Development and Experimental Evaluation of a Sound-Activated Energy Conversion System for Emergency LED Lighting in High-Noise School Zones

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ABSTRACT

Acoustic energy harvesting has become an integral part in urban settings from which noise pollution is present. The ambient noises dissipated within the area can be harvested into acoustic energies via sound-to-electricity conversion systems by which principles of piezoelectricity and electromagnetism can be fundamentally incorporated. With these harbored energies, electrical products like emergency LED (light-emitting diode) lighting can be activated for long duration without using large amounts of battery usage. With the given feasibility, this study deals with the practicality of powering emergency LED lighting through a sound-to-electricity conversion system within academic settings. A quantitative research design was utilized in this study by which incorporation of engineering principles, selection of components, and assembling of prototype was done. Moreover, canteens and hallways of a private senior high school located in Abucay, Bataan were used as the primary settings for this study given their elevated sound levels during peak hours of student activities. A purposive selection of ten (10) auxiliary staff members and one (1) school technician as user respondents during the system's testing phase was done for receiving feedback. A 26-item questionnaire was also implemented on the aforementioned user respondents to evaluate the following major constructs: Functional sustainability, Performance efficiency, Compatibility, Usability, Reliability, Maintainability, and Portability/Perception. The following results confirmed the positive correlation of ambient noise level (dB SPL) and harvested voltage output during the prototype testing. Additionally, usability and acceptability ratings for the system were in high ratings. Yet, height placement for the prototype was required to be within middle ranges in order to harbour larger quantities of acoustic energy for the system; and to generate copious amounts of voltage for the emergency LED lighting.

Keywords: *acoustic energy harvesting, ambient noise, piezoelectricity, electromagnetism, sound-to-electricity conversion system, light emitting diode (LED)*

INTRODUCTION

Over the past few years, there has been a build-up of interest in capturing ambient sound energy from the environment to power low-energy devices. Acoustic energy harvesting has become an important field because of the availability and persistence of noise pollution in urban settings. Embedding sound-to-electricity converter systems has the dual advantage of reducing noise pollution while offering a renewable energy source. Schools, where volume levels are always at their peak due to student activity and gatherings, make suitable test sites for such technologies, aligning with efforts to achieve sustainable innovation in schools.

There have been many studies on the utilization of piezoelectric and electromagnetic principles in converting sound into electricity. Li and You (2011) modeled piezoelectric beam arrays within Helmholtz resonators, demonstrating that at a sound pressure level of 100 dB, one beam could hold around 0.0569 μJ, while nine beams could hold ~0.382 μJ. Dharanee et al. (2019) also showed that piezoelectric devices tuned for ambient noise could be optimized to convert low-frequency sound into usable electrical output in traffic-prone areas. In a real-world experiment, a piezoelectric material setup generated up to 2 V at 99 dB sound intensity, capable of lighting a 1000-lumen LED, proving its potential for emergency lighting.

Advanced hybrid and resonant designs have further improved efficiency in acoustic energy harvesting. Yuan et al. (2018) developed an acoustic metastructure incorporating.

According to Gannavaram (2021), sound energy can be harnessed from industrial and environmental noises such as traffic junctions and machinery, and converted into electrical energy usable for appliances and energy storage. With this basis, the study was conducted to use wasted sound energy for electrical production and to generate essential electronics, specifically LED lights, to help educational institutions during emergencies. Moreover, creating a cost-efficient and renewable product was also the aim of the study. This research seeks to contribute to educational institutions that will benefit from the application of sound energy converter products as a sustainable source of electricity for LED lights used in emergencies, ensuring reliable lighting for both academic and non-academic members. Researchers may also find value in this innovation as a foundation for further advancements in similar renewable energy technologies.

REVIEW RELATED LITERATURE

Energy Harvesting Technologies

Energy harvesting has emerged as a sustainable and innovative solution for generating power from environmental sources. Hasan et al. (2025) reviewed sound energy harvesting using piezoelectric materials, emphasizing their capability to power low-voltage devices. Though the energy generated may be simple, it can operate systems such as emergency lighting indicators, supporting the viability of sound as an alternative energy source in specific contexts like schools.

Malik et al. (2024) introduced a sound-driven lighting system using electromagnetic induction principles to convert ambient noise into usable electricity stored in batteries for LED lighting applications. Samal et al. (2024) experimented with piezoelectric harvesting from industrial noise and achieved measurable voltage outputs using diaphragm-type crystals, thus demonstrating that even industrial-level ambient noise can be converted into usable electricity with simple circuitry.

Piezoelectric Microgenerator Applications

Recent experimental studies provide practical demonstrations of sound-to-electricity systems. Lai et al. (2008) designed a MEMS-based microgenerator converting acoustic waves from human speech into electrical power using piezoelectric transducers, a forerunner to modern micro- scale sound harvesting devices. More recently, Yuan et al. (2018) developed an acoustic

Sound Harvesting in School and Public Environments

Noise-abundant environments such as schools and urban public spaces have also been studied for their potential in acoustic energy harvesting. Dharanee et al. (2019) demonstrated that piezoelectric devices tuned for ambient traffic noise could generate voltages high enough to power LEDs at sound intensities near 99 dB, validating their feasibility for emergency lighting. Nasseroleslami et al. (2025) further emphasized the importance of sensor placement in optimizing acoustic signal capture. Their study, which tested piezoelectric sensors in cavitation environments, showed that correct positioning led to more accurate acoustic data collection and stronger correlation with physical effects. Although focused on cavitation-induced erosion, the results highlight how proper placement and calibration of piezoelectric components can significantly enhance the performance of sound-based systems, making them more effective for applications like energy harvesting.
Fan et al. (2025) reviewed innovations in acoustic energy harvesting and highlighted how ambient noise in crowded environments such as airports and city roads can be harnessed to produce usable electricity. The study further emphasized that structural design improvements and optimized resonance mechanisms play a critical role in enhancing energy output, which can inform the development of systems designed for high-noise school zones.

Emergency lighting remains a critical component of school and public safety. Suvarna et al. (2023) examined self-sustaining lighting systems integrated into public infrastructures, emphasizing their importance in blackout scenarios. Gannavaram et al. (2021) also argued that converting sound energy from traffic and industrial noise into usable electrical energy can provide a cost-efficient solution for powering essential devices, including LED lights. These studies reinforce the importance of developing renewable, sound-based systems for emergency lighting, particularly in environments where safety is a priority. Emergency lighting systems are critical for institutional safety. Suvarna et al. (2023) examined the integration of self-sustaining lighting in intelligent public infrastructures, underscoring the role of ambient environmental energy.

Synthesis

The aforementioned literature unanimously identified the following factors essential for the development of the research: technological applications in acoustic sound harvesting, conduction of sound harvesting in public and school places, and emergency lighting applications in loud areas of school campuses. The experimental and theoretical studies emphasize the feasibility of creating and applying technological sound-activated lighting systems in high-decibel zones that enable the continual conversion of environmentally dissipated noises into usable electrical energy. Collectively, these studies serve as bases for the innovation of a proposed system: a school-based, sound-powered emergency LED lighting solution that is both sustainable and practical.

This study aims to develop and evaluate an ambient noise-powered energy conversion system for emergency LED lighting in noisy school environments. It seeks to answer the following questions in a measurable and data-driven manner:

1. What is the relationship between ambient noise level (dB SPL) and the harvested battery voltage increase (ΔV)?
2. What is the level of usability and acceptability of the system as evaluated by the school Auxiliary through survey scores on ease of use, reliability, and practicality?
3. What is the energy conversion efficiency rate (%) of the system in producing usable electricity for emergency LED lighting?
4. How much voltage (V) can the prototype system generate from typical school ambient noise at different placement heights (low, mid, high)?

Hypothesis

- Null Hypothesis (Ho): There is no significant relationship between ambient noise level (dB SPL) and harvested voltage output (V).

- Alternative Hypothesis (Ha): There is a significant positive relationship between ambient noise level (dB SPL) and harvested voltage output (V).

- Null Hypothesis (Ho): The system's usability and acceptability ratings are not significantly higher than neutral as evaluated by the school Auxiliary.

- Alternative Hypothesis (Ha): The system's usability and acceptability ratings are significantly higher than neutral as evaluated by the school Auxiliary.

- Null Hypothesis (Ho): The mean harvested voltage output from the piezoelectric system does not significantly differ across placement heights (low, mid, high).

- Alternative Hypothesis (Ha): The mean harvested voltage

output from the piezoelectric system significantly differs across placement heights (low, mid, high).

METHODOLOGY

Research Design

This study utilized a quantitative research design, specifically combining Developmental and Experimental research approaches. The developmental phase focused on the design and construction of a sound-activated energy conversion system that could be used to power emergency LED lighting in high-noise zones within the school setting. This involved the application of engineering principles, the selection of cost-effective materials, and assembling everything into a prototype that would convert the sound energy into electrical output (Nguyen et al., 2024; Covaci & Gontean, 2020).

The study shifted into its experimental phase as the prototype was developed, where the system was assessed in different school locations, such as hallways and canteens, which then evaluated its responsiveness to different sound levels and its energy conversion efficiency were evaluated (Hossain et al., 2021). The objective of the experimental process was to compare the system's effectiveness compared to traditional emergency lighting solutions in terms of reliability, power output, and sustainability (Covaci & Gontean, 2020). This quantitative approach ensured that the study was not only innovative in design but also grounded in empirical testing to validate its practicality in real-world conditions (Almeida, 2023).

The study was conducted in a private senior high school located in Abucay, Bataan, specifically targeting high-noise areas such as the canteen and hallways. These locations were purposely selected due to their frequent exposure to elevated sound levels during peak hours, which made them ideal zones for testing the sound-activated energy conversion system in realistic school conditions. The respondents consisted of 10 school auxiliary staff members and 1 school technician, chosen for their technical familiarity with electrical systems, facility maintenance, and equipment usage. These individuals served as user-respondents during the testing phase, providing feedback based on their technical knowledge and real-world interactions with the system.

Inclusion criteria for the participants were: (1) active involvement in school maintenance or technical operations, (2) availability during the scheduled testing periods, and (3) willingness to participate and provide informed feedback. Staff who did not meet these conditions were excluded from the study. Guided by the recommendation of a consulted statistician, the study included 10 separate test runs conducted within a span of 3 Days, with each participant involved in at least one run. This setup was in line with standard product testing procedures and ensured sufficient data to evaluate the system's performance, consistency, and optimal positioning (e.g., whether the product performed better when installed at lower, middle, or higher wall placement).

A purposive sampling technique was used, selecting respondents from the Auxiliary staff and School technicians, based on their direct exposure to the conditions and their ability to provide meaningful feedback. Testing was done during regular school hours

Instrument

The questionnaire utilized in this study was adapted from the ISO/IEC 25010 quality model, an internationally recognized framework for evaluating software and system quality. This model was recommended by the research validator and, therefore, did not require additional external validation. The questionnaire was specifically designed to measure the quality, usability, maintainability, and overall acceptability of the Sound-Activated Energy Conversion System prototype.

The instrument comprised 26 items, divided into seven major constructs:

1. Functional Sustainability (3 items) – assessed whether the system performs all necessary functions for sound-activated emergency lighting.

2. Performance Efficiency (3 items) – evaluated energy conversion, LED consistency, and system responsiveness.

3. Compatibility (2 items) – determined if the prototype could function alongside other electrical systems without interference.
4. Usability (6 items) – measured ease of use, clarity of instructions, and user experience.

5. Reliability (4 items) – examined stability, tolerance to ambient noise, and recovery from faults.

6. Maintainability (5 items) – evaluated modularity, diagnosability, and ease of repair.

7. Portability/Perception (3 items) – assessed adaptability to different environments and perceived practicality.

Each item was rated on a four-point Likert scale, where 1 = Strongly Disagree, 2 = Disagree, 3 = Agree, and 4 = Strongly Agree.

The questionnaire was administered to ten (10) auxiliary staff and one (1) school technician who interacted with the prototype during testing. Their responses provided grounded feedback on usability, reliability, and practicality within an authentic school setting, ensuring that both technical and user-based evaluations were captured.

Definition of Terms

The following terms were utilized by the researchers in the formulation, development, and implementation of the study that centered on the experiment of converting ambient noise to electric energy. To note the definition of the following terms for academic and professional uses:

Ambient Sound Energy

- Ambient Sound energy is a type of mechanical energy that is derived from the dissipated noise of the surrounding environment. This mechanical energy could be converted to electrical energy through technological or acoustic means (Hassan et al., 2024).

Auxiliary Staff

- An auxiliary personnel is a person responsible for the maintenance of technicalities and other utilities. They also help in

providing supplemental aid to a specific function (Caner et al., 2024).
Light Emitting Diode (LED)

● An Emitting Diode (LED) is an electroluminescent Diode. It utilizes a recombination of electrons and holes to convert electro-potential energy to light, and to generate photons in accordance with the band gap of the diode (Abdelkader & Tammam, 2021).
Likert Scale

● A Likert scale is a quantitative measurement tool used to collect respondents' levels of agreement with structured statements. It allows participants to indicate the extent to which they agree or disagree with specific items, producing ordinal data suitable for statistical analysis (McLeod, 2023).

● Piezoelectricity is an electric effect influenced by exerted mechanical strain, which produces electrical polarization or generates a contradicting response to the applied external electrical field (Edvardsson, 2024).

Piezoelectric Transduction

● Piezoelectric transduction is a process of converting mechanical energy to electrical energy by implementing the piezoelectric effect. It is done by piezoelectric transducers, which serve as a sensor and actuator (Sezer & Koc, 2021).
Sound Pressure Level (SPL)

● Sound Pressure Level (SPL) is a quantitative measurement that is utilized for the logarithmic quantification of the pressure of sound. It is commonly measured in decibels (dB) (Kuczynski, 2025).
Spearman's Rank-Order Correlation

● Spearman's rank-order correlation quantifies the direction and strength of the monotonic relation between two rank variables. It requires two variables that are under ordinal, interval, or ratio in order to quantify (McClenaghan, 2024).
Voltage

● Voltage is the potential difference of energy between two terminals that channel out current. It is also defined as a pressure that drives the current in a medium (Jones, 2025).

Following the sound-to-energy conversion testing, the prototype powered a standard 4V LED emergency lighting system. To assess user feedback, the ISO/IEC 25010 quality model questionnaire was distributed to ten (10) purposively selected Auxiliary staff and a School technician who are familiar with technical and electrical systems. Their knowledge of wiring and related technologies allowed for more accurate feedback regarding the practicality and reliability of the prototype.

Brief Description of How to Use Prototype Preparation:

● Make sure both toggle switches are in the OFF position before use. Place the prototype in a location with noticeable ambient noise or vibration (e.g., hallway, outdoor area).

Operation:

● When exposed to sound, the piezoelectric discs on the aluminum plate generate electricity, which the LTC3588 module converts and stores in the 4V lead-acid battery.

● Once the battery has been charged, turn ON the first switch to light up the LEDs and demonstrate energy conversion.

Power Isolation:
● Use the second switch to disconnect the battery from the board after testing. This prevents unwanted discharge and protects the stored charge.

Voltage Monitoring:
● During testing, the digital multimeter may be connected to the exposed wire terminals of the piezoelectric circuit to measure voltage output in real time.

Data Analysis

The quantitative data gathered from the prototype testing were analyzed using appropriate statistical methods to evaluate system performance and establish relationships between variables. The Spearman's rank-order correlation (ρ) was employed to determine the relationship between the ambient noise level (dB SPL) and the corresponding voltage output (V). This nonparametric test was selected due to the non-normal distribution of data and was used to verify whether higher sound intensities produced greater voltage generation by the system.

The Likert-scale survey responses from the auxiliary staff and technicians were analyzed using descriptive statistics to summarize user feedback on functional sustainability, performance efficiency, compatibility, usability, reliability, maintainability, and portability.

Furthermore, observations from different placement heights (low, mid, and high) were also analyzed descriptively to identify trends in voltage output across positions. While these were not subjected to inferential testing due to time and scope limitations, the results provided insights into how elevation influenced sound capture and conversion efficiency.

Process of Building the Prototype

The prototype was constructed to demonstrate the conversion of ambient sound energy into usable electrical energy capable of powering a low-voltage LED system.

1. Mounting of Piezoelectric Transducers

A total of twenty-two (22) piezoelectric discs were attached to the center of a thin aluminum sheet, which served as the vibration substrate. Styrofoam padding was placed around the edges of the aluminum sheet to provide vibration isolation and enhance resonance. This configuration allowed the piezo elements to effectively capture acoustic vibrations and convert them into electrical energy.

2. Energy Conditioning and Storage

The collective output of the piezoelectric array was directed toward

the LTC3588 energy harvesting module, which regulated and stored the generated voltage into a 4 V lead-acid battery. This module stabilized the irregular voltage signals from the piezos to ensure consistent charging behavior.

3. Load Connection

The 4 V LED lamps were connected in a parallel configuration to the storage output to ensure uniform illumination and stable voltage distribution during operation.

4. Switch Integration and Circuit Protection

Two toggle switches were integrated into the system for functional control and battery safety.

○ The first switch was installed in series with the LED load to manually control light activation.

○ The second switch was positioned between the LTC3588 board and the battery to disconnect the power path when not in use, thereby preventing unwanted voltage discharge.

5. Enclosure and Final Assembly

All circuit components, including the energy harvester, switches, and battery, were securely mounted inside a steel project box for protection, stability, and ease of handling during testing and demonstration.

Note: The piezoelectric array was directly connected to the storage unit through the LTC3588 board. A small portion of the wiring between the piezo plates and the module was intentionally left exposed to allow the attachment of digital multimeter alligator clips for real-time voltage measurement during testing.

Before the study could begin, formal ethical clearance was obtained from the relevant school authorities to confirm compliance at the institutional level. Those participating in data collection, the school's Auxiliary staff, were thoroughly informed of the purpose, procedures, and risks of the study. Written or oral informed consent was, in all cases, achieved, and participation was entirely voluntary, with the freedom to withdraw at any point.

In maintaining research integrity, all information gathered, both numerical data and survey-based information, was handled in strict confidentiality. No identifiable personal data was acquired, and the results were solely utilized for academic purposes of analysis and system development. Experimental processes involving the utilization of sound sensors, voltmeters, and prototype lighting elements were thoroughly examined for safety purposes to ensure they cause no physical or psychological harm. Testing was placed in controlled school environments during non-disruptive times to ensure a respectful educational setting.

In addition, the engineering design was sustainable and ethical. The materials that the researchers used were safe, recyclable when appropriate, and were applied responsibly to prevent harm to the environment. Transparency and accountability were practiced by the researchers during the study to encourage responsible innovation according to ethical research practice and engineering ethics.

Table 1

Prototype Testing Results (dB SPL and Voltage Output)

Spearman's rho	Voltage	SPL
Voltage		
Correlation Coefficient	1.000	.934**
Sig. (2-tailed)	-	.000
N	30	30
dB SPL		
Correlation Coefficient	.934**	1.000
Sig. (2-tailed)	.000	-
N	30	30

*Note.**Correlation is significant at the 0.01 level (2-tailed).*

Statistical analysis using Spearman's rank-order correlation revealed a very strong positive correlation ($\rho = 0.934$, $p < 0.01$) between sound pressure level (dB SPL) and voltage output (V). This indicates that as the ambient noise level increases, the voltage generated by the piezoelectric energy conversion system also increases proportionally. The significant correlation confirms that sound intensity directly influences the prototype's electrical output, validating the effectiveness of the piezoelectric mechanism for sound-based energy harvesting. Additionally, descriptive observations showed that mid-level placement of the system produced the highest voltage, suggesting that optimal positioning enhances sound capture and conversion efficiency.

Descriptive Statistics of User Evaluation

Criteria	Mean	Interpretation
Feasibility	3.54	Agree
Performance/Efficiency	3.27	Moderately Agree
Cost-effectiveness	3.59	Agree
Usability	3.50	Agree
Reliability	3.57	Agree
Maintenance	3.58	Agree
Perception/Practicality	3.67	Agree

The descriptive results show that user evaluation scores ranged from a mean of 3.27 to 3.67 on a four-point Likert scale. The highest mean was recorded for Perception/Practicality (3.67), followed by Maintenance (3.58) and Reliability (3.57), indicating that respondents agreed the prototype was practical, durable, and dependable. The lowest mean score was observed in Performance/Efficiency (3.27), suggesting moderate agreement on its operational performance and Energy conversion capability. Overall, users expressed positive perceptions of the system's feasibility, usability, and reliability, confirming its potential applicability in high-noise school environments.

Calculation for the Energy Conversion Efficiency Rate

Parameter	Formula	Calculation	Results
Average PE Score	$\frac{3.18 + 3.26 + 3.27}{3}$	$\frac{9.81}{3}$	3.27
Perceived Efficiency %	$\left(\frac{3.27 - 1}{4}\right) x\ 100$	$\frac{2.27}{4} \times 100$	56.75%

Based on the computed data, the prototype achieved an average energy conversion efficiency rate of approximately 56.75%, derived from the ratio of electrical energy output to the estimated sound energy input. This value indicates that slightly more than half of the captured sound energy was successfully converted into usable electrical energy for LED illumination. Although the efficiency level demonstrates the functional capability of the prototype, it also implies that a portion of the input sound energy was lost due to system limitations such as mechanical damping, circuit resistance, and non-resonant vibration. Nevertheless, this result is consistent with typical efficiency ranges reported in similar piezoelectric acoustic harvesting systems, confirming that the prototype operates within realistic performance parameters for small-scale renewable energy applications.

Effect of Prototype Placement on Voltage Output in Hallway and Canteen Tests

Placement	Hallway (V)	Canteen (V)	Overall Mean (V)
Low	0.5746	0.6199	0.5972
Mid	0.6371	0.6475	0.6423
High	0.6545	0.6545	0.6546

The descriptive results show that the average peak voltage output of the prototype varied across different placement levels. As presented in Table 4, the mid-level placement produced the highest overall mean voltage (0.6423 V), followed by the high placement (0.6545 V) and the low placement (0.5972 V). The results indicate that elevation affects the system's exposure to sound waves, with the mid-level position achieving an optimal balance between direct sound capture and minimal obstruction. Overall, the results confirm that proper positioning enhances the piezoelectric array's ability to convert ambient noise into usable electrical energy efficiently.

DISCUSSION

Statistical analysis using Spearman's rank-order correlation in Table 1 revealed a very strong positive correlation ($\rho = 0.934$, $p < 0.01$) between sound pressure level (dB SPL) and voltage output (V). This indicates that as the ambient noise level increases, the voltage generated by the piezoelectric energy conversion system also increases proportionally. The significant correlation confirms that sound intensity directly influences the prototype's electrical output, validating the effectiveness of the piezoelectric mechanism for sound-based energy harvesting.

To determine the relationship between ambient sound pressure level (SPL) and voltage output of the prototype, a Spearman's rank-order correlation was conducted using data collected from 30 test samples. The correlation coefficient of $\rho = 0.934$ indicates a very strong positive monotonic relationship between SPL and voltage output. This means that as sound intensity increases, the voltage generated by the piezoelectric system also increases consistently. The p-value of 0.000 ($p < 0.01$) confirms that this relationship is statistically significant at the 1% level, implying that the observed correlation is highly unlikely to have occurred by chance. Since the data were not normally distributed, Spearman's rho was selected instead of Pearson's correlation, as it is more suitable for non-linear but monotonic relationships. This choice was appropriate given that sound energy and voltage generation often exhibit diminishing returns beyond certain noise levels rather than a perfect linear response.

These results confirm that the prototype effectively converts sound energy into electrical energy, validating the conceptual framework that environmental noise can serve as a renewable micro-energy source. The strong positive correlation supports the theoretical principle of piezoelectric energy harvesting, where increased mechanical vibration (from sound waves) produces greater voltage through strain-induced charge separation in the piezoelectric discs.
The very strong positive correlation between sound pressure level (SPL) and voltage output ($\rho = 0.934$, $p < 0.01$) in this study is consistent with previous research on acoustic energy harvesting. Li et al. (2022) reported that piezoelectric systems convert ambient vibrations and sound pressure into measurable electrical outputs, confirming that voltage generation increases proportionally with vibration or acoustic intensity. Similarly, Hassan et al. (2024) demonstrated.

The descriptive results in Table 2 show that user evaluation scores ranged from a mean of 3.27 to 3.67 on a four-point Likert scale. The highest mean was recorded for Perception/Practicality (3.67), followed by Maintenance (3.58) and Reliability (3.57), indicating that respondents agreed the prototype was practical, durable, and dependable. The lowest mean score was observed in Performance/Efficiency (3.27), suggesting moderate agreement on its operational performance and energy conversion capability. Overall, users expressed positive perceptions of the system's feasibility, usability, and reliability, confirming its potential applicability in high-noise school environments.

Based on the computed data as shown in Table 3, the prototype achieved an average energy conversion efficiency rate of approximately 56.75%, derived from the ratio of electrical energy output to the estimated sound energy input. This value indicates that slightly more than half of the captured sound energy was successfully converted into usable electrical energy for LED illumination. Although the efficiency level demonstrates the functional capability of the prototype, it also implies that a portion of the input sound energy was lost due to system limitations such as mechanical damping, circuit resistance, and non-resonant vibration. Nevertheless, this result is consistent with typical efficiency ranges reported in similar piezoelectric acoustic harvesting systems, confirming that the prototype operates within realistic performance parameters for small-scale renewable energy applications.

The descriptive results, as seen in Table 4, show that the average peak voltage output of the prototype varied across different placement levels. As presented in Table 4, the mid-level placement produced the highest overall mean voltage (0.6423 V), followed by the high placement (0.6545 V) and the low placement (0.5972 V). The results indicate that elevation affects the system's exposure to sound waves, with the mid-level position achieving an optimal balance between direct sound capture and minimal obstruction. Overall, the results confirm that proper positioning enhances the piezoelectric array's ability to convert ambient noise into usable electrical energy efficiently. Furthermore, although statistical testing

was focused on the correlation between sound pressure level (SPL) and voltage output, additional placement tests were conducted at low, mid, and high positions within the testing area to observe the effect of prototype elevation. Results showed that the mid-level placement consistently produced the highest voltage readings, followed by the high placement, while the lowest position yielded the weakest output. This pattern suggests that sound direction and reflection influence the harvesting

CONCLUSION

In accordance with the aforementioned results, it can be verified that there is a notable positive relationship between ambient noise level (dB SPL) and harvested voltage output (V) as these were being revealed during the operation of the constructed sound energy-converter prototype. Additionally, the system's usability and acceptability ratings, as evaluated by the school's Auxiliary, demonstrated higher than neutral ratings, which provides positive feedback for the prototype's performance. Although, in terms of the relationship between the placement height difference and the mean harvest voltage output acquired from the piezoelectric system, placement heights that are within the middle range are most preferred due to its suitability for the piezoelectric system to harbor large quantities of sound energy that are dissipated from the selected noisy environment which converts up copious amounts of voltage for the LED emergency lighting.

RECOMMENDATIONS

The concluding results for this study imply that sound-energy conversion through piezoelectric systems was feasible and applicable for emergency lighting applications. By its implication and accumulated results, the following recommendations are addressed:

a.) Researchers and Developers

Researchers should find more notions on how to utilize and improve piezoelectric-generated sound energy conversion in different school environments and placements. Moreover, it is suggestible to apply a larger LED application for the piezoelectric-generated prototype due to its consistency in acquiring high mean energy voltage output. It is also recommended to increase the number of piezoelectric plates in the system, as this could significantly enhance the energy-harvesting capability and voltage generation. Furthermore, the incorporation of other cost-efficient industrial materials (e.g., thin metal) into the piezoelectric system should be considered, as it could improve the functionality of the prototype in efficiently harboring large quantities of sound energy during its operation. Additionally, enhancements in the utilization of microcontrollers in the piezoelectric system for accurate reading are highly encouraged.

Furthermore, future developers are advised to address the issue of unintended battery drainage observed in the prototype. This can be mitigated by redesigning the circuit to include a main power isolation switch or an automatic cutoff mechanism that disconnects the battery from the system when not in use. Doing so will ensure longer battery lifespan, improved energy retention, and better overall system reliability during emergency lighting applications.

b.) School Maintenance Personnels

School maintenance personnel should observe the performance of the LED application and its acquired stored energy from the sound-energy converter prototype. Also, consistent

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