Investigation of fuel consumption by independent heaters depending on bus operating conditions

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Abstract. The article provides a rationale for the adjustment of fuel consumption rates by autonomous heaters in the bus operating conditions in winter. It was determined that the regulatory documents fuel consumption is assigned to the continuous operation of the heater and does not depend on changes in climatic factors and the characteristics of the thermal and structural characteristics of the bus body. The authors monitored the mileage and fuel consumption of buses of the Volzhskiy city motor company No. 1732 in the winter and summer months under operating conditions. A method has been developed that makes it possible to statistically determine fuel consumption and plan these costs in winter. The proposed fuel consumption standards buses during the winter operation. It contains recommendations for adjusting fuel consumption rates.

1. Introduction
The fuel consumption of autonomous heaters in the bus operating conditions on the line is influenced by external factors. These include climatic conditions, thermal and structural characteristics of the body of buses. However, at present, the Methodological Recommendations of the Ministry of Transport of the Russian Federation NAM-23-P, the value of the standard fuel consumption is assigned to the continuous operation of the heater during a shift and is conditional.

Preliminary analysis of fuel consumption by heaters showed that it was necessary to adjust for certain factors. For planning operating costs, a method has been developed that allows for adjustments in fuel consumption rates in winter.

The purpose of the study is to find the standard value of fuel consumption by autonomous heaters depending on the outdoor air temperature, for example, buses operating suburban routes in the city of Volzhsky for the winter period.

The main task of the work is the calculation of fuel consumption indicators of heaters on buses in winter.

2. Selection research technique
Until now, when planning fuel consumption, taking into account the work of autonomous heaters of buses' coolant during the cold season, the rules on the Methodological Recommendations of the Russian Transport Ministry No. IA-159-p [1] are applied. These standards recommend planning fuel consumption when the heater is on during a shift with a switch on duration of 100% during a shift, regardless of the climatic zone at ambient temperatures below +5 °C. The authors determined that in
addition to heat the fluid coming from the cooling system of the internal combustion engine, it is advisable at an ambient temperature below -7 °C.

In this regard, a research methodology has been developed, including an analysis of the actual fuel consumption in bus heaters operating on suburban routes belonging to the Municipal Unitary Enterprise “Volzhsky city motor company No. 1732”. The application of the technique will allow to estimate the actual fuel consumption of autonomous heaters and offer recommendations on the development of updated standards for certain climatic zones of bus operation.

In the course of the work, the studies and studies published in [2] were used. The authors have certain achievements in determining the heat capacity of an autonomous heater for thermal preparation and heating of a large class bus; problems on fuel economy and ways to solve these problems are identified [3,4,5].

The use of an autonomous heater (hereinafter referred to as heater) in a car is assumed during the cold season with an average daily temperature below +5 °C. The heater automatically turns on at +73 °C and off at +78 °C of the temperature of the liquid coming from the engine cooling system. Obviously, the lower the ambient temperature, the greater the need for heat in the bus and the longer the heater will turn on. The choice of the heater is influenced by the climate zone of operation. Thermal power and fuel consumption are considered to be their main characteristics [3].

The heater provides pre-heating of the engine, favorable thermal conditions in the passenger compartment and the bus driver's workplace. The thermal capacity of the autonomous heater for the bus depends on the average daily ambient temperature of the region of operation, the required pre-start engine preheating time (5 ... 8 minutes), the passenger compartment warming up and the driver's workplace (not more than 15 ... 30 minutes) to the minimum allowable temperature [2 , 3], the mass of the heated engine, the volume and temperature of the heated cabin of the bus.

Consider the graph (Figure 1) of the calculated required heat output to maintain a 12 meter large bus in the cabin of a minimum air temperature of 15 °C in the passenger compartment and the driver’s workplace 16 °C depending on the ambient temperature [4].

Figure 1. Dependence of the required thermal capacity of the heating system of the city bus cabin on the outside air temperature.
From the graph in figure 1 it can be seen that the amount of heat entering the passenger compartment and the bus driver’s cabin from a continuously operating 30 kW heater and from the engine cooling system (15 ... 20 kW) is sufficient to maintain an acceptable internal air temperature at an outside temperature to minus 28 °C. When the outside temperature is above minus 7 °C, the heat of the cooling system of the bus engine will be enough to maintain a favorable temperature in the cabin.

City buses are most often operated during the day and the autonomous heater can operate with a low turn-on time or not turn on after the bus is warming up.

At present, at motor transport enterprises and organizations that operate motor vehicles, fuel consumption rationing is carried out in accordance with the Methodological Recommendations of the Russian Transport Ministry NAM-23-P “Fuel consumption rate and lubricants for road transport [1].

For buses, the standard value of fuel consumption is calculated according to the formula (1):

\[ Q_n = 0.01 \cdot H_s \cdot S \cdot (1 + 0.01 \cdot D) + H_{heater} \cdot \tau_n, \]  (1)

where \( Q_n \) - the standard fuel consumption, l;
\( H_s \) - the transportation rate of fuel consumption per bus run, l / 100 km;
\( S \) - bus mileage, km;
\( H_{heater} \) - heaters fuel consumption rate, l / h;
\( \tau_n \) - car operating time with the heater turned on, h;
\( D \) - the correction factor (total relative allowance or reduction) to the norm, %.

When calculating in accordance with existing guidelines, the value of the standard fuel consumption is assigned to the heater's continuous operation during a shift and is conditional, since it does not depend on changes in climatic factors and the characteristics of the thermal and structural characteristics of the vehicle body.

We set the task.
1. Determine the fuel consumption in the winter time by the heater on the automobile enterprise in the operating conditions of the buses on the line.
2. To offer fuel consumption standards for buses during periods of summer and winter operation.

In the formula (1), the second term \( H_{heater} \cdot \tau_n \) cannot be calculated, since the duration of switching on the heater in specific temperature conditions of operation is unknown.

Therefore, a method was developed that allows you to statistically determine fuel consumption and plan these costs in winter.

The study involved five buses model Volzhany-5270.04 and Volzhnyan-5270.02 with an engine YMZ-236NE rated at 169 kW, with a “Pramatronic” heater model 141.8106.000 with thermal power of 30 kW. Buses were fixed and worked constantly on suburban routes №№: 104, 111, 102, 117, 146.

The aim of the study is to develop and apply a method for determining the fuel consumption of a heater on buses operating on suburban routes in the city of Volzhsky.

Among the factors that affect the fuel consumption of the heater, there are variables and constants. Under the terms of the study (buses of the same model with the same engines and heaters, work on fixed suburban routes) the constant factors are:
- heat transfer coefficient;
- the area of the bus body fences;
- heat dissipation 15 ... 20 kW engine cooling system to bus heating system (according to the Scania service bulletin).

Variable factors:
- the number of passengers in the bus;
- outdoor temperature;
- fuel consumption heater;
- operational speed of the bus on the route.

Passengers in the cabin create a cargo load when the bus is moving along the route and emit on average thermal energy of 100 W each.

The outdoor temperature is taken according to the Volgograd Hydrometeorological Center.
The fuel consumption of the heater is determined by the total fuel consumption of buses on routes in comparison of the winter and summer periods of operation.

The research tasks include the following work.

1. Processing and analysis of air temperature indicators according to the Volgograd Hydrometeorological Center.

2. Processing and analysis of the data of the production and technical department of the Volzhsky city motor company No. 1732 on the mileage and fuel consumption of buses: in the winter months - December 2017, January and February 2018; in the summer months of the same buses - June, July and August 2018

3. Processing and analysis of data on selected buses of the planning and economic department of the Volzhsky city motor company No. 1732 with the following indicators: operating hours on routes; the number of passengers carried during the winter months is December 2017, January and February 2018; In the summer months - June, July and August 2018.

4. Calculation of fuel consumption of heaters on buses in the winter.

3. Research results

Consider the temperature indicators in the city of Volzhsky in the winter of 2017-2018, according to the Hydrometeorological Center.

The average monthly temperature was, °C:

- December 2017 – 0.10;
- January 2018 – 5.59;
- February 2018 – 5.64;
- June 2018 + 21.6;
- July 2018 + 24.10;
- August 2018 + 24.40.

Consequently, the heaters for the entire winter season worked to ensure the preheating of the engine, heating the passenger compartment and the driver’s workplace to the minimum allowable temperature, mass of the engine being heated, volume and temperature of the heated passenger compartment of the bus.

1. The data obtained from the production-technical and planning-economic departments are summarized in table 1.

### Table 1. Initial data.

| Indicators                                      | Period                  |
|------------------------------------------------|-------------------------|
|                                                  | December | January | February | Total | June | July | August | Total |
| Fuel consumption, l                            | 6983     | 6335    | 6458     | 19776  | 6944 | 8414 | 8129    | 23487 |
| Total mileage, km                               | 16916    | 14584   | 14996    | 46496  | 18083| 21784| 21078   | 60945 |
| Hours on the routes, h                          | 437,14   | 367,18  | 367,18   | 1178,99| 413,43| 502,37 | 511,50   | 1427,30 |
| Specific fuel consumption by buses, l/100 km, Report / Norms | 41,28/ | 43,44 / | 43,06 / | 42,53/ | 38,40/ | 38,62/ | 38,57/ | 38,54/ |
|                                                | 44,70    | 44,70   | 44,70    | 44,70  | 38,60 | 38,60 | 38,60   | 38,60 |
| Specific consumption fuel by buses, l/h Report  | 15,97    | 17,25   | 17,24    | 16,77  | 16,80 | 16,75 | 15,89   | 16,46 |
| Number of passengers, pers.                    | 8706     | 7063    | 7093     | 22862  | 6843 | 9338 | 9255    | 25436 |
| Capacity, person / h                           | 19,92    | 19,24   | 18,93    | 19,39  | 16,55 | 18,59 | 18,10   | 17,82 |
2. The results of statistical studies are shown in Tables 2 and 3.

**Table 2.** According to the report, the average fuel consumption of \( g_{100\text{km}} \) of the bus was 1/100 km.

| №  | Winter \( g_{100\text{km}} \) | Summer \( g_{100\text{km}} \) |
|----|-------------------------------|-----------------------------|
| 1  | Month | Year | Standard | Report | Month | Year | Standard | Report |
| 2  | November | 2017 | 44.70 | 41.28 | June | 2018 | 38.60 | 38.40 |
| 3  | January | 2018 | 44.70 | 43.44 | July | 2018 | 38.60 | 38.62 |
| 4  | February | 2018 | 44.70 | 43.06 | August | 2018 | 38.60 | 38.57 |
| 5  | Average | value | 42.53 | Average | value | 38.54 |

**Table 3.** The average fuel consumption \( q_{1/\text{h}} \) of the bus was according to the report, 1/ h.

| №  | Winter \( q_{1/\text{h}} \) | Summer \( q_{1/\text{h}} \) |
|----|----------------------------|----------------------------|
| 1  | Month | Year | Report | Month | Year | Report |
| 2  | December | 2017 | 15.97 | June | 2018 | 16.80 |
| 3  | January | 2018 | 17.25 | July | 2018 | 16.75 |
| 4  | February | 2018 | 17.24 | August | 2018 | 15.89 |
| 5  | Average | value | 16.77 | Average | value | 16.46 |

3. Passenger capacity (people / h) in the winter and summer periods varies by only 9 percent on suburban routes. Therefore, this factor is taken as a constant value.

4. The average speed \( v_{\text{CP}} \) of the buses on the suburban routes according to the statistical data given in the table is for periods, km / h:

- Winter period: 39.44 km/h
- Summer period: 42.77 km/h

The change in the average speed of movement in the winter and summer periods is 9 percent, therefore, this factor is taken as a constant value.

5. The fuel consumption of buses on suburban routes is mainly influenced by two variables: the average monthly outdoor temperature; fuel consumption heater.

6. Fuel consumption by «Pramatronic» heaters 141.8106.000 on buses of the model Volzhann-5270.04 and Volzhann-5270.02 on suburban routes on average during the winter period we find using formulas (2) and (3):

- liters per hour of bus operation on suburban routes, l / h:
  \[ \Delta q = q_{1/\text{h, winter}} - q_{1/\text{h, summer}} \]  \( \text{(2)} \)
  \[ \Delta q = 16.77 - 16.46 = 0.31; \]

- liters per 100 kilometers, l / 100 km:
  \[ \Delta g = g_{100\text{km, winter}} - g_{100\text{km, summer}} \]  \( \text{(3)} \)
  \[ \Delta g = 42.53 - 38.54 = 3.99. \]

7. For buses, the standard value of fuel consumption is proposed to be calculated using formulas (4), replacing the second term \( H_{\text{heater}} \cdot \tau_{\text{п}} \), in formula (1), l:

\[ Q_{\text{n}} = 0.01 \cdot H_{\text{s}} \cdot S (1 + 0.01 \cdot D) + \Delta g \cdot S, \]  \( \text{(4)} \)

where \( H_{\text{s}} \) - the standard of fuel consumption of buses in the summer, corrected according to the statistical data of the study, l / 100 km - 38.54; \( D \) is the correction factor (total relative allowance or reduction) to the norm, %, taken as \( D = 0. \)

8. Perform the calculation according to the formula (4) of the standard fuel consumption \( Q_{\text{n}} \) for a bus for the winter period with mileage, for example, 100 km, l:

\[ Q_{\text{n}} = 0.01 \cdot 38.54 \cdot 100 (1 + 0.01 \cdot 0) + 3.99 = 42.53. \]

9. The standards for winter fuel consumption for suburban routes should be set not higher than 42.53 l / 100 km.
10. The ratio of the standard values of fuel consumption for the winter and summer periods is $D_N%$:

$$D_N = \frac{44.70}{38.60} - 1 \cdot 100 = (1.158 - 1) \cdot 100 = 15.8$$

(5)

The ratio of actual, reported, average values of fuel consumption for the winter and summer periods is $D_R$:

$$D_R = \frac{42.53}{38.54} - 1 \cdot 100 = (1.104 - 1) \cdot 100 = 10.4.$$

4. Findings

1. The proposed method for determining the fuel consumption of a heater makes it possible to more reliably plan the costs of buses for the winter period along various routes, taking into account the outdoor temperature.

2. It is recommended to increase the standard fuel consumption of buses on suburban routes of the city of Volzhsky for the winter period by 10.4% instead of - 15.8.

3. Economic efficiency will be, when planning the cost of fuel for the winter period of five buses, by reducing purchases - 50 thousand rubles.

The authors are grateful to the specialists of the Municipal unitary enterprise Volzhsky city motor company No. 1732 for the opportunity to conduct research on buses.

References

[1] Order of the Ministry of Transport of the Russian Federation of September 20, 2018 No. IA-159-p “On Amending the Methodological Recommendations of the” Rates of Fuel and Lubricants for Automobile Transport”, put into effect by order of the Ministry of Transport of the Russian Federation of March 14, 2008 No. AM-23-p "

[2] Naiman V S All about pre-start heaters and heaters. - M.: AST: Astrel: The Keeper,.- 160 p. (2007)

[3] Kulko A P, Kulko P A Determination of the thermal capacity of an autonomous heater for thermal preparation and heating of a large class bus. Automotive industry - № 4. - pp. 19-24 (2017)

[4] Kulko A P, Kulko P A Energy-saving climate system bus: problems and solutions. Automotive industry. - № 3. - pp. 11-15. (2018)

[5] Kulko A P, Mitin R A, Agarkov O S and Moiseev Y I, Rationing of fuel consumption of cars during the operation of automatic heaters. Young scientist. - № 10 (114), part 3. - pp. 275-278. (2016)