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ESTABLISHING THE REGULARITIES OF CORRELATION BETWEEN AMBIENT TEMPERATURE AND FUEL CONSUMPTION BY CITY DIESEL BUSES

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Motor transport is the main consumer of energy resources in most countries. Atmospheric conditions, along with the vehicle design, its technical condition, driver's skill, road, and transport conditions significantly affect fuel consumption. However, in mathematical modeling, they are often taken into account by average values which can affect the accuracy of the results.

The nature of the relationship between ambient temperature and fuel consumption by city diesel buses was established on the basis of experimental and analytical studies. According to the results of the analysis of experimental data, it was found that this relationship is described by polynomial regressions of the second order. The accuracy of the regression model was confirmed by Fisher's test for two city routes.

Analytical studies of the effect of air density, rolling resistance, transmission efficiency, and all three factors together on fuel consumption were performed using mathematical modeling using the Physical Emission Rate Estimator methodology. It was found that rolling resistance and transmission efficiency have the greatest impact on fuel consumption. In both cases, the difference between the highest and lowest estimated value was 2.5 %. However, in absolute units, the difference is greater by 0.2 l/100 km for rolling resistance.

The obtained results can be used in mathematical models of vehicle movement, in particular city buses, to take into account the dynamics of changes in fuel consumption depending on the ambient temperature. They will also be useful in mathematical models for determining harmful emissions to calculate fuel consumption at various ambient temperatures

Keywords: fuel consumption, ambient temperature, city diesel buses, experimental data

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1. Introduction

Motor transport is one of the most common types of passenger transport. For example, 92.3 % of ground passenger transportation in the European Union (EU) is carried out by road. Of this figure, 9.4 % are intercity and city buses and trolleybuses [1]. In countries with less powerful economies, these figures are much smaller. About 50 % of all passenger transportation can be carried out by motor transport [2]. Despite this difference, the transport sector is the largest consumer of energy resources in both cases. Analysis of energy consumption in developed economies showed that the transport industry (30.8 %) is predominant [3]. In particular, motor transport is the dominant transport type consuming 93.4% of all energy resources [4]. In countries with less developed economies, more than 75 % of petroleum products are consumed by the transport industry including 97 % by motor transport [2]. As can be seen from the statistics, rational use of energy resources, in particular in motor transport, is an extremely important issue. Establishing a relationship between fuel consumption and ambient temperature will ensure a more rational approach to the choice of rolling stock for urban passenger transportation. Such studies will create a basis for the analysis of the economic feasibility of replacing the motor rolling stock of bus fleets with electric buses. At the same time, assessing the impact of individual components on fuel consumption at various ambient temperatures will help companies choose the focus when choosing a strategy to reduce operational fuel consumption in the winter season.

2. Literature review and problem statement

Fuel consumption depends on many factors, including perfection of vehicle design, the technical condition of its units and systems, driver skills, operating conditions, and more. In turn, operating conditions are divided into storage, road, transport, atmospheric and climatic conditions [5, 6]. Atmospheric and climatic conditions are characterized by a combination of such basic parameters as ambient temperature, atmospheric pressure, humidity, wind speed, and direction. They also include the level of solar radiation, cloudiness, precipitation, and the presence of other atmospheric phenomena (ice, fog, thunderstorm, etc.) [7].

Atmospheric conditions are taken into account in many regulations and mathematical models related to the determination of fuel consumption. For example, the Physical Emission Rate Estimator (PERE) mathematical model [8] includes air density which depends on ambient temperature as initial data. This model is used by the US Environmental Protection Agency (EPA) to calculate fuel consumption in the Motor Vehicle Emissions Simulator (MOVES) software [9]. A percentage increase in fuel consumption depending on actual ambient temperature is taken into account in [10]. Besides, the percentage increase in fuel consumption to maintain comfortable temperature conditions in buses was taken into account. In addition, fuel density which directly depends on ambient temperature can be found in many equations of fuel consumption [11].

Fuel is mainly consumed by a motor vehicle (MV) to overcome thermodynamic and mechanical losses of the engine, transmission resistance, road resistance, in particular, rolling and aerodynamic resistance [12]. Fig. 1 shows the distribution of energy losses to set in motion a motor vehicle [13].

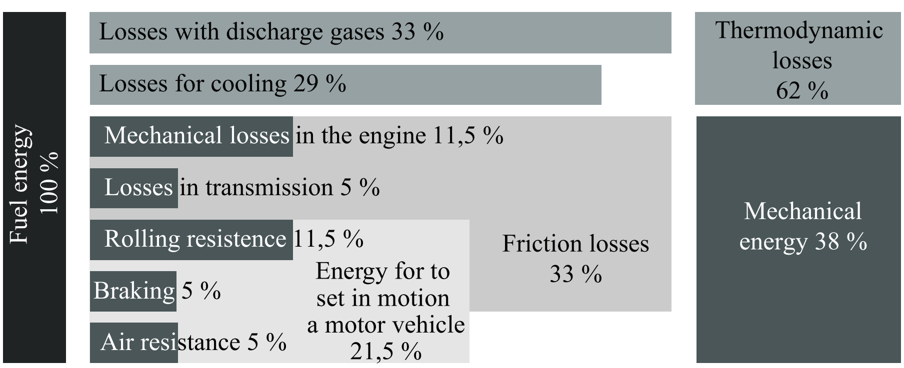

Fig. 1. Energy losses in an internal combustion engine

The combustion process is significantly affected by the nonoptimal thermal conditions of the engine. A decrease in ambient temperature makes it difficult to start a diesel engine because of increased kinematic viscosity and density of diesel fuel [14]. Diesel parameters such as viscosity, density, and surface tension affect the fineness of spraying, completeness of combustion, and fuel consumption. The smaller the value of these indicators, the better spraying, the smaller diameter of the droplets formed in fuel spraying, the better evaporation. However, this reduces the range of the jet because small droplets have a small reserve of kinetic energy. Uneven formation of the combustible mixture, incomplete combustion, and fuel consumption caused by underutilization of oxygen are observed [15]. As viscosity decreases, the lubricating properties of diesel fuel deteriorate. When diesel fuel viscosity increases, the depth of jet penetration increases because large-diameter droplets are formed and homogeneity of the combustible mixture improves. But at the same time, evaporation and completeness of fuel combustion worsen. This provokes fuel overconsumption, loss of power, increased smoke, and toxicity of exhaust gases [16]. At low temperatures, the engine overcooling as well [17]. As a result, the engine oil thickens, the crankshaft torque resistance grows leading to increased fuel consumption [18]. In addition, low ambient temperature leads to a decrease in temperature of the working fluid at the end of the compression stroke in the engine cylinder, and the period of delay of fuel self-ignition increases. This is accompanied by an increased rate of pressure rise and incomplete combustion [19].

The study results in [20] showed that cold weather increases heat losses in the exhaust manifold and metal pipes and leads to greater heat losses in exhaust gases. As a result, 10.5 % of the fuel is lost because of heat losses and heat transfer by metal to the exhaust system.

The increase in transmission resistance at low temperatures is brought about by the increase in transmission fluid viscosity. Viscosity is an extremely important indicator for hydrodynamic power transmissions because of its significant effect on friction in the flow channel. A lower viscosity means lower circular mass flow velocity losses in the flow channel of the hydrodynamic transmission [21]. According to the study results presented in [22], transmission efficiency has a linear dependence on the temperature of the transmission oil in idle and full load operating modes. In partial load modes, the transmission efficiency ranges from 1 % in the temperature range from −5 °C to +20 °C. At higher temperatures, it also begins to rise linearly.

One of the main factors in increasing fuel consumption at low ambient temperatures is an increase in the rolling resistance of tires. According to [23], the rolling resistance characteristics for car tires are almost linear depending on the ambient temperature while characteristics of truck tires are much better described by linear regression of the second order.

Air resistance is the force of resistance that acts from the air on a moving object. The force of resistance depends on air density, vehicle speed, dimensionless coefficient of the vehicle resistance, and frontal area of the vehicle [24]. Among all these variables, air density is the most significant. Cold air is denser than warm air, so resistance is higher in winter. At –10 °C, the resistance force is approximately 12 % greater than at +20 °C [25].

Fuel economy tests have shown that in urban driving, the mileage of petrol vehicles is approximately 15 % lower at –7 °C than at +25 °C. These values increase to 24 % when riding for very short (5–6 km) distances [26]. Low ambient temperature also leads to an increase in harmful emissions from vehicles [27, 28]. This is especially true for cold engine start modes when temperatures of the engine oil, coolant and cylinder block are equal or close to the ambient temperature [29–32].

Determining the effect of ambient temperature on fuel consumption requires a large amount of statistical data which significantly complicates the study. Thus, from the point of view of scientific research, it is very important to identify patterns of change in these parameters. Results of the study of the influence of ambient temperature and atmospheric pressure on fuel consumption by a gasoline engine by means of mathematical modeling are presented in [33]. The studies were performed for a wide range of temperatures, humidity, and atmospheric pressure. However, they focused on fuel consumption by the engine and not the vehicle as a whole, so they did not take into account a number of parameters that are specific for operating conditions. A technique that makes it possible to adjust norms of fuel consumption by commercial vehicles depending on ambient temperature is given in [34]. At the same time, modes of operation of city buses and commercial vehicles differ significantly which leaves room for studies in this area. Results of experimental studies of the influence of ambient temperature on fuel consumption by specialized rolling stock are given in [35]. The peculiarity of operation of this type of rolling stock consists in that a part of the fuel is spent on the drive of specialized equipment which is not typical for most vehicles. A comparative analysis of fuel consumption by trucks operating in diesel and gas-diesel cycles depending on the ambient temperature and load level is given in [36]. Although diesel engines that are installed on trucks and buses are similar in design, their operating conditions differ significantly, so the results of these studies must be clarified for urban passenger transportation. In addition, the question remains open as to which components of fuel consumption determine the largest increase at various ambient temperatures. The above suggests that it is appropriate to conduct studies to establish the nature of the relationship between fuel consumption and ambient temperature for urban passenger transport. Also, these studies have to assess the impact of individual components on total fuel consumption.

3. The aim and objectives of the study

The study objective is to determine the patterns of influence of ambient temperature on fuel consumption by city diesel buses. This will make it possible to take into account the obtained dependences in mathematical models of vehicle movement and determine levels of harmful emissions when calculating fuel consumption for various ambient temperatures.

This objective involves solving the following tasks:

– conduct experimental studies to determine the ambient temperature and fuel consumption for buses operated on two city routes;

– build a regression mathematical model of the influence of ambient temperature on fuel consumption by city diesel buses.

4. Materials and methods used in studying the effect of ambient temperature on fuel consumption

4. 1. Experimental studies

The experimental data on fuel consumption were collected on several city routes for buses of a utility company in Kyiv. The study was conducted from 01.01.2017 to 06.30.2018.

In order to reduce the impact of the technical condition of buses on the results obtained, 26 buses produced in 2017 and 2018 were selected as the study object. A brief technical description of the buses under consideration is given in Table 1.

Table 1

Brief technical characteristics of the buses under consideration

Parameter	Value
Overall dimensions, mm	
length	11,980
width	2,550
height	2,774
Wheels, (tire size)	275/70 R22.5
Total weight, kg	18,000
Engine	Daimler OM 906 hLa EURO 5
– capacity, l	6.37
– power, kW (h.p.)/min^{-1}	210 (285)/2,200
– maximum torque, Nm/min^{-1}	1,120/1,200–1,600
Transmission	ZF 6HP-504C

To select routes, the number of rides per year on each of the routes was analyzed for the study (Fig. 2).

As can be seen from Fig. 2, the largest number of rides per year was on routes A, B, C, and D. However, route B was started at the time of the study and passenger flow was very small. Therefore, the data obtained in the study would not reflect real data when the route will go to a steady operating mode. Route C connects the city center with industrial suburbs and therefore is not in demand but performs the social function of uniting the city areas. Thus, routes A (Fig. 3) and D (Fig. 4) were chosen for the study because they have been operating for a long time and have a steady flow of passengers. They perform the largest number of rides per year and therefore provide sufficient statistics to ensure accurate study results.

Route parameters were recorded using a GlobalSat ND-105C GPS sensor. An example of a speed map of the graph of dynamics of changes in the longitudinal road slope is shown in Fig. 5, 6. The main characteristics of the routes are given in Table 2.

Ambient temperature was measured with a TRM 10 digital thermometer with an external sensor having a measurement range of –50 to 80 °C and a measurement error of ±1 °C.

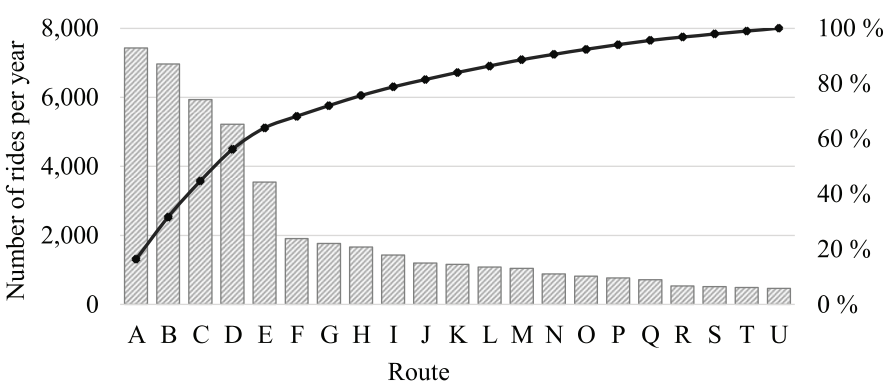

Fig. 2. Number of rides per year on the routes

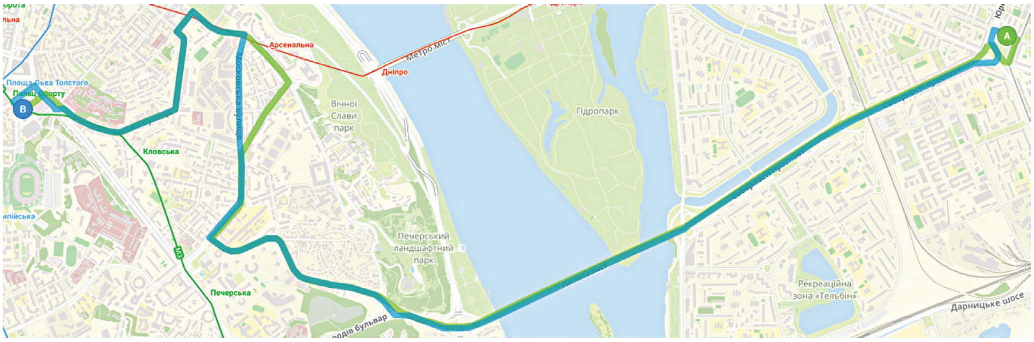

Fig. 3. Route A diagram

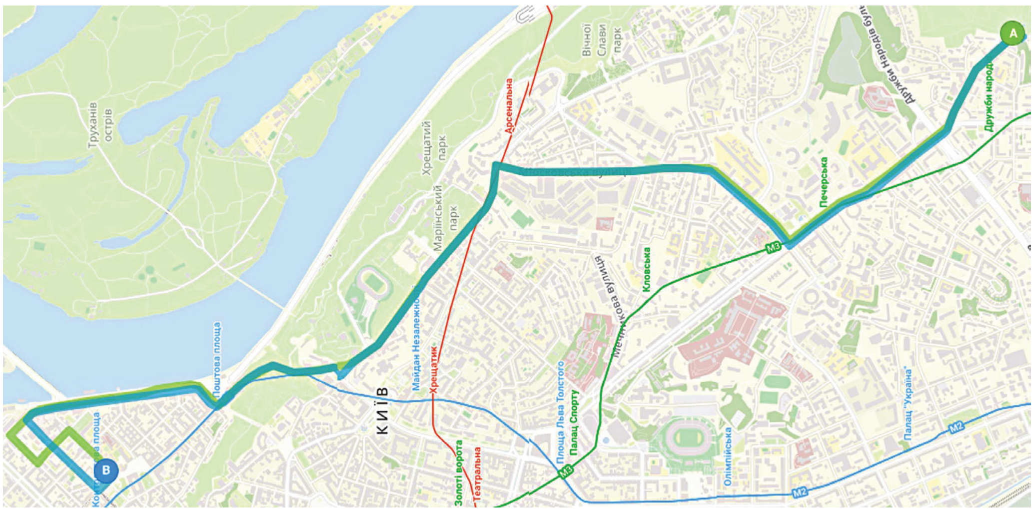

Fig. 4. Route D diagram

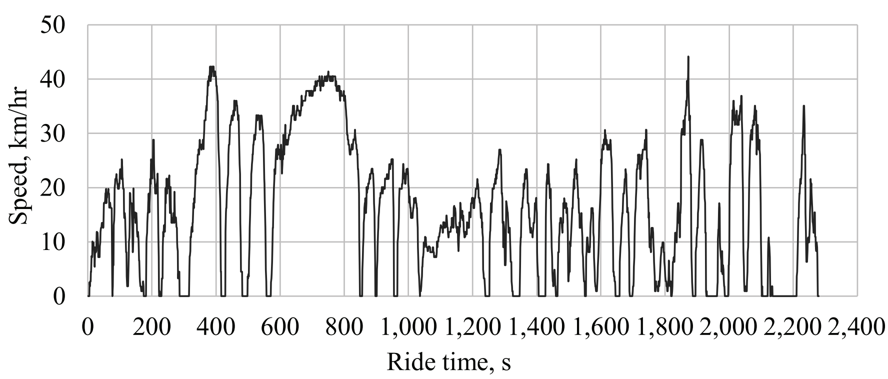

Fig. 5. Speed map. Route A. Ride from point A to point B

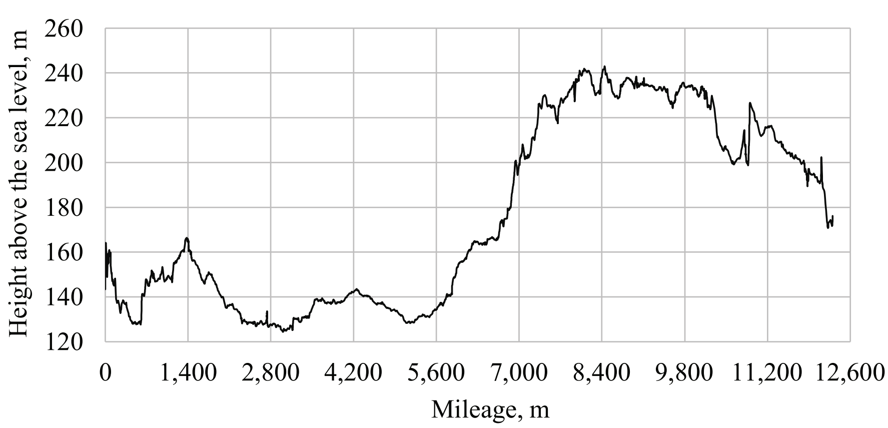

Fig. 6. Graph of dynamics of changes in the longitudinal road slope. Route A. Ride from point A to point B

Table 2

Brief description of the routes

Parameter	Value	
	Route A	Route D
Mileage, m		
A–B	12,300	8,410
B–A	12,220	8,000
Average speed, km/h	18.6	14.4
Maximum longitudinal slope,%	13.2	9.2

All test buses were equipped with satellite fuel consumption monitoring systems, so data on the amount of fuel consumed were obtained from the company's accounting database. Control measurements of fuel consumption were also performed by the method of "filling to the brim". This method was chosen because, according to the company's instructions, the bus must be filled to a full tank at the end of the shift.

Control measurements were performed in the following sequence:

1. GPS data recording was turned on at the shift start and the bus left for the route.

2. Bus was refueled to the full tank after returning to the bus park at the end of the shift. The amount of fuel was recorded using an automatic modular filling station (Fig. 7). In this case, the amount of fuel consumed per shift is equal to the amount of filling the fuel tank to the brim after returning to the park.

3. Fuel consumption was calculated as a ratio of fuel consumed to total mileage per shift and multiplied by 100 in order to convert the value to l/100 km.

Fig. 7. Automatic modular filling station

Control measurements were performed for 8 days: three measurements on weekdays and one on weekends for each of the routes. Control measurements confirmed the accuracy of accounting. The total deviation of the measured values in comparison with the data obtained from the information base did not exceed 3 %.

The minimum sufficient sample size to achieve a given accuracy in statistical studies can be determined from the formula:

$$n = \frac{T^2 \cdot \sigma^2 \cdot N}{\Delta^2 \cdot N + T^2 \cdot \sigma^2}, \quad (1)$$

where T^2 is the critical value of the Student criterion at the appropriate level of significance. For the significance level 0.05, T^2=1.96; σ is the standard deviation of the measured value; Δ is the maximum permissible error; N is the volume of the general population.

4. 2. Analytical studies

The main purpose of the analytical studies implied determining the effect of air density, rolling resistance, transmission efficiency, and all three factors together on fuel consumption by means of mathematical modeling. PERE mathematical model was used for calculations [8]. Per second speed maps, graphs of the dynamics of changes in the longitudinal upward slope (Fig. 4, 5) and the bus technical characteristics were taken as initial data (Table 1). The relationships between air density, rolling resistance, transmission efficiency, and ambient temperature were taken from [22, 23, 25], respectively.

The mathematical model was calibrated in the first step. The day with known values of ambient temperature and fuel consumption was randomly selected from the experimental data. Then, constant input data and variable values of the corresponding ambient temperature were substituted into the mathematical model. To match the calculated and experimental fuel consumption values, the weight of the bus was reduced from 18,000 kg to 14,200 kg which corresponded to the average load per shift.

Following the model calibration, values of air density, rolling resistance, and transmission efficiency depending on the ambient temperature in the range from −14 to +26 °C were substituted into the mathematical model one by one and then all together.

5. The results obtained in studying the relationship between ambient temperature and fuel consumption

5. 1. The results of experimental studies

Changes in ambient temperature were cyclic and sinusoidal during the year (Fig. 8). Daily fluctuations did not exceed 10 °C. Thus, seasonal changes in fuel consumption caused by temperature fluctuations must also be cyclical. This means that they are predictable. The ability to anticipate such changes is an important aspect of financial planning for enterprises.

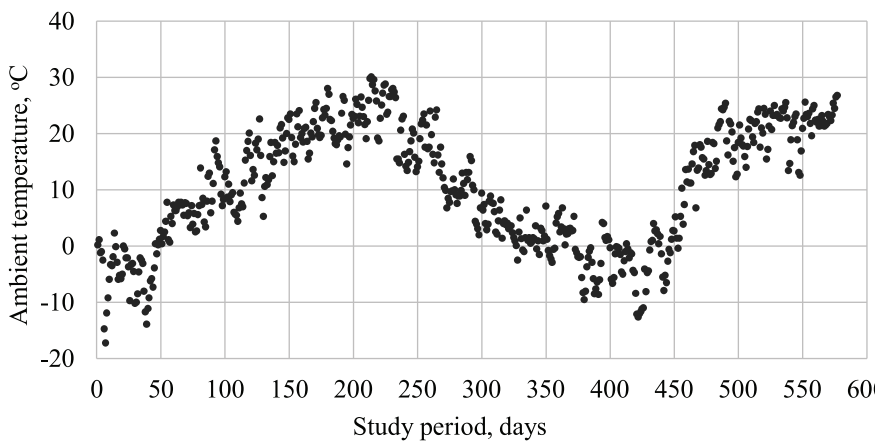

Fig. 8. Graph of changes in ambient temperature from 01.01.2017 to 30.06.2018

During the study period, 549 values of fuel consumption for route A and 252 values for route D were taken from the enterprise accounting base for the temperature range from −13 °C to +26 °C.

The results of calculations of minimum sufficient sample sizes from formula (1) are given in Table 3 for the obtained values of fuel consumption.

Table 3

The results of determining minimum sufficient sample sizes to achieve the specified accuracy in statistical studies

Route	Confidence probability	Error margin	Standard deviation	Size of the general population	Amount of sampling
A	95 %	5 %	0.681	549	310
D	95 %	5 %	0.725	252	192

Average values and standard deviations of fuel consumption were determined in the first stage to estimate their variance for each temperature value. This has made it possible to check the availability of data that differed significantly from the average values and could indicate the factors that would affect the accuracy of the final results (Fig. 9, 10).

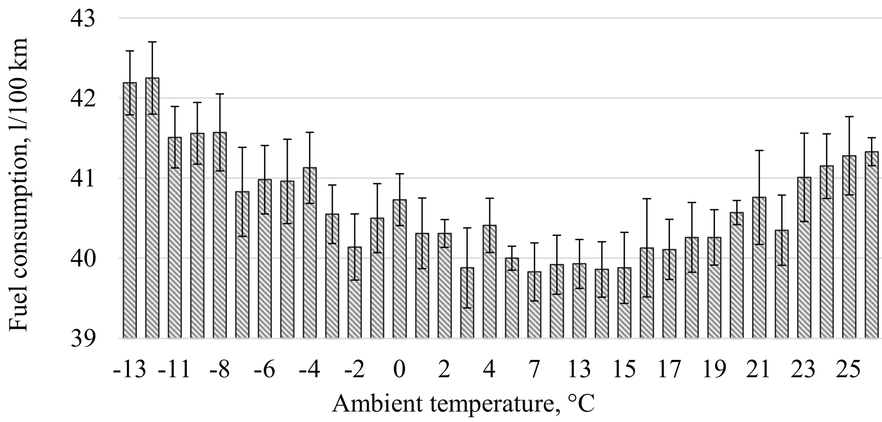

Fig. 9. Average values and mean-square deviations of fuel consumption. Route A

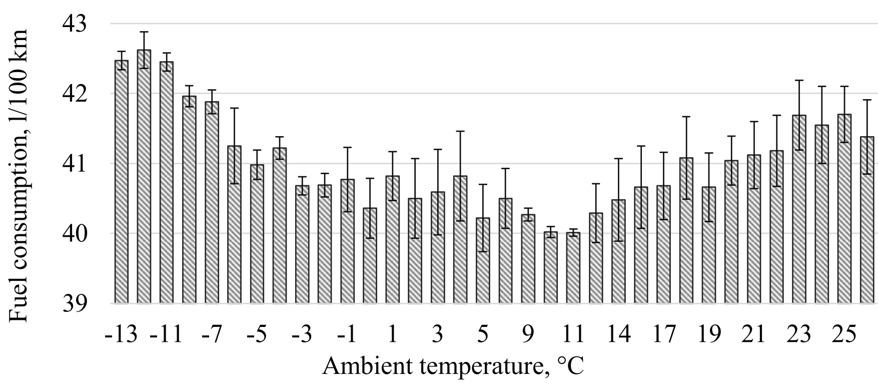

Fig. 10. Average values and mean-square deviations of fuel consumption. Route D

As can be seen from the graphs (Fig. 9, 10), extremely high values of the mean-square deviation for the considered routes were not found. It was in the range of 0.15–0.614 for route A and in the range of 0.05–0.64 for route D. The smaller values of the lower limit value for the route D can be explained by the fact that only 2 fuel consumption measurements were performed for some temperature values.

5. 2. Construction of regression models of the influence of ambient temperature on fuel consumption

The next step implied defining a regression model that describes the relationship between fuel consumption and ambient temperature. For this purpose, dependence graphics were constructed on the basis of the obtained data (Fig. 11, 12).

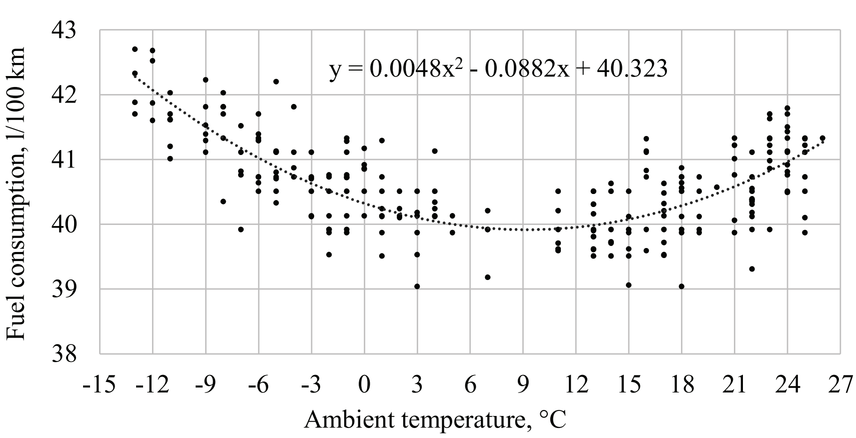

Fig. 11. The graph of dependence of fuel consumption on the ambient temperature. Route A

Polynomial dependences (Table 4) of fuel consumption Q_s on ambient temperature t were obtained by the method of least squares. The accuracy of approximation was checked by the Fisher coefficient. In general, this dependence can be described by a second-order regression equation:

$$Q_s(t) = a \cdot t^2 + b \cdot t + c, \qquad (2)$$

where *a, b, c* are the polynomial coefficients.

As can be seen from Table 4, the dependences have very close values of the coefficients *a* and *b*. At the same time, the coefficient *c* is proportional to the fuel consumption by the new bus on a particular route (Q_{s0}). The ratio of *c* to Q_{s0} is in the range of 1.15–1.45 %.

The results given in Table 4 can be summarized in a general form by the equation for determining fuel consumption at a given temperature. For this purpose, arithmetic mean values of the coefficients *a* and *b* were determined. The coefficient *c* was presented as the product of arithmetic mean values from column 4 of Table 4 and Q_{s0}.

$$Q_s(t) = 0.005 \cdot t^2 - 0.0885 \cdot t + 1.013 \cdot Q_{s0}. \qquad (3)$$

To check the accuracy of dependence (3), the values of ambient temperatures were randomly selected from the experimental data. For these values, fuel consumption was calculated using dependence (3). Next, the calculated values of fuel consumption were compared with experimental ones. The relationship between experimental and calculated values was confirmed using the Fisher coefficient. Deviation of the calculated and experimental data did not exceed 1.15 %. The calculation results are given in Table 5.

The Fisher coefficient indicates the high accuracy of the proposed polynomial dependence (3).

The results of analytical studies are shown in Fig. 13 and Table 6. The point of intersection in Fig. 13 corresponds to the data used to calibrate the mathematical model.

According to the results of analytical studies, air density had the least impact on fuel consumption among the three studied factors (Fig. 13). The difference between the minimum and maximum values of fuel consumption was 0.12 %. This dependence is described by the second-order regression equation (Table 6). However, since the coefficient before the first equation term is very small ($5.69 \cdot 10^{-6}$), this dependence can be simplified to a linear one. In this case, the equation takes

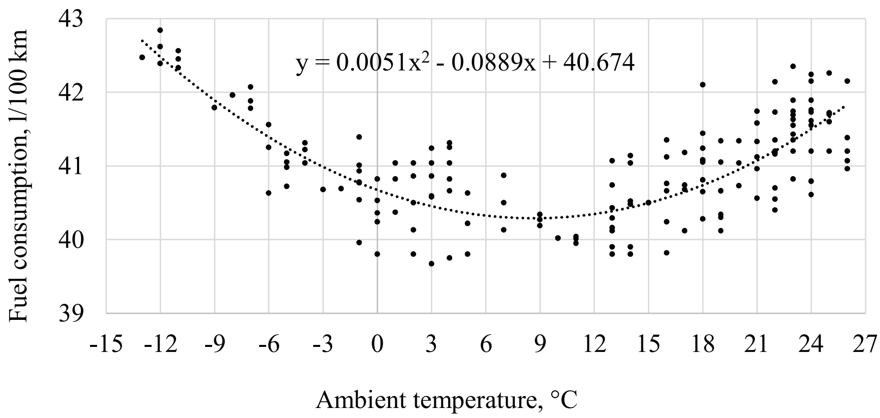

Fig. 12. The graph of dependence of fuel consumption on the ambient temperature. Route D

Table 4

Influence of ambient temperature on fuel consumption. The results of approximation of experimental data

Route	Polynomial regression	Actual fuel consumption in the first month of operation, l/100 km	c/Q_{s0}	The Fisher coefficient (a=0.05)
A	$Q_s(t)=0.0048\cdot t^2-0.0882\cdot t+40.32$	39.74	1.0145	553.53>1.964
D	$Q_s(t)=0.0051\cdot t^2-0.0889\cdot t+40.673$	40.21	1.0115	282.28>1.969

the form $Q_s(t)=-0.001253\cdot t+40.38$ (R^2=0.9626). Rolling resistance has the greatest effect. The difference between the minimum and maximum fuel consumption is 2.5 %. This dependence can also be described by the second-order regression equation (Table 5).

Higher transmission efficiency in warm weather leads to a reduction in fuel consumption by 2.5 %, as in the case of rolling resistance. However, the difference is slightly smaller in absolute units ($\Delta Q_s(\eta)=1.1<\Delta Q_s(C_r)=$ $=1.3$ l/100 km) and fuel consumption varies linearly. The simultaneous influence of all three factors can be described by the second-order regression equation (Table 6).

The calculation results correspond to average values of fuel consumption obtained experimentally in the range of ambient temperatures from −12 to +10 °C. At higher temperatures, experimental values of fuel consumption grow while the calculated values continue to decrease (Fig. 14).

Table 5

The results of calculations of fuel consumption depending on the ambient temperature in comparison with experimental data

Ambient temperature, °C	Actual fuel consumption, l/100 km	Calculated fuel consumption, l/100 km	The Fisher coefficient (a=0.05)
Route A			
−13	42.19	42.25	253.24>2.201
−9	41.56	41.46	
−6	40.98	40.97	
−3	40.55	40.57	
0	40.73	40.26	
3	39.88	40.04	
7	39.83	39.88	
11	39.92	39.89	
14	39.86	40.00	
17	40.11	40.20	
20	40.57	40.49	
23	41.01	40.87	
26	41.33	41.34	
Route D			
−13	42.47	42.73	94.69>2.201
−9	41.79	41.93	
−6	41.25	41.44	
−3	40.68	41.04	
0	40.36	40.73	
3	40.59	40.51	
7	40.50	40.36	
11	40.01	40.36	
14	40.48	40.47	
17	40.68	40.67	
20	41.04	40.96	
23	41.69	41.34	
26	41.38	41.81	

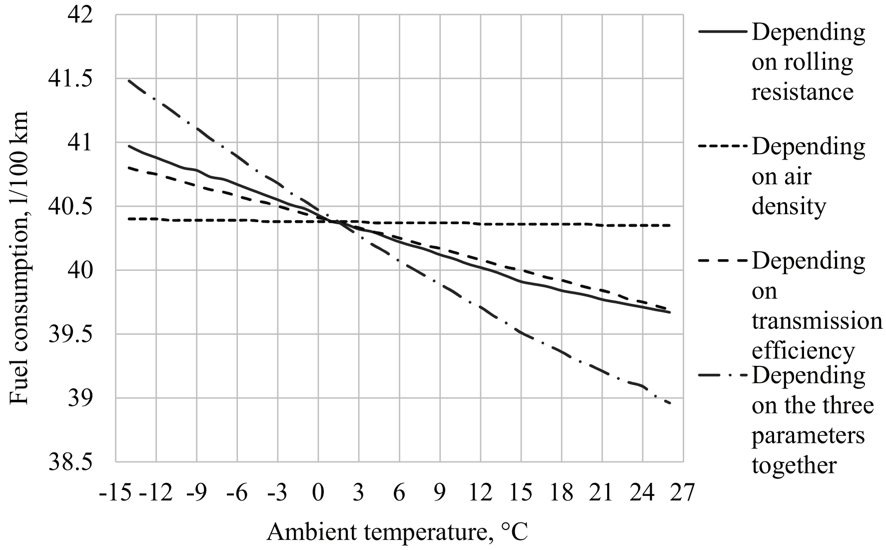

Fig. 13. The graph of fuel consumption depending on changes in rolling resistance, air density, and transmission efficiency at various ambient temperatures

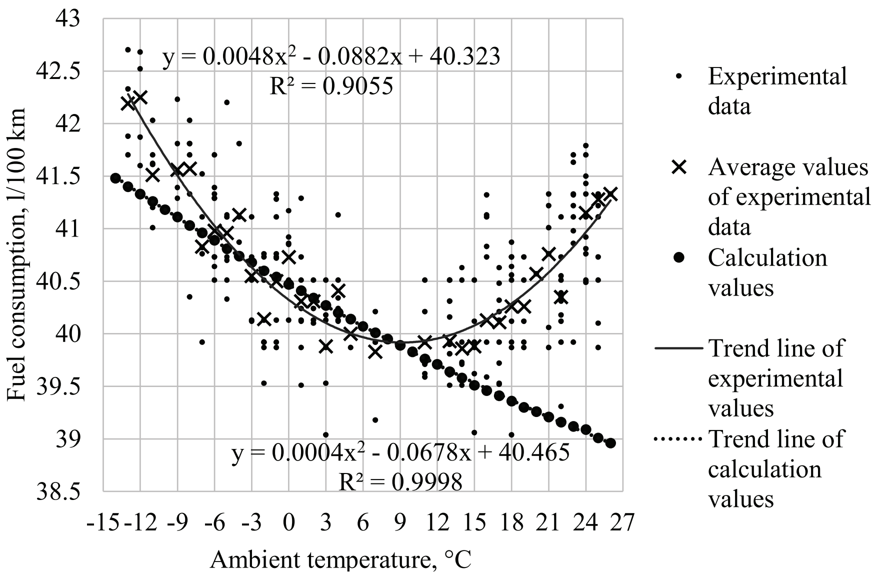

Fig. 14. Comparison of calculated and experimental values of fuel consumption

Table 6

Polynomial dependences of fuel consumption depending on the change in rolling resistance, air density, and transmission efficiency at various ambient temperatures

Factor name	Dependence	R^2
Rolling resistance	$Q_s(t)=0.0002\cdot t^2-0.0361\cdot t+40.427$	0.9990
Air density	$Q_s(t)=5.69\cdot 10^{-6}\cdot t^2-0.001321\cdot t+40.38$	0.9648
Transmission efficiency	$Q_s(t)=-0.02768\cdot t+40.414$	0.9998
Three factors together	$Q_s(t)=0.0004\cdot t^2-0.0678\cdot t+40.465$	0.9998

The total discrepancy between experimental and calculated values did not exceed 1 % in the temperature range from −8 to +15 °C. The discrepancy begins to increase significantly above +16 °C and reaches 5.9 % at +26 °C. The same trend can be seen at temperatures below −9 °C.

6. Discussion of the results obtained in the study of the influence of ambient temperature on fuel consumption

The study results have made it possible to establish the nature of dependence between ambient temperature and fuel consumption by city diesel buses. This dependence is described by second-order polynomial equations (Table 4) which were obtained by processing and analyzing experimental data (Fig. 11, 12).

Given the close values of the polynomial coefficients during approximation of the experimental data (Table 4), a general form of equation (3) was proposed to determine fuel consumption at a known ambient temperature.

The accuracy of the regression models was confirmed by the Fisher coefficient for two city bus routes ($F(0.05)=253.24>2.039$ for route A; $F(0.05)=94.69>2.201$ for route D). The discrepancy of calculated and experimental data did not exceed 1.15 % (Table 5).

The obtained results are similar to those obtained in previous studies [34–36]. In all the cases considered, the relationship between ambient temperature and fuel consumption is described by second-order polynomial equations. The obtained results confirm previous studies and supplement them with one more type of rolling stock.

Analytical studies were also performed to determine the effect of air density, rolling resistance, and transmission efficiency on fuel consumption by mathematical modeling (Fig. 13). It was estimated that rolling resistance and transmission efficiency have the greatest impact on fuel consumption among these three factors. The difference between maximum and minimum calculated values was 2.5 % in both cases (Fig. 13).

The results of calculations using the three factors correspond to average experimental values of fuel consumption in the range of ambient temperatures from −12 to +10 °C. At higher temperatures, experimental values of fuel consumption increase while the calculated values continue to decrease (Fig. 14). This can be explained by the fact that, as noted in [15], an increase in ambient temperature leads to a decrease in the spray area and the jet range because of increased fuel evaporation which affects the efficiency of fuel combustion. In addition, the increase in fuel consumption in the summer season can be caused by the use of air conditioning. These factors as well as the change in fuel density depending on ambient temperature were not taken into account in the mathematical modeling.

The total discrepancy between experimental and calculated values did not exceed 1 % in the temperature range from −7 to +15 °C. For temperatures above +16 °C, the discrepancy begins to increase rapidly and reaches 5.9 % at +26 °C (Fig. 14).

The increase in total deviation in the temperature range below −9 °C can be explained by a significant increase in viscosity of diesel fuel which leads to a decrease in evaporation and deterioration of combustion completeness [16]. In addition, higher viscosity increases the force of fuel friction against the nozzle wall of the injector nozzle [15] which affects the speed of fuel supply and completeness of its combustion.

Similar relationships between fuel consumption and ambient temperature obtained by mathematical modeling were presented in [24].

The obtained results can be used in complex mathematical models of vehicle movement, in particular for city buses, and mathematical models for determining harmful emissions in calculations of fuel consumption for various values of ambient temperatures.

Limitations of this study are related to the use of a specific model of the buses operating in certain conditions. However, this study, along with previous studies in this area, confirms the nature of the relationship between fuel consumption and ambient temperature. Therefore, additional studies are needed to determine polynomial coefficients for other brands and models of city buses.

7. Conclusions

1. According to the results of experimental studies, it was found that the dynamics of changes in ambient temperature in a temperate climate zone have a sinusoidal character and ranges from −15 to +30 °C. Such climatic conditions lead to the fact that within the temperature limits of fuel consumption by city diesel buses increases to 7 %. At the same time, its minimum values were observed at +9 °C. This trend is in line with previous results for other types of vehicles and engines. However, higher values of fuel consumption at high temperatures relative to the minimums than in the previous studies were observed in this study. This can be explained by the fact that air conditioning is used in the buses to maintain a comfortable temperature in the cabin in the summer season. This, in turn, applies extra strain on the engine and increases fuel consumption.

2. The nature of the influence of ambient temperature on fuel consumption was described by second-order polynomial regressions. Accuracy of the obtained dependences was confirmed by Fisher's test ($F(0.05)=253.24>2.039$ for route A; $F(0.05)=94.69>2.201$ for route D). The results are in line with the trends described in previous studies. It was found additionally that the free term of the equations corresponds to the actual fuel consumption by a new bus on a given route.

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