ENERGY EFFICIENCY OF DIFFERENT BUS SUBSYSTEMS IN BELGRADE PUBLIC TRANSPORT

by

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Research in this paper comprised experimental determination of energy efficiency of different bus subsystems (diesel bus, trolleybus and fully electric bus) on chosen public transport route in Belgrade, Serbia. Experimental measuring of energy efficiency of each bus type has been done based on the analysis of parameters of vehicle driving cycles between stops. Results of this analysis were basis for development of theoretical simulation model of energy efficiency. The model was latter compared with the results of simulation done by "Solaris Bus & Coach" company for the chosen electric bus route. Based on demonstrated simulation, characteristics of electric bus batteries were defined, the method and dynamic of their re-charge was suggested, as well as choice for other aggregates for drive system and technical characteristics for the electric buses were suggested.

Key words: *energy efficiency, electric bus, diesel bus, trolleybus*

Introduction

City Public Transport Company BELGRADE (CPTCB) is the biggest and the most important operator in the public transport system in Belgrade and is comprised of the three transport subsystems:

- tram subsystem (135 trams operating on 11 routes),
- trolleybus subsystem (94 trolleys operating on 8 routes), and
- bus subsystem (650 buses operating on 118 routes).

On daily basis, CPTCB provides transport for about 1,580,000 passengers. Share of the bus subsystem in the transport work is about 70%. From 650 buses in fleet 640 are diesel powered and 10 are compresed natural gas (CNG) buses. Share of drive aggregates, according to Euro standards, is: Euro 2 (21.8%), Euro 3 (26.9%), Euro 4 (15.3%), Euro 5 (30%), and EEV (5.8%) [1].

Today, there is a trend of increasing number of buses with pure electric drive worldwide. From the year 2013, in more than 50 cities of Europe (Barcelona, Milan, Copenhagen, Geneva, London, Vienna, Düsseldorf, Bremen, Hamburg, Belgrade, Sofia, *etc.*) the test trials were performed on electric buses (E-Bus) with different systems for charging batteries. Typical

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examples of electric buses that were or still are in trial or demonstration test across Europe are: Solaris Urbino E12, BYD E12, VDL Citea, Skoda Perun, SOR BN 12, EMOSS, Siemens/Rampini, Hybricon Arctic Whisper (HAW 12 LE), Caetano Bus (Cobus 2500 EL), and many others [2]. In its development plans CPTCB puts special attention to possibility of application of E-Bus concept to operate on ecologically most vulnerable corridors. In the previous period, the emphasis was put on monitoring the trends of E-Bus development, exchange of experiences with public transport companies and bus manufacturers, and performing pilot research with BYD E12 bus. Positive experiences with exploitation of BYD electric bus encouraged CPTCB to plan purchasing the first 5 buses (solo version) in the year 2016. This would be the first step in the company's long-term strategy of using electric buses.

The preliminary trials of Chinese buses BYD E12 prompted the authors of this paper to make more comprehensive research through comparative testing of the energy efficiency of three different bus subsystems on the selected line of public transport in Belgrade. The study included diesel bus, trolleybus, and electric bus. For typical parameters of the vehicle driving cycle experimental measuring of energy efficiency was done and results were used as input for theoretical calculations of energy efficiency of all subsystems. The results of Belgrade energy efficiency model was then compared with the results of simulation done by "“Solaris Bus & Coach” company for the chosen electric bus route. Based on this analysis features of electric bus batteries were defined, as well as the method and dynamic of their recharge.

Basic characteristics of vehicle driving cycle parameters

By analyzing topography of the lines of public city transport in Belgrade, including the available infrastructure, from the aspect of future development of appropriate systems for fast charging of electric buses, trolleybus line 41 (Studentski trg – Banjica II) was selected. This line was considered to be appropriate for testing the buses having different bus subsystems including fully electric bus. The experimental measurements of energy consumption were taken on the line 41 for three different bus subsystems: trolleybus (BKM-321), diesel bus (IK-112N), and fully electric bus (BYD E-12). Urban public transport line 41 represents a typical radial urban public transport line that connects town center with broader urban core, fig. 1. The mean length of the line is 9.7 km. The number of stops is 20 in forward and 18 in backward direction. The mean exploitation speed on the line is about 17.5 km/h.

Figure 1. Route of urban public transport line 41

From the of exploitation point of view, line 41 is characterized by intensive passenger flows, expressed longitudinal slopes and falls along the route, fig. 2, a common regime of steady work, especially in the central city zone due to a large number of traffic lights, *etc*.

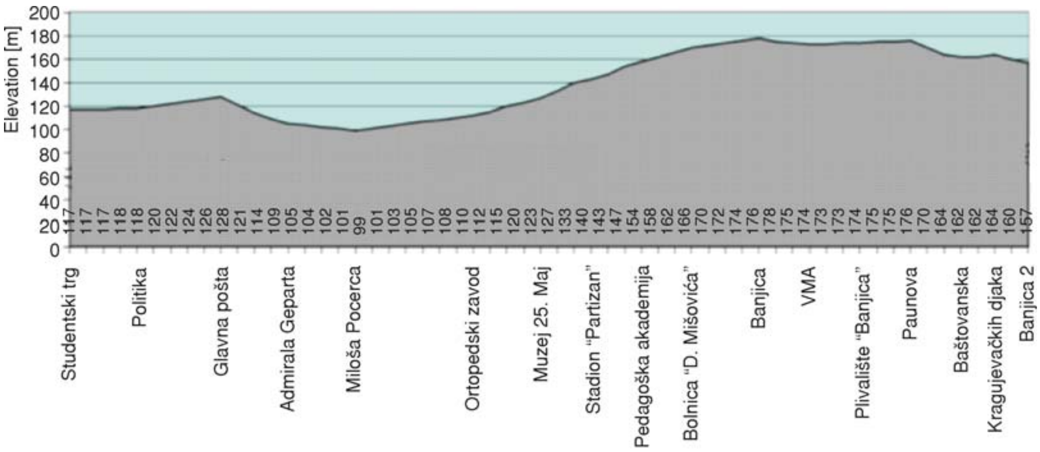

Figure 2. Elevation characteristics of line 41

For the purpose of driving cycle parameters identification along the selected line, the measurements using an experimental vehicle (trolleybus) have been undertaken in order to register the characteristic parameters of vehicle movement such as: trip time and dwell time at each part of the route, stop distance, number of passengers, and recording of topography elements of each part of the route. In tabs. 1 and 2, a part of the registered parameters are shown, that relate to performed loads in forward and backward direction.

Table 1. Research results for line 41 – forward direction (afternoon rush hour/period)

Stop	Arrival time [hh:mm:ss]	Departure time [hh:mm:ss]	Dwell time [mm:ss]	Stop distance [m]	Trip time [s]	Exploatation speed [ms^{-1}]	Exploatation speed [kmh^{-1}]	Elevation [m]	Passenger volume	Angle α [°]
Studentski trg	17:31:03	17:35:00	03:57	0				117	19	
Politika	17:39:16	17:39:34	00:18	650	256	2.54	9	121	28	0.353
Glavna Posta	17:44:35	17:44:47	00:12	812	301	2.70	10	131	33	0.706
Admirala Geprata	17:46:59	17:47:15	00:16	679	132	5.14	19	106	36	–2.110
Milosa Pocerca	17:48:47	17:48:55	00:08	635	92	6.90	25	100	39	–0.541
Ortopedski zavod	17:50:36	17:50:48	00:12	1245	101	12.33	44	112	34	0.552
Muzej 25.Maj	17:52:13	17:52:20	00:07	625	85	7.35	26	129	29	1.559
Stadion-Partizan	17:53:12	17:53:18	00:06	463	52	8.90	32	142	29	1.609
Ped. Akademija	17:54:07	17:54:15	00:08	490	49	10.00	36	162	28	2.339
Bolnica-D. Misovic	17:55:58	17:56:07	00:09	487	103	4.73	17	174	30	1.412
Paje Adamova	17:57:59	17:58:07	00:08	677	112	6.04	22	178	30	0.339
Banjica	17:58:53	17:59:00	00:07	464	46	10.09	36	179	31	0.123
Raska VMA	18:00:28	18:00:39	00:11	485	88	5.51	20	173	30	–0.709
Plivaliste Banjica	18:01:29	18:01:35	00:06	396	50	7.92	29	175	28	0.289
Paunova	18:03:52	18:04:10	00:18	514	137	3.75	14	177	14	0.223
Bastovanska	18:05:02	18:05:10	00:08	392	52	7.54	27	162	4	–2.193
Kragujevackih djaka	18:06:04	18:06:09	00:05	320	54	5.93	21	163	2	0.179
Banjica II	18:06:59			287	50	5.74	21	156	0	–1.398
		0:35:36	**06:36**	**9621**	**1760**	**4.46**	**16.06**			

Table 2. Research result for line 41 – backward direction *morning rush hour/period)

Stop	Arrival time [hh:mm:ss]	Departure time [hh:mm:ss]	Dwell time [mm:ss]	Stop distance [m]	Trip time [s]	Exploatation speed [ms^{-1}]	Exploatation speed [kmh^{-1}]	Elevation [m]	Passenger volume	Angle α [°]
Banjica II	6:25:55	6:29:07	03:12	0				157	10	
Kragujevackih djaka	6:30:14	6:30:26	00:12	484	67	7.22	26	166	22	1.065
Bastovanska	6:31:00	6:31:14	00:14	298	34	8.76	32	162	33	–0.769
Paunova	6:32:27	6:32:59	00:32	378	73	5.18	19	177	58	2.274
Plivaliste Banjica	6:34:28	6:34:40	00:12	573	89	6.44	23	171	59	–0.600
Raska VMA	6:35:21	6:35:36	00:15	340	41	8.29	30	174	53	0.506
Banjica	6:36:30	6:36:53	00:23	493	54	9.13	33	181	50	0.814
Paja Adamova	6:37:45	6:38:00	00:15	475	52	9.13	33	177	49	–0.482
Bolnica D. Misovic	6:39:24	6:39:41	00:17	572	84	6.81	25	173	45	–0.401
Ped. akademija	6:40:37	6:40:43	00:06	398	56	7.11	26	156	45	–2.448
Stadion Partizan	6:41:25	6:41:30	00:05	520	42	12.38	45	143	46	–1.433
Muzej 25 Maj	6:42:34	6:42:49	00:15	675	64	10.55	38	129	45	–1.188
Ortopedski zavod	6:45:12	6:45:25	00:13	643	143	4.50	16	101	44	–2.496
Visegradska	6:46:55	6:47:19	00:24	888	90	9.87	36	103	35	0.129
Bircaninova	6:48:09	6:48:27	00:18	516	50	10.32	37	105	29	0.222
London	6:49:10	6:49:30	00:20	419	43	9.74	35	119	19	1.915
Glavna posta	6:50:17	6:50:29	00:12	602	47	12.81	46	130	10	1.047
Politika	6:53:25	6:53:35	00:10	820	176	4.66	17	119	7	–0.769
Trg Republike	6:56:03	6:56:13	00:10	435	148	2.94	11	123	3	0.527
Studentski trg	6:57:08			329	55	5.98	22	117	0	–1.045
		0:31:13	**07:45**	**9858**	**1408**	**5.26**	**18.95**			

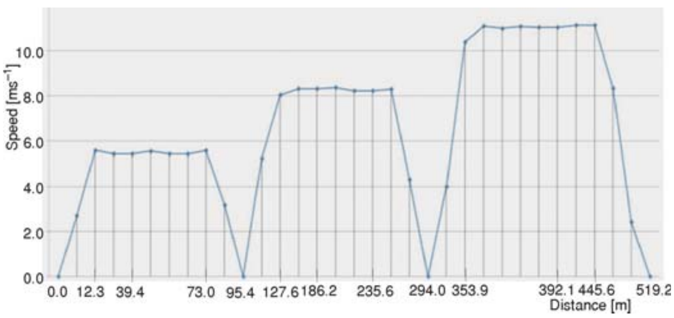

Figure 3. Distribution of experimetnal diesel bus speed alone a typical stop distance

From the point of view of vehicle movement along typical stop distance, the regimes of acceleration, constant speed driving, braking, and stopping the vehicle are very important. For a typical stop distance of 520 meters in an urban driving cycle, fig. 3, the vehicle has three phases of acceleration reaching speeds of 20, 30, and 40 km/h, including two stopovers due to traffic conditions and stopping at the next bus stop. Figure 3 presents standard driving cycle that approximates the real driving conditions on line 41. Results obtained experimentally measured on the test vehicle at polygon [3]. Particularly are important the results of acceleration and deceleration used in the theoretical model. The maximum value of E-Bus acceleration and trolleybuses was adopted to 1.3 m/s^2, diesel bus 1.03 m/s^2, while average deceleration adopted at 0.8 m/s^2.

Experimental measuring of energy efficiency of different bus subsystems

Comparative experimental measurements of energy consumption were taken on the line 41 for three different bus subsystems: trolleybus BKM-321, fig. 4, diesel bus IK-112N, fig. 5, and fully electric bus BYD E-12, fig. 6 [1]. Their basic technical characteristics are presented in tab. 3.

Figure 4. Trolleybus

Figure 5. Diesel bus

Figure 6. BYD E-12

Table 3. Technical characteristics of tested bus subsystems

Bus subsystem	Trolley BKM-321	Diesel bus IK-112N	Electric bus BYD E-12
Length	11.825 m	11.940 m	12.000 m
Curb weight	11,100 kg	12,090 kg	14,300 kg
Engine/motor	Electric motor	Diesel MAN D2066 (Euro 4)	2 electric motors
Power	180 kW	235 kW	2 × 90 kW
Torque	–	1100 Nm	2 × 350 Nm
Passengers	101	105	78

Measurements of energy efficiency of trolleybus

The measurement of electric energy consumption of trolleybus was performed by using the measuring equipment *Fluke* that is incorporated in the trolleybus of this type. In tab. 4, results of the measurements of electric power consumption of trolleybus BKM-321 in real exploitation condition on line 41 are presented, for one typical working day in November 2014 [4]. Total distance covered was 245 km. Total amount of the consumed energy by the trolleybus was 440 kWh. Energy spent on traction was 225 kWh (51.1%), while on powering of auxiliary devices and heating was spent 215 kWh (48.8%). From that we can see that the consumed energy per kilometre was 1.796 kWh/km. Trolleybus BKM-321 has energy recuperation of 13-15% compared to the total exchanged energy.

Table 4. Results of energy consumption measurement (trolleybus)

Outside temperature	7
Distance covered	245
Operation hours	18
Exchanged energy	510 (100%)
The energy consumed	440 (85.02%)
The generated braking energy	93 (18.2%)
Recuperated energy	71(13.7%)
Energy consumed for traction	225 (51.1%)
Energy spent on auxiliary devices and heating	215 (48.8%)
Total energy consumption per kilometer	1.796

Several measurements without the use of heating in certain periods of the day

(6.00 a. m. to 10.00 a. m. and 2.00 p. m.-5.00 p. m.) was conducted in October 2014. Average consumption in the trolleybus was about 1.46 kWh/km.

Measurements of energy efficiency of diesel bus IK-112N

Measuring fuel consumption of diesel bus IK-112N was performed by using appropriate flow-meter, in multiple half-turns on line 41 [5]. Results of the measurements are shown in tab. 5. When calculating energy consumption of this diesel bus, the applied data for the diesel fuel was energy content of 36 MJ/litre. In the vehicle were 40 passengers as realistically reflect the average occupancy on the line 41.

Table 5. Results of fuel/energy consumption measurement (bus IK-112N)

Number of measurements		1	2	3	4	5	6	Average consumption
Direction		Forward	Backward	Forward	Backward	Forward	Backward	–
Consumption	l/100 km	51.2	46.2	49.1	45.9	50.2	46.4	48.2
	MJ/km	18.43	16.63	17.67	16.52	18.00	16.70	17.35
	kWh/km	5.11	4.61	4.90	4.58	5.00	4.63	4.82

Measurements of energy efficiency of BYD E-12 bus

During April 2014, CPTCB, in the co-operation with famous manufacturer of electric buses BYD, performed trial tests of a solo E-bus BYD-E12. The goal of these tests was to obtain an overview of the possibilities of using electric buses in Belgrade. The trial tests were performed during the period from April 12-14, 2014 on two typical urban public transport lines: line 26 and line 41. In this part of paper the results of testing on line 41 are shown. The measurement of energy consumption of this bus was performed by registering changes in battery capacity – the state of charge (SOC) and distance covered. The bus was loaded by bags of sand of total weight of 2,500 kg, in order to simulate average number of passengers in the vehicles. The vehicle made stops at all of the stations, the doors were opened and closed, *i. e.* thus the time was simulated for passengers' boarding/alighting. In tab. 6, results of electric power consumption measurements of electric buses BYD are shown.

From tab. 6, we can conclude that average consumption of electric energy is 1.24 kWh/km. In the terms of half-turns, the energy consumption was 1.34 kWh/km, in forward direction, and 1.15 kWh/km in backward direction. The less consumed energy in backward direction was a consequence of bigger recuperation of electric energy that is made with brakes, on the long falls in this direction of movement. General observation with the electric drive buses is that it is possible to achieve recuperation of energy by about 25-30%. In tab. 7, overall results of energy consumption measurements of the tested vehicles are shown. During the process of charging the battery, loses are about 5% of energy. If we take this fact, average consumption of electric bus is increased by that percentage so that we can adopt average consumption of E-Bus of 1.30 kWh/km.

The results obtained confirm the hypothesis of a significantly greater energy efficiency of electric buses compared to diesel buses. By the example of line 41 it is proved that diesel bus IK-112N has greater energy consumption compared to the BYD E-12 E-Bus by 3.7 times. The comparison of energy consumption in this case is the so called tank-to-wheel (TTW).

Table 6. Results of electric energy consumption measurement (bus BYD E-12)

Direction	Measurement	SOC [%]	Distance covered [km]	Trip time [minute]	Average speed [kmh^{-1}]	Energy consumption [kWh]	Energy consumption per km [kWhkm^{-1}]
Forward	1	4.0	9.7	38	15.3	12.96	1.34
	2	4.0	9.6	41	14.0	12.96	1.35
	3	4.0	9.7	43	13.5	12.96	1.34
Backward	1	4.0	9.9	45	13.2	12.96	1.31
	2	3.0	9.8	38	15.5	9.72	0.99
	3	3.5	9.9	40	14.9	11.34	1.14
Total		22.5	58.6	245	14.35	72.9	1.24

Table 7. Comparative results of energy efficiency of different bus subsystems

Bus subsystem	Average load [%]	Recuperation of energy without A/C [%]	Energy consumption without A/C [kWhkm^{-1}]
Diesel bus IK-112N	40	0	4.82
Trolleybus BKM-321	40	15	1.46
BYD E-12 bus	40 (2,500 kg)	25-30	1.30
Note: Energy consumption measurement with use heating by using the measuring equipment on the trolleybus showed that in this working regime the consumption of energy is increased by 24 to 26%.			

Compared to trolleybus BKM-321, energy efficiency of BYD E-12 bus is greater by 12%, which can be explained by a lower degree of recuperation that trolleybus BKM-321 has compared to BYD E-12.

Determination of energy efficiency – a theoretical approach

Based on whole-day recording of vehicle driving cycle parameters on the experimental vehicle on the line 41 [4], was developed a theoretical model [6] that was called *Belgrade model*, by which engaged power for vehicle movement, including energy spent for powering auxiliary devices were calculated, using equations from the theory of vehicle movement. Using the recorded data from vehicle driving cycle, which are partly shown in tabs. 1 and 2, bus manufacturer Solaris Bus & Coach performed the simulation of movement of E-Bus Solaris E12 (*SOLARIS model*) and made the choice for its main aggregates.

Theoretical evaluation of energy efficiency – BELGRADE model

Figure 7 shows the forces acting on the vehicle in movement, where F is the driving force, F_f – the rolling resistance, F_u – the grading resistance, F_v – the air resistance, F_a – the acceleration resistance, F_G – the vehicle weight force, and F_N – normal load acting on the wheel.

Calculation of the necessary power for the movement of the bus is done by the method of balance of power [7]. Elements of recorded data calculation: speed on sections, trip and dwell time, vehicle load, inclination shares, for working day on line 41 were obtained. Part of the data relating to peak load are presented in tabs. 1 and 2. Figure 3 presents the distribution of experi-

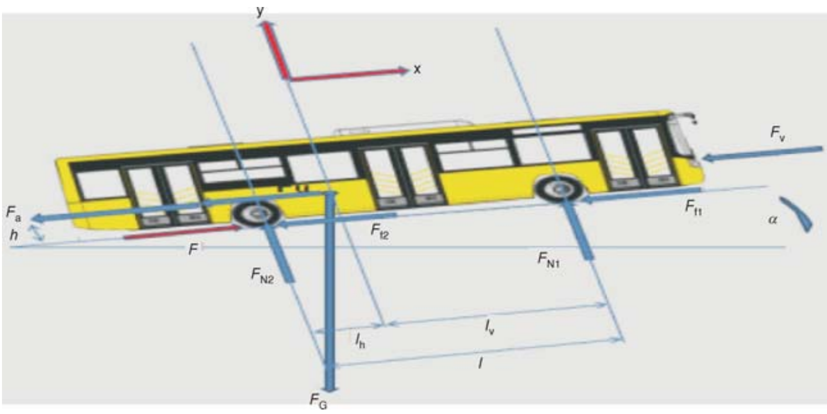

Figure 7. Forces that affect on the bus during movement

mental vehicle speed alone a typical stop distance. The necessary power for the movement of buses with electric drive and diesel buses is given by eq. (1):

$$\begin{gathered} P_{\mathrm{el}} = P_{tre} + P_{\mathrm{f}} + P_{\mathrm{u}} + P_{\mathrm{v}} + P_{\mathrm{a}} + P_{\mathrm{aux}} + P_{\mathrm{ac}} \\ P_{\mathrm{ed}} = P_{\mathrm{trd}} + P_{\mathrm{f}} + P_{\mathrm{u}} + P_{\mathrm{v}} + P_{\mathrm{a}} + P_{\mathrm{ac}} \end{gathered} \tag{1}$$

where P_{el}, and P_{ed} are the effective power of the electric motor and Diesel engine, respectively, P_{tre}, and P_{trd} – the power consumed for the losses between the electric motor/Diesel engine and the drive wheels, respectively, P_{f} – the needed power for overcoming rolling resistance, P_{u} – the power needed to overcome the resistance of grade of road, P_{v} – the needed power for overcoming air resistance, P_{a} – the power needed for overcoming resistance to inertial force, P_{aux} – the needed power to operate auxiliary devices (steering pump, air compressor, an inverter – convertor block, cooling electronics), and P_{ac} – the power needed to operate the air conditioner.

Some powers are defined by eqs. (2)-(6):

$$P_{\mathrm{tre}} = (1-\eta)P_{\mathrm{el}}, \quad P_{\mathrm{trd}}\,(1-\eta)P_{\mathrm{ed}} \tag{2}$$

$$P_{\mathrm{f}} = \frac{fG\cos\alpha v}{3600} = \frac{f_0(1+bv^2)G\cos\alpha v}{3600} \tag{3}$$

$$P_{\mathrm{u}} = \frac{G\sin\alpha v}{3600} \tag{4}$$

$$P_{\mathrm{v}} = \frac{kAv^3}{46.656} \tag{5}$$

$$P_{\mathrm{a}} = \frac{G}{g}\delta a \frac{v}{3600} \tag{6}$$

where η is the efficiency coefficient of transmission, f – the overall of rolling resistance coefficient, $f_{\mathrm{o}} = 0.012\text{-}0.017$ – the coefficient of rolling resistance for asphalt, $b = (4\text{-}5)10^{-5}$ – the constant, v – the speed of vehicle, G – the total weight of bus, α – the road angle, $k = 0.54\text{-}0.74$ – the reduced air resistance coefficient, A – frontal area of the buses, a – longitudinal acceleration, $\delta =$ $= 1.16\text{-}1.32$ – coefficient of influence of rotating masses. Total number of recorded trips on the line 41 was 24, 12 for each direction. Based on recorded data and equation for vehicle movement theory, consumption of energy was calculated for vehicles: BKM-321, IK-112N, and BYD E-12, during all day period of work (that is 17.5 hours and distance covered of 236.2 km). The *Belgrade model* is used for the calculation of the power needed to move for each stop distance as a function of vehicle load, longitudinal slope, speed, acceleration, deceleration also take into account the power which used to run auxiliary devices (air conditioning compressor, power steering pump, electronics, control and management block). Air conditioning has the average consumption about 7.2 kW. E-Bus is consumed to the control block with a system for cooling around 6,5 kW. The E-Bus has passed the recuperation of 27.5%, trolleybuses 15%). Results are based on measurements that have been implemented in some cities with similar types of E-Bus. (example Sofia).

Results obtained for energy consumption using simulation model (for all three vehicles), are given in tab. 8, are similar to the results that were obtained with direct measurement. Somewhat smaller values, in this case, are the consequence of smaller load of the vehicle (30%) which was taken based on registered passenger volume.

Table 8. Comparative values of energy efficiency obtained by simulation

Bus subsystem	Load [%]	Recuperation of energy without A/C [%]	Energy consumption without A/C [kWhkm^{-1}]
Diesel bus IK-112N	30	0	4.54
Trolley BKM-321	30	13.7	1.43
BYD E-12	30	27.5	1.28
Note: Values of energy of movement with A/C-on increases for 24 do 26 %; under the assumption that A/C was working 65% of operating time			

Theoretical determination of energy efficiency – Solaris model

The CPTCB has 200 diesel buses from bus manufacturer Solaris Bus & Coach in fleet, which is one of the leading manufacturers of E-Buses. Technical characteristics of fully E-Bus, fig. 8, which was used for the simulation, are shown in tab. 9 [8].

Figure 8. Solaris E12 bus

Table 9. Solaris E12 bus – technical data

Length/width/height	12000/2550/3250 mm
Curb weight	12500 kg
Number of doors	3
Pneumatics	275/70/R22.5
Max. speed	70 km/h
Electric motor	asynchronous AC
Max. power	160 kW
Batteries	Li-Ion
Capacity	80 kWh
Power of charge	400 kW
Time of charge (pantograph)	5 min

Based on performed simulation [9] real indicator was reached for energy consumption of E-Bus, based on which manufacturer Solaris Bus & Coach proposed the solution for the bus with batteries (characteristics are shown in tab. 10), with pantograph re-charge system.

Table 10. Values of simulation for Solaris E12 bus (*SOLARIS model*) Battery 80 kWh

Bus type	E1.2
Battery capacity	80 [kWh]
Charger power at the bus stop	400 [kW]
Charger power in depot	32 [kW]
Place of charging	Banjica II
Everage energy consumption	1.46 [kWh/km]
Consumed energy	363.4 [kWh]
Daily mileage	249.738 [m]
Number of chargings	12
Everage time o single charging	00:05:12 [hh:mm:ss]
Stop time in depot	06:31:10 [hh:mm:ss]
Time needed for charging in depot	00:55:00 [hh:mm:ss]
Driving time	17:28:50 [hh:mm:ss]

The frequency and number of charging battery, obtained by simulation model, are shown in fig. 9.

When the *Belgrade model* was applied to simulate the movement of the Solaris bus on the line 41, we obtained data of energy consumption, which are quite similar to data *Solaris model*. The results of this simulation are shown in tab. 11.

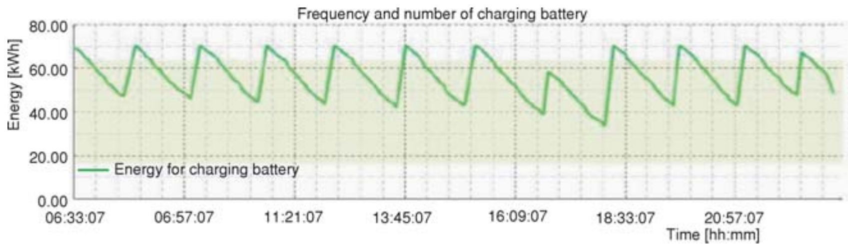

Figure 9. Simulation of charging Solaris E12 bus on terminal Banjica II

Table 11. Values of simulation for Solaris E12 bus (with *Belgrade model*)

Values of simulation for Solaris E12 bus on line 41		BELGRADE model	SOLARIS model
Mileage	km	236.2	249.738
Trip time	hh:mm:ss	17:31:05	17:28:50
Dwell time	hh:mm:ss	5:09:31	–
Exploitation speed	km/h	13.5	–
Consumption energy for driving	kWh	253.2	–
Consumption energy for equipment	kWh	123.5	–
Consumption energy for A/C	kWh	89.8	–
Total consumption energy	kWh	466.5	–
Consumption energy with recuperation (27.5%)	kWh	338.2	363.4
Consumption energy per km	kWh/km	1.43	1.46

Conclusions

The analysis showed that a electric drive bus, in complex operating conditions such as those present in Belgrade, in relation to the trolleybus and especially the diesel bus is a much more efficient means of transport from the energy point of view. The two presented a theoretical model for calculating the energy efficiency of the buses showed good compatibility with the experimental results, so they can be effectively used in further work on determining the performance of electric buses and battery capacity on the selected line of public transport. The results obtained by theoretical model enables different simulation scenarios of various influencing factors on energy consumption for different drive concepts for city buses and the possibility of their comparison, which can be important when choosing the concept of a bus system on a line.

Trial test of bus BYD E-12, which was performed by CPTCB, present the first step in direction of mass application of buses with fully electric drive in vehicle fleet of CPTCB. Results obtained from testing and positive experiences of the companies that use electric buses show that using electric drive buses has perspective in Belgrade as well. Buses with fully electric drive as proved ecologically *clean* and energetically efficient vehicles, in the next period, will give growing contribution to sustainable development of the cities, with ultimate goal by the year 2050 to be primary means in the public transportation system.

Conducted research showed that buses with fully electric drive can be successfully used in the urban public transport system in Belgrade. Theoretical models presented in the paper can be applied in other urban public transport systems.

Nomenclature

A – frontal area buses, [m^2]
a – longitudinal acceleration, [ms–^{2}]
b – constant, [–]
F – driving force, [N]
F_a – acceleration resistance, [N]
F_G – vehicle weight force, [N]
F_f – rolling resistance, [N]
F_N – normal load acting on the wheel, [N]
F_u – grading resistance, [N]
F_v – air resistance, [N]
f – overall coefficient of rolling resistance, [–]
f_o – coefficient of rolling resistance on asphalt, [–]
k – reduced air resistance coefficient, [Ns^{2}m^{-4}]
P_a – power needed for overcoming resistance to inertial force, [kW]
P_{ac} – power needed to operate the air conditioner, [kW]
P_{aux} – power needed to operate auxiliary devices, [kW]
P_{ed} – effective power of the electric motor and – diesel engine, respectively, [kW]
P_{el} – effective power of the electric motor, [kW]
P_f – needed power for overcoming rolling resistance, [kW]
P_{tre} – power consumed for the losses between the electric motor and the drive wheels, [kW]
P_{trd} – power consumed for the losses between the diesel engine and the drive wheels, [kW]
P_u – power needed to overcome the resistance of inclination road, [kW]
P_v – power needed for overcoming air resistance, [kW]
v – vehicle speed, [kmh^{-1}]

Acronyms

CPTCB – City Public Transport Company BELGRADE
E-Bus – electric bus
EEV – enhanced environmentally friendly vehicle
TTW – tank-to-wheel

Greek symbols

δ – coefficient of influence of rotating masses,
α – road angle, [°]
η – coefficient of efficiency of transmission, [–]

Subscripts

a – acceleration
ac – air conditioner.
aux – auxiliary
ed – diesel
el – electric
f – rolling
G – weight
N – normal
u – grading
v – speed
tre – transmission – electric motor
trd – transmission – diesel engine

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