ENERGY REQUIREMENTS OF CHARACTERISTIC URBAN BLOCKS

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ABSTRACT

The present article analyses energy requirements for heating and cooling typical urban blocks in the Region Ile de France. The analysis has been designed to be applicable at the agglomeration level in France through an automatic classification of urban blocks. It provides a contrasted view on the incidence of compactness and urban organisation upon energy requirements and potential solar gains.

INTRODUCTION

It is usually argued that more compact urban forms would significantly reduce energy consumption both in the building and transport sectors. Whilst this may be true at a general level, the present article proposes to measure the potential effects of the urban organisation upon energy consumption, both for new and existing settlements. In doing so it will focus on energy consumption in the building sector.

In 2004, building consumption indeed represented 37% of final energy in the European Union, which remained higher than consumption in industry (28 %) and transport (32 %). Reducing energy consumption in the building sector hence appears as an important policy target both at the European and the national level. A clear example of such policies is the European Energy Performance of Buildings Directive (EPBD) that is now being transposed by all Member States. Still it has to be admitted that, if a great deal of effort has been directed towards measures at the building level, such parameters like the location and distribution of these buildings have somehow been underestimated until now. Still these factors are key for the global energy performance of cities. Urban density largely influences energy consumption per capita as it is related to building types and compactness, mobility needs of inhabitants and enterprises and, last but not least, available transport means [1].

The present paper is centred on the share of building consumption that can be attributed to urban factors. It hence both addresses constructive and geometrical aspects of the issue along with occupation patterns in residential urban areas. Building consumption include both domestic and non-domestic building consumption . Wide differences in energy intensity according to building types have been documented [2]. Office and retail are, for instance, known to be energy intensive occupation types. On the other hand, an increased diversity of functions between retail, housing and office uses can be viewed as a way to reduce transport needs [3]. It would both contribute to reduce energy consumption and to maintain active and lively urban environments.

In an effort to single out the share of energy consumption specifically related to urban factors, the present paper suggests to compare energy consumption for heating and cooling of different types of residential blocks. The research is oriented towards a better understanding of energy consumption in existing buildings at the national level in France. As the energy reduction potential for technical solutions at the building level is now well identified [4], it claims to evaluate the weight of those factors specifically related to the urban organisation.

METHOD

All being equal, energy consumption in the residential sector highly depends upon the geometry of the urban form. Compactness indeed reduces the external built envelope and hence energy consumption , though it can also significantly reduce energy gains by the multiplication of solar obstructions.

Comparisons in this domain have usually been based on theoretical urban patterns, which tends to ignore the intricacies of actual urban settlements. Obviously the balance between gains and losses is not so easily predictable in existing patterns. It varies with a series of factors, amongst which the geometric distribution of the urban pattern, climate factors like temperature and solar path and the possible use of renewable energies (depending on roof inclination and orientation etc.). Furthermore present comparisons between different urban layouts are generally based on static analyses when the importance of temporal distributions, and especially consumption peaks, is a key factor in this domain especially when air conditioning is at stake.

Three main approaches have been proposed in the literature for addressing the relation between urban form and energy consumption.

A first approach is based on building simulation models. Steemers [5] analysed areas of 400 x 400 meters in the city of London with the LT tool enriched with a DEM model. The objective was to establish the relations between urban form and energy along with more detailed characteristics of buildings (thermal conductivity of external walls, window percentage etc.). The analysis was based on three geometric parameters : building depth, street prospect and urban compactness. A similar analysis was then performed by Ratti [6]. The selected variables were here the distance between facades, orientation of the facades and lighting obstructions. The analysis was further applied to three cities (London, Toulouse, Berlin) and once again completed by a DEM. The advantage of these approaches is that it allows to single out the impact of the urban form upon energy consumption though it solely covers energy consumption in buildings without considering transport.

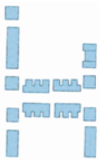
A second approach is based on a statistical approach for the prediction of building consumption . The Energy and Environment Prediction (EEP) model [7] is based on a national database that provides energy consumption for a series of 100 building typologies. The variables considered in the typology are heated floor area, facade area, window percentage and age. This tool allows to compare different energy policies at the urban level. Still the urban form is not analysed per se, but induced from the typology of buildings. The application of this model to large urban agglomerations is possible though it requires to classify all buildings of the agglomeration along the existing building typology which is not straightforward.

Finally a third approach is based on land use analyses [8]. Energy consumption are estimated for certain types of land uses : residential, office buildings etc. The advantage of these approaches is that they are covering a wide range of activities and integrating both building and transport energy consumption . Steadman et al. [9] adopted such an approach to compare different urban organisations from the analysis of the city of Swindon : compact city, dispersed settlements, polycentric development along public transport lines etc. Obviously his method heavily relies on the availability and quality of data for selected building uses and organisations (detached housing, terraced, multi-floor etc.). Furthermore the impact of urban form upon energy consumption is mainly addressed at the agglomeration level and is not of direct use for operational scales at the block level.

It is hereby proposed to adopt an intermediate approach based on energy simulations applied to representative urban blocks. An urban block is here defined as a group of contiguous land parcels delineated by streets or public spaces. It is somehow similar to the first approach described here above. Still it includes a wider diversity of urban blocks in order to cover all typologies observed in an urban region, including dispersed settlements. Furthermore the analysis will be completed by a transport analysis considering mobility patterns in different urban configurations. For obvious limitations of length the present article has been focused on energy consumption in buildings.

A typology of 25 different urban blocks was established in 1995 by IAURIF (Institut d'Aménagement et d'Urbanisme de l'Ile de France) for the classification of the urban fabric of the Region Ile-de-France [10]. This typology includes an aerial view of each urban block, an analysis of its plan, occupation mode and density. It covers both individual and collective types of housing and it has been designed and validated by IAURIF for the classification of all urban blocks of the Region Ile-the-France. It is hereby assumed that it is further applicable to other French cities ; simply the proportion of each of the 25 urban layout types will vary from one city to another. Amongst the 25 types identified by IAURIF, only 18 were effectively selected in this research. By definition, all these types consist in actual urban blocks that are assumed to be representative of a series of urban blocks of the city.

This typology is presented in Table 1, which provides the following indicators for each type of urban block : the ground floor area of buildings (sqm), the average height of buildings (nbr of levels), the surface of external walls (sqm) and the perimeter of the façade (meters). It can be seen from the table that densities vary quite importantly from one type to another as the ground floor area of type 2.3 (Cergy New Town) is 3.247 sqm with a mean height of 2.2 levels while collective "low" housing in the centre of Paris (type 5.4) has a ground floor area of 5.284 sqm for an average height of 8.58 levels.

TYPE URBAIN	1.1	2.1	2.2	2.3	2.4	4.1	4.2	4.3	4.4
DESCRIPTION	Habitat individuel à Colombet	Habitat individuel identique à Saint Nom le Bretèche	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel identique à Colombet	Habitat individuel continu bas Cergy ville nouvelle	Habitat collectif continu bas à Rueil-Malmaison	Habitat collectif continu bas à Le Vésinet	Habitat collectif continu bas à Poissy
IND./COL.	IND	IND	IND	IND	IND	IND	COL	COL	COL
PLAN MASSE									
Date de construction	de 1915 à 1948	de 1968 à 1974	de 1968 à 1974	de 1968 à 1974	de 1968 à 1974	de 1975 à 1981	de 1915 à 1948	de 1915 à 1948	av. 1914
Emprise au sol nette (m²)	5835	9228	4225	3247	3830	3597	6413	2588	2893
Hauteur moyenne (Nbr de niveaux)	2.23	2.4	1.59	2.2	1.76	3.05	4.37	3.06	3.18
Surface de façade verticale (m²)	14373	17255	7650	6560	5947	9017	17467	5349	7220
périmètre de façade (ml)	2149	2396	1609	994	1126	986	1332	582	756

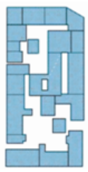
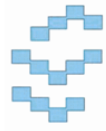
TYPE URBAIN	5.1	5.2	5.3	5.4	6.1	6.2	6.3	6.4	6.5
DESCRIPTION	Habitat collectif continu haut à Levallois	Habitat collectif continu haut à Boulogne-Billancourt	Habitat collectif continu bas à Mantes-la-Jolie	Habitat collectif continu bas à Paris, Porte de Champerret	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Suresnes	Habitat collectif discontinu à Le Chesnay	Habitat collectif discontinu à Beauregard (Poissy)
IND./COL.	COL	COL	COL	COL	COL	COL	COL	COL	COL
PLAN MASSE									
Date de construction	av. 1914	de 1915 à 1948	de 1949 à 1967	de 1915 à 1948	de 1949 à 1967	de 1975 à 1981	de 1915 à 1948	de 1975 à 1981	de 1968 à 1974
Emprise au sol nette (m²)	4106	4798	2533	5284	4587	1427	1969	4711	2525
Hauteur moyenne (Nbr de niveaux)	5.19	4.89	3.73	8.58	4.15	3.92	4.89	5.88	4.86
Surface de façade verticale (m²)	14741	15646	6715	27003	10528	3385	6441	16231	10176
périmètre de façade (ml)	946	1066	600	1049	845	288	439	920	698

Table 1 – Geometrical characteristics of the 18 types of urban blocks identified by [10].

The average age of construction of buildings in each urban block (figure 1) was estimated by the research team. It has been used to approximate a mean thermal conductivity of external faces, a mean percentage of windows and a mean ventilation rate of buildings. It was then possible to perform an energy consumption analysis of these 18 types of urban blocks. The software used at this purpose was TAS (Thermal Analysis Software). It includes a geometrical 3D modeller for the estimation of solar shadings between buildings and an interface for thermal variables (climate conditions, building materials, internal conditions and periods of use of the building). It has to be stressed that the simulation considers the effective insulation rate of buildings. It is not limited to geometrical aspects but considers most probable construction techniques of each of the 18 representative urban blocks.

RESULTS

Table 2 presents energy consumption required for heating and for cooling buildings as well as potential solar gains on facades and roofs. Types are grouped in four categories for facilitating the reading of the table : discontinuous collective housing, continuous collective housing, dense individual housing and dispersed individual housing.

It can be seen from Table 2 that energy required for heating is on average 4 times higher than the one required for the cooling of the same urban block in the reference city adopted for this analysis (Paris).

Heating loads vary from 51,59 kWh/m2/an (type 6.4 – collective discontinuous housing) to 139,43 kWh/m2/an (type 2.2 – individual dispersed housing), which means a range from 1 to 2.7 for existing urban blocks considering their constructive characteristics at present. For the later case, type 1.1, 2.2 and 2.4, there is clearly an issue about whether it is more appropriate to transform existing buildings or substitute them with more efficient typologies as it is presently been done in some European countries where heating is more demanding than cooling needs.

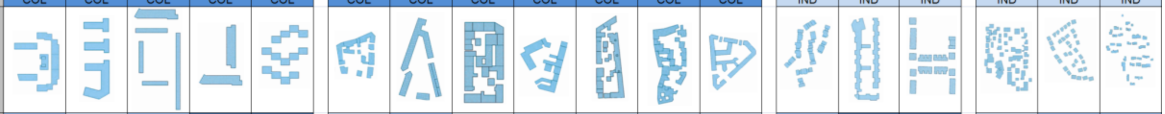
	HABITAT COLLECTIF DISCONTINU					HABITAT COLLECTIF CONTINU (îlot)							HABITAT INDIVIDUEL DENSE			HABITAT INDIVIDUEL EPARS		
TYPE URBAIN	6,1	6,3	6,5	6,2	6,4	4,4	5,3	5,1	4,3	5,2	4,2	5,4	2,4	4,1	2,3	1,1	2,2	2,1
DESCRIPTION	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Suresnes	Habitat collectif discontinu à Beauregard (Poissy)	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Le Chesnay	Habitat collectif continu bas à Poissy	Habitat collectif continu bas à Mantes-la-Jolie	Habitat collectif continu haut à Levallois	Habitat collectif continu bas à Le Vésinet	Habitat collectif continu haut à Boulogne-Billancourt	Habitat collectif continu bas à Rueil-Malmaison	Habitat collectif continu bas à Paris, Porte de Champerret	Habitat individuel identique à Colombet	Habitat individuel continu bas Cergy ville nouvelle	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel à Colombet	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel identique à Saint Nom le Bretèche
IND,/COL,	COL	COL	COL	COL	COL	COL	COL	COL	COL	COL	COL	COL	IND	IND	IND	IND	IND	IND
PLAN MASSE																		
Date de construction	de 1949 à 1967	de 1915 à 1948	de 1968 à 1974	de 1975 à 1981	de 1975 à 1981	av, 1914	de 1949 à 1967	av, 1914	de 1915 à 1948	de 1915 à 1948	de 1915 à 1948	de 1915 à 1948	de 1968 à 1974	de 1975 à 1981	de 1975 à 1981	de 1915 à 1948	de 1968 à 1974	de 1968 à 1974
U bat W/m²,°C	2,356	2,188	2,01	2,25	2,25	2,088	2,356	2,088	2,188	2,188	2,188	2,188	1,789	1,475	1,075	2,04	1,789	1,789
Besoins chauds kWh/m²SHON,an	76,76	73,61	67,99	55,23	51,59	102,31	90,12	86,29	85,75	75,86	75,65	69,39	120,46	59,23	52,07	128,35	139,43	98,66
CLASSEMENT	10	7	5	3	1	15	13	12	11	9	8	6	16	4	2	17	18	14
Besoins froids kWh/m²SHON,an	16,37	23,22	30,34	20,34	22,4	17,97	18,28	18,12	21,96	25,85	21,35	32,53	14,79	23,58	33,8	18,59	17,42	16,48
CLASSEMENT	2	13	16	9	12	5	7	6	11	15	10	17	1	14	18	8	4	3
Apports solaires kWh/m²SHON,an	69,52	98,18	134,78	88,23	80,87	89,25	87,31	75,7	99,34	96,25	86,64	82,36	111,87	93,53	106,48	117,08	139,03	99,87
CLASSEMENT	18	8	2	12	16	11	13	17	7	9	14	15	4	10	5	3	1	6

Table 2 – Heating and cooling needs of the 16 types of urban blocks with potential solar gains

A clear difference can be further be observed between buildings constructed before and after the thermal regulation adopted in France in 1974. Those constructed after this period generally have heating consumption inferior to 55 kWh/m2 SHON/an. For buildings produced before 1974, individual housing are clearly the most energy intensive, especially for dispersed types (98 to 140 kWh/m2/an). For dense individual housing, energy consumption are contained in a range between 52 kWh/m2/an (post 1974) to 120 kWh/m2/an (pre 1974). Collective discontinuous types are the most efficient ones in terms of heating needs (52 kWh/m2/an to 77 kWh/m2/an), especially for those built before 1974 that perform much better than other types built in this period.

Cooling loads vary from 14.79 kWh/m2/an (type 2.4 - dense individual housing) to 33.8 kWh/m2/an (type 2.3 – dense individual housing), which means a range of 1 to 2.3 in the same class of urban block. This can be explained by the fact that buildings of block 2.3 are much more recent and have a lower thermal conductivity than the ones of block 2.4 (see Table 1). Generally speaking urban blocks that require most energy for heating are the most efficient in terms of cooling needs. Dispersed individual housing perform much better in this respect. This can be explained by the large external surfaces of these types of buildings. This effect is somehow limited in the case of continuous individual housing (terraced houses), which explains why this urban type is globally more efficient in terms of thermal regulation.

Finally those urban blocks that receive most solar gains (between 100 and 139.03 kWh/m2/an) are dispersed individual housing types. It means that retrofitting existing dispersed individual housing blocks may be interesting for warmer climates provided that the potential for solar gains is effectively valorised. Very dense urban blocks (type 5.1, 5.4) perform quite badly in terms of potential solar gains, even though their heating consumption is not bad for buildings produced in this period (86.29 & 69.39 kWh/m2/an).

Four sensitivity analyses were performed in order to identify most relevant variables apart the geometry of the urban block. These concerned climate conditions, ground temperature, window percentage and orientation. As regard with climate, six representative cities were selected in order to test the sensitivity of energy consumption with climate conditions. These cities were Nice, Biarritz, Bordeaux, Nantes, Paris and Strasbourg. They were selected for their representativeness of climate variations within France. It has been demonstrated that all 18 types are reacting in the same way to varying climate conditions. It has been further demonstrated that solar energy on vertical walls and roofs vary only marginally with orientation of the urban block (less than 3%). This is due to the lack of optimisation of these typical urban blocks in terms of solar accessibility.

DISCUSSION

The analysis highlights that, for existing urban blocks, the benefits of compactness are much more limited than what is generally expected by policy makers. This is also true for potential energy gains over facades. Effects of compactness may be much more important for new buildings and new urban developments where building orientations can be optimised for solar gains though

Different scenarios should now be compared and tested for these existing urban blocks : retrofitting the buildings in order to improve their thermal conductivity (for cool climates) or ventilation rate (for warmer climates) etc. The performance of existing blocks, possibly retrofitted, should then be compared to the one of “optimal” urban blocks designed to get the best of given climate conditions. This will help us to determine the potential energy gains specifically related to the urban organisation.

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