City Energy Management: A Case Study on the Urban Area of Liège in Belgium

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***Abstract*— Within the framework of sustainable development, it is important to take into account environmental aspects of urban areas related to their energy use. In this research, a typology of urban blocks is drawn up for the urban area of Liège through the use of GIS tools in order to assess energy uses of residential buildings and transport of residents at the city scale. For each class of this typology, a representative block is selected in order to model energy use at the city scale, as well as to consider the possible evolution of the city energy consumption and to simulate the effects of some strategies of urban renewal. An application study on the residential buildings energy consumption part of this typology is given to compare different energy management strategies. This case study allow to conclude that the European Directive on the Energy Performance of Buildings and even more selective energy policies on new buildings are not sufficient to widely decrease the energy consumption of Liège building stock but that renovation of the existing building stock has a much larger positive impact on city energy consumption reductions. These conclusions put forward the benefits of using urban GIS for policymaking and city management. Energy management is an important GIS application field.**

Keywords - Urban GIS, energy consumptio, forecast scenarios.

I. INTRODUCTION

In the actual context of growing interests in environmental issues, reducing energy consumptions in the building and the transport sectors (which represent respectively 37% and 32% of final energy in the European Union) appears as important policy targets. Urban areas are supposed to present high potentialities in terms of energy reduction. However, existing models often adopt the perspective of the individual building as an autonomous entity, and neglect the importance of phenomena linked to larger scales [1].

This research focuses on city level energy management. In this paper, a typology of urban blocks is drawn up for the urban area of Liege (in Belgium) through the use of GIS tools in order to assess energy uses at the city scale. This typology of urban blocks is organized into two parts: the residential buildings energy consumption and the transport energy consumption of residents. For each topic of this typology, representative blocks are selected in order to model the energy use at the city scale, as well as to consider the possible evolution of the city energy consumption and to simulate the effects of some strategies of urban renewal. An application study uses this typology to compare the effects of the European Directive on Energy Performance of Buildings with even more selective energy policies on new buildings and with renovation strategies on the existing building stock of the urban area of Liège.

The structure of this paper is developed in eight sections: the introduction, the state of the art and method, the study area and chosen criteria, the cartographic work, the typology of urban blocks generated, the calculations of the energy performance of the city, a discussion on the results and the conclusion.

II. STATE OF THE ART AND METHOD

This section describes the most important references on city energy management and the methodology used in this research.

A. State of the art

There are a lot of modeling tools to assess energy management of a specific building. However, such an approach makes it difficult to generalize the results in order to determine the best strategies at the urban scale. On the other hand, there are two types of modeling methods used to predict energy consumption at a large scale (for example, for national predictions): the top-down and bottom-up approaches. These methodologies have already been described in details [2,3]. The top-down modeling is generally used to investigate the inter-relationships between the energy and economy sectors. They study the influence of economic variables such as income or fuel prices on the energy consumption of countries. These models lack details on the building stock to be able to quantify the effectiveness of some specific energy policy measures on the urban energy performance. Bottom-up methods are based on typologies and components clustering modeling approach. These components can be buildings [4,5], urban blocks or neighborhoods [6]. This implies that they need extensive databases to support the choice and description of each component of their typologies. This is usually done by a combination of building physics modeling, empirical data (for example from housing surveys), statistics on national or regional data sets and some assumptions about buildings performance. The bottom-up method is very useful to assess the energy consumption of existing building stocks.

B. *The method*

This research uses an Urban GIS in order to develop an energy model of the residential building stock of Liège and to spatialize its major components. Our approach combines global statistics, that are not associated with buildings (top-down approach), with features related to buildings and urban form (bottom-up approach). The evolution of the number of buildings in the residential stock is deducted from global trends of recent years (top-down approach), while the energy consumption of buildings are obtained thanks to empirical data and results of buildings energy modeling (bottom-up approach). This combined approach provides a set of data as accurate as possible.

III. STUDY AREA AND CHOSEN CRITERIA

Our study is focused on the urban area of Liège and more specifically on its residential urban blocks. Delimitation of city blocks was performed using data from the PICC, that is a computer project of continued mapping from the Public Service of the Walloon Region of Belgium. These data are provided in the form of vector map layers that characterize the natural environment (rivers, forests), the built environment (buildings) and the infrastructure (roads, railways, etc.) at scale 1/1000. The spatial position of these objects is known by their position (x, y) and their altitude (z) with an accuracy of 25 cm.

The first part of this research develops a typology of Liège's urban blocks. First, a large number of variables were selected to characterize the energy efficiency of city blocks, using an extensive literature review on this subject. Then, a statistical treatment of these parameters was performed using a Principal Component Analysis. This methodology [7,8], allows crossing a large number of criteria and grouping them according to their similarities. This statistical treatment reduced the number of our selected criteria to characterize the energy performance of the residential building stock of Liège. These are the six chosen criteria:

- Buildings' date of construction (before 1930, from 1931 to 1969, from 1970 to 1985, from 1985 to 1996, from 1996 to today), depending on the types of construction related to Belgian regulations. These data are defined across the urban blocks from the cadastre.
- Type of buildings (two, three or four frontages). Indeed, a terraced house uses less energy than a separate house [9]. These data are defined across the urban blocks from the cadastre.
- Type of housing (collective or individual). These data are defined across the urban blocks from the cadastre.
- Urban functions (residential, trade, school or socio-cultural facilities, services). Each block may contain one to four of these functions. The functional mix reduces energy consumption associated with shorter distances between the different activities' locations of everyday life.
- Index of energy performance for residents' travels to their work places [10,11]. This index is based on statistical data available at the census block scale (that is the smallest geographical unit in which data are available in Belgium). These data come from national censuses, carried out every ten years in Belgium. Weighted average of the built area of each city block has been achieved to adapt these data from the census block scale to the scale of the city block.
- Potential modal shares for alternatives to the car, following [12]. This calculation takes into account the daily frequency of trains and buses weighted by their type and destination.

IV. CARTOGRAPHIC WORK

The information in the cadastre has been linked to the file map showing the layout of the plots using their cadastral number. Then, the spatial relationship between the plots and the PICC data was established through the ArcMap function "Spatial join". This helped to know the date of buildings construction given on the cadastral maps.

It is important to note that some plots of the PICC found no match in the database of the cadastre. No data will be taken into account for the buildings constructed on these plots. Note that these differences arise because the data from the PICC were developed from aerial rectified photographs and the data from the cadastre were developed from digital cadastral maps. However, these data can be considered acceptable because only 383 buildings could not be taken into account, which represents only 0.2% of the residential building stock of the urban area of Liège.

To convert, as consistently as possible, the data known at the census block to the scale of the urban block, the data associated with each statistical area were distributed in a grid, which has a resolution of 10 m wide (see Figure 1).

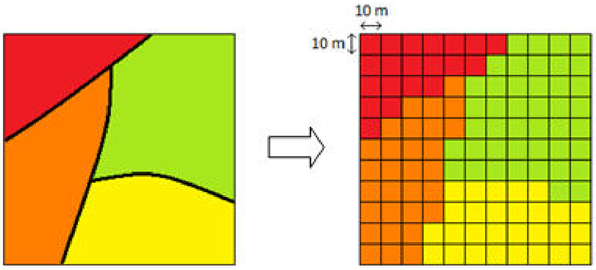

Figure 1 : Distribution of the data associated with four census blocks to a spatial grid of 10m wide.

Then, a weighting is applied according to the surfaces of the urban blocks that are related to one or several census blocks. For example, in Figure 2, the urban block value will be calculated by adding twice the value of red cells, sixteen times the value of green cells, six times the value of yellow cells and 9 times the value of orange cells, and dividing the sum by 33 (the number of census cells covered by the urban block).

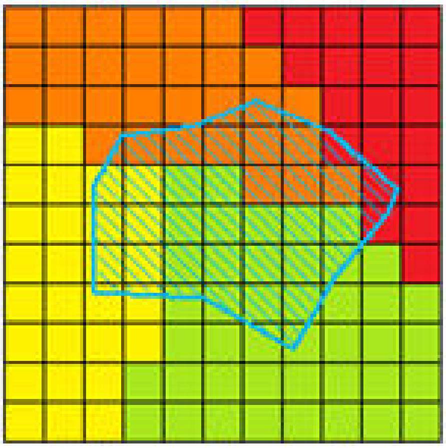

Figure 2: Wheighting calculation of the urban block (in blue) data on basis of four census blocks data.

However, it should be noted that the transport consumption criteria, based on this mapping work, are less accurate than the buildings consumption criteria, based on the cadastral values, because of the assumption that statistical data are evenly distributed in each census block.

V. TYPOLOGY OF URBAN BLOCKS

The typology of urban blocks is organized into two topics: residential buildings energy consumption and transport energy consumption of residents. For each topic of this typology, representative blocks are selected in order to model energy use at the city scale, as well as to consider the possible evolution of the city energy consumptions and to simulate the effects of some strategies of urban renewal. The proposed representative blocks were selected by choosing for each topic the representative criteria into the list of six criteria previously determined and then crossing them at the urban block scale. The six criteria that were taken into account are buildings date of construction, type of buildings (two, three or four frontages), type of housing (collective or individual), index of energy performance for residents' travels to their work places, potential modal shares for alternatives to the car and mix of urban functions (residential, trade, school or socio-cultural facilities, services).

For the first topic "residential buildings energy consumption", the following criteria were selected: buildings date of construction , type of buildings (number of frontages) and type of housing (collective or individual). After crossing these three criteria at the urban block scale, only the main classes, that include the largest number of urban blocks were selected. So, fourteen types of urban blocks have been defined, which represent 97% of the blocks of the urban area of Liège. For example, there are 508 blocks built before 1930, where over 66.6% of the buildings are terraced houses and most of them are individual housing; this type of urban block corresponds to 12% of the residential building stock of Liège (see Figure 3). Another block type is constructed after 1970, where over 66.6% of the buildings are separate and most of them are individual housings; there are 314 urban blocks of this type in the urban area of Liège, which corresponds to 7% of the residential building stock (see Figure 4). Within each of these 14 types, a representative block was chosen to allow modeling more accurately the energy consumption of buildings.

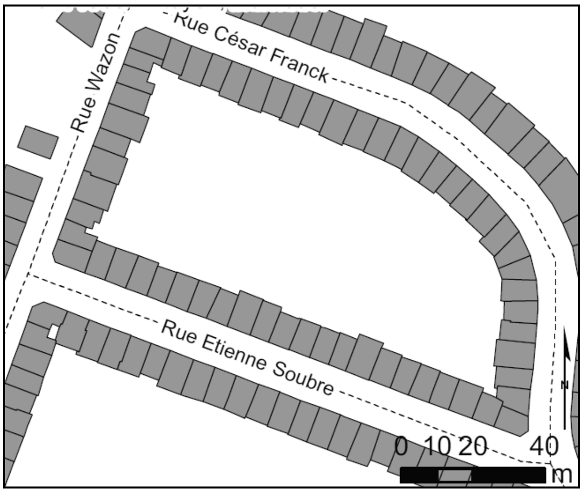

Figure 3: One type of urban block that represents 12% of the residential building stock of Liège.

Figure 4: One type of urban block that represents 7% of the residential building stock of Liège.

For the second topic "energy consumption by transport of residents", the following criteria were selected: the mix of urban functions (residential, trade, school or socio-cultural facilities, services), the index of energy performance for residents' travels to their work places and the potential modal shares for alternatives to the car.

After crossing these three criteria at the urban block scale, only the main classes, that include more than 0,5% of all the urban blocks, were selected. The selection of blocks representative of each class of theme 2 is performed identically to theme1.

VI. MODELING THE ENERGY PERFORMANCE

The three criteria that are taken into account to achieve the energy assessment of the residential housing stock are the age of buildings, their number of frontages and the type of housing (individual or collective). The energy consumption for each type of housing in the Walloon Region (including heating, hot water and lighting) are determined on basis of empirical values and simulation results. When these values are related to each building, it is possible to establish the evolution of the energy consumption of the whole urban area of Liège since 1850, that is the first date of construction of a building identified in the cadastre (see Figure 5). Before 1931, the dates of buildings construction are aggregated for periods lasting from 20 to 25 years, which explains the larger width of the bars in the Figure 5.

The most important actual energy policy measure in the EU is the Directive on the Energy Performance of Buildings (Directive 2002/91/EC) that came into force in 2002 with legislation in member states by 2006 [13]. These policy measures focus on energy efficiency when new buildings are constructed or when big buildings (larger than 1000m²) undergo a major renovation. However, there might be energy efficient measures that are environmental efficient and cost effective also on the existing residential building stock, on smaller buildings and/or lighter renovation processes. Note that in the Danish implementation of the EPB directive all existing buildings (including single family houses) are covered by the energy efficiency measures when they undergo a major renovation [4].

It is thus useful to model some forecast scenarios to compare the effects of the European Directive on Energy Performance of Buildings (EPB directive) with even more selective energy policies on new buildings and with renovation strategies on the existing building stock.

The demographic data of the population of our study area are known at the census block scale. The simplest hypothesis would estimate that the residential building stock changes proportionally to the population. However, the number of buildings in urban area of Liege during the last eight years did not increase as rapidly as the population during those years. We have thus established a base curve of the evolution of the built stock according to the statistics of its evolution between 2000 and 2008. This trend is represented by the following equation:

$$Y = 477{,}35 \ln (x) + 161\ 348 \qquad (1)$$

with x = forecast year – 2000 and Y = Number of buildings. This curve follows very well the recent trend of development of the residential building stock since the coefficient of determination calculated from the data observed between 2000 and 2008 amounts to 99.7%.

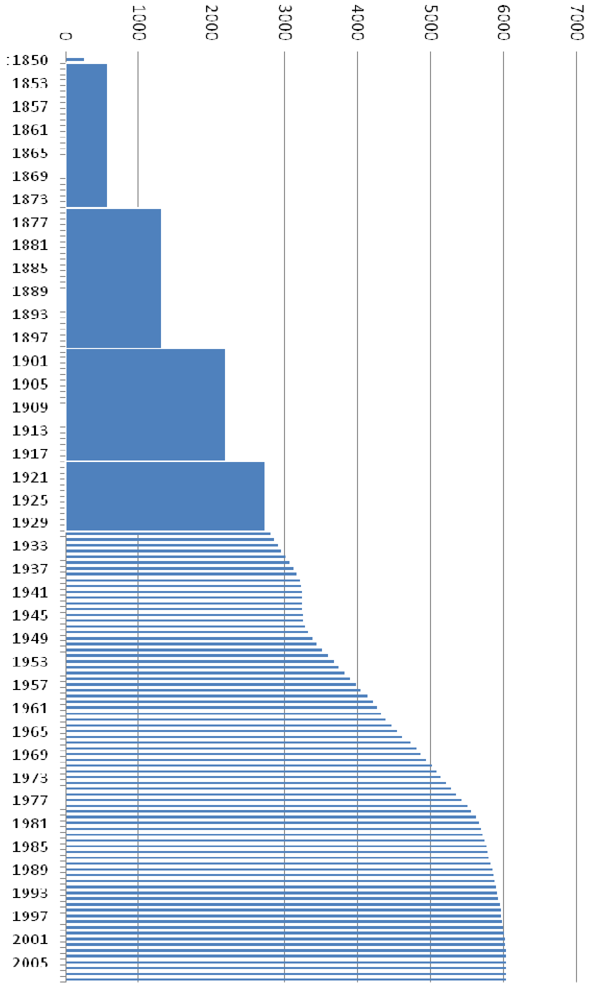

Figure 5: Evolution of the energy consumption of the urban area of Liège (in GWh/year) since 1850.

A. Scenario 1: new buildings following EPB

In this first scenario, the existing building stock remains unchanged, but new buildings are constructed according to the actual standard on the energy performance of buildings (EPB): the building's energy consumption should not exceed 115 kWh/m² per year. It is therefore the most likely evolution of Liège's building stock if the energy policies are not changed in the future. Following this first scenario, the energy consumption for the city of Liège in 2061 is estimated at 6067.74 GWh per year.

B. Scenario 2: strengthening of energy policy on new buildings

Considering that 5% of new housing stock will have low energy performances (LE: 95 kWh/m² per year), 2% of buildings very low energy performances (VLE: 65 kWh/m² per year) and 1% will reach the standard passive house (50 kWh/m² per year), energy consumption decreases from 679 MWh for the year 2061 compared to the first scenario, which represents a reduction of only 0.01% for a period of fifty years.

Achieving 10% reduction in energy consumption of all buildings constructed after 2010 would require that the new stock meets the following constructive standards: 63% of buildings achieving the EPB standard, 21% of LE buildings, 10% of VLE buildings and 5% of passive buildings. But on the whole building stock, this reduction generates a very small decrease in energy consumption (0.06%) compared to Scenario 1, corresponding to the actual regulations.

C. Scenario 3: roof insulation of the old building stock

Following Verbeek and Hens, insulation of the roof is the most effective and durable measure for energy performance increase of households in Belgium [14].

A rate of renovation of buildings of 0.6% per year is chosen to simulate a realistic policy for roof insulation of the existing building stock equal to two thirds of the total rate of renovations observed in the Walloon Region on an annual basis. It is also assumed that the energy management is carried out efficiently: the oldest and least energy efficient buildings are the first to be renovated. Renovating the roof insulation of this old building stock will be incorporated as a reduction of 40% of energy consumption in comparison to the initial energy performance of these renovated buildings.

It appears that the renovation of existing buildings can drastically reduce energy consumption across the urban area. The total estimated consumption amounts to 5439.27 GWh/year in 2061, of which 99.5% is attributed to the existing stock. The decrease in total energy consumption is therefore 10.36% (628.46 GWh/year) compared to 6067.74 GWh/year for Scenario 1.

D. Scenario 4: renovation of the old building stock reaching EPB

This scenario aims to assess the amount of energy that could be saved if the existing building stock was renovated, at a rate of 0,6% per year, to meet the current EPB standard in Belgium (115 kWh/m² per year), while all the new buildings meet the same energy performances. Following this scenario 4, the estimated energy consumption for the city of Liège reach 5307.20 GWh/year in 2061. It is 760.54 GWh/year (13%) less compared to scenario 1.

E. Scenario 5 : renovation of all the existing building stock reaching EPB

The renovation of all the buildings of the residential building stock of Liège to the level of the current EPB standard in Belgium (115 kWh / m² per year), would result in significant reductions in energy consumption of the urban area, see Figure.6. Indeed, the global energy consumption would drop to 3178.23 GWh/year only, which represents a reduction of 47.6% compared to 6067.74 GWh/year of the scenario 1 (where the new buildings reached already the standard EPB, but where no renovation was undertaken).

However, to achieve the complete renovation of the existing housing stock by 2060, the rate of renovation of the urban area of Liege should increase sharply, to a minimum of 1.92% per year, which would require strong policies to accelerate and strengthen the process of renovating existing buildings.

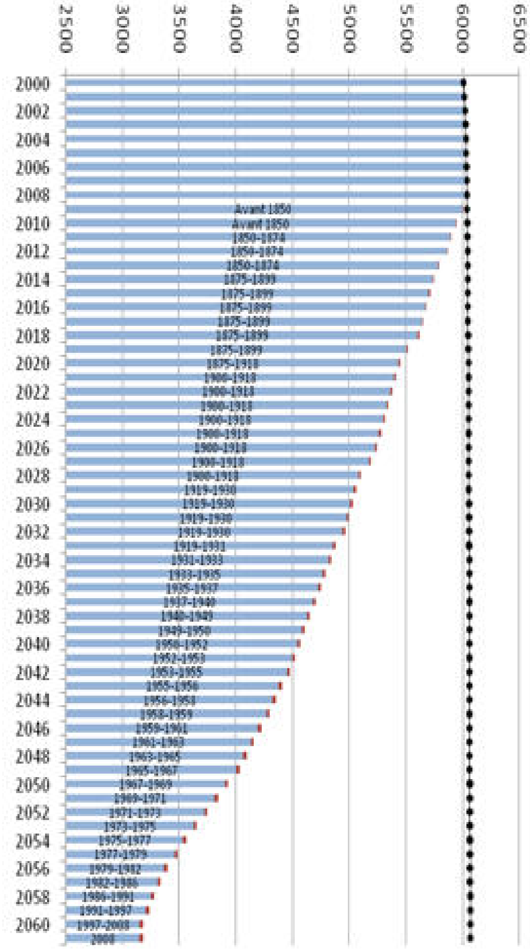

Figure 6: Energy consumption of the urban area of Liège (in GWh/year) from 2000 to 2061, following the scenario 5 (blue results) and comparison with scenario 1 (black dotted curve).

F. Scenario 6 : all the existing building stock reaching EPB and new buildings reaching the passive standard

This scenario uses the same renewal policy that the previous scenario but it is also assumed that each new housing built from 2012 will reach the passive standard (50 kWh/m² per year). The result of scenario 6 is very close to the previous scenario. The total energy of the urban area in 2061 amounts to 3161.57 GWh/year, which represents only a reduction of 0.5% compared to scenario 5.

VII. DISCUSSION

The studied scenarios show that the actual city energy challenge lies mainly in the renovation of the existing building stock. Indeed, the first two scenarios and the small difference between scenarios 5 and 6 show that it is not possible to ensure a significant reduction in energy consumption at the city scale applying only energy policies for new buildings, like the standard EPB already in use or by enhancing the performance of new buildings to low energy level, very low energy level and even to the passive housing standard.

However, scenarios of existing housing stock renewal (scenarios 3 to 5) can significantly reduce the overall consumption of the urban area of Liege in the following proportions:

- 10.36 % of energy consumption reduction in 2061 through the roof insulation of the oldest buildings at a renovation rate of 0.6% of the building stock per year.
- 13 % of energy consumption reduction in 2061 through a renovation reaching the EPB level of the oldest buildings at a renovation rate of 0.6% of the building stock per year.
- 47.6 % of energy consumption reduction in 2061 through a renovation reaching the EPB level of all the existing residential building stock, which corresponds to a renovation rate of 1.92 % per year.

Thus, the National climate change targets in Belgium will be impossible without a strategic increase of the existing housing stock renovation.

VIII. CONCLUSION

In this research, a typology of urban blocks is drawn up for the urban area of Liege through the use of GIS tools in order to assess energy uses of residential buildings and transport of residents at the city scale. An application study on the residential buildings energy consumption part of this typology is given to compare different energy management strategies. This case study allow to conclude that the European Directive on the Energy Performance of Buildings and even more selective energy policies on new buildings are not sufficient to widely decrease the energy consumption of Liège’s building stock but that renovation of the existing building stock has a much larger positive impact on city energy consumption reductions. This research also proves the benefits of using urban GIS for city management and policymaking.

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