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THEORETICAL SUBSTANTIATION OF INCREASING THE RANGE OF AN ELECTRIC CAR DUE TO THE USE OF AN ADDITIONAL HEATING SYSTEM FOR THE CAR INTERIOR

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Abstract: This article systematizes and compares the main approaches to increasing the range of an electric vehicle: innovations in batteries, optimization of energy management, energy recovery, aerodynamics, weight reduction, infrastructure development and software and algorithmic solutions. A comparative table of the effectiveness of these methods and a diagram of their interrelations are presented. It is noted that the combined application of measures (for example, improved batteries + effective thermal management + recuperation + "eco-guide") can provide a significant increase in mileage (conditionally tens of percent in total). A modeling plan is proposed to assess the combined effect of the methods (scenarios of changes in the parameters of the car, climatic conditions and the profile of the trip - range and energy consumption). The work is supported by the analysis of modern research and official sources.

Keywords: Range, Energy Management, Recuperation, Efficient Thermal Management, Liquid Fuel Heaters, Heat Pump

Introduction

Electric vehicles (EVs) are one of the main means of "green" mobility, but their mileage on a single charge is still significantly inferior to the range of cars with internal combustion engines. Limited range causes "range anxiety" - drivers' anxiety about the need to recharge. From an environmental and political point of view (the goals set to reduce CO_2 and abandon hydrocarbons), the extension of the distance of electric transport is critical. Mileage expansion can be achieved in two main ways: to increase the capacity of energy storage (battery) or to reduce specific energy consumption (optimization of car systems and external factors). Modern studies distinguish several parallel directions (Table 1). These include the development of new battery technologies (lithium-ion with improved density, solid-state, etc.), the improvement of energy management systems (intelligent battery balancing and thermoregulation, efficient compressors/pumps), the use of regenerative braking, the optimization of aerodynamics and vehicle weight reduction, the development of charging infrastructure (fast/wireless charging) and algorithmic solutions (eco-driving modes, route optimization, network V2X interaction). A review of the literature shows that different methods complement each other and require a comprehensive analysis. The purpose of this work is to substantiate the efficiency of using liquid-fuel heaters in the cold season, to show the relationships and to provide approximate numerical estimates of the effect on the range. A simulation plan is also proposed to assess the combined effects of multiple measures.

Research Methods and the Received Results

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A systematic review of scientific papers and technical reports (2017–2025) in these areas was carried out. To expand the review, the following keywords were used: "EV range extension", "energy management EV", "regenerative braking efficiency", "aerodynamics electric vehicle", "lightweight EV", "charging infrastructure", "eco-driving EV". The main sources were peer-reviewed journals and official releases (see literature).

Next, a comparative analysis of methods is formed. A summary table has been compiled that combines the following criteria: effect on range (in % or km, if available), complexity of implementation, cost, technology maturity, limitations/risks. The values are indicative, based on published estimates or expert opinions (ranges or assumptions are indicated in the table, if necessary).

Finally, a modeling plan has been developed to evaluate combinations of methods. It is proposed to use software simulation (e.g. on the Matlab/Simulink platform or specialized packages for cars) or bench tests. Input parameters will include: basic EM model (mass, aerodynamic CX, battery capacity and characteristics, drive efficiency), traffic profile (city/highway, speed), temperature conditions (important for thermal management).

The diagram below shows the relationship between the methods and their impact on the overall energy consumption of the vehicle:

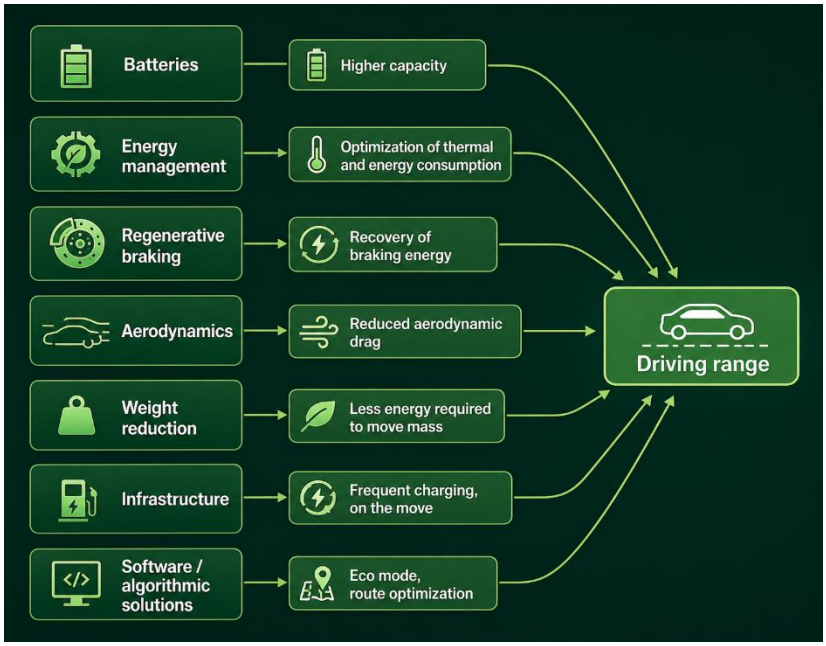


Fig-1. The relationship between the methods and their impact on the overall energy consumption of the vehicle.

Table 1

Comparison of Key Methods for Extending the Range of an Electric Vehicle (Estimated Values)

Method	Range Effect	Complexity of implementation	Cost	Maturity	Limitations/Risks
Batteries	+20–50% (Capacity Increase) *	High (new materials, build)	High	Medium (new technologies are being developed)	Safety (thermal stability), deficiency of rare elements.
Energy Management	+5–20% (System Optimization)	Medium (ECU, software, HVAC	Low-medium	High (current EV kits)	It is effective in specific modes and

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Method	Range Effect	Complexity of implementation	Cost	Maturity	Limitations/Risks
consumption		systems)			requires adaptability.
Energy recovery	+5–15% (depends on braking cycle)	Low (initially in EV)	Low	High (standard in EV)	Possible only when slowing down; Efficiency <100%, limited by inverters.
Aerodynamics	+5–8% for every –10% Cd	Medium (body redesign)	Medium	High (already used in CFDs)	Conflict with design/interior, efficiency is higher on the track.
Weight reduction	+5–10% for every –10% of weight*	High (lightweight materials)	High	Medium (applied selectively)	Expensive materials, structural strength, safety.
Infrastructure	Virtually unlimited (fast charges, induction)	Very high (network of charging stations)	Very high	Low/medium (fast stations available, roads are pilots)	Construction cost, standardization, network load.
Algorithmic solutions	+5–30% (Eco Mode, Optimization)	Low (Software)	Low	High (software packages)	Depends on the driver's behavior, data mileage limits.
Use of a liquid-fuel heater	With a 30% reduction in energy consumption for heating, the range can increase by 10-25%, depending on the operating conditions.	Low (installation in workshop conditions)	Low	Medium	Efficiency <100%, limited only in the cold season.

(*) – assessments based on the declared improvements; The actual effect can vary greatly depending on the conditions.

As you can see, each method has its own contribution, but the greatest potential is provided by integrated solutions. For example, the combination of increased battery capacity, efficient thermal management (heat pump + recuperation), improved aerodynamics and "soft" driving can give a synergistic increase in range of tens of percent compared to the original model. However, every measure requires resources: new batteries and lightweight materials are expensive, smart aerodynamics and improved systems are difficult to develop and test, infrastructure is capricious to deploy.

Energy balance of an electric car

The energy balance of an electric car can be represented as the distribution of battery energy between the main consumers:

- traction motor;
- heating and air conditioning system;

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- auxiliary systems.

The total power consumption is determined by the expression:

$$E_{total}=E_{drive}+E_{heating}+E_{aux} \quad (1)$$

where:
- Edrive is the energy spent on movement;
- Eheating — energy for heating;
- Eaux is the energy of auxiliary systems.

The range of an electric car is defined as:

$$L=E_{battery}/E_{per\ km} \quad (2)$$

where: Eper km is the specific energy consumption.

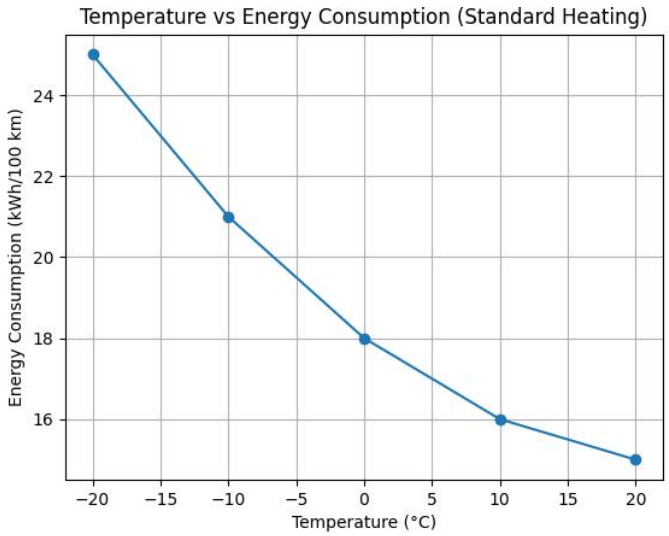
Influence of ambient temperature

The ambient temperature has a significant impact on the efficiency of an electric vehicle. When the temperature drops:
- the internal resistance of the battery increases;
- battery capacity decreases;
- the need for heating is increasing.

Energy costs for heating can be estimated using the formula:

$$Q=k \cdot A \cdot (Tin-T_{out}) \quad (3)$$

where:
- k is the coefficient of heat transfer;
- A is the heat exchange area;
- Tin , Tout - temperatures inside and outside the cabin.



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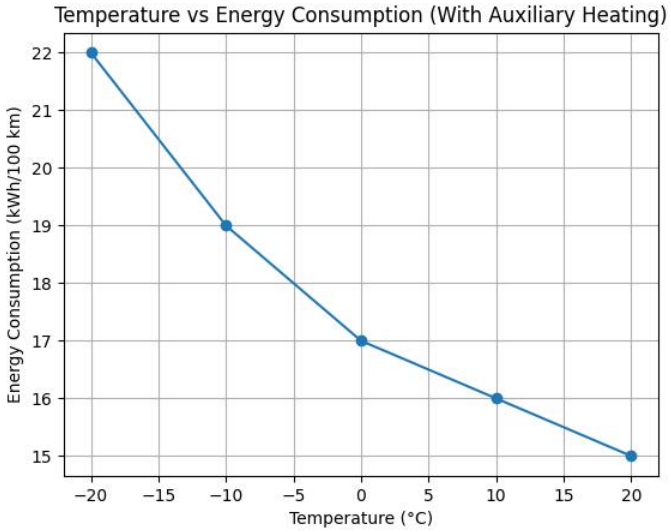


Fig-2. Influence of temperature on the energy consumption of an electric car.

Traditional heating systems

Most electric vehicles use the following types of heating systems:

- Resistive heaters
- Heat pumps

Resistive heaters are characterized by simplicity, but have low efficiency, since all the energy is taken from the battery.

Heat pumps are more efficient, but their efficiency decreases at low temperatures.

Additional heating systems

Additional heating systems can use:

- liquid fuel (diesel, gasoline);
- gas;
- heat recovery.

The main advantage of such systems is the reduction of the load on the battery.

Energy efficiency can be expressed as:

$$\eta = Q_{useful} / E_{battery} \quad (4)$$

When an auxiliary heater is used, the $E_{battery}$ value decreases, resulting in a longer range.

Theoretical evaluation of the range increase

Let's consider two modes:

1. No additional heating
2. With additional heating

In the first case:

$$E_{total1} = E_{drive} + E_{heating} \quad (5)$$

In the second case:

$$E_{total2} = E_{drive} + E'_{heating} \quad (6)$$

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where E′heating<Eheating
Relative range increase:

$$\Delta L = L2 - L1 / L1 \cdot 100 \quad (7)$$

With a 30% reduction in energy consumption for heating, the range can increase by 10-25%, depending on the operating conditions.

Conclusion

In the course of calculations, the following was established:
- Temperature has a significant impact on the energy consumption of an electric vehicle;
- the heating system is one of the main factors of energy losses;
- the use of additional heating reduces the load on the battery;
- The range is extended by up to 30% in cold conditions.

References:

1. Neubauer, J., Wood, E.“ Thru-life impacts of driver aggression, climate, cabin thermal management, and battery thermal management on battery electric vehicle utility” Journal of Power Sources, 2014
2. Tillahodjaev R.R.; Mirzayev A.A "Calculation of an electric motor for a SPARK car" -"- Conference: International Scientific and Practical Conference "Automobile and Tractor Engineering" At: May 2019 Minsk
3. Yuksel, T., Michalek, J. J.“ Effects of regional temperature on electric vehicle efficiency, range, and emissions” Environmental Science & Technology, 2015
4. Tillahodjaev R.R.; Jurabayev A.Z "Calculation of the electric motor for a production car with internal combustion engine" -"- . Republican scientific and technical conference "Problems and prospects of innovative equipment and technology". So, Tashkent state University, 5-6 April 2019
5. Wang, Q., et al.“ Thermal management of electric vehicle battery systems” Energy, 2014
6. Tillahodjaev R.R.; Jurabayev A.Z “Analysis of batteries for electric vehicles and their calculations” -"- International scientific and technical journal Innovation technical and technology vol.2, No.2. 2021.
7. Rugh, J., Farrington, R. “Vehicle Ancillary Load Reduction Project Close-Out Report” National Renewable Energy Laboratory (NREL), 2008
8. Jakhongir Mirzaabdullaev.; Rustam Tillahodjaev.; Oybek Daminov.; Rustamjon Mirzajonov. “Review And Analysis Of Batteries For Electric Vehicles In The Central Asian Climate” SCITEPRESS– Science and Technology Publications, with VAT number 509223192 proceedings of the scientific event I-CRAFT 2024 by SCITEPRESS, in response to the Client solicitation, hereinafter called “Event’. The event details can be seen at the website: https://icraft-conference.com/i-craft-2024-tashkent/
9. Eberle, U., von Helmolt, R.“ Sustainable transportation based on electric vehicle concepts: a brief overview” Energy & Environmental Science, 2010
10. Zhao, L., et al.“ Fuel-fired heater for electric vehicles: Performance and emission characteristics” Applied Thermal Engineering, 2018
11. Lajunen, A.“ Energy consumption and cost-benefit analysis of hybrid and electric city buses” Transportation Research Part C, 2014

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

12. Wu, X., Freese, D., Cabrera, A., Kitch, W.“ Electric vehicles’ energy consumption measurement and estimation” Transportation Research Record, 2015
13. AAA (American Automobile Association) “Electric Vehicle Range Testing in Extreme Temperatures”, 2019
14. IEA (International Energy Agency) "Global EV Outlook" (annual reports)
15. Jeffers, M. A., Chaney, L., Rugh, J.“ Climate control load reduction strategies for electric vehicles in cold weather” SAE Technical Paper, 2016
16. Kim, J., Lee, K., Cho, H.“ Performance analysis of heat pump system for electric vehicles at low temperature conditions” International Journal of Automotive Technology, 2017