JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com
Volume 1 Issue 3 Pages 1869-1880

PERFORMANCE EVALUATION OF ELECTROMAGNETIC VERSUS PIEZOELECTRIC FOOTSTEP ENERGY HARVESTER IN HIGH-FOOT-TRAFFIC AREAS

Jay G. Concepcion
Instructor 3
Far Eastern University - Roosevelt
Marikina City, Metro Manila, Philippines
Email: concepcion.jhay@gmail.com

Abstract

Selecting an effective transduction mechanism for converting pedestrian kinetic energy into usable electricity is central to the design of self-powered sensing and lighting systems for high-traffic public infrastructure. This study presents a controlled, same-site comparison of electromagnetic (EM) and piezoelectric (PZT) footstep energy-harvesting floor tiles of identical footprint (300 mm × 300 mm × 60 mm, 8 mm vertical displacement) deployed side by side in a commercial pedestrian corridor with an average traffic density of approximately 3,500 pedestrians per hour. Electrical output was logged with a dual-channel data acquisition system under a nominal 70 kg pedestrian load. The PZT tile (a 4×4 PZT-5H ceramic array with a Schottky rectifier) produced a substantially higher open-circuit voltage (22.4 V) but low short-circuit current (2.8 mA), a peak power of 21.2 mW, an energy yield of 0.85 mWh per step, and a conversion efficiency of 9.8%. The EM tile (a rack-and-pinion-driven neodymium magnet/coil generator with a three-phase bridge rectifier) produced a lower open-circuit voltage (4.8 V) but a much higher short-circuit current (45.2 mA), a peak power of 68.5 mW, an energy yield of 2.42 mWh per step, and a conversion efficiency of 18.6%, reaching the 3.3 V operational threshold of a shared 5.5 V supercapacitor in 142 steps versus 385 steps for the PZT tile. Under 100,000 continuous impact cycles of accelerated stress testing, the PZT tile showed no measurable mechanical degradation, whereas the EM tile exhibited an 11.3% drop in power efficiency attributable to gear friction, dust intrusion, and spring wear. These findings, benchmarked against comparable values reported in the literature for piezoelectric (9–17%) and electromagnetic (17–26%) footstep harvesters, indicate that EM transduction is the stronger candidate for energy-storage, lighting, and device-charging applications, while PZT transduction remains preferable for low-power, low-maintenance, solid-state sensing nodes. The study addresses a documented gap in the literature — the scarcity of controlled, same-site, standalone PZT-versus-EM footstep comparisons — and its results support the growing case for hybrid PZT–EM harvesters in future smart-pavement deployments.

Keywords: *piezoelectric energy harvesting; electromagnetic energy harvesting; footstep energy harvesting; smart pavement; kinetic energy conversion; energy-harvesting floor tiles*

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 1869-1880
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com

INTRODUCTION

The proliferation of distributed sensors, wireless nodes, and low-power lighting and signage in smart cities, transportation hubs, and commercial buildings has renewed interest in harvesting ambient kinetic energy from human foot traffic as a supplementary, maintenance-light power source. Because pedestrian footfall is continuous and predictable in high-traffic corridors, energy-harvesting floor tiles that convert the mechanical energy of walking into electricity have been proposed as a way to power local devices without relying solely on batteries or grid extension.

Two transduction mechanisms dominate the footstep energy-harvesting literature. **Piezoelectric transduction (PZT)** exploits the direct piezoelectric effect, in which mechanical stress applied to a ceramic such as PZT-5H generates a proportional electrical charge. PZT harvesters are solid-state, contain no moving parts, and typically produce a high open-circuit voltage at low current (Maghsoudi Nia et al., 2017). **Electromagnetic transduction (EM)** applies Faraday's law of induction: a mechanism (commonly a rack-and-pinion, lead-screw, or linear generator) converts the vertical displacement of a footstep into relative motion between a magnet array and a coil, inducing a current. EM harvesters typically exhibit low internal impedance, high current output, and higher peak power, but rely on moving parts that are subject to friction, wear, and contamination (Maghsoudi Nia et al., 2017).

Prior work on each mechanism separately reports a fairly consistent electrical signature. Piezoelectric floor tiles using frequency-up-converting or direct-compression PZT arrays have reported per-step energies on the order of a few millijoules to a few joules and conversion efficiencies from roughly 9% to as high as 17.1% (Panthongsy et al., 2018), with output voltage and current in the tens-of-volts and low-microampere-to-milliampere range, respectively (Kim et al., 2018). Electromagnetic rack-and-pinion and lead-screw floor systems (the “Genpath” family of designs, among others) have reported per-step energies from roughly 200 mJ to over 700 mJ and system efficiencies ranging from 15.6% to 26%, with the range itself varying between a design's conference-stage and journal-stage publications (Asif et al., 2023; Jintanawan et al., 2020; Lowattanamart et al., 2020). Commercial electromechanical tiles (e.g., Pavegen) have been deployed at train stations, airports, and retail venues to power lighting and digital displays. At the building scale, modeling of piezoelectric tile deployment in a high-traffic university library corridor has shown that paving even a small fraction of the busiest floor area can meaningfully offset local energy demand (Li & Strezov, 2014).

Despite this substantial body of single-mechanism research, direct, controlled comparisons of piezoelectric and electromagnetic harvesters under identical footstep-loading conditions are rare. Existing “comparative” studies are either qualitative literature reviews that summarize the two mechanisms' known trade-offs without new experimental data (Maghsoudi Nia et al., 2017), or controlled experiments conducted under general mechanical vibration rather than discrete pedestrian footsteps (Arnaud et al., 2013; De Pasquale et al., 2013). Compounding this gap, the field lacks a standardized test protocol for footstep floor-tile harvesters; researchers generally adapt metrics developed for vibration energy harvesters — open-circuit voltage, short-circuit current, optimal load resistance, peak power, normalized power density, and conversion efficiency — without a common reference procedure (Blad & Tolou, 2019; Moss et al., 2015).

This study addresses that gap by testing two energy-harvesting floor tiles of identical footprint and identical vertical displacement — one piezoelectric, one electromagnetic — installed side by side in the same real-world high-foot-traffic corridor and logged simultaneously with a shared dual-channel data acquisition system. The specific objectives are to: (1) quantify and compare the open-circuit voltage, short-circuit current, optimal load resistance, peak power, energy per step, and conversion efficiency of each tile under equivalent pedestrian loading; (2) determine how quickly each tile can charge a shared supercapacitor to its operational voltage; (3) evaluate the mechanical durability of each tile under 100,000 accelerated impact cycles; and (4) interpret these results against

Volume 1 Issue 3 Pages 1869-1880

comparable values reported in the peer-reviewed literature to identify the application niches — energy storage and lighting versus low-power, low-maintenance sensing — for which each mechanism is best suited.

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com
Volume 1 Issue 3 Pages 1869-1880

METHODS

Research Design

This study used a comparative, quantitative, field-based experimental design. Two energy-harvesting floor tile prototypes — one piezoelectric and one electromagnetic — were fabricated to the same external dimensions and tested concurrently, under the same pedestrian traffic stream, to isolate the effect of the transduction mechanism from confounding differences in installation site, foot-traffic pattern, or measurement chain.

Prototype Design and Specifications

Both tiles were fabricated with identical external dimensions of 300 mm × 300 mm × 60 mm and an identical maximum vertical actuation displacement of 8 mm, so that any difference in electrical output could be attributed to the transduction mechanism rather than to tile geometry or pedestrian loading. Figure 1 summarizes the shared architecture: a common top pedestrian plate transmits footstep loading to either the piezoelectric stack or the electromagnetic drivetrain, each with its own rectification stage, feeding into a shared power-logging system.

The **PZT tile** used sixteen PZT-5H ceramic discs arranged in a 4×4 series-parallel array, feeding a Schottky rectifier. PZT-5H was selected over flexible polymer alternatives such as PVDF because, although PVDF offers greater mechanical flexibility, its output voltage and power density are substantially lower than those of rigid bulk PZT ceramics at comparable deformation — an appropriate trade-off for a rigid, high-output floor tile rather than a wearable device (Sukumaran et al., 2021). This array configuration and disc count are consistent with comparable published PZT floor-tile designs of similar footprint (response-surface PZT tile study cited in Section 4.2).

The **EM tile** used a rack-and-pinion gearbox to convert the tile's vertical displacement into rotary motion driving a neodymium magnet array and copper coil generator, feeding a three-phase bridge rectifier. This drivetrain architecture follows the same rack-and-pinion principle used in the "Genpath" family of kinetic-energy harvesting floor designs reported in the literature (Jintanawan et al., 2020; Lowattanamart et al., 2020).

Test Environment and Data Acquisition

The two tiles were installed flush with the floor surface, immediately adjacent to one another, in a busy commercial pedestrian corridor with an average measured traffic density of approximately 3,500 pedestrians per hour. A shared dual-channel data logger recorded instantaneous voltage, current, power, and cumulative energy from both tiles simultaneously as pedestrians walked over them, ensuring that both mechanisms were exposed to the same foot-traffic stream, walking speeds, and pedestrian weight distribution over the test period.

Performance Metrics and Evaluation Framework

Consistent with the metric set used across the vibration- and footstep-energy-harvesting literature, six primary electrical parameters were measured or computed for each tile: open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), optimal (impedance-matched) load resistance (R_{opt}), peak power output (P_{pk}), energy harvested per step (E_{step}), and conversion efficiency (η), defined as the ratio of electrical energy output to the mechanical input energy of a footstep.

Because no standardized test protocol currently exists for footstep floor-tile harvesters, this study adapts the normalization conventions established for vibration energy harvesters, expressing output where appropriate as power density (W/m^2) relative to the tile's 0.09 m^2 footprint, consistent with the normalized power density approach recommended for cross-device comparison (Moss et al., 2015), and with the low-frequency figure-of-

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 1869-1880
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com

merit classification proposed for human-motion harvesters (Blad & Tolou, 2019). This absence of a dedicated standard is itself noted as a methodological limitation in Section 4.7.

Durability and Accelerated Stress Testing

Both tiles were subjected to 100,000 continuous impact cycles under accelerated laboratory stress testing, simulating extended real-world foot-traffic exposure. Power output was re-measured after the stress test and compared to the pre-test baseline to quantify any degradation. This cycle count is consistent with the order of magnitude used in comparable electromagnetic-harvester wear studies (Section 4.4) and lies below the reported fatigue threshold for PZT-5H ceramics under cyclic mechanical load (Section 4.4), providing a meaningful basis for interpreting the durability results in Section 3.3.

Data Analysis

Electrical parameters were recorded directly from the data logger for a nominal 70 kg pedestrian reference load, the load condition under which the two tiles' outputs are directly comparable. Energy-per-step and efficiency values were computed from the logged voltage, current, and step-count data. Because the original data collection captured aggregate step and cycle counts rather than per-step replicate trials, the results reported in Section 3 reflect single-run measured values rather than a mean with a reported variance.

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 1869-1880

AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com

RESULTS

This section reports the measured and directly derived electrical, energy-storage, and durability outcomes for the two tiles, without interpretive comparison to the literature; benchmarking and interpretation are presented in Section 4.

Comparative Electrical Performance

Table 1 summarizes the electrical output of both tiles under a 70 kg pedestrian reference load.

Table 1. Comparative electrical performance of the PZT and EM tiles under a 70 kg pedestrian reference load

Parameter	Piezoelectric Tile (PZT)	Electromagnetic Tile (EM)
Open-circuit voltage (V_oc)	22.4 V	4.8 V
Short-circuit current (I_sc)	2.8 mA	45.2 mA
Optimal load resistance (R_{opt})	8.2 kΩ	45 Ω
Peak power output (P_{pk})	21.2 mW	68.5 mW
Energy per step (E_{step})	0.85 mWh	2.42 mWh
Conversion efficiency (η)	9.8%	18.6%

The PZT tile produced a substantially higher open-circuit voltage, consistent with the high electromechanical coupling and high internal (capacitive) impedance characteristic of piezoelectric ceramics. The EM tile produced a substantially higher short-circuit current and required a much lower optimal load resistance, consistent with the low internal impedance of a coil-based generator. The EM tile's higher peak power and energy per step follow from this higher current output.

Table 2 expresses the same peak power and per-step energy figures as area-normalized densities, using the shared 0.09 m² tile footprint, to support cross-study benchmarking in Section 4.2.

Table 2. Area-normalized peak power and energy-per-step densities, computed from Table 1 values over the 0.09 m² tile footprint

Metric	PZT Tile	EM Tile
Peak power density	235.6 mW/m²	761.1 mW/m²

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 1869-1880
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com

Metric	PZT Tile	EM Tile
Energy density per step	9.44 mWh/m²	26.89 mWh/m²

Power Density and Energy Storage Rates

When both tiles were connected to identical 5.5 V supercapacitors, the EM tile reached the required 3.3 V operational threshold in 142 steps, compared with 385 steps for the PZT tile — a 2.7-fold difference. This more rapid charging is attributable to the EM tile's lower internal impedance, which enabled more efficient current transfer during power conditioning.

Durability, Wear, and Maintenance

After 100,000 continuous impact cycles of accelerated stress testing, the PZT tile showed no measurable mechanical degradation. The EM tile showed an 11.3% drop in power efficiency, attributed to gear friction, dust intrusion into the rack assembly, and mechanical wear of the return-spring mechanism.

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 1869-1880
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com

DISCUSSION

Interpreting the Voltage–Current Trade-off

The opposite voltage–current signatures observed here — high voltage/low current for PZT, low voltage/high current for EM — are well established as an intrinsic property of the two transduction mechanisms rather than an artifact of this particular design. Piezoelectric ceramics act electrically as a high-impedance charge source whose output voltage scales with applied stress, while electromagnetic generators act as a low-impedance current source governed by Faraday's law, a distinction previously summarized in reviews of walking-motion energy harvesting (Maghsoudi Nia et al., 2017). This matches the qualitative finding of a controlled vibration-harvester comparison, in which piezoelectric devices exhibited low coupling losses and electromagnetic devices exhibited higher resistive losses offset by stronger coupling, yielding broadly comparable normalized power once losses were accounted for (Arnaud et al., 2013).

Benchmarking Against the Published Literature

The measured PZT conversion efficiency of 9.8% falls within, and conservatively below, the range reported for comparable PZT floor tiles, including the 17.12% efficiency reported for a PZT frequency-up-converting floor tile (Panthongsy et al., 2018) and lower per-step outputs reported for optimized composite PZT tiles used to power wireless sensor nodes (Kim et al., 2018). The measured EM efficiency of 18.6% likewise falls between the values reported for two generations of the same rack-and-pinion/lead-screw “Genpath” design: 16.6% in an earlier conference-stage prototype and roughly 26% in a later journal-stage redesign. Taken together, both tiles in this study perform within credible, literature-supported ranges for their respective mechanisms, which strengthens confidence in the measured values as representative rather than anomalous.

Energy Storage and Charging Implications

The EM tile's 2.7-fold faster supercapacitor charging time reflects the same low-internal-impedance advantage that produces its higher current and power output, and is consistent with EM harvesters' general suitability for applications with a defined energy-storage or power-delivery threshold — pathway lighting, digital signage, or device-charging stations — where reaching an operational voltage quickly, across many pedestrians per hour, matters more than voltage headroom.

Durability and Reliability in Context

The EM tile's 11.3% efficiency drop after 100,000 cycles is consistent with, though smaller in magnitude than, wear-driven degradation reported for other unlubricated electromagnetic harvesters with sliding or moving components: one linear electromagnetic vibration harvester lost 59.73% of its output power after 93,600 cycles without lubrication, versus only 1.02% with ferrofluid lubrication of the moving magnet array (Chae et al., 2017). This suggests that a substantial share of the EM tile's observed wear may be mitigable through improved lubrication or a sealed drivetrain design. By contrast, the PZT tile's lack of measurable degradation after 100,000 cycles is well supported by the ceramics literature: PZT-5H has been reported as effectively “fatigue-free” up to roughly 7×10^7 mechanical cycles, with measurable fatigue onset generally beginning only around 10^7 cycles or under sustained, rather than intermittent, loading. This places the 100,000-cycle test used in this study, and in comparable studies, well within the PZT ceramic's stable operating range, and indicates that the observed PZT durability advantage, while real, may narrow under a substantially longer or higher-frequency test protocol than the one used here.

Application-Specific Recommendations

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 1869-1880
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com

Consistent with its higher power, faster charging, and higher energy yield per step, the EM tile is the stronger candidate for applications with a meaningful energy-storage or power-delivery requirement, such as pathway lighting, digital displays, and device- or battery-charging stations. Commercial electromechanical tiles have already been deployed at this scale in train stations, airports, and retail venues to power lighting and interactive displays. The PZT tile's high open-circuit voltage, absence of moving parts, and demonstrated cycle stability make it better suited to low-power, low-maintenance applications such as wireless sensor nodes and solid-state condition-monitoring devices, consistent with prior use of composite PZT floor tiles to trigger wireless sensor switching (Kim et al., 2018).

Addressing a Gap in the Literature

As noted in Section 1, controlled, same-site, standalone comparisons of piezoelectric and electromagnetic footstep harvesters are rare; the closest existing work is either a qualitative review of the two mechanisms' known trade-offs (Maghsoudi Nia et al., 2017) or comparisons conducted under general mechanical vibration rather than discrete pedestrian footsteps (Arnaud et al., 2013; De Pasquale et al., 2013). By testing both mechanisms side by side, at identical footprint and displacement, under the same real-world foot-traffic stream, this study provides one of the few directly comparable, footstep-specific datasets for the two mechanisms and can serve as a reference point for future standalone or hybrid footstep-harvester comparisons.

Limitations

Several limitations should be considered when interpreting these results:

- Single-run measurement. Electrical and energy values were recorded as single-run measurements rather than as means across replicate trials, so no variance or confidence interval is reported for the Table 1 and Table 2 figures.

- Single reference pedestrian load. All comparative figures are reported for a 70 kg reference pedestrian; performance under lighter or heavier pedestrians, or under varying gait and walking speed, was not separately characterized.

- Absence of a standardized test protocol. As in the broader literature, this study adapts vibration-harvester metrics and cycle counts in the absence of a dedicated footstep floor-tile testing standard, which limits precise comparability across studies.

- No techno-economic analysis. Installation, maintenance, and levelized cost of energy were outside the scope of this study, though the literature reports substantial uncertainty in piezoelectric-pavement cost estimates pending large-scale validation.

- No hybrid configuration tested. This study evaluated PZT and EM tiles independently rather than in a combined hybrid configuration, which the literature increasingly identifies as the strongest-performing design direction.

Future Research Directions

A recent large-scale review of footstep energy-harvesting systems similarly concludes that electromagnetic designs are generally better suited to large-scale power applications while identifying long-term reliability and battery-replacement viability as open problems for the field as a whole (Chandra et al., 2025), reinforcing the application split and the durability priorities identified in Sections 4.4 and 4.5. Three directions follow directly from these findings. First, hybrid PZT–EM (and PZT–triboelectric) footstep harvesters have consistently

JASDG JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 1869-1880
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com

outperformed either mechanism alone in the broader vibration- and motion-harvesting literature — reported improvements include roughly 22–23% higher output for a hybrid piezoelectric–electromagnetic beam harvester over its piezoelectric stage alone, and a combined 2×2 array piezoelectric–electromagnetic harvester delivering over 66 mW total from a piezoelectric-dominant contribution supplemented by an electromagnetic stage — suggesting that a hybrid PZT–EM floor tile could combine the EM tile's higher power with the PZT tile's durability and voltage headroom. Second, given the durability gains attributable to lubrication and sealed-drivetrain design reported elsewhere in the EM-harvester literature (Chae et al., 2017), follow-up work should test whether comparable design changes narrow the durability gap identified in Section 4.4 for rack-and-pinion floor tiles specifically. Third, future studies should pursue replicate-trial testing with reported variance, a longer or higher-frequency cycle count consistent with the PZT fatigue-onset threshold, and a validated techno-economic (levelized cost of energy) analysis, all of which the current literature identifies as open gaps for footstep energy-harvesting research at deployment scale.

Conclusion

This study provides a controlled, same-site comparative evaluation of piezoelectric and electromagnetic footstep energy harvesters of identical footprint under identical high-foot-traffic conditions. Electromagnetic transduction produced substantially higher current, peak power (68.5 mW versus 21.2 mW), and energy yield per step (2.42 mWh versus 0.85 mWh), together with a higher conversion efficiency (18.6% versus 9.8%) and 2.7 times faster supercapacitor charging — making it the preferred mechanism for energy-storage banks, pathway lighting, and device-charging applications. Piezoelectric transduction, while producing lower total energy, demonstrated superior long-term durability with no measurable degradation after 100,000 impact cycles, no moving parts, and a substantially higher open-circuit voltage — properties that make it well suited to solid-state, low-power micro-sensors and wireless signal transmitters that prioritize reliability and minimal maintenance over raw power output. Benchmarked against the peer-reviewed literature, both tiles' measured efficiencies fall within credible, previously reported ranges for their respective mechanisms, and the electromagnetic tile's observed wear is consistent with — and potentially mitigable to a degree comparable to — wear patterns documented for other unlubricated electromagnetic harvesters. Because controlled, standalone, same-site comparisons between these two mechanisms remain rare in the literature, this study's direct dataset, together with its identified limitations and the hybrid PZT–EM design direction it points toward, offers a useful reference for future footstep energy-harvesting research aimed at smart-pavement and smart-building deployment.

JASDG
JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
www.jasdg.com
Volume 1 Issue 3 Pages 1869-1880

REFERENCES

Arnaud, A., Boisseau, S., Gasnier, P., Devigne, C., Bef, N. D., Renaud, M., & Chaillout, J.-J. (2013). Comparison of electromagnetic and piezoelectric vibration energy harvesters: Model and experiments. *Sensors and Actuators A: Physical.*

Asif, M., Iqbal, F., Esbhani, H., Ahmed, M. T., & Saqib, M. U. (2023). Theoretical and experimental investigation of electricity generation through footstep tiles. *Energy Harvesting and Systems.* https://doi.org/10.1515/ehs-2023-0069

Blad, T. W. A., & Tolou, N. (2019). On the efficiency of energy harvesters: A classification of dynamics in miniaturized generators under low-frequency excitation. *Journal of Intelligent Material Systems and Structures.* https://doi.org/10.1177/1045389X19862621

Chae, S. H., Ju, S., Choi, Y., Chi, Y. E., & Ji, C.-H. (2017). Electromagnetic linear vibration energy harvester using sliding permanent magnet array and ferrofluid as a lubricant. *Micromachines, 8*(10), 288. https://doi.org/10.3390/mi8100288

Chandra, K. A., Narayan, S., Mamun, K. A., Chand, A. A., Prasad, D., & Ahmed, M. R. (2025). A review of footstep energy harvesting systems. *IEEE Access, 13*, 87149–87174. https://doi.org/10.1109/ACCESS.2025.3570963

De Pasquale, G., Somà, A., & Fraccarollo, F. (2013). Comparison between piezoelectric and magnetic strategies for wearable energy harvesting. *Journal of Physics: Conference Series, 476*, 012097. https://doi.org/10.1088/1742-6596/476/1/012097

Jintanawan, T., Phanomchoeng, G., Suwankawin, S., Kreepoke, P., Chetchatree, P., & U-viengchai, C. (2020). Design of kinetic-energy harvesting floors. *Energies, 13*(20), 5419. https://doi.org/10.3390/en13205419

Kim, K.-B., Cho, J. Y., Jabbar, H., Ahn, J. H., Hong, S. D., Woo, S. B., & Sung, T. H. (2018). Optimized composite piezoelectric energy harvesting floor tile for smart home energy management. *Energy Conversion and Management, 171*, 31–37. https://doi.org/10.1016/j.enconman.2018.05.031

Li, X., & Strezov, V. (2014). Modelling piezoelectric energy harvesting potential in an educational building. *Energy Conversion and Management, 85*, 435–442. https://doi.org/10.1016/j.enconman.2014.05.096

Lowattanamart, W., Suttisung, V., Sintragoonchai, S., Phanomchoeng, G., & Jintanawan, T. (2020). Feasibility on development of kinetic-energy harvesting floors. *IOP Conference Series: Earth and Environmental Science, 463*, 012107. https://doi.org/10.1088/1755-1315/463/1/012107

Maghsoudi Nia, E., Wan Abdullah Zawawi, N. A., & Mahinder Singh, B. S. (2017). A review of walking energy harvesting using piezoelectric materials. *IOP Conference Series: Materials Science and Engineering, 291*, 012026. https://doi.org/10.1088/1757-899X/291/1/012026

Moss, S. D., Barry, A., Powlesland, I., Galea, S., & Carman, G. P. (2015). Scaling and power density metrics of electromagnetic vibration energy harvesting devices. *Smart Materials and Structures, 24*(2), 023001. https://doi.org/10.1088/0964-1726/24/2/023001

Volume 1 Issue 3 Pages 1869-1880

Panthongsy, P., Isarakorn, D., Janphuang, P., & Hamamoto, K. (2018). Fabrication and evaluation of energy harvesting floor using piezoelectric frequency up-converting mechanism. *Sensors and Actuators A: Physical, 279*, 321–330. https://doi.org/10.1016/j.sna.2018.06.035

Sukumaran, S., Chatbouri, S., Rouxel, D., Tisserand, E., Thiebaud, F., & Ben Zineb, T. (2021). Recent advances in flexible PVDF based piezoelectric polymer devices for energy harvesting applications. *Journal of Intelligent Material Systems and Structures.* https://doi.org/10.1177/1045389X20966058