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Automated Car Ventilation System Using Peltier Module

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Abstract
The current paper discusses a new thermoelectric ventilating system that can operate on a 12V 7Ah Lead Acid-Battery using solid-state thermoelectric modules and which is capable of providing reliable and low noise cooling services without necessarily involving the use of traditional types of refrigerants in order to meet the international demand for environmentally friendly and energy-saving cooling systems. Integrating advanced control algorithms and a microcontroller platform, the system is dynamically adjusted to the real-time data related to the characteristics of temperatures and humidity and, accordingly, the cooling supply and airflow are optimally controlled to reduce the amount of consumed power and, consequently, the battery life. The experimental evaluations demonstrate the capability of the system to reduce the interior temperatures by less than 25 degrees Celsius under unfavorable ambient conditions, and maintain operational independent features with capable control of the battery. Although the natural cooling power and material stability of Peltier devices cause limitations to its usage, this off-grid, battery-powered cooling system is highly promising as a sustainable, off-grid cooling system. This paper suggests further developments in the thermoelectric material science and system design, to enhance its functionality and increase its utility in many, energy-prohibited settings.
Keywords: *Thermoelectric cooling, Peltier modules, Eco-friendly cooling system, Off-grid cooling, Battery-powered ventilation, Lead-acid battery, Microcontroller-based control, Energy-efficient cooling, Sustainable cooling technology, Temperature and humidity control.*

1. Introduction
Thermal control is still a thorn in the flesh of small spaces like vehicle cabins, smaller residential areas, medical units on wheels, and temporary shelters. With the growing global temperatures and the growing pace of urbanization, the probability of excess heat retention in such areas rises and can be very uncomfortable, may eventually affect the material and even cause health risks to people occupying the buildings[1]. Although with high efficiency, traditional air conditioning systems are over-reliant on grid-based electricity, internal combustion engines, and often rely on chemical refrigerants, which are recognized as the causes of greenhouse gas emissions and environmental degradation. Alternative and sustainable cooling technology has been sought after particularly in off-grid and part-time occupied places. Through the development of thermoelectric cooling technology, particularly, Peltier-based devices, thermoelectric devices have become a possible solid-state answer to localized cooling needs. When powered by an electric current, Peltier modules actively conduct heat across one side to the other, to deliver cooling without any moving parts, toxic refrigerants or complex assemblies involved. These characteristics render them appealing to autonomous, small-scale, and maintenance free systems. However, the common use of thermoelectric coolers is limited due to their low cooling capacity as well as the low coefficient of performance. This is because (COP) is outperforming more traditional vapour compression systems [2]. Although some previous solutions have sought to include renewable energy sources such as solar panels to power up such modules, the options are limited by fluctuating irradiance, area to install a PV, and erratic operation in the absence of sunlight. To

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counter these shortcomings, this paper discusses the application of a high capacity, rechargeable 12V 7Ah Lead Acid battery as the major energy source of automated thermoelectric ventilation and cooling systems. The strategy will allow the system to provide dependable off-grid cooling that is not dependent on external weather conditions and provide the flexibility of deployment in any location, time of the day, or weather conditions. The suggested system uses the constant and high-current capacity of LiPo batteries to power various thermoelectric modules and other auxiliary equipment, including fans and microcontroller units (MCUs). Through the incorporation of intelligent control through sensor feedback, the system extends an automated control of cooling operations according to real-time temperature and humidity conditions[3]. Not only does this increase the efficiency of the energy usage of the onboard battery but it also streamlines the comfort of the user and system viability by adding safety limits and efficient power usage. The fact that the proposed solution does not rely on the use of chemical refrigerants or fossil fuels supports the environmental advantages associated with the proposed solution. In this paper, a thorough review and design of battery-powered, thermoelectric cooling systems in vehicles and closed areas are described. Focus is put on choice and arrangement of core elements, energy control and safety automation procedure, considerations of critical design, including heat dispensing and module layout and prototype outcomes. The main issues such as battery life, scalability of the components, and optimization of the system to the various applications are addressed. The results illustrate the possibility of free-standing 12V 7Ah Lead Acid-Battery -powered thermoelectric systems to offer sustainable, independent climatic control -and help mitigate carbon emissions as well as increase the endurance of the vehicle and shelter surroundings [4].

2. Methods and Mechanisms

2.1.Peltier Powered Cooling Systems with Battery

To curb thermal issues in confined areas, the proposed system employs the high-capacity 12 V 7Ah Lead Acid Battery as the main source of energy. The adoption of a high-end LiPo battery can offer the extended and mobile delivery of energy that can support the reliable functioning in the varied areas and conditions, including the intervals when the sun is not shining or the grid connection is unavailable[5]. This configuration was also useful in real-world experiments where it was required to stabilize the output to run several Peltier modules and additional cooling fans so that the temperature could be properly regulated even when the ambient temperature is high. The battery bank is modular to enable enhancement of the capacity of the entire system according to the needs of particular usage conditions.

2.2.Thermoelectric Cooling Technologies (Peltier Modules)

The integration of the thermoelectric Peltier modules forms the basis of the cooling mechanism since they conduct the transfer of heat when exposed to an electric current. The solid-state devices provide accurate, localized cooling and also they are highly compatible with small spaces because of their small size, low-noise performance, and they do not have moving components[6]. It was noted through iterative prototyping that more modules enhance aggregate cooling capacity although the power requirements also increase. Optimized deployments, e.g. six TEC1-12706 modules in action.Parallel to the core battery array, provided high and sustained cooling with no maintenance difficulties in comparison to traditional refrigeration systems. Further stabilization and enhancement of Peltier operation was identified to be further improved through the use of high-efficiency thermal paste, better contact surfaces, and purpose-designed heat sinks.

2.3.Environmental Factor and Dust Mitigation Effects.

Although the battery-based power scheme of the system eliminates the reliance on the changing sunlight intensity, other environmental factors like heat radiation and the presence of mineral dust are important factors that need to be taken into account to ensure efficient performance[7]. An example is dust that can settle on the heat sink fin and exhaust paths and block convection, increasing thermal resistance. Generally, cleaning procedures and routine inspection of airways were introduced, and optional mesh filters were installed in the fan inlet.

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These approaches were always able to enhance the cooling rates of the systems and preserve the integrity of thermal management during longer working periods.

2.4.Developments on Thermoelectric Cooling Integration.

The technology in both the field of battery control and the technology of thermoelectric modules has considerably increased the efficiency and reliability of the system. A voltage monitoring circuit is a real-time circuit that assists in keeping the lead-acid battery within an acceptable operating range to avoid over-discharge and enhance its overall service life. On the cooling side, phase change materials (PCM) as supplementary heat buffers were used together with specially designed aluminium heatsinks, and this effectively extended the operation of the Peltier modules when subjected to more extreme temperature differences without overheating it. In addition, the microcontroller automatically controls the fan speed and the duty cycle of the modules in line with live temperature readings so as to have a balanced trade-off between the consumption of energy and the comfort of the passengers. Economic evaluation was put on the determination of the optimal cost-performance by adjusting the sum total of power consumption of the chosen Peltier and fan modules in the rated energy of the 12V 7Ah Lead Acid-Battery bank. An increase in thermal load or modules did not increase battery run time or system efficiency. The total amount of energy consumed by calibration of the module count and setting smart control routines of intermittent operation based on real-time sensing increased the hours of operation per charge cycle. This solution made the solar panels and charge controllers unnecessary, which not only reduced the system architecture complexity but also reduced both initial costs and maintenance overheads in the solution, thus making the solution viable to even a broader set of both mobile and stationary applications. The modular battery design is easily replaceable or allowable and also enhances the value in the long term [8].

3. Methodology

A detailed methodology used to design, prototype, and test an automated battery-operated ventilation system in combination with thermoelectric Peltier modules will be given in this section. The design of the approach was built to guarantee effective autonomous cooling performance in a limited space like inside the vehicle cabin, with only an off-grid battery source powering the system. The methodology is based on the ideas of iterative development, experimental validation, and a strong orientation on the improvement of the practical performance and user comfort.

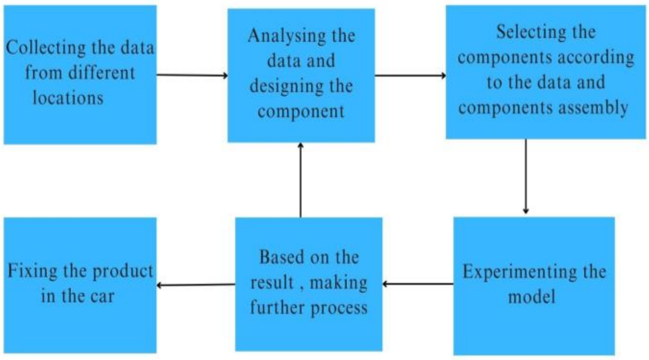

Figure 1 Flowchart

3.1.A. Data Acquisition and Requirement Analysis.

The first stage was comprised of collecting the voluminous information on the environment and user feedback which can be considered representative of the applications the system is to be used in. The temperature and humidity were measured in several vehicles parked in varying climatic conditions and strategic digital sensors recorded the spatial temperature variations and time changes in the cabin microclimate. The concurrent user surveys were used to test the amount of heat-induced discomfort as well as determining interest in automated ventilation systems as driven by a separate source of battery[9]. In conjunction, other extraneous variables such as ambient temperature, solar irradiance, and vehicle orientation were carefully examined in order to gain an insight into their role in heat accumulation. Such settlement information helped to determine specific critical temperature limits and cyclic thermal loading. Operational requirements were therefore set to ensure that occupant thermal comfort existed within a good temperature range of 20-25 degrees Celsius.

3.2.System Design and Components Selection

Based on the obtained requirements, a modular

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system was designed, with a focus on autonomous off-grid functioning.The major elements were selected with much care to achieve a balance between performance, cost and efficiency. It has adopted a 12V 7Ah Lead Acid Battery Pack because of its high energy density, constant discharge, and rapid recharge period, which means that it can operate for several hours without an external power supply. To achieve the needed cooling capacity, thermoelectric cooling equipment TEC1- 12706, 12 V, 6 A each were selected to fit within the discharge capability of batteries. Electrical circuits that were series/parallel combinations were tuned to suit voltage and current attributes of the battery[10], [11]. In thermal management, aluminium heat sinks with high conductivity were combined with low noise DC axial fans that dissipate the heat on the hot sides of the Peltier to avoid the thermal saturation to maintain the cooling efficiency. The high-accuracy digital temperature and relative humidity sensors in the cabin allowed real-time sensing, which gave the cabin a strong environmental feedback. CAD tools were exploited in the mechanical design of the stable enclosure that holds the components, protects them against environmental harm, and directs the flow of air to make the most of cooling results. An all-encompassing block diagram comprised of the most important components such as the battery management system (BMS), relays used to toggle loads and sensor feedback to the microcontroller.

3.3.Assembly and Prototype Building

The prototype was made keeping in mind the final design specifications. To offer environmental protection and durability of operations, the battery pack and power electronics were enclosed in a waterproof and shock-resistant enclosure. The peltier modules were attached onto aluminium heat sinks with thermally conductive paste to reduce the resistance at the interface as well as enhance better heat transfer. The axial fans were used to enhance sufficient forced convection to cover the heat sinks and eliminate overheating to extend the length of life of modules. The microcontroller was wired together with the sensors and relays using wiring harnesses and inline fuses were added to ensure the protection of electrical components and prevent faults. The sensors were checked and placed at the cabin to provide accurate monitoring of the environment that would reflect the real occupant environment. The whole system was tested on a test vehicle cabin to simulate conditions on the field. The comprehensive recording of the assembly and installation procedure enabled the refinements of the mechanical fitment, wiring arrangement, and thermal performance to be done in an iterative manner.

3.4.Control Strategy Development

The development included firmware development with autonomous cooling control by continuously monitoring the environment. Real-time monitoring of temperature and humidity occurred, which initiated the activation of the Peltier modules and the cooling fans when the cabin temperature was higher than the predetermined temperature, usually 30degC. The control algorithm used the speed of the fans and the duty cycle of the Peltier modules dynamically to control cooling efficiency against energy consumption to optimize the use of the battery. Constant battery voltage control was used, which provided protective cutoffs to prevent undervoltage conditions and deep discharge which may lead to compromised battery health. Also, the system went into low power standby mode when there were low-power requirements. reducing cooling load or cold battery in order to increase run time. The ability to override manually with status display and the wireless interface of a mobile app improved the usability of the system. The control logic has been experimentally tested through laboratory tests and field tests where it was repeatedly calibrated in order to enhance responsiveness, reliability, and power efficiency.

3.5.Experimental Testing and Performance Evaluation.

The work done on the assembled prototype was fully tested in terms of performance in controlled laboratory as well as in actual environmental conditions. Testing on solar simulator emulated the different power inputs, testing electrical consumption and cooling output at different operational voltages and current ranges of the system. The thermal behaviour was continuously measured inside the vehicle cabin evaluating initial rapid temperature variations with an increase in solar loading and long-term thermal stability. Battery life was measured by

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taking discharge profiles at realistic cooling load cycles, defining realistic run times. Field tests were used to test the system under various ambient temperature and humidity conditions and to test the strength and stability of the cooling effect. Thermal shutdown and overcurrent protections are some of the safety features that have been systematically tested. Empirical evidence was taken to provide the iterative hardware and firmware enhancements to maintain the desired cooling performance, optimize the system autonomy, and improve the occupant comfort.

3.6.Optimization and Dynamic Improvement.

Several optimization processes were done to develop heat dissipation, energy efficiency, and system reliability after initial testing stages. This focused on improvements in thermal interface material and optimization of geometries of heat sinks to increase heat rejection capacity. The algorithms controlling the fans were tuned to minimize the energy consumption with proper airflow, hence. maximizing the cooling efficiency. The electrical configuration of the Peltier modules was also manipulated to maximize the power to cooling outputs ratios[10]. The battery management algorithms were revised to maximize the lifespan, safety and operation margins. The features of the user interface and system feedback mechanisms were also improved to make the system easy to operate and give diagnostic transparency. The phases of modifications were succeeded by the next rounds of the performance testing to test the effectiveness and provide a stable functioning under various environmental conditions.

3.7.Final System Integration.

The optimized system was deployed to field in application environment over a long period of time. The stability and reliability were shown by constant checks of energy consumption, cabin temperature, and battery health of the vehicle used daily under the different environmental conditions. This was confirmed by user feedback that showed marked improvement of the thermal comfort and system usability. Maintenance procedures were adopted which included sensor recalibration and fan cooling which guarantees long-term performance [12]. Extensive tests confirmed the system to be a practical, independent ventilation system that can be controlled using solely onboard battery energy and is appropriate in off-grid engagements that require ambient noise-reducing, efficient, and environmentally friendly climate control.

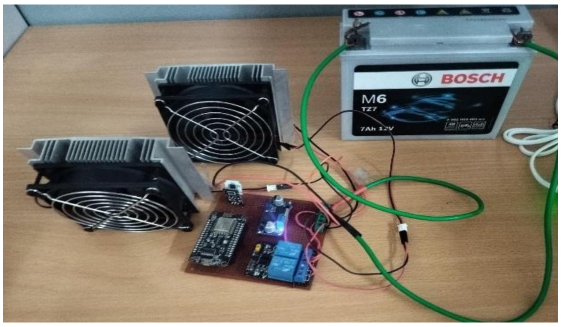

Figure 1 Whole Setup

4. System Components

The battery-powered ventilation system is an automated system that generates power to drive thermoelectric cooling modules to ensure that it operates sustainably and off-grid. Its basic elements are thoroughly chosen and engineered to achieve optimal performance, reliability, and energy efficiency of the system.

4.1.Thermoelectric Peltier Modules (TEC1-12706)

Cooling is achieved by means of several thermoelectric Peltier modules (TEC1-12706) which can produce a up to 67degC cold to hot temperatures when operating on 12 V DC and 6 A. Modules can be used in parallel and/or series to talk up voltage and current requirements to match the power produced by the solar panels and battery storage system[12], [13]. Scalability in relation to the modular configuration also allows the scalability to suit the cooling needs of different vehicle cabin sizes or applications.

Figure 2 Peltier Module (TEC1-12706)

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4.2.4.2 Microcontroller Unit (MCU)

Figure 3 ESP8266 Microcontroller Unit (MCU)

The ESP8266 microcontroller unit is used to provide an automation of the work of the system. The MCU has low power consumption and will constantly receive real-time information via temperature and humidity sensor (e.g., the DHT22) and act upon it by turning the Peltier modules and ventilation fans on and off. The logic thresholds coded into the MCU guarantee that it will only operate once cabin temperature hits the comfort levels previously set, and this will make the system conserve power and extend its service life.

4.3.Cooling Fans and Heat Sinks

Good thermal control of the Peltier modules is important to ensure there is cooling performance. The high-speed axial cooling fans (12 V DC, 0.2 A) are connected to aluminium heat sinks intended to effectively remove heat from the hot surface of the Peltier devices. Also, this active cooling can avoid thermal saturation and establish optimally favorable temperature gradients to achieve constant cooling capacity and last longer Peltier modules.

Figure 4 Cooling Fans and Heat Sinks

4.4.Sensors of Temperature and Humidity.

The digital temperature and relative humidity sensors (+-0.5degC and +-2% RH accuracy) are installed inside the cabin or an enclosed area of the vehicle to allow limited control of the surroundings. These sensors enable thermal tracking of conditions on a constant basis to feed the microcontroller with essential feedback used to control the dynamic system.

Figure 5 Temperature and Humidity Sensor

5. Tools and Components and System Description.

The suggested ventilation system would incorporate a battery-powered thermoelectric cooling system that would be used to regulate thermal conditions in a small area like a vehicle cabin. This system architecture focuses on small size, power efficiency and self-contained functionality, with components being chosen to strike a balance between performance and affordability [16].

5.1.Battery Power Supply

A 12V 7Ah Lead Acid battery bank is used as the main power source to supply a constant DC voltage and a large current capacity to propel the Peltier modules and other auxiliary components. The lead-acid chemistry has high energy density, low self-discharge, and long cycle life which provides guaranteed operation in longer periods. To avoid the abuse of the battery, the Embedded Battery Management System (BMS) circuits are used to monitor safe charging, in the event of over-discharge, and thermal safety. The battery pack helps in the continuous operation of the systems when external power is unavailable to the systems, thereby improving the autonomy of the ventilation unit.

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5.2.Peltier Modules of thermoelectric.

Cooling is attained using a series of TEC1- 12706 Peltier modules, both of which could operate on a 12 V system, 6 A with the ability to generate a temperature difference of 67 degree Celsius. Electrical installation of the modules is done to suit the 24 V supply with current loads and normally a series or parallel combination depending on the design demands. This is because, in its solid-state form, there are no vibrating internal parts to maintain, and the process is silent and vibration-free, thus keeping the maintenance requirements low. High-conductivity thermal interface materials are used between the surfaces of the modules and heat sinks to maximize the heat transfer efficiency [17].

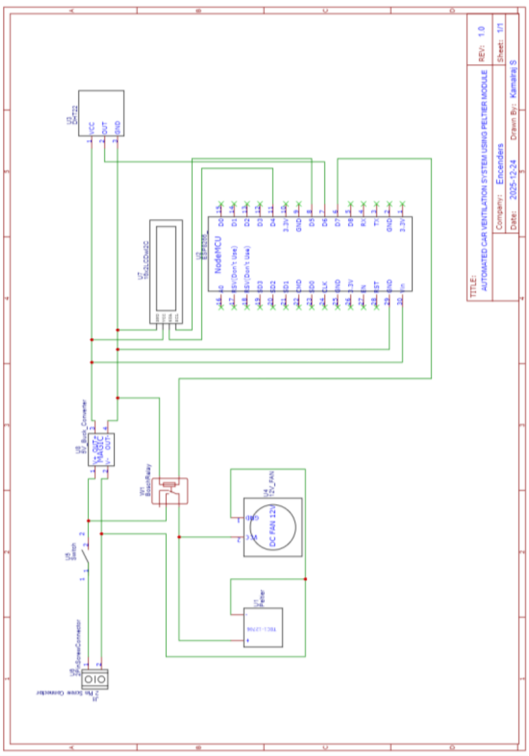

Figure 6 **Electrical CAD and circuit explanation**

5.3.Heat Sinks and Fans

To ensure the performance and life of the Peltier modules it is important to allow proper and effective heat dissipation. Massive aluminium heat sinks are used to take up and distribute heat effectively on the hot side of the modules. Forced convection is also imposed with high-speed axial fans of 12 V whose duty is to expel heat out of the heat sinks into the ambient environment. The combination of the two makes sure that the thermal gradient required in continuous cooling is maintained under varying operating conditions.

5.4.Microcontroller and Sensors

The ventilation system is operated by the logic which is coordinated by an ESP8266 microcontroller unit. The MCU constantly takes the readings of onboard temperature and humidity sensors (like the DHT22), therefore, providing real-time monitoring of the environment. The MCU also controls the on and controlled settings of the Peltier modules and fans based on sensor input and predetermined limits to maximize cooling effectiveness with a minimum amount of energy usage [15]. Other protection features such as voltage monitoring, fault detection are added at the controller level to ensure the safety of the system components and safe operation.

6. Data Collection & Samples

The temperatures that were recorded within the first three days (Day 1 to Day 3) of observation and the measurements were under shaded conditions and their possible range was 33.6degC to 39.9degC.An incremental increase between morning and afternoon made itself felt on all three days, but the total variability was not very large, which is reflective of a middle thermal stability. On the other hand, measurements conducted during the last four days (Day 4 to Day 7) with direct sunlight prevailing showed considerably high temperatures ranging between 34.1degC to 56.6degC. The highest temperature was always observed in the afternoon of the seventh day which is 56.6degC. Thus, the dataset clearly displays the fact that direct sunlight produces significantly more and more erratic thermal conditions in comparison with those, which occur in the shadows.

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Table 1 Data Collection & Samples

Day	Condition	Time	Temperature (°C)
Day 1	Under Shadow	10:00 AM	33.6
		12:00 PM	36.0
		2:00 PM	37.0
Day 2	Under Shadow	10:00 AM	37.0
		12:00 PM	39.7
		2:00 PM	39.9
Day 3	Under Shadow	10:00 AM	37.8
		12:00 PM	37.0
		2:00 PM	38.0
Day 4	Direct Sunlight	10:00 AM	39.5
		3:00 PM	41.7
Day 5	Direct Sunlight	10:00 AM	40.6
		3:00 PM	47.3
Day 6	Direct Sunlight	10:00 AM	42.8
		1:00 PM	45.9
		2:00 PM	47.7
Day 7	Direct Sunlight	11:00 AM	34.1
		1:00 PM	47.8
		2:00 PM	56.6

7. Results and Discussion

7.1.Performance Metrics

The Peltier ventilation system proved to be effective in thermal control in closed spaces, which is powered by batteries. Experimental study revealed that the system was able to cool the cabin with a range of about 8-10degC of temperature in 30-60 minutes of operation depending on the normal ambient temperatures between 35degC and 40degC. High external thermal stress was observed to be stabilized at 25-28degC, which is good evidence of reliable and consistent cooling performance in the conditions of enhanced occupant comfort in parked conditions.

7.2.Energy Consumption and efficiency

Optimization of energy consumption was achieved by means of a 12V 7Ah Lead Acid Battery in combination with intelligent control of both Peltier modules duty cycles and fan speed. This has greatly increased the battery life, which could now take a number of hours of autonomous cooling without external recharge. The battery management built-in system was capable of measuring both voltage and current to avoid deep discharge and overcurrent situations hence protecting the health of the battery and enhancing battery life. Cooling output/electric

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input ratio was estimated to be about 12-15% due to the effective thermal control and power modulation scheme, which is an indication of overall system efficiency.

7.3.Environmental Impact and Economic considerations.

Installing this battery- powered thermoelectric ventilation system in place of traditional grid powered air conditioners would lessen the use of fossil energy and toxic refrigerant gases and provide the benefit of a low-carbon, environmentally-friendly cooler. The lack of noise pollution and low-maintenance is also a fact that could be attributed to silent working and no moving parts of the Peltier modules. The economic benefits of the system are 40-60% in the operational costs in 5- 7year time, which is based on the reduced electricity costs and longer system life by virtue of reduced thermal degradation within the cabin.

7.4.Challenges and Limitations

Although useful in small enclosed spaces, the cooling capability of the system is still limited by the performance limitations of Peltier modules that are less powerful compared to traditional vapour-compression AC units. The additional modules and increase in battery capacity needed to operate an expanded coverage complicated and increased its cost. Repeated cycling also increases the thermal fatigue on modules and in turn reduces the lifespan of the modules, and usually, the modules are forced to be replaced after 2-4 years unless new materials or designs are developed. The solutions to these problems require further studies on high-efficiency thermoelectric materials, combination cooling systems, and additional development of the energy control techniques.

Conclusion

This paper has designed and tested a thermoelectric ventilation system powered by a battery, evaluating the application of a 12V 7Ah Lead Acid Battery in the efficient temperature regulation in a small compartment such as vehicle cabin. The system uses the thermoelectric Peltier effect to offer an off-grid cooling system that is sustainable and does not require external power sources. It was experimentally proven to have stable and reliable temperature drops of up to 10degC under high ambient heat loads, thereby greatly improving the comfort of occupants. Optimized energy consumption, long battery life, and the safety of system operation were guaranteed by the integration of intelligent microcontroller-based control and thermal management components. The cooling capacity is limited by nature of the Peltier modules, but the system provides a quiet and maintenance free alternative to the conventional air conditioner and the use of the refrigerant and the environmentally harmful effects of the refrigerant are eliminated. Future studies are recommended to work on enhancing the efficiency of thermoelectric materials, discovering hybrid cooling systems, and advancing energy storage technology to ensure expanded capacity and life of the system. Altogether, the battery-driven thermoelectric ventilation system offers a feasible, environmentally friendly product and is compatible with the rising energy sustainability requirements and the rising demand for autonomous cooling in off-grid facilities.

Reference

[1]. L. Shi et al., “Economic cost analysis of air-cooling process using different numbers of Peltier modules; Experimental case study,” Case Studies in Thermal Engineering, vol. 41, Jan. 2023, doi: 10.1016/j.csite.2022.102627.
[2]. T. Wang, Y. Ge, L. Chen, H. Feng, and J. Yu, “Optimal heat exchanger area distribution and low-temperature heat sink temperature for power optimization of an endoreversible space carnot cycle,” Entropy, vol. 23, no. 10, Oct. 2021, doi: 10.3390/e23101285.
[3]. Z. R. Abdulghani, “A novel experimental case study on optimization of Peltier air cooler using Taguchi method,” Results in Engineering, vol. 16, Dec. 2022, doi: 10.1016/j.rineng.2022.100627.
[4]. A. Elghool, F. Basrawi, T. K. Ibrahim, K. Habib, H. Ibrahim, and D. M. N. D. Idris, “A review on heat sink for thermo-electric power generation: Classifications and parameters affecting performance,” 2017, Elsevier Ltd. doi: 10.1016/j.enconman.2016.12.046.
[5]. R. Binninger, S. Unmüßig, M. Vergez, M. Bartel, and O. Schäfer-Welsen, “Customized measuring station for Peltier modules,” Heliyon, vol. 10, no. 4, Feb. 2024, doi:

10.1016/j.heliyon.2024.e25743.

[6]. H. Moria, S. Pourhedayat, H. S. Dizaji, A. M. Abusorrah, N. H. Abu-Hamdeh, and M. Wae-hayee, "Exergoeconomic analysis of a Peltier effect air cooler using experimental data," Appl. Therm. Eng., vol. 186, Mar. 2021, doi: 10.1016/j.applthermaleng.2020.116513.

[7]. A. Al-Sharafi, A. B. Ahmadullah, G. Hassan, H. Al-Qahtani, A. A. Abubakar, and B. S. Yilbas, "Influence of environmental dust accumulation on the performance and economics of solar energy systems: A comprehensive review," Aug. 01, 2024, Elsevier B.V. doi: 10.1016/j.cles.2024.100125.

[8]. I. O. Harmailil, S. M. Sultan, C. P. Tso, A. Fudholi, M. Mohammad, and A. Ibrahim, "A review on recent photovoltaic module cooling techniques: Types and assessment methods," Jun. 01, 2024, Elsevier B.V. doi: 10.1016/j.rineng.2024.102225.

[9]. B. S. P. F. Cotorogea, G. Marino, and S. Vogl, "Data driven health monitoring of Peltier modules using machine-learning-methods," SLAS Technol., vol. 27, no. 5, pp. 319–326, Oct. 2022, doi: 10.1016/j.slast.2022.07.002.

[10]. [10] M. M. Salman, M. M. Mahdi, and M. K. Ahmed, "Optimization of solar powered air conditioning system using alternating Peltier power supply," Bulletin of Electrical Engineering and Informatics, vol. 13, no. 1, pp. 20–30, Feb. 2024, doi: 10.11591/eei.v13i1.5864.

[11]. M. Setiyo, B. Waluyo, N. Widodo, M. L. Rochman, S. Munahar, and S. D. Fatmaryanti, "Cooling effect and heat index (HI) assessment on car cabin cooler powered by solar panel in parked car," Case Studies in Thermal Engineering, vol. 28, Dec. 2021, doi: 10.1016/j.csite.2021.101386.

[12]. A. A. F. Al-Hamadani and N. A. H. A. Taher, "Thermoelectric Cooling System for Vehicle Cabin during Parking Powered by Solar Photovoltaic Energy," Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 121, no. 1, pp. 17–26, 2024, doi: 10.37934/arfmts.121.1.1726.

[13]. M. T. Rahman Mitul, N. Mondol, M. N. Reza, S. Roy, and M. N. Islam, "Enhance the efficiency of solar modules and produce electricity from waste heat using thermoelectric generators (TEGs): A comprehensive practical work," Heliyon, vol. 11, no. 5, Mar. 2025, doi: 10.1016/j.heliyon.2025.e42869.