

PERFORMANCE ANALYSIS OF SDT SHIELDED PIEZO (TE1000288-0) AND LDT1-028K PIEZOELECTRIC TRANSDUCERS IN ENERGY HARVESTING FROM A CHILLER PLANT

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Abstract

In recent years, the harvesting of energy from noise pollution has emerged as a promising field of research. Industrial activities, such as chiller operations, manufacturing equipment, and construction, naturally generate significant noise, which can be difficult to isolate from the surrounding environment. Nevertheless, there is a lack of research on piezoelectric-based noise energy harvesting. Further investigations are needed to optimise system design to achieve higher energy conversion efficiency. This paper presents the performance analysis of piezoelectric transducers for harvesting energy from noise generated at a chiller plant. The sound levels on the piezoelectric devices were experimentally measured at a range of 82-100 dB, corresponding to the noise zones classified in the chiller plant. Two types of piezoelectric transducers, namely LDT1-028K and SDT-TE1000288-0, both fabricated from polyvinylidene fluoride, were investigated as energy harvesters. The experimental setup included a noise harvesting system consisting of a capacitor and a rectifier. The results indicate that LDT1-028K exhibits superior energy harvesting efficiency compared to the SDT-TE1000288-0 piezo sensor, achieving a maximum voltage output response of ~~0.0258 mV~~ 0.0258 V at 95 dB. The results show that noise pollution from sources such as chiller operations, industrial machinery, and construction activities can be converted into usable electrical energy. By harnessing and utilising unregulated noise, this approach offers a promising solution for powering compact electronic devices, including mobile phones, monitoring sensors, and industrial appliances.

Keywords: Acoustic energy harvesting, Energy harvesting, Piezoelectric materials, Piezoelectric transducers, Sound energy.

1. Introduction

The current drive towards reducing noise pollution in the industry pressures organisations worldwide to implement procedures for controlling noise sources. Industrial activities, such as chiller operations, manufacturing equipment, and construction, naturally generate significant noise, which can be difficult to isolate from the surrounding environment. In addressing the issues associated with noise pollution, researchers have explored innovative technologies to convert noise into usable energy, a concept referred to as noise energy harvesting. This field has attracted increasing attention as a promising green technology solution. Noise energy harvesting aims to capture acoustic energy from environmental noise and convert it into electrical energy. Electrical systems and small- to medium-sized electronic devices could be powered by the efficient conversion of uncontrolled ambient noise [1].

However, this otherwise disruptive noise presents an untapped opportunity: the potential to generate useful electrical energy. Although the concept of generating electricity from noise is not entirely new, recent advancements indicate significant promise for its practical application. A key enabler of this technology is piezoelectric materials (PMs), which generate an electric charge when subjected to mechanical stress from sound waves. This phenomenon, known as the piezoelectric effect, occurs when mechanical vibrations displace electric charges within the material, resulting in a voltage output [2]. Despite the potential of this approach, research on piezoelectric-based noise energy harvesting remains limited. Further investigations are needed to optimise system design for higher energy conversion efficiency.

This study aims to evaluate and analyse the performance of SDT Shielded Piezo (TE1000288-0) and LDT1-028K piezoelectric transducers (PTs) in harvesting energy from noise pollution at a district cooling plant, and also to investigate their potential for conversion into useful electrical energy. This innovative approach addresses the issue of energy sustainability and also contributes to the development of efficient energy systems that benefit both society and the ecosystem.

2. Method

A case study was conducted at the Mechanical and Electrical Plant (MEP) Building of the University of Malaysia Sarawak (UNIMAS) in Sarawak, East Malaysia. The facility contains four centrifugal chillers and ten water pumps. Noise risk measurements were carried out in accordance with the Industry Code of Practice for Management of Occupational Noise Exposure and Hearing Conservation 2019 to evaluate sound intensity, with the aim of exploring potential energy harvesting opportunities within the district cooling plant. The findings were categorised into three zones-white, yellow, and red-based on intensity levels. Subsequently, an analysis of noise intensity relative to voltage output was conducted by measuring the voltage output in each respective zone. A piezoelectric circuit was designed to capture ambient vibrations from the chiller plant across all zones. This circuit comprised a PT, a rectifier, additional transducers, an alternating current-direct current (AC-DC) converter, and a capacitor for energy storage. Once implemented, the circuit converted mechanical vibrations into electrical energy, with voltage and current outputs every 30 min recorded using a multimeter. The multimeter also provided digital readings for power calculations, while a sound level meter was employed to measure noise intensity in decibels. The experiment utilised two types of PMs: LDT1-028K piezo film and SDT Shielded Piezo (TE1000288-0).

2.1. Piezoelectric materials

Piezoelectric materials generate an electrical charge in response to mechanical stress, such as vibrations induced by noise. In energy harvesting systems, this mechanical stress is typically produced by vibrations originating from sound waves, whether from ambient acoustic noise or mechanical sources. When these sound waves interact with PMs, the material undergoes deformation, resulting in the generation of an electrical charge that can then be captured and stored in capacitors or batteries. The harvested energy can subsequently be used to power small devices or sensors.

Numerous studies have highlighted the potential of PMs in energy harvesting applications. For instance, Kamardan et al. [3] conducted a study in Peninsular Malaysia utilising vehicle movement to generate electricity for street lighting. Their findings demonstrated that the modified design produced 3.50 V, approximately 30% higher than that of a commercial piezoelectric design and was capable of supplying low current to an automated street light system. Hossain et al. [4] performed experimental work and produced an ideal voltage output of 0.5-1.0 V, which was subsequently increased using a transformer while maintaining the affordability and usability of the system.

Sarker et al. [5] showed that the output voltage is directly influenced by sound waves, while the voltage increases proportionally to frequency. Their system provided a stable voltage output, enabling effective charging of a mobile phone within a short period. Suleiman and Abdulhamid [6] developed footpads embedded with 35 piezoelectric sensors connected in series and covered with a hardwood board. As people walked on the footpads, alternating current voltage was generated, and their results indicated that approximately 10,812 steps were required to charge a 6 V battery.

In the present study, the PM used is polyvinylidene fluoride (PVDF). The LDT1-028K piezo sensor features a piezo film element laminated onto a sheet of polyester. The input voltage for this piezoelectric sensor ranges from 10 mV to 100 V, depending on the applied force and impedance. Specifically, LDT1-028K operates at 12 V with a frequency of 150 Hz. Conversely, the SDT Shielded Piezo (TE1000288-0) is a shielded sensor from the SDT series, functioning at an input voltage of 15 V. Experimental data collected included voltage (measured in V), running time (measured in min), and noise levels (measured in dB) at the MEP Building. Figure 1 shows the types of PMs used in the experiment, while their configurations are presented in Fig. 2.



Fig. 1. Types of PTs used to harvest noise energy [7, 8].

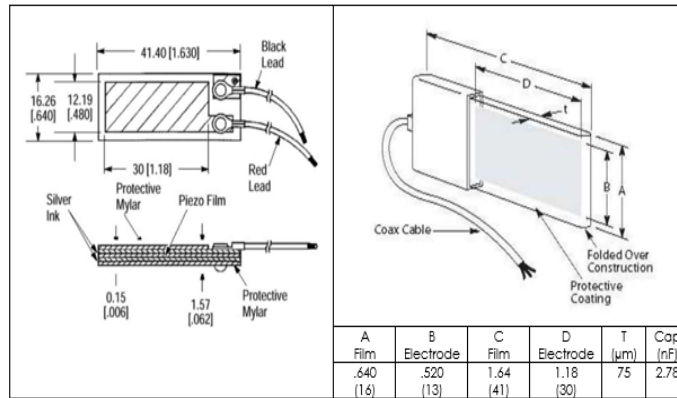


Fig. 2. Description of PTs and custom configurations [7, 8].

2.2. Noise mapping of the MEP building, UNIMAS

A noise survey involves conducting noise measurements throughout an entire plant to identify noisy areas. This process yields valuable information that facilitates the identification of machines and equipment that generate harmful noise levels. By using the “walk-through survey” technique, area noise mapping was carried out to categorise the premises into three noise zones. The maximum sound pressure level was measured on all four sides of each machine at a distance of 1 m from the source and 1 m above the ground, using a calibrated sound level meter. The instrument was directed towards the noise source, and the highest reading was recorded. Area measurements were used to delineate noise zones at 82 dBA (White Zone), 86 dBA (Yellow Zone), and 115 dBA (Red Zone), which were later marked on the layout plan, as depicted in Fig. 3.

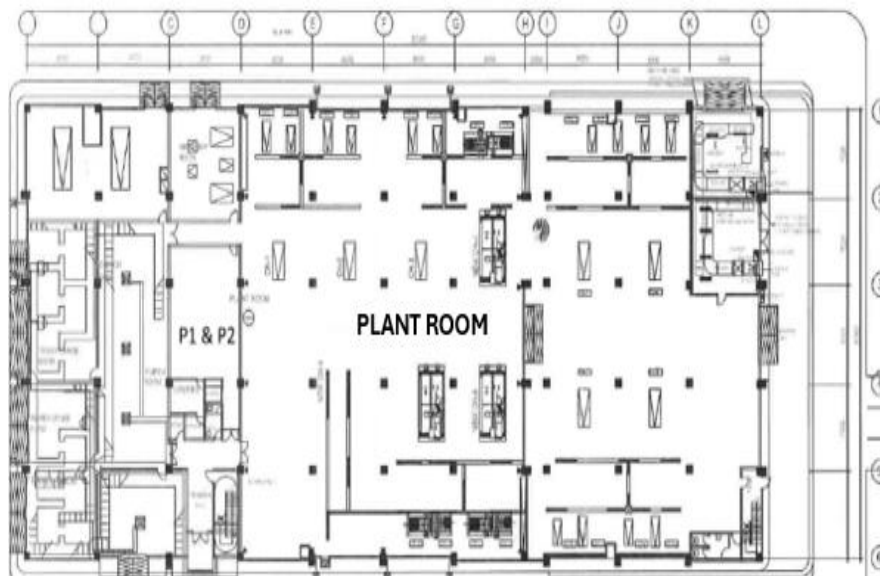


Fig. 3. The layout plan of the chiller plant at the MEP Building, UNIMAS.

2.3. Development of a piezoelectric energy harvesting system

The piezoelectric circuit is designed to harvest ambient noise from the chiller plant. As shown in Fig. 4, the setup consists of a PT, a rectifier, and a capacitor. The PT plays a crucial role in capturing environmental noise and converting it into electrical energy. Subsequently, the rectifier transforms the resulting AC into DC, making it suitable for powering DC devices. Finally, the capacitor stores the converted electrical energy, ensuring a stable and continuous supply. Overall, this system effectively converts noise energy from the chiller plant into usable electrical energy, highlighting the practical application of energy harvesting technologies.

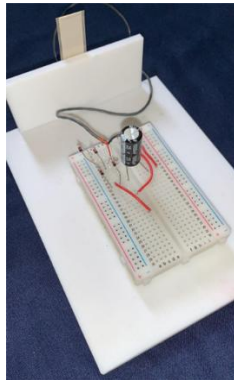


Fig. 4. The piezoelectric energy harvesting system.

Figure 5 shows the framework of the piezoelectric energy harvester (PEH) implemented in this study, while the circuit diagram in Fig. 6 provides a visual representation of the design and construction of the harvester.

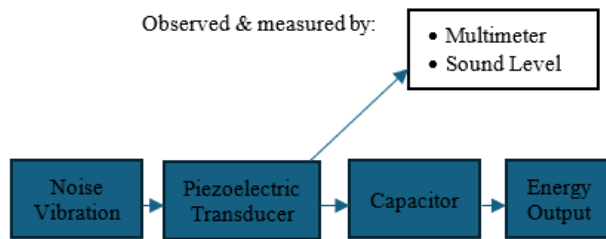


Fig. 5. PEH flow system outline.

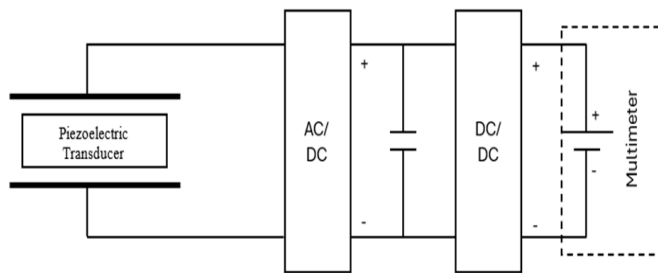


Fig. 6. Schematic diagram of the PEH.

3. Results and Discussion

3.1. Analysis of energy output

The effective voltage output was measured by installing PEHs in different zones based on the decibel range, categorised as Red Zone, Yellow Zone, and White Zone. In this study, LDT1-028K and SDT-TE1000288-0 PTs are used as energy harvesters. These transducers convert sound wave vibrations into DC electricity. The PEHs were tested in the MEP Building. The results for both transducers, in terms of their ability to harvest and convert industrial noise into electrical energy, are presented in Tables 1 and 2, with corresponding graphs shown in Figs. 7 and 8.

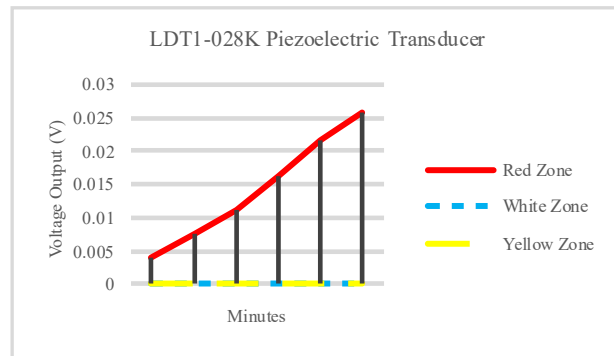


Fig. 7. Voltage output (V) vs. time interval (min) for the LDT1-028K piezo film.

Table 1. Output energy values as a function of time for the LDT1-028K piezo film.

Time (min)	5	10	15	20	25	30	dB(A) Range Reference
Colour zone	White						≤82
Output (V)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
Colour zone	Yellow						>82 to 85
Output (V)	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Colour zone	Red						>85 to 115
Output (V)	0.004	0.0077	0.0113	0.0163	0.0216	0.0258	

Figure 7 illustrates the relationship between voltage output and time for the LDT1-028K piezo film system over a 30-min period across three different zones. The trend reveals a clear distinction in voltage outputs corresponding to the sound levels in each zone. In the White Zone, the voltage output remained consistently low, starting at approximately 0.0001 V and exhibiting minimal increase over time, indicating that the sound levels in this zone are too low to generate significant energy. Similarly, the Yellow Zone showed a nearly flat trend with negligible voltage output throughout the 30-min interval, further suggesting insufficient sound intensity for effective energy harvesting. Conversely, the Red Zone displayed a noticeable increase in voltage output, highlighting its comparatively higher sound levels and confirming its greater potential for energy storage.

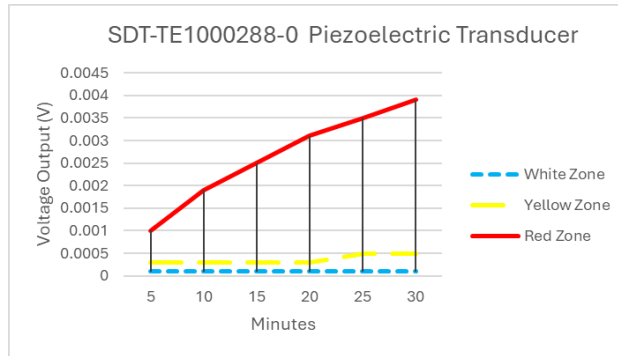


Fig. 8. Voltage output (V) vs. time interval (min) for SDT-TE1000288-0 shielded sensor.

Table 2. Output energy values as a function of time for the SDT-TE1000288-0 shielded sensor.

Time (min)	5	10	15	20	25	30	dB(A) Range Reference
Colour zone	White						≤82
Output (V)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
Colour zone	Yellow						>82 to 85
Output (V)	0.0003	0.0003	0.0003	0.0003	0.0005	0.0005	
Colour zone	Red						>85 to 115
Output (V)	0.001	0.0019	0.0025	0.0031	0.0035	0.0039	

In the subsequent test using the SDT-TE1000288-0 shielded sensor, the voltage output in the White Zone remained very low, starting at approximately 0.0001 V and exhibiting only a gradual increase, as shown in Fig. 8. This suggests that the ambient noise levels in this zone were insufficient to generate meaningful electrical energy. Similarly, the Yellow Zone displayed an almost flat trend with minimal voltage output over the 30-min interval, suggesting limited energy harvesting potential due to low sound intensity.

In contrast, both transducers demonstrated higher energy collection in the Red Zone, where elevated sound levels were recorded, as summarised in Table 2. Furthermore, the PTs demonstrated a consistent performance across all zones, as confirmed by tests conducted in each zone. The only noticeable difference is the variations in output values between different transducer types, likely resulting from factors such as material composition and design specifications, which affect sensitivity and response time.

Empirical evidence suggests that several constraints limit energy absorption, including inadequate reception of mechanical vibrations or operating beyond the appropriate frequency range [7]. Consequently, it is reasonable to infer that the SDT-TE1000288-0 shielded sensor may induce indirect vibration effects, thereby reducing the amount of vibration absorbed by the piezoelectric film and limiting its energy harvesting capability.

3.2. Comparison of energy output

Figures 7 and 8 show that the LDT1-028K PT achieves the highest energy storage voltage within the Red Zone. This finding aligns with previous research by Li et al. [8] and Setiawan and Sifa [9], who established that measurable power output can be generated from noise levels exceeding 90 dB. The Red Zone, characterised by high noise levels, corresponds to significant mechanical vibrations that induce excessive flexing of the cantilever beam, resulting in higher voltage outputs.

Consequently, the LDT1-028K PT exhibits particular efficacy in high-noise environments, where it can harvest substantial energy from mechanical stress, consistent with the findings reported by Song et al. [10]. In contrast, the SDT-TE1000288-0 shielded sensor, although sensitive and flexible, does not generate voltage outputs comparable to those of the LDT1-028K piezo film under identical conditions. The superior performance of LDT1-028K can be attributed to the cantilever beam's ability to flex and dynamically respond to high-intensity vibrations in the Red Zone, facilitating enhanced energy storage.

LDT1-028K is a piezoelectric sensor transducer that functions by bending or flexing in response to mechanical stress. According to Xu et al. [11], this deformation generates an electric charge proportional to the degree of deflection. This type of transducer offers high sensitivity to mechanical vibrations and can produce substantial voltage output, especially in environments with significant vibration. Nevertheless, as highlighted by Fang et al. [12], it also presents certain limitations, such as susceptibility to mechanical fatigue over extended use and the need for specific mounting configurations to optimise energy harvesting performance.

PVDF serves as the material for the SDT-TE1000288-0 shielded sensor, which generates an electric charge in response to mechanical stress or acoustic vibrations [13]. Its main advantages include flexibility, a lightweight structure, and high sensitivity over a wide frequency range. These characteristics make it particularly suitable for applications requiring conformity to curved surfaces or minimised weight. However, compared to the LDT1-028K sensor, the shielded sensor tends to produce lower voltage outputs under low-stress environments. This finding aligns with the results of Stamatellou [14], who noted that the shielded design can affect power absorption. Consequently, optimising the sensor's thickness has been proposed as a strategy to improve output efficiency.

The importance of capacitors is often underestimated. Capacitors play a crucial role in PEH systems. Their capacity to efficiently manage energy is essential for optimising the performance of PEH systems, enabling them to power small electronic devices effectively. As explained in previous studies by Stamatellou [14] and Subasinghage and Gunawardane [15], this factor is critical for the effective capture and storage of harvested energy for future use. Conversely, insufficient capacitance can result in energy loss, ultimately reducing the overall efficiency of the system. To maximise performance, researchers emphasise the importance of fine-tuning these components to suit specific operational conditions and energy demands.

3.3. Comparative studies of energy conversion efficiency

As illustrated in Fig. 9, the highest efficiency recorded was 0.290%, achieved in the Red Zone using the LDT1-028K piezo sensor. Nevertheless, the overall efficiency remains below 1%, highlighting significant challenges in energy

conversion. This low efficiency can be attributed to limited energy storage capacity, which is influenced by the permittivity of the PM, thereby restricting its ability to store electrical energy effectively. These findings are consistent with those reported by Ismaili et al. [1] and Aldahri et al. [16], who demonstrated that materials with lower piezoelectric strain constants and higher permittivity generate less energy.

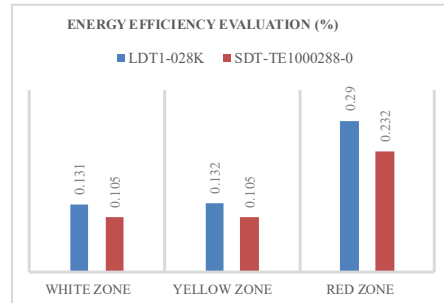


Fig. 9. Comparison of the energy conversion efficiency for LDT1-028K and SDT-TE1000288-0.

Optimising figures of merit through structural modifications may help to address this issue. Additionally, Fang et al. [12] and Meng et al. [17] reported that environmental factors such as temperature and humidity influence the mechanical and piezoelectric properties of these materials. Therefore, PMs with higher Curie temperatures are preferred [18, 19], as they retain their properties over a wider range of conditions, thereby improving performance in real-world applications.

It is essential to consider the energy storage components within the harvester system, particularly capacitors. Capacitors are integral to storing the electrical energy generated by PMs, with higher capacitance enabling more efficient energy storage during mechanical vibrations or deformations. This aspect is fundamental to ensure that the harvested energy is effectively captured and retained for future use, as insufficient capacitance can result in energy loss and consequently reduce the overall efficiency of the system [7, 15]. To maximise the storage and utilisation of harvested energy, the development of high-efficiency circuits is necessary. Although the principles of piezoelectric energy harvesting are well established, the selection of optimal materials, the application of appropriate techniques, and the implementation of effective strategies are vital for achieving higher power outputs and making the process more viable in practical applications.

4. Conclusions

The comparative analysis of the LDT1-028K and SDT-TE1000288-0 PTs demonstrates their distinct advantages in noise energy harvesting applications. The LDT1-028K piezo sensor shows superior performance in high-noise environments due to its mechanical sensitivity, which facilitates higher voltage outputs and stronger correlations between noise levels and energy storage. Conversely, the SDT-TE1000288-0 shielded sensor offers flexibility, a lightweight design, and broad frequency sensitivity, making it suitable for applications where adaptability is critical, although it demonstrates lower output efficiency under high-vibration settings.

A significant finding of this work is the established relationship between noise zone selection and energy harvesting efficiency. Specifically, zones exceeding 85 dB (designated as the Red Zone) are associated with significant mechanical vibrations that induce extensive flexing of the cantilever beam. This dynamic response results in increased voltage outputs and greater energy storage capacity, confirming the importance of operating conditions in optimising transducer performance.

Overall, this comparative analysis advances the understanding of piezoelectric sensor behaviour in acoustic environments and offers guidance for future designs of noise-based energy harvesting systems. Furthermore, the findings provide insights into material-specific performance and emphasise the importance of optimising sensor design parameters, such as geometry, thickness, and shielding, to enhance efficiency. Future research should focus on scaling these systems for industrial applications, particularly in noise-intensive environments, to facilitate the development of practical and sustainable energy harvesting technologies.

Acknowledgement

This research was fully supported by the Fundamental Research Grant Scheme (FRGS), grant number FRGS/1/2021/TK0/UNIMAS/03/3. The authors fully acknowledged the Ministry of Higher Education of Malaysia (MOHE), UNIMAS, and *i*-CATS University College, which made it possible to conduct and publish this research.

Abbreviations

AC	Alternating Current
DC	Direct Current
MEP	Mechanical and Electrical Plant
PEH	Piezoelectric Energy Harvester
PM	Piezoelectric Material
PT	Piezoelectric Transducer
PVDF	Polyvinylidene Fluoride
UNIMAS	University of Malaysia Sarawak

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