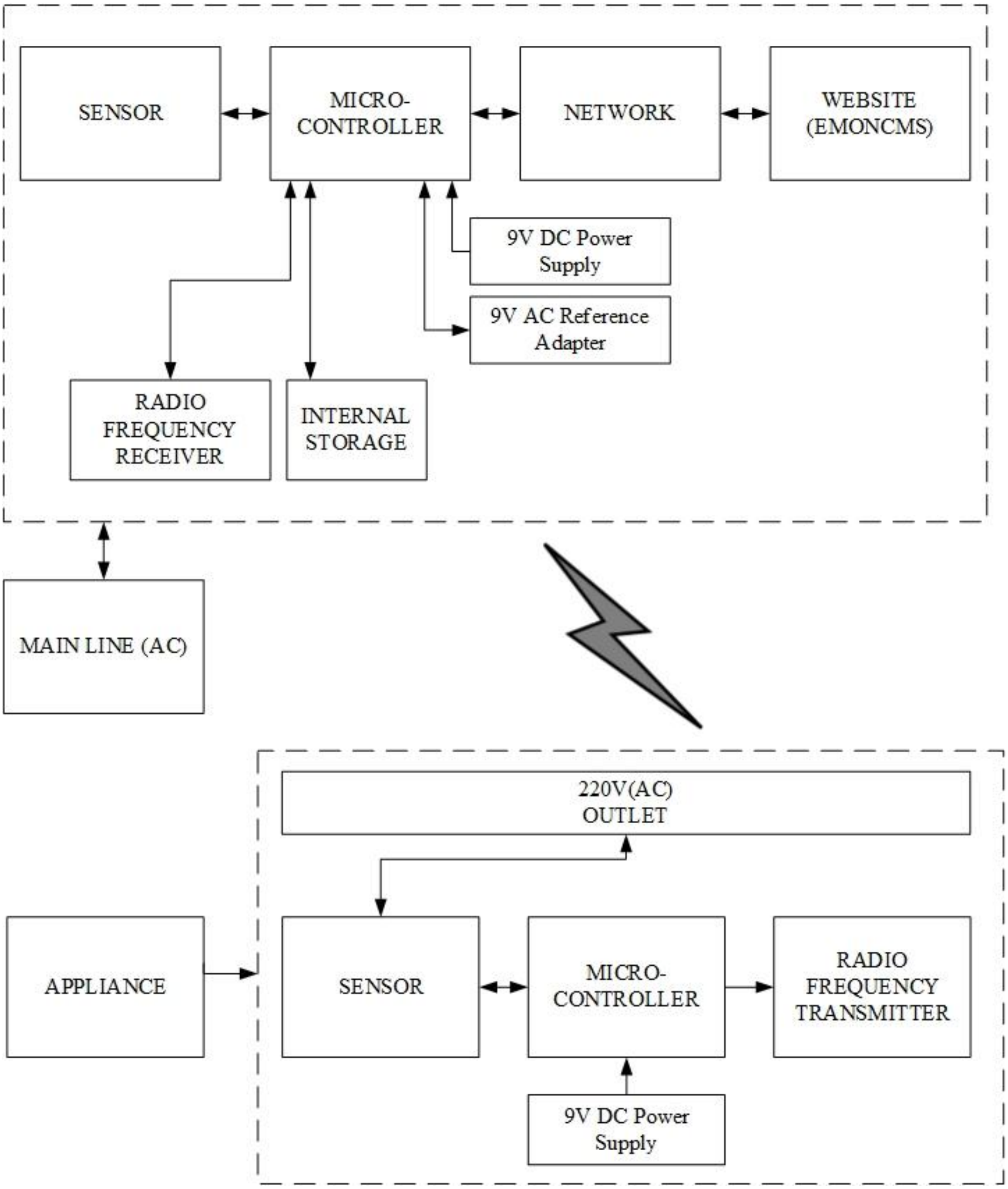

Figure 1. Block Diagram

The Device

The development aspect of the device used an Arduino microcontroller as the central processing unit of the main module and sub-module. The main module requires an internet connection and must be connected to a router with a LAN port. To monitor the overall consumption of a household, the non-invasive current transformer (clip-on) should be attached on one side of the main line (live or neutral), which can be located at the main circuit breaker of the house to read the current flowing. The maximum reading of the main module's sensor was 22000 Watts or 100 Amperes. The main module required two power supplies: 9 volts DC and 9 volts AC adapter.

A separate Arduino Uno was used for the independent sensor module with a built-in electrical outlet. It contained a current sensor and a Radio Frequency (RF) transmitter, which transmitted at a frequency rate of 433 MHz. The module transmits the amount of power in Watts generated by the appliance or device plugged into its outlet to the main module. The current sensor was limited to a maximum input power rating of 2000 Watts. The said module was susceptible to wireless interference.

The account from EMONCMS was embedded in the main module. The entire device was limited to household use only. Moreover, the researcher believes this project will be innovative and valuable to the residents of Bacolod City and the whole Philippines.

Project Design and Materials

The construction and development of the device and its software involved electronics and electrical aspects for the additional circuits, programming for each module's firmware, and hardware-software communication from analog to digital or vice versa.

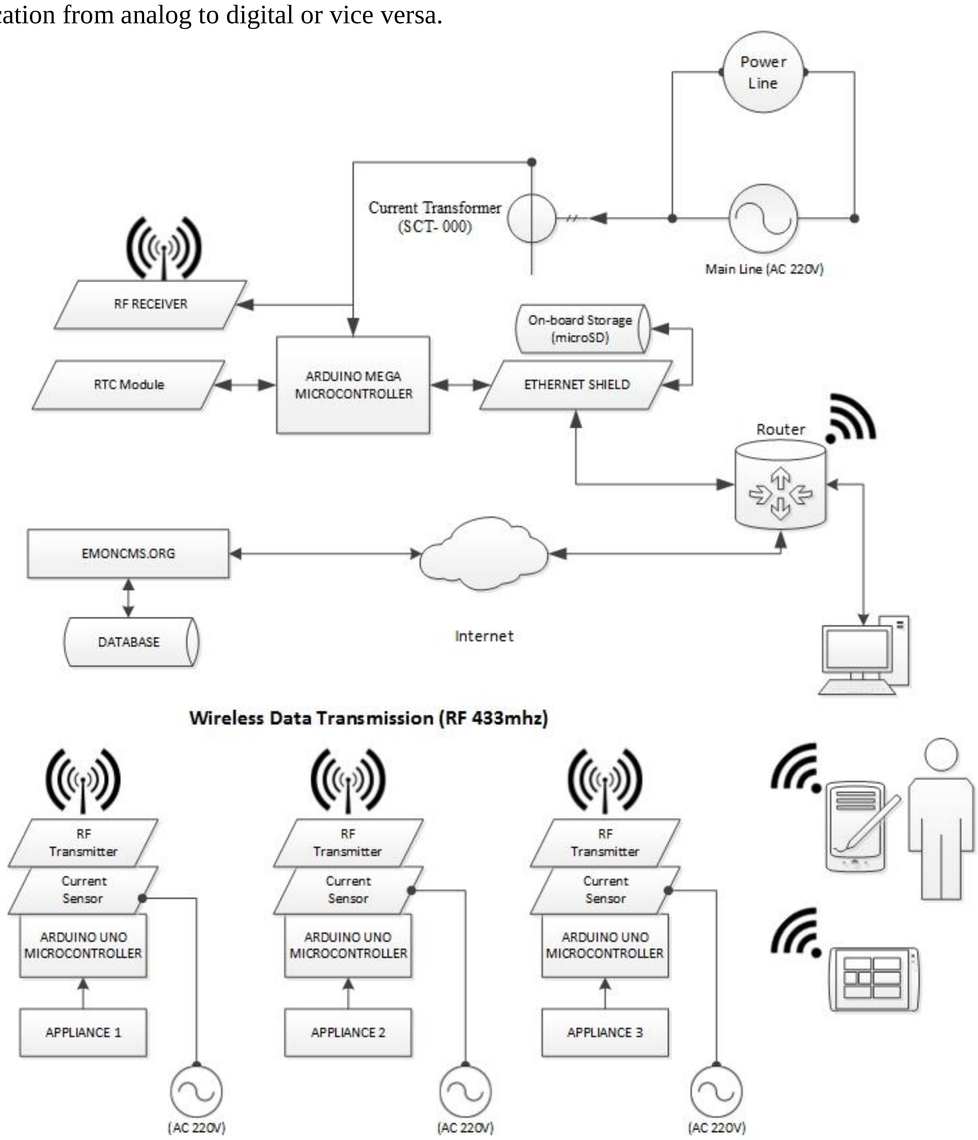

Figure 2. System Design Architecture

Construction Procedures

The device comprised multiple modules connected to the microcontroller. Two designs are involved: the main controller module and the client module. The two designs have specific firmware developed for their tasks. All modules must be tested individually and later combined with other project modules for maximum compatibility. Separate tests should be conducted during the integration of various modules.

Current Transformer Calibration

The current transformer (SCT-013-000) used has a rating of 100A. This was selected to handle high-level electrical loads on all household appliances and devices. The current transformer and a 9-volt AC adapter must be attached to the main module to measure the current on the main line. The additional AC adapter for voltage measurement provided better accuracy than a fixed AC Voltage value. Appendix H: Current Transformer shows a function created explicitly for the Current Transformer (SCT-013-000), which uses a library called "emonlib"*;* this library is responsible for converting analog data to digital, which results in power in watts.

Current Sensor Calibration

The current Sensor and Transmitter demonstrated how the ACS712 current sensor will be calibrated while still using the "emonlib" library for the calculations involved.

Radio Frequency (RF) Transmitter and Receiver Communication

A specialized code must handle these modules and transmit and receive data via the radio frequency (rf) module. The source code from Appendix H: Current Sensor and RF Transmitter and Main Module RF Receiver used the "virtual wire" library, which allowed the main module and sub-module to communicate.

Ethernet Shield (ENC28J60) Testing

The ethernet shield (ENC28J60) required Arduino's specific library (EtherCard) to make it work accordingly. The default library for the Ethernet functionality of the Arduino will not work since it was designed for a different model. An internet connection was required for the main module to upload data to the EMONCMS server. The ethernet shield was only limited to LAN connection. Hence, a router with at least one available LAN port was used. Due to its simplicity, dynamic Host Configuration Protocol (DHCP) was recommended for the Internet Protocol (IP) configuration. The source codes from Appendix H: Main Module Network Communication and Main Module EMONCMS Communication were part of the main module, which handled network connection and data transmission from the sensors to the server.

Data Gathering

To develop the device, the researcher conducted a thorough analysis of how electrical companies here in Negros Occidental function and charge their clients. This gave the researcher a clear idea of how to calculate energy consumption, which is a vital part of the module's firmware. The researcher consulted an electrical engineer to provide inputs for the overall concept of the device alongside the various scenarios encountered in its implementation. An employee from Central Negros Electric Cooperative (CENECO), who is in charge of the monthly meter reading, was also consulted to determine the current meter reading procedures per household and the calculations they made, which reflect on the consumers' monthly bill.

Hardware Components Analysis and Testing

Numerous tests were conducted on the Arduino microcontroller to determine its optimum performance. In addition, individual module testing had been done to guarantee maximum compatibility with the Arduino platform. The testing was done individually per module alongside the Arduino microcontroller to avoid code complexity and redundancy. After all the tests and experimentation, another phase combined the modules and the central controller. All firmware used in the tests was carefully analyzed for possible conflicts with other modules upon integration.

Sensor Testing

The electrical readings of the current transformer and sensors were checked individually and properly calibrated on its corresponding firmware to avoid off-the-mark readings when a load was applied and removed. Each sensor fed data to the Arduino microcontroller, which was calculated and processed to informative electrical data. These electrical data were forwarded to the EMONCMS content management system. The results of the tests were evaluated and served as reference designs for the Energy Consumption Monitoring System prototype.

III. RESULTS

As to the level of acceptability of the energy consumption monitoring system, when taken as a whole, the level of acceptability of the energy consumption monitoring system was "very high" with a mean score of 3.3924. This means that the energy consumption monitoring system got the acceptance level from the participants. This may imply that the energy consumption monitoring system has reached a level where the device must undergo this acceptability degree to meet the required standard from the clientele. Table 1 shows the data.\

Regarding the level of acceptability of the energy consumption monitoring system when classified according to the tracking and real-time energy consumption, the result was "very high," as revealed in the mean score of 3.3593 when the tracking energy consumption is considered. This finding proved that tracking energy consumption possesses an acceptability level in tracking the energy consumption of every appliance in the household. When real-time energy consumption is considered, the result is "very high," as indicated in the mean score of 3.4254, slightly higher than the tracking energy consumption. This implies that real-time energy consumption can satisfy the end user's demand for efficient monitoring. Moreover, this finding proved the high level of acceptability that the device could monitor on a real-time basis and fits the lifestyle of internet-connected and mobile device-dependent people. Table 1 shows the data.

Table 1. ACCEPTABILITY OF ENERGY CONSUMPTION, WHEN TAKEN AS A WHOLE

	N	Mean	Std. Deviation	Description
ACCEPTABILITY OF ENERGY CONSUMPTION (WHOLE)	59	3.3924	.42313	Very High
Tracking Energy Consumption	59	3.3593	.44687	Very High
Real-Time Energy Consumption	59	3.4254	.43928	Very High

As to the level of capability of the energy consumption monitoring system, when taken as a whole group, the result was "very high" with a mean score of 3.4771 when the level of capability of the energy consumption monitoring system was considered. This means that the energy consumption monitoring system can check energy consumption. This may imply that the energy consumption monitoring system has reached a level where the device can meet the target market's required standard. Table 2 shows the data.

As to the level of capability of the energy consumption monitoring system when classified according to the tracking and real-time energy consumption categories, the result was "very high," as revealed in the mean score of 3.4610 when the tracking energy consumption was considered. This finding proved that the device can track energy consumption correctly and accurately, including overall consumption and individual appliances and devices in the household. When the real-time energy consumption was considered, the result was "very high," as indicated in the mean score of 3.4932, slightly higher than the tracking energy consumption. This implies that the device can provide highly accessible energy consumption readings. Moreover, this finding proved the device's high level of capability for performance in its real-time energy consumption reading. Table 2 shows the data.

Table 2. CAPABILITY OF ENERGY CONSUMPTION WHEN TAKEN AS A WHOLE

	N	Mean	Std. Deviation	Description
CAPABILITY OF ENERGY CONSUMPTION (WHOLE)	59	3.4771	.38789	Very High
Tracking Energy Consumption	59	3.4610	.39217	Very High
Real-Time Energy Consumption	59	3.4932	.41683	Very High

As to the differences in the level of acceptability of the energy consumption monitoring system according to the tracking and real-time energy consumption categories, the t-test results revealed that the tracking and real-time energy consumption are not significantly different, with the mean score of -.06610. Moreover, when the results are based on the t-value of -1.930 for df = 59, the obtained p-value of .058 is higher than the set alpha level of .05. This means that the level of acceptability of the energy consumption monitoring system according to variables of the categories of tracking and real-time energy consumption have no difference at all. This may imply that the device's tracking and real-time energy consumption features can work and function independently without interference. The previously cited studies support this finding that when the other functions of the device will not work, other functions should continue working so that the entire operation will not be put at risk. Table 3 shows the data.

Table 3. Differences in Acceptability

		Paired Differences					t	df	Sig. (2-tailed)	Decision
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower	Upper				
Pair 1	Tracking Energy Consumption – Real-Time Energy Consumption	-.06610	.26301	.03424	-.13464	.00244	-1.930	59	.058**	Accept Null

*S - significant at .05 set of alpha
**NS - not significant at .05 set of alpha

As to the differences in the level of capability of the energy consumption monitoring system according to the tracking and real-time energy consumption categories, the t-test computation shows that the tracking and real-time energy consumption do not significantly differ from one another with the mean score of -.03220. Moreover, when the results were based on the t-value of -1.072 for df=59, the obtained p-value of .288 is higher than the set alpha level of .05. This means that the level of capability of the energy consumption monitoring system according to variables of the categories of tracking and real-time energy consumption has no difference in any angle. This may imply that the device's features in terms of tracking energy consumption and real-time energy consumption can be capable and can function sufficiently without intrusion or dependence on each other, e.g., tracking and real-time. Thus, the cited studies support the finding that other problematic functions must not obstruct other device functions. Otherwise, the accuracy of the said device will be consistent. Table 4 shows the data.

Table 4. Differences in Capability

		Paired Differences					t	df	Sig. (2-tailed)	Decision
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower	Upper				
Pair 1	Tracking Energy Consumption - Real-Time Energy Consumption	-.03220	.23077	.03004	-.09234	.02794	-1.072	59	.288	Accept Null

*S - significant at .05 set of alpha
**NS - not significant at .05 set of alpha

As to the correlations between the level of acceptability and the level of capability of the energy consumption monitoring system, the PPM computation revealed that there is no manifestation of correlation between the level of acceptability and the level of capability of the energy consumption monitoring system with r-value of .910 thus, the finding shows that the level of acceptability and capability are insignificantly related to each other. Moreover, the acceptability and capability level only matter if the device is capable or acceptable to the end-users or vice versa.

Furthermore, this finding proved that the device does not follow the "domino effect": If the device is not acceptable, it is capable, or if the device is not, it is acceptable. This further implies that a product must constantly be updated and upgraded in the world of technology to meet society's demand and compete with the fast-changing market. Thus, the previously cited systems support this finding that the primary objective of the device must be capable and functional. Hence, it can be helpful and valuable in today's technology age. Table 5 shows the data.

Table 5. Correlation of ACCEPTABILITY AND CAPABILITY

		ACCEPTABILITY OF ENERGY CONSUMPTION	CAPABILITY OF ENERGY CONSUMPTION	Decision
ACCEPTABILITY OF ENERGY CONSUMPTION	Pearson Correlation	1	.910**	Accept Null
	Sig. (2-tailed)		.000	
	N	59	59	
CAPABILITY OF ENERGY CONSUMPTION	Pearson Correlation	.910**	1	
	Sig. (2-tailed)	.000		
	N	59	59	

*S - significant at .05 set of alpha
**NS - not significant at .05 set of alpha

As to the non-technical category for the bases of inclusion and exclusion of the features of the device, the computation shows that in the non-technical category, "functionality" ranked 1 out of 4 with a mean score of 4.25, described as "excellent," while "appearance" ranked 2.5 out of 4 with the mean score of 3.97 described as "very good" on the other hand, "installation" ranked 2.5 out of 4 with the mean score of 3.97 described as "very good" and finally, the "maintenance" ranked 4 out of 4 with the mean score of 3.78 described as "very good."

The overall impression of the non-technical category was "very good," with a mean score of 3.9925. This finding suggests that the device's prototype's non-technical categories are sufficient for the end user but still have room for further improvements. However, the proponent has noted that the device must be improved to meet the standard of the criteria set by the DOST (Department of Science and Technology) for further enhancement and possible funding for the project in the future.

As to the technical category for the bases of inclusion and exclusion of the features of the device, the computation showed that in the technical category, "hardware-software integration ranked 1 out of 4 with a mean score of 4.14, described as "very good" while "circuit schematics" ranked 2 out of 4 with the mean score of 4.12 described as "very good" and "sensor accuracy" ranked 3 out of 4 with the mean score of 4.07 described as "very good." Meanwhile, "source code" ranked 4 out of 4 with the mean score of 3.97 described as "very good."

The overall impression of the technical category was "very good," with a mean score of 4.075. This finding may mean that the technical aspect of the device met an acceptable level and implies that the existing features will be retained. However, the proponent noted that the device would still undergo continuous development to meet the Philippine's electronics industry standards and be a highly competitive product worldwide. Table 6 shows the data.

Table 6. NON-TECHNICAL AND TECHNICAL CATEGORY

NON-TECHNICAL CATEGORY	MEAN	SD	RANK	DESCRIPTION
APPEARANCE	3.97	0.81	2.5	VERY GOOD
FUNCTIONALITY	4.25	0.86	1	EXCELLENT
INSTALLATION	3.97	0.96	2.5	VERY GOOD

MAINTENANCE	3.78	0.91	4	VERY GOOD
(Whole) Total	**3.9925**			**VERY GOOD**
TECHNICAL CATEGORY	**MEAN**	**SD**	**RANK**	**DESCRIPTION**
SOURCE CODE	3.97	0.93	4	VERY GOOD
HARDWARE-SOFTWARE INTEGRATION	4.14	0.88	1	VERY GOOD
CIRCUIT SCHEMATICS	4.12	0.95	2	VERY GOOD
SENSOR ACCURACY	4.07	0.87	3	VERY GOOD
(Whole) Total	**4.0750**			**VERY GOOD**

The following are the findings of the study:

1. The level of acceptability of the energy consumption monitoring system, when taken as a whole and classified according to the categories of variables such as tracking energy consumption and real-time energy consumption, is "Very High” (see Table 1).
2. The capability of the energy consumption monitoring system, when taken as a whole and classified according to the categories of variables such as tracking energy consumption and real-time energy consumption, is "Very High" (see Table 2).
3. The study's results revealed that the acceptability of the energy consumption monitoring system is similar when classified according to the categories of variables, such as tracking energy consumption and real-time energy consumption (see Table 3).
4. The study's result revealed that the capability of the energy consumption monitoring system is similar when classified according to the categories of variables, such as tracking energy consumption and real-time energy consumption (see Table 4).
5. The study's result revealed no significant correlation between the acceptability and capability of the energy consumption monitoring system (see Table 5).
6. Based on the prototype, the result of the study revealed that both non-technical and technical categories of the device are “Very Good” (see Table 6).

IV. CONCLUSIONS

In assessment of the preceding findings, the following conclusions are made:

1. The overall results of the acceptability and capability of energy consumption monitoring systems, both tracking and real-time energy consumption, are "Very High" (see Tables 1 and 6).
2. The acceptability and capability of energy consumption monitoring systems are similar when classified according to variables such as tracking and real-time energy consumption (see Tables 3 and 8). Therefore, the hypothesis states that there are no significant differences in the acceptability and capability of energy consumption monitoring systems.
3. There is no significant correlation between the acceptability and capability of the energy consumption monitoring system (see Table 5). The hypothesis, which states that there is no significant relationship between the acceptability and capability of the energy consumption monitoring system, is therefore accepted.
4. The study's results based on the prototype revealed both non-technical and technical categories as "VERY GOOD" (see Table 6). Therefore, there are no exclusions in the features of the device.

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