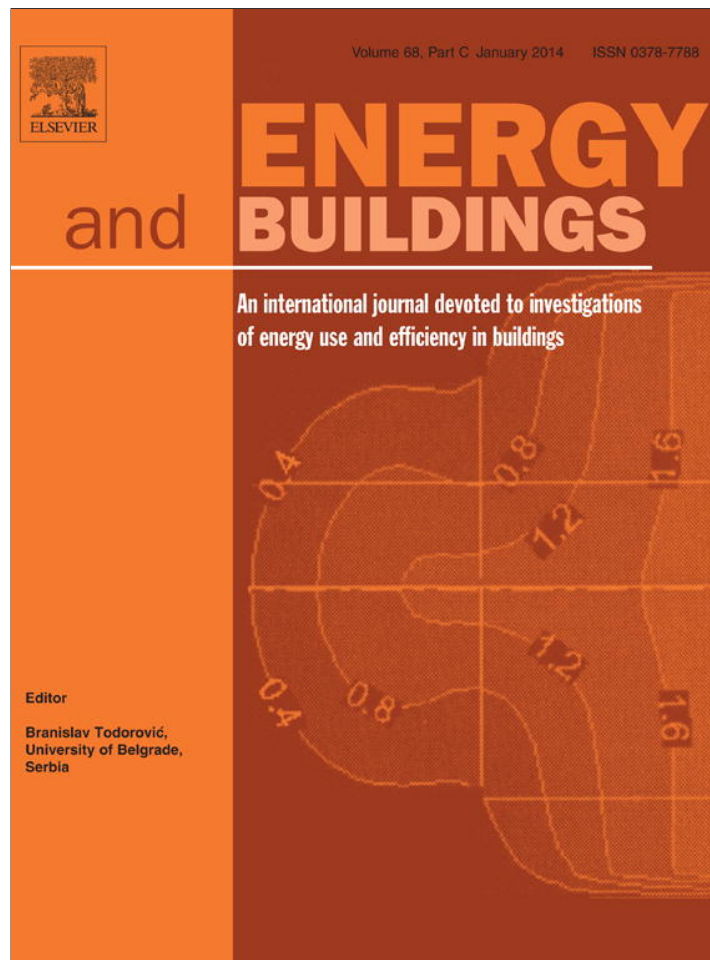


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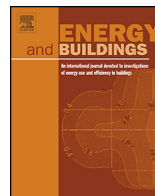
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Spatial planning as a driver of change in mobility and residential energy consumption

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ABSTRACT

This paper analyses the impact of territorial structures upon energy consumption in the Walloon Region (Belgium). The rationale for this research is to consider the long-term influence of spatial planning decisions upon energy consumption in both residential building stock and home-to-work commuting. The analysis has been conducted on a regional scale (16,844 km²) and includes urban, peri-urban and rural settlements. Those settlements that perform well in mobility also appear to perform well in terms of building energy consumption. Even though this is not generally the case, it further reveals that some rural settlements characterized by low density show good performance in terms of energy efficiency. This permits a much more progressive approach in terms of spatial planning, whereby compact cities may be viewed as part of the solution, albeit not the whole solution.

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1. Introduction

The influence of the spatial pattern of human activities on energy consumption in the transportation and/or the building sectors has been the subject of a great deal of empirical, theoretical and policy research.

Based on the observation that existing computer models adopt the perspective of the individual building as an autonomous entity and neglect phenomena linked to larger scales [1], a growing body of literature since the late 1990s has explored the effects of urban structures on building energy consumption. It highlights that decisions made at the neighbourhood and city levels regarding built volume and surface, orientation of façades and obstructions have important consequences for the performance of individual buildings in heating, ventilation and cooling [1–3]. Conversely, for the same level of insulation, lower density and detached types of houses tend to require more energy to heat than multi-unit developments or terraced housing [4,5]. In the same vein, the Energy and Environment Prediction (EEP) model [6] is based on a regional database that provides energy consumption figures for 100 building types. The variables considered in the typology are heated floor area, facade area, window percentage and age. Integrating these values into a Geographic Information System (GIS) allows comparison of energy policies at the city level. It highlights the magnitude

of potential energy savings at the urban level through a renewal of existing building stock.

The relationship between urban form and transport energy consumption is also discussed. Based on data from 32 large international cities, Newman and Kenworthy [7,8] highlighted a strong inverse relationship between urban density and transport energy consumption. Nonetheless, their work is only valid under certain conditions and is often criticized by other scholars [9,10] mainly for methodological reasons. Bannister [11] applied a similar approach to British cities, but based on statistical data obtained from a national survey. He demonstrated that transportation energy consumption is slightly higher in London than in smaller cities, which refutes Newman and Kenworthy's observations. Boarnet and Crane [12] are also sceptical about the relationship between urban design and transportation behaviour. By analysing case studies, they suggested that the use of land and the urban form impact transportation behaviour because of the price of travel (public transport prices are reduced in dense areas). Gordon and Richardson [13] demonstrated that urban density only plays a limited role in energy consumption in transport if fuel prices are included in the analysis. In the sample of cities used by Newman and Kenworthy, Breheny and Gordon [14] demonstrated that the density coefficient and its statistical significance decrease when petrol price and income are included as explanatory variables. Breheny [15] emphasized minor reductions in transportation energy consumption because of the compact city model. His experiments showed that energy used in transport could only be reduced by 10–15%, even under very strict conditions that are difficult to reproduce. By studying 10 cities around the world, Souche [16] showed that the most

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statistically significant variables for transport energy consumption are transport cost and urban density. Finally, Ewing and Cervero [17] highlighted that per capita vehicle travel tends to decline and the use of alternative modes to increase with a rise in density. For these authors, compact developments, which reflect the cumulative effects of increased density, functional mix and transit accessibility, typically reduce the per capita vehicle travel by 25–30%. Similarly, Stead [18] found that if 43% of the variation in distances travelled is explained by socio-economic variables, 27% of this variation is directly related to land-use variables, which is considerable.

Various studies argue that more compact urban forms would significantly reduce energy consumption, in both the building and transportation sectors [2,19–21] by combining such factors as high density, mixing land uses and a better share of active commuting, whereas other authors [22] indicate that lower energy consumption may be achieved by decentralized concentration.

Considering this background, the present paper specifically analyses the impact of territorial structures on energy consumption in the Walloon Region (Belgium), examining both residential building stock and home-to-work commuting. Territorial structures are discussed here in terms of three main components: the location of households, the location of employment and mobility infrastructure (roads, buses, trains). It is considered that the interaction between these three components is a structural property of a territory that may affect energy use via mobility and housing consumption patterns. Increasing household densities generally entail more compact buildings (terraced houses and apartments), which tends to lessen energy losses. Mixing places of employment and households allows people to find jobs at closer locations, which may reduce the distances they travel to work, or to destinations for purposes such as shopping or leisure. Adequate access to transportation facilities may impact travel modes, and indirectly, housing densities and energy consumption. Obviously it should be acknowledged that there is an important behavioural dimension in these relations [23]. The proximity of jobs does not constitute a guarantee that householders will effectively select a job near home. Developing the analysis on a statistical basis reveals empirical trends in the relation between these variables and observed behaviour.

The combination of these three variables is assumed to be an element that can somehow be handled by urban planning policies. The effective influence of urban planning upon employment and household locations is obviously limited [15]. Still it should be acknowledged that planning policies at a European level lead to striking differences in this respect, as is evident in the relative extent of sprawl in different regions [24].

Accordingly, Section 2 describes the general methodology adopted in this research, which is based on a combination of Geographic Information Systems with survey and cadastre data at the regional level. Sections 3 and 4 introduce and discuss maps of energy consumption, respectively, for home-to-work commuting

and for residential building heating in the Walloon Region. Section 5 combines observed results and indicators of density and mixed use to highlight the impact of territorial structures on energy consumption. The concluding section is a general discussion of the results and possible policy recommendations regarding spatial planning policies.

2. Methodology

The overall methodology of this research is based on spatial correlations between energy performance indicators, namely mean home-to-work commute energy consumption and mean residential building energy consumption, with two territorial indicators, namely mean density and mixed use. Each of these four indicators has been calculated on the scale of statistical units. The territory of the Walloon Region is covered by 9876 statistical units. The area of these statistical units varies between 1.3 ha and 5834 ha with a median value of 47.7 ha, which corresponds to a circle of slightly less than 400 m in radius. Statistical units correspond to neighbourhoods in urban areas and encompass large depopulated zones in rural areas. It is important to note that the analysis has been conducted for all statistical units in the entire region (16,844 km²) and includes urban, peri-urban and rural settlements. This is an important difference from the approach developed by Newman and Kenworthy [7], who deliberately focused on large scale agglomerations.

For home-to-work commute, the model is based on the general survey undertaken in Belgium every 10 years amongst all citizens over 16 years of age. The survey provides figures about home-to-work distances travelled by workers and their choice of mode of travel. Altogether, data from 8,572,000 respondents were extracted from the census survey. This represents approximately 73.1% of Wallonia's working population in 2001. These data were used to build a mobility energy performance index, following Boussauw and Witlox [25]. It was calculated for 1991 and 2001, corresponding to the two most recent general surveys in Belgium. The following conversion table was used to estimate kWh and CO₂ emissions per kilometre travelled and passenger on the various modes of travel. Table 1 also provides regional energy consumption and CO₂ emissions for home-to-work commuting, considering annual distance travelled and mode choice of all respondents to the survey.

Figures for energy consumption and CO₂ emissions per kilometre travelled and passenger were obtained by dividing the total amount of energy consumed for a given travel mode, calculated on the basis of the annual kilometres travelled and fuel type, by the occupancy rate of that mode. Conversion factors for electricity to CO₂ emissions were provided by the Walloon Air and Climate Agency (AWAC). Details of the calculation were published in [26]. A mean number of passengers for each travel mode is considered here; the calculation does not consider known variations of energy consumption within public transport according to occupancy rate.

Table 1
Specific energy consumption and CO₂ emissions by travel mode in the Walloon Region.

Mode	Modal share 2001 (%)	Energy consumption by km travelled and passenger (kWh per km)	CO ₂ emissions by km travelled and passenger (gCDE per km [gram of CO ₂ equivalent per passenger and km])	Regional energy consumptions for home-to-work commute (GWh)	Regional CO ₂ emissions for home-to-work commute (TCDE [metric tonne of CO ₂ equivalent])
Car	80.2	0.45	118.3	18,722.0	4894.7
Moto, scooter	1.9	0.41	105.0	251.4	64.6
Bus, tram, metro	4.1	0.35	79.5	417.6	93.7
Train	7.2	0.15	35.7	451.1	104.4
Bike	1.2	–	–	–	–
Walking	5.4	–	–	–	–
Total	100	–	–	19,842.1	5157.5

Table 2

Thermal performance of envelopes by building period in the Walloon Region.

Building period	Share of the housing stock (%)	U wall (W/m ² K)	U window (W/m ² K)	U roof (W/m ² K)	U floor (W/m ² K)	Ventilation rate (V/h)	Window (%)
Before 1945	52	2.2	3.3	1.6	1.9	1	24
1945–1970	19	1.4	3.3	1.4	1.5	1	27
1971–1985	15	0.8	3	1.0	2.4	0.9	25
1986–1996	6	0.5	2.6	0.9	0.7	0.9	25
1997–2010	8	0.5	2.4	0.7	0.7	0.7	26

It is hence unfavourable to urban transport, which has higher occupancy rates than in rural areas. For instance, the ratio between specific emissions of a car when compared with that of a train is about 3:1. The relatively small difference between the two modes can be explained by the fact that the figures are based on regional figures and mean occupation rates. It can further be observed in Table 1 that more than 80% of home-to-work travel is by car in the Walloon Region. The average trip length was 23.3 km in 2001 and this grew by 16% between 1991 and 2001.

Regarding residential building energy consumption, the model was based on combining cadastre surveys with building heights provided by photogrammetric data for some 850,000 residential buildings in the Walloon Region, which corresponds to some 66% of residential building stock. The cadastre provides the age of buildings. This variable was used to estimate envelope and heating system performance for each building, following the approach used by Maïzia et al. [27] and Jones et al. [6].

Energy consumption of buildings was then estimated using a conventional degree-days method [28]. This method considers the insulation of the envelope, internal and solar gains as well as the degree-days registered close to the location of the building. A mean value was used for the orientation of buildings. It was considered that there is no preferred mean orientation of buildings in the existing urban fabric [27]. Solar masks vary between 0% and 40% according to the density of the urban fabric where the building is located. The age of buildings was used to estimate the performance of the heating system.

Building periods were defined to match important technical/thermal turning points, for instance the adoption/changes of thermal regulations in the Walloon Region (in 1985, 1996 and 2010). Table 2 provides an overview of thermal performance parameters used in the model. It is based on the most recent housing survey undertaken in the Walloon Region, which provides information about insulation of buildings for a sample of 6000 dwellings [29]. Information from Carlier et al. [29] was used to determine, for each building period, the proportion of existing buildings that is isolated, considering the four main components of the envelope that were considered in the survey: slabs, walls and roofs, as well as type of glazing in the building. This information for each period was combined with construction types to derive typical envelope compositions, with and without insulation.

It can be seen in Table 2 that the thermal performance of residential building envelopes is very poor for older buildings in the Walloon Region. Policy measures established in the early 1980s to stimulate the refurbishment of buildings, whether tax incentives or direct subsidies for homeowners, had a very limited impact on the improvement of the energy performance of the building stock. They mostly concerned windows and window frames; a large majority of external walls and even roofs have not yet been insulated, while insulating the roof is often presented as the most effective and durable measure to improve the energy performance of the building stock [30].

It should be stressed in this respect that in 2010, some 52% of the housing stock in the Walloon Region predated 1945; 87% of the stock was built before 1985 when the first regulations on the insulation of new buildings were adopted.

3. Home-to-work commute energy consumption

The analysis highlights an increase of 20% in energy consumption per kilometre travelled by each passenger in the Walloon Region between 1991 and 2001. This is mainly due to the extent of sprawl and a modification of the employment catchment areas of Brussels and Luxembourg City. It is striking that amongst the 20 municipalities that witnessed the largest increases in their emissions related to mobility, 18 are located in the south of the region and polarized by Luxembourg City.

Fig. 1 highlights that urban areas located along the old and dense “Liege–Charleroi–Mons” industrial axis are characterized by lower energy consumption. At the opposite extreme, rural and peri-urban areas are characterized by much higher energy consumption. The situation of peri-urban areas is especially challenging because they now attract large populations, especially in the south of Brussels. Interestingly, some of these peri-urban areas experienced a decrease or stabilization in their energy consumption for home-to-work commute over the 1991–2001 period, due to the relocation of jobs outside main agglomerations.

In terms of urban planning, this should lead to contrasting solutions in the various urban patterns. Although urban areas show better performance than rural and peri-urban areas, energy consumption per kilometre travelled and passenger should still be reduced because they gather a large proportion of the regional population and number of trips. Conversely, population growth in remote rural areas should be contained because it usually leads to long distances usually done by car. Finally, in peri-urban areas, a combination of reconcentration of housing and economic activities around efficient public transport hubs is probably the best option to curb the current mobility and energy consumption trends.

4. Residential building energy consumption

When total housing stock is considered, the annual energy consumption by square metre of floor space appears largely related to the age of construction (Table 3), although it is also influenced by urban compactness and climate factors. It should be noted in this respect that the standard deviation is particularly important for buildings built before 1945. Although their thermal insulation is very poor, this can be compensated by greater compactness of buildings located in dense urban centres.

Globally, the thermal performance of residential buildings is very poor, with a mean annual consumption of approximately 350 kWh/floor m². It is striking that consolidated urban areas

Table 3

Energy consumption in building stock by class of construction.

	Mean annual energy consumption (kWh/m ²)	Standard deviation (kWh/m ²)
<1945	407.8	163.4
1945–1970	343.7	81.9
1971–1985	328.5	90.7
1986–1996	203.8	35.8
>1996	172.3	40.2

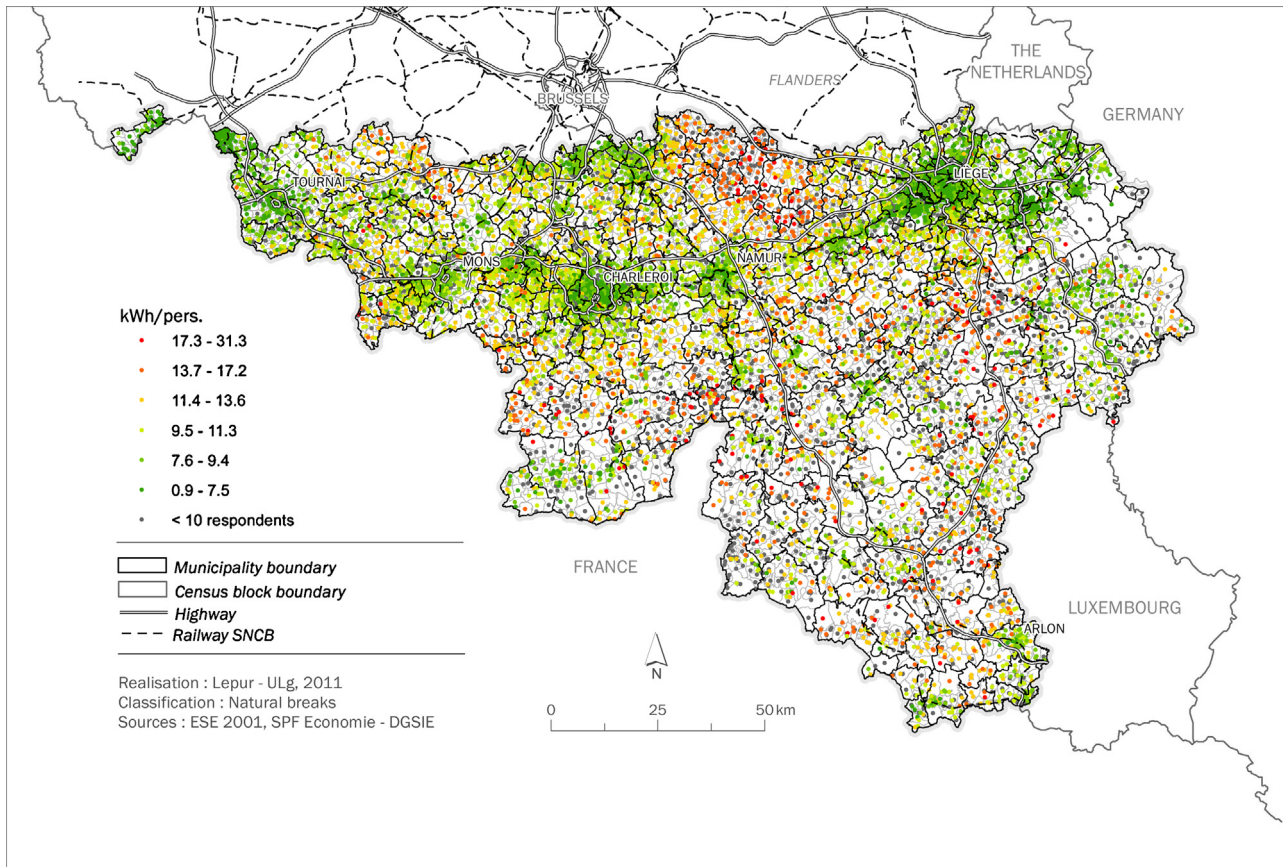


Fig. 1. Energy consumption per km travelled and passenger for home-to-work commute in the Walloon Region at the statistical unit level.

generally show better performance than peri-urban areas (Fig. 2), especially for those buildings erected before 1985, at a time when there was no regulation of thermal performance of buildings. The decades between 1945 and 1985 correspond to a period of very intense sprawl in the Walloon Region. It should be stressed that detached buildings largely dominated post-war construction in the region, as in the rest of Belgium. When these buildings are not insulated, as was usually the case before 1985, their energy consumption can be very high.

Furthermore, it can be observed that in some remote rural areas, especially in the south-east of the region, the performance of buildings is rather good, because some of these sectors have experienced strong growth of their building stock over the past 10 years.

In dense urban areas, where the network of streets and buildings is consolidated, improving the performance of buildings should now be an objective fully integrated into all urban regeneration policies. By contrast, in peri-urban areas, improving building performance could rather be achieved through demolition/reconstruction and densification operations, especially in cases when there is access to public transport and other services.

5. Residential vs. mobility energy consumption

It is not possible to compare directly home-to-work consumption with building energy consumption because these estimations are based on distinct assumptions. On the one hand, home-to-work consumption is based on reported distances and modes of travel while the calculation of building energy consumption conventionally assumes that buildings are occupied and heated throughout the day, which is obviously not always the case. Furthermore, home-to-work travel represents only a share of the total kilometres travelled

in 1 day by members of households. In the Walloon Region, the home-to-work commute represents 38% of the kilometres travelled on a working day, which accounts for 22.6% of the number of trips [31].

If it makes little sense to compare absolute values of energy consumption calculated for these two domains, they may still be related to territorial structures. As documented in the literature, it appears that the energy consumption of home-to-work travel and the heating of buildings are both correlated with human density and mixed use. Net human density is defined as the number of inhabitants plus jobs divided by the urbanized surface of a given area [32]. Urbanized area is defined as the sum of parcels of land occupied by buildings. The mixed use indicator has been defined as the number of uses of land that can be observed within a radius of 500 m. It was calculated on a grid of 10 by 10 m covering the entire land occupation survey map of the Walloon Region.

A mean value of all these four indices—mobility energy consumption, building energy consumption, density and mixed use—has been calculated for all statistical sectors of the Walloon Region. It was then possible to analyze the correlation between them at this scale of analysis.

It can be seen from Table 4 that the correlation between energy consumption and the two urban indicators (density and mixed use) is statistically significant, although the correlation coefficients are rather weak. This basically means that those statistical sectors with a higher mean density and/or mixed use value are generally characterized by lower energy consumption, both for mobility and residential building heating, although there are quite a number of sectors where this relation is not observed. It further appears that the correlation coefficient of mobility performance with mixed use is higher than that with density, although it should be noted that

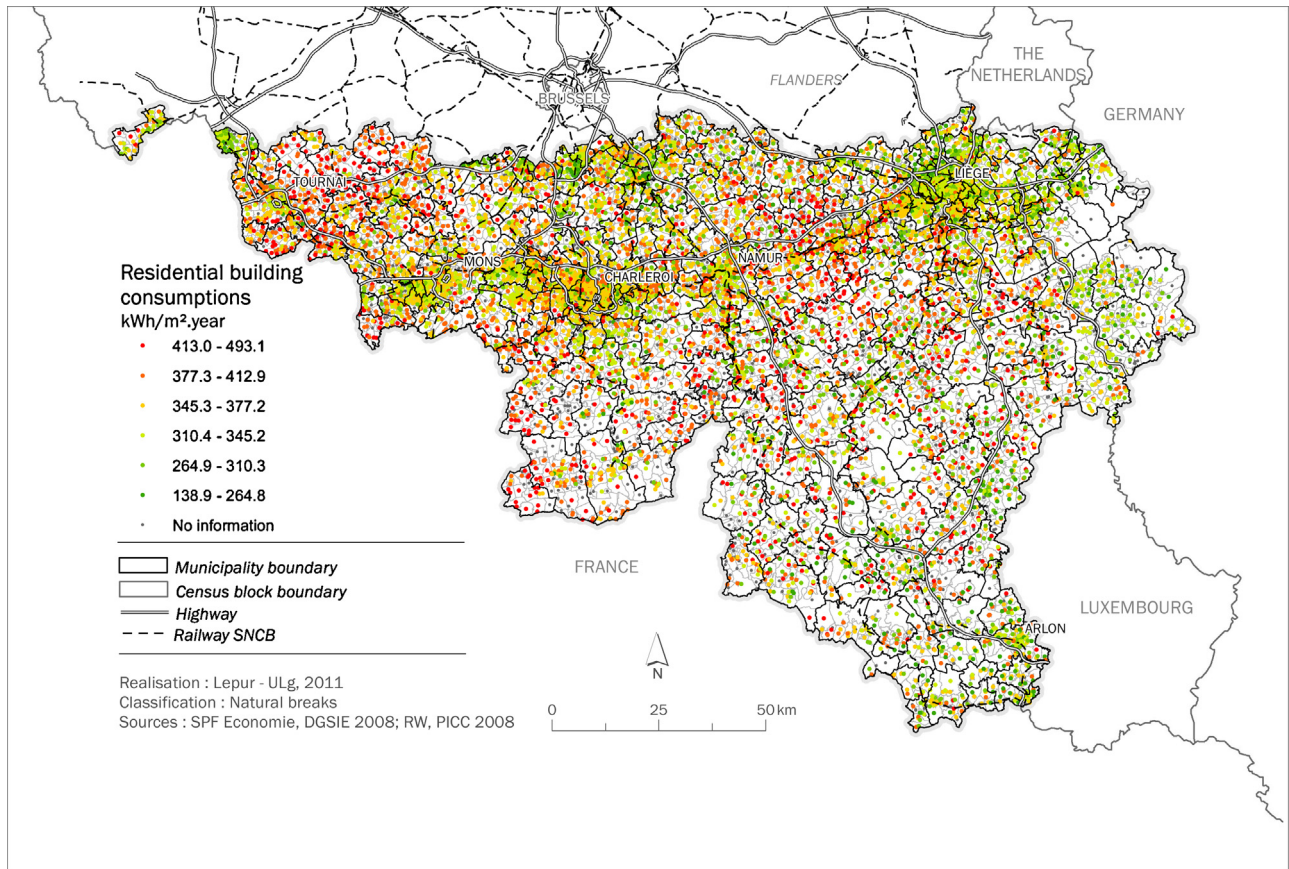


Fig. 2. Energy consumption in residential buildings in the Walloon Region at the statistical unit level.

these last two variables are themselves correlated. Because it is directly related to the accessibility of jobs and services within a short distance, mixed use influences patterns of displacement of households and individuals, both in terms of distance travelled and travel mode, because mixed-use areas are usually characterized by better access to public transportation.

By contrast, the correlation coefficient of residential building performances with density is higher than that with mixed use. This is obviously related to the fact that density is directly linked to building compactness, which influences energy consumption via a reduction of the thermal envelope relative to square metres of floor space. The fact that building energy consumption is also related to mixed use is mainly due to the subjacent relation between mixed use and density.

These results raise questions regarding assertions by Newman and Kenworthy linking energy performance of cities solely to density. First, because there is substantial variation amongst statistical units along the observed trend; low density units may be

characterized by very good performance especially when they are located close to employment centres (for commuting) or have been built recently (for energy consumption in buildings). Additionally, the results stress the importance of mixed use besides density for understanding and influencing travel behaviour.

Finally, the performance of statistical units along the two dimensions observed until now can be compared for the entire region (Fig. 3). After grouping statistical units by former municipality (the geographical scale above the statistical unit), they were classified according to their position in a hierarchy of eight classes of municipalities in Belgium [33]. This hierarchy is based on a classification of municipalities according to their size and level of facilities (e.g., presence of higher education institutions, metropolitan services or schools). It distinguishes four types of municipalities: main cities, regional cities, small towns and rural (non-urban) municipalities. For the last two categories, small towns and rural municipalities, the classification distinguishes high-, medium- and low-level facilities.

In general terms, it appears from Fig. 3 that those sectors that perform well in terms of mobility also tend to perform well in terms of building energy consumption, and that the reverse is also true. Additionally, most rural settlements are located on the upper right side of the graph; they have higher than average consumption for both mobility and building. Finally, and most importantly, all settlements are represented on the lower left side of the graph, which corresponds to energy consumption below the regional average for both mobility and residential building heating. This means that good performance is observed in all eight types of human settlements, be they urban, rural or peri-urban, depending on the distance to centres of employment and specificities of the urban pattern.

Table 4
Pearson's coefficients of correlation between energy performance indices and indicators of density and mixed use.

	Net human density (inhabitants + jobs/ha)	Net functional mixed use (nb of functions)
Mobility energy consumption (kWh/trip passenger)	-0.483**	-0.504**
Building energy consumption (kWh/floor m ²)	-0.603**	-0.545**

** Correlation significant at 0.01 (2-tailed).

**Comparaison des performances énergétiques des déplacements domicile-travail et du bâti en Wallonie
selon la hiérarchie des communes de Van Hecke (par ancienne commune)**

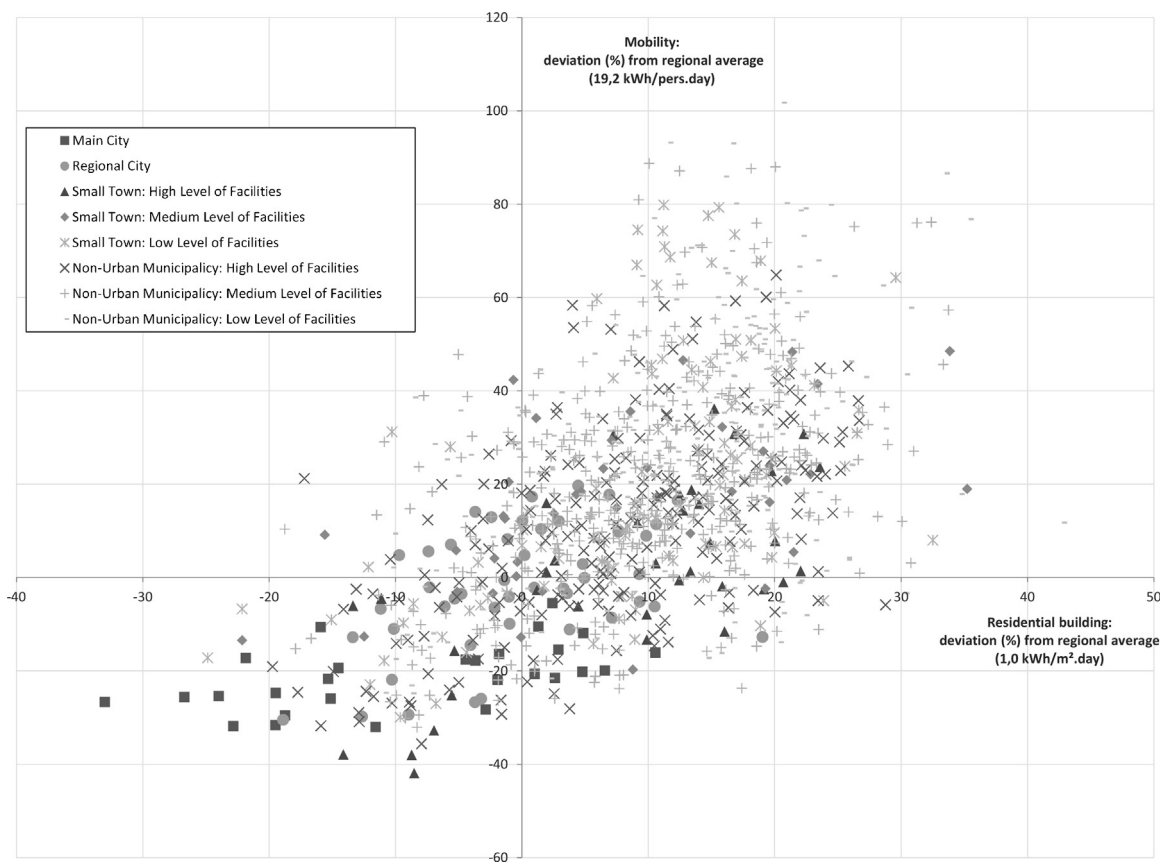


Fig. 3. Scatter diagram of mobility and building performance indicators according to the hierarchy of municipalities established by [33] for Belgium.

This opens an avenue for a much more progressive approach in terms of spatial planning, whereby compact cities may be viewed as part of the solution, albeit not the whole solution. Indeed, planning policies should be tailored to each settlement type to move the entire scatter of points in Fig. 3 to the lower left side of the graph rather than pursue a very hypothetical and unrealistic aim to concentrate the population in compact cities. This way of planning, based on shared efforts amongst all settlement types, is especially pertinent when one considers the entire territorial structure of a region and its strong inertia over time.

6. Conclusions

A method for a combined analysis of building and mobility performance has been established and applied to statistical units in the Walloon Region of Belgium. Results indicate that such performance is closely related to the nature of the statistical unit, both in terms of density and mixed use, and that performance along these two axes is closely related. It confirms that density and mixed use play an important role in reducing consumption for both home-to-work travel and the heating of buildings. Accordingly, spatial planning policies should ensure that the location of new buildings and economic activities is directed towards existing settlements with a view to densifying and diversifying their built environment.

The analysis further highlights that entities with better-than-average performance can be identified in all types of settlements, be they urban, peri-urban or rural. This is an argument for subtler solutions than the traditional compact city model, which is not

readily applicable to existing peri-urban and rural settlements. In these configurations, priority should be given to the relocation of activities to lessen their dependency on remote centres of employment. The development of those areas where this is not possible should probably be limited by adequate containment policies.

Finally, the analysis reveals the important potential for energy savings in current building stock. Spatial planning may be directed towards accelerating the renovation and/or the densification of existing urban fabric through containment policies. In some cases, it may be directed to increasing the substitution of existing houses by new ones with contemporary energy standards and higher densities. This is especially important in those peri-urban areas characterized by poor performance of their building stock and good accessibility by public transport to urban centres.

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