Study of method for reducing fuel consumption and amount of specific emissions of harmful substances with exhaust gases of passenger cars when using “climate control” system

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Abstract. The article deals with the issue of improving fuel efficiency and the ecological nature of passenger cars, servicing the administrative and management personnel of the oil and gas complex. 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, the authors 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 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 0.8-2.3%.

1. Introduction
Currently, in the field of transport services for administrative and management personnel of the oil and gas industry, there is an increase in the number of vehicles. Limited reserves of natural energy sources cause a rise in prices for all types of fuel. This causes the need to improve fuel efficiency of vehicles in use [1, 2, 3, 4]. Reducing fuel consumption leads to increased environmental friendliness of vehicles. 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. 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.

Thus, cars servicing the administrative and management personnel of the oil and gas complex must achieve minimum fuel consumption and emissions of harmful substances with exhaust gases. [6-12].

Currently, there are some specific features of the passenger car operation in urban conditions: 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 - 30 ... 35% [13-16].

When identifying features of the passenger car operation in modern cities, one should also take into account the effect of high temperatures. In the Russian Federation, 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. [19-22]. 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 ecological nature and fuel efficiency of 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. Assessment of the impact of operating conditions on the microclimate in the vehicles was carried out by Palutin Yu.I., Kormin A.M., Semikin S.N., Shelyakin A.S. and others. 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, leads 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). However, the effective ambient temperature is an uncontrolled factor, and the coefficient of light reflection of the opaque car body elements is a controlled input indicator that can be quite simply changed by giving the car the color characterized by the maximum coefficient of light reflection. Thus, it is necessary to develop a method for reducing the increase in fuel consumption of a passenger car using the “climate control” system.

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 analyser 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, grey 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 60,000 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

Analysing 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 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 Fig. 1.

![Figure 1](image.jpg)

**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 elements.

An increase in the coefficient of light reflection leads to a decrease in specific emissions of carbon monoxide and hydrocarbons with exhaust gases. Thus, in order to reduce fuel consumption and specific emissions of harmful substances with exhaust gases, opaque body elements must be painted in colors characterized by a high coefficient of light reflection. However, the amount of heat entering the interior of the car is also affected by the internal arrangement of the opaque body elements. The diagram of the internal arrangement of the opaque body elements is shown in Fig. 4.
The sequence of layers inside the roof structure is: steel, noise and vibration insulating film, air, plastic. In the doors, there are additional layers of expanded polystyrene and air. Each of them is characterised 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 causes an increased amount of heat entering the interior through this opaque body element. When studying the peculiarities of heat gain inside the car, it is established that the area of this structural element of a passenger car is between 45 and 52%. The results of measurements of the area of vehicle structural components are presented in Table 1.

Table 1. Areas of structural elements of cars

|                     | Ford Focus | Mitsubishi Lancer | Toyota Corolla |
|---------------------|------------|-------------------|----------------|
| **Roof area, m²**   | 1.69       | 1.66              | 1.56           |
| **Door area, m²**   | 1.50       | 1.57              | 1.70           |
| **Area of opaque body elements, m²** | 3.19 | 3.23 | 3.26 |

The greatest amount of heat enters the interior through the roof, due to its internal features, which consists in the absence of two additional layers (foam polystyrene and air) in comparison with the structural design of doors, a large area, and a perpendicular location relative to solar radiation at the warmest time of day (from 10:00 to 16:00). Thus, a reduction in fuel consumption and specific emissions of harmful substances with exhaust gases of a passenger car using the “climate control” system can be achieved by painting the roof of a car white.

To prove the proposed assumption, calculation of the amount of heat entering the passenger car interior through a roof painted in various colors was initially performed. The results of the calculation are presented in Table 2.

Table 2. The amount of heat coming into the car interior, at an ambient temperature of +30°C and a temperature inside the car +24°C (due to heat transfer and heat radiation)

| Car               | Roof area, m² | Amount of heat entering the passenger car interior, 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          |
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, the results that attest to the feasibility of introducing the developed method are obtained. 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 5 and 6.

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.

![Figure 5](image1.png)

**Figure 5.** Change in the fuel consumption of a car equipped with the “climate control” system with the introduction of the developed method

![Figure 6](image2.png)

**Figure 6.** Decrease in specific emissions of carbon monoxide and hydrocarbons with exhaust gases of cars equipped with the “climate control” system
Thus, painting the roof of a vehicle white will reduce the fuel consumption of a car by 5.5-10.3% and the total amount of specific emissions of harmful substances with the exhaust gases - by 0.8-2.3%.

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. This made it possible to reveal that the greatest amount of heat enters the interior through the roof, due to its internal features, which consists in the absence of two additional layers (foam polystyrene and air) in comparison with the structural design of doors, a large area, and a perpendicular location relative to solar radiation at the warmest time of day (from 10:00 to 16:00). 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 total amount of specific emissions of harmful substances with the exhaust gases - by 0.8-2.3%.

References
[1] Anisimov I, Magaril E, Magaril R, Chikishev E, Chainikov D, Gavaev A, ErtmanS, Ertman Yu and Ivanov A 2016 Improving vehicle adaptability to the operating conditions of “smart” cities in the northern regions E3S Web of Conf. Rev. 6 02003
[2] Panuccio P, Amodeo L, D’agostino P, Lamari D and Scattarreggia T 2015 Urban Regeneration and smart city according to EU strategies: an urban distribution center in city logistics WIT Transactions on The Built Environment 146 313-324
[3] Monfaredzadeh T and Berardi U 2014 How can cities lead the way towards a sustainable, competitive and smart future? WIT Transactions on Ecology and the Environment 191 1063-1074
[4] Russo F, Rindone C and Panuccio P 2014 The process of smart city definition at an EU level WIT Transactions on Ecology and the Environment 191 979-989
[5] Government of the Russian Federation 2014 Transport Strategy of the Russian Federation until 2030 (Moscow: Government of the Russian Federation)
[6] Chikishev E, Chainikov D and Anisimov I 2017 Increasing the use of natural gas on motor transport by an efficient location of the NGV RS IOP Conf. Ser.: Earth Environ. Sci. Rev. 50 012004
[7] Chikishev E, Chikisheva A, Anisimov I and Chainikov D 2017 Natural gas use on minibuses, engaged in the carriage of passengers and baggage on the regular routes, as a measure for decrease I harmful environment effects IOP Conf. Ser.: Earth Environ. Sci. Rev. 50 012008
[8] Chainikov D, Chikishev E, Anisimov I and Gavaev A 2016 Influence temperature on the CO2 emitted with exhaust gases of gasoline vehicles IOP Conf. Ser.: Mater. Sci. Eng. Rev. 142 012109
[9] Chikishev E, Ivanov A, Anisimov I and Chainikov D 2016 Prospects of and problems in using natural gas for motor transport in russia IOP Conf. Ser.: Mater. Sci. Eng. Rev. 142 012110
[10] Ertman J, Ertman S, Anisimov I, Chainikov D and Chikishev Y 2015 Complex characteristic estimation of vehicle adaptability for low temperature operation conditions Research Journal of Pharmaceutical, Biological and Chemical Sciences Electronic Materials 6 1761-70
[11] Anisimov I, Ivanov A, Chekishev E, Chainikov D and Reznik L 2014 Assessment of gas cylinder vehicles adaptability for operation at low ambient temperature conditions WIT Transactions on Ecology and the Environment 190 685-695
[12] Ertman S, Ertman J and Zaharov D 2016 Raising of operating a motor vehicle effects on environment in winter Innovative Technologies in Engineering Rev. 142 12119
[13] Cloke J and Layfield R 1996 The environmental impacts of traffic management schemes WIT Transactions on The Built Environment 26 11
[14] Ntzeremes P, Kirytopoulos K and Tatsiopoulos I 2016 Management of infrastructure’s safety under the influence of normative provisions WIT Transactions on The Built Environment 164 51-59
[15] Langeland A 2015 Sustainable transport in cities: learning from best and worst practice? WIT Transactions on The Built Environment 146 93-103
[16] Langer D and Mattrish G Future trends and driving forces in transport and logistics WIT Transactions on the Built Environment 75 10
[17] Galderisi A 2014 Adapting cities for a changing climate: an integrated approach for sustainable urban development WIT Transactions on Ecology and the Environment 191 549-560
[18] Alisov B and Poltaraus B 1974 Climatology (Moscow: Publishing House of Moscow University)
[19] Jacyna M and Merkisz J 2015 Estimations in real urban traffic conditions as a determinant of shaping sustainable urban development WIT Transactions on The Built Environment 146 219-231
[20] Gong R and Waring P 1996 Investigation of emission behaviour in an urban driving cycle with a remote sensing system WIT Transactions on The Built Environment 26 10
[21] Tong H and Hung W 1999 Vehicular modal emission and fuel consumption factors in Hong Kong WIT Transactions on Ecology and the Environment 37 8
[22] Kazopoulo M, El-Fadel M and Kaysi I 2004 Emissions Standards Development for an I/M program WIT Transactions on Ecology and the Environment 74 10
[23] Bogoslovski V 1985 Air conditioning and refrigeration (Moscow: Stroiizdat)
[24] Ertman S, Ertman J and Zakharov D 2016 Raising of operating a motor vehicle effects on environment in winter Innovative Technologies in Engineering Rev. 142 12119