INFLUENCING FACTORS ON ELECTRICITY CONSUMPTION OF ELECTRIC BUS IN REAL OPERATING CONDITIONS

by

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The research of influencing factors on the electricity consumption of electric buses Higer KLQ6125GEV3 in real working conditions is the result of experimental measurements conducted on the EKO 1 line in Belgrade over a long period which included typical seasonal periods (winter, summer, transitional) of E-bus operation as well as characteristic periods of work during the day (peak load, intermediate period, first/last departures). The results of this research are the basis for reviewing and ranking the influential factors on the electricity consumption of E-buses that are of great importance in planning operations of the line, analysis of energy efficiency and operating conditions.

Key words: *electric bus, electricity consumption, energy efficiency, influencing factors*

1. Introduction

The electric bus (E-bus) is a concept of environmentally friendly and energy-efficient bus subsystem of public transport in many cities around the world. China is the world leader in the production of electric buses and their implementation in many public urban transport systems. The introduction of electric buses in Chinese cities is a state project, as one of the ways to reduce air pollution, especially in large cities, such as Beijing, Shanghai, Shenzhen ... The city of Shenzhen is the first city in the world to have 16,500 electric buses in operation since 2018, which makes the bus subsystem of public city transport 100% "electrified" [1]. Outside of China, the cities with the largest use of electric buses are Moscow (about 1,000 E-buses), Santiago de Chile (776), London (500), and Bogota (351) [1]. According to the EU Clean Vehicles Directive (2019/1161), electric buses are the best option for energy-efficient vehicles with zero emissions. By the end of 2025, their share should be 22.5%, by the end of 2030, 32.5%, while the full implementation is expected from 2050 [2].

The energy (electricity) consumption of the E-bus, expressed in kWh or $kWh\cdot km^{-1}$, is many times lower compared to buses that use conventional fuels (diesel, CNG) as a result of higher energy efficiency of the inverter-electric motor system, which in optimal case is 92% [3], in relation to buses whose propulsion systems are diesel engines, where the energy efficiency in the optimal case is 35-

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45% [4]. Electric buses have the ability to recover electricity in the deceleration and braking phase, which further increases energy efficiency and reduces the electricity consumption of vehicles. The use of electricity to power electric buses from entirely renewable sources such as wind generators or solar panels is an additional quality in the use of this type of vehicle, which significantly reduces carbon dioxide emissions. It is for these reasons that electric buses are gaining in importance as the main promoter of new technologies in the implementation of the strategy of sustainable development of the city and the improvement of energy efficiency. The electricity consumption of electric buses is a complex function of several factors. The most important construction factors are the mass of the vehicle, energy efficiency of the inverter-electric drive system, the level of losses in the system for charging and storing electricity, conductors, transmission, and auxiliary devices on the vehicle. Operational factors that are present during the usage of electric buses on a line are: characteristics of the driving cycle, number of passengers in the vehicle, topographic characteristics of the route, driving style of the driver, usage of heating and cooling systems.

A detailed analysis of the most significant influencing factors on the electricity consumption of E-buses observed over a longer period of time on the city line EKO 1 in Belgrade represents the main goal of the research presented in the paper in order to reach the most realistic results related to this area of research. In the literature related to this area of research, the most often analyzed are some of the influential factors on the electricity consumption of E-buses in a shorter period of time, that is, a smaller sample. It is exactly for the above reasons that the research presented in this paper, which covered a significantly longer period and a greater number of influential factors, makes this paper unique and different from those that have been published so far. For example, the results of the research of electricity consumption during the characteristic periods of daily operation (morning peak load, afternoon peak load, evening load…) of the E-buses on the line depending on the load of the vehicle (number of passengers in the vehicle) are presented for the first time in this scientific paper, considering that until now there has been no similar research.

The main contributions of this paper are: the identification and influence of the most significant factors on the consumption of electric energy of E-buses in real operating conditions, the applied methodology, and the representative results of measuring the consumption of electric energy that covered a longer period of time, as well as an overview of the state of affairs in the scientific field related to the energy consumption of E-buses.

2. Related Research

One of the first surveys of electricity consumption in fully electric buses was conducted in Rotterdam [5], wherein the period from 2009 to 2012, the standard 12-meter VDL Citea E-bus was tested on city line number 46. Depending on the load of the vehicle (empty-full), electricity consumption was 1.15-1.4 $kWh\cdot km^{-1}$. A significant contribution to the study of energy performance in fully electric buses was given in a study by Pütz et al. [6] conducted in Sofia (Bulgaria) on the Higer KLQ6-A6L E-bus using a supercapacitor for electricity storage. This research was performed in real conditions of exploitation on the city line. The vehicle was loaded with 22 passengers, which is about 25% of the vehicle's capacity. According to this research, the average electricity consumption was 0.95 $kWh\cdot km^{-1}$. A study conducted by the VTT Technical Research Center of Finland, by Erkkila and NyLund [7], analysed the electricity consumption of an electric bus according to the city driving cycles that are often encountered when modelling the operation of electric buses. The total electricity consumption of the loaded vehicle obtained by the Braunschweig driving cycle simulation was 9.3 kWh or 0.853 kWh·km^{-1}. A comparison of the energy efficiency of a standard electric city bus and a diesel-powered bus on the example of the Chinese city of Zhengzhou proved a significantly higherenergy efficiency of the E-bus. The average energy consumption of the E-bus was 1.0 kWh·km^{-1}, while the energy consumption of the diesel bus was 4.0 kWh·km^{-1} [8]. An example of an E-bus simulation according to the driving cycle on line 11 in the city of Espoo (Finland) and a comparison with the measurement results obtained on chassis dyno, where the driving cycle on line 11 was also used, was published in Halmeaho et al. [9]. The results of total consumed electricity of 5.38 kWh by simulation and 5.30 kWh by measurement on chassis dyno were obtained. The use of fully electric buses in public urban passenger transport is the subject of research by Varga [10]. The UDC (Urban Drive Cycle) is simulated the operation of a standard electric city bus using the AVL Cruise simulation program, for the selected city driving cycle. According to the distance travelled, the consumption is 1.19 kWh·km^{-1}.Kim et al. [11] measured the electricity consumption of electric buses in real working conditions on a city line in the Pohang (South Korea), where the consumption of 1.11 kWh·km^{-1} was measured. Measurement of electricity recovery in Higer KLQ6125GEV3 electric buses and the influence of route configuration on electricity consumption on the city line 29 in Belgrade was announced in the paper by Misanovic et al. [12]. In the direction of the ascending movement of the E-bus, the average consumption of an unladen vehicle was 1.444 kWh·km^{-1}, while in the opposite direction, the average consumption was 0.886 kWh·km^{-1}. In the United States, an analysis of Proter's electric-powered city buses from an energy-efficiency perspective and is provided in a report by NREL (National Renewable Energy Laboratory) conducted by Eudy et al. [13]. The operation of 12 electric buses was analysed. Energy consumption per one mile for an electric bus was 2.15 kWh.Measurements of power consumption using measuring equipment for standard city buses with diesel fuel, CNG, and electric drive are presented in the paper Gis et al. [14]. A polygon test of energy consumption was performed according to the SORT 2 (Standardized On-Road Test Cycles) driving cycle and test methodology. The following consumption values were measured: electric bus 0.95 kWh·km^{-1}; diesel bus 3.90 kWh·km^{-1}; CNG bus 4.98 kWh·km^{-1}. The development of a simulation model that includes as many influencing factors as possible on electricity consumption in electric buses is presented in the paper by Vepsäläinen et al. [15]. The influences of the number of vehicle stops during the operation on the line, the influence of driving style, traffic conditions, topographic characteristics of the route in the cases of the most favourable and most unfavourable scenarios was analysed. It has been shown that the consumption of a standard electric bus can vary from 0.70-1.34 kWh·km^{-1}, depending on the case.The application of this simulation model was published in Kivekäs [16], where the example of the line 11 in the Finnish city of Espoo, a simulation of buses with different propulsion systems was performed. Consumption results of 0.804 kWh·km^{-1} for E-bus were obtained; 3.592 kWh·km^{-1} for a bus running on diesel fuel and 4.103 kWh·km^{-1} for a bus running on CNG. Measurement of energy consumption of a standard city bus on fully electric BYD E12, a bus with diesel fuel IK-112N in Belgrade on the city line 41 was published by Misanovic et al.[17]. Consumption of BYD E12 was 1.30 kWh·km^{-1} while IK-112N achieved 4.82 kWh·km^{-1}.

The influence of the driving style of the E-bus Higer KLQ6125GEV3 on the polygon test and line EKO 1 in Belgrade was done in the research of Blagojevic et al.[18]. Based on polygon tests, the recommended energy-efficient driving style of the E-bus between two stops includes a phase of continuous acceleration of the vehicle until the maximum speed, deceleration of the vehicle by inertia where regenerative braking is present, and braking of the vehicle with the service brake, where it is recommended if traffic conditions allow longer braking time at the pedal position up to 28% of the maximum position, whereby only recovery braking is present when the electric motor is operating in generator (recovery) mode. In real operating conditions on line EKO 1 direction, "A" Monument of V.Karadzic-Belville when the driver followed the recommended energy-efficient driving style, 9.559 kWh energy was consumed and 2.789 kWh energy was recovered. In the case of aggressive driving, 11.766 kWh of energy was consumed and 2.890 kWh was recovered. The ratio of recovered and consumed electrical energy of the E-bus is 29.2% in the first case or 24.5% with aggressive driving.

The research of the influence of the speed of the E-bus on the electricity consumption of the E-bus is presented in the work of Taratakovsky et al. [19]. On typical urban lines, driving cycles of E-buses are characterized by shorter inter-station distances, a greater number of stops due to encountering traffic lights at intersections, and stop caused by traffic jams, which affects the relatively low average transport speeds of vehicles, which are usually 12÷14 $km \cdot h^{-1}$. In the mode of operation on suburban lines, the inter-station distances are longer, and the number of stops is lower, i.e. the vehicle's stopping time is shorter, which results in higher transport speeds, usually 28÷30 $km \cdot h^{-1}$, compared to the mode of operation on city lines. A correlative dependence has been proven, where the consumption decreases with the increasing speed of the E-bus. According to a study by Vepsalainen et al. [20], operating conditions such as weather conditions and the number of passengers in a vehicle have caused variations in the energy consumption of electric buses. The influence of the vehicle's heating and cooling system operation on the electricity consumption of the E-bus is shown in the papers [20,21,22,23,24,25,26,27,28]. In extreme cases, especially when using the vehicle heating system, the consumption of the E-bus can be twice as high as when the system is switched off.

Based on the researched literature related to electric buses, the largest number of relevant papers were published in the last seven years, which coincides with the significant use of E-buses in many cities of the world. Dominant are the papers where the research was done on the basis of modeling and simulation of E-bus operation based on the adopted driving cycles in relation to the research that was carried out in realistic conditions. Research on the influence of driving style on the energy efficiency of E-buses on polygon and real operation on lines has never been investigated in the previous period and appears for the first time in the research of Blagojevic et al.[18]. It can be considered that the papers related to E-buses belong to a relatively new scientific field, which is a good motive for new research.

3. Characteristics of the EKO 1 line

In Belgrade, the first line of public city transport EKO 1 (Monument of Vuk Karadzic-Belville), on which only fully electric buses operate, was put into operation on September 1, 2016. EKO 1 line is a diametrical city line that connects the old part of Belgrade with New Belgrade, passing through the central city zone. There are 5 E-buses in operation on the line. The spatial position of the route of the EKO 1 line is shown in Figure 1.

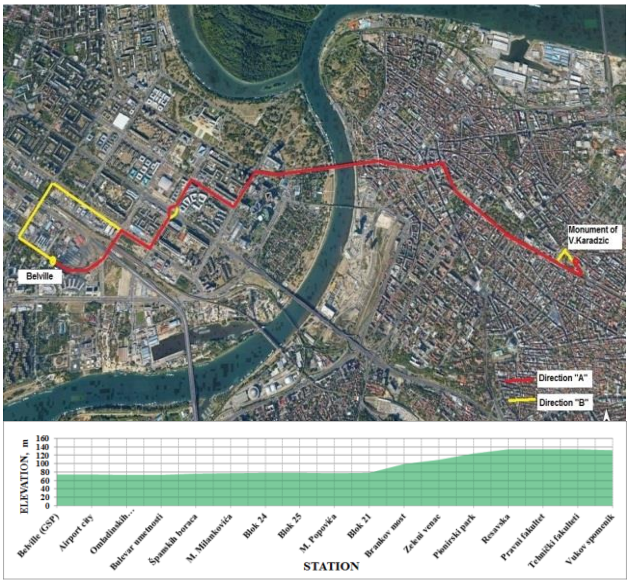

Figure 1. Spatial position and geometric characteristics of the EKO 1 line

Table 1. Characteristic period of work on EKO 1 line

Characteristic period of work during the day	Period [hh:mm]	Part in daily work [%]	Max. vehicle occupancy [%]
First departures	05:00÷6:00	5.5	25
Morning peak load	06:00÷9:00	16.6	70
Intermediate load	09:00÷13:00	22.2	45
Afternoon peak load	13:00÷18:00	27.7	80
Evening load	18:00÷22:00	22.2	40
Last departures	22:00 ÷ 23:00	5.5	30

The specificity of the operation of public transport in Belgrade is that the working hours of the vehicle include six characteristic periods, as shown in Table 1.

The specificity of passenger flows on the EKO 1 line is that the largest number of passengers is transported in the afternoon peak load. The average length of the EKO 1 line is 7995 m. Observed by directions, the length of the route in the direction "A" is 7477 m, where there are 15 stations with an average inter-station distance of 534 m. In the direction "B," the length of the route is 8513 m, where 17 stations are positioned with an average inter-station distance of 532 m [29]. The geometric characteristics of the EKO 1 line route are characterized by a flat configuration with small terrain slopes, primarily in New Belgrade, which makes the route relatively easy to overcome road resistance in terms of topographic characteristics when moving vehicles.

4. Basic technical characteristics of electric bus Higer KLQ6125GEV3

The fully electric bus Higer KLQ6125GEV3 is a modern low-floor solo city bus that meets all technical requirements in accordance with Directive EC /2007/46 and Regulation EU 136/2014, which refers to the fulfilment of technical conditions for buses for public urban passenger transport, including electric buses. The E-bus uses a supercapacitor (ultracapacitor) to store electricity with a capacity of 20 kWh [30]. The E-bus charging system is with fast charging which is performed at the initial-final stops (terminals) where 150 kW chargers are installed. Electric bus Higer KLQ6125GEV3 in the charging phase is shown in Figure 2. The basic technical characteristics are shown in Table 2.

Figure 2. E-bus Higer KLQ6125GEV3

Table 2. Technical characteristics of E-bus

Type	Higer KLQ6125GEV3
Length/width/ height	12000/2550/3680 mm
Curb weight	12540 kg
Passengers	82+1
Max. speed	70 km·h^{-1}
Charging time at the terminus	5÷10 minutes
Supercapacitor	AOWEI, 20 kWh
Traction motors	Siemens (x2) 1PV5135
Power	2x90 kW (peak), 2x67 kW (nominal)
Torque	2x430 Nm
Traction control	Siemens 10DT6

5. Research methodology

The methodology for measuring the electricity consumption of the Higer KLQ6125GEV3 on the EKO 1 line is based on collecting data on the change in the state of charge (SOC) of the supercapacitor at the start of ride and end of the ride. Data were collected in the period from 2016 to 2019 by monitoring the operation of all used 5 vehicles on the EKO1 line. Travel times from the start to the end station were also recorded, based on which the transport speed was calculated. Acquisition of data values is performed via the vehicle's CAN network, the data is stored in the SD memory card located in the battery management system module (BMS) or using the "E-bus data Visualizer" application. The indicator of electricity consumption can be expressed for each realized ride in directions "A" and "B" [31], which provides insight into differences in consumption due to the regime of route specifics (driving cycles, loads, climbs), driving style, use of heating and cooling system of the passenger compartment of E-bus, as shown in the equations:

$$E'_{ebus_A} = \frac{C_{uc} \cdot (SOC_{A_p} - SOC_{A_k})}{\eta_{ch} \cdot L_A}, \tag{1}$$

$$E'_{ebus_B} = \frac{C_{uc} \cdot (SOC_{B_p} - SOC_{B_k})}{\eta_{ch} \cdot L_B}, \tag{2}$$

Based on the transport time of the E-bus, the transport speed for each drive, for each direction was calculated using the equations:

$$v_{t_A} = \frac{60 \cdot L_A}{T_{t_A}}, \tag{3}$$

$$v_{t_B} = \frac{60 \cdot L_B}{T_{t_B}}, \tag{4}$$

Where: for Direction "A": E'_{ebus_A}- electricity consumption of E-bus per ride [kWh·km^{-1}], C_{uc}- maximum capacity of supercapacitor, SOC_{A_p}- state of charge at the start of ride [%], SOC_{A_k}- state of charge at the end of ride [%], η_{ch}- efficiency of charger [%], L_A - length of route in direction "A" [km], T_{t_A}- travel time per ride [min], v_{t_A} - transport speed [km·h^{-1}]; For Direction "B": E'_{ebus_B}- electricity consumption of E-bus per ride [kWh·km^{-1}], C_{uc}-maximum capacity of supercapacitor, SOC_{B_p}- state of charge at the start of ride [%], SOC_{B_k}- state of charge at the end of ride [%], η_{ch}- efficiency of charger [%], L_B - length of route in direction "B" [km], T_{t_B}- travel time per ride [min], v_{t_B} - transport speed [km·h^{-1}].

Measurement of electricity consumption of the E-bus included the spring-autumn, summer and winter period of operation, when outdoor temperatures were in the range from -12 ° C to +38 ° C. Measurement of electricity consumption in the spring-autumn (transition) period was performed on days when the outside temperatures were in the range from +12 ° C to +23 ° C, in order to exclude the influence of the heating and cooling system inside the vehicle, given that the external temperatures are the least likely to use these two systems. In the summer period, electricity consumption was analysed when outdoor temperatures were in range from +22 °C to +38 °C, while in the winter period, a sample of electricity consumption in the temperature range -12 °C to +12 °C was included. The size of the sample that is the subject of the research is 2347 measurements of individual rides. The size of the investigated sample by seasonal periods of exploitation is shown in Table 3 [32].

Table 3. The sample size of research E-bus consumption

Period	Direction "A"	Direction "B"	Direction "A" + "B"
Spring/Autumn	357	347	704
Summer	401	453	854
Winter	397	392	789
Total	**1155**	**1192**	**2347**

Based on representative samples of E-bus electricity consumption per ride, E'_{ebusA} for direction "A" and E'_{ebusB} for direction "B", statistical methods were used for data processing [33]:

• Characteristics of empirical distribution (sample frequency, arithmetic mean $\boldsymbol{X_s}$, standard deviation $\boldsymbol{s_d}$, dispersion $\boldsymbol{s_d}^2$);

• Verification of statistical hypotheses (Chi-square test χ^2 for verification of non-parametric hypothesis, testing the equality of mean values of two basic sets based on their samples);

Test of equality of means of two basic sets using their samples. If X_{s_1} and X_{s_2} mean values of two large samples n_1 and n_2 that have a normal distribution, the question arises whether or not there is a significant difference between $X_{s_1}$and X_{s_2}. The standardized random variable "t" has the form:

$$t = \frac{X_{s_1} - X_{s_2}}{\sqrt{\frac{s_{d_1}{}^2}{n_1} + \frac{s_{d_2}{}^2}{n_2}}} \tag{5}$$

and has normal distribution $N(0,1)$, so it is $t > 1.96 = t_{0.05}$

if $|t| > t_{0.05} = 1.96$, the difference in means values is significant

if $|t| < t_{0.05} = 1.96$, the difference in means values is negligible

• In order to investigate mutual relationships of statistical features or phenomena, it is necessary to determine the form, direction, and strength of the connection. The statistical method used to achieve this is called correlation theory, and the basic indicators of correlation relationships are the regression equation and the correlation coefficient. Based on a set of points that shows pairs of numbers (x_i, y_i) of features, a scattering diagram is obtained in the coordinate system, on the basis of which a line (regression equation) is determined that best represents the connection. The most common forms are shown by equations [33]:

$$y_r = a_0 + a_1 x \text{ , straight line} \tag{6}$$

$$y_r = a_0 + a_1 x + a_2 x^2 \text{, quadratic curve} \tag{7}$$

$$y_r = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \text{, cubic parabola} \tag{8}$$

The correlation coefficient is a measure of the strength of the connection and has the form:

$$R_{xy} = \sqrt{1 - \frac{\Sigma (y_i - y_r)^2}{\Sigma (y_i - \overline{y})^2}} \tag{9}$$

If the value of $R_{xy} > 0.9$ the feature connectivity is very high. If $0.7 < R_{xy} < 0.9$ the feature connectivity is high. If $0.5 < R_{xy} < 0.7$ the feature connectivity is significant [33].

6. Research results and discussion

The empirical distribution of the relevant sample by directions during the spring-autumn period of measurements by classes of electricity consumption is shown in Figures 3 and 4.

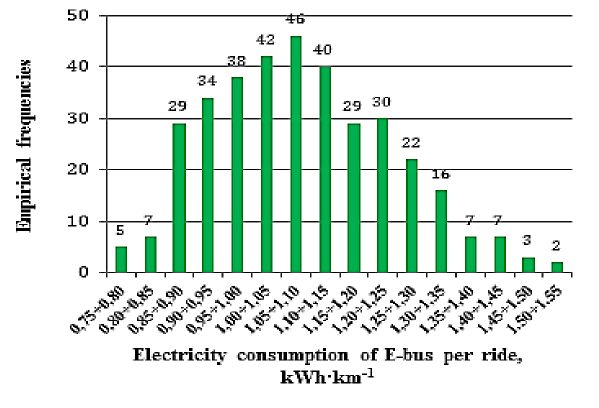

Figure 3. Empirical distribution of electricity consumption of E-bus, Direction "A", spring-autumn period

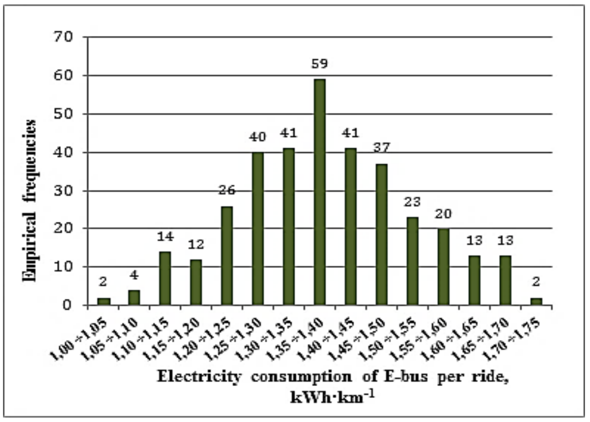

Figure 4. Empirical distribution of electricity consumption of E-bus, Direction "B", spring-autumn period

For both empirical distributions shown, the values of the chi- squares test χ^2 are less than the values in the table (direction "A", χ^2 =18.247< $\chi^{2(11)}_{0,05}$=19.657; direction "B", χ^2 =12.901< $\chi^{2(10)}_{0.05}$=18.307), which proves the hypothesis that the electricity consumption of the E-bus tends to a normal (Gauss) distribution. The empirical distribution of electricity consumption in direction "A" is more asymmetric in relation to direction "B", in favor of lower consumption due to longer sections with downhills where there is a greater effect of electricity recovery in the phase of braking or movement per inertia. The same legality has been proven for the distribution of electricity consumption during the summer and winter periods.

The realized average electricity consumption E^{-}_{ebus} and standard deviation s_{d_E} of the E-bus during the characteristic periods of operation during work days in the spring-autumn period is shown in Tables 4 and 5 [32].

Table 4. Average electricity consumption, direction "A", spring-autumn period

Characteristic period of work during the day	Sample	E^{-}_{ebusA} [kWh·km^{-1}]	$s_{d_{E_A}}$ [kWh·km^{-1}]
First departures	24	0.943	0.145
Morning peak load	64	1.112	0.139
Intermediate load	81	1.043	0.127
Afternoon peak load	91	1.209	0.116
Evening load	71	1.049	0.139
Last departures	26	0.977	0.130
Total	**357**	**1.087**	**0.153**

Table 5.Average electricity consumption, direction "B", spring-autumn period

Characteristic period of work during the day	Sample	E^{-}_{ebusB} [kWh·km^{-1}]	$s_{d_{E_B}}$ [kWh·km^{-1}]
First departures	22	1.212	0.094
Morning peak load	71	1.393	0.099
Intermediate load	82	1.354	0.125
Afternoon peak load	86	1.523	0.120
Evening load	72	1.337	0.100
Last departures	14	1.223	0.068
Total	**347**	**1.386**	**0.143**

Based on a statistical analysis of a sample of 704 measurements of electricity consumption of E-bus Higer KLQ6125GEV3 expressed in [kWh·km^{-1}], which was achieved on the line EKO 1 during the spring-autumn period, when there is no or minimal use of heating or cooling system of E-bus, the average value of electricity consumption of the E-bus in the direction "A" was obtained 1.087 kWh·km^{-1} and the standard deviation is 0.153 kWh·km^{-1}, while the average consumption in the direction "B" was 1.386 kWh·km^{-1} and standard deviation is 0.143 kWh·km^{-1}. It has been proven that the electricity consumption of the E-bus depends on the characteristic period of the E-bus operation during the working day (Tables 4 and 5) as a direct influence of different vehicle loads and traffic conditions. The difference in average electricity consumption was proven in all comparisons of characteristic periods of E-bus operation, except in the case of comparison of average electricity consumption achieved in the period of first and last departures, direction ("A" $|t|$ = 0.870 <1.96; direction "B" $|t|$ = 0.870 <1.96) as well as in the case of comparing inter-peak load and evening load (direction "A" |*t*| = 0.276 <1.96; direction "B" |*t*| = 0.870 <1.96). In the mentioned characteristic periods, the number of transported passengers is approximately the same as the traffic conditions (transport speed), so it is to be expected that there is no statistical significance in the realized average electricity consumption per kilometre travelled.The realized average transport speed $v_{\bar{t}}$ and standard deviation s_{d_t} of the E-bus during the characteristic periods of operation in the spring-autumn period is shown in Tables 6 and 7.

Table 6. Average transport speed, direction "A", spring-autumn period

Characteristic period of work during the day	Sample	$v_{\bar{t}_A}$ [km·h^{-1}]	$s_{d_{t_A}}$ [km·h^{-1}]
First departures	24	15.66	1.59
Morning peak load	64	13.56	1.73
Intermediate load	81	14.24	1.36
Afternoon peak load	91	12.96	1.64
Evening load	71	14.39	1.46
Last departures	26	15.22	1.47
Total	**357**	**13.99**	**1.74**

Table 7. Average transport speed, direction "B", spring-autumn period

Characteristic period of work during the day	Sample	$v_{\bar{t}_B}$ [km·h^{-1}]	$s_{d_{t_B}}$ [km·h^{-1}]
First departures	22	17.46	1.34
Morning peak load	71	14.87	1.54
Intermediate load	82	15.57	1.30
Afternoon peak load	86	13.12	1.54
Evening load	72	15.93	1.54
Last departures	14	16.46	1.47
Total	**347**	**14.81**	**1.92**

Average electricity consumption and transport speeds achieved in the directions "A" and direction "B" are shown in Table 8 and Table 9 [32].

Table 8. Average electricity consumption and the transport speed of E-bus, direction "A"

Interval of transport speed [km·h^{-1}]	Frequency	Average consumption in interval [kWh·km^{-1}]
9.0 ÷10.0	1	1.368
10.0÷11.0	13	1.259
11.0÷12.0	30	1.182
12.0÷13.0	66	1.130
13.0÷14.0	71	1.086
14.0÷15.0	71	1.086
15.0÷16.0	51	1.022
16.0÷17.0	39	1.029
17.0÷18.0	15	0.931
Total	**357**	

Table 9. Average electricity consumption and the transport speed of E-bus, direction "B"

Interval of transport speed [km·h^{-1}]	Frequency	Average consumption in interval [kWh·km^{-1}]
9.0 ÷10.0	1	1.682
10.0÷11.0	5	1.502
11.0÷12.0	17	1.536
12.0÷13.0	39	1.443
13.0÷14.0	53	1.446
14.0÷15.0	80	1.411
15.0÷16.0	64	1.362
16.0÷17.0	44	1.289
17.0÷18.0	25	1.286
18.0÷19.0	11	1.255
19.0÷20.0	8	1.240
Total	**347**	

Relation between of the average electricity consumption and achieved transport speeds (Tables 8 and 9), is described by the degree function of the second-order $y_r = 0.0037x^2 - 0.1471x + 2.4104$, with a high degree of correlative dependence R_{xy}=0.980 for direction "A", and $y_r = 0.0022x^2 - 0.1033x + 2.4289$, R_{xy}=0.964 for direction "B". In the characteristic periods when the lowest electricity consumption was realized (first and last departures), the highest transport speed was achieved. In the characteristic periods with the highest electricity consumption (afternoon and morning peak load), the lowest transport speeds were achieved. Transport speeds achieved in intermediate and evening loads have approximate values, so the difference has no statistical significance. The dependence of the electricity consumption of the E-bus on the outside temperature achieved in the direction "A" and "B" during the winter, transition (spring/autumn), and summer period is shown in Figures 5 and 6 [32].

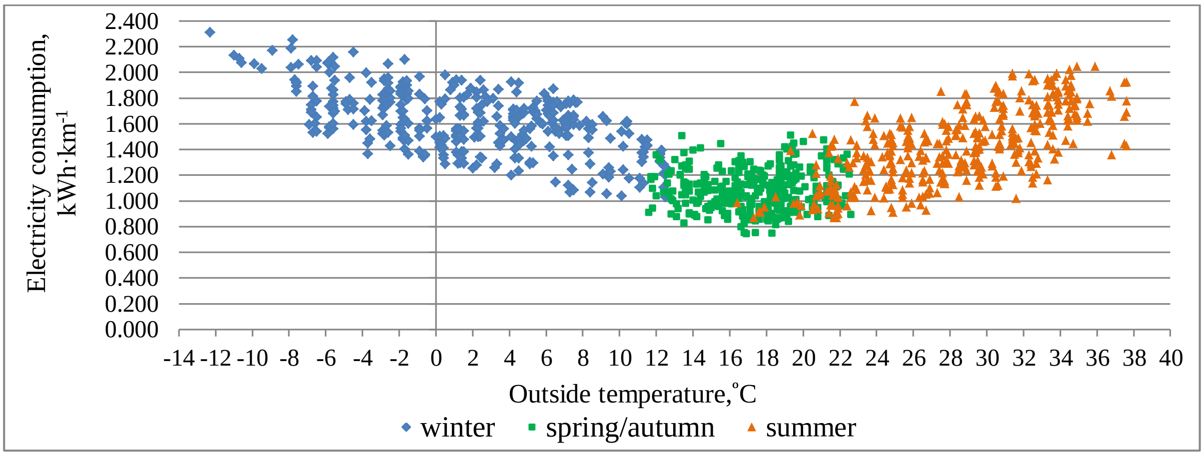

Figure 5. Electricity consumption and outside temperature, direction ''A'', winter, transition and summer period

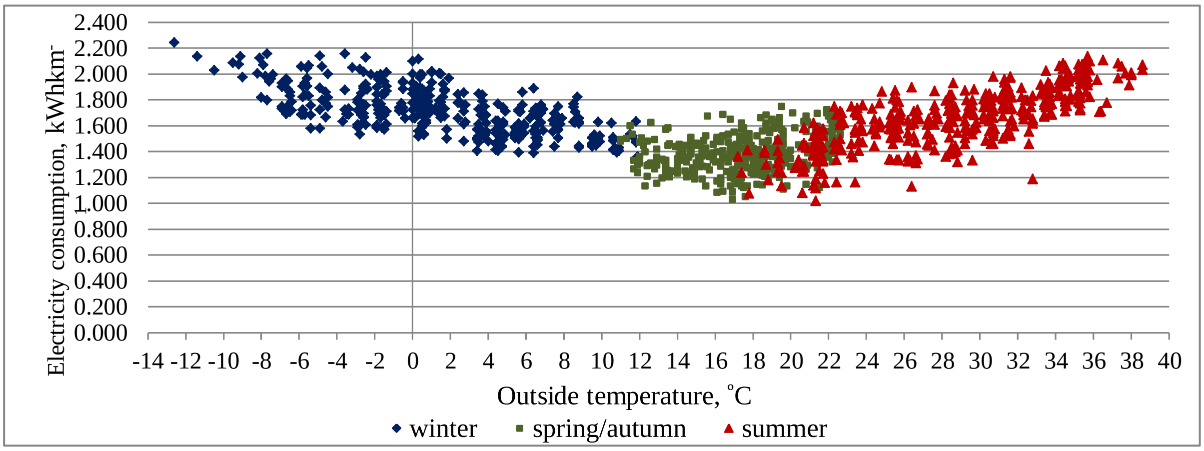

Figure 6. Electricity consumption and outside temperature, direction ''B'', winter, transition and summer period

In the spring-autumn period, the electricity consumption of the E-bus was analyzed depending on the outside temperatures which were registered during the operation of the E-bus. During the selection of the days when the outdoor temperature measurements were made, they ranged from +12 °C to +23 °C. The dependence of the electricity consumption of the E-bus and the outdoor temperature measured in the directions "A" and "B", is shown in Table 10 and Table 11 [32].

Table 10. Average electricity consumption and outside temperature, direction "A", spring-autumn period

Interval of outside temperature [°C]	Frequency	Average consumption in interval [kWh·km^{-1}]
12.0÷13.0	24	1.105
13.0÷14.0	17	1.104
14.0÷15.0	26	1.070
15.0÷16.0	53	1.057
16.0÷17.0	46	1.074
17.0÷18.0	44	1.043
18.0÷19.0	57	1.068
19.0÷20.0	25	1.119
20.0÷21.0	19	1.141
21.0÷22.0	19	1.122
22.0÷23.0	27	1.171
Total	**357**	

Table 11. Average electricity consumption and outside temperature, direction "B", sprng-autumn period

Interval of outside temperature [°C]	Frequency	Average consumption in interval [kWh·km^{-1}]
12.0÷13.0	14	1.385
13.0÷14.0	23	1.319
14.0÷15.0	29	1.343
15.0÷16.0	47	1.346
16.0÷17.0	50	1.376
17.0÷18.0	52	1.366
18.0÷19.0	58	1.389
19.0÷20.0	18	1.452
20.0÷21.0	27	1.459
21.0÷22.0	23	1.476
22.0÷23.0	6	1.508
Total	**347**	

Based on the results shown in Table 10 and Table 11, in the temperature range from +14 ℃ to +19 ℃, the difference in the realized average consumption is minimal. In the observed temperature range, the difference in consumption between the minimum and maximum electricity consumption is only 2.97% in direction "A" and 3.42% in direction "B". At outside temperatures of +12 ℃ to +14 ℃, some individual results of E-bus electricity consumption have higher values as a consequence of using the passenger space heating system most often in the morning hours of vehicle operation. The individual influence of the driver regarding the use of the system for heating the passenger and driver's space in the vehicle is also expressed, which has an impact on the consumption of electricity. At outdoor temperatures from +19 ℃ to +23 ℃, where the air-conditioning system is used, there is an increase in the average electricity consumption of the vehicle, most often during the afternoon peak load when the number of passengers in the vehicle is the highest and when outside temperatures reach their maximum value. Analysing figures 5 and 6, it can be concluded that at outdoor temperatures between +16 ℃ and +18 ℃, the lowest individual electricity consumption of the E-bus is achieved, which means that these are the optimal outdoor temperatures when the E-bus has the lowest electricity consumption. It is assumed that in this specified temperature range the probability of using the heating or cooling system in the vehicle is the lowest, in order to minimize the impact of these factors on the electricity consumption of E-buses. In this case, the main influence on consumption was vehicle load and traffic speed, i.e. characteristic period of vehicle operation and driving style.

In the summer and winter period operation of the E-bus, in order to provide satisfactory travel comfort, there is the intensive use of cooling system (air condition) or heating system for cooling or heating the passenger and driver's space, which has an impact on higher electricity consumption E-bus energy. A sample of 823 measurements of bus electricity consumption during the summer period, which included external temperatures between +16 ℃ and +40 ℃, are shown in the Table 12 and Table 13 [32].

Table 12. Average electricity consumption and outside temperature, direction "A", summer period

Interval of outside temperature [℃]	Frequency	Average consumption in interval [kWh·km^{-1}]
16.0÷18.0	5	0.927
18.0÷20.0	6	1.040
20.0÷22.0	38	1.093
22.0÷24.0	38	1.284
24.0÷26.0	55	1.300
26.0÷28.0	49	1.298
28.0÷30.0	58	1.444
30.0÷32.0	50	1.537
32.0÷34.0	58	1.632
34.0÷36.0	33	1.747
36.0÷38.0	11	1.721
Total	**401**	

Table 13. Average electricity consumption and outside temperature, direction "B", summer period

Interval of outside temperature [℃]	Frequency	Average consumption in interval [kWh·km^{-1}]
16.0÷18.0	4	1.268
18.0÷20.0	11	1.312
20.0÷22.0	46	1.373
22.0÷24.0	37	1.554
24.0÷26.0	46	1.595
26.0÷28.0	36	1.555
28.0÷30.0	53	1.635
30.0÷32.0	63	1.722
32.0÷34.0	46	1.756
34.0÷36.0	65	1.939
36.0÷38.0	10	1.927
38.0÷40.0	5	2.108
Total	**422**	

The dependence of the electricity consumption of the E-bus expressed in [kWh·km^{-1}] and the outdoor temperature expressed in [℃], which was achieved in the summer period shown in Table 12 and Table 13, is described by the degree function of the second-order, direction "A", $y_r = -0.0003x^2 + 0.0551x + 0.0755$, R_{xy}=0.987; direction "B", $y_r = 0.0004x^2 + 0.0149x + 0.9253$, R_{xy}=0.980, which confirms the extremely high dependence of these two quantities. The summer period of E-bus operation is characterized by a constant increase of outdoor temperature from morning to afternoon. In order to provide the necessary thermal comfort for the passengers, a system for cooling the interior of the vehicle is intensively used. In the summer period of the E-bus operation, the lowest electricity consumption of the E-bus is in the first morning departures when the outside temperatures are between 16 ℃ and 18 ℃, when there is no need to use a cooling system and when the number of passengers is the lowest. With the increase of the outside temperature and the number of passengers in the vehicle, the intensity of use and the engaged power of the air-conditioning system increase, so that the total consumption of the E-bus increases according to the described degree function of the second order.

A sample of 789 measurements of bus electricity consumption during the winter period, which included external temperatures between -12 ℃ and +12 ℃, are shown in the Table 14 and Table 15 [32].

Table 14. Average electricity consumption and outside temperature, direction "A", winter period

Interval of outside temperature [℃]	Frequency	Average consumption in interval [kWh·km^{-1}]
-12.0 ÷ -10.0	4	2.159
-10.0 ÷ -8.0	3	2.089
-8.0 ÷ -6.0	23	1.864
-6,0 ÷ -4.0	30	1.792
-4.0 ÷ -2.0	40	1.727
-2.0 ÷ 0.0	54	1.692
0.0 ÷ 2.0	53	1.570
2.0 ÷ 4.0	35	1.590
4.0 ÷ 6.0	50	1.580
6.0 ÷ 8.0	52	1.601
8.0 ÷10.0	17	1.377
10.0 ÷12.0	36	1.325
Total	**397**	

Table 15. Average electricity consumption and outside temperature, direction "B", winter period

Interval of outside temperature [℃]	Frequency	Average consumption in interval [kWh·km^{-1}]
-12.0 ÷ -10.0	3	2.135
-10.0 ÷ -8.0	7	2.030
-8.0 ÷ -6.0	23	1.866
-6,0 ÷ -4.0	30	1.837
-4.0 ÷ -2.0	39	1.781
-2.0 ÷ 0.0	57	1,785
0.0 ÷ 2.0	71	1.770
2.0 ÷ 4.0	37	1.639
4.0 ÷ 6.0	47	1.576
6.0 ÷ 8.0	41	1.608
8.0 ÷10.0	23	1.572
10.0 ÷12.0	14	1.471
Total	**392**	

The dependence of E-bus electricity consumption and outdoor temperature, which was achieved in the winter period for directions (Table 14 and Table 15) is described by the degree function of the third order, for direction "A", $y_r = -0.0002x^3 + 0.0009x^2 - 0.0182x + 1.646$, R_{xy}=0.984 and for direction "B", $y_r = -0.000073x^3 + 0.00056x^2 - 0.0194x + 1.727$, R_{xy}=0.982. In the winter period of E-bus operation, the highest electricity consumption of E-buses is at extremely low temperatures, which are the most common in the early-morning hours, when the use of heating systems is the most intensive with the highest power to achieve the required ambient temperature in the passengers and driver space. At extremely low temperatures (below -8 ℃), the total consumption of the E-bus exceeds the value of 2.0 kWh·km^{-1}, which is almost twice the consumption compared to the optimal consumption during the spring-autumn period at temperatures between 16℃ and 18℃. As the outside temperature rises, consumption decreases according to the function presented. At outdoor temperatures from 0 ℃ to 5 ℃, the electricity consumption has approximately the same value, and with a further increase in the outdoor temperature, there is a decrease in the electricity consumption of the E-bus. Based on a detailed statistical analysis of electricity consumption made during the spring-autumn, summer, and winter period of operation of the E-bus on the line EKO 1, it is possible to compare the results obtained for directions "A" and "B"'. Figures 7 and 8 show the results of the average electricity consumption of the E-bus by characteristic periods for directions.

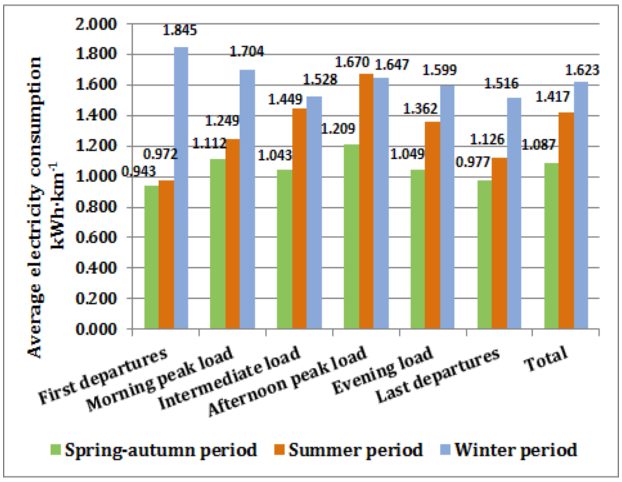

Figure 7. Average electricity consumption of E-bus on line EKO 1, spring-autumn, summer and winter operation period, direction "A"

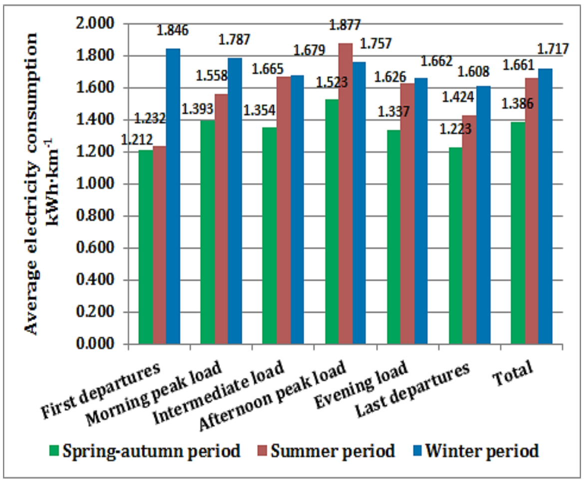

Figure 8. Average electricity consumption of E-bus on line EKO 1, spring-autumn, summer and winter operation period, direction "B"

The analysis of the results of the average electricity consumption according to the characteristic periods of the E-bus operation in the winter period (Figures 7 and 8) differs significantly compared to the summer, and especially the spring-autumn period. In winter, during the first departures, when traffic conditions are the most favorable in terms of the smallest number of passengers in the vehicle and the highest transport speed, registered the highest electricity consumption is E-bus (direction "A "1.845 kWh·km^{-1}, direction "B", 1.846 kWh·km^{-1}), which, in comparison with the spring-autumn period for first departures is higher by 95.6% observed for direction "A" or 52.3% for direction "B". which proves the dominant influence of the heating system on the electricity consumption of the E-bus. In the direction "A," the difference in average electricity consumption is random compared to the afternoon peak load during the summer and winter periods $|t|=0.748<1.96$. In all other comparisons, the differences in average electricity consumption have a statistically significant difference. In the direction "B," the difference in average electricity consumption is random compared to the intermediate load during the summer and winter periods $|t| = 0.599 <1.96$ and the evening load $|t|=1.428 <1.96$. In all other comparisons, the differences in average electricity consumption have a statistically significant difference. It should be noted that the degree of use of the E-bus heating system when moving in the direction "B" is lower than moving in the direction "A," due to the generally higher consumption of E-bus present in the direction "B," in order to prevent excessive discharge of the supercapacitor, which would result in a decrease in the autonomy of movement, i.e. forced stopping on the route. Electricity consumption of E-bus during the first departures in spring-autumn and summer period of operation is approximately the same (Figures 11 and 12), i.e. the difference is random since for direction "A" $|t| = 0.843 <1.96$, direction "B" $|t| = 0.626 <1.96$. An overview of the average value of electricity consumption of the E-bus for each period of operation during the year is given in Table 16.

Table 16. Overview of average electricity consumption by periods of E-bus operation on the line EKO1

Period	Direction "A" [kWh·km^{-1}]	Direction "B" [kWh·km^{-1}]	Average (A+B)/2 [kWh·km^{-1}]
Spring-autumn	1.087	1.386	1.237
Summer	1.417	1.661	1.539
Winter	1.623	1.717	1.670
Annual average	**1.393**	**1.593**	**1.493**

If it is adopted that the winter period of operation lasts 5 months, spring-autumn 4 months, and summer 3 months, it follows that the average annual electricity consumption of E-buses on the line EKO 1 is 1.493 $kWh \cdot km^{-1}$.

The way the driver drives the electric bus is an influential factor on the electricity consumption of the E-bus. In order to investigate whether the way of driving an E-bus impacts on the electricity consumption of the E-bus, an analysis of "zero rides" of E-bus was done. "Zero ride" is realized at the beginning and end of the working day, when the E-bus moves from the depot (garage) to the starting station on the line, the i.e. terminus or vice versa, without standing at stations and without passengers. On the example of "zero rides" from the depot at Dorcol location to the Belville terminal, 7.00 km long, which were realized in the early morning hours between 04:30 and 05:00, electricity consumption and driving time was measured.

The sample of 37 measurements was analysed that were realized in the period from May 29, 2019, to September 10, 2019 [32]. Table 17, shows the distribution of the sample of 37 measurements of electricity consumption of the E-buses that were achieved during the "zero rides" on the Dorcol-Belville route by 8 drivers.

Table 17. Distribution of E-bus electricity consumption, "Zero ride", route "Dorcol– Belville"

Electricity consumption [$kWh \cdot km^{-1}$]	Frequencies
0.65÷0.70	2
0.70÷0.75	9
0.75÷0.80	10
0.80÷0.85	8
0.85÷0.90	8
Total	**37**

The average value of electricity consumption of the E-bus is 0.792 $kWh \cdot km^{-1}$ and the standard deviation is 0.063 $kWh \cdot km^{-1}$. The lowest value of the realized electricity consumption of the E-bus is 0.690 $kWh \cdot km^{-1}$ and the highest 0.895 $kWh \cdot km^{-1}$ [32]. The percentage difference between the minimum and maximum value is 29.7%. The obtained values of electricity consumption of the E-bus are the outcomes of different driving styles without any prior driver training.

After training drivers for energy-efficient E-bus driving style, the percentage difference between “energy efficient” and "aggressive" driving styles is even greater. It has been proven that the recommended energy-efficient driving style can reduce the electricity consumption of the E-bus on the EKO 1 line, observed in $kWh \cdot km^{-1}$, between 31.1% and 35.2% compared to the "aggressive" driving style [18].

The obtained results of electricity consumption during "zero" runs represent cases of electricity consumption of the E-bus, without load, without the impact of the heating-cooling system, and with minimal impact of traffic flow. Consumption differences are due to the driving style in the acceleration phase (continuous pressing of the acceleration pedal) [18], movement by inertia and braking of the vehicle, and the driver's ability to cross the section from the depot to the starting station (terminus) with fewer stops, especially at traffic lights, which proves that the influence of driving style can significantly affect the increase in electricity consumption of the E-bus in approximately the same operating conditions.

The presence of sections of the route on the line with a negative slope (sections in decline) which is present in the direction "A" (Fig. 1) and the impact on the possibility of achieving greater recovery of electricity in the braking and deceleration phase is directly related to driving style and electricity consumption. In all comparisons of the average consumption of E-buses realized by directions of movement and characteristic periods, the consumption was lower where there was a greater presence of sections of the route line with a negative slope.

7. Conclusion

Electricity consumption of E-bus in real operating conditions can have significant differences as a result of certain influencing factors. Based on the conducted research, it has been proven that the winter period of work, when the system for heating the passengers and driver space is intensively used, has the greatest impact on increasing the consumption of E-bus. At low temperatures below -8℃, the maximum electricity consumption of the E-bus is over 2.0 $kWh\cdot km^{-1}$, During the first morning departures, the average consumption is between 1.845 $kWh\cdot km^{-1}$ and 1.846 $kWh\cdot km^{-1}$. The impact of the operation of the cooling system (air-conditioning) for passengers and driver compartment during the summer period also has a large impact on the electricity consumption of the E-bus, which is most pronounced during the afternoon peak load when the average consumption is between 1.670 $kWh\cdot km^{-1}$ and 1.877 $kWh\cdot km^{-1}$. When these two systems are not used on the E-bus, during the spring-autumn period, the highest electricity consumption is present during the afternoon peak load as a result of maximum vehicle load and low transport speeds due to traffic conditions, (regime "go-stop", congestion traffic), the average consumption is between 1.209 $kWh\cdot km^{-1}$ and 1.523 $kWh\cdot km^{-1}$. The lowest electricity consumption of the E-bus is during the spring-autumn period of operation, when the vehicle air conditioning or heating system is not used, while the outdoor temperatures range between 16 ℃ and 18 ℃, with low to medium passenger occupancy, and traffic conditions with no disturbances on the route and using an economical driving style. In those situations, the consumption is about 0.92 $kWh\cdot km^{-1}$ in direction "A" and 1.1 $kWh\cdot km^{-1}$ for direction "B".Sections of the route with a negative slope, which are present in direction "A", affect the lower engaged power of the vehicle's propulsion system during the acceleration phase and the phase where the vehicle has a constant speed of movement, and in the phase of deceleration and braking, it enables greater recovery of electrical energy which manifests itself in the lower average consumption of E-buses in direction "A" compared to direction "B". If an inefficient driving style is present, the electricity consumption of the E-bus will have an even greater value. Conversely, energy-efficient driving, which includes proper acceleration, optimal constant speed path, and braking, while achieving maximum energy recovery, reduces electricity consumption. It has been proven that this way of driving can reduce the electricity consumption of the E-bus by up to 35%. The research on the influencing factors of the electricity consumption of E-bus, which was carried out in the paper, has limitations. Obtained results in the paper are related to the Higer KLQ6125GEV3 electric buses, which use the supercapacitor for storing electricity with a capacity of 20 kWh. This needs to be emphasized considering that with electric-powered buses, depending on the applied electrical energy storage system, the type and capacity of the battery or supercapacitor, there are significant differences in the weight of the empty vehicle. The greater mass of the empty vehicle additionally affects the overcoming of the vehicle's movement resistance, i.e. it increases the E-bus electricity consumption. In addition to the aforementioned influencing factors of the consumption of electricity that are present in the real exploitation of the E-bus and which are investigated in detail in the paper, some factors that have an influence on the consumption such as frontal and side-impact of wind, the condition of the road with different surfaces (asphalt, asphalt-concrete), the adhesion of pneumatics and the surface in some specific conditions where the surface is covered with snow, ice and water, have not been investigated in detail and represent research limitations.The results presented in the paper can serve as a basis and benchmark for future similar research that will be carried out with electric buses of different concepts under the conditions of operation on public city transport lines. It is realistic to expect that, in the future, vehicles will be technically improved in terms of mass reduction, further optimization of the operation of drive systems, electrical energy storage systems, auxiliary devices, as well as heating and cooling systems, which will contribute to reducing electrical losses. One of the directions of further research is a larger investigation of the influence of driving style on the consumption of electricity and the recovery of E-buses in different operating modes.

Nomenclature

$E'_{ebus_{L_A}}$ - electricity consumption of E-bus per ride, direction "A", [kWh·km^{-1}]
SOC_{A_p} - state of charge at the start of ride, direction "A", [%]
SOC_{A_k}-state of charge at the end of ride, direction "A", [%]
L_A - length of route in direction "A", [km]
T_{t_A}- travel time, direction "A", [min]
v_{t_A} - transport speed, direction"A", [km·h^{-1}]
C_b - max. capacity supercapacitor, [kWh]
η_{ch} - coefficient efficiency of charger, [-]
E_{ebus}^{-} - average value of consumption, [kWh·km^{-1}]
s_{d_E} - standard deviation of consumption, [kWh·km^{-1}]
χ^2- chi-square test, [-]
|t| - test of equality mean value two basic sets, [-]
R_{xy}- coefficient of correlative dependence, [-]

$E'_{ebus_{L_B}}$ - electricity consumption of E-bus, per ride, direction "B", [kWh·km^{-1}]
SOC_{B_p} - state of charge at the start of ride, direction "B", [%]
SOC_{B_k}-state of charge at the end of ride, direction "B", [%]
L_B - length of route in direction "B", [km]
T_{t_B}- travel time, direction "B", [min]
v_{t_B} - transport speed, direction "B", [km·h^{-1}]
v_t^{-} - average transport speed, [km·h^{-1}]
s_{d_t} - standard deviation of transport speed, [km·h^{-1}]

Acronyms:
E-bus –Electric bus
EKO 1 – E-bus line in Belgrade
Higer KLQ6125GEV3 – brand and model of E-bus

References

[1] Mišanović, S.: History, Curent status and trends for further introductionof electric buses in the cities of Europa and world, *Proceedings*, 8th International Conference “Towardsa human city”, New Mobility Challenges, Novi Sad, Serbia, 2021, ISBN 978-86-6022-371-7, pp.361-370.

[2] Directive (EU) 2019/1161 of the European Parliament and of the Council, 20 June 2019.

[3] Hentunen, A., Suomela, J., *et al.*, Full-Scale Hardware-in-the-Loop Verification Environment for Heavy Duty Hybrid Electric Vehicles, *Proceedings*, EVS25 World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Shenzhen, China, 2010. World electric Vehicle Journal Vol.4 - ISSN 2032-6653–2010 WEVA, pp. 119 -127.

[4] Tomić, M., Jovanović, Z., *et al.*, Some energetic and ecological aspects of different city bus drive systems, *Thermal Science*, 22 (2018), 3, pp.1493-1504, ISSN 2334-7163, DOI: https://doi.org/10.2298/TSCI171027310T

[5] Rieck, F.G, Electric buses at Rotterdam, Clean fleets, Bremen, 2014. https://clean-fleets.eu/fileadmin/files/e-Busz_Rotterdam_final_Ecomobiel-Bremen_-_Rieck_small_.pdf

[6] Pütz, R., Operational Analysis with a HIGER-Electrobus with AOWEI-Supercaps using Energy Consumption Data in Real Operation on an Urban Bus Route in Sofia. Report No. BELICON/CHMO-1-25.10.2014.

[7] Erkkila, K. and NyLund N., Test mule Energy consumption, Pre-results from laboratory tests (new methods), VTT Technical Research Centre of Finland, 2014.

[8] Grutter, J., Real world performances of Hybrid and Electric buses-Environmental and Financial Performance of Hybrid and Battery Electric Transit Buses, Grutter Consulting, 2014.

[9] Halmeaho, T., Tammi, K., Ruotsalainen, S. *et al.*, Electric City Bus Energy Flow Model and its Validation by Dynamometer Test, *Proceedings*, 2015 IEEE Vehicle Power and Propulsion Conference (VPPC), Montreal, QC, Canada, 2015, DOI:10.1109/VPPC.2015.7352942.

[10] Varga, B.O. and Iclodean, C., Electric Buses For Urban Transportation: Assessments On Cost, Infrastructure And Exploitation, Annals of Oradea University, Fascicle of Management and Technological Engineering, ISSUE#1, May 2015, pp.253-258. http:// www.imtuoradea.ro/auo.fmte/ .

[11] Kim, J., Song, I., Choi, W., An Electric Bus a Batery Exchange System, *Energies* 2015,8, ISSN 1996-1073, pp.6806-6819; DOI:10.3390/en8076806.

[12] Mišanović, S., Glišović, J., Taranović, D., *et al.*, Electric Energy Consumption and Recuperation on E-bus in Different Exploitation Conditions, *Proceedings*,18th Symposium on Thermal Science and Engineering of Serbia, Sokobanja, Serbia, 2017, ISBN 978-86-6055-098-1, pp.961-976.

[13] Eudy, L., Prohaska, R., Kelly, K., *et al.*, Foothil Transit Battery Electric Bus Demonstration Results, Technical Report NREL/TP-5400-65274, 2016, National Renewable Energy Laboratory 15013 Denver West Parkway, Golden, USA.

[14] Gis, W., Kruczynski, S., Taubert, S., *et al.*, Studies of energy use by electric buses in SORT tests, *Combustion Engines*, 170(2017), 3, pp. 135-138. DOI: 10.19206/CE-2017-323.

[15] Vepsäläinen, J., Kivekäs, K., Otto K.,Lajunen A., *et al.*, Development and validation of energy demand uncertainty model for electric city buses, *Transportation Research Part D*, 63 (2018), pp. 347-361, https://doi.org/10.1016/j.trd.2018.06.004.

[16] Kivekäs, K., Lajunen, A., Vepsäläinen, J., *et al.*, City Bus Powertrain Comparasion: Driving Cycle Variation and Passenger Load Sensitivity Analysis, *Energies*,11(2018), 1755; doi:10.3390/en11071755.

[17] Mišanović, S., Živanović, Z., Tica, S., Energy efficiency of different bus subsystems in Belgrade public transport, *Thermal Science*, 19(2015), 6, pp.2233-2244, ISSN 2334-7163, DOI: https://doi.org/10.2298/TSCI151116193M.

[18] Blagojević, I., Popović, V., Mitić, S., et al., Project- Research on the impact of driving style on energy efficiency in electric buses, Faculty of Mechanical Engineering in Belgrade, 2020. Client of the project City Administration Belgrade-Secretariat for Public Transport (in Serbian language).

[19] Taratakovsky, L., Gutman, M., Mosyak, A., Energy Efficiency of Road Vehicles-Trends and Challanges,In: *Energy Efficiency*, Chapter 3, (Eds: Santos Cavalcanti and M.Ribeiro Barbosa), 2012 Nova Science Publischers, Inc. ISBN: 978-1-62081-817-6.

[20] Vepsäläinen, J, Otto, K, Lajunen, A, *et al.*, Computationally efficient model for energy demand prediction of electric city bus in varying operating conditions. *Energy* 169(2019), pp.433-443, DOI:10.1016/j.energy.2018.12.064

[21] Knote, T., Auswirkungen elektrischer Heizungen auf die Einsatzmöglichkeiten von Batteriebussen, Fraunhofer-Institut für Verkehrs-und Infrastruktursysteme Dresden, Report, Eliptic workshop, 5 2017, Bremen.

[22] Kratzing, R., HEAT2GO-Entwicklung eines schnellladefähigen Latentwärmescpeichers für die Beheizung von Elektrobussen, Fraunhofer-Institut für Verkehrs-und Infrastruktursysteme, Dresden, Report, Eliptic workshop, 2017, Bremen.

[23] Schmitz, F., Ansätze aus Sich der Verkehrsunternehmen am Beispiel Deutschland, VDV Report, Eliptic workshop, 2017, Bremen.

[24] Basile, R., Scheid, H., Tanke, D., *et al.*, Valeo Thermal Bus Systems Beheizungsstrategien für Elektrobusse, Report, Eliptic workshop, 2017, Bremen.

[25] ***, Klimatisierung von linienbussen der Zulassung klassen I und II, fur konventionell angetriebene Diesel-und dasbusse als auch fur Hybrid und Elektrobuse, VDV-Schrift 236, Stand 03/2018.

[26] Mišanović, S.,Taranović, D.,Lukić, J., *et al*, Exploitation Specificities of E-buses in winter conditions from aspect of energy efficiency, *Proceedings*, 14. International Conference on accomplishments in electrical, mechanical and information engineering DEMI 2017, Banja Luka, 2017, pp.703-711, ISBN 978-99938-39-72-9.

[27] Hegazy, O., Coosemans, T., Electrified buses in Brussels: Design considerations and charging strategy, Vrije Universitet Brussel, CIVITAS ELIPTIC Webinar: E-bus planning supported with simulation tools, 2017, Brussels.

[28] Sabate, M., Air conditioning consumption in TMB Barcelona, UITP-working group E-bus thermal comfort, meeting, 2018, Brussels.

[29] JKP GSP "Belgrade": Static and dynamic elements of the bus subsystem, November 2018 (in Serbian language).

[30] HIGER BUS COMPANY LIMITED: Electric bus KLQ6125GEV3 - Technical documentation, 2016.

[31] "UITP Project E-SORT- Cycles for electric vehicles, UITP,D/2017/0105/9, 2017 .

[32] Mišanović, S ., Energy and environmental performance of electric buses in the passenger transport system, Doctoral dissertation, Faculty of Engineering, University of Kragujevac, 2021 (in Serbian language)

[33] Vukadinović, S., Elements of probability theory and mathematical statistics, Economic Review Belgrade, 1990 (in Serbian language).

Submitted: 09.7.2022.
Revised: 15.9.2022.
Accepted: 22.9.2022.