

**RANCANG BANGUN *COOLING BOX* PORTABEL BERBASIS PELTIER
DENGAN *FUZZY LOGIC* DAN DAYA BATERAI UNTUK EFISIENSI
ENERGI DAN PENGAWETAN MAKANAN**



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Diajukan untuk memenuhi sebagian syarat untuk memperoleh gelar Sarjana
Pendidikan pada Program Studi Pendidikan Teknik Otomasi Industri dan
Robotika, Fakultas Pendidikan Teknik dan Industri, Universitas Pendidikan
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ABSTRAK

Makanan merupakan kebutuhan pokok yang harus dijaga kualitas dan keamanannya. Penurunan mutu dapat terjadi akibat aktivitas mikroorganisme dan kondisi penyimpanan yang tidak stabil. Pendinginan merupakan metode pengawetan yang umum digunakan karena mampu memperlambat pertumbuhan mikroorganisme tanpa merusak kandungan gizi. Sistem pendingin konvensional umumnya menggunakan refrigeran seperti HCFC dan HFC yang memiliki efisiensi termal tinggi, namun berdampak negatif terhadap lingkungan, seperti merusak lapisan ozon dan potensi pemanasan global. Teknologi Peltier menjadi salah satu solusi karena tidak menggunakan bahan kimia dan ramah lingkungan, meskipun efisiensinya yang masih rendah ($COP < 1$). Oleh karena itu, metode *fuzzy logic* diterapkan untuk meningkatkan efisiensi energi dan kestabilan temperatur. Penelitian ini bertujuan untuk merancang dan membangun *cooling box* portabel berbasis Peltier dengan kontrol fuzzy logic dan sumber daya baterai. Penelitian ini menggunakan metode *Research and Development* (R&D) dengan pendekatan eksperimental. Hasil menunjukkan bahwa nilai COP meningkat dari 0,846 menjadi 1,14 dengan tingkat akurasi 99,47% dan selisih temperatur 0,1°C dari set point. Sistem memiliki *delay time* sebesar 299 detik, *rise time* selama 872 detik, *settling time* tercapai pada detik ke-1.681 dan *peak time* tercapai pada detik ke-1.985. Sistem dengan kendali *fuzzy logic* mampu beroperasi selama 6.029 detik (± 100 menit), lebih lama 1,81 kali dibandingkan sistem tanpa kendali fuzzy logic yang mampu beroperasi selama 3.335 detik (± 56 menit), dengan selisih waktu sebesar 2.694 detik (± 45 menit). Peningkatan ini menunjukkan bahwa pemilihan desain fisik, isolasi termal yang tepat serta penerapan *fuzzy logic* mampu meningkatkan efisiensi energi sistem, mempercepat pendinginan dan menjaga kestabilan temperatur di dalam box.

Kata Kunci: *Cooling Box* Portabel, Peltier, *Fuzzy Logic*, Efisiensi Energi, Pengawetan Makanan

ABSTRACT

Food is a primary necessity that must be maintained in terms of quality and safety. Quality degradation can occur due to microbial activity and unstable storage conditions. Cooling is a commonly used preservation method because it can slow down microbial growth without damaging nutritional content. Conventional cooling systems generally use refrigerants such as HCFCs and HFCs, which have high thermal efficiency but negatively impact the environment, including ozone layer depletion and global warming potential. Peltier technology offers an alternative solution because it does not use chemical substances and is environmentally friendly, although its efficiency remains relatively low ($COP < 1$). Therefore, fuzzy logic control is applied to improve energy efficiency and temperature stability. This study aims to design and develop a portable cooling box based on Peltier modules with fuzzy logic control and battery power supply. The research employed the Research and Development (R&D) method with an experimental approach. The results show that the COP value increased from 0.846 to 1.14, with an accuracy of 99.47% and a temperature deviation of only 0.1°C from the set point. The system achieved a delay time of 299 seconds, a rise time of 872 seconds, a settling time at 1,681 seconds, and a peak time at 1,985 seconds. The fuzzy logic-controlled system operated for 6,029 seconds (± 100 minutes), which is 1.81 times longer compared to the system without fuzzy logic control that operated for 3,335 seconds (± 56 minutes), with a time difference of 2,694 seconds (± 45 minutes). This improvement indicates that the selection of physical design, appropriate thermal insulation, and the application of fuzzy logic can enhance the system's energy efficiency, accelerate cooling, and maintain temperature stability inside the box.

Keywords: *Portable Cooling Box, Peltier, Fuzzy Logic, Energy Efficiency, Food Preservation*

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DAFTAR PUSTAKA

- Abdulghani, Z. R. (2022). A novel experimental case study on optimization of Peltier air cooler using Taguchi method. *Results in Engineering*, 16(September), 100627. <https://doi.org/10.1016/j.rineng.2022.100627>
- Ac, M., & Fan, A. C. (n.d.). *Muffin AC* (. 028029, 2–4.
- Al-Humairi, S. N. S., Ghani, M. A., & Ci, W. Y. (2022). Design and Fabrication of a Vaccine Refrigeration Box. *2022 IEEE 13th Control and System Graduate Research Colloquium, ICSGRC 2022 - Conference Proceedings, July*, 56–60. <https://doi.org/10.1109/ICSGRC55096.2022.9845168>
- Al-Saadi, T., Rossiter, J. A., & Panoutsos, G. (2022). Fuzzy Logic Control in Metal Additive Manufacturing: A Literature Review and Case Study. *IFAC-PapersOnLine*, 55(21), 37–42. <https://doi.org/10.1016/j.ifacol.2022.09.240>
- Alsenani, T. R., & Morai, H. (2024). Enhanced Peltier refrigerator using an innovative hot-side heat-rejection mechanism ; Experimental study under both transient and. *Energy*, 309(July), 133132. <https://doi.org/10.1016/j.energy.2024.133132>
- Annabatt. (2017). *LIFEPO BATTERY CELL 4 26650-3.2V-3200mAh*. 26650.
- Arfaoui, J., Feki, E., Mami, A., & Manar, E. (2015). *PID and Fuzzy Logic Optimized Controller for*.
- Asiah, N., Cempaka, L., Ramadhan, K., & Matatula, S. H. (2020). Prinsip Dasar Penyimpanan Pangan Pada Suhu Rendah. In *Nasmedia* (Vol. 1, Issue December).
- Asst. Prof. Mrs. Deepa Shivshant Bhandarel and Dr. Prof. Mrs. N. R.Kulkarni. (2022). *Performances Evaluation and Comparison of PID Controller and Fuzzy Logic Controller for Process Liquid Level Control*. 16(1), 1–23.
- Bai, Y., & Wang, D. (2006). Fundamentals of fuzzy logic control — fuzzy sets, fuzzy rules and defuzzifications. *Advances in Industrial Control*, 9781846284687, 17–36. https://doi.org/10.1007/978-1-84628-469-4_2
- Bernhard Linke, P. M. T. S. (2008). *Overview of I-Wire Technology and Its Use What Is Special About I-Wire ?* 1–13.
- Bhatti, S. S., Kumar, A., R, R., & Singh, R. (2024). Environment-Friendly Refrigerants for Sustainable Refrigeration and Air Conditioning: A Review. *Current World Environment*, 18(3), 933–947. <https://doi.org/10.12944/cwe.18.3.03>
- Bolanakis, Di. E. (2019). A Survey of Research in Microcontroller Education. *Revista Iberoamericana de Tecnologias Del Aprendizaje*, 14(2), 50–57. <https://doi.org/10.1109/RITA.2019.2922856>
- Byar^a, M., Abounada^a, A., Brahmi^b, A., & Byar, M. (2022). *JOURNAL OF ELECTRICAL SYSTEMS & AUTOMATION Article Title A Performance comparison between PID and Fuzzy logic controllers for a DC-DC boost converter for photovoltaic applications*.
- Castro, J. L. (1995). *Fuzzy Logic Controllers Are Universal Approximators*. 176(1961), 171–176.

- Chen, Y., Kang, Y., Zhao, Y., Wang, L., Liu, J., Li, Y., Liang, Z., He, X., Li, X., Tavajohi, N., & Li, B. (2021). A review of lithium-ion battery safety concerns: The issues, strategies, and testing standards. *Journal of Energy Chemistry*, 59, 83–99. <https://doi.org/10.1016/j.jechem.2020.10.017>
- Components101. (n.d.-a). *DHT11 Temperature and Humidity Sensor*. <https://components101.com/sensors/dht11-temperature-sensor>
- Components101. (n.d.-b). *DHT22 Temperature and Humidity Sensor*. <https://components101.com/sensors/dht22-pinout-specs-datasheet>
- Components101. (n.d.-c). *LM35 Temperature Sensor*. <https://components101.com/sensors/lm35-temperature-sensor>
- Control, A. P. W. M., & Pwm, W. (n.d.). *Pulse-Width Modulation (PWM) Technology*.
- Domanski, P. A., & Mclinden, M. O. (2025). Updating the limited options for low-global-warming-potential refrigerants. *International Journal of Refrigeration*, 178(January), 410–417. <https://doi.org/10.1016/j.ijrefrig.2025.07.011>
- EEMB. (2010). Lithium-Ion Battery Data Sheet. *EEMB Battery*, 1–9. <https://www.ineltro.ch/media/downloads/SAAItem/45/45958/36e3e7f3-2049-4adb-a2a7-79c654d92915.pdf>
- Eslami Majd, A., Tchenbou-Magaia, F., Meless, A. M., Adebayo, D. S., & Ekere, N. N. (2023). A Review on Cooling Systems for Portable Energy Storage Units. *Energies*, 16(18). <https://doi.org/10.3390/en16186525>
- ETC2. (2003). TEC1-12706 Datasheet. *HB Corporation*, 4–6. <https://pdf1.alldatasheet.com/datasheet-pdf/view/227422/ETC2/TEC1-12706.html>
- Hoffmann, T. G., Mahajan, P. V., Praeger, U., Geyer, M., Sturm, B., & Linke, M. (2023). Small Peltier element to detect real-time heat flux between apple and environment during postharvest storage. *Computers and Electronics in Agriculture*, 213(August), 108247. <https://doi.org/10.1016/j.compag.2023.108247>
- IDuino. (n.d.). *Battery Management System (BMS)*. Retrieved January 3, 2025, from <https://iduino.co.in/>
- Jang, C., Lee, J., Sung, M., & Lee, J. (2019). Optimal design of cooling fan for 200kW class low voltage motor by numerical analysis. *2019 IEEE International Electric Machines and Drives Conference, IEMDC 2019*, 1163–1168. <https://doi.org/10.1109/IEMDC.2019.8785180>
- Joni Kusnadi. (2018). *Pengawet Alami untuk Makanan*. Universitas Brawijaya Press. https://www.google.co.id/books/edition/Pengawet_Alami_untuk_Makanan/WtaJDwAAQBAJ
- Khan, N., Ooi, C. A., Alturki, A., Amir, M., Shreasth, & Alharbi, T. (2024). A critical review of battery cell balancing techniques, optimal design, converter topologies, and performance evaluation for optimizing storage system in electric vehicles. *Energy Reports*, 11(April), 4999–5032. <https://doi.org/10.1016/j.egyr.2024.04.041>

- Kherkhar, A., Chiba, Y., Tlemçani, A., & Mamur, H. (2022). Thermal investigation of a thermoelectric cooler based on Arduino and PID control approach. *Case Studies in Thermal Engineering*, 36(June), 102249. <https://doi.org/10.1016/j.csite.2022.102249>
- Kiyak, E., & Gol, G. (2016). A comparison of fuzzy logic and PID controller for a single-axis solar tracking system. *Renewables: Wind, Water, and Solar*, 3(1). <https://doi.org/10.1186/s40807-016-0023-7>
- Kravchenko, Y., Bondarenko, V., Tyshchenko, M., Herasymenko, K., Trush, O., & Starkova, O. (2021). An Expert System for Testing of Microcontroller Systems Designers. *2020 IEEE International Conference on Problems of Infocommunications Science and Technology, PIC S and T 2020 - Proceedings*, 791–796. <https://doi.org/10.1109/PICST51311.2020.9468081>
- L.T. Hebei. (2013). *TEC1-12715 Datasheet*. 2–4. <https://peltiermodules.com/peltier.datasheet/TEC1-12715.pdf>
- Lawal, O. M., & Chang, Z. (2021). Development of an effective TE cooler box for food storage. *Case Studies in Thermal Engineering*, 28(August), 101564. <https://doi.org/10.1016/j.csite.2021.101564>
- Lin, C. M., Liu, H. Y., Tseng, K. Y., & Lin, S. F. (2019). Heating, ventilation, and air conditioning system optimization control strategy involving fan coil unit temperature control. *Applied Sciences (Switzerland)*, 9(11). <https://doi.org/10.3390/app9112391>
- Mahalingam, M., Hemanth, D., & Subramanian, K. (2024). *Peltier Module Based Cooling System for Food Security and Reducing Post Harvest Losses with Temperature Regulation*. 45(2), 1395–1405.
- Manual, P. R. (1972a). Target Areas. *The Lancet (Arduino Uno R3)*, 300(7770), 222. [https://doi.org/10.1016/S0140-6736\(72\)91649-2](https://doi.org/10.1016/S0140-6736(72)91649-2)
- Manual, P. R. (1972b). Target Areas. *The Lancet (Arduino Mega 2560 Rev3)*, 300(7770), 222. [https://doi.org/10.1016/S0140-6736\(72\)91649-2](https://doi.org/10.1016/S0140-6736(72)91649-2)
- Manual, T. R. (2008). ESP32 Datasheet. *Espressif Systems*, 604, 1–43. https://www.espressif.com/sites/default/files/documentation/esp32_technical_reference_manual_en.pdf
- Marek J. Paytra, Janos L. Grantner, K. K. (1996). Digital Fuzzy Logic Controller: Design and Implementation. *Proceedings of the SICE Annual Conference*, 4(4), 1477–1482.
- Mastrocinque, E., Lamberti, E., Ramirez, F. J., & Petrovic, D. (2022). Measuring open innovation under uncertainty: A fuzzy logic approach. *Journal of Engineering and Technology Management - JET-M*, 63, 101673. <https://doi.org/10.1016/j.jengtecman.2022.101673>
- Mattia Rossi, Nicola Toscani, M. M. et al. (2021). Introduction to Microcontroller Programming for Power Electronics Control Applications Coding with MATLAB® and Simulink®. In *Sustainability (Switzerland)* (Vol. 11, Issue 1). <http://scioteca.caf.com/bitstream/handle/123456789/1091/RED2017-Eng-8ene.pdf?sequence=12&isAllowed=y%0Ahttp://dx.doi.org/10.1016/j.regsciurbeco.2008.06.005%0Ahttps://www.researchgate.net/publication/305320484>

_SISTEM_PEMBETUNGAN_TERPUSAT_STRATEGI_MELESTARI

- Meje, K. C., Bokopane, L., Kusakana, K., & Siti, M. (2021). Real-time power dispatch in a standalone hybrid multisource distributed energy system using an Arduino board. *Energy Reports*, 7, 479–486. <https://doi.org/10.1016/j.egyr.2021.08.016>
- Microcontroller, A. (1972). Target Areas. *The Lancet (Arduino Nano)*, 300(7770), 222. [https://doi.org/10.1016/S0140-6736\(72\)91649-2](https://doi.org/10.1016/S0140-6736(72)91649-2)
- Mirmanto, M., Syahrul, S., & Wirdan, Y. (2019). Experimental performances of a thermoelectric cooler box with thermoelectric position variations. *Engineering Science and Technology, an International Journal*, 22(1), 177–184. <https://doi.org/10.1016/j.jestch.2018.09.006>
- Mossali, E., Picone, N., Gentilini, L., Rodriguez, O., Pérez, J. M., & Colledani, M. (2020). Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments. *Journal of Environmental Management*, 264. <https://doi.org/10.1016/j.jenvman.2020.110500>
- Natari, S. U., & Mutaqin, B. K. (2021). Kajian Umur Simpan Bakso Ayam pada Suhu Pendinginan yang Berbeda. *Jurnal Teknologi Hasil Peternakan*, 2(1), 24. <https://doi.org/10.24198/jthp.v2i1.33080>
- Piowowski, M., & Jakowski, D. (2023). Areas of Fan Research—A Review of the Literature in Terms of Improving Operating Efficiency and Reducing Noise Emissions. *Energies*, 16(3), 1–27. <https://doi.org/10.3390/en16031042>
- Pratama, D. (2021). Implementasi Pulse Width Modulation (Pwm) Pada Sistem Blending Kacang Menggunakan Sensorloadcell Berbasis Mikrokontroler. *Jurnal Teknisi*, 1(1), 1. <https://doi.org/10.54314/teknisi.v1i1.462>
- Prayogi, U., & Sugiono, R. (2022). Analisis Global Warming Potential (Gwp) Dan Ozone Depletion Potential (Odp), Pada Refrigeran R32, R290, R407C, R410a, Sebagai Pengganti R22. *Jurnal Teknik Mesin*, 11(1), 14–20.
- Roffi, M., Ferreira, F. J. T. E., & De Almeida, A. T. (2017). Comparison of different cooling fan designs for electric motors. *2017 IEEE International Electric Machines and Drives Conference, IEMDC 2017, October*. <https://doi.org/10.1109/IEMDC.2017.8002270>
- Rosdi Ab Rahman, Mahmod Abd Hakim Mohamad, Masiri Kaamin, Mohd Faizal Mohideen Batcha, Mohammad Daniel Aiman Mazlan, Muhammad Luqman Rosli, & Mohamad Azrul Arif Che Aziz. (2022). Experimental study of Peltier-Based Thermoelectric Cooling Box System. *Journal of Advanced Research in Applied Mechanics*, 94(1), 1–6. <https://doi.org/10.37934/aram.94.1.16>
- Saatchi, R. (2024). Fuzzy Logic Concepts, Developments and Implementation. *Information (Switzerland)*, 15(10). <https://doi.org/10.3390/info15100656>
- Sarkar, A., Khetan, A., Shahane, P., Harikrishnan, R., Phade, G., & Morankar, G. (2024). Biodegradable Automated Thermal Container Using Peltier Technology. *Mathematical Modelling of Engineering Problems*, 11(7), 1859–1866. <https://doi.org/10.18280/mmep.110715>
- Semiconductor, A. & O. (n.d.). *OB4184 40V N-Channel MOSFET General*.

- SHAIK, M. H., KOLLA, S., & SAIRAM, Y. N. V. (2025). Exploring low-GWP refrigerants for enhanced domestic refrigerator performance: A comprehensive investigation. *Journal of Thermal Engineering*, 11(1), 40–48. <https://doi.org/10.14744/thermal.0000902>
- Shi, L., Eldin, S. M., Abdulghani, Z. R., Ali, E., Guo, W., Anqi, A. E., & Alkhamis, N. (2023). Economic-effectiveness experimental case study for instant cooling of drinking-water using Peltier module. *Case Studies in Thermal Engineering*, 42(January), 102710. <https://doi.org/10.1016/j.csite.2023.102710>
- Shi, X., Iu, L., & Hang, S. (2011). Research for digital DC PWM controlling system. *Energy Procedia*, 16(PART C), 1547–1552. <https://doi.org/10.1016/j.egypro.2012.01.242>
- Shilpa, M. K., Raheman, M. A., Aabid, A., Baig, M., Veerasha, R. K., & Kudva, N. (2022). A Systematic Review of Thermoelectric Peltier Devices: Applications and Limitations. *Fluid Dynamics and Materials Processing*, 19(1), 187–206. <https://doi.org/10.32604/fdmp.2022.020351>
- Sihite, N., Antisa, P. S., Sriwiyanti, S., Hartati, Y., & Rotua, M. (2024). Sistem Penyimpanan Bahan Makanan Segar dan Kering di RS Pusri Palembang Berdasarkan Suhu Penyimpanan. *Jurnal Pustaka Padi (Pusat Akses Kajian Pangan Dan Gizi)*, 3(1), 12–19. <https://doi.org/10.55382/jurnalpustakapadi.v3i1.708>
- Siliconix, V. (2021). *Power MOSFET IRF520*. 1–8. <https://www.vishay.com/docs/91115/91115.pdf>
- Sonwani, T. P., Kumar, A., Sahu, G. C., & Sahu, K. L. (2020). *Thermoelectric Refrigerator Using Peltier Module*. May, 5–8.
- STMicroelectronics. (2000). *L298 DUAL FULL-BRIDGE DRIVER*
- Suganya, R., Joseph, L. M. I. L., & Kollem, S. (2024). Understanding lithium-ion battery management systems in electric vehicles: Environmental and health impacts, comparative study, and future trends: A review. *Results in Engineering*, 24(September), 103047. <https://doi.org/10.1016/j.rineng.2024.103047>
- Sugiyono. (2013). *Metode Penelitian Pendidikan: Pendekatan Kuantitatif, Kualitatif, dan R&D*. Alfabeta.
- Sunon. (2006). *D.C Brushless Fan*. 415. [http://www.sunon.com/uFiles/file/03_products/08-catalog_download/Sunon DC Brushless Fan & Blower_\(240-E\).pdf](http://www.sunon.com/uFiles/file/03_products/08-catalog_download/Sunon_DC_Brushless_Fan_&Blower_(240-E).pdf)
- Suprayogi, A., Rosyida, I., Wiyanti, D. T., & Safaatullah, M. F. (2021). Implementation of mamdani fuzzy implication in predicting traffic volume and duration of green lights on an intersection. *Journal of Physics: Conference Series*, 2106(1). <https://doi.org/10.1088/1742-6596/2106/1/012020>
- Surkanti, P. R., & Furth, P. M. (2013). High-efficiency, high-dimming ratio LED driver. *Midwest Symposium on Circuits and Systems, November*, 360–363. <https://doi.org/10.1109/MWSCAS.2013.6674660>
- Szopa, S. ., & V. Naik. (2023). Intergovernmental Panel on Climate Change: Short-lived Climate Forcers. In *Climate Change 2021 – The Physical Science Basis*.

<https://doi.org/10.1017/9781009157896.008.817>

- Tang, H. H., & Ahmad, N. S. (2024). Fuzzy logic approach for controlling uncertain and nonlinear systems: a comprehensive review of applications and advances. *Systems Science and Control Engineering*, 12(1). <https://doi.org/10.1080/21642583.2024.2394429>
- Thermonamic. (n.d.). *Specification of thermoelectric module TEC1-12707*. <http://www.thermonamic.com.cn/DF>
- Tinycircuits. (2020). Lithium Ion Cell 18650 2500mAh Battery Datasheet. *Ciccuits Datasheet*, July 2022, 1–10.
- Tom Almy. (2021). *One Wire and the DHT11/DHT22 sensor*. <https://tomalmy.com/one-wire-and-the-dht11-dht22-sensor/>
- Tomaszewska, A., Chu, Z., Feng, X., O’Kane, S., Liu, X., Chen, J., Ji, C., Endler, E., Li, R., Liu, L., Li, Y., Zheng, S., Vetterlein, S., Gao, M., Du, J., Parkes, M., Ouyang, M., Marinescu, M., Offer, G., & Wu, B. (2019). Lithium-ion battery fast charging: A review. *ETransportation*, 1, 100011. <https://doi.org/10.1016/j.etrans.2019.100011>
- Umang Gajera. (2017). *Basics of Interfacing DHT11/DHT22 Humidity and Temperature Sensor with MCU*. <https://www.ocfreaks.com/basics-interfacing-dht11-dht22-humidity-temperature-sensor-mcu/>
- Wang, Y., Pan, R., Yang, D., Tang, X., & Chen, Z. (2017). Remaining Useful Life Prediction of Lithium-ion Battery Based on Discrete Wavelet Transform. *Energy Procedia*, 105(July 2019), 2053–2058. <https://doi.org/10.1016/j.egypro.2017.03.582>
- Wibawa, I. M. S., & Putra, I. K. (2022). Design of air temperature and humidity measurement based on Arduino ATmega 328P with DHT22 sensor. *International Journal of Physical Sciences and Engineering*, 6(1), 9–17. <https://doi.org/10.53730/ijpse.v6n1.3065>
- Yang, J. K., Lee, H. J., Park, S. H., Chae, Y. T., Choi, J. S., & Park, D. Y. (2023). Performance and economic efficiency analysis of an integrated, outdoor fan-ventilated cooling device. *Heliyon*, 9(3), e13927. <https://doi.org/10.1016/j.heliyon.2023.e13927>
- Yenare, R. R., Sonawane, C. R., Sur, A., Singh, B., Panchal, H., Kumar, A., Sadasivuni, K. K., Siddiqui, M. I. H., & Bhalerao, Y. (2024). A comprehensive review of portable cold storage: Technologies, applications, and future trends. *Alexandria Engineering Journal*, 94(March), 23–33. <https://doi.org/10.1016/j.aej.2024.03.014>
- Zaferani, S. H., Sams, M. W., Ghomashchi, R., & Chen, Z. G. (2021). Thermoelectric coolers as thermal management systems for medical applications: Design, optimization, and advancement. *Nano Energy*, 90(PA), 106572. <https://doi.org/10.1016/j.nanoen.2021.106572>