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PERFORMANCE OF AN IMPROVISED SOLAR-HYBRID ELECTRIC STOVE

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ABSTRACT

Fuel used in cooking is becoming expensive because of the rapidly growing demands for cooking fuel and there is a scarcity of sources of fuel used in cooking. There is an evident imbalance concerning the supply and demand for fuels used in cooking. The improvised solar electric stove was developed and tested to come up with an alternative cooking device. The study aimed to develop an improvised stove utilizing cheaper, locally available materials and solar energy as its source of power. It also aimed to test and compare the performance of the stove to other cooking devices. The study adapted the minimum viable products (MVP) model. The development of the stove involved construction, performance testing, comparison of time of cooking or boiling, current rating, and power consumption. Results revealed that the improvised solar electric stove has lower power consumption compared to the commercial electric stove and has comparable performance to other electric cooking devices in terms of the time of cooking, current rating, and power consumption. It was concluded that the developed improvised stove has comparable performance it is technically feasible to develop utilizing locally available materials and solar energy as its source of power.

Keywords: development, electric stove, MVP model, performance testing, solar.

INTRODUCTION

Cooking is indispensable and a part of the daily routine for every household. Majority of our food intake which nourishes our body is prepared through cooking. Now a day, fuel used in cooking is becoming expensive because of the rapidly growing demands for cooking fuel and there is a scarcity of sources of fuel used in cooking. Fuel and energy sources continue to deplete, while users continue to multiply. In India alone, the value of power per capita is greater than the age of power. Besides, more than 300 million Indian people had no access to electricity until December 2011. The interest is expanding further with the increasing population [1]. There is an evident imbalance concerning the supply and demand for fuels used in cooking. About 58 percent of American households cook with electricity, but for some reason, gas cooking is becoming popular [2]. Recent economic, industrial, and environmental innovations need to make enormous use of renewable energy resources and friendly renewable electricity to minimize emissions, thus enabling sustainable growth [3-4].

Traditional fuels continue to destroy our environment since almost all activities currently depend on electricity [5]. Many countries continue to legislate to control emissions. In the United States since 1992, the Phase II EPA (Environmental Protection Agency) Woodstove Regulations require that all wood stoves being manufactured limit particulate emission to 7.5 grams per hour for stoves with afterburners or 4.1 grams per hour for stoves with catalytic converters [6]. The quest for healthier, cleaner, and economical stoves remain an important undertaking in the field of modern technology. Stoves in common use around the world especially in developing countries are considered fire hazards and worse according to the World Health Organization [7]. New strategies have been made to improve stove designs because of issues about air pollution, deforestation, and climate change. Laboratory studies indicate that improved cooking stoves can decrease indoor air pollution, improve health, and reduce greenhouse gas emissions [8].

In the Philippines, RA 8749 otherwise known as "The Philippine Clean Air Act" mandates the state to pursue a policy of balancing development and environmental protection [9], and Republic Act 9513 known as the Renewable Energy Act of 2008 was signed into law to intensify the utilization of renewable energy, one of which is solar energy [10]. Solar power is one of the most readily available types of renewable and clean energy sources, and about 200 MW/km square of solar power is received by the Indian subcontinent [11]. In our energy market, the use of solar energy is growing rapidly [12]. Solar photovoltaic (PV) systems have an important position and considered the most promising among the renewable energy sources, and it is the main source used today because it simplifies the installation process [13-18].

There is a need and growing demand to develop an alternative cooking machine and look for other sources of fuel and energy used for cooking. Solar energy is a major renewable energy source, environmentally sustainable, and green source of inexhaustible energy, as an alternative to reducing the use of fossil fuels [19]. The development of affordable, inexhaustible, and clean solar energy technologies will have huge longer-term benefits. This energy is non-polluting and can be used as a renewable alternative to conventional fossil fuel-based energy [20]. To maximize the use of solar energy, various technologies have been developed such as solar chargers, solar-powered vehicles, and solar-powered households to mention a few.

The prevailing retail price of 11-kg LPG in Metro Manila as of 2020 is ranging from 600 to 800 pesos. Also in the cost of our electricity, based on Manila Electric Company's (MERALCO) tariffs, using residential rates of 200 kilowatt-hours per month consumption, which

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averaged 24 US cents per kilowatt-hour in 2013, the price of electricity is the fifth highest in the world. If electricity prices were the criterion for membership, the Philippines is in the league of the richest countries in Europe, and the local rates are even a bit higher than Japan (Kansai region), 24 US cents, and Singapore, 23 cents [21]. The capital cost for the stoves and cylinders is estimated to be $50 per household. On that basis, the overall stove and cylinder cost will be $13.6 billion in the period to 2015, or $1.5 billion per year, and $14.5 billion in the period 2015-2030. Spending needs would be highest in India [22].

Further, the main cooking fuels used in the Philippines include agricultural residues and waste; firewood, charcoal, LPG, and Kerosene. Liquefied Petroleum Gas or propane is becoming a more popular fuel choice, especially in countries with large urban areas and rising income levels. It is popular with middle and upper-income families because it is clean burning and quick-cooking compressed gas with an adjustable heat output [23]. Further, the primary source of power generation has been biomass for a long time. There are, however, many environmental and sustainability concerns that are of interest to many experts. Therefore, there is a need for clean and renewable resources [24]. In developing countries, biomass demand comes mostly from the power generation and industrial sectors, while in developing countries these sectors represent only 12%, according to the Food and Agriculture Organization of the United Nations [25]. Households typically use a variety of energy sources for cooking that can be classified as traditional such as dung, crop residues, and firewood; secondary such as charcoal and kerosene, or modern such as LPG, biogas, ethanol gel, plant oils, dimethyl ether (DME) and electricity [26]. Electricity is mainly used for lighting and appliances, rather than cooking, and represents a small share of total household consumption in energy. The use of several fuels offers a sense of energy protection since complete reliance on a single fuel or technology leaves households exposed to price fluctuations and unreliable services such as an increase in electricity usage and monthly electric bills due to an increase in student population in a university [27]. Many citizens in developing countries still depend heavily on the national electricity grid, which serves a vast population [28].

This literature further explains the importance of clean, economical, and sustainable energy used in cooking. Although it shows no direct evidence on the use of solar energy in cooking through the use of PV panels, there are solar cookers but it uses direct heat energy from the sun, which has many limitations.

This study aimed to develop and fabricate an improvised solar electric stove utilizing cheaper and locally available materials and solar energy as its source of power; test the performance of the improvised solar electric stove with the varied size of filament, power source, and in terms of power consumption, current rating, and time of cooking or boiling; test the performance the common household electrical cooking and heating appliances, commercial electric stove and liquefied petroleum gas (LPG) stove in terms of energy consumption, current rating and time of cooking or boiling; and compare their performance to the improvised solar electric stove in terms of energy consumption, current rating and time of cooking or boiling.

RESEARCH METHOD

Research Design

This study used descriptive research and adapted the minimum viable products (MVP) model with the principles of build, measure, and learn. In favor of smaller experiments, this strategy minimizes initial investment in constructing complex technologies, slowly rolled out, which can be tested and evaluated early and frequently by releasing them to real consumers. Therefore, when the solution is being built itself the strategy allows you and development teams the ability to refine the solution based on input from actual use thereby helping you to produce what is needed [29].

Build

The first step taken was the development of the improvised stove implementing three prototypes with a distinctive arrangement and design of nichrome wires. This involved designing, fabrication, and assembling.

Measure

The prototypes have been subjected to performance tests based on cooking or boiling time, power usage, and current rating. The performance testing of the power sources and power supply for the stove is also included in the calculation. It also included the testing of other appliances for cooking and heating.

Learn

The outcomes were carefully evaluated and analyzed for each output test performed to incorporate changes and revisions for each prototype. The design which produced the best result was subjected to performance testing and comparison with other appliances for cooking and heating. The final prototype was also presented to selected end-users for inputs.

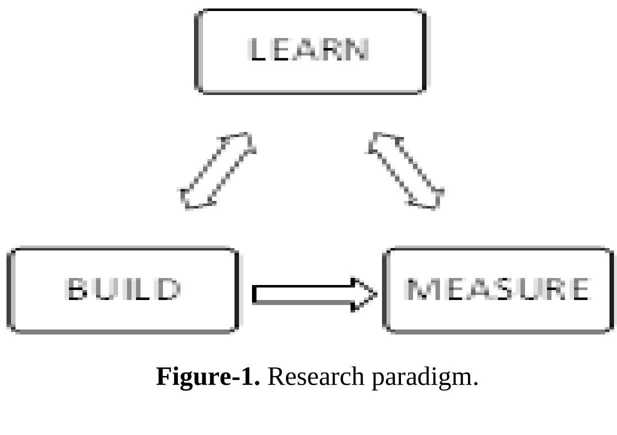

Figure-1. Research paradigm.

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Principle of Operation

The Improvise Solar Electric Stove applied commercial electric stove technology. It utilized a nichrome wire as its heating element, a material usually used in heating and cooking appliances such as rice cookers, electric air pots, and toasters. The developed stove tested different lengths and mounting strategies of the heating element to obtain the best result and performance. One critical feature of the device is the power supply or energy source of the stove. A developed power supply, 50 watts, and 100 watts PV panel system was tested as a power source or power supply. These power sources provided an amount of voltage for the nichrome wire to produce heat. The stove has two sets of nichrome wire as its heating element. The first is two pieces at 9 inches long which is energized by a power supply and the second set is five pieces of nichrome wire at 1.87 inches long which is also powered by the 100 watts solar or PV panel system. The two systems, the solar panel, and power supply can be used separately or in combination, thus, it is solar-hybrid or a combination of non-renewable energy sources and renewable energy sources [30]. The prime objective of trying different sources of energy is to reduce power consumption for cheaper cooking. Enough voltage and current are applied to the nichrome wire so that it can produce enough heat energy. The user may select the AC source or solar panel source or in combination to energize the stove using the selector switch. The stove is also protected with a fuse and auto shut-off by the controller.

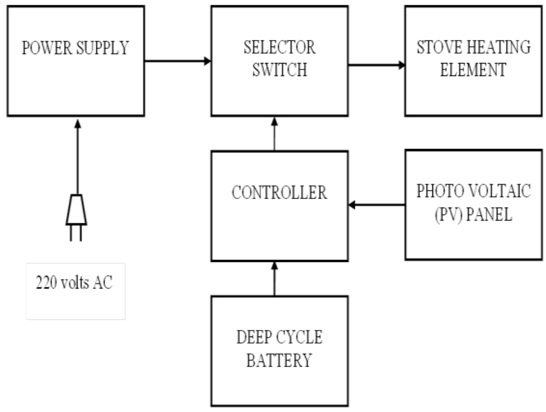

Figure-2. System block diagram of the improvised solar electric stove.

RESULTS AND ANALYSIS

Performance Testing of the Improvised Solar Electric Stove in Boiling 1 Liter of Water

The project implemented and tested three prototypes and designs of nichrome wire using one-liter of water as the constant variable used in performance testing. The performance testing was focused on the time of cooking or boiling, power consumption, and current rating.

Performance Testing Energized by a Power Supply

Table-1. Performance testing of the improvised solar electric stove energized by a power supply in boiling 1 liter of water.

Trials	Length (in inches) & Number of Filaments	Time of Cooking (min.)	Power Consumption (kWh)	Current Rating (Amp.)	Power Supply Output (Volt)
1	5 Filaments @ 2.25	48	0.166	1.12	55.6
2	5 Filaments @ 2.25	46	0.193	1.13	55.6
3	5 Filaments @ 2.25	45	0.21	1.15	55.6
Mean		46.33	0.19	1.123	55.6
1	4 Filaments @ 2.25	41	.25	1.24	57.6
2	4 Filaments @ 2.25	40	.24	1.23	57.6
3	4 Filaments @ 2.25	40	.24	1.23	57.6
Mean		40.33	.243	1.233	57.6
1	2 Filaments @ 9.0	23	.18	2.19	54.7
2	2 Filaments @ 9.0	23	.18	2.18	54.7
3	2 Filaments @ 9.0	22	.16	2.18	54.7
Mean		22.67	.173	2.183	54.7

Energized by an assembled 60 volts AC by 15 amperes power supply, the project was tested at a varied length of nichrome wire filament with 0.25-inch filament diameter in boiling one liter of water. Three trials were performed for each size. Table-1 shows the performance of the stove energized by a power supply. The stove's performance in cooking and heating was tested by boiling 1 liter of water. It is done with three trials from 2 to 4 pm

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on different days. The stove's performance was tested using 3 different specifications, particularly the length of the nichrome wire. Results revealed that the design with 2 filaments at 9 inches has the best performance with an average of 22.67 minutes of boiling 1-liter water, with 0.173 kilowatt-hours (KWH) power consumption.

Performance Testing Energized by a Photovoltaic (PV) System

Table-2 is the performance testing of the stove energized by 50 watts and 100 watts Photo Voltaic (PV) Panel with a deep cycle battery.

Table-2. Performance testing of the improvised solar electric stove energized by photo voltaic (PV) system in boiling 1 liter of water.

Trials	Length (in inches) and Number of Filaments	Time of Cooking (in Minutes.)	Wattage of PV Panel (Watts)
1	5 Filaments @ 1.87	12.20 (Load Cut-off)	50 W
2	5 Filaments @ 1.87	12.30 (Load Cut-off)	50W
3	5 Filaments @ 1.87	12.20 (Load Cut-off)	50W
Ave.		12.23 (Load Cut-off)	
1	5 Filaments @ 1.87	34	100 W
2	5 Filaments @ 1.87	33	100 W
3	5 Filaments @ 1.87	33	100 W
Ave.		33.33	

From the 3 trials for each specification and design, results revealed that the 50 watts PV panel failed to energize the improvised electric stove to boil 1 liter of water since “load cut-off” happen after an average of 12.23 minutes. These results show that a 50 watts solar power system cannot energize the improvised stove. However, the 100 watts solar power system can able to energize the stove with an average of 33.33 minutes in boiling 1 liter of water. This means that higher wattage of the PV panel is required to energize the stove and an additional deep cycle battery and PV panel can enhance the performance of the stove.

Performance Testing Energized by a Combination of a Power Supply and 100 Watts PV System

Table-3 shows the performance of the stove powered by combining a power supply and PV panel system which reflects that the average time of cooking is 12.67 minutes with an average power consumption of 0.0988 kWh and an average current rating of 2.15 amperes. The data revealed the better performance of the stove if energized by a power supply and PV panel system.

Table-3. Performance testing of the improvised solar electric stove energize by a combination of a power supply and 100 watts PV system in boiling 1 liter of water.

Trials	Specification (inches)	Time of Cooking (min.)	Power Consumption (kWh)	Current Rating (Amperes)
1	5 Filaments @ 1.87 & 2 Filaments @ 9	13	0.1014	2.13
2	5 Filaments @ 1.87 & 2 Filaments @ 9	12	0.0936	2.15
3	5 Filaments @ 1.87 & 2 Filaments @ 9	13	0.1014	2.17
Ave.		12.67	0.0988	2.15

Performance Testing of Commonly Used Cooking Appliances in Boiling 1 Liter of Water

Performance testing of a commercial electric stove

Table-4 reflects the performance of a commercial electric stove (Standard brand) in boiling 1-liter water. With the 3 trials conducted, using the same cooking utensil, also from 2 to 4 pm, the stove has an average of 10.72 minutes of cooking and 0.26 KWH consumption at a high setting.

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Table-4. Performance testing of the commercial electric stove (standard) in boiling 1 liter of water.

Trials	Setting	Time of Cooking (min.)	Power Consumption(kWh)	Current Rating (Amp.)
1	High	10.33	0.25	4.38
2	High	10.47	.27	4.38
3	High	11.36	.26	4.33
Ave.		10.72	.26	4.363

Performance testing of liquefied petroleum gas (LPG) stove

Table-5 revealed that the average time of boiling 1-liter water using a gas stove at the maximum setting is only 4.67 minutes. These results manifest that the time of cooking of electric stoves and gas stoves is incomparable.

Table-5. Performance testing of liquefied petroleum gas stove in boiling 1 liter of water.

Trials	Setting	Time of Cooking (min.)
1	Maximum	5
2	Maximum	5
3	Maximum	4
Average		4.67

Comparison of average performance of the improvised solar electric stove to selected cooking appliances in boiling 1 liter of water

Tabl-6 compares the performance of the improvised solar electric stove powered by a power supply and PV panel system. It also compares its performance to the other cooking and heating devices. Results show that the commercial electric stove has the highest power consumption with an average of 0.26 kWh and the highest average current rating of 4.363 amperes. This result coincides with the findings of the California Energy Commission from the article "Consumer Guide to Home Energy Savings" which revealed that electric ovens and other commercial electric cooking appliances have a higher cost of electricity. However, the commercial electric stove has the fastest time of boiling 1 liter of water with an average of 10.72 minutes from the 3 trials conducted. These findings also revealed that the improvised stove is powered by a combination of power supply and the PV panel system has the lowest power consumption with an average of 0.0988 kWh and a comparable time of cooking to other appliances. The table also reflects that the improvised electric stove is powered by 100 watts has the longest time of cooking with an average of 33.33 minutes.

Table-6. Comparison of average performance of the improvised solar electric stove to selected cooking appliances in boiling 1 liter of water

Device/Appliance	Time (minute)	Power Consumption (kWh)	Current Rating (Amperes)
1. Improvised Electric Stove (Powered by a Power Supply)	22.67	.173	2.183
2. Improvised Electric Stove (Powered by PV Panel System)	33.33	0.056	2.05
3. Improvised Electric Stove (Powered by a Power Supply & PV Panel System)	12.67	0.0988	2.15
4. Commercial Electric Stove	10.72	.26	4.363
5. Rice Cooker	24	.145	1.82
6. Electric Air Pot	12	.11	2.61

Electrical Cost in Boiling 1 Liter of Water

Table-7 shows a price comparison of the devices which reflects that the improvised electric stove powered by a combination of an assembled power supply and a 100 watts PV panel system has the lowest electric costs at Php 109.24, a difference of Php 178.24 against the commercial electric stove which has the highest electrical consumption if the cooking or boiling is done 100 times at 11.057 pesos per kilowatt-hour, based on Isabela Electric Cooperative I (ISELCO I) rate. The table also reveals that the improvised electric stove is powered by a 100 watts PV panel system that has free electrical consumption because it uses solar energy. However, the initial investment is needed to put up a 100 watts solar power system.

Table-7. Electrical cost comparison in boiling 1 liter of water.

Device	Power Consumption	Multiplied by 100 times of cooking	Cost per kWh @ Php 11.057 (ISELCO-I Rate)
1. Improvised Electric Stove (Powered by a Power Supply)	.173	17.3	191.29
2. Improvised Electric Stove (Powered by PV Panel System)	0.056	5.6	Free (off-grid)
3. Improvised Electric Stove (Powered by a Power Supply & PV Panel System)	0.0988	9.88	109.24
4. Commercial Electric Stove	.26	26	287.48
5. Rice Cooker	.145	14.5	160.33
6. Electric Airpot	.11	11	121.63

CONCLUSIONS

The data shows that the design with 2 filaments at 9 inches has the best performance with an average of 22.67 minutes of boiling 1-liter water, with 0.173 kilowatt-hours (kWh) power consumption. It was also found out that the improvised solar electric stove has lower power consumption (0.0988 kWh) compared to the commercial electric stove and has comparable performance to other electric cooking devices in terms of the time of cooking, current rating, and power consumption. However, the improvised stove has a long time of cooking (12.76 min.) compared to the commercial electric stove (10.72 min). In conclusion, it is technically feasible to design and construct an improvised solar electric stove utilizing cheaper, locally available materials and solar energy as its source of energy. It is also found out that the performance of the improvised solar electric stove in terms of power consumption is better than the other electric cooking devices and has comparable performance to other devices in terms of the time of cooking and current rating. The improvised solar electric stove has the lowest power consumption compared to the commercial electric stove and other cooking devices, therefore it is a cheaper cooking device in terms of electrical consumption. It is also concluded that the 50 watts PV panel cannot provide enough energy to the improvised electric stove, however, the 100 watts PV panel system was able to energize the stove. The use of a PV system is encouraged, only additional PV panels are needed to improve its performance which means additional cost and initial investment. A more concrete analysis of its cost-benefit and return-of-investment is also recommended.

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