A Method to Evaluate the Energy Consumption of Suburban Neighborhoods

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Energy use in buildings, transportation systems and lighting networks represents a significant contribution to the overall energy consumption in urban and suburban areas. This paper presents a method to evaluate the energy consumption of suburban neighborhoods from these three points of view, aiming to highlight the most relevant variables linking urban form and neighborhoods energy consumptions. The method includes three parts: 1) a computational approach combining dynamic simulation tools and a database of building typologies to determine the energy consumed in heating; 2) an empirical approach to assess the energy consumed by transportation systems (four purposes of travel are taking into account: work, school, leisure and shopping); and 3) a simplified approach to calculate the energy consumed by public lighting. Results from the application of the method to three characteristic suburban neighborhoods in Belgium are presented along with a life cycle energy assessment of buildings. A sensitivity analysis was conducted to determine the effects of building and neighborhood characteristics and of building inhabitant behavior on calculated energy consumption. Results from the analysis show that building insulation, building distribution, heating system management and neighborhood location are critically important factors in the energy efficiency of suburban residential areas.

INTRODUCTION

The problems associated with energy use, such as global climate change caused by the release of carbon dioxide (CO_2) and other greenhouse gases, are receiving an increasing amount of attention (Glicksman 2007). In the context of increasing environmental awareness, energy efficiency is often presented as a viable approach to the mitigation of climate change. The reduction of energy consumption and greenhouse gas emissions in the building and transportation sectors, which represent 37% and 32%, respectively, of final energy use in the European Union, are central policy targets (Maïzia et al. 2009) at the local, regional, national, and European Union levels in Europe (CEC 2005).

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In this context, the expansion of urban areas, commonly referred to as urban sprawl, has been identified as a major issue for sustainable development (EEA 2006). The environmental impacts of urban sprawl and uncontrolled urban growth, such as increased pollution and large-scale climate change, are well documented (CPDT 2002; He et al. 2010; UTF 1999; Young et al. 1996). Energy consumption by buildings, transportation systems and lighting networks represents a significant contribution to the overall consumption in urban and suburban areas. Sprawl spatially separates activities, resulting in an increase in travel distances and energy consumption in transportation (Jenks and Burgess 2002; Silva et al. 2007). Although opponents of sprawl argue that more compact urban forms would significantly reduce energy consumption both in the building and transportation sectors (Maïzia et al. 2009; Newman and Kenworthy 1989 and 1999; Steemers 2003), low-density residential suburban districts continue to grow. Such patterns of development are found in both developed and developing countries (Nesamani 2010; Silva et al. 2007; Yaping and Min 2009).

Specific evaluation tools and methods that could be used by local authorities, architects and developers to evaluate the impacts of new and existing suburban developments and of suburban renewal strategies are lacking (Tweed and Jones 2000). Existing energy consumption models for urban areas are mainly focused on individual buildings and thus neglect the importance of larger-scale phenomena (Ratti et al. 2005). Moreover, although many tools have been developed to evaluate energy efficiency in buildings, they are designed by engineers for use by other trained engineers and are not simple enough to evaluate quickly the performance of different design concepts or strategies (Glicksman 2003). Therefore, a method has been developed to quickly model the energy consumption of suburban neighborhoods, to improve their energy efficiency and to compare different strategies of suburban renewal. The main aim of this exercise is to highlight the most relevant variables linking urban form and neighborhoods energy consumption in order to quantify their influence. The three-part method assesses the energy consumption needed for heating residential buildings and using transportation systems and public lighting. It addresses the impacts of energy consumption at the neighborhood level because decisions made at this level have important consequences for the performance of individual buildings and for the transportation habits of inhabitants (Popovici and Peuportier 2004). 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 also sufficiently general for application in many other suburban areas in Europe and beyond, by adjusting parameters, such as those relating to climate, vehicles performances or insulation characteristics.

We first describe the three components of the method. Then, we present results from the application of the method to three characteristic Walloon suburban blocks. To promote the most efficient development strategies, we discuss the influence of often-underestimated parameters, such as building distribution and location on the energy efficiency of suburban neighborhoods. We present results of this exercise and discuss its limits. Finally, we summarize our main findings and discuss the reproducibility of the method.

METHOD

The building component

The first part of the method developed to evaluate energy consumption of suburban neighborhoods calculates the energy requirements for buildings heating. In fact, empirical surveys (CEEW 2007; ICEDD 2005; Kints 2008) show that heating represent the largest part of the overall energy consumption of Belgian households (76%). Home appliance, production of hot water and cooking represent respectively 10%, 11% and 3% of the total as shown on Figure 1, part a. 14% of the home appliance item are dedicated to indoor lighting as shown on Figure 1, part b.

Figure 1, part a: Energy Consumption of Belgian Households according to the Type of Utilization

Figure 1, part b : Repartition of the Electrical Appliance

A typology of detached, semi-detached and terraced houses was established to classify the residential suburban building stock of the Walloon region of Belgium. It covers only single-family buildings because urban sprawl in this region is predominantly residential, and it was designed for the classification of all residential suburban neighborhoods of the Walloon region. This typological approach, also used by Jones et al. (2001), Maïzia et al. (2009) and Popovici (2006), is based on the following factors: common ownership, the area of the house in square meters (m²), the number of levels and the date of construction. Four age categories (pre-1950, 1951-1980, 1981-1995 and 1996-2008) are considered based on the evolution of regional policies concerning building energy performance and the evolution of construction techniques. These age categories are used to approximate a mean thermal conductivity of external façades from a "standard" composition of façades and glazing attributes for buildings in each category (Table 1). An additional age category will be added eventually for houses built after 2008, as the European Energy Performance of Buildings Directive (EPBD) was adopted in Walloon regional laws in 2008 and will be completely integrated by September 2011. The EPBD, which will significantly reduce the energy consumption of residential and tertiary buildings built after 2008, aims primarily to establish minimum standards on the energy performance of new buildings and existing buildings larger than 1000 m² subject to major renovation (EP 2002).

Table 1. Main Characteristics of External Façades and Glazing by Age Category

	Pre-1950	**1951-1980**	**1981-1995**	**1996-2008**
Wall composition	Concrete blocks	Concrete blocks	Concrete blocks + 30 mm (1.18 in.) insulation	Concrete blocks + 60 mm (2.36 in.) insulation
Roof composition	Clay tiles	Clay tiles	Clay tiles + 80 mm (3.15 in.) mineral wood	Clay tiles + 100 mm (3.94 in.) mineral wood
Slab composition	140 mm (5.51 in.) concrete	140 mm (5.51 in.) concrete	140 mm (5.51 in.) concrete + 30 mm (1.18 in.) insulation	140 mm (5.51 in.) concrete + 60 mm (2.36 in.) insulation
Glazing type	Simple glazing	Standard double glazing	Standard double glazing	Standard double glazing
Glazing U, W/m²K	4.08	2.96	2.76	2.76

Our classification of buildings currently includes 72 types of houses. The most common type in the Walloon region is the single-family detached house built on a large plot (1000 m² (1,196 sq. yd) or more), with one ground floor and one story under the attic and with a surface area in the range of 120 m² (143 sq. yd) to 150 m² (179 sq. yd). This type of house, which has spread rapidly since the 1950s, still constitutes the ideal housing standard for many suburban households.

Renovations and improvements made by home owners are then captured. Cadastre mentions, at the individual scale, the buildings that have undergone significant upgrades together with the year of construction and the year of the improvement work. The most common upgrades consist in adding insulation in the roof and replacing windows. Following Verbeek and Hens (2005), insulation of the roof is the most effective and durable measure for energy performance increase of Belgian households. As adding insulation in the slab and the walls is pretty rare (MRW 2007) retrofitted buildings energy consumption is improved but do not reach the actual standard.

Using this classification, an energy consumption analysis is performed with thermal simulation software (Pleiades + Comfie) that includes a three-dimensional modeler and an interface for the input of thermal information (climate conditions, building materials, internal conditions and periods of use of the house). We modeled the energy required to heat each type of building as well as potential solar gains on vertical façades and roofs.

The energy requirements for heating at the neighborhood scale were calculated by adding the results from the energy consumption analysis for each type of house according to their distribution in the neighborhood. Cooling requirements were neglected because they are minimal in Belgium. Indeed, the Belgian climate is a temperate climate. The mean temperature for the typical year used in the simulations is 10.3°C (50.5°F) and the cooling degree hours amount to 2548°Ch per year (if the considered inner temperature is 18°C (64.4°F)). Moreover, the overheating indicator defined in the European energy Performance of Building Directive (EP 2002) and transposed into the regional laws (MB 2008) has been calculated. It remains, for all the typical buildings considered in this analysis, under the threshold value proposed in the Directive (17500 Kh), which indicate that the overheating is not unacceptable and do not requires the installation of cooling system. In the worst of our cases, the overheating indicator raises 12274 Kh.

In addition, energy consumption relating to hot water, electrical appliance and cooking were added in the overall consumption to give a more complete image of energy consumption relating to buildings in suburban areas. As these items are not strictly linked to the characteristics of the buildings and the neighbourhoods but mainly depend upon the behavior of the households and the user habits, we considered in our calculation the regional average consumption (53 kWh/m².year; Kints 2008, see Figure 1, part a). We assumed that this value remains unchanged when the building envelope is improved.

Life cycle assessments (LCA) for several types of houses were also performed using the software Equer, which was linked with the thermal simulation tool (Peuportier 2001). An LCA analyzes the environmental impacts of a given product, system or service over its entire life cycle by quantifying resource use and emissions to the environment (ISO 2006a, 2006b).

The transportation component

The approach developed to assess energy consumption in the transportation sector comprises two parts. The first one deals with home-to-work and home-to-school travels and is based on empirical data available at the census block level, the smallest geographical unit in which data are available in Belgium. These data come from the national censuses, which are carried out every ten years in Belgium. In this study, we used one-day travel diary data from male and female heads of households from the 1991 and 2001 censuses. For these households, information about demographics, socioeconomic status, car ownership, travel distances, main mode of transportation used and the number of working days per week and per worker is available at the census block level. These data were also used by Boussauw and Witlox (2009) to develop a commute-energy performance index for Flanders and the Brussels Capital Region of Belgium that investigates the link between spatial structure and energy consumption for home-to-work travel at the regional scale. Unlike our method, this index is not context-specific; it uses standardized values for all types of urban fabrics (urban, suburban and rural) and does not include home-to-school and home-to-station travel.

To determine the total number of kilometers logged annually by various modes of transportation (car, bus, train, motorbike, bicycle or on foot) for home-to-work travel in each district, our method first combines the number of workers in a census block with the number of trips per week (determined by repartitioning the number of working days per week in the census block), the one-way distance from home to work and the mode of transportation used. For home-to-school travel, instead of using the number of working days, we used the mean number of school days per year in our calculations.

The second part of the approach developed to assess energy consumption in the transport sector deals with two other activities: the shopping and the leisure, which are also known to be 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 calculation based on "type-profiles". According to socio-economic data, we have established several representative types of households living in a district and attributed, to each type of households, mobility characteristics for home-to-shop and home-to-leisure travels, as proposed by Marique and Reiter (2010) and Saunders et al. (2008). 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.

A correction factor is applied to short distances covered by train and long distances covered by bus to preserve the relationship between mode of transportation and travel distance. Nonmotorized trips are not considered in the calculations because they do not consume energy. Motorbike trips are neglected because they represent a negligibly small portion of home-to-work and home-to-school travel. When the main mode of transportation is the train, we include travel from home to the train station because travel by car to the station can play a significant role in energy consumption in suburban areas. A Geographical Information System (GIS) is used to determine the mode of transportation for these home-to-station trips according to the distance traveled and the bus services available in each district.

Distances covered by diesel-burning cars are separated from those covered by gasoline-burning cars according to the distribution of the vehicle stock in the Walloon region (55% diesel-burning and 45% gasoline-burning cars). In the final step of the method, consumption factors are allocated to the distances covered by each category of vehicle (diesel-burning car, gasoline-burning car, bus or train) to convert distance to energy consumption in kilowatt-hours (kWh). Conversion to kWh allows comparison among transportation energy consumption, energy consumption in heating and energy consumption by public lighting. Consumption factors consider the mean fuel consumption of the vehicles (liter per km), the passenger rate and the fuel characteristics (Table 2). For the trains, which are electric in Belgium, the consumption factor is based on the production of electricity. The value used in this paper was calculated for Belgium by CPDT (2005).

Table 2. Consumption Factors (per km and per person) Used to Convert Kilometers into kWh, Based on Mean Regional Values

	Diesel-burning car	Gasoline-burning car	Bus	Train
Consumption per kilometer, L/km	0.068 (34.6 mpg)	0.080 (29.4 mpg)	0.46 (5.1 mpg)	-
Occupancy rate	1.2	1.2	10	-
Density of the fuel, per 1000 L in toe	0.859	0.745	0.859	-
Consumption factor	0.6134	0.6259	0.4986	0.3888

The public lighting component

A simplified calculation was developed to account for the energy consumed by public lighting and to compare this amount with the energy consumed by the buildings and by various modes of transportation. The number of street lamps in an area is multiplied by the power rating of the lamps, including the ballast, and by the standard running time of a lamp (4100 hours per year) to give the annual consumption of the public lighting network in kWh.

Synthesis

The annual energy consumption estimates from buildings heating, hot water, appliances and cooking, transportation and public lighting are expressed in the same unit (kWh) and can be added to give the overall energy consumption of a neighborhood. This overall neighborhood-scale energy consumption is divided by the number of inhabitants to give an indicator, in kWh per inhabitant, which facilitates comparison among neighborhoods and the evaluation of strategies to improve energy efficiency.

Case studies

An application of the method to three suburban neighborhoods of the Walloon region of Belgium, where urban sprawl is a concern in a large portion of the territory, is presented below. In this region, 52% of the building stock is detached and semi-detached houses (Kints 2008), and 50% of the census blocks of the region have a mean housing density between five and twelve dwellings per hectare (Vanneste et al. 2007). The main characteristics of the three neighborhoods under study are presented in Table 3. The first part of the assessment is a present-day inventory of these areas. The second part describes a sensitivity analysis conducted to identify relevant factors for the energy performance of suburban areas and to highlight the best strategies for reducing energy consumption in these areas.

Table 3. Main Characteristics of the Three Neighborhoods

	Tintigny	Fontaine	Jambes
Main types of houses	Detached houses	Semi-detached and terraced houses	Detached houses
Percentage of houses built:			
before 1950	0%	43.9%	0%
between 1951 and 1980	52.5%	26.8%	43.5%
between 1981 and 1995	34.4%	29.3%	49.1%
after 1996	13.1%	0%	7.3%
Total percentage of houses retrofitted/upgraded:	21,3%	0% (social housing, public management)	24,6%
between 1951 and 1980	11.5%	-	5.9%
between 1981 and 1995	9.8%	-	16.7%

after 1996	0%	-	2.0%
Distance to city center (km)	29 (18 mi.)	9 (5.6 mi.)	6 (3.7 mi.)
Distance to train station (km)	8 (5 mi.)	9 (5.6 mi.)	6 (3.7 mi.)
Bus services	Very low	Good	Low

RESULTS

Table 4 presents the energy consumption index calculated for each component (building heating, hot water, electrical appliances and cooking, transportation and public lighting) of the three neighborhoods.

Table 4. Impact of Each Component on Overall Consumption, in kWh per Inhabitant and per Year

	Case 1: Tintigny		**Case 2: Fontaine**		**Case 3: Jambes**	
Component	**Index kWh/p/year**	**%**	**Index kWh/p/year**	**%**	**Index kWh/p/year**	**%**
Building (Heating, including retrofitted buildings)	8340	53.3.%	8213	69.4%	5351	52.0%
Building (hot water, electrical appliances and cooking)	2284	14.6%	2177	18.4%	2048	19.9%
Transportation	4987	31.9%	1394	11.8%	2780	27.0%
(home-to-work)	(2428)		(844)		(1928)	
(home-to-school)	(343)		(136)		(253)	
(home-to-shop-and-leisure)	(2216)		(414)		(599)	
Public lighting	25	0.2%	50	0.4%	111	1.1%
Total	15636	100%	11834	100%	10290	100%

Energy consumed by the heating of buildings is the most important portion of calculated consumption at the neighborhood level. Depending on available bus services and distance to the city center, transportation represents 11.8% to 31.9% of the consumption of a neighborhood. Public lighting plays a comparatively minor role in overall energy consumption.

Key factors in the energy performance of suburban neighborhoods

A clear difference is observed between the heating energy requirements of houses and neighborhoods built before and after the first thermal regulation adopted in the Walloon region. Houses built after the first regulation annually consume 130 kWh/m² or less, whereas those built before 1980, especially dispersed houses, annually consume from 235 to 401 kWh/m². For semi-detached and terraced houses, annual energy consumption falls between 84 and 319 kWh/m² depending on the age of the building. For buildings of the same age, semi-detached and terraced houses consume 14.6% to 23.6% less energy than detached houses, highlighting the effect of connectivity on the energy performance of buildings.

The simulations show that adding insulation in the roof and replacing windows by high-performance glazing (that are the most common upgrades made by home owners) allow to significantly improve the energy performance of buildings (up to 40% in comparison with a non-insulated house). Adding insulation in the slab and the walls is also efficient but is more difficult to realize.

Figure 2 shows heating energy requirements per square meter of the three case studies. The regional mean, the heating energy requirements of the European Energy Performance of Building Directive and of the “low energy” and “passive” standards are added to calibrate these results. Energy used for hot water, appliance (including lighting) and cooking, that is based on the mean regional value and assumed to remain unchanged, are mentioned on the Figure (light grey section) to delineate its impact on building energy consumption.

Figure 2: Energy Requirements (kWh/m².year) attributed to Heating (dark grey) and Hot Water, Electrical Appliance and Cooking (light grey) of the Three Case Studies and Comparison with Regional Mean and “EPDB”, “Low energy” and “Passive” Standards.

The third factor that seems to have a significant effect on energy performance is compactness; for the same insulation values and total surface area (100 m² (120 sq. yd)), energy consumption is 35% lower in a two-story house than in a single-story house.

The buildings that received the most solar gains were detached single-family houses. This can be explained by their relatively large external surfaces. Moreover, masking effects from vegetation and neighboring houses are limited in comparison to denser urban areas where obstructions are more common. If masking effects are included, the calculated solar energy falling on vertical façades and roofs varies only slightly (less than 11%). The effect on energy consumption is further limited (less than 2%) by the lack of optimization of solar accessibility in traditional suburban houses. Therefore, solar gains could be utilized to reduce the amount of energy required for heating, which is currently not the case in existing suburban Walloon neighborhoods.

Using LCA, we compared different types of thermal insulation, corresponding to the mean level of insulation in three of the four age categories described in Table 1 (no insulation; 30 mm (1.18 in.) of polyurethane in the slab and the façades and 80 mm (3.15 in.) in the roof; 60 mm (2.36 in.) of polyurethane in the slab and the façades and 100 mm (3.94 in.) in the roof) and to the most common upgrades (adding insulation in the roof and replacing windows). The results of the LCA show that the operation phase represents the biggest impact over the entire life cycle; energy use over the 80-year service life was calculated to be between 95.9% and 97.9% according to the type of house. LCA results show that all types of houses used in the classification behave similarly. In agreement with values reported in the literature, the relative impact from the operation phase decreases for shorter periods of analysis (92.4% for 40 years and 90.6% for 30 years) but nevertheless remains important. In fact, the literature suggests that over the entire life cycle, the operation phase, with approximately 80–98% of total impacts, is the phase with the highest environmental impact. Alternatively, the construction phase accounts for 1–20% of impacts, and the dismantling phase accounts for less than 0.2–5% (Adalberth et al. 2001; Blengini 2009; Huberman and Pearlmutter 2008; Peuportier 2001; Schreuer et al. 2003). Therefore, reducing fluxes of energy, water and waste during the operation phase will have a greater impact than using high-performance materials. The second main result concerns the insulation; for all types of houses, insulating external façades significantly reduces all the environmental impacts calculated by the software. The first centimeters of insulation are the most important. Insulating only the roof and replacing the windows by high-performance glazing also reduce the environmental impacts over the entire life cycle, because although more material is used in the renovation phase, the energy consumption is significantly reduced after the upgrades. The reduction of impacts is greater between the non-insulated house and the lightly insulated house than it is between the lightly insulated house and the standard insulated house.

In terms of transportation, the Fontaine neighborhood, located close to a city center with good bus service, consumes less energy per capita for all types of trips (work, school, shopping and leisure) taken into account than the two other neighborhoods. In each case, home-to-work trips consume more energy per capita than home-to-school and home-to-shop and leisure trips because travel distances are greater. In fact, most Walloon towns, even the most rural ones, have several schools and shops, whereas work locations are concentrated in larges city centers and suburban business parks. Finally, the use of public buses is higher for home-to-school trips than for home-to-work trips, which also explains the better results obtained for this activity.

Sensitivity analysis

Sensitivity analysis was performed to identify the most relevant factors for improving the energy efficiency of the neighborhoods under study. These factors included insulation (three scenario are tested) and orientation and building distribution, both relating to urban form. We tested the impact of location (in terms of distance to city center and bus services), vehicle performance, travel distance and modal choice on the overall energy consumption. Finally, the management of the heating system was analyzed to determine the impact of inhabitant behavior.

Table 5 summarizes the energy consumption reductions for all the components (building heating + building hot water, appliance and cooking + transportation + public lighting).

Table 5. Overall Energy Consumption Reductions Obtained for Each Strategy

	Case 1: Tintigny	Case 2: Fontaine	Case 3: Jambes
Energy performance of buildings			

1. Improving the insulation of houses (all houses are retrofitted to reach the actual standard)	-29.7%	-39.5%	-21.8%
2. 50% of the pre-1981 stock is upgraded (insulation in the roof)	-2.2.%	-8.9%	-1.0%
3. 50% of the pre-1981 stock is upgraded (insulation in the roof and new high-performance glazing)	-3.3%	-10.8%	-1.8%
4. Orientation of the houses and neighborhoods	-1.3%	-1.2%	-1.3%
5. More compact distribution of buildings (terraced and semi-detached houses)	-14.9%	-	-10.0%
Transportation			
6. Favorable location (as in Case 2)	-18.0%	-	-6.1%
7. Improving vehicle performance (private cars and public buses) by 10%	-6.1%	-2.5%	-4.8%
8. 20% of the inhabitants opting public transportation instead of private car	-2.4%	-1.0%	-1.8%
Inhabitant behavior			
9. More efficient management of the heating system (19°C/15°C versus 19°C constant)	-11.5%	-13.8%	-16.5%

These results indicate that improving building insulation is the most relevant strategy in the reduction of overall energy consumption. Assuming that all the houses were retrofitted with 60 mm (2.36 in.) of polyurethane insulation in the vertical façades and the slab and with 100 mm (3.94 in.) of mineral wool insulation in the roof, the overall consumption is reduced by 29.7%, 39.5% and 21.8% in the three neighborhoods. These results are mainly due to the low rate of insulation in the Walloon region of Belgium in relation to the temperate climate. Adding insulation in the roof and replacing windows by high-performance glazing of 50% of the building stock built before the first thermal regulation is a more credible approach for the households but do not allow to reach the actual standard. A part of the potential energy savings highlighted in the first analysis concern thus also buildings that have already been retrofitted. These types of strategies are efficient, particularly in non-insulated neighbourhoods.

In terms of orientation, we determined that energy consumption in buildings varied only marginally (less than 2%) with the orientation of the neighborhood and the solar energy effect on vertical façades and roofs. This is due to the lack of optimization for solar accessibility in these types of neighborhoods. A potential for the use of bioclimatic principles exists and should be better utilized, namely through a more advantageous positioning of windows on façades.

The impact of building distribution was tested for two areas with detached houses. The number of houses in each neighborhood was held constant, but we assumed the houses were grouped in fours (two terraced houses and two semi-detached houses). In these configurations, overall energy consumption decreased by 14.9% in the first case and by 10.0% in the third (case 2 already included terraced houses), confirming the influence of building distribution on energy consumption. Building distribution is more significant for buildings with less insulation.

The sixth sensitivity analysis highlights the impact of location on overall energy consumption. If the first and third cases had the same benefits as the second (better bus services and proximity to urban centers), the overall energy consumption would decrease by 18.0% and 6.1%, respectively, mainly from a reduction in the number and distance of car trips (particularly in the first case study that is located far from city centre). Improving the performance of private and public vehicles, favoring shorter travels to work and school (by better housing locations) and favoring public transportation instead of private cars are also strategies for the improvement of energy efficiency in suburban areas. But, as older Belgian houses are poorly insulated, the absolute priority is to improve insulation in existing buildings. However, households' location (that allows to reduce travel distances) and the performances of the vehicles will be more significant for new buildings and neighborhoods because the passing of the EPBD guarantees that new buildings are well insulated and more energy efficient. If all the buildings in a neighborhood were well insulated (as in the first scenario), these strategies could significantly increase the potential energy savings. Finally, our calculations show that more efficient management of the heating system could substantially reduce energy consumption in buildings.

DISCUSSIONS

The application of the method developed to evaluate energy consumption of suburban neighborhoods to three representative neighborhoods in the Walloon region of Belgium demonstrates that energy performance in existing suburban neighborhoods is poor. A strong potential for the application of bioclimatic principles exists because solar gains are significant and masking effects are low.

The sensitivity analyses demonstrate the benefits of several buildings renewal strategies. Increasing the insulation rate and favoring a more compact distribution of buildings significantly improve energy performance in buildings. LCA results showing the importance of the operation phase and the savings obtained through renovation (adding insulation in the roof and replacing windows) in energy consumption reinforce these strategies. Better management of the heating system, namely, activating or deactivating the system according to the occupation of the house, can easily improve the energy efficiency of buildings and neighborhoods.

The results from this study highlight the importance of location on overall energy consumption and emphasize the importance for comprehensive energy analyses that consider both the building and the transportation sectors. Energy consumption in home-to-work, home-to-school, home-to-shop and home-to-leisure trips plays a significant role in overall consumption, especially when the energy performance of buildings is good. Location is thus an important factor to take into account when new districts are built.

As far as limitations are concerned, our method uses dynamic simulation tools to assess heating consumption in buildings, which have been shown to give results significantly different from those observed in reality because of variations in inhabitant behaviors. Indeed, building operation and maintenance, occupant activity and indoor environmental quality, all of which are related to human behavior, are known to have an influence as great as or greater than climate, building envelop and energy systems (Hilderson et al. 2010), confirming the idea that green buildings and sustainability require more than efficient designs (Brandemuehl 2004). Real climatic conditions can also differ from the standardized data used in simulations. The software used in this analysis has been validated by the International Energy Agency Bestest (Benchmark for Building Energy Simulation Programs) (Peuportier 1989; Peuportier 2005). Nevertheless, it is not possible to compare the results presented in this paper with in situ measurements because of high variation in inhabitant behaviors. That is also the case for the consumption relating to hot water, electrical appliances and cooking that are known to be too dependent of the user habits (Verbeeck and Hens 2005). Thus, the figures presented here must be discussed by comparison to one another and with respect to the hypotheses and assumed conditions. However, they are useful in the identification of important factors related to energy efficiency.

The conclusions and discussions presented in this paper are only valid for poorly or non insulated buildings and districts. Indeed, if the insulation of the houses is improved to fit the actual standard or if a more compact urban form is promoted, the relative percentage of building heating component (Table 4) falls below 50%. In these cases, or in newly built districts, others strategies, namely those relating to transportation and inhabitant behavior, must be promoted to reduce overall energy consumption.

Finally, to transfer the main results of our research to citizens and stakeholders, an interactive decision making tool has been developed on the basis of the methods in this paper and made available on the internet. Our goal is to provide an assessment tool dedicated to building performance and transportation in Belgium. The tool will help public authorities and private developers to plan more efficient suburban developments and to improve energy efficiency in existing neighborhoods. Users of the tool can also identify practical strategies to reduce their energy consumption and test the impacts of different neighborhoods before choosing their housing location.

CONCLUSIONS

Although the environmental impacts and energy requirements associated with urban sprawl are well documented, low-density suburban areas continue to develop all over the world. To reduce the overall energy consumption of housing and transportation in the Walloon region of Belgium, a method has been developed to assess existing and proposed suburban neighborhoods. It considers the energy consumed by the heating systems in residential buildings, the public lighting network and transportation. The proposed method combines a classification of buildings, thermal simulations and empirical data. Results from an application of the method to three typical suburban neighborhoods demonstrated the applicability of the method and its ability to identify key factors and strategies for the improvement of energy efficiency in suburban areas. We highlighted the role of building insulation, the compactness of building distribution and the location of neighborhoods in energy consumption. Inhabitant behavior also has a significant impact on the energy performance of suburban areas. By adjusting parameters, such as those related to climate, insulation or vehicle characteristics, the method can be transferred from the Walloon context to other countries and regions, including urban and rural ones. Further, the method can be used to design and build more energy efficient neighborhoods but also to retrofit existing ones, and thus, to combat urban sprawl, a common phenomenon in many areas all over the world.

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FIGURE CAPTIONS AND TABLE TITLES

Figure 1, part a: Energy Consumption of Belgian Households according to the Type of Utilization

Figure 1, part b : Repartition of the Electrical Appliance

Figure 2: Heating Energy Requirements (kWh/m².year) attributed to Heating (dark grey) and Hot Water, Electrical Appliance and Cooking (light grey) of the Three Case Studies and Comparison with Regional Mean and “EPDB”, “Low energy” and “Passive” Standards.

Table 1. Main Characteristics of External Façades and Glazing by Age Category

Table 2. Consumption Factors (per km and per person) Used to Convert Kilometers into kWh, Based on Mean Regional Values

Table 3. Main Characteristics of the Three Neighborhoods

Table 4. Impact of Each Component on Overall Consumption, in kWh per Inhabitant and per Year

Table 5. Overall Energy Consumption Reductions Obtained for Each Strategy