A method to assess global energy requirements of suburban areas at the neighbourhood scale

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ABSTRACT
This article presents the method developed to assess existing suburban neighbourhoods in order to improve their energy efficiency. It combines the use of dynamic simulation tools to evaluate energy requirements for heating and lighting residential buildings, a statistical approach to assess the transport system and a simplified calculation to take also into account public lighting. The method is completed by a life-cycle analysis of buildings. An application is presented concerning the comparison of three typical suburban structures in the Walloon region of Belgium. The influence of parameters which are often underestimated, like the distribution of buildings or location, on the global energy performances of suburban fabrics is tested. The results of this exercise are presented and its limits are discussed.

KEYWORDS
Urban sprawl, suburban renewal, energy efficiency, building and transport.

INTRODUCTION
The process of urban sprawl is familiar in many urban regions, and particularly in the Walloon region of Belgium, where 52% of the building stock is composed of detached or semi-detached houses. Because of the personal preferences of the Walloon households for single family houses with a large garden in a rural environment and the regulatory environment which allows this kind of developments to grow, urban sprawl concerns now a large part of the regional territory. The main characteristics of this phenomenon are the low density, the mono-functionality of the developments (it mainly concerns housing but also commercial or industrial functions) and the huge dependence upon cars, because these neighbourhoods are often developed far away from city centres, where land prices are lower. Urban sprawl represents thus a significant contribution to the global energy consumptions, as far as buildings energy but also transport needs are concerned. However, although the environmental impacts of urban sprawl are now well known (CPDT, 2002; Urban Task Force, 1999; Young et al, 1996) and although it is usually argued that more compact urban forms would significantly reduce energy consumption both in the building and transport sectors (Maïzia et al, 2009; Steemers, 2003; Newman and Kenworthy, 1995), low density suburban developments continue to grow regardless of their future or renewal potentialities.

In the current context of growing interests in environmental issues, reducing energy consumptions in the building and transport sectors (which represent respectively 37% and 32% of final energy in the European Union) often appears as important policy targets. Suburban areas are supposed to present high potentialities in terms of energy reduction but transports needs, despite their role in the global consumptions, are rarely taken into account when the energy efficiency of these areas is studied. Moreover, existing models often adopt the perspective of the individual building as an autonomous entity and neglect the importance of phenomenon linked to larger scales (Ratti et al, 2005).

Finally, specific tools to assess suburban neighbourhoods, and their specificities, are lacking. In this context, a method has been developed to assess Walloon existing suburban neighbourhoods in order to improve their energy efficiency and compare different strategies of suburban renewal.

METHODS

The method proposed here aims at performing the global energy modelling of suburban areas, including the energy assessment of buildings, transport and public lighting. The research addresses their influences at the neighbourhood scale because, even if the urban context has been mostly neglected in building energy analyses so far, decisions made at the neighbourhood level have important consequences on the performance of individual buildings and on the transport habits of the inhabitants (Popovici and Peuportier, 2004).

The building sector

The first part of the method concerns energy requirements in buildings. A typology of different detached, semi-detached and terraced houses is established in order to classify the suburban building stock of the Walloon region of Belgium. It covers only single family types of buildings and has been designed for the classification of all suburban neighbourhoods of the Walloon Region. This typological approach, often used in the literature (Popovici, 2006; Jones et al, 2001), provides the following indicators for each type of houses: the area of buildings (sqm), the number of levels and the average age of construction. Four categories of age are taken into account ([before 1950], [1951-1980], [1981-1995] and [after 1996]), according to the evolution of the regional policies concerning energy performance of buildings and the statistical data available on the energetic performance of the Walloon building stock. The age categories have been used to approximate a mean thermal conductivity of external facades, according to a "standard" composition of external facades and glazing.

Table 1. Main characteristics of external facades and glazing according to the categories of age

Characteristics	Before 1950	1951-1980	1981-1995	After 1996
Insulation type	-	External	External	External
Wall composition	Concrete blocks	Concrete blocks	Concrete blocks + 3 cm insulation (pur)	Concrete blocks + 6 cm insulation (pur)
Roof composition	Clay tiles	Clay tiles	Clay tiles + 8 cm mineral wool	Clay tiles + 10 cm mineral wool
Slab composition	14 cm concrete slab	14 cm concrete slab	14 cm concrete slab upon 3 cm insulation (pur)	14 cm concrete slab upon 3 cm insulation (pur)
Glazing type	Simple glazing	Standard double glazing	Standard double glazing	Standard double glazing
Glazing U	4,08 W/m².K	2,96 W/m².K	2,76 W/m².K	2,76 W/m².K

An energy consumption analysis of each type of housing is then performed. The software used for this purpose is Pleiades+Comfie. It includes a geometrical 3D modeller and an interface for thermal indicators (climate conditions, building materials, internal conditions and periods of use of the house). The solar shading between buildings is taken into account. This software is linked with Equer, a life cycle analysis software (Peuportier, 1999). We modelled the energy consumption required for heating and lighting each type of buildings as well as potential solar gains on vertical facades and roofs. The cooling needs were neglected because they are very marginal in Belgium. Life cycle assessments of several types of houses were also performed.

Finally, the energy requirements at the neighbourhood scale are calculated by adding the energy requirements given by the energy consumption analysis for each type of houses, according to their distribution in the neighbourhood.

The transport sector

The approach developed to assess energy consumptions in the transport sector uses statistical data available at the neighbourhood scale. These data come from a national survey, carried out in 1991. One-day travel-diary data from male and female heads of households are used. For these households, information is available in each neighbourhood about car ownership, travel distances, main means of transport used, part-time or full time work, etc. together with their demographic and socioeconomic situation. The survey only concerns two purposes of travel: travelling to work and travelling to school, which are supposed to represent the main part of the mobility pattern and play a founding role on it because they are commuting journeys.

After processing these data, we are able to determinate for each neighbourhood how many kilometres are covered annually by car, by bus and by train as far as travelling to work and to school is concerned. If the main mean of transport used is the train, we can also take into account journeys from the house to the station because suburban neighbourhoods are often located far away from stations. Travelling by car to the station can thus play a significant role in the energy consumptions.

Kilometres covered by diesel cars are separated from those covered by petrol cars, according to the regional distribution of the vehicle stock (55% diesel and 45% petrol cars). The final step of the method consists in allocating consumption factors to the kilometres covered in each category of vehicles in order to convert kilometres into kWh. Consumption factors take into account the consumption of the vehicles (liter per km), the passenger rate and the characteristics of the fuel. For the train, the consumption factor used depends on the production of electricity because in Belgium trains are mainly electrified.

Table 2. Consumptions factors used to convert kilometres into kWh

Characteristics	Diesel car	Fuel car	Bus	Train
Consumption per kilometre	0,068 litre	0,080 litre	0,46 litre	-
Passenger rate	1.2	1.2	10	-
Density of the fuel (/1000 litre in tep)	0,859	0,745	0,859	-
Consumption factor (per km and per person)	**0,6134**	**0,6259**	**0,4986**	**0,3888**

The public lighting sector

The number of street lamps is multiplied by the power of the lamps, including the ballast, and by standard running times (4.100 hours per year) to give the annual consumptions attributable to the public lighting network in kWh.

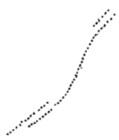
Synthesis

The consumptions attributable to the three sectors taken into account in the method are expressed in the same unit (kWh) and can be added to give the global energy consumption of the neighbourhood. This result is finally divided by the number of inhabitants (or the number of square meters) in the neighbourhood to give an indicator which allows making comparisons between different neighbourhoods.

Case studies

An application of the method is presented concerning the comparison of three typical suburban structures in the Walloon region of Belgium: the “linear” neighbourhood, the “semi-detached” neighbourhood and the “plot” neighbourhood. Three existing neighborhoods have been selected as case studies. The first part of the assessment consists in studying these three case studies representative of each typical structure. The second part develops sensitivity analyses to identify relevant indicators of the energy performances of suburban areas.

Table 3. Main characteristics of the three case studies

Characteristics	Case 1	Case 2	Case 3
Neighbourhood type	Linear	Semi-detached	Plot
			
Houses type	Detached houses	Semi-detached and terraced houses	Detached houses
Houses built:			
- [before 1950]	-	36	-
- [1951, 1980]	32	22	172
- [1981, 1995]	21	24	194
- [After 1996]	8	-	29
Mean size of the plots	12.5 ares	1,5 ares	9 ares
Distance to city center	29 km	9 km	6 km
Distance to the station	8 km	9 km	6 km
Bus service	Low	Good	Very low

RESULTS

The following two tables present the impact of each sector (building, transport and public lighting) on the global consumptions, for the three case studies.

Table 4. Impact of each sector on the global consumptions, in kWh/inhabitant.year

Sector	Case 1: linear	Case 2: semi-detached	Case 3: plot
Building	8 874	8 213	5 681
Transport	2 771	980	2 181
Public lighting	25	50	111
Total	**11 669**	**9 196**	**7 973**

Table 5. Impact of each sector on the global consumptions, in %

Sector	Case 1: linear	Case 2: semi-detached	Case 3: plot
Building	76.0 %	89.3 %	71.3 %
Transport	23.7 %	10.2 %	27.4 %
Public lighting	0.3 %	0.5 %	1.3 %
Total	100 %	100 %	100 %

Energy for heating and lighting buildings is the most important part of the global consumptions at the neighbourhood scale. Transport (only travels to work and to school are taken into account in our method) represents 10.2% to 27.4% of the global consumptions, depending on the bus services and distance to the city centre. Public lighting only plays a very marginal role in the global consumptions.

On the basis of these results and as it is not possible to present all the results here, we have chosen to highlight the energetic performances of buildings in this paper. Key indicators are discussed in the first part of this section. The results of sensitivity analyses are then presented.

Key indicators of the energy performances of suburban houses

As far as energy consumptions for heating and lighting buildings are concerned, a clear difference can be observed between houses and neighbourhoods built before and after the first thermal regulation adopted in the Walloon region of Belgium. Those built after the first regulation have heating consumption inferior to 130 kWh/m².year, while the buildings built before 1980 are clearly most energy intensive, especially for dispersed types of houses (from 235 to 401 kWh/m².year). The simulations moreover show that the insulation of the vertical facades, the slab and especially the roofs are the most important steps to improve the energy performances of buildings. The use of high-performance glazing has only significant potential to reduce energy consumptions if all the facades and the roof are well insulated.

For semi-detached and terraced houses, energy consumptions are contained in a range between 84 and 319 kWh/m².year, according to the age of the constructions. For the same age of construction, those types of buildings have energy consumptions 14.6 % to 23.6 % lower than detached houses, which highlight the effect of continuity on the energy performances of buildings.

The third indicator that seems to have a significant effect on energy performances is compactness: for the same insulation and the same living area (100 m²), energy consumptions are 35% lower in a “ground floor + one storey under attic” volume than in a house entirely built at street level.

As regard with solar accessibility, the buildings that received most solar gains are detached single family houses. This can be explained by the large external surfaces of this type of houses compared to terraced houses. Moreover, masking effects, due to the vegetation and the neighbouring houses, stay quite limited, in comparison with dense urban centres where obstructions to sun and light are numerous. It has been calculated for several types of detached houses that the solar energy on vertical facades and roofs vary only lightly (less than 11%) if the masks are included in the simulations. The resulting effect on the energy consumptions is also very limited (less than 2%) because of the lack of optimisation of traditional suburban houses in terms of solar accessibility. A potential for solar gains exists thus and should be valorised, which is not the case in existing suburban Walloon neighbourhoods.

We have finally performed a life cycle assessment of several types of detached houses in order to compare the results of different types of thermal insulation, corresponding to the mean level of insulation allocated to three categories of age described in Table 1 ([1950-1980], [1981, 1995] and [after 1996]). We just illustrate here two main results. The utilisation phase presents the main impact on the whole life cycle: between 95.9 % and 97.9 %, according to the type of houses, for a service life of 80 years. The impact of the utilisation phase decreases for shorter periods of analysis (92.4 % for 40 years and 90.6 % for 30 years) but remains important. Therefore, trying to reduce fluxes (energy, water and waste) in the utilisation phase seems to be more useful than using high-performance material. The second result concerns the insulation: for all types of houses, insulating external facades allows a significant reduction of all the environmental impacts calculated by the software. The first centimetres of insulation are the most efficient. As it can be seen on Figure 1, the reduction of the impacts is bigger between the non-insulated house and the light-insulated one (3 cm of PUR in all the external facades) than between the light-insulated house and the standard-insulated house (6 cm of PUR).

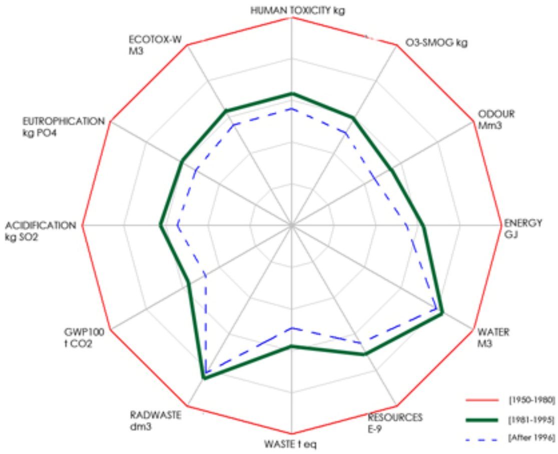


Figure 1. Comparative ecoprofile for three types of insulation: the non-insulated house (regular line), the light-insulated house (bold line) and the standard insulated house (dotted line), calculated with the EQUER LCA software.

Sensitivity analyses

Four sensitivity analyses are finally performed in order to identify most relevant indicators, apart from the geometry of the houses and the comportment of the occupants. These concern insulation, orientation and distribution of buildings as far as energy performances of buildings are concerned. We finally test the impact of the location (distance to the city centre and bus services) on the global consumptions of the three case studies.

Insulation is the most relevant indicator in order to reduce energy consumptions. If we suppose that all the houses of the neighbourhoods are insulated with 6 centimetres of PUR in the vertical facades and the slab and 10 centimetres of mineral wool in the roof, which should be a credible strategy of renewal, the consumptions attributable to buildings decrease by 58.4 % in case 1, 56.7 % in case 2 and 45.2 % in case 3. The effect of this strategy on the global consumptions (building + transport + public lighting) is a reduction of respectively 44.4 %, 50.5 % and 32.2 % for the three case studies. The part attributable to buildings in the global results decreases too and represents then 56.9 %, 77.5 % and 57.6 % of global results (compare with table 5). These results are mainly due to the low rate of insulation in buildings in the Walloon region of Belgium, in relation with the climate.

As regards the orientation, it has been calculated that buildings energy consumption related to solar energy on vertical facades and roofs vary only marginally (less than 2 %) with the orientation of the neighbourhood. This is due to the lack of optimisation of these kinds of neighbourhoods in terms of solar accessibility.

The impact of the distribution of buildings is tested for the “linear” and the “plot” case studies. We have kept the same number of houses in each neighbourhood but we have considered that houses are grouped by 4 (2 terraced houses and to semi-detached houses). In these configurations, the energy consumptions of buildings decrease by 31.9 % in the “linear” neighbourhood and by 23.4 % in the “plot” neighbourhood, which tends to confirm the influence of the distribution of houses on the energy consumptions. This impact seems to be higher if the insulation rate is low.

The last analysis highlights the importance of the location on global energy consumptions. If the “linear” and the “plot” neighbourhoods benefit from the same location than the “semi-detached” one (better bus services and proximity of urban centres), the global energy consumptions, including building, transport and public lighting, decrease: - 7.7% in the first case, - 22.9 % in the second one, especially because journeys by car are shorter and less numerous. The part of the transport sector in the global results decreases too: 17.4 % instead of 23.7 % for the “linear” case and 5.8 % instead 27.4 % for the “plot” case.

DISCUSSIONS

The application of the method to three typical suburban blocks highlights that energy performances in Walloon existing suburban neighbourhoods are low. A strong potential for bioclimatic principles exists because solar gains are huge and masking effects low, but is not exploited. The sensitivity analysis shows, however, that the benefits of several renewal strategies exist: increasing the insulation rate and favoring a more compact distribution of buildings can give significant results as far as energy performance of buildings is concerned. It is all the more important because life cycle analyses show that the utilization phase is crucial in terms of energy consumptions.

The analysis also highlights the importance of location on global energy consumptions and emphasizes the necessity for global energy analyses, taking into account both the building and the transport sectors, which stays rare in existing methods. Consumptions due to travelling to work and to school, that are only a part of the mobility of the inhabitants, play a significant role in the global results, especially when the energy performances of buildings are good.

The limits of the method essentially concern the transport sector because only travelling to work and to school are taken into account. It should thus be completed in the future by travels to shops, services and leisure to give a more complete approach. Finally, the method to assess energy consumptions in buildings uses dynamic simulation tools and experience shows that simulations results can be significantly lower than in reality because of user behavior and real climatic circumstances.

CONCLUSIONS

A method has been developed to assess existing suburban neighbourhoods in the Walloon region of Belgium. It takes into account energy consumptions for heating and lighting the residential buildings, consumptions attributable to the public lighting network, but also the impact of the location of the neighbourhoods through journeys to work and to school. An application to three typical suburban blocks has shown the applicability of the method and its potentialities to identify key parameters in energy efficiency of neighbourhoods and to compare neighbourhoods and strategies of renewal in suburban fabrics. As far as the validation of the method is concerned, the software used for the analyses are validated by the International Energy Agency Besttest (Benchmark for Building energy Simulation Programs) (Peuportier, 1989; Peuportier, 2005). Nevertheless, it is not possible to compare the results presented in the paper with in situ measures because of high variations in the real comportment of the occupants. The figures presented here must thus be discussed only by comparison and for the hypotheses and conditions presented in the paper.

An interactive decision making tool, accessible on the web, will further be developed, on the basis of the method presented in this paper. It will help stakeholders and developers to plan more efficient new suburban neighbourhoods and to improve energy efficiency in existing neighbourhoods. Occupants could also use the tool to find practical avenues to reduce their energy consumptions or to test the impact of different neighbourhoods before choosing their housing location. The method, tested in the Walloon context, should also be applied to foreign case studies because urban sprawl is a reality in numerous regions and namely in emerging countries where the Walloon experience could be useful to avoid repeating existing bad practices.

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