Journal of Information Technology and Computer Science (INTECOMS)
Volume 7 Nomor 5, Tahun 2024
e-ISSN : 2614-1574
p-ISSN : 2621-3249

PENERAPAN *PIEZOELECTRIC ENERGY HARVESTING* DI BANDAR UDARA: SUMBER ENERGI, MATERIAL DAN DESAIN

APPLICATION OF PIEZOELECTRIC ENERGY HARVESTING AT AIRPORTS: ENERGY SOURCES, MATERIALS AND DESIGN

Direstu Amalia[1], Viktor Suryan[2], M. Indra Martadinata[3], Yeti Komalasari[4], Almuzani[5], M. Alamsyah[6], Nabila Hasna Arinda[7], Made Putra Darsana[8]
[1,2,3,4,5,6,7]Politeknik Penerbangan Palembang
direstu@poltekbangplg.ac.id

ABSTRACT

Airports have many areas with intensive activities that can be potential sources for Piezoelectric Energy Harvesting because airports are places that produce much mechanical energy that has not been realized. This mechanical energy comes from various sources, such as passenger and visitor traffic, vehicle movement, elevator and conveyor use, and aircraft activity on runways and taxiways. The research methodology used is a Literature Review. This article reviews the factors that affect PEH, namely energy sources, materials, and design, and it is a literature study article related to smart airport technology. This article aims to establish hypotheses of influence between variables as a reference for further research. This literature review article will produce: 1) Energy source affects Piezoelectric Energy Harvesting; 2) Materials affect Piezoelectric Energy Harvesting; and 3) Design affects Piezoelectric Energy Harvesting. This research will produce a deeper understanding of the potential mechanical energy utilized at airports and how energy harvesting technology can be applied to optimize these mechanical energy sources. Hopefully, this article will provide an overview of designing Piezoelectric Energy Harvesting suitable for airports.

Keywords: *Piezoelectric, Energy Harvesting, Energy Sources, Materials and Design.*

ABSTRAK

Bandar udara memiliki banyak area dengan aktivitas intensif yang dapat menjadi sumber potensial untuk Piezoelectric Energy Harvesting karena bandar udara adalah tempat yang menghasilkan banyak energi mekanis yang selama ini belum disadari kebermanfaatannya. Energi mekanis ini berasal dari berbagai sumber, seperti lalu lalang penumpang dan pengunjung, pergerakan kendaraan, penggunaan elevator dan conveyor, serta aktivitas pesawat di runway dan taxiway. Metodologi penelitian yang digunakan adalah literature review sehingga artikel ini melakukan review terhadap faktor-faktor yang mempengaruhi Piezoelectric Energy Harvesting, yaitu Sumber Energi, Material dan Desain, sebuah artikel studi literatur terkait smart airport technology. Tujuan penulisan artikel ini untuk menegakkan hipotesis pengaruh antar variabel sebagai acuan bagi riset lanjutan. Artikel literature review ini akan menghasilkan: 1) Sumber Energi berpengaruh terhadap Piezoelectric Energy Harvesting ; 2) Material berpengaruh terhadap Piezoelectric Energy Harvesting ; dan 3) Desain berpengaruh terhadap Piezoelectric Energy Harvesting . Penelitian ini diharapkan menghasilkan pemahaman yang lebih mendalam tentang potensi energi mekanis yang dapat dimanfaatkan di bandara dan bagaimana teknologi energy harvesting dapat diterapkan untuk mengoptimalkan sumber energi mekanis tersebut. Harapannya, artikel ini memberi gambaran dalam melakukan perancangan Piezoelectric Energy Harvesting yang sesuai dengan bandar udara.

Kata Kunci: Piezoelectric, Energy Harvesting, Energy Source, Material, Design.

PENDAHULUAN

Airports require large amounts of energy for various purposes, such as lighting, cooling, operation of security systems, navigation equipment, and others. With the increasing number of passengers and flight frequency, this energy demand also continues to increase. It encourages airport managers to find solutions to increase energy supply efficiently and sustainably. Using conventional energy sources, such as fossil fuels, creates negative environmental impacts, including greenhouse gas emissions and air pollution, and global pressure to reduce carbon footprints and adopt cleaner energy sources. On the other side, we can find several energy sources that we can harvest from the ambient. Piezoelectric Energy Harvesting can be part of the solution, as it utilizes mechanical energy converted into electrical energy without harmful emissions (Sezer & Koç, 2021). Piezoelectric Energy Harvesting is a mechanical energy harvesting system derived from the most ubiquitous environmental energy that can be captured and converted into useful electrical power. Piezoelectric transduction is a prominent mechanical energy harvesting mechanism. Several studies mentioned potential energy sources for Piezoelectric Energy Harvesting such as wind, vibration from buildings, friction from equipment, friction from skin or and pressure from footsteps (Abadi et al., 2018; Bairagi et al., 2023; Orrego et al., 2017; Sharma et al., 2022; Tianchen et al., 2014; N. Wu et al., 2021; Y. Wu et al., 2021), and categorized the types of piezoelectrics used according to the energy source.

Piezoelectric types are generally divided into three classes: ceramic, polymer, and composite (Kovácikova et al., 2023; Zhao & Wang, 2020). The ceramic type is the strongest in piezoelectric properties but is stiff and brittle compared to polymer and composite, so this type is most widely applied (Habib et al., 2022; Sapkal et al., 2022). However, when implemented in medical equipment and textiles, the polymer type is more suitable, while composite materials are more suitable for tactile sensors and gait energy harvesting. Energy harvesting at the airport has been done by modifying the runway pavement structure, utilizing the energy source in the form of vibrations from aircraft taking off on the airside (Kovácikova et al., 2023; Zhao & Wang, 2020). The indicators of Piezoelectric Energy Harvesting are its high electromechanical coupling factor and piezoelectric coefficient compared to electrostatic, electromagnetic, and triboelectric transduction.

Piezoelectric Energy Harvesting is also described as an energy harvesting technique based on the properties of piezo materials in generating electric fields when mechanical force is applied. *Piezoelectricity* is a phenomenon that shows the ability of a material or several materials to produce electric voltage when given input in the form of pressure or voltage. This phenomenon is known as the direct piezoelectric effect (Covaci & Gontean, 2020). The dimensions or indicators of applying Piezoelectric Energy Harvesting are the energy source, energy harvesting mechanism, and place where PEH is implemented.

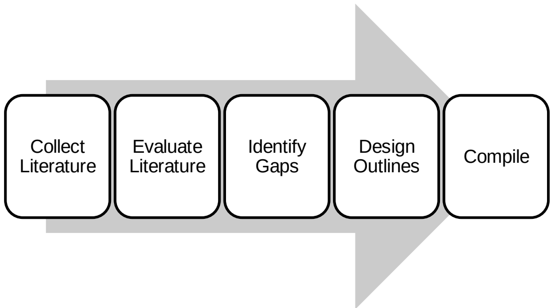
Piezoelectric Energy Harvesting is a new energy solution and piezoelectric mechanism, a new idea regarding piezoelectric energy harvesting from environmental vibrations and natural resources which explains that the dimensions or indicators of Piezoelectric Energy Harvesting are the mechanism and flexibility of piezoelectric energy generation materials. Factors that also affect Piezoelectric Energy Harvesting are the type of material and installation technique (Pradeesh et al., 2022). The application of Piezoelectric Energy Harvesting has been widely studied by previous researchers, including (Abadi et al., 2018; Febrawi & Wonoyudo, 2013; Lee & Youn, 2011; Sharma et al., 2022; Yang et al., 2018).

Based on the movement data 2023 at Sultan Mahmud Badaruddin II Airport Palembang, an average of 305,783 passengers arrived and departed. The average take-off aircraft amounted to 2,137 aircraft per month, and the total baggage recorded by passengers passed on the conveyor amounted to 2,319,826 baggage. By installing piezoelectric materials in strategic areas, energy from the pressure generated by passenger footsteps or vehicle wheel movements can be converted into electrical energy. This energy can then be used for various purposes at the airport, such as lighting, charging electronic devices, and monitoring systems. Considering the increasing energy demand, the pressure to use green energy, the vast potential of strategic airport locations, and the economic and operational advantages, Piezoelectric Energy Harvesting emerges as a relevant and promising solution. The design of this technology at airports can be a step forward in the effort to achieve greater sustainability and energy efficiency. It is expected to help save energy and reduce operational costs in the long run. The initial investment in this technology can be offset by reducing conventional energy costs and contributing to the company's sustainability goals. In addition, an additional sustainable energy source can improve the reliability of the energy supply at the airport.

Based on the background, problems can be formulated and discussed to build hypotheses for further research: 1) Does energy source affect piezoelectric energy harvesting? 2) Does Material Affect Piezoelectric Energy Harvesting? 3) Does design affect Piezoelectric Energy Harvesting? This article discusses the influence of Energy Sources, Materials, and Design on Piezoelectric Energy Harvesting, a literature review study in energy harvesting technology. This research is expected to provide an overview of what factors need to be considered when implementing Piezoelectric Energy Harvesting at the airport in terms of energy sources, types of materials, and designs following the characteristics of airport activities.

METHOD

This research is a literature review that studies the theory and the relationship between variables: energy source, material, and design. The literature review is a method that can be employed to carry out research endeavors. The literature review is considered the most authoritative form of evidence. Literature reviews are a systematic process employed to collect information or strategies for addressing specific issues. They entail a systematic procedure that generates reports to conduct research or concentrate on a specific topic. Nevertheless, the evidence suggests that conducting a literature review might be difficult because researchers must thoroughly understand how to investigate a specific issue to compile a review. According to Zed's research (Kartiningrum, 2015), the literature review is needed as preliminary research to understand emerging societal issues better. Using this research, the researchers hope to gain a deeper insight into the potential application of piezoelectric nanogenerators at airports. In his 2018 research, Cronin states that to create a comprehensive literature review effectively, a writer must meticulously adhere to five distinct steps during the preparation and writing (Cahyono et al., 2019).



This research collects scientific articles from trusted publisher journals with indexes. The library studies are structured and grouped to approach methodological assumptions. The library study is presented inductively and exploratory to provide a clear overview of current literary references to the theme of piezoelectric energy harvesting.

RESULT AND DISCUSSION

Piezoelectric Energy Sources in Airports

Energy sources for piezoelectric energy are ambient energy sources, usually solar, heat, and vibrational energy. Among these energy sources, vibrational energy is continuously present in nature and man-made structures (Safaei et al., 2019). Mechanical energy generated by the pressure of people or objects has also been shown to be a source of PEH (Abadi et al., 2018; Sharma et al., 2022; Yulia et al., 2016). The Energy Source indicator for ambient energy is a stable source and transduction mechanism that can convert vibrational energy into useful electrical energy.

Energy sources are produced by flexible piezoelectric devices that harvest wind energy (Orrego et al., 2017). Energy source indicators include wind stability and Piezoelectric Energy Harvesting design. Energy Source for piezoelectric energy harvesting uses direct energy conversion from vibration and mechanical deformation into electrical energy. Piezoelectric Energy Harvesting is a promising technique for supplying power sources in standalone electronic devices, wireless sensor nodes, micro-electronic devices, etc (Kang et al., 2016). Energy Source indicators are simple structural designs and materials influencing higher energy conversion efficiency. Energy Sources obtained from noise and vibration include noise from aircraft near airports, vibrations from jet and supersonic aircraft, aircraft engine tests, aircraft runway noise, and supersonic booms (Kovácikоvá et al., 2023). Indicators of energy sources are the intense vibrations that are produced.

The energy source is obtained from the flexible airfield pavement structure, the pressure generated by aircraft activity on the aircraft runway (Zhao & Wang, 2020). The indicators of the Energy Source are the strength of the pressure generated and the stackable design of the piezoelectric system embedded in the flexible pavement. Energy sources have been studied extensively by previous researchers, including (Altabey & Kouritem, 2023; Bairagi et al., 2023; Febrawi & Wonoyudo, 2013; Mohammadpourfazeli et al., 2023; Nechibvute et al., 2012; Sarker et al., 2022).

Airport characteristics can be a potential Piezoelectric Energy Harvesting source as places with intensive activities generate much wasted mechanical energy. This energy comes from various sources, such as passenger and visitor traffic, vehicle movement, elevator and conveyor use, and aircraft activity on runways and taxiways (Lee & Youn, 2011; Safaei et al., 2019; Sekhar et al., 2023). In addition, airside wind speeds and vibrations generated by building structures also offer an additional energy source. Converting mechanical energy into alternative electrical energy through piezoelectric technology can improve airport operations' energy efficiency and sustainability.

Piezoelectric Materials in Airports

The materials used in energy harvesting activities are divided based on the type of effect used, namely piezoelectric (PENG), triboelectric (TENG), and pyroelectric (PyENG), which was first developed by Wang in 2006 (Indira et al., 2019). The indicators are the energy source, material characteristics, and implementation based on the type of effect selected. Materials that utilize the piezoelectric effect are divided into three types: polymers, ceramics, and composites (Sekhar et al., 2023). These material indicators are energy sources, properties, and characteristics appropriate to the application's location.

Polymer-type materials are usually selected with a focus on the flexibility and malleability of inorganic, polymeric, and bio-piezoelectric materials, explaining their properties for monitoring physiological signals, motion detection, and force sensing (Mohammadpourfazeli et al., 2023), where (Y. Wu et al., 2021) Therefore, PLLA/PDMS, electro-spun PVDF, and ZnO/PVDF have a higher elastic modulus and are more suitable for wearable devices. The dimensions or indicators of the material are the types of polymers and composites that match human skin as the modulus of elasticity. The lead zirconate titanate or PZT ceramic type material is most widely used because of its durability (Kang et al., 2016) because it is considered to have the highest piezoelectric effect even though the characteristics of PZT are classified as stiff and brittle (Habib et al., 2022). The power generated from this type of Piezoelectric Energy Harvesting is capable of biasing several electronic devices at once (Ambrosio et al., 2011). PZT material dimensions or indicators are material characteristics capable of providing optimal performance, as evidenced by the resulting power output.

Composite materials have advantages compared to ceramic and polymer materials because the nature of the material is easy to modify, both in structure and composition (Fabiani et al., 2019; Habib et al., 2022. For example, piezoelectric polymer nanofibers were successfully embedded in composite laminates for self-sensing applications, as mentioned in the research (Selleri et al., 2022). Material indicators are the flexibility of structure and composition. Many studies related to materials have been conducted by previous researchers, including (Habib et al., 2022; Liu et al., 2018; Safaei et al., 2019; Sekhar et al., 2023).

The type of materials has to match the airport's energy source. The airport's energy source character can be found based on the activities that generate much wasted mechanical energy. Ceramic materials have strong piezoelectric properties but are stiff and brittle. Where PZT has the highest piezoelectricity compared to others. In addition, the modified BaTiO3 and KNN also have suitable piezoelectric constants. However, AlN and LiNbO3 are better choices at high temperatures. Therefore, all ceramic piezoelectric materials in this study have high Young's modulus values, making them unlikely to be employed in applications requiring large deflection, except microfabricated PZT. Although polymer materials are lighter and more flexible than ceramic materials, they do not exhibit excellent piezoelectric performance. Cellular PP, likewise categorized as a ferroelectric, is the exception. It has been determined that composite materials combine the best qualities of ceramic and polymer materials with the flexibility to change their composition and structure to achieve the desired results.

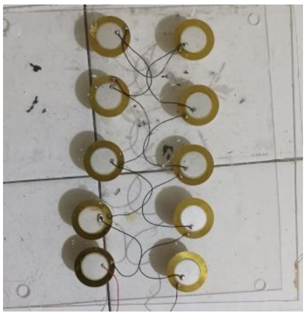


Figure 1. PZT material and design for footstep (source: owner documentation)

In addition, each material's advantages vary depending on the application. Composite materials are better suited for tactile sensors and energy harvesting from gait, polymer materials for electronic textiles and biomedical devices, and ceramic materials for underwater sonar and MEM resonators.

Piezoelectric Design in Airports

The design by (Diniardi et al., 2017) combines a piezoelectric membrane and solar cells as a medium for producing electrical energy from the influence of compressive or impact forces originating from raindrops and sunlight-based regions in Indonesia. The design dimensions or indicators are designed accurately, which includes accuracy in calculating forces, distance between piezos, and the stress obtained. The design by (Sivasubramanian et al., 2021) combines photovoltaic hybrid cells and nanogenerators as a medium for producing electrical energy. The design indicators are the design structure and the resulting energy output. Piezoelectric designs sourced from energy from footsteps were reviewed by (Sharma et al., 2022). Several Piezoelectric Energy Harvesting designs are embedded in building floors and state that the dimensions or design indicators lie in the installation mechanism and electronic circuit design specified.

The piezoelectric design (Nuh & Hendrowati, 2017) took the form of a Piezoelectric Energy Harvesting prototype, which was tested in the laboratory using a case study on ocean waves. These design dimensions or indicators are related to the energy harvesting mechanism and the amount of input generated from sea waves. The design has been extensively researched by previous researchers, including (Ambrosio et al., 2011; Bairagi et al., 2023; Diniardi et al., 2017; Febrawi & Wonoyudo, 2013; Nechibvute et al., 2012; Orrego et al., 2017; Selleri et al., 2022). Based on the result above, we can describe the three relations of piezoelectric energy harvesting with an energy source, material, and design, as stated below.

Influence of Energy Source on Piezoelectric Energy Harvesting in Airport

Energy Sources influence Piezoelectric Energy Harvesting where the indicators of energy sources in airports include stable sources and transduction mechanisms that can convert vibrational energy into valuable electrical energy, influencing indicators of Piezoelectric Energy Harvesting in research (Bairagi et al., 2023; Febrawi & Wonoyudo, 2013; Mohammadpourfazeli et al., 2023; Nechibvute et al., 2012) which is determined by the size and stability of the energy source obtained (Safaei et al., 2019).

Another source of Piezoelectric Energy Harvesting comes from sea tides (Nuh & Hendrowati, 2017), requiring stability of the energy source and several stages of testing to obtain design accuracy. We can find a water flow in the airport in the water treatment system. It is necessary to identify a harvest location for energy sources that is stable, large enough, and equipped with the necessary design and testing stages in order to maximize the potential for adopting piezoelectric energy harvesting by paying attention to energy sources (Orrego et al., 2017).

Piezoelectric Energy Harvesting in Airports may influenced by the type of energy sources used. Employing the appropriate technology to collect energy sources will generate a Piezoelectric Energy Harvesting effect. It may be inferred that mechanical energy sources notably influence its performance. The findings indicated that vibration was piezoelectric energy harvesting's most efficient energy source, surpassing other mechanical energy sources. The results of this study have consequences for the development and improvement of systems, particularly in applications that necessitate energy utilization. This aligns with the research (Covaci & Gontean, 2020; Liu et al., 2018; Pradeesh et al., 2022; Sapkal et al., 2022).

Influence of Material on Piezoelectric Energy Harvesting in Airports

Materials influence Piezoelectric Energy Harvesting in airports, where indicators of mechanical energy sources originating from vibration, pressure, friction, wind, and waves influence indicators of the amount of electrical energy output produced. To improve Piezoelectric Energy Harvesting by paying attention to energy sources, the correct selection of materials must be made, which influences higher energy conversion efficiency (Kang et al., 2016).

Materials influence Piezoelectric Energy Harvesting. Suppose the material has appropriate energy harvesting characteristics. In that case, this will improve quality and provide optimal performance, as evidenced by the power output produced by Piezoelectric Energy Harvesting (Ambrosio et al., 2011; Habib et al., 2022).

Materials influence Piezoelectric Energy Harvesting conclusions obtained from previous research results show the significant impact of piezoelectric materials on Piezoelectric Energy Harvesting performance in airports. The results show that PZT is the most effective material for Piezoelectric Energy Harvesting in airports, followed by lead zirconate and barium titanate. The findings of this research have implications for the design and optimization of Piezoelectric Energy Harvesting systems, especially in applications that require mechanical energy. The results of this research align with research conducted by (Habib et al., 2022; Safaei et al., 2019; Sekhar et al., 2023).

Influence of Design on Piezoelectric Energy Harvesting

Design influences Piezoelectric Energy Harvesting where the indicators of Energy Sources in airports resulting from vibration, pressure, friction, wind, and waves influence the indicators of Piezoelectric Energy Harvesting, design accuracy, which includes accuracy in material selection, calculation of force, distance between piezo, and stress obtained (Diniardi et al., 2017). In order to enhance Piezoelectric Energy Harvesting in airports, it is crucial to focus on the design, installation mechanism, and design of the specific electronic circuit that fits the situation of the airport. These factors have a direct impact on the energy output that is obtained (Sivasubramanian et al., 2021).

Design influences implementation in airports; if a stable energy source is supported by a transduction mechanism that can convert vibration energy into electrical energy, this will improve the quality of Piezoelectric Energy Harvesting (Kang et al., 2016). Design is proven to affect Piezoelectric Energy Harvesting in airports; conclusions from previous research results show that energy harvester design significantly affects its performance. The size, the material properties, and the distance between the piezo, the transducer, and the rectifier for maximizing the voltage obtained should be appropriately calculated to make the best performance of the energy harvesting system in airports.

The design of piezoelectric energy harvesting systems at airports must consider several critical (Sivasubramanian et al., 2021) factors. These include placing piezoelectric sensors in areas with the highest vibration frequencies, integrating with airport electrical systems, and ensuring long-term maintenance and durability. The design must also ensure that the sensor installation does not interfere with normal airport activities and adheres to strict safety standards. An efficient energy management system is also needed to store and distribute the energy produced. This significantly influences the accuracy of Piezoelectric Energy Harvesting and plays an essential role in determining its performance. This conclusion is in line with research conducted by (Ambrosio et al., 2011; Bairagi et al., 2023; Diniardi et al., 2017; Febrawi & Wonoyudo, 2013; Nechibvute et al., 2012; Orrego et al., 2017; Selleri et al., 2022; Sharma et al., 2022).

The conceptual framework is structured based on problem formulation, theoretical study, relevant research, and discussion related to the influence between variables x1, x2, and x3, thus obtaining the framework of thinking below.

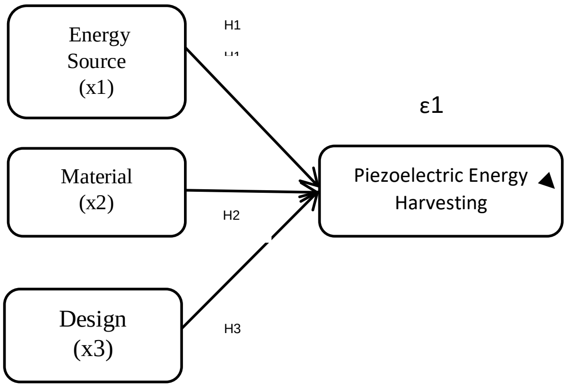


Figure 1. Conceptual Framework

Based on the conceptual framework above, Energy Sources, Materials, and Design influence Piezoelectric Energy Harvesting in airports. In addition to the three exogenous variables that affect Piezoelectric Energy harvesting, many other variables influence it, including a) x4: System testing steps by (Arimurti et al., 2020), b) x5: Location to implement by (Zhao & Wang, 2020), c) x6: Hybrid System by (Diniardi et al., 2017; Sivasubramanian et al., 2021)

Table 1. Relevant Study

No	Author (year)	Research Result	Similarities with this article	Differences with this article
1.	Sekhar et al. (2023)	Reviewing Energy Sources (x1), Materials (x2) and Piezoelectric Applications (x3).	Energy sources (x1), materials (x2), and design (x3) influence Piezoelectric Energy Harvesting (PEH).	Our article reviews literature related to Energy Resources, Materials, and Design, focusing on the airport.
2.	Shaukat et al. (2023)	Energy sources (x1), materials (x2), and design (x3) have a positive and significant influence on Piezoelectric Energy Harvesting (PEH). This article focuses on the development of PEH technology in general.	Energy Resources and design impact Piezoelectric Energy Harvesting (PEH) and show the potential of PEH applications in various fields, such as energy use for sensor networks, wearable electronics, and IoT components.	Application Piezoelectric Energy Harvesting at Airports: Energy Resources, Materials and Design" is more specific and focused on airport applications.
3.	Arimurti et al. (2020)	Energy sources (x1), materials (x2), and test stages (x4) have a positive and significant impact on Piezoelectric Energy Harvesting. This study discussed the material type polycrystalline ceramic and the piezo vibration sensor of PVDF material (polyvinylidene fluoride).	Energy Sources & Materials Influencing Piezoelectric Energy Harvesting.	The research deals only with one source of energy: footsteps and the type of ceramic material alone. In this study, the author reviews the literature on energy sources, materials, and airport design in general.
4.	Yulia et al. (2016)	Energy sources (x1) and design (x3) transducer systems positively and significantly influence Piezoelectric Energy Harvesting. Piezoelectric sleep police received input from motor vehicle pressure with a cantilever system for the system.	Energy sources from vehicle traffic on the sleeping police and design influence the Piezoelectric Energy Harvesting.	(Yulia et al., 2016) only discusses the energy sources of vehicle traffic and the design of transducer systems influencing Piezoelectric Energy Harvesting and does not discuss the selected material.
5.	Zhao & Wang (2020)	Energy sources (x1) and implementation location (x5), testing techniques have a positive and significant impact on Piezoelectric Energy Harvesting. This research suggests that designs can affect power output and the horizontal location of energy harvesters.	Energy sources of building structures influence Piezoelectric Energy Harvesting.	The power source is the load and speed of the aircraft, with the installation location on the Pavement System on the runway only, not on the airport generally.
6.	Kováciková et al. (2023)	The size of the energy source (x1) and the design of the structure (x3), have a positive influence on Piezoelectric Energy Harvesting. The research uses sources at the airport that include aircraft noise near airports, vibrations from jet and supersonic aircraft, aircraft engine tests, airplane runway noise, and supersonic noise.	The energy source of the flight operations can be used as a piezoelectric source.	The power source raised is only vibration from the airside of the airport, with installation locations on the Pavement System on the runway, not at the airports generally.
7.	(Sivasubramanian et al., 2021)	Material (x1), Design (x3), hybrid photovoltaic technology (x6)have a positive and significant influence on Piezoelectric Energy Harvesting.	Materials and design influence Piezoelectric Energy Harvesting.	Hybrid photovoltaic technology influences Piezoelectric Energy Harvesting .
8.	(Diniardi et al., 2017)	Material (x1), Design (x2), hybrid photovoltaic technology (x6) have a positive and significant influence on Piezoelectric Energy Harvesting.	Materials and design influence Piezoelectric Energy Harvesting.	Hybrid photovoltaic technology influences Piezoelectric Energy Harvesting.

CONCLUSION

By considering the theory, relevant publications, and debates, it is feasible to develop hypotheses for future research. One such hypothesis is that energy sources impact Piezoelectric Energy Harvesting in airports. 2) At airports, Materials impact the process of converting mechanical energy into electrical energy, known as piezoelectric energy harvesting. 3) Designs impact the Piezoelectric Energy Harvesting system at airports. Implementing piezoelectric energy harvesting technology at airports has the potential to be an innovative solution that promotes sustainability and enhances energy efficiency. Piezoelectric materials can convert mechanical energy into electrical energy by harnessing vibrations and pressure generated by activities at the airport, such as passenger movement, airplane operations, and car traffic. Using piezoelectric energy harvesting technology, airports can decrease reliance on traditional energy sources and minimize carbon emissions. This represents a significant advancement in incorporating environmentally friendly technologies into contemporary infrastructure, enhancing airports' sustainability and efficiency

DAFTAR PUSTAKA

Abadi, P. B., Darlis, D., & Suraatmadja, M. S. (2018). Green Energy Harvesting from Human Footsteps. *MATEC Web of Conferences*, *197*. https://doi.org/10.1051/matecconf/201819711015

Altabey, W. A., & Kouritem, S. A. (2023). An Overview of the Topics of the Special Issue “The New Techniques for Piezoelectric Energy Harvesting: Design, Optimization, Applications, and Analysis.” *Energies 2023, Vol. 16, Page 3357*, *16*(8), 3357. https://doi.org/10.3390/EN16083357

Ambrosio, R., Jimenez, A., Mireles, J., Moreno, M., Monfil, K., & Heredia, H. (2011). Study of Piezoelectric Energy Harvesting System Based on PZT. *Integrated Ferroelectrics*, *126*(1), 77–86. https://doi.org/10.1080/10584587.2011.574989

Arimurti, Y., Radiyono, Y., & Surantoro, S. (2020). Studi Awal Implementasi Transduser Piezoelektrik sebagai

Piranti Pemanen Energi pada Lantai. *Jurnal Ilmu Fisika | Universitas Andalas*, *12*(2). https://doi.org/10.25077/jif.12.2.89-97.2020

Bairagi, S., Shahid-ul-Islam, Shahadat, M., Mulvihill, D. M., & Ali, W. (2023). Mechanical Energy Harvesting and Self-Powered Electronic Applications of Textile-Based Piezoelectric Nanogenerators: A Systematic Review. In *Nano Energy* (Vol. 111). https://doi.org/10.1016/j.nanoen.2023.108414

Cahyono, E. A., Sutomo, & Harsono, A. (2019). Literatur Review: Panduan Penulisan dan Penyusunan. *Jurnal Keperawatan*.

Covaci, C., & Gontean, A. (2020). Piezoelectric Energy Harvesting Solutions: A Review. In *Sensors (Switzerland)* (Vol. 20, Issue 12). https://doi.org/10.3390/s20123512

Diniardi, E., Syawaluddin, S., Ramadhan, A. I., Isnaini, W., Dermawan, E., & Almanda, D. (2017). Analisis Desain Pickup Piezoelektrik dari Model Hybrid Solar Cell-Piezoelectric untuk Daya Rendah. *Jurnal Teknologi*, *9*(2). https://doi.org/10.24853/jurtek.9.2.83-88

Fabiani, D., Grolli, F., Selleri, G., Speranza, M., Brugo, T. M., Maccaferri, E., Cocchi, D., & Zucchelli, A. (2019). Nanofibrous Piezoelectric Structures for Composite Materials to be Used in Electrical and Electronic Components. *Proceedings of the Nordic Insulation Symposium*, *26*. https://doi.org/10.5324/nordis.v0i26.3263

Febrawi, T., & Wonoyudo, B. D. (2013). Vibration Energy Harvesting pada Mesin Cuci dengan Mekanisme Piezoelectric. *Jurnal Teknik Pomits*, *2*(1).

Habib, M., Lantgios, I., & Hornbostel, K. (2022). A Review of Ceramic, Polymer and Composite Piezoelectric Materials. In *Journal of Physics D: Applied Physics* (Vol. 55, Issue 42). https://doi.org/10.1088/1361-6463/ac8687

Indira, S. S., Vaithilingam, C. A., Oruganti, K. S. P., Mohd, F., & Rahman, S. (2019). Nanogenerators as a Sustainable Power Source: State of Art, Applications, and Challenges. *Nanomaterials*, *9*(5). https://doi.org/10.3390/NANO9050773

Kang, M. G., Jung, W. S., Kang, C. Y., & Yoon, S. J. (2016). Recent Progress on PZT Based Piezoelectric Energy Harvesting Technologies. In *Actuators* (Vol. 5, Issue 1). https://doi.org/10.3390/act5010005

Kartiningrum, E. D. (2015). Panduan Penyusunan Studi Literatur. *Lembaga Penelitian Dan Pengabdian Masyarakat Politeknik Kesehatan Majapahit, Mojokerto*.

Kováciková, K., Novák, A., Kováciková, M., & Sedlácková, A. N. (2023). Comparison Of Selected Airports in Terms of Sustainability. *Transportation Research Procedia*, *75*. https://doi.org/10.1016/j.trpro.2023.12.007

Lee, S., & Youn, B. D. (2011). A New Piezoelectric Energy Harvesting Design Concept: Multimodal Energy Harvesting Skin. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, *58*(3). https://doi.org/10.1109/TUFFC.2011.5733266

Liu, H., Zhong, J., Lee, C., Lee, S. W., & Lin, L. (2018). A Comprehensive Review on Piezoelectric Energy Harvesting Technology: Materials, Mechanisms, and Applications. In *Applied Physics Reviews* (Vol. 5, Issue 4). https://doi.org/10.1063/1.5074184

Mohammadpourfazeli, S., Arash, S., Ansari, A., Yang, S., Mallick, K., & Bagherzadeh, R. (2023). Future Prospects and Recent Developments of Polyvinylidene Fluoride (PVDF) Piezoelectric Polymer; Fabrication Methods, Structure, and Electro-Mechanical Properties. In *RSC Advances* (Vol. 13, Issue 1). https://doi.org/10.1039/d2ra06774a

Nechibvute, A., Chawanda, A., & Luhanga, P. (2012). Piezoelectric Energy Harvesting Devices: An Alternative Energy Source for Wireless Sensors. *Smart Materials Research*, *2012*. https://doi.org/10.1155/2012/853481

Nuh, A. F., & Hendrowati, W. (2017). Studi Eksperimental Energi Listrik yang Dihasilkan oleh Mekanisme Ocean Wave Energy Harvester Tipe Pelampung Bola dengan Metode Cantilever Piezoelectric. *Jurnal Teknik ITS*, *5*(2). https://doi.org/10.12962/j23373539.v5i2.20433

Orrego, S., Shoele, K., Ruas, A., Doran, K., Caggiano, B., Mittal, R., & Kang, S. H. (2017). Harvesting Ambient Wind Energy With an Inverted Piezoelectric Flag. *Applied Energy*, *194*. https://doi.org/10.1016/j.apenergy.2017.03.016

Pradeesh, E. L., Udhayakumar, S., Vasundhara, M. G., & Kalavathi, G. K. (2022). A Review on Piezoelectric Energy Harvesting. In *Microsystem Technologies* (Vol. 28, Issue 8, pp. 1797–1830). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s00542-022-05334-4

Safaei, M., Sodano, H. A., & Anton, S. R. (2019). A Review of Energy Harvesting Using Piezoelectric Materials: State-of-the-Art a Decade Later (2008-2018). *Smart Materials and Structures*, *28*(11). https://doi.org/10.1088/1361-665X/ab36e4

Sapkal, S., Kandasubramanian, B., & Panda, H. S. (2022). A Review of Piezoelectric Materials for Nanogenerator Applications. In *Journal of Materials Science: Materials in Electronics* (Vol. 33, Issue 36). https://doi.org/10.1007/s10854-022-09339-7

Sarker, M. R., Saad, M. H. M., Riaz, A., Hossain Lipu, M. S., Olazagoitia, J. L., & Arshad, H. (2022). A Bibliometric Analysis of Low-Cost Piezoelectric Micro-Energy Harvesting Systems from Ambient Energy Sources: Current Trends, Issues and Suggestions. In *Micromachines* (Vol. 13, Issue 6). https://doi.org/10.3390/mi13060975

Sekhar, M. C., Veena, E., Kumar, N. S., Naidu, K. C. B., Mallikarjuna, A., & Basha, D. B. (2023). A Review on Piezoelectric Materials and Their Applications. In *Crystal Research and Technology* (Vol. 58, Issue 2). https://doi.org/10.1002/crat.202200130

Selleri, G., Gino, M. E., Brugo, T. M., D'Anniballe, R., Tabucol, J., Focarete, M. L., Carloni, R., Fabiani, D., & Zucchelli, A. (2022). Self-Sensing Composite Material Based on Piezoelectric Nanofibers. *Materials and Design*, *219*. https://doi.org/10.1016/j.matdes.2022.110787

Sezer, N., & Koç, M. (2021). A Comprehensive Review on the State-of-the-Art of Piezoelectric Energy Harvesting. In *Nano Energy* (Vol. 80). https://doi.org/10.1016/j.nanoen.2020.105567

Sharma, S., Kiran, R., Azad, P., & Vaish, R. (2022). A Review of Piezoelectric Energy Harvesting Tiles: Available

Designs and Future Perspective. *Energy Conversion and Management*, *254*, 115272. https://doi.org/10.1016/J.ENCONMAN.2022.115272

Shaukat, H., Ali, A., Bibi, S., Altabey, W. A., Noori, M., & Kouritem, S. A. (2023). A Review of the Recent Advances in Piezoelectric Materials, Energy Harvester Structures, and Their Applications in Analytical Chemistry. In *Applied Sciences (Switzerland)* (Vol. 13, Issue 3). https://doi.org/10.3390/app13031300

Sivasubramanian, R., Aravind Vaithilingam, C., Indira, S. S., Paiman, S., Misron, N., & Abubakar, S. (2021). A Review on Photovoltaic and Nanogenerator Hybrid System. In *Materials Today Energy* (Vol. 20). https://doi.org/10.1016/j.mtener.2021.100772

Tianchen, Y., Jian, Y., Ruigang, S., & Xiaowei, L. (2014). Vibration Energy Harvesting System for Railroad Safety Based on Running Vehicles. *Smart Materials and Structures*, *23*(12). https://doi.org/10.1088/0964-1726/23/12/125046

Wu, N., Bao, B., & Wang, Q. (2021). Review on Engineering Structural Designs for Efficient Piezoelectric Energy Harvesting to Obtain High Power Output. In *Engineering Structures* (Vol. 235). https://doi.org/10.1016/j.engstruct.2021.112068

Wu, Y., Ma, Y., Zheng, H., & Ramakrishna, S. (2021). Piezoelectric Materials for Flexible and Wearable Electronics: A Review. In *Materials and Design* (Vol. 211). https://doi.org/10.1016/j.matdes.2021.110164

Yang, Z., Zhou, S., Zu, J., & Inman, D. (2018). High-Performance Piezoelectric Energy Harvesters and Their Applications. In *Joule* (Vol. 2, Issue 4). https://doi.org/10.1016/j.joule.2018.03.011

Yulia, E., Permana Putra, E., Ekawati, E., & Nugraha, N. (2016). Polisi Tidur Piezoelektrik Sebagai Pembangkit Listrik dengan Memanfaatkan Energi Mekanik Kendaraan Bermotor. *Jurnal Otomasi Kontrol Dan Instrumentasi*, *8*(1). https://doi.org/10.5614/joki.2016.8.1.9

Zhao, J., & Wang, H. (2020). Mechanistic Modeling and Economic Analysis of Piezoelectric Energy Harvesting Potential in Airport Pavements. *Transportation Research Record, 2674*(11). https://doi.org/10.1177/0361198120942503.