Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 9s (2025)

Enhancing Performance through Geometry and Structure Optimization in Thermoelectric Systems

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Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract:

This study aims to create and simulate a highly advantageous device is the thermoelectric generator for the waste heat recovery by optimizing its geometric configuration for high efficiency. Each thermoelectric module operates based on the Seebeck effect. Electrons move from the hot junction T_H to the cold junction T_C through thermoelectric materials due to variations in electron density. This movement generates an electric field, linked to the temperature difference via the Seebeck effect caused by hole and electron motion. The potential difference V is proportional to the α temperature difference across the thermoelectric device ΔT, and the Seebeck coefficient is defined as α = VΔT.[4] Although To enhance the efficiency, the figure of merit and in this work mainly focus on the impact of geometry design factors, including the cross sectional area and height of the device using TE materials Bi2Te3(P,N Type) on the Thermoelectric Generator performance. Geometric module Geometry studies are carried out using the Comsol Multiphysics to optimize the TEG's performance of the Efficiency [2]. The results show that employing Bi2Te3(P,N-Type at different hot side temperatures and cold side at different temperatures, different TEG modules designed, one particular geometry of TEG module increases TEG efficiency by 17.4% at ΔT = 323˚K compared different geometry cases of the TEG modules. However, a maximum power output of 7.3W was Achieved by varying the Geometry of Thermoelectric Generator modules with different cases, at particular case-III of Geometry TEG got high conversion efficiency.

Keywords: Thermoelectric generator, Geometry of Thermoelectric Generator, Seebeck Effect, Figure of merit, heat transfer, efficiency.

1. Introduction

Sustainable energy production is a key focus for the future of global power generation [12]. Compared with fossil fuels, renewable sources offer cleaner and more user-friendly alternatives. In this era of sustainability, the advantages of renewable energy have surpassed its limitations. As access to electricity is crucial for societal development, the challenge lies in generating sufficient power without causing environmental harm. Thermoelectric devices (TEs) can Transform the heat into Electricity through the Seebeck Effect. These devices having numerous benefits, and including zero emissions, compact design, noiseless operation, durability, and absence of moving components. However, the widespread adoption of TEs has been hindered by their low conversion efficiency, which impedes market growth in power generation, temperature control, and waste heat recovery applications. Additionally, the current high cost of TEs is difficult to justify given their low efficiency. [1,2] Consequently, their future viability depends on enhancing efficiency while reducing costs. This has led to extensive research aimed at Improving the conversion efficiency of thermoelectric generators, The unique capabilities of TEGs make them a crucial technology in clean electricity production. Furthermore, TEG utilization of the Pointer Effect of TEGs enables their application in both the cooling and heating processes.

In recent years, significant research efforts have been directed towards two primary approaches for enhancing thermoelectric (TE) efficiency [13][14] while keeping material expenses low[13], geometry and material optimization.[2] [13]in thermoelectric geometry and structural optimization aimed at enhancing the performance of thermoelectric generators. It focuses not only on the potential for improving the electrical performance efficiency, [13] through TEG geometry and structure optimization research, but also on enhancing the mechanical performance [13] through similar optimization techniques. Furthermore, this review addresses the significant impact of thermal stress on TE leg longevity, recognizing this as a crucial area of study. [2],[5] Various thermoelectric geometries and structural configurations were examined, and geometry optimization was performed.

2. Methodology

Thermoelectric generator (TEG) efficiency enhancement occurs through geometrical optimization of important design parameters including Leg length and cross sectional area together with overall device geometry.[2]Users develop TEG models in simulation software such as COMSOL Multiphysics followed by objective function definition such as optimizing efficiency and the application of optimization algorithms for discovering the most suitable design configuration. Multiple optimization cycles with sensitivity analyses and physical constraint incorporation and geometric variable parameterization allow the design to be refined iteratively.[2,7] Optimum design factors such as thermoelectric material segmentation and leg aspect ratio and fill factor need to be considered. Experimental and simulation testing of optimized designs requires verification to justify their effectiveness. The systematic method enables researchers to examine various design possibilities leading to TEG structures with superior conversion efficiency than ordinary designs.

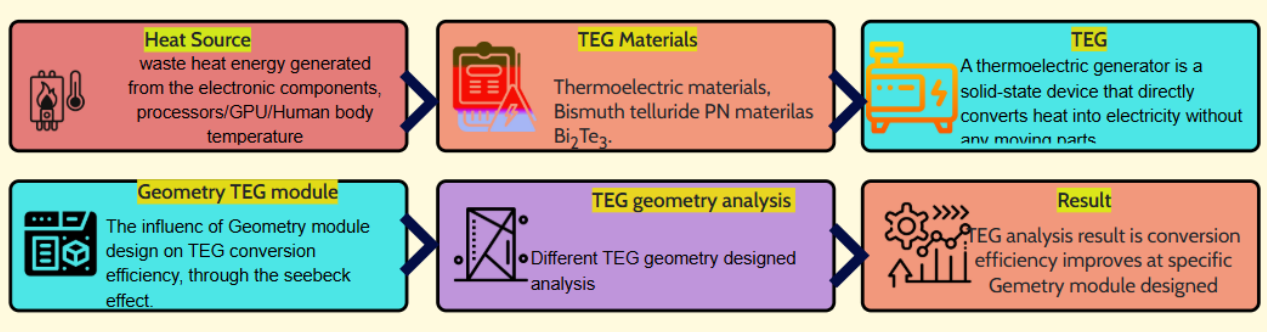

Figure.1 thermoelectric generator.

Enables the geometric optimization of thermoelectric generators (TEGs) to enhance their efficiency by modifying their size. parameterised geometry, utilizing parameterization capabilities to establish key geometric parameters as variables. design Elements Identifying and parameterizing geometric variables that significantly impact TEG efficiency. These may encompass the overall generator design, thermoelectric leg dimensions, and spacing between them.[9]

The enhancement module COMSOL Multiphysics offers optimization tools to improve its simulation capabilities. These modules allow users to configure and address optimization challenges. Simulations are regularly used to verify optimized designs and, when possible, to compared results changes in the geometric parameters affect TEG performance. Progressive Improvement Execute multiple optimization cycles and refine the design by incorporating insights from the previous iterations.

2.1 Mathematical Modelling:

Mathematical modelling of the TEG generated voltage ‘V.’[6]

V=αΔT---(1)

$Q_H = P + Q_c$--(2)

Q_H is the input quantity of heat flow

$Q_H = \alpha I T_H - \frac{1}{2} I^2 R + k\Delta T$ ---(3)

Thermoelectric generator generated power, P.

$P = I^2 R_L$ ---(4)

TEG current I.

$$I = \frac{v}{(R + R_L)}$$

R is the internal resistance,

$R_L$is the Load resistance of the thermoelectric generator closed circuit.[14][6]

Thermoelectric generator temperature difference ΔT, Due to the temperature difference Temperature gradient of the [13] TEG, ΔT.

$\Delta T = T_H - T_C$ --(5)

$V = \alpha \Delta T$

Thermoelectric generator resistance, R.

$$R = \rho \frac{L}{A}$$

R is the TEG resistance, $'\rho'$ is the Resistivity of the thermoelectric material, ‘L’ is the length of the[6] thermoelectric generator, ‘A’ is the area of the thermoelectric generator.[2]

$$k = k \cdot \frac{A}{L}$$

Power $P_L = \left(\frac{\alpha \Delta T}{R + R_L}\right)^2 R_L$

$P_{max} = \left(\frac{\alpha \Delta T}{4R}\right)^2$--(6)

Thermoelectric generator conversion efficiency η

$$Efficiency\ \ \eta = (power\ developed, PL)/(heat\ flow, Q) = \left(\frac{\propto\Delta T}{4R}\right)^2$$

$$\text{Efficiency} = \frac{\left(\frac{\propto\Delta T}{4R}\right)^2}{Q}$$

Q_H =Heat input to the thermoelectric generator

Q_C = Waste heat

α = Seebeck coefficient

k = Thermal conductivity

T_H = Hot side temperature

T_C =Cold side temperature

R_L =Load resistance

A = Cross sectional area of pellet

P= Output power

V_{oc} = Open circuit voltage.

L= Length of TE Leg.

Z= Figure-of-merit.

ρ = Electrical resistivity.

I= Current.

Various efficient thermoelectric materials have been developed to introduce nanostructures into these materials. The introduction of nanostructures efficiently reduces the thermal conductivity of materials $_L$ $_H$ with high thermal conductivity. [6,7]

The thermoelectric conversion efficiency ${T_C}/{T_H}$

$$\eta_{\max} = \frac{T_H - T_C}{T_H}\,\frac{\sqrt{1+\frac{z(T_H+T_C)}{2}}-1}{\sqrt{1+\frac{z(T_H+T_C)}{2}}+}\,{T_C}/{T_H} \quad \text{--}(7)$$

2.2 Finite Element Analysis:

The Finite element analysis of thermoelectric generators (TEGs) using COMSOL Multiphysics typically focuses on optimizing geometry for improved performance. Key aspects of this analysis include Leg geometry optimization. Evaluate variations in leg length and cross-sectional area Analyse trade-offs between electrical resistance, thermal conductance, and power output Determine optimal leg aspect ratio for maximum efficiency,[5] Determine most efficient overall device configuration.

Performance improvement quantification, Measure efficiency gains through geometrical optimization,[4] compare with conventional TEG configurations, this analysis provides valuable insights for designing more efficient TEGs through geometric optimization, balancing performance improvements with practical considerations. Materials: Bismuth TellurideBi2Te3, P-Type, N-Type.

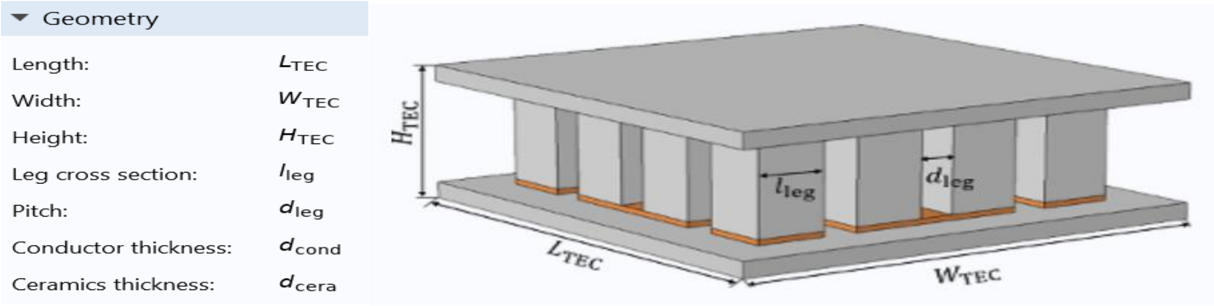

Figure.3: Geometrical thermoelectric generator.

Thermoelectric generator modules output cases.

The results and discussion on geometrical optimization of thermoelectric generators (TEGs) for efficiency improvement typically focus on the following key aspects, Optimal leg geometry, Analysis of how varying leg length[13] and the cross sectional area affects TEG operation performance, Discussion of the trade-offs between the Electrical Resistance, Thermal conductance, and power output, Presentation of the optimal leg aspect ratio that maximizes efficiency, Identification of the optimal fill factor for maximum efficiency, Analysis of how device geometry affects heat distribution[5] and thermal management, Performance improvements, Quantification of efficiency gains achieved through geometrical optimization[17].

Case-1

Here, in case-1 conducted the TEG modulation Varying the l-leg from 0.5 mm to 1.2 mm with respective the make constant parameters of W-leg= 10 mm, H-leg=3 mm, d-leg=0.5 mm of the TEG designed.

Table 1. Output voltages, output current, and Resistances for Varying l-leg of TEG.

Varying l-leg	W-teg	H-teg	d-teg	ΔT_{max}	I_{max}	V_{max}	R	Q_{max}
(mm)	(mm)	(mm)	(mm)	(k)	(A)	(V)	(Ω)	(W)
0.5 × 1.2	10	3	0.5	83.38	1.17	3.28	2.8	2.36
1.0 × 1.2	10	3	0.5	83.32	2.34	2.46	1	3.53
1.2 × 1.2	10	3	0.5	83.3	2.81	1.64	0.58	2.81

Upon analysing the results of the thermoelectric generator (TEG) design with varying leg geometry dimensions, it was observed that the output conversion power increased as the Thermoelectric generator L-leg length grew from 0.5 mm to 1.2 mm. Concurrently, the voltage and resistance decrease as the generated output current increases. The maximum current was achieved when the TEG l-leg dimensions were 1.2 × 1.2 mm. The researchers modified only the l-leg structure components of the TEG throughout this experiment. The TEG achieved its maximum output power when it used l-leg dimensions of 1.0 × 1.2 mm after analyzing various design specifications.

Case-II

Table 2. Output voltages, output current, and resistances for varying H leg of TEG.

Varying H-leg	W-teg	l-teg	d-teg	ΔT_{max}	I_{max}	V_{max}	R	Q_{max}
(mm)	(mm)	(mm)	(mm)	(k)	(A)	(V)	(Ω)	(W)
2	10	1.2×1.2	0.75	82.69	5.1	1.31	o.26	4.07
2.5	10	1.2×1.2	0.75	83.03	3.62	1.31	0.36	2.9
3	10	1.2×1.2	0.75	83.22	2.81	1.31	0.47	2.25

This second design alteration for the thermoelectric generator (TEG) involved elevating the leg height from 2 to 3 millimeters. All additional characteristics maintained their original values where the leg width equaled 10 mm and the leg length measured 1.2 × 1.2 mm alongside a leg cross-section of 0.75 mm. The height increment shifted TEG output current from 5.1 Amp to 2.81 Amp and its internal resistance from 0.26 Ω to 0.47 Ω.

You can obtain maximum output current by using a TEG leg height of 2 mm in case-II TEG design. The generated current levels decreased when we extended the height from 2 to 3 mm.The H-leg produced the highest current of 5.1 Amp at a height of 2 mm. In the Case-II TEG design, altering the height of the PN legs resulted in a decrease in resistance from 0.26 to 0.47 Ω. The resistance of the leg-TEG was affected by its geometric configuration. Varying leg cross-section, L=10mm,W=10mm,Tempe=313.15k H=2.0mm, N=15,

Case-III

Table 3. Output voltages, output current, and Resistances for Varying l-leg of TEG.

Varying l-leg	W-teg	H-teg	d-teg	ΔT_{max}	I_{max}	V_{max}	R	Q_{max}
(mm)	(mm)	(mm)	(mm)	(k)	(A)	(V)	(Ω)	(W)
0.5×1.2	10	2	0.5	82.98	2.14	3.27	1.5	4.28
1.0×1.2	10	2	0.5	82.87	4.28	2.46	0.57	6.41
1.2×1.2	10	2	0.5	82.83	5.11	1.63	0.32	5.08

In this third case study, the TEG leg length (l-legs) is varied from 0.5 mm to 1.2 mm, while other parameters remain constant: W-leg at 10 mm, H-leg at 2 mm, L at 10 mm, and d-leg at 0.5 mm. As the leg length increases in this TEG design, the output current rises from 2.14 Amp to 5.1 Amp, while the Internal Resistance decreases from 1.5 Ω to 0.32 Ω. The temperature remained steady at 313.15 K throughout these variations. Varying leg cross-section, L=10 mm, W=10mm, Temperature=313.15k, height H=2.0mm, N=15, In this study, we examined the output.

Case-IV TEG design by altering the parameters related to the thermoelectric generator leg height. While maintaining a constant H-leg (2.5 mm, we observed that increasing the L-leg length resulted in an improved power output conversion and efficiency. The efficiency reached its peak at 1.2×1.2 mm, with the energy conversion being influenced by factors such as heat transfer coefficients and carrier concentrations.

Figure.6: Geometrical optimization of thermoelectric generator leg-power graph.

Varying cross section, L=10mm, W=10mm,Temp=313.15k H=2.5mm, N=15,Sheet-2 table-2,The leg height H varies, while the leg cross-section remains constant at 1.0*1.2 mm. L=5mm, W=5mm, and the temperature is 313.15k. H=2.0mm, N=15.

Case-V

For case V, the Thermoelectric generator was designed with varying geometries. The TEG Height of the legs (H-leg) was adjusted from 2 to 3 mm, while the other parameters remained constant. mm, cross section of the Legs (L-leg) (2.5 mm, cross section of the legs (L-leg) at 1×1.2 mm, and cross section of the legs (d-leg) at 0.5 mm.

Table 5. Output voltages, output current, and Resistances for Varying H leg of TEG.

Varying H-leg	L-teg	W-teg	d-teg	ΔT_{max}	I_{max}	V_{max}	R	Q_{max}
(mm)	(mm)	(mm)	(mm)	(k)	(A)	(V)	(Ω)	(W)
2	1×1.2	2.5	0.5	83.24	4.2	0.267	0.064	0.682
2.5	1×1.2	2.5	0.5	83.16	2.98	1.4	0.47	2.55
3	1×1.2	2.5	0.5	83.13	2.31	1.4	0.61	1.98

In this study, we examined the output of a case-V thermoelectric generator (TEG) design by altering the parameters based on the thermoelectric generator leg height. While maintaining a constant H-leg (2.5 mm, we found that Increasing the L-leg length improved the power Output conversion and efficiency. The output efficiency reached its peak at 1.2×1.2 mm, with performance influenced by heat transfer coefficients and energy conversion carrier concentrations.

Case-VI

For case VI, a thermoelectric generator was designed with varying geometries. The Height of the legs (H-leg) was adjusted from 2 to 3 mm, while the length (L) remained at 8 mm. Several parameters were kept constant: the Width of the legs (w-leg) at 5 mm, the cross section of the legs (l-leg) at 0.5×1.2 mm, and the cross section of the legs (d-leg) at 0.5 mm. Additionally, N was set to 15 and the temperature was maintained at 313.15◦K.

Table 6. Output voltages, output current, and Resistances for Varying H leg of TEG.

Varying H-leg	L-teg	W-teg	d-teg	ΔT_{max}	I_{max}	V_{max}	R	Q_{max}
(mm)	(mm)	(mm)	(mm)	(k)	(A)	(V)	(Ω)	(W)
2	0.5×1.2	5	0.5	72.99	2.11	2.1	1	2.7
2.5	0.5×1.2	5	0.5	73.24	1.5	2.11	1.4	1.92
3	0.5×1.2	55	0.5	73.38	1.16	2.1	1.8	1.49

The research investigated the effects of changing thermoelectric generator leg height parameters in case-VI TEG design output analysis. The performance output and energy conversion efficiency increased when the L-leg length increased as the H-leg (2.5 mm remained constant. The maximum efficiency point occurred at a dimension of 1.2×1.2 mm while the performance was determined by heat transfer coefficients and energy conversion carrier concentrations.

Case-VII

The thermoelectric generator (TEG) received different geometrical designs in case VI. The research examined height variations of the legs (H-leg) from 2 to 3 millimeters without changing the remaining design characteristics.These fixed dimensions included the width of the legs (w-leg) at 5 mm, the cross section of the Legs (L-leg) at 1×1.2 mm, and the leg cross-section (d-leg) at 0.5 mm. The temperature was maintained at 323˚ K throughout the experiment.

Table 7. Output voltage, output current, and resistance for varying H leg of TEG.

Varying H-leg	L-teg	W-teg	d-teg	ΔT_{max}	I_{max}	V_{max}	R	Q_{max}
(mm)	(mm)	(mm)	(mm)	(k)	(A)	(V)	(Ω)	(W)
2	1×1.2	5	0.5	73.17	4.2	0.267	0.064	0.682
2.5	1×1.2	5	0.5	73.17	2.98	1.4	0.47	2.55
3	1×1.2	55	0.5	73.33	2.31	1.4	0.61	1.98

In this study, we examined the case-VII TEG design output by altering the parameters related to the thermoelectric generator leg height. While maintaining a constant L-leg dimension of 1×1.2 mm, we increased the H-legs from 2 mm to 3 mm.

After case-VII designed the geometry of the TEG, it was observed and analysed through TEG height of the legs versus the current of the legs; in this case, as the height of the thermoelectric generator [14] (TEG) legs was increased, the current flowing through them decreased linearly. The resistance of the TEG legs showed a linear increase up to a leg height of 2.6 mm, after which it remained relatively constant despite further increase in height.

3. Results

The results showed an inverse relationship then the height of thermoelectric generator Legs increased, the current in legs decreased linearly. This demonstrates that leg height geometry significantly affects the generated current. The TEG design parameters included leg heights (H-leg) ranging from 2 to 3 mm, which had a notable influence. Other constant parameters were leg width (w-leg) at 5 mm, leg cross-section (L-leg) at 1×1.2 mm, leg cross-section (d-leg) at 0.5 mm, and a height temperature of 323 °K

The output power generated by the TEG legs exhibited a linear increase up to a leg height of 2.6 mm, beyond which it decreased. The maximum output power was observed at a leg height of 2.6 mm. The output power alongside the current output of a TEG depends heavily on the length of its legs. The length of the legs showed an opposite connection with current levels in the TEG design geometry. The investigation used H-leg measures from 2 mm to 3 mm with fixed w-leg at 5 mm and L-leg at 1×1.2 mm and d-leg at 0.5 mm and T at 323◦K.

Table 8. Comparison of Output Power for different TEG geometry Cases.

T=323° K	Case: I	Case:II	Case:III	Case:IV	Case:V	Case:VI	Case:VII
	Power (W)	Power (W)	Power (W)	Power (W)	Power (W)	Power (W)	Power (W)
	3.8	6.6	6.7	4.9	1.2	4.4	1.1
	5.7	4.7	**7.3**	6.0	4.1	3.1	4.1
	4.6	3.6	6.76	5.8	3.2	2.4	3.2

The above table presents different arrangements of TEG module geometric parameters and their related power outputs. This provides a comprehensive comparison of the power generated across different cases. Upon analysing the generator's performance with varying TEG dimensional geometries, it was observed that case-III and its associated TEG model geometry yielded the highest power output.

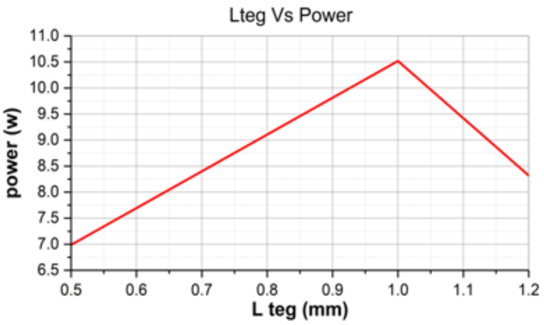

Figure.: Thermoelectric generator Leg (mm)Vs Power (W).

The TEG leg's l-legs were adjusted from 0.5 mm to 1.2 mm, while the H-teg was modified accordingly. The other parameters remained constant: W-leg at 10 mm, length L at 10 mm, and leg cross-section d-leg at 0.5 mm. In this TEG design, as the leg height increased, the output current rose from 2.14 Amp to 5.1 Amp, while the Internal Resistance decreased from 1.5 Ω to 0.26 Ω. The generated powers are 6.2, 7.3, and 6.76 W.

Table 9: Efficiency Comparison in different TEG module Geometry.

Case:I	**Case:II**	**Case:III**	**Case:IV**	**Case:V**	**Case:VI**	**Case:VII**
Efficiency (%)	Efficiency (%)	Efficiency (%)	Efficiency (%)	Efficiency (%)	Efficiency (%)	Efficiency (%)
4.5	8.1	16.0	6.1	1.34	6.0	1.74
6.5	5.6	**17.4**	8.88	5.01	4.30	5.65
5.4	4.45	16.1	7.13	3.90	3.30	4.43

Upon evaluating the efficiencies of the various TEG model geometries, the Case-III TEG configuration was found to have the highest efficiency of 17.4%.

4. Discussion

The optimized design was evaluated against the current TEG system. Limitations and future work: Acknowledgment of constraints and assumptions in the optimization process, Identification of areas for further research and potential improvements in the optimization methodology. The discussion typically synthesizes these results to provide a comprehensive understanding of how geometrical optimization can significantly enhance TEG efficiency, while also addressing practical considerations for implementation in real-world scenarios.

References

[1] Ibrahim, A., Bochmann, A., Löhnert, R., & Töpfer, J. (2024). Enhancing the Performance of Oxide-Based Transverse Thermoelectric Generators by Optimized Internal Geometry. *Advanced Functional Materials*. https://doi.org/10.1002/adfm.202413166.

[1] Ibrahim, A., Bochmann, A., Löhnert, R., & Töpfer, J. (2024). Enhancing the Performance of Oxide-Based Transverse Thermoelectric Generators by Optimized Internal Geometry. *Advanced Functional Materials*. https://doi.org/10.1002/adfm.202413166.

[2] R. Kaur, A. Tanwar, P. Gupta, N. Padmanathan, P. O'Brien and K. M. Razeeb, "Design Optimization of Micro-Thermoelectric Cooler for Thermal Management using Finite Element Simulations," *2022 28th International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, Dublin, Ireland, 2022, pp. 1-6, doi: 10.1109/THERMINIC57263.2022.9950684.

[3] Nan, B., Guo, T., Deng, H., Zhang, G., Shi, R., Xin, J., Tang, C., & Xu, G. (2024). Output performance improvement for thermoelectric transistor with the consideration of the Thomson effect and geometry optimization. *Applied Energy*, *357*, 122523. https://doi.org/10.1016/j.apenergy.2023.122523.

[4] Geometry Design-Based Thermoelectric Optimization Module. (2023). *Jurnal Sains Materi Indonesia*, *24*(2), 89–96. https://doi.org/10.55981/jsmi.2023.761.

[5] Dalkiranis, G. G., Bocchi, J., Oliveira, O. N., & Faria, G. C. (2023). Geometry Optimization for Miniaturized Thermoelectric Generators. *ACS Omega*, *8*, 9364–9370. https://doi.org/10.1021/acsomega.2c07916.

[6] Jaldurgam, F. F., & Ahmad, Z. (2022). A systematic review of structures, and geometries of the thermoelectric generators. *Applied Research*. https://doi.org/10.1002/appl.202200074.

[7] Xing, J., Luo, Y., Deng, Y., Wu, S., & Gai, Y. L. (2022). Topology optimization design of deformable flexible thermoelectric devices for voltage enhancement. *Engineering Optimization*, 1–18. https://doi.org/10.1080/0305215x.2022.2108416.

[8] Yongchen, Rao., Tamara, Bechtold., Dennis, Hohlfeld. (2022). Design optimization of a packaged thermoelectric generator for electrically active implants. Microelectronic Reliability, doi: 10.1016/j.microrel.2022.114843.

[9] Chuanping, Sun., Ya, Ge., Kui, He., Liehui, Xiao., Wu-Zhi, Yuan., Si-Min, Huang. (2022). Geometric optimization of a thermoelectric generator with variable cross-section legs by coupling the finite element method and optimization algorithm. Renewable Energy, doi: 10.1016/J.RENENE.2021.11.016.

[10] V., H., Juárez-Huerta., N., Sánchez-Salas., Juan, C., Chimal-Eguia. (2022). Optimization Criteria and Efficiency of Thermoelectric Generator. Entropy, doi: 10.3390/e24121812.

[11] Amit, Tanwar., Swatchith, Lal., Kafil, M., Razeeb. (2021). Structural design optimization of micro-thermoelectric generators for wearable biomedical devices. Energies, doi: 10.3390/EN14082339.

[12] Víctor, Cazurro, Barahona., WenChao, Zhu., Zebin, Weng., Yang, Li., Leiqi, Zhang., Bo, Zhao., Changjun, Xie., Ying, Shi., Liang, Huang., Yonggao, Yan. (2022). Theoretical analysis of the effect of shape factor on the performance of annular thermoelectric generators under different thermal boundary conditions. Energy, doi: 10.1016/J.ENERGY.2021.122285.

[13] Shittu, S., Li, G., Zhao, X., & Ma, X. (2020). Review of thermoelectric geometry and structure optimization for performance enhancement. Applied energy, 268, Article 115075. https://doi.org/10.1016/j.apenergy.2020.115075.

[14] R. Kaur, A. Tanwar, P. Gupta, N. Padmanathan, P. O'Brien and K. M. Razeeb, "Design Optimization of Micro-Thermoelectric Cooler for Thermal Management using Finite Element

Simulations," *2022 28th International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, Dublin, Ireland, 2022, pp. 1-6, doi: 10.1109/THERMINIC57263.2022.9950684.

[15] R. Kaur, A. Tanwar, P. Gupta, N. Padmanathan, P. O'Brien and K. M. Razeeb, "Design Optimization of Micro-Thermoelectric Cooler for Thermal Management using Finite Element Simulations," *2022 28th International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)*, Dublin, Ireland, 2022, pp. 1-6, doi: 10.1109/THERMINIC57263.2022.9950684.

[16] Chika, Maduabuchi., Chika, Maduabuchi., Howard, O., Njoku., Howard, O., Njoku., MN, Eke., Chigbo, A., Mgbemene., Ravita, Lamba., J.S., Ibrahim. (2021). Overall performance optimization of tapered leg geometry-based solar thermoelectric generators under isoflux conditions. Journal of Power Sources, doi: 10.1016/J.JPOWSOUR.2021.229989.

[17] Yin, Tao., Zhenming, Li., Peng, Peng., Liu, Wei., Yu-Ying, Shao., He, Zhizhu. (2021). Performance analysis and design optimization of compact thermoelectric generator with T-shaped configuration. Energy, doi: 10.1016/J.ENERGY.2021.120652.

[18] Yongchen, Rao., Yongchen, Rao., Chengdong, Yuan., Chengdong, Yuan., Gunasheela, Sadashivaiah., Dennis, Hohlfeld., Tamara, Bechtold., Tamara, Bechtold. (2021). Efficient design optimization of a miniaturized thermoelectric generator for electrically active implants based on parametric model order reduction. International Journal for Numerical Methods in Biomedical Engineering, doi: 10.1002/CNM.3517.

[19] Giovanni, Pennelli., Elisabetta, Dimaggio., Massimo, Macucci. (2021). Electrical and thermal optimization of energy-conversion systems based on thermoelectric generators. Energy, doi: 10.1016/J.ENERGY.2021.122494.

[20] Samson, Shittu., Guiqiang, Li., Xudong, Zhao., Xiaoli, Ma. (2021). Numerical Analysis of a Segmented Annular Thermoelectric Generator. doi: 10.1007/978-981-33-4765-6_77.

[21] Tao, Yin., Wen-Tao, Li., Ke, Li., Zhi-Zhu, He. (2021). Multiparameter optimization and uncertainty analysis of a multistage thermoelectric generator with temperature-dependent materials. Energy Reports, doi: 10.1016/J.EGYR.2021.10.079.

[22] Samson, Shittu., Guiqiang, Li., Xudong, Zhao., Xudong, Zhao., Xiaoli, Ma. (2020). Review of thermoelectric geometry and structural optimization for performance enhancement. Applied Energy, doi: 10.1016/J.APENERGY.2020.115075.

[23] Shittu, S., Li, G., Zhao, X., & Ma, X. (2020). Review of thermoelectric geometry and structure optimization for performance enhancement. Applied energy, 268, Article 115075. https://doi.org/10.1016/j.apenergy.2020.115075.

[24] Machine learning enabled thermoelectric generator design and optimization by Yuxiao Zhu.

[25] Practical Implementation of Maximum Power Tracking Based Short-Current Pulse Method for Thermoelectric Generators Systems Khalid Yahya†, Mehmet Zeki Bilgin*, and Tarik Erfidan* †,*Department of Electrical Engineering, Kocaeli University, Kocaeli, Turkey.

[26] Lei, Zhu., Huaqi, Li., Sen, Chen., Xiaoyan, Tian., Xiaoya, Kang., Xinbiao, Jiang., Suizheng, Qiu. (2020). Optimization analysis of segmented thermoelectric generator based on genetic algorithm. Renewable Energy, doi: 10.1016/J.RENENE.2020.04.120.

[27] Chengdong, Yuan, Dennis, Hohlfeld, Tamara, Bechtold. (2020). Design Optimization of a Miniaturized Thermoelectric Generator. doi: 10.1109/EUROSIME48426.2020.9152746.

[28] Naveen, K., Karri., Changki, Mo. (2019). Geometry optimization for structural reliability and performance of a thermoelectric generator. doi: 10.1007/S42452-019-1120-1.

[29] Daniel, W., Newbrook., Ruomeng, Huang., Stephen, P., Richards., Shivank, Sharma., Gillian, Reid., Andrew, L., Hector., C.H., de, Groot. (2020). Mathematical model and optimization of a thin-film thermoelectric generator. doi: 10.1088/2515-7655/AB4242.

[30] Ya, Ge., Lin, Yousheng., Qing, He., Wenhao, Wang., Jiechao, Chen., Si-Min, Huang. (2021). Geometric optimization of segmented thermoelectric generators for waste heat recovery systems using a genetic algorithm. Energy, doi: 10.1016/J.ENERGY.2021.121220.

[31] Practical Implementation of Maximum Power Tracking Based Short-Current Pulse Method for Thermoelectric Generators Systems Khalid Yahya†, Mehmet Zeki Bilgin*, and Tarik Erfidan* †,*Department of Electrical Engineering, Kocaeli University, Kocaeli, Turkey.

[32] A., Mellalou., L., Nkhaili., Qasim, Mahmood., Bakhtiar, Ul, Haq., A., Narjis., Abdelkader, Outzourhit. (2021). Optimal Designs of Thermoelectric Generators for Supplying Maximum External Load. Journal of Electronic Materials, doi: 10.1007/S11664-021-09224-9.

[33] Xuejian, Wang., Ji, Qi., Deng, Wei., Deng, Wei., Gongping, Li., Xudong, Gao., Luanxuan, He., Shixu, Zhang. (2021). Optimized design approach for thermoelectric generators with frustum-shaped legs based on a three-dimensional multiphysics model. Energy, doi: 10.1016/J.ENERGY.2021.120810.

[34] Wei, Hsin, Chen., Yi, Bin, Chiou. (2020). Geometry design for maximizing output power of segmented skutterudite thermoelectric generator by evolutionary computation. Applied Energy, doi: 10.1016/J.APENERGY.2020.115296.

[35] Chengdong, Yuan., Chengdong, Yuan, Dennis, Hohlfeld, Tamara, Bechtold., Tamara, Bechtold.(2021). Design optimization of miniaturized thermoelectric generator via parametricm odelorder reduction. Microelectronics Reliability, doi: 10.1016/J.MICROREL.2021.114075.

[36] Henan, Sun., Ya, Ge., Wei, Liu., Zhichun, Liu. (2019). Geometric optimization of two-stage thermoelectric generator using genetic algorithms and thermodynamic analysis. Energy, doi: 10.1016/J.ENERGY.2019.01.003.

[37] Shaowei, Q., Alireza, R., Rezania, Lasse, Rosendahl, Xiaolong, Gou. (2018). Analytical model for performance optimization of thermoelectric generators with temperature-dependent materials. IEEE Access, doi: 10.1109/ACCESS.2018.2874947.

[38] Zhichun, Liu., Shiping, Zhu., Ya, Ge., Feng, Shan., Lingping, Zeng., Wei, Liu. (2017). Geometry optimization of two-stage thermoelectric generators using the simplified conjugate-gradient method. Applied Energy, doi: 10.1016/J.APENERGY.2017.01.002.

[39] Ravi, Anant, Kishore., Mohan, Sanghadasa., Shashank, Priya. (2017). Optimization of segmented thermoelectric generator using Taguchi and ANOVA techniques. Scientific Reports, doi: 10.1038/S41598-017-16372-8.

[40] Lanlan, Cai., Peng, Li., Luo, Qi., Pengcheng, Zhai., Qingjie, Zhang. (2017). Geometry optimization of a segmented thermoelectric generator based on multiparameter and nonlinear optimization methods. Journal of Electronic Materials, doi: 10.1007/S11664-016-5198-6.

[41] O., M., Al-Habahbeh., A., Mohammad., A., Al-khalidi., M., Khanfer., M., Obeid. (2016). Design optimization of large-scale thermoelectric generators. Journal of King Saud University: Engineering Sciences, doi: 10.1016/J.JKSUES.2016.01.007.

[42] Linhao, Fan., Guobin, Zhang., Renfang, Wang., Kui, Jiao. (2016). Comprehensive and time-efficient model for determining the thermoelectric generator length and cross-sectional area. Energy Conversion and Management, doi: 10.1016/J.ENCONMAN.2016.05.064.

[43] Jiao, Kui., Guobin, Zhang., Fan, Linhao., Zhiqiang, Niu. (2015). Segmental thermoelectric generator structure design method.

[44] Hua, Tian., Xiuxiu, Sun., Jia, Qi., Xingyu, Liang., Gequn, Shu., Xu, Wang. (2015). Comparison and parameter optimization of segmented thermoelectric generator using high-temperature exhaust of diesel engine. Energy, doi: 10.1016/J.ENERGY.2015.02.063

[45] Tingzhen, Ming., Tingzhen, Ming., Yongjia, Wu., Chong, Peng., Yong, X., Tao. (2015). Thermal analysis of segmented thermoelectric generator. Energy, doi: 10.1016/J.ENERGY.2014.11.080

[46] Jing-Hui, Meng., Xinxin, Zhang., Xiao-Dong, Wang. (2014). Multi-objective and multiparameter optimization of a thermo–electric generator module. Energy, doi: 10.1016/J.ENERGY.2014.04.082

[47] F., Assion., C., Fischer., M., Schonhof., Ulrich, Hilleringmann., Christian, Hedayat. (2013). Designing output-power-optimized thermoelectric generators via analytic and finite element method modelling. doi: 10.1109/ICIT.2013.6505756

[48] Lingen, Chen., Fankai, Meng., Fengrui, Sun. (2013). Simultaneous internal and external optimization of irreversible thermoelectric generator for maximum power output. International Journal of Low-carbon Technologies, doi: 10.1093/IJLCT/CTS014.