CLIMATE CHANGE MITIGATION: HYPOTHESIS-FORMULATION AND ANALYSIS OF INTERVENTIONS

ILYA ANISIMOV[1], ANASTASIYA BURAKOVA[1], ELENA MAGARIL[2], ROMEN MAGARIL[3], DENIS CHAINIKOV[1], DEBORAH PANEPINTO[4], ELENA CRISTINA RADA[5] & MARIA CHIARA ZANETTI[4]
[1]Department of Motor Transport Operation, Tyumen Industrial University, Russian Federation
[2]Department of Environmental Economics, Ural Federal University, Russian Federation
[3]Department of Oil and Gas Processing Technology, Tyumen Industrial University, Russian Federation
[4]Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Italy
[5]Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy

ABSTRACT

Nowadays the world energy consumption continuously increases due to various human-related activities. Increasing energy efficiency and decarbonizing the economic development, especially with measures aimed at the most energy-intensive sectors (industry, buildings, and mobility) is therefore a way towards the "eco-sustainable" community. The energy efficiency improving has environmental implications as it results in a reduction of the atmosphere polluting emissions. For the GHG (and in particular for the carbon dioxide) it is necessary to study and to analyze the so-called "negative technologies" – technologies that allow a carbon dioxide concentrations reduction. Considering the strategies in order to limit the climate change and to improve the air quality, it is necessary to assess the impacts of both these phenomena and therefore to identify synergies (win – win) and avoiding solutions that improve one of the two phenomena and worsen the other one (win – lose). The aim of this work is to analyze the opportunities of the "negative technologies" application for the climate change mitigation and to formulate the hypothesis of mobility modification using methods for the fuel consumption reduction. The negative technologies were studied from a technological point of view analyzing the potential advantages and disadvantages and stressing the technical challenge. The new approach for reduction of environmental and climatic impacts of vehicle operation on the environment by changes in the albedo of a vehicle roof is suggested. The proposed method allows to reduce the fuel consumption and greenhouse gases emission while idle with the engine running. The cost-effective modification in fuel quality using the microdose of the developed surface-active additive enables to reduce the specific fuel consumption dramatically, and substantially improves the environmental characteristics of vehicles operation. The combination of the proposed methods provides the opportunity for significant reduction of the GNG and toxic substances emissions by motor transport.
Keywords: climate change mitigation, environmental impact assessment, mobility modification, fuel consumption reduction, vehicle operation, albedo, surface-active fuel additive.

1 INTRODUCTION

In the recent years there has been a continuous energy consumption increase due to various activities. Reducing and decarbonizing energy consumption, especially with actions aimed at the most energy-intensive sectors (industry, buildings, and mobility) is therefore a way to go in order to reach "eco-sustainable" community [1]–[4].

Greening urban areas can also make a difference. Cities are responsible for three-quarters of energy consumption and 80% of carbon emissions [5]–[7]. Retro-fitting buildings to make them more energy efficient and cutting the impact of transport emissions represent some of the strategies for doing this. The field of the energy efficiency improving has environmental implications as it results in a reduction of the atmosphere polluting emissions [8].

The relationship between climate change and air quality is very complex: the interactions in atmosphere between different pollutants, between pollutants and greenhouse gases (GHG), between pollutants and meteorological variables altered by climate change, as well as the

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interactions with terrestrial ecosystems and the chemical of the pollutants transformations into the atmosphere according to the climatic regime are the subject of the most current scientific debate. The physico-chemical mechanisms describing the reciprocal influence between climate change and air quality are not fully known, as well as the interactions and synergies between these different processes. Also, the modelling, which is used for the production of air quality future scenarios, is not able to represent them always adequately [9], [10].

Greenhouse gases are emitted by many economic activities. The main amount is due to power generation (about 26%), followed by industry generally (about 19%) and transportation (13%), deforestation and forest degradation (about 17%) [11].

Innovation policies will play a central role in making a mitigation strategy affordable but Research and Development (R&D) efforts, however intensive, cannot by themselves accomplish enough if the incentives to deploy new technologies are weak [11], [12]. While such an R&D-led approach clearly yields some results, OECD estimates suggest that these are not nearly enough. For the GHG (and in particular for the carbon dioxide) it is necessary to study and analyze the so-called "negative emission technologies" (technologies that allow a carbon dioxide concentrations reduction).

It is necessary to emphasize that, considering the strategies in order to limit the climate change and, at the same time, to improve the air quality, it is necessary to assess the impacts of both these phenomena and therefore seek to identify synergies (win–win) and avoiding solutions that improve one of the two phenomena and worsen the other one (win–lose).

2 THE NEGATIVE EMISSIONS TECHNOLOGIES: LIMITATIONS AND CHALLENGES

Since some carbon emissions cannot be avoided completely, carbon dioxide (CO_2) would have to be removed from air, resulting in "negative emissions" that compensate for the remaining emissions. Most of the climate stabilization scenarios of the Intergovernmental Panel on Climate Change assume the use of negative emissions technologies. Recent reports by Oxford University and the US National Academy of Sciences agree that negative emission technologies are not a substitute for substantial cuts in emissions, but they are expected to play an important role in climate stabilization by compensating for remaining emissions [13], [14].

Taking into account that, from the political point of view, these are new technologies, investors do not understand why mechanisms to support development and distribution have not emerged. Considering that these technologies can play a significant role in the field of the climate change mitigation, this state of affairs needs to modify quickly. For negative emissions technologies to mature successfully it is necessary that a credible market path for investors will be created.

Table 1 demonstrates the main limitations and technical challenge/environmental impacts of the promising negative emissions technologies. Fig. 1 shows the net estimate costs (expressed as €/tCO_2 removed) for the negative emissions technologies.

In this frame, it is interesting to report also the option of CO_2 recovery and liquefaction for industrial uses that can be performed when biomethane is produced by the treatment of biogas. The recovery can be obtained treating the CO_2-rich off-gas generated by the biogas upgrading. The role of CO_2 depends on case by case but potentially this option can avoid the production of CO_2 from non-biogenic pathways.

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Table 1: Summary of the limitations and environmental impact of the chosen negative technologies. *(Source: modified from [14].)*

Negative technologies	**Limitations**	**Technical challenges/Environmental Impacts**
Biochar Involves the production of enriched carbon material by the slow pyrolysis process (the biochar can be considered a negative emissions technology in account of his capacity to fixes, in a stable way, the carbon dioxide presents in the atmosphere as stable)	Availability of the input material. Competition of the use of the biomass with other uses	Study of the slow pyrolysis technology and analysis of consolidated plant working in full scale Study of mean residence time across feedstock streams taking into account different conditions of the soil Evaluation of the possible environmental impacts
Augmented Ocean Disposal ("Ocean liming"), uses lime in oceans to trap CO_2 in a stable form (in account of the effect on ocean acidification, due to the lime use, it is possible a rapid absorption of CO_2 from the atmosphere).	Shipping capacity availability. Conflict with international disposition.	More studies concerning the calcination processes that require to be improved. Necessity to transport infrastructure in order to integrate the different processes. Necessity to study the possible impacts for the marine environment.
BECCS (Bio-Energy with Carbon Capture and Storage) The combination of two mitigation options: biomass combustion to generate energy and Carbon Capture and Storage (CCS). The BECCS process achieve negative emissions by storing the carbon dioxide resulting from the combustion of plants, which have previously removed CO_2 from the air through photosynthesis.	Availability of the input material. Competition of the use of the biomass with other uses.	More studies concerning the possible Integration of the biomass combustion technology with CCS technology. Evaluation of the possible environment impacts.
Direct Air Capture Refers to industrial methods for removing carbon dioxide from the air by putting the air in contact with a chemical sorbent that captures the molecules of carbon dioxide (for example the "Artificial Trees" technology).	Main electricity demand. Development of a CCS network.	More studies in order to evaluate possible solutions for reduce energy input and water requirements. More studies in order to improve thermodynamic efficiency.
Soda/Lime process This process is similar to the Direct Air Capture and in particular to the artificial trees technologies but uses a chemical scrubbing method to enhance CO_2 capture.	Main electricity demand. Carbon transport and storage network development.	More studies in order to evaluate possible solutions for reduce energy input and water requirements. More studies in order to improve thermodynamic efficiency. Implementation of studies in order to reduce the size of the scrubbing towers.

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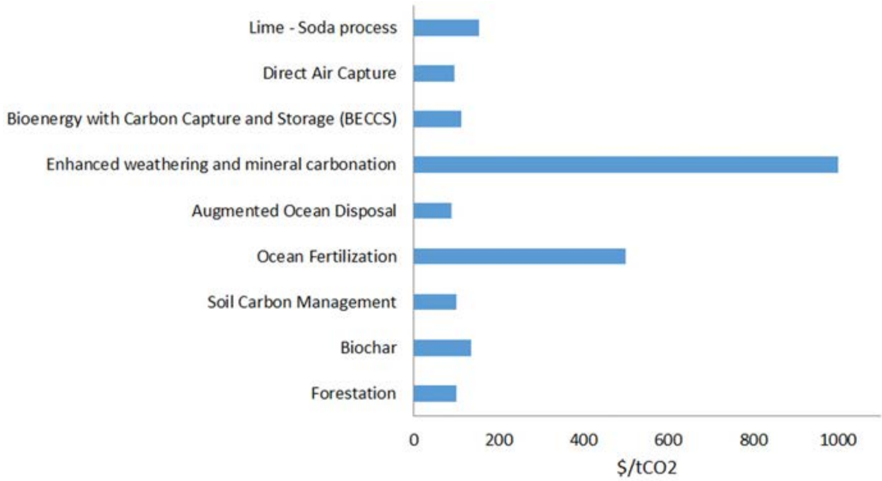

Figure 1: Cost indication of the different negative emissions technologies.

3 REDUCTION OF ENVIRONMENTAL AND CLIMATIC IMPACTS OF VEHICLE OPERATION

A reduction in greenhouse gases emission from cars can be achieved also by increasing their fuel efficiency [15]–[17]. Fuel quality, internal combustion engine power, operating conditions, and power required for the operation of auxiliary equipment, particularly the climate system, influence the fuel consumption.

3.1 Reduction of the negative environmental impact of cars equipped with a climate system

Modern passenger cars have auxiliary equipment to create comfortable conditions for its operation. It is climate system, which receives energy to work from the engine of a car. The restoration of this energy is carried out by increasing fuel consumption and its value depends on driving mode of a vehicle. When a car is idling, the greatest increase in fuel consumption is observed, since the internal combustion engine generates a minimum of effective power, and the outer surface of the body elements is not cooled by the air streams that occur during the movement. In Russia at the present time the share of cars idle time is 30–35% [18]–[21]. Therefore, the fuel consumption of a car with a climate system should be reduced during idling.

The temperature in a cabin of a vehicle depends on climatic parameters of the environment, which penetrate through barriers by a different type a heat input [20]. The correlation of microclimatic parameters in a cabin of a vehicle from the conditions of its operation was previously investigated and results are presented in a number of research works [17], [22]–[29].

The color of barriers is the determining factor of the heat amount that penetrates into cabin by thermal radiation. Quantitatively, it is estimated by the coefficient of light reflection or albedo of barriers. In accordance with the theoretical data, the values of this coefficient are in the range from 0 to 1. However, there aren’t absolutely white and black bodies in nature, so the maximum albedo corresponds to a white car and it is equal to 0.95, and the minimum value is black car (0.05). Determining factors of air temperature in a cabin of a passenger car

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are the effective temperature of the ambient air and the albedo of opaque elements (barriers). Its change causes fluctuations in microclimatic parameters in order to restore and maintain the constancy of which the climate system is used.

The energy consumption of the climate system is estimated by such parameters as its cooling capacity and power, which depend on the amount of excess heat and the volume of cooled air. Consequently, an increase in these parameters causes a rise in the proportion of power that is required for the operation of the climate system. The value of these input parameters depends on the ratio of the volume of cooled air and the power of the internal combustion engine. Authors proposed to evaluate it by the specific climatic power Θ. This is the proportion of the capacity of the internal combustion engine, which is consumed by the climate system with cooling of 1m^3 of air (eqn (1)):

$$\theta = \frac{N}{V_c}, \tag{1}$$

where N is the internal combustion engine power, kW/h; V_c is the volume of cooled air (volume of a cabin), m^3.

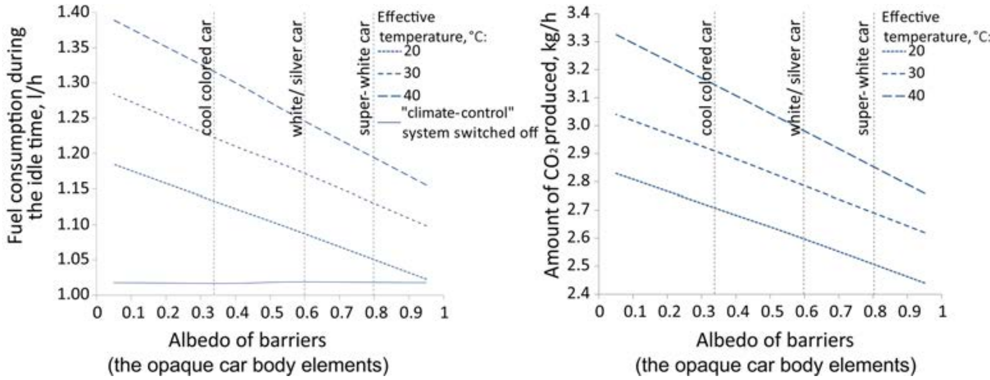
Thus, the effective temperature of ambient air, the albedo of barriers and the specific climatic power are factors that determine the fuel consumption of a passenger car with a climatic system, hence, they have to affect the amount of carbon dioxide emission. At the same time, the effective ambient temperature is uncontrolled factor, but the albedo of barriers is a controlled input indicator that can be quite simply changed by coloring the car in color, which has its maximum value.

Three brands of passenger cars, which had different values of the internal combustion engine power and the color of barriers, participated in the experiment. Initially measurements of natural and climatic factors of the ambient air and microclimatic parameters in a cabin of a vehicle were carried out by the Assmann psychrometer, Fuss anemometer, digital and mercury thermometers. The course of experiment consisted of stages of warming up the vehicle cabin on a site with uniform illumination, cooling it with the use of the climate system to constant microclimatic parameters and measuring fuel consumption by adapter BT-ECU CAN and software complex of Check-Engine, after which the mass of the formed CO_2 was calculated.

When the climate system is switched off, the color of the vehicle does not affect its fuel consumption. Color affects only the amount of heat entering the vehicle cabin, and, respectively, the power required for the operation of the auxiliary equipment under study. A white car is characterized by the minimum change in its fuel consumption when the climate system is switched on at the effective ambient air temperature of 20°C. Fig. 2(a) shows the change in the fuel consumption of cars during the idle time when the climate system is in operation.

A rise in the effective temperature of ambient air and a reduction in the albedo of barriers in the transition from white to black color cause a rise in the power required for the operation of the climate system, hence, the increase in fuel consumption and carbon dioxide emissions. Fig. 2(b) demonstrates the effect of the albedo (coefficient of light reflection) at various effective ambient air temperatures on the amount of carbon dioxide by a passenger car while idle during the operation of the climate system.

Thus, in order to reduce the fuel consumption and specific emissions of greenhouse gases, car barriers must be painted in colors characterized by a high albedo.



(a) (b)

Figure 2: Influence of the albedo of car barriers when the climate system is used during the idle time. (a) On fuel consumption; (b) On CO_2 emissions.

It should be noted that the temperature of air inside the car depends on the internal composition of barriers. Fig. 3 shows the diagram of the internal arrangement of the barriers (opaque body elements).

Sequence of layers inside the roof structure: steel, noise and vibration insulating film, air, plastic. In the doors, there are additional layers of expanded polystyrene and air. Each of them is characterized by the coefficient of thermal conductivity which is the ability of a substance to conduct heat. Depending on this indicator, some of the heat will be absorbed by air interlayers and noise, vibration and thermal insulation.

The absence of additional layers inside the roof, which has an area of 45–52% of the total area of the barriers, reduces the amount of reflected heat and promotes a rise in temperature in the cabin. Table 2 presents the results of measurements of the area of car structural components.

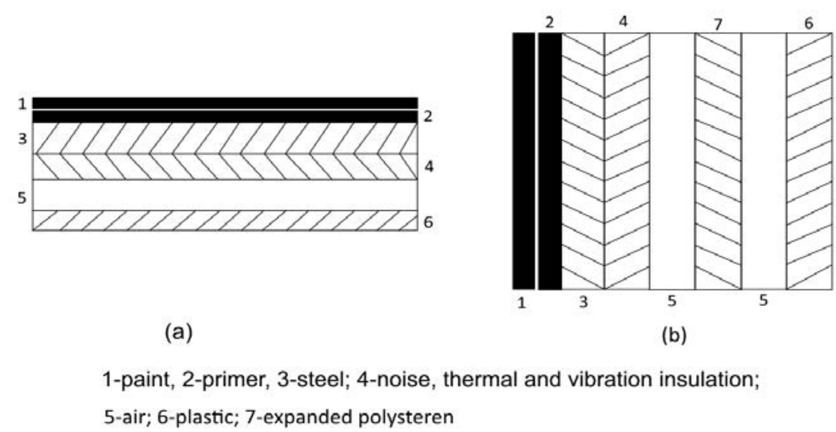


Figure 3: Diagram of the internal arrangement. (a) The roof; (b) Doors.

Table 2: Areas of structural elements of cars.

Opaque body element of car	Ford Focus	Mitsubishi Lancer	Toyota Corolla
Roof area, m^2	1.69	1.66	1.56
Door area, m^2	1.50	1.57	1.70
Area of opaque body elements, m^2	3.19	3.23	3.26

The greatest amount of heat enters the cabin through the roof, due to its internal features, which consists in the absence of two additional layers (expanded polystyrene and air) in comparison with the structural design of doors, a large area, and constant exposure to solar radiation (42% of the total duration of the day). Thus, the roof coloring in white causes a reduction in fuel consumption and carbon dioxide emissions by a passenger car with the climate system.

To prove the proposed assumption, calculation of the amount of heat entering the passenger car cabin through a roof painted in various colors was initially performed by the known equation for calculating heat transfer through a flat wall, taking into account both the coefficient of thermal conductivity and heat transfer and the albedo of the barriers. Table 3 presents the results of calculation.

Results of the theoretical calculation confirm the hypothesis put forward on the reduction of fuel consumption and carbon dioxide emissions when the roof of the car is painted white. This assumption was also confirmed by an experiment, the results of which are shown in the Fig. 4.

Reduction of fuel consumption decreases carbon dioxide emissions by 5.5–10.3% when the developed method is implemented. These values don't make contribution to the overall fuel consumption in the full cycle, but given an increase in the vehicle idle time and the significance of the impact of the inclusion of auxiliary equipment, in the particular the climate system, on the fuel consumption and the total size of the vehicle fleet, when there is a massive change in the car roof color to white, the overall fuel economy and reduced climate impact will be considerable. Painting the roof of the silver-coloured car in white resulted in a fuel consumption corresponding to its value of the white car.

Table 3: Amount of heat entering the car cabin, at an ambient temperature +30°C and a temperature inside the car +24°C (due to heat transfer and heat radiation).

Car	Roof area, m^2	Amount of heat entering the passenger car cabin, kW/day			
		white (ρ=0.95)	silver (ρ=0.57)	silver-gray (ρ=0.38)	black (ρ=0.05)
Ford Focus	1.69	0.51	3.41	6.04	7.39
Toyota Corolla	1.56	0.48	3.16	5.59	6.83
Mitsubishi Lancer	1.66	0.51	3.36	5.94	7.26

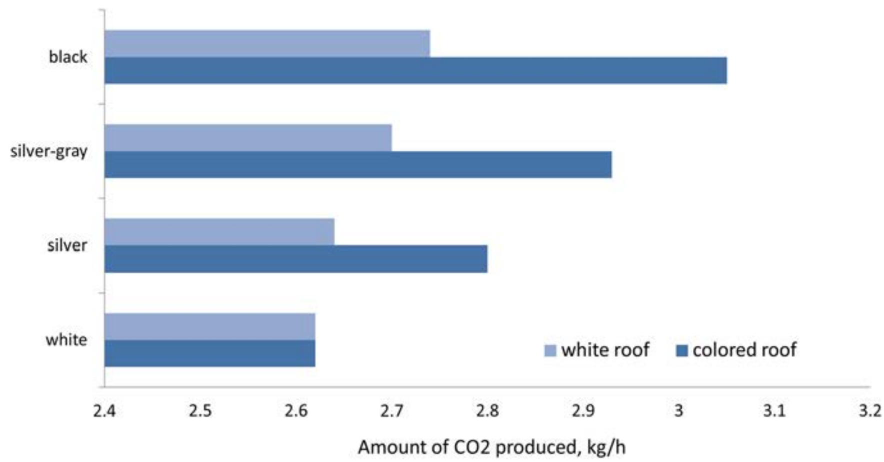


Figure 4: Reduction emissions of carbon dioxide by a passenger car with climate system at idle.

3.2 Reduction of carbon dioxide emissions in the vehicles operation using fuel additive

The quality of the motor fuels has a very significant effect on their specific consumption by vehicles [30], [31]. The most quickly implemented and inexpensive way to improve the fuel quality is the introduction of fuel additives that improve some properties or have a complex positive effect. A multifunctional additive for fuels, which is both a surfactant and a catalyst for carbon gasification has been developed [32]–[35]. Application of the additive improves the mixture formation in the engine, due to the formation of smaller fuel droplets. Elimination of carbon deposits with an additive improves the heat transfer through the engine walls [36]–[38]. This complex action significantly improves the combustion process in the engine, which increases fuel economy. Fig. 5 demonstrates a decrease in the specific consumption of gasoline by cars after application of the additive by up to 10–12%. Reduced specific fuel consumption leads to a corresponding reduction in carbon dioxide emissions, which is very significant, given the scale of consumption of motor fuels. It should be noted that eliminating carbon deposits in the engine leads to a reduction in the requirements for the octane number of gasoline by 7–12 points.

The obtained results can be explained as follows. In the normal burning of gasoline, without detonation, shockwaves are generated in the engine, creating acoustic oscillations with a maximum amplitude at 5000–6000 Hz to 35–45 dB [39]. These oscillations can be interpreted as the result of a micro-detonation caused by the same reasons as macro detonation. Such a micro-detonation, like the usual detonation, reduces the efficiency of the engine. The complex effect of a multifunctional additive, reducing micro-detonation, increases the proportion of the energy efficiently expended during the combustion of fuel.

The use of an additive significantly reduces emissions of toxic substances during the operation of cars (NO_x, CO, C_mH_n, benzo(α)pyrene, PM) [32]–[35].

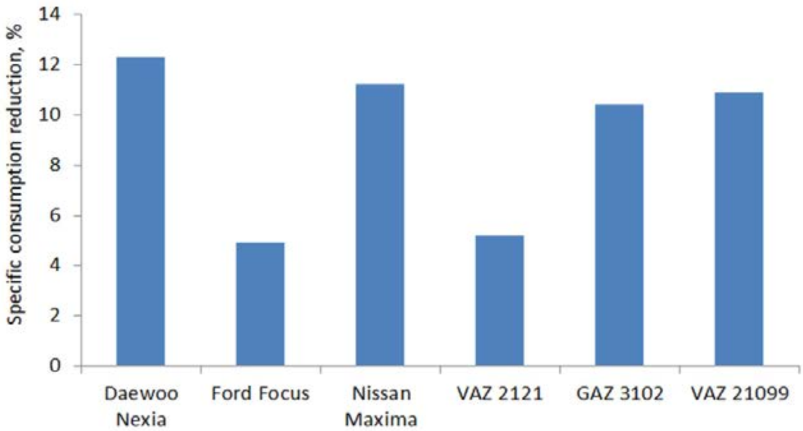


Figure 5: Reduction in specific fuel consumption after application of additive.

4 CONCLUSIONS

The advantages and disadvantages of the most promising negative emissions technologies are demonstrated. These technologies are expected to contribute significantly to climate stabilization. Anyway, the current state of the art demonstrates that the most problem and so the open research field is the amount of energy necessary in order to apply these technologies. An increase in the effective temperature of the ambient air and a decrease in the albedo of barriers when colored in dark colors cause a rise in fuel consumption and emission of carbon dioxide by a passenger car with the climate system.

It has been determined that the greatest amount of heat enters the cabin through the roof, due to its internal features, which consists in the absence of two additional layers (expanded polystyrene and air) in comparison with the structural design of doors, a large area, and constant exposure to solar radiation 42% of the total duration of the day. A method has been proposed, which allows to reduce fuel consumption and carbon dioxide emissions by 5.5–10.3% at idle, through painting the roof of the car in white.

Improving the quality of fuels in vehicles operation using a multifunctional additive significantly increases fuel efficiency and improves the environmental and performance characteristics of vehicles.

The use of the proposed approaches presents the possibility of a significant mitigation of climate impacts during the operation of automobiles and, in general, an increase in the environmental safety of motor vehicles.

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