A method for evaluating transport energy consumption in suburban areas

1. INTRODUCTION

The process of urban sprawl, which commonly describes physically expanding urban areas, is a major issue for sustainable development (European Environment Agency, 2006). Urban sprawl is known to represent a significant contribution to the overall energy consumption of a territory for energy needs in buildings and for transport. In fact, for the same standard of insulation, detached houses need more energy for heating than terraced houses (Marique and Reiter, 2010). Moreover, suburban developments have created farther spatial separation of activities, which results in an increase in travel distances and transport energy consumption (Silva et al., 2007). In suburban residential neighborhoods mainly composed of detached houses and often located far away from city centers, car ownership is often high and public transport is generally less available, which tends to favor the use of private cars.

Although the environmental impact of urban sprawl and uncontrollable urbanization are receiving an increasing amount of attention and may give rise to various issues, such as environmental pollution or large-scale climate change (CPDT, 2002; He et al., 2010; Urban Task Force, 1999; Young et al., 1996), and despite the growing importance of the energy issues in public debate, low-density suburban developments continue to grow, regardless of their location. Such developments are found all over Europe, the United States and even emerging countries (Nesamani, 2010; Silva et al., 2007; Yaping and Min, 2009). An evaluation on the sustainability of these suburban neighborhoods is necessary and requires appropriate methods and tools, especially as far as the 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 reduction efforts in greenhouse gases emissions play an important role in current discussions and policies. Even new districts that set themselves up as “eco” or “sustainable” are sometimes built far from city centers and are not necessarily very sound from an ecological point of view because of higher transport energy consumption (Harmaajärvi, 2000).

Section 2 presents a brief review of the literature relating to the interdependences between spatial planning and transport energy consumption. Section 3 describes a quantitative method that was developed to assess transport consumption at the neighborhood scale to create a decision-making tool, to highlight the most efficient strategies needed to promote awareness and to give practical hints on how to reduce energy consumption linked to urban sprawl. Statistical data available at the neighborhood scale and characteristics of cars and public vehicles were used to predict transport needs and assess consumption as far as home-to-work and home-to-school travels are concerned. “Type-profiles” were developed to complete this approach and give an approximation of transport energy consumption related to leisure and commercial purposes. Section 4 presents an application of this method concerning a comparison of four suburban districts located in the Walloon region of Belgium, which confirms that the method is applicable and practical. Finally, Sections 5 and 6 summarize our main findings and discuss the reproducibility and the limits of this approach.

2. BACKGROUND TO THE EVALUATION OF TRANSPORT CONSUMPTION

In the current context of growing interest in environmental issues, reducing energy consumption in the transport sector, which represents 32% of the overall energy in the European Union (the building sector represents 37%), appears as an important policy target (Maïzia et al., 2009). Politicians, stakeholders and even citizens are now aware of the issue of energy consumption in buildings, namely through the passing of the European Energy Performance of Buildings Directive (EPBD) and its adaptation to the Member States laws; however, efforts and regulations to control transport needs and consumption are more limited. Nevertheless, although transport and mobility are often neglected, they are crucial in terms of urban sprawl because global oil use has allowed the appearance of sprawling urban forms (Jenks and Burgess, 2002). Therefore, the performances of transport networks determine whether a piece of land is of interest to developers who are likely to expand towns (Halleux, 2008).

Existing scientific work dealing with transport consumption is mainly concerned with dense urban areas, focusing on relationships between transport energy consumption and building density, and this work remains undecided on the effects of densification strategies for 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 and 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 is often criticized by other works (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 and Kenworthy observations. Boarnet and Crane (2001) are also skeptical on the relationship between urban design and transport behaviors. On the basis of several case studies, they estimate that if the use of the soil and the urban form impact transport behaviors, it is through the price of travel (public transport prices are reduced in dense areas). Gordon and Richardson (1997) demonstrated that if fuel prices are included in the analysis, urban density only plays a limited role on energy consumption in transport. Ewing and Cervero (2001), on the basis of a number of case studies, concluded that the impact of urban density on car travel reduction stays marginal. Elasticity is evaluated at -0.05, which means that if the density of a district is multiplied by two, private car commutes are only reduced by 5% because of the rise of congestion. Finally, Breheny (1995) has emphasized minor reductions in transport energy consumption thanks to the compact city model. His experiments show that, even under very strict conditions that are difficult to reproduce, energy used in transport could only be reduced by 10 to 15%. More recently, Boussauw and Witlox (2009) have developed a commute-energy performance index and tested it for Flanders and the Brussels-capital region in Belgium, including rural and suburban parts of these territories, to investigate the link between spatial structure and energy consumption for home-to-work travels at the regional scale. This method is based on statistical data available at the district scale, taking into account commuting distances, modal shares of non-car travel modes and aspects of infrastructure. This index allows for a better understanding of the energy consumption levels for commuting (home-to-work travels) in cities and less dense areas.

3. THE METHOD

We have developed a quantitative method to assess transport energy consumption, in suburban areas, at the neighborhood scale. Energy consumption in transport is in fact an interesting indicator because it is a composite measure of travel distance, modal choice and journey frequency (Banister, 1998; Muniz and Galindo, 2005). The method takes into account four purposes of travel (work, school, shopping and leisure) and will help us have a better understanding of the regional suburban situation, find the most relevant indicators to reduce transport energy consumption in suburban areas and compare different strategies of intervention in these specific types of structures. It will help to fill the critical lack of evaluation tools that local authorities could use to evaluate new and existing residential developments (Tweed and Jones, 2000), especially those dedicated to transport and location.

The method proposed in this paper only deals with transport energy consumption, which is one of the three parts of an overall method that aims at performing the total energy modeling of suburban areas. The complete package includes the energy assessment of buildings, transport and public lighting, and addresses their influences at the neighborhood scale because, even if the urban context has been mostly neglected in building energy analyses so far, decisions made at the neighborhood level have important consequences on the performance of individual buildings and on the transport habits of the inhabitants (Popovici and Peuportier, 2004). Marique and Reiter (2010; In press) described the first part of the method, dedicated to the energy assessment of suburban houses, at the district scale, and presented its application to three typical suburban districts. The overall method has also the advantage of allowing the comparison between the energy requirements in the building sector and in the transport sector, and thus, for every specific district, to highlight which strategy would be the most efficient to reduce the overall energy consumption.

3.1 Home-to-work travels

To assess energy consumption relating to home-to-work travels, we adapted and completed the performance index developed by Boussauw and Witlox (2009) for Flanders. In fact, the statistical data used in the Flemish commute-energy performance index are also available for the Walloon part of the country. However, other important parameters are not taken into account in the approach developed by Boussauw and Witlox (2009), such as type of fuel, characteristics of the local public transport network in suburban areas (significant differences exist between cities and suburban neighborhoods), number of working days per workers, pre-transportation, etc.

The input data come from the national censuses, which are carried out every ten years in Belgium and are available at the census block scale (the smallest geographical unit in which data are available in Belgium). We have considered the two last censuses, respectively carried out in 1991 and 2001. One-day travel-diary data from male and female heads of households were used. For these households, information was available in each census block about car ownership, travel distances, main mode of transport used, the number of working days per week and per worker, etc. together with their demographic and socioeconomic situation. The survey only concerns two purposes of travel: home-to-work travels and home-to-school travels, which represent the majority of travel.

To determine the total number of kilometers logged annually by various modes of transportation for home-to-work travels, the first step of the method is to combine the number of workers in a census block with the number of travels per week (thought the repartition of the number of working days in the census block), the distance travelled for home-to-work travel (one way) and the modes of transport used (car, bus, train, motorbike, bike or on foot) in this census block. A correction factor was applied to short distances covered by train and long distances covered by bus to keep the relationship between the mode and the distance travelled. As distances travelled per mode of transport are aggregated by census block in the national survey, this correction factor was calculated for each census block, on the basis of the following assumptions: trips by train shorter than 5 kilometers and trips by bus longer than 30 kilometers are spread over the others classes of distances. Non motorized trips (bike, on foot) were not considered in the following calculations because they do not consume any energy. Motorbike trips were neglected because they represent a very small part of home-to-work and home-to-school travels. In addition, if the main mode of transport used was the train, we also took into account travels from the house to the train station to investigate the role of home-to-station travels in total transport energy consumption. The mode of transport used for home-to-station travels was determined by a Geographical Information System (GIS) according to the distance travelled and the bus services available in each district.

Distances covered by diesel cars were separated from those covered by fuel cars according to the regional distribution of the vehicle stock in the Walloon region (55% diesel and 45% fuel cars). The final step of the method consists in allocating consumption factors to the distances covered in each category of vehicles (diesel car, fuel car, bus or train) to convert the distances into energy in terms of kilowatt hour (kWh). The unit of energy, kWh, was chosen to allow a comparison between energy consumption in transport with energy consumption to heat buildings in the overall method (Marique and Reiter, In press). Consumption factors take into account the mean consumption of the vehicles (liter per km), the passenger rate and the characteristics of the fuel (Table 1). For the train, the consumption factor used depends on the production of electricity as trains in Belgium are electric. The value used in this paper was calculated, for Belgium, by CPDT (2005).

Table 1

Consumption factors (per km and per person) used to convert kilometers into kWh, based on regional mean values

	Type of vehicles			
Characteristics	Diesel car	Fuel car	Bus	Train
Consumption per kilometer	0.068 l.	0.080 l.	0.46 l.	-
Occupancy rate	1.2	1.2	10	-
Density of the fuel (/1000 l. in toe)	0.859	0.745	0.859	-
Factor	**0.6134**	**0.6259**	**0.4986**	**0.3888**

Finally, we divided the total amount of energy consumption for home-to-work travels per census block by the working population that lives in the considered area to obtain an index that gives the mean annual energy consumption for home-to-work travels for one worker living in the considered district.

3.2 Home-to-school travels

The method developed for home-to-work travels is also applicable to home-to-school travels because the same types of data are available in the national census. Instead of using the number of working days, we used a mean number of days of school per year. The total amount of energy consumption for home-to-school travels per census block was divided by the number of students living in the census block to give the mean annual energy consumption for home-to-school travels for one student living in the considered census block.

3.3 Others purposes of travel

As previously mentioned, home-to-work and home-to-school travels represent only a part of the mobility of a household. Leisure and shopping are two other important purposes of travel (Hubert and Toint, 2002). Unfortunately, national censuses do not give information about those purposes of travel. As a result, we have developed a simplified calculation to take into account home-to-leisure and home-to-shop travels and compared them to home-to-work and home-to-school travels to give a more complete image of the energy consumption for transport in a district. This approach was based on “type-profiles”. According to socio-economic data, we have established several representative types of households living in a district (a family with two children, two elderly persons, a couple of unemployed people, etc.) and attributed, to each type of households, mobility characteristics for home-to-shop and home-to-leisure travels. These characteristics mainly concerned distances travelled from home to shop or leisure activities (according to the geographical location of each district) and the frequencies of travels (according to the socio-economic composition of the household). The mode of transport used was determined according to hypotheses made on the distances to travel, the distance to bus stops and the bus services available. This required information was collected by using a GIS. Different locations were taken into account: proximity shops, suburban shopping centers and main city centers. Finally, households are now known to try to combine different trips to minimize distances (Wiel, 1997); therefore, a correction factor can be applied to distances to take these “chained trips” into account. At the end, we are still able to distinguish the contribution of each mode in the final results.

4. APPLICATION OF THE METHOD

4.1 Specificities of the Walloon region of Belgium and case studies

Urban sprawl is familiar in many European regions and countries and particularly in the Walloon region of Belgium, where 52% of the building stock is made of detached or semi-detached houses (Kints, 2008). Because of the personal preferences of Walloon households for single family houses with large gardens in a rural environment, and the regulatory framework, which allows this kind of developments to grow, urban sprawl is now a concern in a large part of the regional territory. The Walloon urban sprawl presents several specificities in comparison with the neighboring regions and countries. According to cadastral data (Vanneste et al., 2007), 50% of Walloon census blocks present a mean housing density in the range between 5 and 12 dwellings per hectare, which is very low. In comparison to Flanders, where public authorities are now trying to reduce the size of the plots in new developments, or the Netherlands, where land supplies are historically very limited, land pressure stay limited in the Walloon region and land supplies are still available in large quantity. Moreover, Walloon suburban districts are not developed in continuity with dense urban centers or rural cores but are spread out on the whole regional territory according to land supplies availability and car accessibility (which is high because the transport network is very developed all over the Walloon region).

The majority of those districts are only residential, even if urban sprawl also concerns commercial or industrial functions.

As far as mobility is concerned, the dependence of these suburban areas upon cars is huge. National surveys held every ten years in Belgium show that car ownership is higher in suburban areas than in more densely populated areas (Verhetsel et al., 2007). According to these surveys, distances from home to work are also higher in suburban areas than in more densely populated areas because these neighborhoods are often developed far away from city centers where most of the employment areas are located. Moreover, because of the low population density of the Walloon suburban neighborhoods, public buses are often available at very low frequencies with low commercial speed and do not constitute a credible alternative to individual mobility.

An application of the method is presented concerning the comparison of four existing suburban neighborhoods in the Walloon region of Belgium. Given that urban sprawl is observed throughout the whole region, one representative suburban district has been selected in every urban region identified in Belgium, namely by Sporck et al. (1985), whose aim was to present a typology of the Belgian urban regions and to define their borders. This typology was used in numerous studies and research about urban sprawl, specifically in two statistical censuses held in 1998 and 2007 (Luyten and Van Hecke, 2007; Merenne-Schoumaker et al., 1998). The "operational agglomeration" was based on the morphological agglomeration, or dense urban core. Its limits were determined by the continuity of the building stock and adapted to administrative borders. The "suburbs" were the first suburban area of a city. Areas located further from the city, while keeping strong relationships with it (through home-to-work travels), constituted the "alternating migrants area," whereas remaining areas were regrouped under the "other areas" term and represent rural and less dense areas located far away from city centers. The main characteristics of the four neighborhoods are presented in Table 2.

Table 2

Main characteristics of the four studied neighborhoods

	Studied areas (suburban neighborhoods)			
Characteristics	Jambes	Fontaine	Rotheux	Tintigny

Urban area	“operational agglomeration”	suburbs”	“alternating migrants”	“other areas”
Main types of houses	Detached houses (pretty new)	Semi-detached and terraced houses	Rural core, farms, detached houses	Detached houses (pretty old)
Distance to city center	6 km	9 km	17 km	29 km
Distance to train station	6 km	9 km	15 km	8 km
Bus services	Low	Good	Low	Very low

4.2 Main results and key indicators

The application of the method developed in section 3 to the four representative suburban neighborhoods presented in section 4.1 gave the following results (Table 3):

Table 3

Index for home-to-work, home-to-school and home-to-shop-and-leisure travels

	Studied areas (suburban neighborhoods)			
Index	Jambes “operational agglomeration”	Fontaine “suburbs”	Rotheux “alterning migrants”	Tintigny “other areas”
Home-to-work kWh/worker.year	4 646	3 945	4 782	5 785
Home-to-school kWh/student.year	888	429	2 152	2 376
Home-to-shop and home-to-leisure kWh/person.year	599	414	1335	2 216

The first main finding of the application of the method to the four case studies was that, in each case, home-to-work travels represent the most important part of the total energy consumption. Home-to-school travels, which were calculated with the same kind of data and the same method, can thus be easily comparable; they consume less energy per capita than home-to-work travels. The first explanation is that distances from home to school are shorter than distances from home to work. Several schools are indeed located in most Walloon towns, even in the more rural ones, whereas work locations remain concentrated in bigger cities and in some suburban business parks. Moreover, the use of public transport is higher for home-to-school travels than for home-to-work ones which could also explain the better results obtained for home-to-school travels.

Home-to-station travels were included in the previous results and represent between 0.9% and 3.7% of home-to-work travels and between 1.1% and 4.8% of home-to-school ones, whereas the modal part of the train was very low. These results show that it is important to take home-to-station travels into account in suburban areas. Moreover, trying to increase the modal part of the train in suburban areas should be a good strategy, but only if alternatives to individual car are proposed for home-to-station travels.

Annual home-to-work and home-to-school energy consumption was higher in the two residential districts located far away from city centers (Tintigny and Rotheux), whereas home-to-work consumption was high in Jambes, but home-to-school consumption was lower than in others districts. As Jambes is located closer to a big city center (6 kilometers), students can more easily use alternative non polluting modes of transport.

Home-to-shop and home-to-leisure travels represent between 62.0% and 96.5% of the annual energy consumption for home-to-school travels, as seen in Table 3. These values mainly depend on the distances to shops, services and leisure. The more equipped the neighborhood and its surrounding are, the smaller the energy consumption rate for home-to-shop and home-to-leisure travels is. As those purposes of travels were calculated according to “type-profiles” and not according to statistical data, results were not as robust as home-to-work and home-to-school consumption but seem to give credible results. Shops and leisure, just as schools, are spread out on the whole region, even in most rural areas (rural core, suburban centers, etc.) which allow for reduced distances from home to destination.

4.3 Sensitivity analyses

Several sensitivity analyses were performed to identify the most relevant indicators that act upon transport energy consumption. Since the main key indicators that seem to be highlighted by the first results were the distance between home and final destination and the bus services, the first sensitivity analysis deals with the location of the districts. If we consider, as a first approach, that all the studied neighborhoods keep their socio-economic characteristics but could now benefit from the same good location than the neighborhood presenting the lowest energy consumption rate (Fontaine neighborhood, close to a city center, good bus services, higher mix in functions), energy consumption relating to home-to-work and home-to-school travels decrease significantly: -55.4% in Tintigny, -22.5% in Jambes and -32.4% in Rotheux, mainly because trips by car are shorter and less numerous. These results highlight that location is paramount as far as transport energy consumption is concerned. To try to isolate the impact of the distance, we then considered that the distances between home and work and between home and school mentioned in the national census were reduced by 10% in a first theoretical calculation and by 20% in a second one. These simulations confirmed that the impact of distances on energy consumption in transport is high (see Table 4). However, these results remain purely theoretical because it is not possible to change the location of existing neighborhoods. Nevertheless, these results show the importance of promoting the implementation of future neighborhoods in areas close to large employment centers and services and increasing the population of these areas when they are already built.

The third type of sensitivity analysis deals with the energy consumption of the vehicles. If we considered that the performances of all the vehicles (fuel consumption per mode) are improved by 10%, which is a credible approach, home-to-work and home-to-school energy consumption decrease from 6.6% to 9.6%. These savings are further improved if the performances of the vehicles are improved by 20%. If only the performances of public buses are improved, resulting savings for home-to-work and home-to-school travels are low: energy consumption only decreases by 1.7% to 2.7% because the modal part of the bus is very low in these districts. Therefore, improving the performances of public vehicles will only give good results in areas where buses are used by a large part of the population.

To favor home-workers is also a credible strategy to reduce transport energy consumption. It was calculated that if 5% of the workers of a district are allowed to work at home, energy consumption savings (home-to-work and home-to-school travels) are in the range of 2.3% to 3.6%, according to the district. If the percentage of “home workers” rises to 10%, energy reductions can reach 6.9%.

The last type of sensitivity analysis deals with modal transfer. If we considered that, in each district, 10% of the workers who used a car to go to work will change their habits and use the bus, then energy consumption (home-to-work and home-to-school travels) are reduced by a maximum of 3%. If the modal transfer rises 20%, energy consumption reductions can reach 5% in one of the four studied areas. If modal transfers deal with home-to-work travels and home-to school travels, energy savings are higher by up to 8%. Therefore, the mode of transport used (car, train or bus) has, in comparison with other strategies, a smaller impact on transport energy consumption relating to home-to-work and home-to-school travels. Even if a car has a level of consumption per kilometer higher than trains or buses, home-to-work travels and home-to-school travels made by train are much longer, and the differences between energy factors for car and for bus is not very important because the bus occupation rate is low.

Table 4

Summary of the sensitivity analyses: energy consumption (home-to-work and home-to-school travels) reductions in % for each scenario tested

	Studied areas (suburban neighborhoods)			
Scenario	Jambes	Fontaine	Rotheux	Tintigny
1.All the districts have the same location as Fontaine	-22.5%	-	-32.4%	-55.4 %
2(a).Distances (home to work and school):-10%	-9.7 %	-9.8 %	-9.6 %	-9.7 %
2(b).Distances (home to work and school): -20%	-19.5 %	- 19.5 %	-19.2 %	-19.4 %
3(a).Performances of vehicles: +10%	-9.0%	-6.6%	-9.6%	-9.6 %
3(b).Performances of vehicles: +20%	-17.9%	-13.2%	-19.2%	-19.1 %
3(c).Performances of the buses only: +20%	-1.7%	-2.7%	-2.1%	-2.1 %
4(a).Home workers: 5%	-3.4%	-2.6%	-3.6%	-2.3 %
4(b).Home workers: 10%	-6.9%	-5.6%	-6.8%	-5.3 %
5(a).Modal transfer (home-to-work): 10%	-2.3%	-1.9%	-2.9%	-1.9 %
5(b).Modal transfer (home-to-work): 20%	-4.2%	-3.9%	-4.6%	-3.3 %
5(c).Modal transfer (home-to-work & school): 10%	-4.0%	-2.5%	-5.0%	-4.6 %
5(d).Modal transfer (home-to-work & school): 20%	-6.7%	-4.9%	-7.8%	-7.4 %

Table 4 summarizes the energy consumption reductions for each sensitivity analyses tested. The results indicate that location is the major impact on energy consumption. Location includes a lot of different factors and it is very difficult to isolate these spatial parameters; however, distances from home to final destination seems to have a huge impact on transport energy consumption. The second most efficient strategy is to improve the vehicles' performances. Mode choice only gives limited results in the existing suburban situation. So, in the debate presented in section 2 about the impact of density on transport energy consumption, our results indicate that distance from home to work, to school and to others activities is paramount. As a result, rather than population and building density, a good mix between work, schools, shops and dwellings, at the living area scale, seems to be the best strategy to reduce transport energy consumption in existing suburban areas.

5. DISCUSSIONS AND PERSPECTIVES

The application of the quantitative method presented in section 3 to four suburban blocks, chosen in each urban region identified by the literature in the Walloon region of Belgium, highlights that energy performances related to transport are low and that the use of public transport is low as well; therefore, suburban districts are very dependent on private cars because cars are more efficient than public transport in these types of structures (low frequencies, low commercial speed, etc.). The sensitivity analyses show, however, that the benefits of several renewal strategies exist: choosing a better location could give significant results as far as energy performances in transport are concerned. Not only is this important for new developments, but also for households who want to reduce their energy consumption and their car and fuel costs. We have also highlighted the great influence of the distance between home and destination, as well as the performances of the vehicles, and the percentage of workers working at home to a lesser extent. We have finally showed that increasing the modal part of buses gives more limited results in the studied areas.

The method is developed and tested for the Walloon region of Belgium, where urban sprawl is a concern in a large portion of the area, but it is transposable to other regions and districts that are also affected by urban sprawl in Europe and beyond, by adjusting parameters, such as those relating to vehicles performances and public transport network, on the basis on local mean values. Input data come from national surveys or are collected using a GIS that are both commonly used tools in numerous regions and countries. Surveys similar to the one used in the case studies were for example carried out by the French National Institute of Statistics

(INSEE) in France, the Office for National Statistics (ONS) in the United Kingdom or the Census and Statistics of Population (IDESCAT) in Catalunya whereas GIS oriented towards urban planning are now largely used by researchers and territorial communities.

Even if many studies dedicated to transport and energy consumption only focus on home-to-work data because they are the most often available, the limits of this method arise from the fact that data about only two types of trips (home-to-work and home-to-school travels) are available in national censuses. Those types of travels are not representative of all trips of a household even if they play a founding role in it because they are commuting journeys and affect significantly related trips for leisure or commercial purposes. We have thus developed “type-profiles” to approach this reality but, even if this approach is also used in others research, such as those performed by Cornet et al. (2005), Kritikou et al. (2009) and Saunders et al. (2008), the results obtained are only theoretical and cannot currently be validated by comparing them with in situ measures; therefore, they should be used with caution.

Finally, an interactive decision making tool, accessible on the web, is developed, on the basis of the method presented in this paper. The aim is to transfer the main results of our research to citizens and stakeholders and inject them into policy and decision making. It will help developers to plan new suburban neighborhoods, and public authorities to take location and transport energy consumption into account when issuing authorization to build new districts or transforming exiting ones. Occupants and inhabitants can also use the tool to evaluate transport energy consumption and bus services in their districts and to test the impact of different locations before choosing their future dwelling.

6. CONCLUSIONS

Although the environmental impact of urban sprawl and their associated energy consumption are receiving an increasing amount of attention, low density suburban developments continue to grow all over the world. Aiming to reduce energy consumption linked to urban sprawl, a quantitative method has been developed to assess transport energy consumption relating to home-to-work and home-to-schools travels at the district scale, which was based on statistical data available at the census block scale. A simplified calculation completes the method, as far as home-to-shop and home-to-leisure travels are concerned. The method is flexible and parameterized what makes applicable to different contexts and regions. The application of the method to four existing suburban districts and the sensitivity analyses shows its potential in identifying key parameters and strategies to improve transport energy consumption in suburban areas. A good mix between work, schools, shops and dwellings in each neighborhood, which allows reduced travel distances, seems to be the best strategy to reduce transport energy consumption in suburban areas, whereas means of transport used is only of little impact. As highlighted in this paper, it is particularly crucial that the planning of new districts will be based on proper consideration of the location of the area (distance to work places, schools, etc.) and that public authority could use tools allowing them to better take location into account.

7. ACKNOWLEDGEMENT

This research is funded by the Walloon region of Belgium in the framework of the “Suburban Areas Favoring Energy efficiency” project (SAFE).

8. REFERENCES

Banister D. Energy use, transport and settlement patterns. In: Breheny M, editor. Sustainable Development and Urban Form. London: Pion Ltd; 1992. p. 160-181.

Banister D. Sustainable development and transport. Report for the Bundesforschungsantalt für Landeskunde und Raumordnung. The Urban 21 project; 1998.

Boarnet M, Crane R. Travel by design. The influence of urban form on travel. New-York: Oxford University Press; 2001.

Boussauw K, Witlox F. Introducing a commute-energy performance index for Flanders. Transp Res Part A. 2009; 43:580-91.

Breheny M. The compact city and transport energy consumption. Transactions of the Inst of Br geographers. 1995; 20(1):81-101.

Conférence Permanente du Développement Territorial. Les coûts de la désurbanisation. Namur; 2002; 1. 135p.

Conférence Permanente du Développement Territorial. Thème 2. Contribution du développement territorial à la réduction de l’effet de serre. Rapport final de la subvention 2004-2005. Namur ; 2005.

Cornet Y, Daxhelet D, Halleux J-M, Klinkenberg A-C, Lambotte J-M. Cartographie de l’accessibilité par les alternatives à la voiture. In : Proceedings of Les Journées Géographiques Belges. Mobilité, Société et Environnement en Cartes ; 2005. p. 355-64.

European Environment Agency. Urban sprawl in Europe. The ignored challenge. Final report. Copenhagen; European Environment Agency; 2006; 1.

Ewing R, Cervero R. Travel and the built environment: A synthesis. Transp Res Rec. 2001; 1780:87-114.

Gordon P, Richardson H W. Are compact cities a desirable planning goal? J of the Am Plan Association. 1997; 63(1):95-106.

Halleux JM. Urban sprawl, Urban Containment and Land Management. A Reflection on the Concept of Urban Land Supply. In: Sitar M, editor. Urban future: Challenges and opportunities for city and region developments. Maribor: University of Maribor Press; 2008. p. 259-68.

Harmaajärvi I. EcoBalance model for assessing sustainability in residential areas and relevant case studies in Finland. Environ Impact Assess Rev; 2000; 20:373-80.

He J, Bao CK, Shu TF, Yun XY, Jiang D, Brown L. Framework for integration of urban planning, strategic environmental assessment and ecological planning for urban sustainability within the context of China. Environ Impact Assess Rev; 2010, doi:10.1016/j.eiar.2010.09.002.

Hubert JP, Toint P. La mobilité quotidienne des Belges. Namur: Presses universitaires de Namur, Facultés universitaires Notre-Dame de la Paix; 2002.

Jenks M, Burgess R, editors. Compact cities: sustainable urban forms for developing countries. London: spon Press; 2002.

Kints C. La rénovation énergétique et durable des logements wallons. Analyse du bâti existant et mise en évidence des typologies de logements prioritaires. Louvain-La-Neuve: UCL, Architecture & Climat; 2008.
Kritikou Y, Dimitrakopoulos G, Dimitrellou E, Demestichas P. A management scheme for improving transportation efficiency and contributinng to the enhancement of the social fabric. Telematics and Informatics. 2009; 26:375-90.
Luyten S, Van Hecke E. De Belgische Stadsgewesten 2001 [Internet]. Brussels: FPS Economy; 2007. Available from: http://www.statbel.fgov.be/pub/d0/p009n014_nl.pdf /.
Maïzia M, Sèze C, Berge S, Teller J, Reiter S, Ménard R. Energy requirements of characteristic urban blocks. In: Proceedings of the CISBAT 2009 International Scientific Conference on Renewables in a Changing Climate, From Nano to Urban scale; 2009 Sept 2-3; Lausanne, Switzerland. 2009. p. 439-444.
Marique AF, Reiter S. A method to assess global energy requirements of suburban areas at the neighborhood scale. In: Proceedings of the 7th International IAQVEC Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings; 2010 Aug 15-18; Syracuse, New York, USA. 2010.
Marique AF, Reiter S. A Method to Evaluate the Energy Consumption of Suburban Neighborhoods. HVAC&R Res. In press.
Merenne-Schoumaker B, Van der Haegen H, Van Hecke E. Recensement général de la population et des logements au 1 mars 1991, urbanisation. Monographie 11a. Ministère des Affaires économiques: INS, SSTTC; 1998.
Mindali O, Raveh A, Salomon I. Urban density and energy consumption: a new look at old statistics. Transp Res Part A. 2004; 38:143-62.
Muniz I, Galindo A. Urban form and the ecological footprint of commuting. The case of Barcelona. Ecol Econ. 2005;55:499-514.
Nesamani KS. Estimation of automobile emissions and control strategies in India. Science of the Total Environ. 2010;408:1800-11.
Newman P, Kenworthy JR. Cities and Automobile Dependence: A sourcebook. Aldershot: Gower Publishing Co; 1989.
Newman P, Kenworthy JR. Sustainability and Cities: overcoming automobile dependence. Washington DC: Island Press; 1999.
Owens S. A response to Michael Breheny. Transactions of the Inst of Br geographers. 1995; 20:381-86.
Popovici E, Peuportier B. Using life cycle assessment as decision support in the design of settlements. In: Proceedings of the 21th PLEA Conference on Passive and Low Architecture; 2004 Sept 19-22; Eindhoven, The Netherlands. 2004.
Saunders MJ, Kuhnimhof T, Chlond B, da Silva ANR. Incorporating transport energy into urban planning. Trans Res Part A. 2008;42:874-82.
da Silva ANR, Costa GCF, Brondino NCM. Urban sprawl and energy use for transportation in the largest Brazilian cities. Energy for Sustainable Development. 2007;11(3):44-50.
Sporck JA, Van der Haegen H, Pattyns M. L’organisation spatiale de l’espace urbain. La cité belge d’aujourd’hui, quel devenir? Bruxelles: Bulletin trimestriel du Crédit communal de Belgique; 1985.
Steemers K. Energy and the city: density, buildings and transport. Energy and Build. 2003; 35(1):3-14.
Tweed C, Jones P. The role of models in arguments about urban sustainability. Environ Impact Assess Rev; 2000; 20:277-87.
Urban Task Force. Towards an Urban Renaissance. London: Routledge, Queen’s Printer and Controller of HMSO; 1999.
Vanneste D, Thomas I, Goosens L. Le logement en Belgique. SPF Economie et Statistique, SPF Politique scientifique. Bruxelles ; 2007.
Verhetsel A, Van Hecke E, Thomas I, Beelen M, Halleux JM, Lambotte JM et al. Le mouvement pendulaire en Belgique. Les déplacements domicile-lieu de travail. Les déplacements domicile-école. SPF Economie et Statistique, SPF Politique scientifique. Bruxelles ; 2009.
Wiel M. Comportements de mobilité et évolution de l’organisation urbaine. Rapport du FIER; 1997.
Yaping W, Min Z. Urban spill over vs. local urban sprawl: Entangling land-use regulations in the urban growth of China’s megacities. Land Use Policy. 2009; 26:1031-45.
Young W, Bowyer D, Naim RJ. Modeling the environmental impact of changes in urban structure. Computer Environ and Urban Syst. 1996; 20:313-26.