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Energy consumption of commuting from suburban areas

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Abstract. The process of suburbanization begun half a century later in the Czech Republic in comparison to Western Europe. It has given rise to similar changes in the individual behaviour of potential residents, resulting in different land use and the emergence of new requirements involving technical and transport infrastructures. Many factors that characterize suburban land use, e.g., density of population (households), free access to public facilities, availability of transport modes, etc., are closely associated with energy consumption, specifically in transport. Suburban development affects not only transportation inside expanding suburban municipalities but also their surroundings, e.g., the cumulative effect of traffic intensity increasing on roads radially oriented towards the city centre has been observed in recent years. The construction of manufacturing facilities, logistic and commercial complexes, entertainment centres, etc. continues within the suburban areas and it tends to significantly increase traffic movements (e.g., in tangential directions towards the core of the city). The current capacity of transport infrastructures does not correspond to the increased vehicle intensity (even not only during peak hours) and it does not guarantee an adequate quality for transport operation. The results of performed traffic surveys proved that morning traffic intensity (during peak hours) on the roads (of 2$^{nd.}$ or 3$^{rd.}$ class) leading to the city centre has doubled in the last five years. These results mean that transport energy consumption has increased enormously. Transport energy consumption is higher than usually expected in these cases. The energy consumption (fuel consumption) determined according to a vehicle's homologation does not take into account the conditions that may affect driving style in a negative manner, e.g., slow driving, traffic congestions road, vertical alignment and tortuous roads. The mean consumption was 9.2 (l 100 km^{-1}) on the selected trail sections –that is 1.66 more than the combined consumption figure presented by car producers. The selected sections make up 54% of the total trail length. This 'local consumption' is linked with higher emission production, details are available below. The author compared specific fuel consumption per 100 km and found that real consumption is evidently always higher than the quantities claimed to be correct by car producers in view of mixed modes. The same has been found by, e.g. Marique & Reiter, 2012 and other authors.
The conclusions of the research are potentially relevant and should be used in a spatial planning or decision making processes to prevent 'urban sprawl' and the accompanying high energy consumption. Suburban development should go hand in hand with the construction of new transport infrastructures and high-quality public transport.

Key words: energy, transport, commuting, suburban settlements, fuel consumption.

INTRODUCTION

The process of suburbanisation (urban sprawl), which commonly describes physically (unfortunately often insufficiently controlled) expanding urban areas, is a major issue for sustainable development (European Environment Agency, 2006). As Hall Breheny quoted Banister (2005), decentralization has been a consistent and powerful force in Western Europe already since 1945. Although there is evidence that the power of this force has diminished in some countries by today, it remains a major determinant of urban structure.

Research dealing with transport energy consumption is firstly focused on urban area population (or job opportunities) densities, secondly on relationships between transport energy consumption and building density. It is still unclear how densification strategies affect the reduction of transport consumption. Maïzia et al. (2009) and Steemers (2003) argue that more compact urban forms would significantly reduce energy consumption both in the building and transport sectors. Based on data from 32 big cities located all over the world, Newman & Kenworthy (1989; 1999) have highlighted a strong inverse relationship between urban density and transport consumption, but their work is only valid for certain conditions and has been often criticized by others (Mindali et al., 2004; Owens, 1995), mainly for methodological reasons. Banister (1992) applied the same kind of approach to British cities and highlighted, on the basis of statistical data obtained from a national survey, that transport energy consumption is slightly higher in London than in smaller cities, which refutes Newman & Kenworthy's observations. Boarnet & Crane (2001) are also sceptical about the relationship between urban design and transport behaviours. On the basis of several case studies, they estimate that if land use and urban form have an impact on transport behaviours, it is through the price of travel (public transport prices are reduced in dense areas).

Marique & Reiter (2012) proposed that it is necessary to evaluate the sustainability of these suburban neighbourhoods, while it requires appropriate methods and tools, especially as far as private transport is concerned. In fact, transport energy consumption is rarely taken into account when the sustainability of these suburban structures is studied, even if sharp fluctuations in oil prices and efforts to reduce greenhouse gas emissions play an important role in contemporary discussions and policies. Marique & Reiter's study is based on input data from national censuses carried out every 10 years in Belgium, and consumption factors taking into account the mean consumption of vehicles (litre per km), the passenger rate and characteristics of fuel (these values are used in the paper; see discussion on methods).

The process of suburbanisation was delayed in Central and Eastern Europe due to the long-standing dependency on public transport means (mass transit) and reduced usage of private passenger cars in comparison with Western Europe (Ouředníček, 2002). Nevertheless, one of the most important results of contemporary suburbanisation processes is the enormous increase in traffic intensity (mainly caused by passenger cars) that is linked with congestion and other negative impacts on the environment and human health.

MATERIALS AND METHODS

Locations of the traffic survey points (R1 to R5) from Kralupy n/V city to Prague (nearest Metro terminal parking lot), alongside the road II/240 and connected with the road II/241 are shown in Fig. 1. The total length of the drive was 17 km. A traffic survey was performed during morning traffic peak hours (6.00 to 9.00) on working days (Tue, Wed, Thu), and the survey was repeated to obtain statistically plausible values. The surveys have been repeated every year in October since 2009. The surveyed radially oriented road is specific –it does not facilitate eastern tangential drives. This north-western suburban segment is bordered by the river (bridges were not built yet) from the north-eastern part of Prague's suburb. Two tangential directions (R22, R32) were surveyed there. Tangential roads are linked with motorways and Prague's ring. The surveys were compiled manually; data were collected by people, who filled in the prepared forms (number of vehicles and occupancy, modal split during time intervals) and processed in MS Excel. A survey questionnaire issued to the members of the public in the city of origin formed a part of the research.

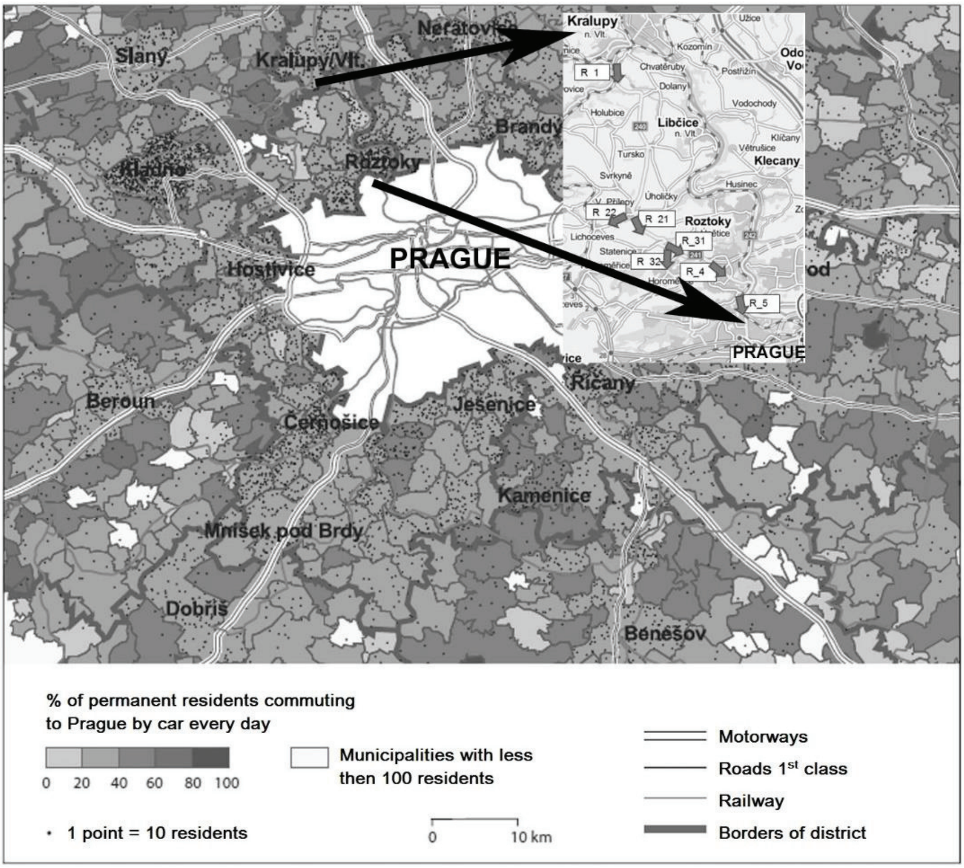

Figure 1. Map of measurement –radially oriented road from Kralupy n/V to Prague (Source: Proudy 2001 in Ouředníček–Urbánková, 2006 modifications regarding this research have been added).

A Skoda Octavia was used as a FDC (floating data car) and its basic parameters are: engine 2.0 (litre) 103 $(kW)^{-1}$ TDI PD – EU4, diesel fuel consumption declared by producer in l for 100 km^{-1}: city 7.0; outside city 4.7; combination 5.5.

The diagnostic system VAG-COM was used for communication with the vehicle's engine control unit and it enabled to collect and save instantaneous quantities (packets). The system consists of a data cable-interface connection (a standardized diagnostic plug OBD-II) on the one side and USB interface on the other side. The system software also features the program VCDS (Vag-com diagnostic system).

The FDC was equipped with the exhaust gas analyser VMK 5 – a special component emission analyser designed for mobile measurements. The device scans at 1 Hz frequency and stores the instantaneous values of CO, CO_2, HC, NO_X and O_2. The emission of carbon components is evaluated with the NDIR method. For sensing, NO_x and O_2 are used in electrochemical cells. The mobile measuring device is also equipped with an integrated Garmin GPS that stores information about the vehicle's instantaneous position and velocity at 5 Hz frequency.

All the detailed parameters of the equipment have not been listed in this paper due to limited space. The complete configuration of measuring equipment is shown in Fig. 2. Drives were repeated during the surveyed hours.

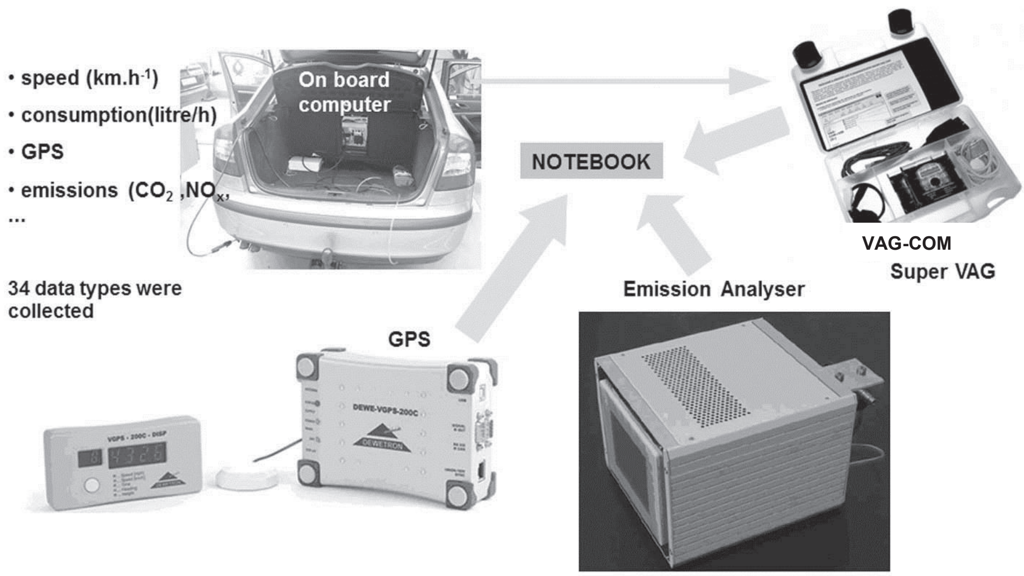

Figure 2. Configuration of measuring equipment.

The next step of data processing involves comparing consumption and occupation rates in real conditions with vehicles (diesel car, fuel car) as presented in Table 1.

Table 1. Consumption and occupation rate based on regional mean values (Source: Marique & Reiter, 2012)

	Type of vehicles			
Characteristics	Diesel car	Fuel car	Bus	Train
Consumption per kilometre	0.068 litre	0.080 litre	0.46 litre	-
Occupation rate	1.2	1.2	10	-

RESULTS AND DISCUSSION

Fig. 3 shows the results of the traffic surveys, i.e., intensities of passenger cars during three hours of morning peak traffic and the maximal one hour intensity within this time interval. Intensities at surveyed points R1 and R5 of the radial road, in other words, the 'entrance and exit' from the suburban area to the city centre, are also analysed. The generally accepted supposition is that the development of the suburban area and Kralupy n/V generates higher intensities within years. This supposition is somewhat supported by the data collected from point R1 but the results were not as definite for point R5 (see Fig. 3) – the coefficient of determination for the three hour intensity at point R1 is 0.5972, and 0.2753 at R5. This shows the differences in intensity between the two points might increase. If the supposition were completely proved, increase at point R5 should be higher (owing to the suburban area and new settlements built there).

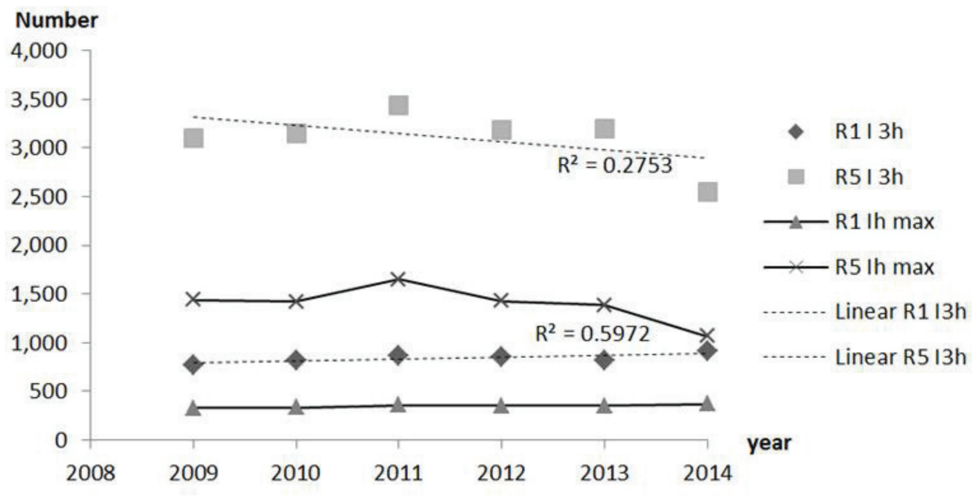

Figure 3. Intensities of passenger cars at points R1 and R5 (direction towards the city of Prague).

The explanation for these unexpected results can be found at points R22 and R32, i.e., the location where tangential movements developed an increasing trend (see Fig. 4). The increasing trends of tangential movements are proved by the coefficients of determinations, which are 0.9544 at R22; and 0.8005 at R32.

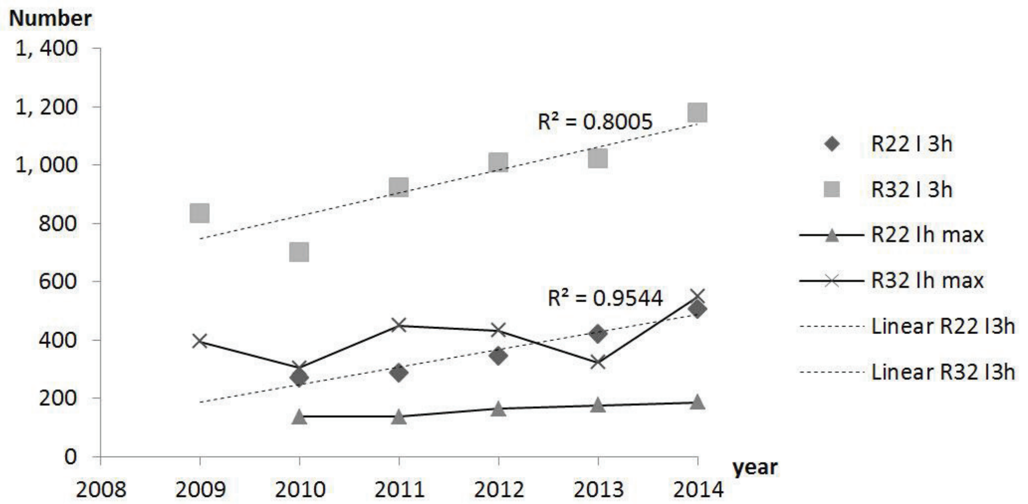

Figure 4. Intensities of passenger cars at points R22 and R32 (tangential direction).

Four sections (parts 1–4) alongside the trail were selected to represent specific driving conditions (see Table 2). Part 1 is located at the beginning of the trail and has a low hourly intensity but its terrain configuration is uphill with the average slope of +5%; the road is straight. Part 2 represents descending and ascending terrain with several curves (tortuous road). Part 3 represents a straight road inside a suburban district with a higher intensity. The traffic flow is interrupted by several pedestrian crosses. Part 4 has the highest intensities, with congestion during morning peaks. The road has traffic lights and it narrows from two lanes into one, which causes problems there.

Table 2. Results of measurements

	dist. (km)	mean velocity ($km\ h^{-1}$)	mean consumption (litre 100 km^{-1})	CO ($g\ km^{-1}$)	CO_2 ($g\ km^{-1}$)	NO_x ($g\ km^{-1}$)	HC ($g\ km^{-1}$)	intensity (p.cars h^{-1})
part1	2.6	49	10.3	2.7	239	3.0	0.031	352
part 2	1.3	46	8.7	2.4	206	3.9	0.032	546
part 3	2.4	43	6.0	1.6	144	1.6	0.019	618
part 4	2.9	14	11.6	4.9	278	2.6	0.058	1,386

Analysis results prove the initial hypothesis that fuel consumption is influenced the most by traffic flow in comparison to a road's vertical alignment and tortuousness. The mean consumption of fuel on these selected trail sections was 9.2 (l 100 km^{-1}) that 1.66 higher than the combined consumption declared by the car producer. The selected sections make up 54% of total trail length. Local consumption is linked with higher emission production as shown in Table as well. The surroundings of these sections face stronger negative impact on the environment and human health due to higher fuel consumption and consequently higher emission production.

Results of the survey questionnaire show that nearly 80% of the 423 people addressed commute to Prague regularly. This high proportion might be caused by the specific time and place the survey was conducted at, age structure of respondents, etc. Nearly 41% of respondents use passenger cars for driving to Prague and the distribution of diesel and fuel (petrol) cars is approximately equal. The respondents use cars with the following engine volumes: 26% under 1.5 litres, 40% from 1.5 to 2 litres and 21% above 2 litres, 6% unknown, 7% refused to answer.

CONCLUSIONS

On the basis of the performed surveys it can be concluded that within the surveyed Prague suburban area the total number of passenger cars is on the increase. Nevertheless, this increase has not been significant in the previous six years. The average number of passenger cars leaving the surveyed area during the three hours of morning peak traffic is 4,355 vehicles. The maximal difference in this figure was recorded between the years 2009 and 2010. The question is whether the six-year surveillance period is plausible for the assessment of transport quantities within a suburban area. Regardless of this objection, the increasing number of vehicles in Prague means constantly increasing energy consumption – mostly fossil fuel obtained from non-renewable sources is used.

The comparison of specific fuel consumption per 100 (km) revealed that real consumption is always higher as opposed to the quantities claimed to be consumed by the producer in mixed mode, as also claimed by, e.g., Marique & Reiter, 2012 and other authors. The total regional (suburban) fuel consumption can be quantified according to the structure of the vehicle fleet (diesel or petrol, engine volumes, etc.) and real specific fuel consumption values per 100 km can be obtained. According to performed measurements, the traffic operation (traffic flow character) and local conditions (vertical alignment and tortuousness) can strongly influence required limits. That should be taken into account in environmental impact assessments.

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