Wasit Journal of Engineering Sciences

Journal homepage: https://ejuow.uowasit.edu.iq

Systematic Review: How to reduce the car cabin temperature using solar energy?

Noor Al-Huda A.Taher[1] and Ali A . F . Al- Hamadani[1]

Affiliations
[1]Mechanecal Engineering Department, Wasit University, Kut, Iraq

Correspondence
Noor Al-Huda A.T.,
Email: ntaher@uowasit.edu.iq

Received
04-November-2023
Revised
28-December-2023
Accepted
15-January-2024
Doi: 10.31185/ejuow.Vol12.Iss2.492

Abstract
The two most significant issues we have are the energy crisis and global warming. Both issues are made worse by the use of traditional air conditioners. Therefore, numerous techniques were devised to overcome that, including solar ventilation, solar cooling, and solar thermoelectric modules. The most suitable choice was solar thermoelectric cooling because it was safe for the environment, provided a significant drop in car cabin temperatures, and avoided using hazardous refrigeration fluids.

Keywords: thermoelectric, ventilation, air conditioning, solar energy, Peltier effect.

الخلاصة: إن أهم قضيتين لدينا هما أزمة الطاقة والاحتباس الحراري. تتفاقم كلتا المشكلتين بسبب استخدام مكيفات الهواء التقليدية. ولذلك، تم ابتكار العديد من التقنيات للتغلب على ذلك، بما في ذلك التهوية الشمسية، والتبريد الشمسي، والوحدات الكهروحرارية الشمسية. وكان الاختيار الأنسب هو التبريد الكهروحراري الشمسي لأنه آمن للبيئة، ويحقق انخفاضًا كبيرًا في درجات حرارة مقصورة السيارة، ويتجنب استخدام موائع التبريد الخطرة.

1. INTRODUCTION

The vehicle cabin becomes very hot in the summer, so the vehicle cooling system needs to be switched. The working of the cooling system means more fuel intake, which increases the greenhouse gases. The greenhouse gases have a bad effect on human health and the environment. Additionally, the ozone layer is severely harmed by using conventional cooling systems that employ harmful refrigerants (R134a). In recent years, the automotive industry has been working to increase thermal comfort while lowering environmental pollution. Especially after the Kyoto Protocol was established, using HFCs (hydrofluorocarbons) as refrigerants for vehicle cooling systems was illegal. Half a ton of ozone molecules can be destroyed by 100 grams of HFCs. Since then, several new technologies that can replace the cooling system have appeared. A thermoelectric cooling system based on the Peltier effect is one of these systems[1].

One eco-friendly and sustainable energy source is solar power. However, this energy's enormous potential hasn't of this energy hasn't, however, been fully realized, particularly in the fields of home air conditioning and transportation. Solar cells can convert solar energy into electrical energy. The thermoelectric cooler uses this electric energy to cool the car's interior by maintaining the temperature on the hot side so that the cold side may absorb heat and reduce the ambient temperature. To meet the need for air conditioning, it must be possible to power cooling equipment both thermally and electrically. Compression cooling techniques dominate traditional cooling technology. Solar radiation, which appears as heat, is emitted by a spectrum region containing photon energy. Semiconductors are modified for solar cell technology. This approach generates electricity by transferring the energy present in photons with an energy level greater than the gap band energy level of the absorbent material. Photons with energies below the slit band energy level are not absorbed by the solar cell when metal back contacts take them up, but they can contribute to its heating up[2].

2. Methods of reducing the car cabin temperature

The world's population is constantly increasing, and vehicles are also growing. The automobile is a daily need for everyone. People require a car for short and long trips for comfort, safety, and the environment. These factors allow for the increasing installation of HVAC systems in automobiles. Today, no one feels comfortable driving without air conditioning. As a result, HVAC becomes essential for human life[3].

Vehicle manufacturers' focus on car thermal comfort has increased over the last several years. Thermal comfort would be achieved by decreasing the car cabin temperature, which has become very high, especially during the summer. To avoid those high temperatures, used different methods, including:

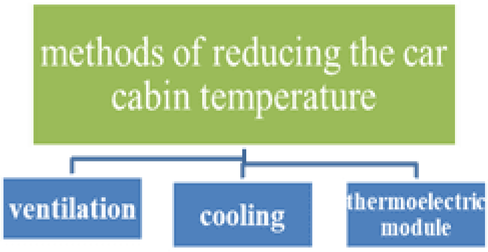

Figure 1 The methods of reducing the car cabin temperature.

2.1 VENTILATION METHOD

Ventilation is essential to any structure, achieved by window opening or infiltration. Ventilation with outdoor air has always helped lower the concentration of air pollutants indoors, leading to discomfort and health risks[4].

K. David et al. (2005) in their numerical study, depended on airflow technology to enhance the temperature distributions in a vehicle to reduce the greenhouse effect. In an open parking space, the temperature inside the automobile reached (60-70 ºC). Before the driver or passenger enters the automobile, the temperature has practically reached the outside temperature. The greenhouse-control system started to remove the hot air from the car while the engine was idling. When the greenhouse control system needed electricity, the engine was idle, or the batteries couldn't provide enough power, intelligent solar power was used, as shown in Figure 2. The technology produced a relaxed environment for the driver and passengers. The study showed that an air intake should be positioned in high-temperature or high-pressure zones to allow hot air to be exhausted due to variations in local pressure quickly[5].

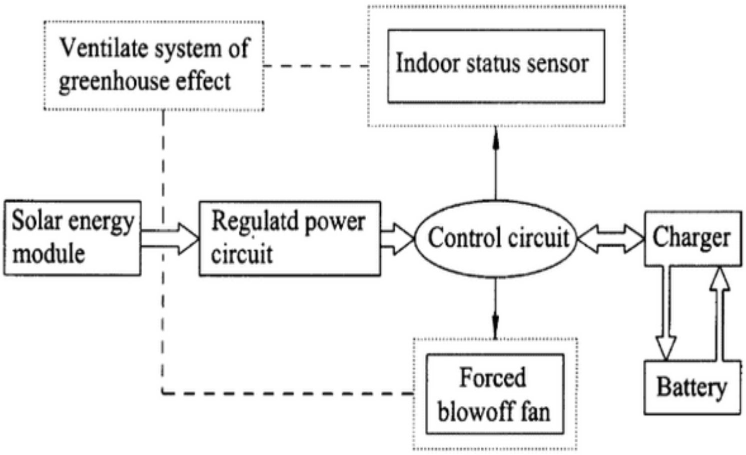

Figure 2: The diagram of the power supply

Saidur et al. (2009) improved solar ventilation system for vehicles parked in open spaces on a sunny day from 11:00 A.M. to 4:00 P.M. A Nissan Sunny in metallic grey was the test vehicle. During sunny days, the ventilators are run by solar energy and driven by a battery, which is charged by solar energy during a cloudy day. The authors modified the ventilator by replacing the motor with a high-speed motor to increase the airflow rate after discovering that the old ventilator wasn't sufficient to provide the necessary comfort, as shown in Figure 3. The position of the existing ventilator's solar panels was unsuitable because it was at the side of the vehicle and did not directly receive sunlight. Therefore, solar panels are installed on the car's roof to increase efficiency. The new solar panel size was (536×446×35 mm). In order for the enhanced ventilator to run at its fastest speed, a solar controller was also employed to control the electricity generated by solar panels. The modification raised the air flow rate from 20cfm to 110.5cfm. The existing ventilation system provided a 9.3 % reduction in temperature compared with a vehicle without any ventilation system, while the improved ventilators provided a 10.9 % reduction in temperature compared to the vehicle that used the existing ventilator. When comparing the car with the enhanced ventilation system to the one without any ventilation, the temperature was lowered by 19.2%[6].

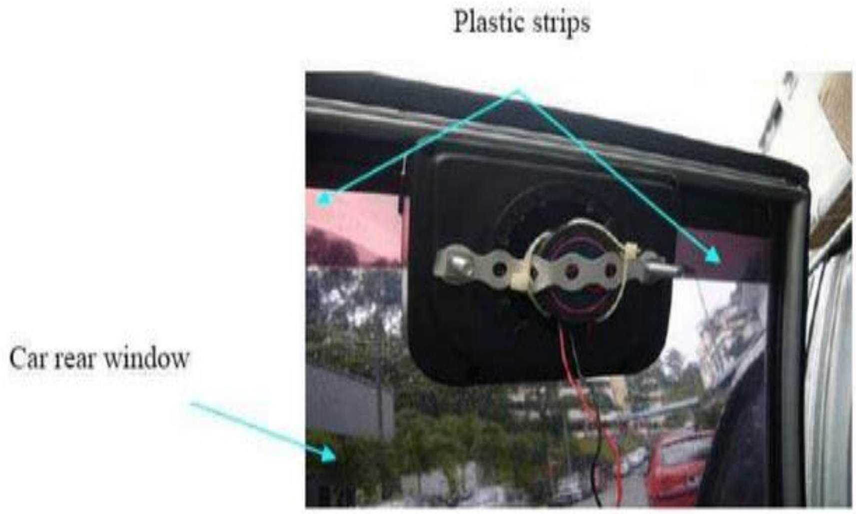

Figure 3:Solar ventilator on the top edge of a window.

Zhiqiang et al. (2015) designed a ventilation system powered by solar energy for a vehicle parking under sunlight in the summer. The car cabin temperature increased quickly and reached 80 °C. The authors relied on a solar-powered ventilation system to keep the cabin cool by maintaining constant air circulation in interior and exterior environments. The static thermal transfer model for the cabin was first constructed. Then, a ventilation model for the outside circulation was built according to the parameters of the prototype ventilation pipe. The cabin inlet air temperature control then established the characteristics of the solar wings. Additionally, the operating circumstances for the solar wing and ventilator were examined. According to the research results, the technology reduced the cabin air temperature by a maximum of 15°C [7].

Sudhir and Jalal Marhoon (2015) developed and constructed a solar-powered photovoltaic car interior ventilation system. The car's windows were closed and parked in direct sunlight. The location in Muscat was exposed to sunshine all day for a long time. The authors used one solar panel with dimensions(335*235*20mm) and three ventilator fans with dimensions (60*60*15 mm) with an airflow of 16.6. One of the fans was put for fresh air and the other for exhaust. The study investigated the impact of solar ventilation on a car's air conditioning system while it was parked under sunlight, as shown in Figure 4. Two days were spent experimenting. In the first test, the ventilation system for the air conditioning unit was activated, and in the second, it was not. The results indicated that turning on the ventilation system reduced the temperature inside the car. The research revealed that compared to values evaluated without a ventilation system, the car's cabin temperature reached a comfortable level more quickly—ideally in less than half the time. Compared to the cabin temperature without a ventilation system, the temperature inside the car was almost 10 ºC lower[8].

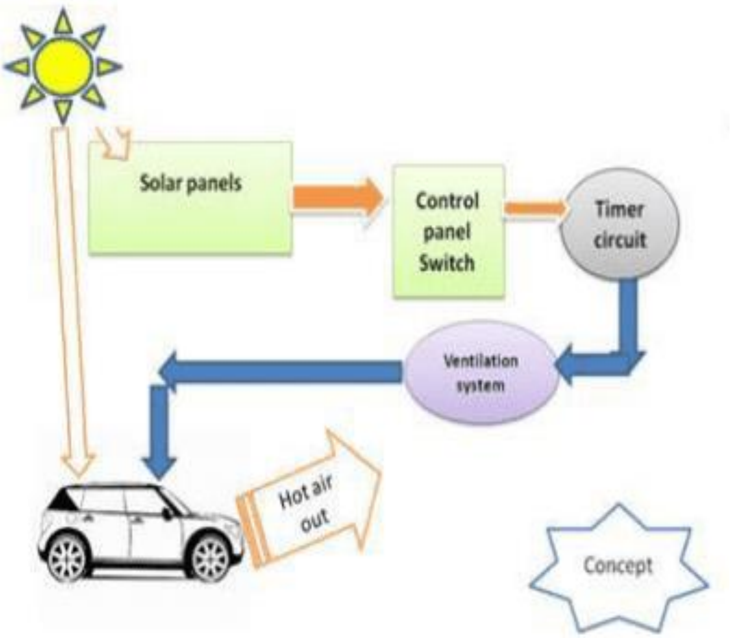

Figure 4: The diagram of the system setup.

Issam Mohammed et al. (2015) investigated in their experimental study how solar radiation affected a vehicle's dashboard, steering wheel, seat, and interior air. During the test, the vehicle was parked in a southern direction. The authors conducted research across six different conditions. (Unshaded car with all windows closed (base case), shaded car with front windshield covered and all windows covered, shaded car with front windshield covered and all windows covered, shaded car with front windshield covered and two side windows parted down by 1 cm, shaded car with front windshield covered and all windows covered, and shaded car with front windshield covered and all windows covered as shown in FFigure 5. The measurements were taken between 8:00 a.m. and 5:00 p.m. on clear summer days, with the highest levels of radiation occurring at 1:00 p.m. The data showed that a stopped car with no shade may quickly reach 70 degrees Celsius inside, with the dashboard temperature climbing close to 100 degrees. The cardboard car shade didn't help much with the interior temperature. The average temperature of interior components was reduced by 70% when the car was covered with 1 cm of part-down side windows compared to the baseline situation[9].

Figure 5: The suggested car cover

S. Khatoon and Man-Hoe (2017) studied three variant ventilation concepts. Air was drawn in through the front intake and exited through the back window in the first case. In the second case, air trickled in from the ceiling through an inlet and exited through two slots on the side walls. In the third case, the air was brought in via porous textile bags and expelled via a back and trickling input ceiling vent. The authors looked at all three cases and compared their performance regarding energy efficiency and passenger comfort (both front and rear). The simulation was carried out using FLUENT 16.0 software. The car was parked in summer conditions, and the engine was running. The analysis token considered summer cooling with different inlet positions but the same velocity value of 0.5 m/s, temperature 13.6 degrees Celsius, and performed the outlet pressure as atmospheric pressure. The results showed that in cases 1, 2, and 3, the average cabin temperature was 24.42 degrees Celsius, 21.85 degrees Celsius, and 19.95 degrees Celsius, and the heat removal efficiency was 0.51 per cent, 0.48 per cent, and 0.46 per cent, respectively[10].

Hairol et al. (2018) developed a solar ventilation system for a car. No original components of the vehicle were repurposed by the authors. Two fans are used with different power (1.62 W and 2.16 W, respectively). The main body of the ventilator was placed on the window's flat surface. The dimensions of the chosen solar panel are (380mm * 305mm) as shown in Figure 6. The desired and necessary temperatures within the vehicle can be determined using a heat sensor, which is detectable at temperatures below 30 degrees Celsius. The PIC Microcontroller was used in the system's simulation created by the Protues program. The authors show the average temperature with and without ventilators versus the time from 11:00 am until 3:00 pm .65.60 °C was the maximum average temperature inside a car without a ventilator, and 57.7 °C was the maximum average temperature inside a vehicle without a ventilator. This means the ventilation system provides about a 12% temperature reduction compared with the car without any ventilation system[11].

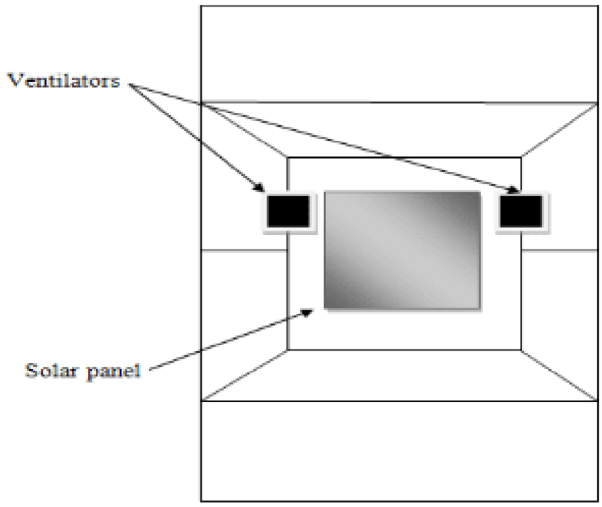

Figure 6: The top view of the position of the PV panel and ventilators

Al-Rawashdeh et al. (2021) studied the impact of solar ventilation on the interior temperature of a parked car. The study was done so that the HVAC system could be powered by renewable energy. This system includes two fans, four photovoltaic solar panels, a battery, a charge controller, and a ventilator. Specifically, the solar PV panel is sized at (480 x 360 x 25 mm) as shown in Figure 7. Both vehicles (with and without solar ventilation) were used in the experiments. The data showed that with solar ventilation, the average daily temperature difference inside the automobile was 7.2 degrees Fahrenheit; without it, it was 20.6 degrees. Without solar ventilation, the average daily temperature difference inside the car was 17.6 degrees Fahrenheit, whereas, with it, it was just 6.2 degrees. Fuel savings (an increase of around 1 km/L) resulted from the study's reduction of vehicle interior temperature by 12 °C and AC compressor power by 49%. Furthermore, the already-low levels of hazardous emissions dropped by almost half. As a result, the authors verified that the technique increased cabin temperature comfort[12].

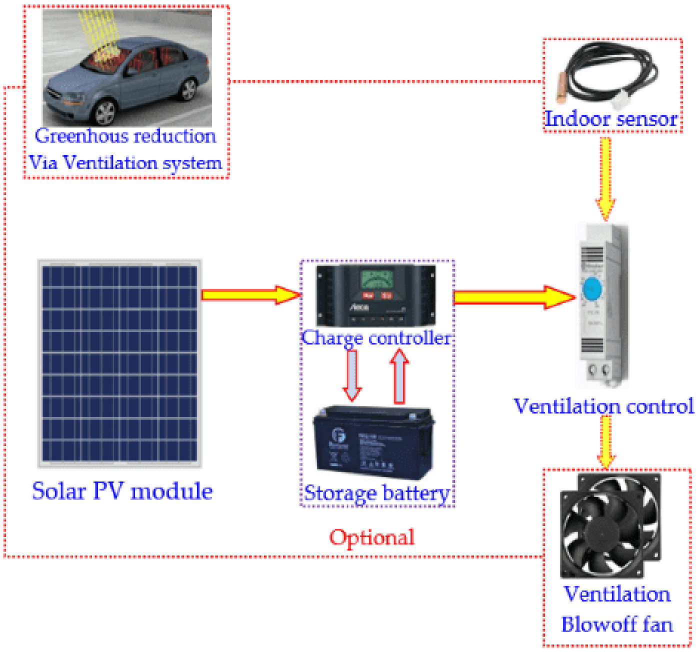

Figure 7: The process flow of PV panel powered ventilation fan.

2.2 COOLING METHOD

The cooling is an essential part of the vehicle, and it uses energy in the form of work that is accomplished to power or drive the compressor or pump[13].

Full- MOHD (2010) used a photovoltaic system as a source to power the cooling system for a vehicle and designed a control system to make the system operate automatically. The system didn't cool the vehicle cabin like any air conditioning system but reduced the vehicle cabin temperature when exposed to the hot sun. The cool air from the outside is drawn into the automobile through the air conditioning duct and any other natural leakage spots, and the hot air is drawn out of the car by the exhaust fan, as shown in Figure 8. Due to the dashboard's direct exposure to sunshine, its temperature decreased by 1.2ºC and was significantly lower. With the automatic cooling system, the interior vehicle air, roof, and rear seat temperatures dropped by 9.5ºC, 4.6ºC, and 7.5ºC, respectively. The system was prepared for human comfort[14].

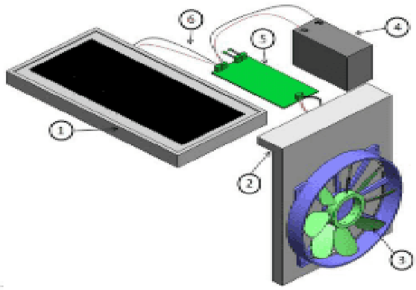

Figure 8: The design of the car cooling system using solar energy.

Anuja and Bhoi (2016) used solar panels made from flexible material and placed on the roof of the (LMV)light motor vehicle to operate the air conditioning system. Two solar panels, a microcontroller, a power supply, an LCD, a battery, an AC adapter, and a mobile charger unit made up the system. The solar panels were made of Silicon and Aluminium with 45W and 12V. Their weight was 4.5 Kg. The battery capacity was 8.2 AH. The AC fan was with 20W and 1.6A. A boost converter is used to increase the output voltage. MATLAB software was used to code ADC to read the solar panel's output, and the LCD showed the voltage, as shown in Figure 9. The boost converter received a PWM signal, and the battery received its voltage. Then the air conditioner ran, and the phone was charged. The solar cooling system minimized pollution and toxic emissions while conserving non-renewable energy[15].

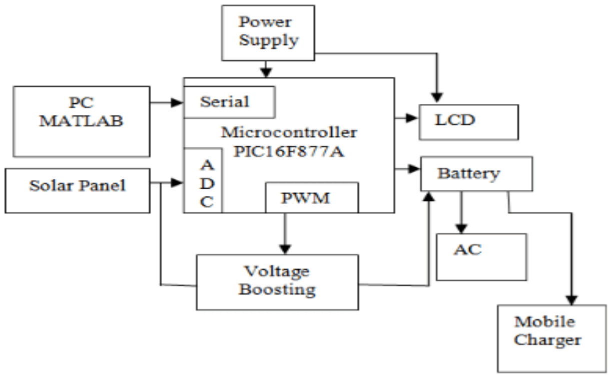

Figure 9: The block diagram of an air conditioning system powered by solar energy for LMV.

Hongye et al. (2017) investigated a wireless power transfer-based portable photovoltaic energy-powered automotive cooling system. The system comprises the solar collecting mechanism, temperature control, energy conduit, and cooling module. The solar collector mechanism's overall dimensions were (145 * 175 * 455) mm, and it was fixed on the cabin roof where a car parked. The solar energy was turned into electric energy using a wireless power transfer unit and stored in supercapacitors without damaging the car's body, as shown in Figure 10. The cooling device achieves automatic temperature using a temperature control and cooling module. Experimental results showed that when the prototype was loaded with (3 and 5), the maximum output power was 2.181 W, and the highest WPT efficiency was 60.3%. SOLIDWORKS was utilized in the simulation to construct the cabin[16].

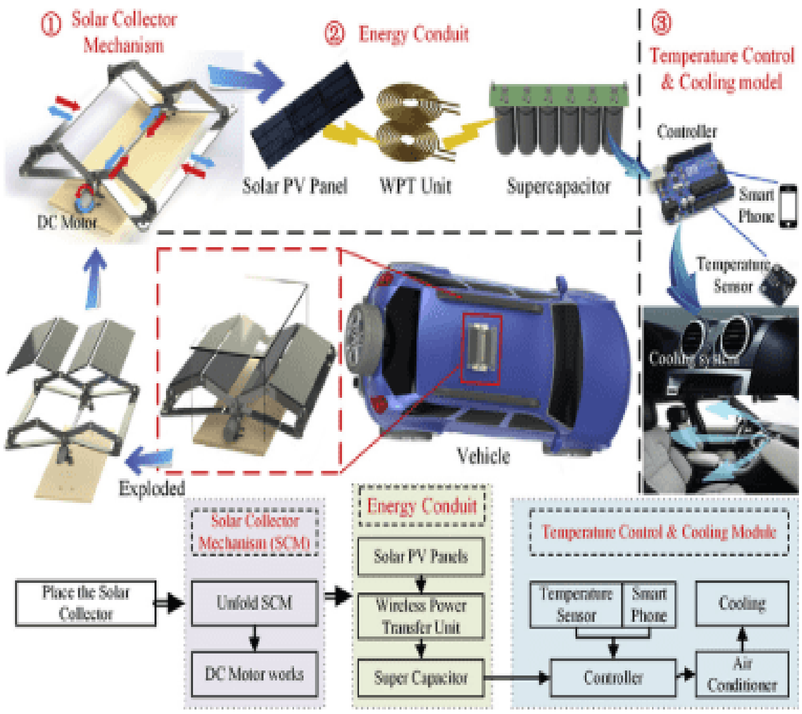

Figure 10: Flowchart of the portable solar cooling system.

Lingfei et al. (2017) created a portable solar air-cooling system based on phase-change material (PCM) for a car cabin. When a car was parked outside and exposed to sunshine, the mechanism kept the inside temperature from getting overly hot. The system's three primary components comprise a solar energy collection module, a phase-change cooling module, and a power storage module. The phase-change cooling module received power from the power-storage module after the solar panel turned solar energy into electric energy and stored it in a supercapacitor. The PCMs and cabin ambient air exchanged heat, resulting in the creation of cold air. First, heated air from the outside was driven into the PCM room by an air pump powered by the energy storage module. Second, the cold air used to cool the car interior was produced via heat exchange between the hot air and the cold PCMs. Third, when the water valve opened at night, cold water stored in the tank poured into the PCM's chamber. In order to cool the PCMs for the subsequent cabin-cooling cycle, the water absorbed the heat that the PCMs produced over the day, as shown in Figure 11. Thermal simulations showed the system's long-term cooling impact. Temperature decreases of 30 °C found during testing indicated that the suggested cooling system was advantageous and effective for cooling car cabins[17].

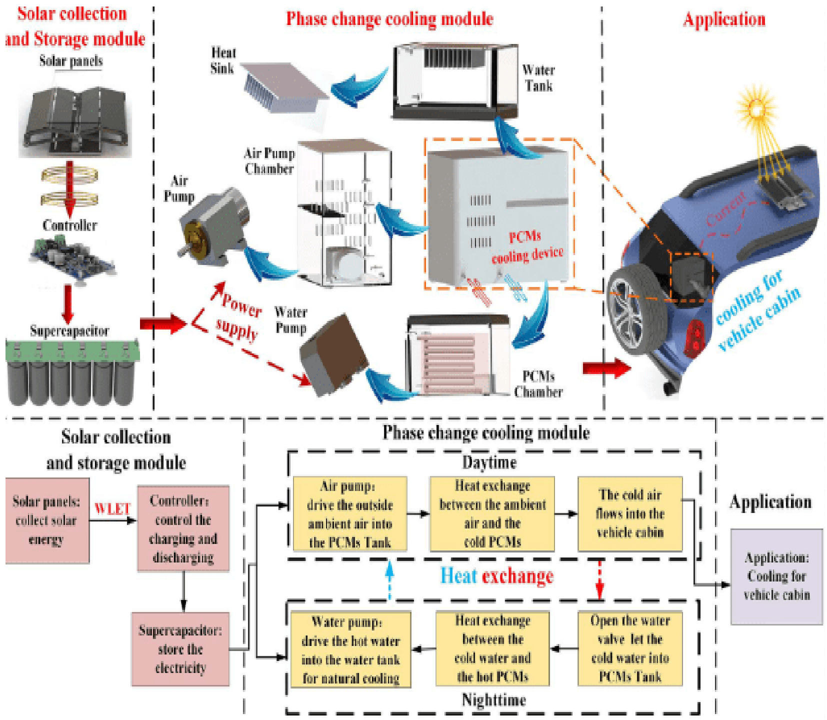

Figure 11: Flowchart of portable solar powered PCM-based cooling system.

Punitharani et al. (2017) replaced fossil fuel with a different energy source, such as solar energy, to run a car's air conditioning system. By eliminating the belt connection from the engine's crank pulley, the air conditioning compressor could separate from the engine. The compressor, evaporator, expansion valve, condenser, and drier were all taken from the original air conditioning system of the Maruthi Alto 800 automobile for assembling the air conditioning unit. R134-a was the refrigerant in use, as shown in Figure 12. Two cars were used in the experiment, which was run in three different traffic conditions. When the air conditioner was turned off, the mileage of the two vehicles increased. It also increased on the highways when compared to peak and light traffic. The average difference in the mileage for the old and new cars was 2.83 kmpl and 2.86 kmpl, respectively. The compressor run at three speeds 1000, 1500, and 2000 revolutions per minute (rpm), and for three different amounts of R-134a (300, 400, and 500 g). The results indicated that the compressor power and the cooling capacity increased as the speed (rpm) increased and decreased as the refrigerant increased. The COP increased as the amount of refrigerant increased and decreased as the speed (rpm) increased. The system saved up to 10.5 litres of fuel per month and around Rs.663 per month on fuel. The maximum coefficient of performance was 5.44 at 500g refrigerant and compressor speed of 1000 RPM[18].

Figure 12: Assembly air conditioning system.

Pang et al. (2018) created a solar photovoltaic air-cooling system for cars to solve the problem of temperature rising inside the car when it stops in the broiling summer. The authors developed a DC air conditioning system using R134a refrigerant and solar power to replace the current power supply. The input refrigerating capacity of the air conditioning system and the temperature change inside the automobile with an operating air conditioning system were calculated theoretically. Four flexible (CIGS) PV panels provide power for the DC compressor. The PV panel's dimensions were 1661 mm 661 mm, and its output power was 165 W (at 25 ^{o}C and 1000 W/m^2), as shown in Figure 13. The measurements were in China during the period (from August 6th to August 18th), and all the experiments were performed at no load conditions. Doors and windows were left open for at least 30 minutes before each test to ensure that the temperature inside the vehicle reached thermal equilibrium. However, the car's windows and doors were closed for the test—the refrigerating capacity of the air conditioning system changed by changing the current of the compressor[19].

Figure 13: Air conditioning system powered by solar energy.

K. Chong et al. (2019) investigated using a standalone solar PV system for cooling automobile cabins. The system consists of a battery with a voltage of 12/24 V, an inverter with an input voltage range of 20V-30 V, and two PV panels with a maximum power of 120 Watt, maximum voltage of 17.2 V, and maximum current of 6.99 for each one as shown in Figure 14. Due to their relative movement, the two PV panels attached to a single-axis sun-tracking system with an active sensor could receive 90% of the sun's energy throughout the day. Low relative humidity was discovered to be an essential variable in reducing the heat load within the vehicle. The amount of heat that evaporative cooling removes. The vehicle's evaporative cooling system performed more efficiently in an area with low humidity. During solar noon, the car's inside temperature rose to about 66 °C, but the mist cooling system brought it down to about 49–50 °C[20].

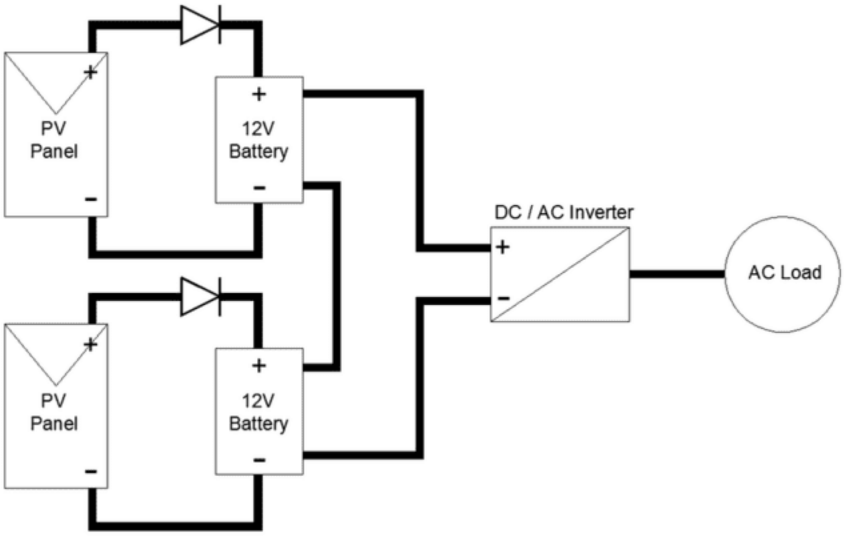

Figure 14: The overall design of a standalone solar system.

Zhang et al. (2020) studied Portable Solar Powered Cooling System (SPCS) based on wireless power transfer (WPT) and a foldable-flower mechanism. The solar foldable flower module, temperature control module, and energy transmission module were the three primary components of the system, as shown in Figure 15. The solar foldable flower module (SFFM) was a cutting-edge foldable mechanism that maximized space by folding and rotating like a flower unfolding its petals. The solar-cell-equipped SFFM gathered solar energy and transformed it into electric energy. The energy transfer module uses a wireless power transfer unit to transfer electric energy from the SFFM to a supercapacitor and store it there. The temperature control module used a cooling device to provide automatic temperature management. According to experimental results, the WPT's efficiency could reach up to 73.6% with a load resistor of 15 and output power could reach up to 7.571 W with a load resistor of 5. According to the thermal simulation data, the system obtained an average temperature reduction of 27.45 ºC, which was practical and efficient for cooling a heated automobile cabin [21].

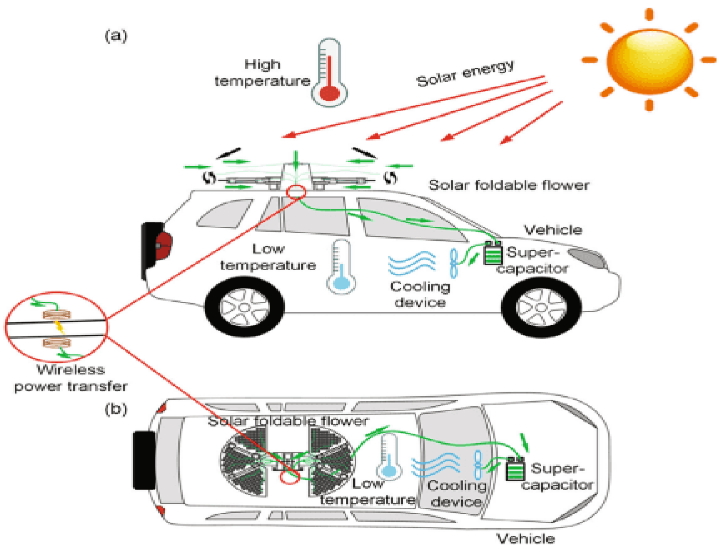

Figure 15:The diagram of solar energy powered cooling system a) Lateral view of solar energy powered cooling system. b) Top view of solar energy powered cooling system.

Carneiro and Soares (2020) examined the possible economic and environmental advantages of solar panels installed on the BLRV roof. The train trip took 60 minutes for a 30 km distance in João Pessoa, Brazil. The energy consumption included six air conditioners of 15kW each one, two fan motors of 2860W and 44 fluorescent lamps of 40W, as shown in Figure 16. The BLRV's nominal consumption is 97.48kWh. During sunny days, the typical energy usage was approximately 27 per cent of the nominal power of 26 kWh for measurement. The result showed economic benefits and environmental benefits. The financial benefit came from the installation of 61 m^2 of solar panels in BLRV, which produced an average of 55.55 kW to be used for comfort energy, such as lighting and air conditioning, and helped the business save about R$ 822,107.35 over ten years. The environmental benefit was that the solar power system reduced the emission of greenhouse gas (GHG) by about 54 tons of CO_2 per year[22].

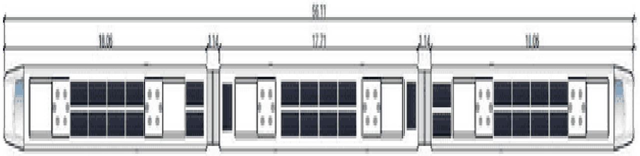

Figure 16: The proposed design of PV system in BLRV.

Vashisht and Rakshit (2021) conducted thorough research on the air conditioning systems of numerous automobiles, classifying them as passive, active, and hybrid systems and examining how each affected the vehicle's performance. Improvements in each category of air conditioning systems were offered as the main outcome of the authors' review, comparison, and comprehensive description. Along with major improvements in energy and fuel economy, applications of hybrid air conditioning systems are also highlighted. In addition, the authors developed and gave future insight into energy efficient and environmentally friendly automobile air conditioning systems after expediting the vapor compression refrigeration system[13].

Wan et al. (2021) created and promoted a novel type of capillary radiant pipe network-connected compression refrigerator and PV power generating panels-equipped radiant cooling air conditioning system for vehicles. This method did not significantly alter the original car construction, and the seats' motion and the airbag's opening were unaffected. The solar panels were installed on the vehicle's roof, and since they used the car's batteries, they eliminated the need to install additional batteries. The capillary radiant panel was then put in place, dressed, and attached to the seat back and floor of the car. The gadget was compact and simple to install because its entire thickness was only about 15mm. Finally, attach the capillary network's connecting water line to the refrigerator. The compression refrigeration module, which is in charge of providing a cold source for the radiation end of the capillary network, was made up of throttling devices, compressors, condensers, water pumps, evaporators, radiating fins, etc., as shown in Figure 17. The technology used a compression chiller powered by solar energy to cool the running water medium in the capillary network installed in the automobile seat, floor, etc. The system generated about 130 kWh of annual power and 2750 kWh cumulative power generated in 20 years. The total emission reduced by about 0.91 tons[23].

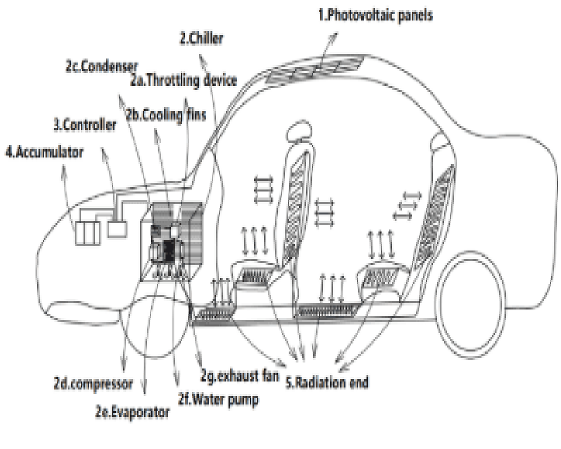

Figure 17: The proposed system.

Yoshitaka et al. (2022) enhanced the vehicle integrated photovoltaic (VIPV) module's thermal design. The authors determined the convective heat transfer coefficient with respect to car speed between the roof surface and surrounding air. The experiment was done on two types of cars (small van and sedan). The flexible photovoltaic module dimensions were (1180 mm × 540 mm × t2 mm) and mounted on the roof, as shown in Figure 18. Average wind speeds were low during calm days (1.12 and 1.5 m/s) in summer (2/August/2021) for small van and in autumn (4/October/2021) for sedan. The car moved at a speed that was gradually increased to a range of (20–60 km/h). The results showed that the car's speed and the body's shape, depending on where it was positioned on the roof, significantly impacted the heat transfer coefficient. The empirical equations approximated the heat transfer coefficient as a function of vehicle speed and location on the roof. Experimental measurements of the VIPV module's temperature change characteristics proved that the heat transfer coefficient is the primary cause of the high-temperature change rate under driving situations[24].

Figure 18: The sensors and PV panel on the roof of the small van(top) and sedan (bottom).

2.3 THERMOELECTRIC COOLING

Air conditioners that use thermoelectric solid-state technology can provide efficient cooling. Having low energy needs and the capacity to deliver cooling and heating from the same unit when necessary. In 1822, Thomas Seebeck discovered that the junctions between two dissimilar metals generate a voltage, which is a function of temperature. Later, Peltier discovered that the Seebeck effect may be reversed. i.e., cold and hot junctions will occur, as shown by applying voltage to two dissimilar metals coupled as junctions. This is known as the Peltier effect, which is shown in **Error! Reference source not found.**.

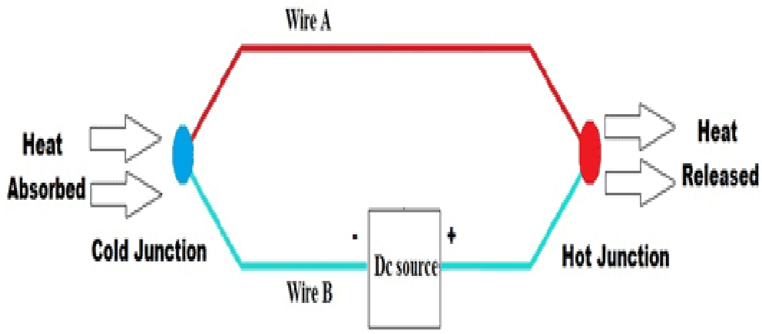

Figure 19:Peltier effect

Based on the Peltier effect, many models were used to develop efficient refrigeration and air conditioning systems.

In particular, the cooler does not exhaust the planet's finite supply of fossil fuels or hurt the environment by reducing ozone levels or releasing greenhouse gases, which both contribute to global warming. The electrical energy input needed to power the cooler is provided by a solar panel. Air is drawn away from the hot side and toward the cold side when the Peltier device generally uses a heat sink on each side, cooling the area around it[25].

Sharma et al. (2009) developed an environmentally beneficial method for installing a cooling or refrigeration system. A solar panel powered the cooler by the input electrical energy. On the heated side of the Peltier device, air would be forced backwards, while on the cold side, it would be forced forward. The region around it was cooled by thermoelectric air conditioning. The Peltier device has heat sinks attached to each side. The cooling system produced temperature changes from 20 to 55 ^{o}C. Solar cell panels served as the DC power supply for the Peltier element. The model was validated using the appropriate hardware, and the outcomes were satisfactory[25].

Manoj et al. (2012) created a cooling system on a standard automotive air conditioner blower. The Peltier effect-based the system. Testing and measurements performed on a vehicle (Maruti Suzuki Zen). The system components included an air blower, duct, fans, TECs, heat sink, cold side heat sinks, and power supply (car battery). Six TECs sandwiched between heat sinks exposed to ambient air blown out by the blower through the duct. The cold heat sinks' one end began to blow chilly air. The automobile battery serves as a DC power source for the TECs. Forced convection is employed in the fan-mounted heat sink on the hot side, as shown in Figure 20. 12V and 4A were the TEC specs. The total required current and voltage became 12A and 24V when each pair of TECs was connected in series, and each group of TECs connected in series was connected in parallel. The results of the experimental study conducted in the case of parking under the sunlight and in the case of running during different times of the day morning, afternoon and night, showed that the system can achieve a temperature difference of 7 ^{O}C[3].

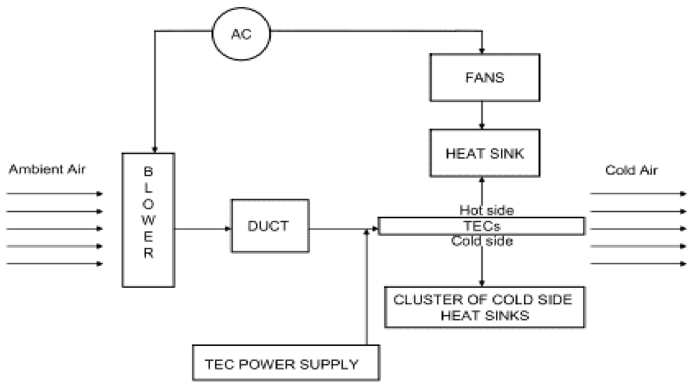

Figure 20: The block diagram of the thermoelectric cooling system.

Mihai et al. (2013) employed the Peltier effect, based on a thermoelectric module, to cool the vehicle's cabin. The thermoelectric cooling system's compact size made it possible to install practically anywhere inside the car. By minimizing or completely removing the need to utilize electric power to run a traditional heater or air conditioner to maintain an effective cabin temperature, the authors increased the overall efficiency of a motor vehicle and an electric vehicle[1].

Sanket et al. (2017) conducted an experimental investigation on a thermoelectric module-based solar heating and cooling system. The authors created and constructed a cheap solar thermoelectric refrigerator for the Bedouin people living in rural areas of Oman without access to power. The main parts of the system were two thermoelectric modules, a solar panel, an aluminium box, plastic plates, a cooling fan, and a finned surface (heat sink). (40*40*3.4 mm), 5 V and 12 A made up the thermoelectric module. The thermoelectric module received power from the solar panel, and the aluminium sheet installed in the refrigerator cabinet ensures even cooling. The heat transfer rate from the heated thermoelectric surface is accelerated using a finned surface (heat sink) and a plastic plate as thermal insulation. The investigation results demonstrated that solar radiation intensity and the temperature difference between the hot and cold sides of the thermoelectric module substantially affected the system's performance. The unit successfully maintained the refrigerator's temperature between 15 and 18 ^{o}C, and the COP was around 0.25[26].

Amina et al. (2019) the authors utilized the solar power extracted from a solar panel to power a system that controlled the interior vehicle temperature. They used the TEG (thermoelectric generators) to provide the cooling inside the car cabin. The system consisted of a TEG module, temperature sensor, solar panel, fan, frame and battery. The 12 V,5 Watt solar panel is used to power the auxiliary battery. A lead acid battery was used to store the electrical energy extracted from the solar panel, as shown in Figure 21. The microcontroller and TEG module are powered by the stored energy. The microprocessor programmed with the desired parameters continuously detected the temperature inside the automobile and activated the TEG as needed. Only when the engine turned off the system came into operation. Even when the engine was shut off, the deployed system successfully kept the temperature in the car cabin[27].

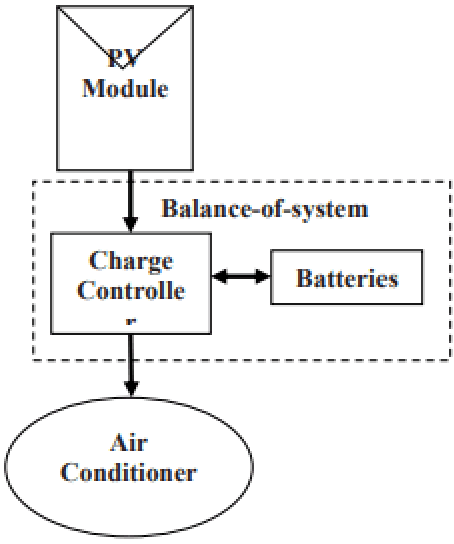

Figure 21: The block diagram of the solar air conditioning system.

Yogesh et al. (2020) developed a car air conditioning system based on the thermoelectric effect to overcome the problem of harmful emissions of fuel and refrigerants. The Peltier effect was the basis for the system's operation; when DC passed through thermoelectric modules, a temperature difference through the ceramic substrates resulted in heating one side of the module and cooling the other, which served as a source to cool the hot car interior. A Maruti Suzuki Zen car was used to perform the testing and measurements. The used Peltier thermometric cooler module was 12V and 5A, and its dimensions were (40*40*3.5 mm) as shown in Figure 22. It concluded that the cooling system was practical based on an investigation of the sizing and design of the thermoelectric air cooling for the vehicle. Also, the readings taken during the test testified that the thermoelectric cooling for the vehicle decreased the ambient temperature 7 ^{O}C[28].

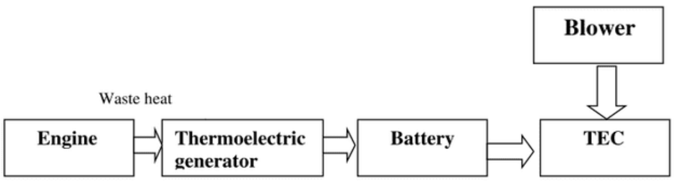

Figure 22: The block diagram of the proposed system.

Rifky and Yogi S. Gaos (2020) combined TEC and PV to cool the vehicle cabin and achieved heat absorption in the city cabin, which produced a temperature of 25 ^{O}C. The authors made a vehicle cabin model shaped like a cooling room. Solar cells were positioned in the presence of sunlight all day. As the output of solar cells provides electrical energy, changes in thermal energy occur on its sides. The hot side emitted heat into the environment, while the cold side absorbed heat from the surroundings. Heatsinks linked to the thermoelectric cold side were used to improve the area of heat absorption. The solar cells in this study produced an average solar radiation energy of 375.03 W with an output power performance of 60.09 W and an efficiency of 16.03%. The results indicated that the cooling room's coefficient of performance (COP) was 1.259, and the lowest temperature achieved was 23.40 ^{o}C[29].

Rifky and Oktarina (2021) transformed solar energy into electrical energy, which was then utilized to cool the car's interior. The research involved three systems: the thermoelectric system, the solar cell system, and the cooling system itself. It wasn't done on actual cars. On top of the car's cabin, which was a cool space, are solar and thermoelectric cells that measure 1005 mm by 665 mm by 30 mm. A heat sink was employed to achieve as much heat absorption as possible on the upper side of the interior of the cooling room. The aluminium heat sink was dimensions 350 mm x 78 mm x 40 mm and featured ten fins. The thermoelectric cold side is connected to a heat sink, while the hot side is closed off to maintain temperature. Solar cells were exposed directly to the sun through all hours of the measurement (from dawn to evening). All of the walls and the floor are made of aluminium metal in the cold chamber, with Styrofoam insulation covering the outside layer. The findings indicated that the circumstances in the cooling room were as follows: the cold room's coefficient of performance (COP) was 0.042, and the lowest temperature that was attained was 25.60 ^{o}C[2].

Hafsa et al. investigated [PV-TEC] systems, which combine solar generators and thermoelectric cooling devices to increase system performance. The authors utilized the Peltier module to boost the PV output power after they researched the solar cell cooling system. The created system included an aluminium plate to make it easier for heat from the Peltier module to diffuse into the PV panel, a fin to remove extra heat from the hot Peltier module face and an Arduino microcontroller control unit to keep the PV panel at 25 ^{o}C. The fin alone wasn't sufficient, so they used two controlled ventilators. The Peltier module was made from Aluminium Oxide, and its dimensions were (40*40*3.8 mm) as shown in Figure 23. The CATIA V5 software was used to study the system components in 3D. The PV cells' temperature lowered, improving the system's efficiency and power output[30].

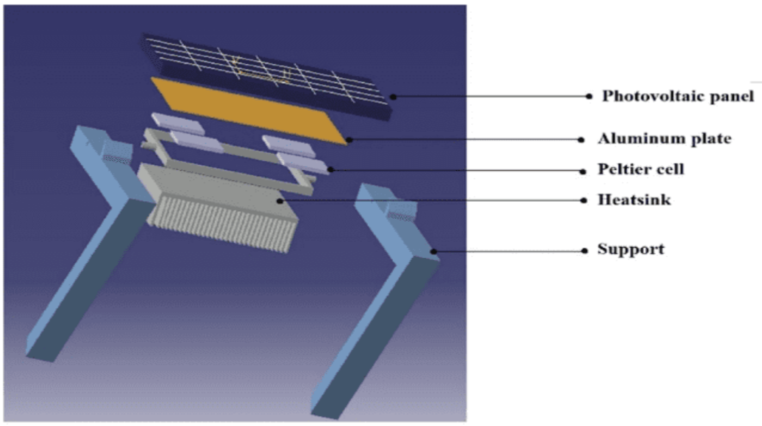

Figure 23: Cooling system coupling with solar system.

Srivastava et al. (2022) created a thermoelectric cooling/heating system powered by solar energy for cars parked in open areas. In the summer, the cabin's normal temperature rose to 32 ^{o}C when the automobile was left in the sun for four hours starting at 10:00 A.M. Similarly, when the car was parked in the sun from 3:00 PM to 8:00 PM during the winter, the average cabin temperature decreased to 16 ^{o}C. The proposed system resolved the sharp rise and fall of car cabin temperature in summer and winter without running the engine. Flexible solar panels CIGS (copper indium gallium selenide) placed on the vehicle roof with an area of 2.5 m^2. The thermoelectric module dimensions were (40 * 40 * 3.9 mm). 12V DC powered a fan for the hot side and cold side heat sink channels.

The hot side was fastened to the heat sink (fins) inside the channel to improve heat rejection, as shown in

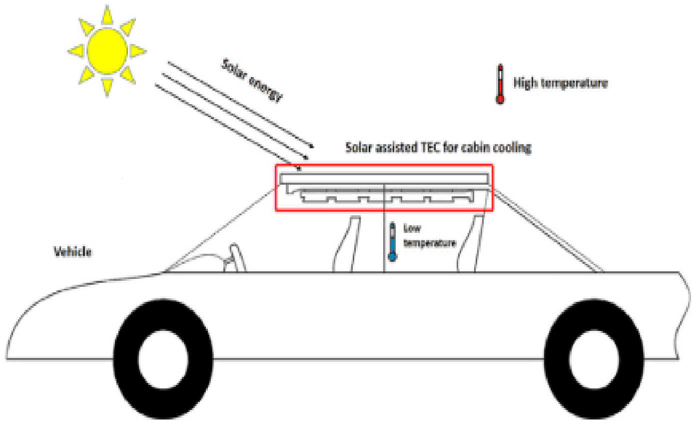

Figure 24. The average cabin space temperature decreased 17 ºC in the summer and increased 15 ºC in the winter, according to the numerical research results for the suggested system. This proved that thermoelectric technology and solar energy can be used to cool and heat a car's interior while parked[31].

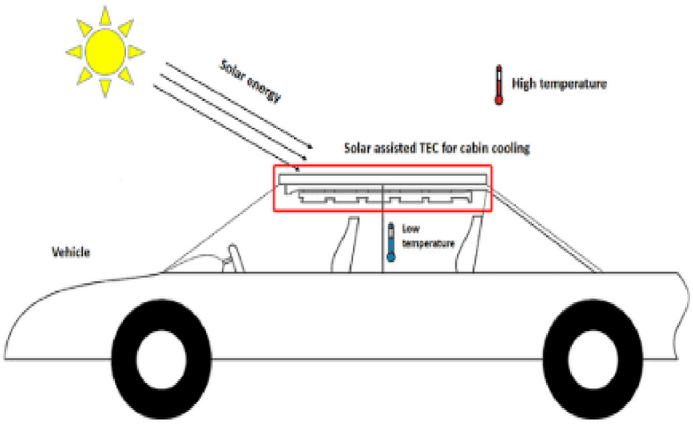

Figure 24: Car standing under the sun in summer with a thermoelectric cooling/heating system.

3. CONCLUSION

Better cooling and energy systems are required due to the daily increase in air temperature. As a result, the temperature inside the car cabin must be dropped. The traditional cooling system uses more fuel, which causes the level of greenhouse gases to increase. The greenhouse gases negatively impact the environment and human health. The necessity to power various techniques of reducing the temperature of a car's cabin led to the introduction of renewable energy sources like solar energy.

- Solar ventilation is environmentally friendly but does not significantly reduce the car cabin temperature. The maximum reduction in the cabin temperature was 15°C.
- Solar cooling or air conditioning uses refrigerants (CFC and HFC) that leak and slowly ascent into the atmosphere. When they reach the ozone layer, they interact with the ozone molecules and destroy it. However, it significantly decreases the automobile cabin's temperature. The maximum decrease in car cabin temperature was 30 °C.
- Solar thermoelectric cooling uses no toxic refrigerants and significantly reduces interior automobile temperature. It is also environmentally beneficial. As a result, using it to lower car cabin temperatures is considered the best option. The max decrease in cabin temperature was 17 ºC.

REFERENCES

[1] M. Stancila, C.-A. Ene, M. Ivanescu, I. Tabacu, and A.-C. Neacsu, "STUDIES ON THE USE OF THERMOELECTRIC ELEMENTS FOR IMPROVING THERMAL CONFORT IN AUTOMOBILE,"

vol. 24, no. 24, pp. 13–20, 2013.

[2] Rifky and O. Heriyani, "Car Cabin Cooling System Using Solar Energy," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1088, no. 1, p. 012055, 2021, doi: 10.1088/1757-899x/1088/1/012055.

[3] M. S. Raut, M. T. Heat, and P. Engg, "Thermoelectric Air Cooling For Cars," *Int. J. Eng. Sci. Technol.*, vol. 4, no. 05, pp. 2381–2395, 2012.

[4] P. Wargocki, "What we know and should know about ventilation Energy 2021," *REHVA J.*, no. 2, pp. 5–15, 2021.

[5] K. D. Huang, S. C. Tzeng, W. P. Ma, and M. F. Wu, "Intelligent solar-powered automobile-ventilation system," *Appl. Energy*, vol. 80, no. 2, pp. 141–154, 2005, doi: 10.1016/j.apenergy.2004.03.010.

[6] R. Saidur, H. H. Masjuki, and M. Hasanuzzaman, "Perfromance of an improved solar car ventilator," *Int. J. Mech. Mater. Eng.*, vol. 4, no. 1, pp. 24–34, 2009.

[7] Z. Hu, G. Tan, Z. Li, H. Xu, W. Huang, and Y. Ye, "Solar Powered Vehicle Parking Ventilation System Pre-Cooling Analysis," *SAE Tech. Pap.*, vol. 0367, no. 1, 2015, doi: 10.4271/2015-01-0367.

[8] C. V. Sudhir and J. M. Al Dhali, "Effect of solar ventilation on air conditioning system performance of the car parked under sun light," *ARPN J. Eng. Appl. Sci.*, vol. 10, no. 22, pp. 10618–10625, 2015.

[9] I. Mohammed, A. Aljubury, A. A. Farhan, and A. Mussa, "Experimental Study of Interior Temperature Distribution Inside Parked Automobile Cabin," *J. Eng.*, vol. 21, no. 3, 2015.

[10] S. Khatoon and M. H. Kim, "Human thermal comfort and heat removal efficiency for ventilation variants in passenger cars," *Energies*, vol. 10, no. 11, 2017, doi: 10.3390/en10111710.

[11] H. N. M. Shah *et al.*, "Develop and implementation of solar powered ventilation system," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 12, no. 3, pp. 1211–1221, 2018, doi: 10.11591/ijeecs.v12.i3.pp1211-1221.

[12] H. Al-Rawashdeh, A. O. Hasan, H. A. Al-Shakhanbeh, M. Al-Dhaifallah, M. R. Gomaa, and H. Rezk, "Investigation of the effect of solar ventilation on the cabin temperature of vehicles parked under the sun," *Sustain.*, vol. 13, no. 24, 2021, doi: 10.3390/su132413963.

[13] S. Vashisht and D. Rakshit, "Recent advances and sustainable solutions in automobile air conditioning systems," *J. Clean. Prod.*, vol. 329, p. 129754, 2021, doi: 10.1016/j.jclepro.2021.129754.

[14] M. Fahim and B. I. N. Ilias, "PRELIMINARY DESIGN OF AN AUTOMATIC COOLING SYSTEM USING SOLAR PHOTOVOLTAIC (PV) SYSTEM," no. 2007270988, 2010.

[15] Anuja.r.jadhav and mr.a.d.bhoi., "SOLAR POWERED AIR CONDITIONING SYSTEM FOR LMV.," *Int. J. Adv. Res.*, vol. 4, no. 6, pp. 1175–1181, 2016, doi: 10.21474/IJAR01.

[16] H. Pan *et al.*, "A portable renewable solar energy-powered cooling system based on wireless power transfer for a vehicle cabin," *Appl. Energy*, vol. 195, pp. 334–343, 2017, doi: 10.1016/j.apenergy.2017.03.069.

[17] L. Qi *et al.*, "A portable solar-powered air-cooling system based on phase-change materials for a vehicle cabin," *Energy Convers. Manag.*, vol. 150, pp. 148–158, 2017, doi: 10.1016/j.enconman.2017.07.067.

[18] K. Punitharani, R. Narendran, A. VM, and J. Mahesh. G, "Experimental Investigation of Solar Powered Air-Conditioning System in a Car," *J. Atmos. Pollut.*, vol. 5, no. 1, pp. 33–39, 2017, doi: 10.12691/jap-5-1-5.

[19] W. Pang, H. Yu, Y. Zhang, and H. Yan, "Solar photovoltaic based air cooling system for vehicles," *Renew. Energy*, vol. 130, pp. 25–31, 2019, doi: 10.1016/j.renene.2018.06.048.

[20] K. K. Chong *et al.*, "Standalone Solar Photovoltaic System and Its Application in Mist Cooling of

Vehicle," *2019 IEEE Conf. Sustain. Util. Dev. Eng. Technol. CSUDET 2019*, pp. 188–193, 2019, doi: 10.1109/CSUDET47057.2019.9214643.

[21] T. Zhang, Y. Feng, X. Wu, Y. Pan, Z. Zhang, and Y. Yuan, "A High-Efficiency, Portable, Solar-Powered Cooling System Based on a Foldable-Flower Mechanism and Wireless Power Transfer Technology for Vehicle Cabins," *Energy Technol.*, vol. 8, no. 6, pp. 1–14, 2020, doi: 10.1002/ente.202000028.

[22] M. de A. Carneiro and D. da F. Soares, "Solar photovoltaic assistance system study for a Brazilian light rail vehicle," *U.Porto J. Eng.*, vol. 6, no. 2, pp. 35–45, 2020, doi: 10.24840/2183-6493_006.002_0004.

[23] L. Wan *et al.*, "Brief introduction of an automobile radiant cooling air-conditioning system based on photovoltaic power generation," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 831, no. 1, 2021, doi: 10.1088/1755-1315/831/1/012035.

[24] Y. Hayakawa, D. Sato, and N. Yamada, "Measurement of the Convective Heat Transfer Coefficient and Temperature of Vehicle-Integrated Photovoltaic Modules," *Energies*, vol. 15, no. 13, 2022, doi: 10.3390/en15134818.

[25] R. Sharma *et al.*, "Peltier effect based solar powered air conditioning system," *CSSim 2009 - 1st Int. Conf. Comput. Intell. Model. Simul.*, pp. 288–292, 2009, doi: 10.1109/CSSim.2009.40.

[26] S. Ingole, M. B. Prof, P. Walke, B. I. T. Ballarpur, and D. Chandrapur, "Experimental Study of Solar Powered Heating & Cooling System using Thermo-Electric Module," vol. 5, no. 06, pp. 126–129, 2017.

[27] B. Fathima, A. R. Raj, C. Mohan, J. E. Rodriguez, and S. J. John, "Solar Powered Automatic Cabin Cooling System," no. May, pp. 252–269, 2019.

[28] G. O. Nawle Yogesh, Shelar Omkar, Gawli Gorakhnath, "Air Conditioning System in Car using Thermoelectric Effect," *Int. J. Eng. Res.*, vol. V9, no. 06, pp. 374–377, 2020, doi: 10.17577/ijertv9is060307.

[29] G. Y. S. Rifky, "Development of Solar-Powered City Car Cabin Cooling Models Using Photovoltaics (PV) and Thermoelectric (TEC)," vol. 10, no. 1, pp. 34–42, 2020.

[30] H. Kandry *et al.*, "Optimized photovoltaic panels power using cooling system based thermoelectric materials," *Mater. Today Proc.*, vol. 66, pp. 479–483, 2022, doi: 10.1016/j.matpr.2022.07.381.

[31] R. S. Srivastava, A. Kumar, H. Thakur, and R. Vaish, "Solar assisted thermoelectric cooling/heating system for vehicle cabin during parking: A numerical study," *Renew. Energy*, vol. 181, pp. 384–403, 2022, doi: 10.1016/j.renene.2021.09.063.