Increasing fuel efficiency of passenger cars with the “climate-control” system as a method of improving the ecological safety of the urban infrastructure

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Abstract. Motor vehicle should provide safety and a high ecological standard of living for the population. One of the methods to improve the ecological friendliness of motor vehicles in particular passenger cars (cars), which are considered in this article, is the growth of their fuel economy. It is established that fuel consumption and the amount of specific emissions of harmful substances with exhaust gases of cars when using the “climate control” system depend on the effective ambient temperature, the color of the opaque car body elements, the power of the car engine and the interior volume. However, the simplest controlled factor is the color of the opaque car body elements, which is characterized by the coefficient of light reflection. In the course of experimental studies, we established the dependences of a change in fuel consumption and a share of reducing emissions of harmful substances with exhaust gases of passenger cars with the “climate control” system on the coefficient of light reflection. A method has been developed to reduce fuel consumption and the amount of specific emissions of harmful substances with the exhaust gases of passenger cars when using the “climate control” system, which involves painting the vehicle roof white and allows reducing fuel consumption by 5.5-10.3% and the amount of specific emissions of harmful substances by 0.37-1.13% (CO) and 0.47-1.08% (CH).

1. Introduction

Motor vehicles are an integral part of urban infrastructure, which should meet the requirements of safety and ecological friendliness of vital activity. The modern concept of its improvement is the direction of management decisions to increase the ecological responsibility through the introduction of new technologies [1,2,3,4]. According to the Transport Strategy of the Russian Federation until 2030, the ecological nature of the transport system plays an important role in the socio-economic development of the country, so reducing the harmful impact of transport on the environment is one of its main tasks [5]. GOST R 52033-2003 “Cars with gasoline engines. Emissions of pollutants with exhaust gases. Norms and methods of control in assessing the technical condition (Amend. No. 1 of 01.07.2012)” indicates values of the content of carbon monoxide and hydrocarbons in exhaust gases.

In the European Union, there is a program that reduces fuel consumption and the negative impact of vehicles on the environment through the formation of behavioral rules of the driver. However, motor vehicles operation specifics in the Russian Federation necessitate the adaptation of these rules to the existing conditions [6,7,8,9,10,11,12]. It is low density of the street and road network, rapid growth in the number of vehicles, separation of pedestrian and traffic flows at intersections. This reduces the throughput and increases the average idle time of vehicles. As a result of the analysis of previous studies, it has been established that for the last 30 years the idle time of cars with a running engine has increased by 18% and in modern conditions is 30 ... 35% [13,14,15,16].

The Russian Federation territory location also influences the operation of motor vehicles. For example, the number of car-days in the operation of cars at temperatures above +20 °C is more than 51%. Deviation of operating conditions from standard affects the motor vehicles by changing the thermal state of the elements of their design. In particular, in the warm period of the year, there is an increased temperature of the ambient air (above +20 °C) and an increase in the amount of solar radiation...
entering the Earth's surface. This causes an increase in the amount of heat entering the interior of the car, hence increasing the air temperature inside the vehicle. According to the norms of POT RM-008-99 “Inter-industry rules for labor protection” in the operation of industrial vehicles, the air temperature at the driver's workplace during the warm season should be 20-25°C or no more than 3°C above the average outside air temperature at 13.00 of the hottest month, but not more than 28°C. To create the required microclimate in the car, “climate control” systems are applied, which are the auxiliary equipment of the car. The inclusion of this in the work leads to an increase in the proportion of the car engine power spent on the work of the auxiliary equipment, which causes an increase in the consumption of fuel by the vehicle. The greatest impact is observed during the idle time of the car with the running engine; it is caused by the absence of streams of air cooling the interior during movement, and the minimum value of the effective capacity of the car engine.

The increase in fuel consumption of cars with the use of “climate control” during the idle time with the engine running increases the amount of exhaust gases [19,20,21,22]. Their composition is 95 ... 98% products of complete combustion, unused oxygen and nitrogen of the air, and 2 ... 5% - several hundred components that determine the degree of a harmful impact of the vehicle on the environment. However, in the products of complete combustion, there are chemical compounds that have a negative effect on the ecological state of the atmosphere, for example, carbon dioxide, which contributes to the development of the greenhouse effect. Reducing the concentration of this compound in the exhaust gas can be achieved by reducing the fuel consumption of cars.

Thus, the purpose of this study is to improve the fuel economy and environmental friendliness of passenger cars when using the “climate control” system during idle time with the engine running.

2. Methodology
The ecological nature of the transport system can be characterized as the ability of cars to carry out transport work or transportation of passengers with the minimum possible emissions of harmful substances in strictly defined conditions. Vedenyapin G.V., Govorushchenko N.Ya., Gutarevich Yu.F., Evtin P.V., Gelagin O.I., Zvono V.A., Magaril E.R., Reznik L.G. studied the problems of reducing the toxicity of exhaust gases and increasing fuel economy. Fuel consumption and the content of harmful substances in the exhaust gases of cars depend on many factors, in particular, on incorporating the auxiliary equipment and operating conditions.

An increase in the ambient air temperature leads to an increase in the number of heat gain to the car interior, therefore, the microclimate inside the vehicle changes [23]. Assessment of the impact of operating conditions on the microclimate in the vehicles was carried out by Palutin Yu.L., Kormin A.M., Semikin S.N., Shelyakin A.S. and others [24]. The given works proposed a set of natural and climatic factors of the conditions of vehicle operation to evaluate the effective temperature of the ambient air with the help of a complex index, the numerical value of which corresponds to the true temperature of the still and saturated air. However, the effective temperature of the ambient air is the determining factor only when heat is supplied to the car interior by heat transfer.

When assessing the heat balance of the vehicle interior, it should be taken into account that heat gain from external sources is realized not only by heat transfer, but also by thermal radiation. The amount of heat entering the passenger car interior through the opaque car body elements with the help of thermal radiation depends on the reflectivity of the paintwork. The color characterizes the reflectivity of the opaque body elements. For example, an absolutely white body has the coefficient of light reflection equal to 1, and absolutely black (soot) -0. However, it is impossible to achieve absolutely white or black colors when painting, therefore, as a rule, cars with a white color of the opaque body elements have the coefficient of light reflection equal to 0.95, and with a black color - 0.05. Thus, the amount of heat entering the interior of the car depends on the effective ambient temperature and the coefficient of light reflection of the opaque body elements and influences the microclimate inside the vehicle. An increase in the amount of heat input causes an increase in the temperature of the air inside the car; in order to reduce and maintain it, within the limits corresponding to comfort conditions, a “climate control” system is used. The main characteristics of its operation affecting the fuel consumption of a car are the cooling
capacity and power consumption which depend not only on the amount of heat entering the interior of the car, but also on the interior volume. An increase in the interior volume, as well as the amount of incoming heat lead to an increase in the power consumption of the “climate control” system. It is established that the increase in the fuel consumption of a car when the “climate control” system is switched on is determined by an increase in the proportion of the power take-off of the automobile engine for the operation of this auxiliary equipment, which is characterized by the ratio of the cooled volume of the interior to the car engine power. This value is characterized by the specific climatic power parameter, which determines the part of the power of the automobile engine spent for cooling the unit volume of the car interior.

The fuel consumption of a passenger car when using the “climate control” system that affects the amount of specific emissions of harmful substances with exhaust gases depends on the effective ambient temperature, the coefficient of light reflection of the opaque car body elements and the specific climatic power parameter (the ratio of the passenger car interior volume to its engine power).

2.1. Equipment and devices used in studies
The experiment involved cars of three makes - Ford Focus, Toyota Corolla, and Mitsubishi Lancer. The light reflection coefficient was measured with a thermal imager. Illumination of the site was assessed using a luxmeter. The effective ambient temperature was taken into account by measuring the three factors: ambient air temperature and humidity - by the Assmann psychrometer and wind velocity - by the Fuss anemometer. The air temperature in the car was measured with mercury and digital thermometers. Fuel consumption was measured using a BT-ECU CAN adapter connected to the diagnostic socket of the car with an adapter and a computer program Check-Engine. To monitor the volume content of harmful substances in the exhaust gases of engines, a gas analyzer GIAM-29M-1 was used. The resulting volume concentrations were converted into specific CO and CH emissions.

2.2. Methodology of research
Passenger cars participating in the experiment consisted of a series of pairs of cars (black, silver, gray and white), one of which had an original roof color and the other was given a white color with the help of a vinyl film. Initially, the area of the opaque car body elements, in particular the roof, was determined.

Then, the vehicles were installed on a uniformly illuminated platform without shading. At the time of the maximum warm-up of the car with the “climate control” system switched off, the air temperature in the car was measured.

Then, the “climate control” system was switched on. When the constant thermal conditions were achieved, the air temperature in the car was measured and checked for compliance with its set value in the “climate control” system. The coefficient of light reflection for opaque body elements of different colors was determined with an illumination of 60000 lux (illumination at noon on a cloudless summer day) using a thermal imager.

Fuel consumption data of a passenger car equipped with a “climate control” system were measured during the idle time at a steady coolant temperature in the operating range of 80-100°C from the vehicle ECU using the BT-ECU CAN adapter and the Check-Engine computer program. Together with the measurement of fuel consumption, carbon dioxide and hydrocarbons in the exhaust gases were measured with a gas analyzer.

3. Results and discussion
Analyzing the state of the matter, it has been revealed that the factors that have the greatest effect on the fuel consumption of a passenger car using the “climate control” system are the effective ambient temperature, the power of the car engine, the interior volume and the color of the opaque car body elements (the light reflection coefficient). Of the presented factors only the power of the car engine, the interior volume and the color of the opaque car body elements are controllable, but the change in the first two factors is difficult. Thus, one of the ways to reduce fuel consumption of a car with the use of the “climate control” system is to impart a color that is characterized by the largest coefficient of light

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reflection (white color). A change in the increase in fuel consumption of a Ford Focus passenger car using the “climate control” system during the idle time with the engine running from the coefficient of light reflection of the opaque body elements is shown in Figure 1.

![Figure 1](image_url)  

**Figure 1.** A change in the increase in fuel consumption of a Ford Focus passenger car using the “climate control” system during the idle time with the engine running from the coefficient of light reflection of the opaque body elements.

An increase in the fuel consumption of a car with the use of the “climate control” system during the idle time with the engine running becomes greater with an increase in the effective ambient temperature and a change in the color of the opaque body elements from light to dark characterized by a smaller coefficient of light reflection. This causes an increase in specific emissions of harmful substances with exhaust gases into the atmosphere, which is shown in Figures 2 and 3.
Figure 2. Reduction in specific emissions of carbon monoxide with exhaust gases of a passenger car when using the “climate control” system during the idle time with the engine running from the coefficient of light reflection of the opaque body elements.

Figure 3. Reduction in specific emissions of hydrocarbons with exhaust gases of a passenger car when using the “climate control” system during the idle time with the engine running from the coefficient of light reflection of the opaque body elements.
An increase in the coefficient of light reflection leads to a decrease in specific emissions of carbon monoxide and hydrocarbons with exhaust gases. As a result of the analysis of the received data it is established that the roof of the car equipped with the “climate control” system should be white to reduce fuel consumption and the amount of specific emissions of harmful substances with the exhaust gases. In the course of experimental studies, results are obtained that attest to the feasibility of introducing the developed method. Experimental data on the effect of the white color of the roof on the change in fuel consumption and the amount of specific emissions of harmful substances with the exhaust gases are presented in Figures 4 and 5.

**Figure 4.** Change in the fuel consumption of a car equipped with the “climate control” system with the introduction of the developed method.

**Figure 5.** Decrease in specific emissions of carbon monoxide and hydrocarbons with exhaust gases of cars equipped with the “climate control” system.
Application of the developed method allowed reducing the fuel consumption of a passenger car using the “climate control” system by 5.5-10.3%. Making the roof of a silver car white led to the achievement of fuel consumption corresponding to that of a white car.

Reducing the fuel consumption of a car with the introduction of the developed method allowed reducing the amount of specific carbon monoxide emissions by 0.37-1.13% and hydrocarbons by 0.47-1.08% with the exhaust gases.

4. Conclusions
In the course of experimental studies, it has been established that when the color of the opaque body elements changes from light to dark (reducing the coefficient of light reflection), fuel consumption and concentration of carbon monoxide and hydrocarbons in the exhaust gases of passenger cars increase when using the “climate control” system.

The area of the opaque body elements and their internal arrangement are analyzed. Based on the results of the preliminary stage of the experiment, a method has been developed for reducing the fuel consumption of a passenger car using the “climate control” system. It is to give a white color to the roof of the vehicle.

According to the obtained results of the experiment, it is established that the application of the developed method allows reducing the fuel consumption of a car by 5.5-10.3% and the amount of specific carbon monoxide emissions by 0.37-1.13%, hydrocarbons by 0.47-1.08% with the exhaust gases.

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