ENERGY REQUIREMENTS AND SOLAR AVAILABILITY IN SUBURBAN AREAS: THE INFLUENCE OF DENSITY IN AN EXISTING DISTRICT

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ABSTRACT

Urban sprawl is a major issue in terms of sustainable development. In fact, low-density suburban neighbourhoods represent a significant contribution to the overall energy consumption of a territory for energy needs in buildings and for transportation. But, although the environmental impacts of urban sprawl and their associated energy consumptions are now well documented, it remains a concern in many regions. This phenomenon is particularly familiar in Belgium, where 52% of the building stock is composed of detached and semi-detached houses, predominantly located in low-density suburban districts (contained in a range between five and twelve dwellings per hectare). In the current context of growing interest in environmental issues, local authorities become aware of this concern and are now trying to limit the development of new low-density suburban districts while households still continue to promote dispersed individual housing types located outside city centres.

In this context, the paper proposes to investigate the influence of an increase in built density, in existing suburban neighbourhoods. The idea is to favour a higher built density in existing neighbourhoods instead of building new low-density neighbourhoods on unbuilt areas. The impacts of four renewal strategies dealing with the density are assessed, at the neighbourhood scale, for three indicators: (1) the potential energy savings for heating houses, (2) the solar energy received by the facades and roofs, as dispersed individual housing types are known to be those that receive most solar gains and (3) the potential area of land savings. The influence of insulation, climate conditions and orientation is finally discussed. The chosen case study is a typical Belgian suburban neighbourhood. Research tools are numerical simulations tools and dynamic thermal modelling software.

The results of this exercise show that it is theoretically (land property is not take into account in our analyses) possible to increase built density in existing suburban neighbourhoods. Energy savings are significant while solar energy received by facades and roofs remain huge. Insulation is a critically important factor. Moreover, increasing the built density in existing neighbourhoods allows to preserve unbuilt areas and to limit the need for new infrastructures and networks, which should help suburban areas to become more sustainable.

INTRODUCTION

The process of urban sprawl, which commonly describes physically expanding urban areas, is a major issue for sustainable development [1]. For the same standard of insulation, detached houses need more energy for heating than terraced houses [2]. Moreover, suburban developments have created farther spatial separation of activities, which results in an increase in travel distances and transport energy consumption [3]. But, although the environmental impacts of urban sprawl and uncontrollable urbanization are now well known and may give rise to various issues, such as environmental pollution or large-scale climate change [4, 5] and despite the growing importance of the energy issues in public debate, low energy-efficient suburban developments are a reality in Belgium where many households and private developers still continue to promote dispersed housing types located outside city centres.

In this context, the paper aims at investigating the influence of a higher built density in existing suburban neighbourhoods. Four scenarios, in which the built density is increased, are defined and assessed. The idea is to promote a higher density in existing neighbourhoods as a solution to avoid building new neighbourhoods on unbuilt areas, which would increase urban sprawl and its undesirable effects on climate, landscapes and pollution.

METHODS

Methods and research tools

A method has been developed to assess energy requirements in Belgian suburban areas. It addresses the influences of individual buildings 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 [6]. Moreover, the urban fabric determines the spatial configuration of building and hence solar energy received by the envelope. A typology of detached, semi-detached and terraced houses was established to classify the residential suburban building stock of Belgium. This typological approach is based on the common ownership, the area of the house in square meters (m²), the number of levels and the date of construction. Five age categories (pre-1950, 1951-1980, 1981-1995, 1996-2010, post-2010) are considered based on the evolution of regional policies concerning building energy performance and the evolution of construction techniques. 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).

	Pre-1950	**1951-1980**	**1981-1995**	**1996-2010**	**Post-2010**
Wall composition	Concrete blocks	Concrete blocks	Concrete blocks + 3cm PUR	Concrete blocks + 6cm PUR	Concrete blocks + 8cm PUR
Roof composition	Clay tiles	Clay tiles	Clay tiles + 8cm mineral wood	Clay tiles + 10cm mineral wood	Clay tiles + 13cm mineral wood
Slab composition	14cm concrete	14cm concrete	14cm concrete + 3cm PUR	14cm concrete + 6cm PUR	14cm concrete + 9cm PUR
Glazing type	Simple glazing	Double glazing	Double glazing	Double glazing	Double glazing
Windows U	4,08W/m².K	2,96W/m².K	2,76W/m².K	2,76W/m².K	1,8W/m².K

Table 1: Main characteristics of external facades and glazing by age category.

Using this classification, an energy consumption analysis was performed with TAS dynamic thermal analysis software to obtain the energy required to heat each type of building and solar energy on facades and roofs. The climate data are those of the Test Reference Year of Brussels (temperate climate). The maximum and minimum temperatures, for the considered year are 34.9 °C and -9,1°C. The inside temperature considered in the calculation is 20°C during the day and 16°C during the night.

The energy requirement for heating at the district scale was finally calculated by adding the results from the energy consumption analysis for each type of house according to their distribution in the district [2]. This total energy requirement is finally divided by the heated surface area of the whole district to give an indicator, in kWh/m².year, allowing the comparison between neighbourhoods and scenarios. This methodology was applied to each scenario discussed below (First line of Table 2).

The last indicators are the surface area and the length of networks saved if the density of the existing neighbourhood is increased and avoid the building of new individual detached houses and infrastructures on unbuilt land. The size of the plots (900m²) and of the houses (140 to 180 m²) used in this evaluation are based on the regional means for suburban territories and on the urban structure of the existing neighbourhood.

Case study

The chosen case study is a typical Belgian suburban neighbourhood located 6 kilometres east of a city centre (106.000 inhabitants). This kind of urban structure, made up individual detached houses built on large plots, represents about 11% of the regional built territory [7]. The neighbourhood is composed of 395 residential houses. 43,5% of the houses were built between 1951 and 1980, 49,1% between 1981 and 1995, 7,2% between 1996 and 2010. The neighbourhood has a surface area of 54 hectares, among which 2,4 hectares are dedicated to green spaces. The built density of the neighbourhood (number of dwellings / (total area – green spaces)) is worth 7,6 dwellings per hectare as things stand at present.

Figure 1: The chosen case study (Aerial view ©SPW-MRW and pictures of two houses ©de Meester) is a typical Belgian suburban neighbourhood located 6km east of a city centre.

Scenarios

Four scenarios have been designed and present different ways to increase built density in the studied neighbourhood. The first one consists in respecting the existing urban structure:

detached houses are built on remaining unbuilt plots. In the second scenario, the size of the plots is exploited to build new houses at the bottom of existing plots. In the third one, new detached houses are built between existing houses while in the fourth case, houses are built between existing houses to form a continuous facade made up terraced and semi-detached houses (Figure 2). In cases 2 to 4, the size of the new plots is smaller (around 400 m²) and the size of existing plots is reduced. In this last case, windows located on lateral facades are transferred to the roof to keep the same surface area of windows. In the four scenarios, new houses are assumed to be built according to the thermal regulations applicable in Belgium since the passing out of the European Energy Performance of Buildings Directive in 2010.

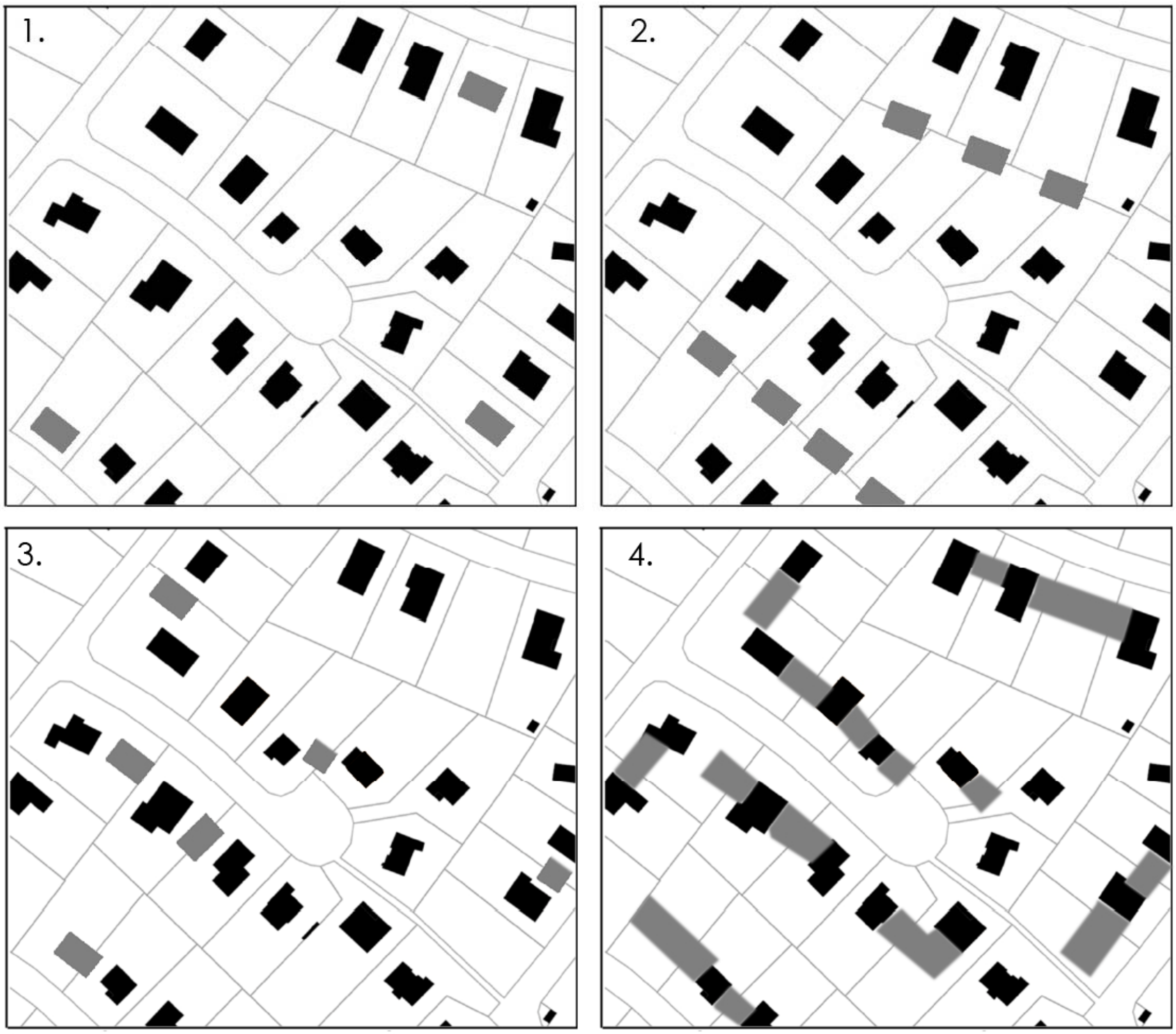

Figure 2: The four scenarios designed to increase built density in the studied neighbourhood – zoom. Existing houses are coloured in black, new houses are in grey.

RESULTS

Energy consumption for heating, solar gains and surface area of land saved

The first part of the assessment is a present-day inventory of the neighbourhood energy consumption for heating. It is calculated according to the above-presented method. Then, energy consumption for heating and energy savings, in comparison with the present-day inventory, are calculated, at the district scale, for the four scenarios designed to increase the built density. Solar gains on vertical facades and roofs are calculated for a reference house.

The new built density of the neighbourhood and an estimation of the surface area of land and of the length of collective networks saved are finally presented (Table 2).

	Present-day	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Mean energy consumption for heating [kWh/m^2.year]	146,9	139,4	121,3	128,0	102,2
Savings in comparison with present-day inventory	/	5,2%	17,4%	12,9%	30,4%
Solar energy received by façades [kWh/m^2.y]	398,6	398,6	398,2	394,6	382,6
Difference with present-day	/	0%	-0,1%	-1,0%	-4,0%
Solar energy received by roofs [kWh/m^2.y]	1005	1005	1005	1005	1005
Built density [houses per ha]	7,6	8,0	9,6	9,3	12,6
Surface area of land saved [ha]	/	2,07	9,27	8,10	23,4
Length of collective network saved[metre]	/	184	824	720	2080

Table 2: Present-day inventory and results for the four scenarios.

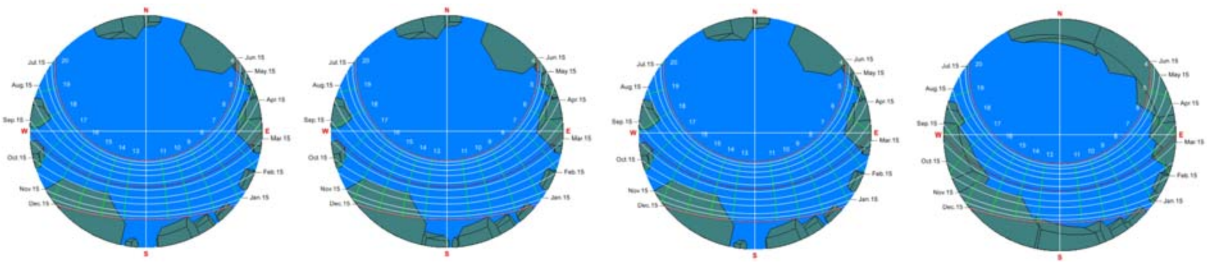

Figure 3: Solar paths and obstructions generated by each scenario, in the middle of the neighbourhood, on the ground, 15th June (Townscope software).

Significant energy savings can be obtained if the built density of the district is increased. The positive effects come from the building of new well-insulated houses, which makes the mean energy consumption decrease, at the district scale, even if houses are still detached (ex: -17,4% in scenario 2). As the present-day density is very low, adding new houses between existing ones allows to reduce energy consumption without reducing too much solar gains on facades and roofs (Figure 3). Note that vegetation was not taken into account. Scenario 4 combines the positive effect of an increase in built density and a more compact distribution of houses (detached houses require more energy for heating than terraced houses). Photovoltaic systems and solar thermal collectors mounted on roofs could be used according to the threshold values proposed by [8] and commonly used in practice.

On top of potential energy savings, increasing the built density of the neighbourhood allows above all to significantly protect unbuilt land from urbanization and to limit the need for new infrastructures and networks. However, even in scenario 4, the built density remains too low (12,6 dwellings / hectare) to organize a more efficient bus service.

Sensitivity analyses

Three sensitivity analyses were finally performed. These concerned insulation, climate conditions and orientation. Insulation offers a large potential for energy savings because the existing building stock is poorly or not insulated. If all the existing houses of the neighbourhood are retrofitted to reach the current standard required in the European Energy Performance of Buildings Directive and if new houses built in the neighbourhood reach the passive standard (<15kWh/m^2.year), which should constitute the standard for new buildings within the year 2020, energy savings, in comparison with present-day inventory, could reach 57,4% (62,6 kWh/m^2.year instead of 146,9 kWh/m^2.year). In this case, the influence of density could reach 6,6%, 18,6%, 16,4% and 37,5%, for the four scenarios described below.

As regard with climate, two representative cities were selected in Belgium (Brussels and Saint Hubert) to test the sensitivity of previous results with climate conditions. These cities are representative of climate variations within Belgium. Heating loads are higher in Saint Hubert (colder climate) but it has been demonstrated that the four scenarios tested are reacting in the same way to varying climate conditions. In terms of orientation, we determined that energy consumption in buildings varied only marginally (less than 4%) with the orientation of the neighbourhood and the solar energy effect on vertical facades and roofs, mainly because of a lack of optimisation for solar accessibility in existing houses and neighbourhoods.

DISCUSSION AND CONCLUSIONS

The analyses highlight that, for the studied existing suburban neighbourhood, the benefits of an increase in built density are significant in terms of both energy consumption and surface area of land saved. These findings are important because numerous similar suburban neighbourhoods are found in Belgium and abroad. Scenarios dealing with renovation versus demolition and reconstruction should now be compared and assessed to give a more complete image of energy consumption in existing suburban neighbourhoods and favour energy efficiency through efficient renewal strategies.

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