# Combining Territorial Data With Thermal Simulations to Improve Energy Management of Suburban Areas

An application to the Walloon region of Belgium

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***Abstract*—Urban sprawl has been identified as a major issue for sustainable development. Energy consumption in suburban buildings, in particular, is a widespread issue because detached types of houses require significantly more energy to be heated than more compact urban forms. Energy efficiency is often presented as a viable approach to the mitigation of climate change, but research and studies mainly contend with individual buildings and do not address this issue at larger territorial scales or for a whole building stock. In this respect, this paper first presents a morphological definition of urban sprawl. This definition uses territorial and cadastral data available for the Walloon region of Belgium. Using this definition, a suburban type classification adapted to thermal studies is drawn up. A representative block of each type is selected to model energy use and to determine the total energy consumption of the whole suburban building stock. An application is then presented concerning a comparison of potential energy savings associated with several renovation strategies. The results of this exercise are presented and highlight the benefits of combining Geographic Information Systems (GIS) tools, territorial data and thermal simulations for the efficient energy management of suburban areas at the scale of the whole building stock.**

***Keywords-urban sprawl; territorial data; urban GIS; energy consumption.***

## I. INTRODUCTION

The expansion of urban areas, commonly referred to as urban sprawl, has been identified as a major issue for sustainable development [1]. Although opponents of sprawl argue that more compact urban forms would significantly reduce energy consumption both in the building and transportation sectors [2][3][4][5], low-density residential suburban districts are a reality in our territories and continue to grow. Such patterns of development are found in both developed and developing countries [6][7][8].

Much research has focused on urban sprawl and has in particular identified energy consumption in suburban houses as a major issue because detached houses consume significantly more energy than compact urban forms [1][9][10][11]. In the actual context of increasing environmental awareness, energy efficiency in buildings is in fact a topic widely studied in the literature and often presented as a viable approach to the mitigation of climate change. It has also become a central policy target in the European Union at both the national and local levels [12]. A well-known example of this dynamic is the adoption in 2002 and the progressive integration into local laws of the European Energy Performance of Buildings Directive (EPBD). This directive requires all European countries to strongly enhance their building regulations and aims primarily to establish minimum standards for the energy performance of new buildings and existing buildings larger than 1000 m² that are subject to major renovation [13].

Although this is a good step towards more sustainability in the building sector, two objections can be made to this directive and to much of the existing research and models. First of all, they adopt the perspective of the individual building as an autonomous entity and neglect the importance of phenomena linked to larger scales, although decisions made at the neighborhood and regional levels have important consequences for the performance of individual buildings and the transportation habits of the occupants [11][14][15]. Moreover, this approach is difficult to generalize to address the sustainability of a whole territory. Secondly, the EPDB Directive mainly applies to new buildings, whereas the existing building stock is huge, often poorly or non-insulated and takes a very long time to be renovated.

To effectively address the issue of energy efficiency in the whole suburban building stock and to help reach the climate change targets adopted in the scope of international agreements, it is essential to surpass this "single-new-building" approach. A large amount of territorial data is available, but it is rarely used where the sustainability of the territory, in particular the issue of energy consumption in buildings, is concerned. We propose to exploit these data, in combination with thermal simulations and energy performance indicators, to draw a regional cadastre of energy consumption in suburban areas and to test the impact of regional strategies applied to the whole suburban building stock. Note that the definition and the building type classification presented in this paper can also be adapted to urban and rural areas to cover the whole regional territory.

In Section 2, the paper presents a morphological definition of urban sprawl adapted to thermal studies. The suburban building stock referred to by this definition is then classified into representative categories of buildings and neighborhoods (Section 3). This typological approach has already been used in the literature and proved to be of interest [2][11][16][17]. Two applications are proposed in Section 4 to highlight the usefulness of this approach: a calculation of the energy consumption of the whole suburban area of the Walloon region and a comparison of three renovation strategies at a regional scale. Our main findings and the reproducibility of this approach are discussed in Section 5.

## II. A Morphological Definition of Urban Sprawl

In this section, the existing classifications commonly used in Belgium are presented together with their limitations as far as morphological studies are concerned. Developed on this basis, our classification of urban types is presented and compared with existing ones and with an empirical survey.

### A. *The existing classifications*

Based on qualitative and quantitative data, Van der Haegen and Van Hecke's urban type classification [18][19] (Figure 1) assigns the 262 Walloon municipalities (589 in Belgium) to four categories based on the level of facilities provided and on residents' locations with respect to work, shopping and services. This classification follows the same philosophy as the UK's OPCP and the ECOTEC's urban categories. The "operational agglomeration" is based on the morphological agglomeration. The "suburbs" are the first suburban area of a city. The density of population remains less than 500 inhabitants per square kilometer. Areas located further from the city, while keeping strong relationships with it (namely through home-to-work commutes), constitute the "alternating migrants area," whereas the remaining areas are grouped under the "other areas" term. This category thus comprises not only rural and suburban districts but also secondary cities and municipalities located outside the influence of the main agglomerations. Although urban sprawl is particularly linked to the "suburbs" and the "alternating migrants areas" [20], low-density suburban neighborhoods are found in the four urban categories because the boundaries of the urban types are adapted to administrative borders, as observed in Figure 2.

The Belgian urban settlements zoning (Figure 3) is a finer representation [21]. The size of an urban settlement (defined as groups of population living in neighborhood buildings) varies from a census block (i.e., a neighborhood in urban areas and a village in rural areas with more than 150 inhabitants) to an aggregation of several census blocks separated by less than 100 meters. Updated in 2001 [22], this classification more adequately fulfills our purpose as it embraces morphologically contiguous urbanized areas and crosses over municipalities' boundaries. However, rural and suburban areas are not differentiated.

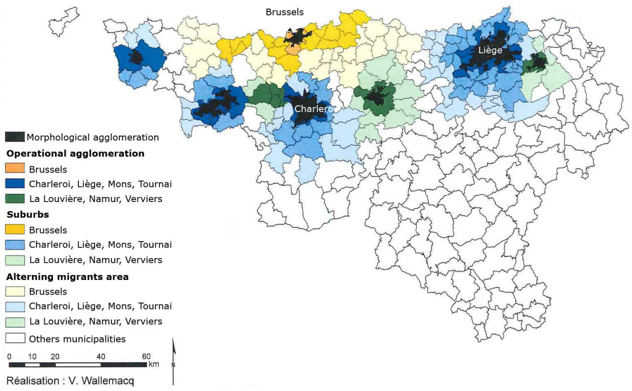


Figure 1. Van der Haegen and Van Hecke's urban type classification. "Operational agglomerations" are black; "suburbs" are dark blue, dark yellow and dark green; "alternating migrants areas" are light blue and light green and "other areas" are white.

Figure 2. Very different types of districts are found inside each urban type highlighted in Van der Haegen and Van Hecke's classification. Example of a very dense district and a suburban district located in the "operational agglomeration" (municipality of Liège).

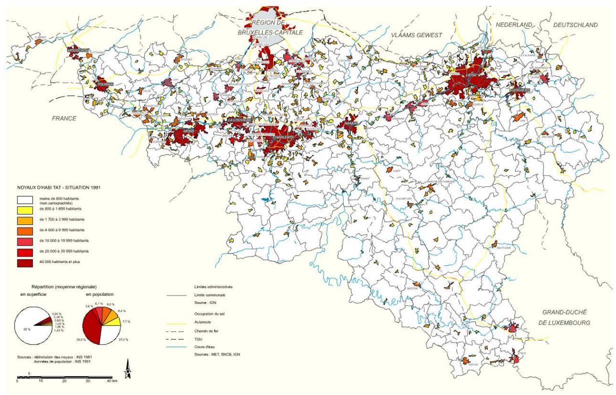


Figure 3. The Belgian urban settlements zoning (in red).

### *B. Drawing a morphological urban type classification*

Although the two previous classifications are often used in national and regional research dealing with population and socio-economic issues, they do not seem adapted to morphological studies and do not allow the clear identification of suburban areas. To propose a better definition, an extensive review of the literature dedicated to urban sprawl was performed and three main characteristics of this phenomenon were highlighted: (1) low density, (2) mono-functionality and (3) discontinuity with traditional urban cores. The first parameter in particular is closely linked to the morphology of buildings.

To determine our morphological urban type classification, we used the following territorial data set at a disaggregated scale:

- Cartography (1/10,000) of the buildings and plots of the Walloon region drawn by the regional administration in charge of cartography;
- Cadastral database: buildings' date of construction, type of buildings (i.e., housing, commercial).

We calculated the density of dwellings (shops, schools and others buildings were eliminated) in each of the 9,730 census blocks of the Walloon region of Belgium. These census blocks were then classified according to the value of this index. The frequency distribution was divided into four parts, each containing a quarter of the population (Figure 4). The two central intervals (density in the range of 5 to 12 dwellings per hectare) are identified as the suburban territory, as 52% of the building stock of Belgium is composed of detached and semi-detached houses. Census blocks presenting a dwelling density higher than 12 dwellings per hectare are identified as "urban districts", and those with a density lower than 5 dwellings per hectare are considered to be "rural districts". Figures 5, 6 and 7 present the census blocks associated with each type. This approach crosses over municipalities' boundaries and distinguishes three urban types based on morphological criteria. Note that in the rest of the paper, we will only consider the suburban territory (Figure 6). However, the developments presented below are also easily applicable to urban and rural areas.

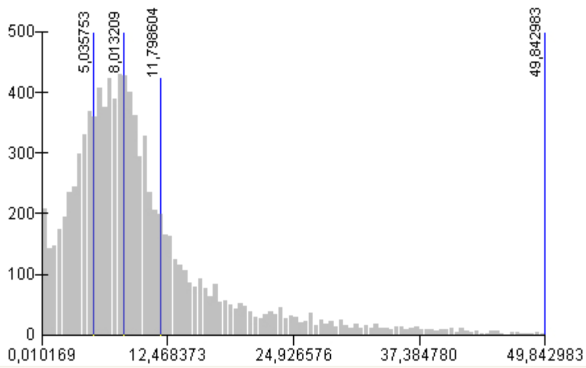


Figure 4. The frequency distribution of the density of the 9,730 census blocks. Quartiles are used to determine the urban area (density > 12 dwellings per hectare), the suburban area (5 dw/ha < density < 12 dw/ha) and the rural area (density < 5 dw/ha).

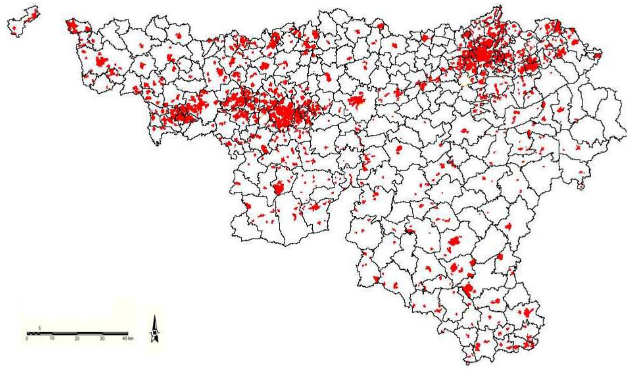

Figure 5. The urban area: districts presenting a built density higher than 12 dwellings per hectare.

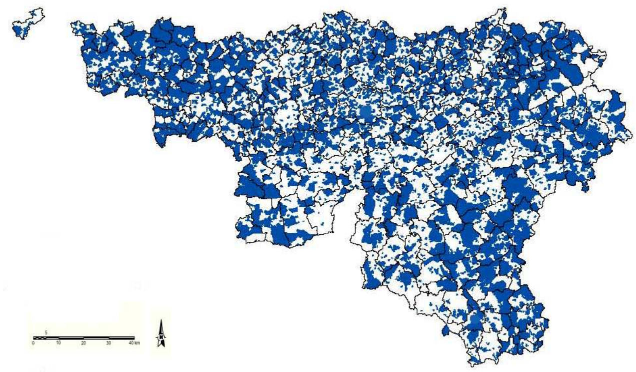

Figure 6. The suburban area: districts presenting a built density in the range of 5 to 12 dwellings per hectare.

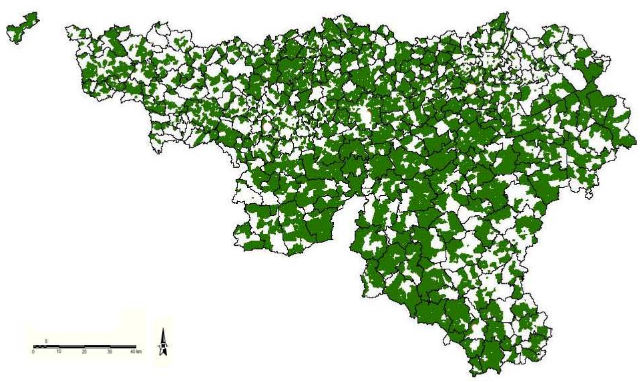

Figure 7. The rural area: districts presenting a built density lower than 5 dwellings per hectare (including unbuilt census blocks).

### *C. Comparison of our classification with existing ones*

The main assumption that guided the definition of our classification is that suburban districts are spread out over the whole territory, as observed in Figure 6. This definition thus resolves the issue highlighted in Section 2 and overcomes the two disadvantages of the existing classifications as far as morphologic research is concerned. Note that our definition of the urban areas corresponds fairly well to the urban settlements zoning. In addition, we are able to differentiate suburban and rural areas.

The number of suburban districts in each municipality was then calculated and is presented in Figure 8 to highlight the parts of the territory where urban sprawl is common. This confirms that central municipalities (in particular the municipality of Namur in the center of the regional territory) may also contain a huge number of suburban low-density districts and that classification based on municipalities' boundaries is not adapted to research dealing with the morphology of the urban form. The north part of the Walloon region (the Walloon Brabant, in the influence area of the metropolitan area of Brussels) is particularly concerned with urban sprawl. To a lesser extent, suburban districts are also located in the southern, less densely populated part of the region, and particularly in the extreme south under the influence of the metropolitan area of Luxembourg.

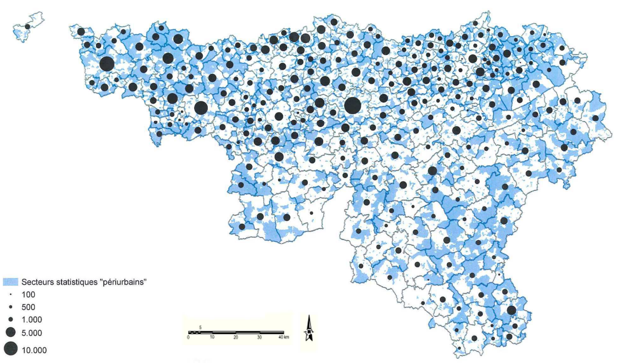


Figure 8. The number of suburban districts (built density in the range of 5 to 12 dwellings per hectare) per municipality.

### *D. Comparison of our classification with a sample of inhabitants*

To test the relevance of the definition of urban sprawl in our urban type classification, a survey was conducted amongst a sample of 480 people working at the University of Liège [23]. These people were asked, amongst other questions dealing with urban sprawl and their quality of life, to give their address and to specify in which area they live (with a choice available between urban, suburban or rural districts) without any former indications. Their responses were encoded in a GIS and compared with our classification based on the built density. The results are quite good, as the majority of the answers given by the sample of people corresponded to our classification. Only 2.7% of respondents chose "suburban area" instead of "urban area", 1.9% answered "suburban area" instead of "rural area" and 6.0% "rural area" instead of "suburban area". This last result can be explained by the large dispersion of suburban districts within the territory; several people chose "rural area" because of a huge distance to the city center. Amongst the criteria given by the respondents to define urban sprawl and justify their choice, low-density, a large detached house with a garden located in a green environment, a quiet environment and the distance to city centers were most often cited.

## III. The Typological Classification

Finally, we studied a random selection of 300 houses amongst the 702,000 suburban buildings identified by our definition (Figure 6). We extracted, for each one, the following data: the type of neighborhood in which the house is located, the dimensions, the number of levels, the type of house (detached, semi-detached and terraced) and the dimensions of the plot on which the house is built.

The neighborhood classification only takes into account the shape of the neighborhood, as our study deals with morphological criteria. The neighborhood classification assigns the 300 samples to four main categories (Figure 9). The linear district is composed of houses located on both sides of a road linking former villages or towns. This type represents 21% of the suburban building stock. The semi-detached district (8%) consists of detached and semi-detached houses. The "plot" district (20%) comes from the division by a private developer of a large site into individual plots and internal roads. The mixed district (30%) is more heterogeneous and is made up of individual houses together with older types of buildings (farms, old houses, etc.). A "composite" type is added to classify suburban blocks consisting of two different types of structures (9%). 12% of our sample does not correspond to any of these types. We considered these biases as acceptable in a study dealing with the whole suburban building stock of a region.

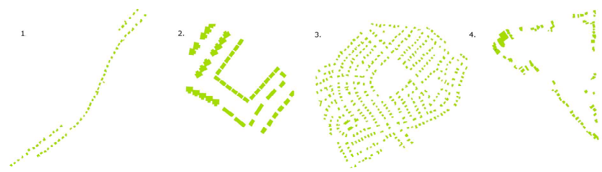


Figure 9. Illustrations of the four suburban blocks: 1. The linear block; 2. The semi-detached block; 3. The plot block; 4. The mixed block.

Analyses were then performed to identify the main characteristics of the suburban building stock. A large amount of the suburban building stock is composed of houses with a surface area in the range of 101 to 150 m². The mean surface area of the suburban building stock is 120 m² (standard deviation=40). The linear type is particularly made up of houses with a surface area in the range of 101 to 150 m². Large houses are also mainly found in plot districts, whereas semi-detached districts are mainly made up of buildings with a surface area less than 100 m². The mixed type is characterized by a wider distribution among the four classes, confirming the definition of this type, which is based on the diversity of the type and surfaces of buildings encountered. Buildings larger than 200 m² are exclusively found in the plot (very large houses on very large plots built by rich households) and mixed (old farms) types of districts. The size of the plots is not linked to the size of the houses as a $R^2$ of only 0.2 has been calculated.

The "before 1930" and "between 1961 and 1980" classes of ages are well represented, which highlights different phenomena. First of all, the existing suburban building stock is old, and the renovation of the building stock is particularly low. Secondly, urban sprawl was particularly popular from the "golden sixties" until the eighties. After that, the phenomenon was still present but slowed down. Buildings built before 1930 are mainly located in mixed districts (64.8%), whereas those built after 1960 are mainly found in plot and, to a lesser extent, linear districts. Semi-detached districts are represented in each class of age of construction, which tends to prove that these kinds of suburban forms (mainly social housing built by public developers) are developed in all time periods.

TABLE I. SURFACE AREA OF THE SUBURBAN BUILDING STOCK

| **Partition by age class** | | | |
|---|---|---|---|
| ***50-100 m²*** | ***101-150 m²*** | ***150-200 m²*** | ***> 200 m²*** |
| 31.5% | 4.5% | 15.0% | 6.0% |

TABLE II. AGE OF THE SUBURBAN BUILDING STOCK

| **Partition by age class** | | | | |
|---|---|---|---|---|
| ***Before 1930*** | ***1931-1960*** | ***1961-1980*** | ***1981-1996*** | ***After 1996*** |
| 38.3% | 14.3% | 30.0% | 10.4% | 7.0% |

We finally combined the surface area of the house, the age of construction and the type of district to highlight the most common combinations:

- 101-150 m² houses built before 1930 in a mixed district (11.9% of the suburban building stock).
- 101-150 m² houses built between 1961 and 1980 in a linear district (6.9%).
- 50-100 m² houses built before 1930 in a mixed district (5.1%).
- 101-150 m² houses built between 1961 and 1980 in a plot district (5.0%).
- 101-150 m² houses built between 1961 and 1980 in a plot district (5.0%).

## IV. APPLICATION: ENERGY MODELING

In this section, the energy modeling of existing building stock based on the previous classification of urban types is first presented. The suburban type classification is then used to compare three renovation strategies at a regional scale.

### A. *Energy modeling of the existing building stock*

A representative block and a representative building of each type highlighted in the classifications were selected to model the energy use of the whole suburban territory of the Walloon region of Belgium. Based on the evolution of regional policies concerning building energy performance and the evolution of construction techniques, the five age categories (pre-1930, 1931-1960, 1961-1980, 1981-1996 and 1996-2008) were used to approximate a mean thermal conductivity of external façades from a "standard" composition of façades and from glazing attributes for the building envelope in each category. Detailed values (glazing and wall heat transfer coefficients and composition) are available in [11]. Dynamic thermal simulation software was then used to model each type of building and to calculate their energy requirements for heating (in kWh/m².year).

The annual energy requirement for heating the whole suburban building stock was calculated according to the partition of each type of building in the whole suburban area of the Walloon region. The total annual energy requirement is equal to 19,914 GWh. The mean consumption for heating is equal to 232.8 kWh/m².year.

A clear difference is observed between the heating energy requirements of houses and neighborhoods built before and after the first thermal regulations adopted in the Walloon region. Houses built after the first regulations consume 130 kWh/m² or less annually, whereas those built before 1980, especially dispersed houses, consume from 235 to 401 kWh/m² annually. For semi-detached and terraced houses, the 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.

### B. *The impact of renovation strategies*

Figure 10 presents the potential energy savings associated with three renovation strategies dealing with energy efficiency in comparison with the existing situation (EX as calculated in the previous section). We determined the potential energy savings associated with a light upgrade (insulation in the roof and new high-performance glazing) of 50% of the pre-1981 building stock (SC 1). This policy could reduce energy consumption of the whole suburban building stock by 10.8%. Adopting a more ambitious policy (improvement of the insulation of the whole building envelope) targeted at the 1961-1980 building stock (SC 2) is more interesting as far as energy savings are concerned.

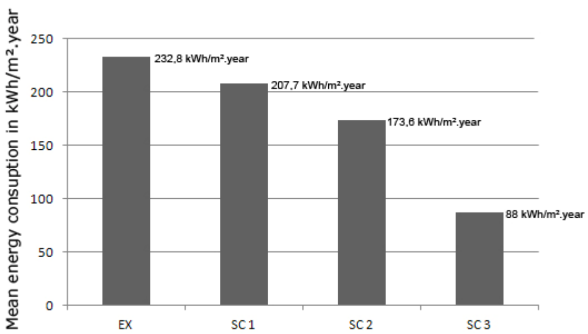


Figure 10. Potential energy savings (in kWh/m².year) related to three renovation strategies dealing with the improvement of energy efficiency in the existing suburban building stock.

In fact, as cavity walls became widely used after 1960, these houses are particularly well adapted to new insulation techniques used to retrofit existing walls (insulation is blown into the cavity), and insulating the roofs, the slabs and replacing glazing is fairly easy to achieve. This approach could reduce energy consumption of the whole suburban building stock by 26.5%. In the last scenario (SC 3), we assumed that the whole suburban building stock was retrofitted to fit actual standards for new buildings. The resulting energy savings are huge (62.6%). However, retrofitting the whole building stock is a very difficult target to reach even if households could significantly reduce their energy consumption.

## V. CONCLUSIONS AND FUTURE WORK

Based on cadastral and territorial data, we developed a morphological definition of the Walloon suburban territory and a typological classification of suburban districts and residential buildings. The proposed definition allowed us to question the relevance of the existing classification of urban types and to prove the validity of a finer representation, especially as far as morphological studies are concerned. Thermal simulations were thus performed on a representative block / building of each type highlighted in the classification to estimate the energy consumption of the whole suburban building stock at a regional scale. The classification was then used to assess the impact of two renovation strategies and to compare their value as far as energy savings are concerned. The paper has thus highlighted the benefits of using GIS tools for territorial management and thermal topics. The combination of thermal simulations with territorial data, in particular, is relevant and useful to effectively address the issues related to energy efficiency in the building sector at a territorial scale. The same exercise will now be used for the urban and rural parts of the territory to address the whole regional building stock and to highlight the urban blocks that are a priority for retrofitting or for increased density. Finally, the method is sufficiently general, and the data used in Belgium are widely available in other regions, which makes the definition and the suburban type classification easily reproducible in other territories.

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