Demolition vs. refurbishment for the old houses: a regional cost-benefit analysis

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Abstract

Cost effectiveness of the energy efficiency measures for the building stock is clearly a keypoint to reach the Green House Gas (GHG) mitigation and energy consumption decrease targets in France. In this frame, for the old and inefficient houses without heritage value (e.g. 3 millions in France built from 1949 to 1974), the question of demolition vs. refurbishment arises.

Actually, the refurbishment of old houses is helpful to enhance their efficiency, but if new small multi-storey residential buildings replace them, this could lead to added energy savings due to advanced thermal efficiency as well as promoting sufficiency with the limited dwelling surface per inhabitant and reducing urban sprawl. Moreover, some co-benefits are expected like reduced individual car travelling, and decreasing real estate market pressure allowing access to low or mid-income households.

In this paper, we present a local cost-benefit analysis from a societal viewpoint with:

- Energy savings due to refurbishment vs. energy consumption of the new built dwellings depending on location,
- Cost of retrofitting vs. cost of demolition and construction of the flats depending of the real estate market,
- Assessment of co-benefits: reducing car transportation, access to new building market in chosen area …

For this purpose, we used data from a recent survey on 2012 French representative households together with other data provided by national statistics agency.

Finally, we evaluate the interest of local urban planning to reduce GHG emissions and energy consumption by replacing old houses by new multi-family building in dense peri-urban areas.

Introduction

It is usually assumed that drastic energy savings in dwellings can't be achieved without strong retrofitting programmes. Consequently, there are a lot of reasons to study efficiency of retrofitting actions and renewable technologies for existing buildings. However, energy efficiency regulation for new building became more drastic over time as claimed by the EPBD[1] directive. In France the next building code revision will be in enforcement in 2012 and requires that new residential buildings present specific consumption under 50 kWh_{pe}/m^2 in primary energy (pe) for the main end-uses (space heating, sanitary hot water, lighting and ventilation). Unfortunately, the amount of destructed old buildings (assumed to be replaced by new ones) stays low in France with an amount of 30,000 dwellings for the time frame 1990-2000 (Traisnel et al. 2010). Moreover, in many forecasting studies presenting scenarios about future residential consumption it is usually assumed that demolition of old dwellings is concerning the worst efficient ones[2] (Traisnel 2001; Chambolle and Pouliquen 2008; Giraudet et al. 2010; Sartori et al. 2009). More recent works (Traisnel et al. 2010) have includ-

1. Energy Performance of Buildings Directive, 2010/31/UE.

2. For example : average efficiency of demolished buildings from 398 kWh/m² in 1973 to 250 kWh/m² in 2050.

ed consideration of urban characteristics in their prospective study for the construction of new dwellings.

Especially, for the old and inefficient houses without heritage value (e.g. 3 millions in France built from 1949 to 1974 (INSEE 2006)), the question of demolition vs. refurbishment arises. According to Power (2008) this last issue were debated along the XXth century and remains not fully resolved.

On the other hand, the question of urban densification and preventing of urban sprawl (new individual housing located in outlying suburbs) occurs to limit the transportation energy consumption linked to this phenomenon. Urban sprawl is a problematic trend due to the costs and availability of plots of land to build new dwellings and the households desire to live in an individual housing. So, the question of the residential sector and energy consumption evolution in France has to take into account a global approach coupling building and transportation considerations. These issues were studied for France among others by Maïzia (2010).

Actually in France, the majority of new dwellings were built in two different areas (J-P.Traisnel et al. 2010) (annual 2005 data):

- Urban and suburbs areas with around 110,000 new mostly composed of multi-storey dwellings (more than 60 %),
- Rural areas with 140,000 new units, mainly composed of individual housing (around 80 %).

Some interesting results were presented showing that an individual housing located in a rural or peri-urban area emits around 3.8 tCO_2/y for transportation and the main dwelling end-uses (space heating and domestic hot water) i.e. 46 % more than a household located in a centre of an urban area (Traisnel 2001). Moreover, the French public statistics agency INSEE has shown in a forecast study that the continuation of migration to peri-urban area could induce a 4 % increase of car transportation in 2020.

Actually, the refurbishment of old houses is helpful to enhance their efficiency, but if new small multi-family buildings were to replace them, this could lead to added energy savings due to higher thermal efficiency as well as promoting sufficiency with limited dwelling surface per inhabitant. Moreover, some co-benefits, not necessarily financial, like reduced individual car travelling and decreasing real estate market pressure allowing access for low or mid-income households are expected. On the other hand, the demolition is associated with social cost and political problems as well as high costs (demolition cost and cost of new building). These issues were recently discussed by Power (2008), showing that the demolition versus refurbishment discussion is not complete unless social and environmental (life cycle analysis or embodied energy of building materials) issues are included, and resulting in a conclusion in favour of retrofitting. In large multi-storey buildings, the social cost of expropriation-demolition and the politic problems arising could be high. Moreover, the demolished multi-dwelling units are generally in a poor condition (including thermal efficiency) in specific district.

Conversely, in this paper as we only deal with old individual housings when they are for sale (i.e. without the necessity to expropriate the household) the social cost should be low. In that case, the driver for demolition should not be the bad condition of the building or the urban planning in specific district, but the real estate market pressure. Then, the relation between demolition of individual housings and their energy consumption has to be reconsidered.

Moreover, economic models of urban structure, based on the classical theory of urban land use and city size, rely on two phenomena: a behavioural part accounting for households weighting proximity of the city centre against the price of the building; a second part accounting for the property developer's willingness to build new dwellings depending on the local level of property prices (Viguié et al. 2010). Another modelling approach of urban development was also done with empirical (past) correlations of the building stock, daily mobility and land urbanization (Maïzia 2010).

This paper will present a French regional study comparing the impact of demolition of an old single family house located in a dense urban area replaced by a small multi-family building (densification scenario) and the continuous trend of urban sprawl (continuous sprawl scenario). The study consists in a first part showing the general relation between variables of property market and the regional density and a second one presenting the comparison of the energy and financial impacts of two different scenarios:

- Refurbishment of an old house, located in an urban area, and building of new ones in a rural area.
- Demolition of this old house replacing it by a new multi-family housing in a urban area.

Methodology and data

This study is divided into two parts where the first part concerns the theoretical approach comparing new buildings and refurbishment of existing ones at French regional level and the second presents case studies based on cross-sectional data. As space heating consumption represents 64 % of the whole energy consumption of main dwellings (CEREN 2010), this work deals only with space heating consumption and will not present data about other end-uses.

It is well known that space heating consumption is firstly depending on climatic conditions, building envelope performance and space heating system efficiency. However, non-technical characteristics such as energy prices or households socio-economic characteristics are also non-negligible determinants of energy consumption (Cayla et al. 2010). Furthermore there is a relation between the location of dwellings, the building structure (vintage, morphology, envelope efficiency) and the type of households (socioeconomic characteristics). As presented by APUR, a correlation is observed between age of buildings and their compactness as well as the thermal transmission of the envelope (APUR 2007). Such relation was also observed in another study (Schuler et al. 2000).

Moreover, it is well established that the urban heat island effect could be of importance on the space heating consumption in very dense urban area as temperature differences between core urban and surrounding rural locations of several degrees are commonly observed (Pigeon et al. 2007; Kolokotroni et al. 2010).

Moreover, the distance between a dwelling and city centre is one of the main determinants of its estate value. The difference between dwelling current estate value and the potential estate

Table 1: Number of questions per topic asked to 2012 representative French households (June 2009).

Topic	Dwelling characteristics	Space heating system	Dwelling environment	Socio-economical data	Behaviour	Energy consumption (bills)
Number of question	39	9	4	16	12	5

value of a new building constructed in place of the current one participates to the financial interest to demolish a dwelling. The first part of the study will explore the link between the potential financial benefit of a dwelling demolition and the energy consumption of this dwelling.

CROSS-SECTIONAL DATA

For the case study analysis, a cross-sectional database was used. It is based on results from a dedicated survey on French representative households (representativeness is guaranteed by TNS Sofres Metascope, which exploit a panel composed of 20,000 French households (Sofres 2011)). This survey have been realized in 2009 on 2012 representative French households with enquiries about their behaviours completed by the technical description of their dwelling as well as their energy bills (Table 1). To be able to extrapolate at the national level, each household is weighted to be representative to the French population. This weight is determined, for each household, from their income, the urban density and location of the dwelling, the family type, the age of the reference person, occupational status, the type of building and the date of construction (Cayla et al. 2010; Cayla et al. 2011).

Finally, after correction and cleaning the sample, this cross-sectional data consist of a total of 900 households representative of the French building stock (each household is weighted to be representative). For this work, we used dwellings from the enquiry composed of 341 individual houses built before 1975 (before first thermal regulation) and 84 new multi-family housings built after year 2000.

Energy savings potentials and space heating consumption were assessed using the data in the cross-sectional survey.

Observed space heating consumption was assessed from household energy bills (gas, fuel oil, LPG, electricity, wood) provided by the questionnaire, using a regression methodology provided by CEREN[3] for hot water and cooking end-uses and a multi-linear regression for the other specific electricity end-uses. The end-uses consumption of the 900 households sample, extrapolated at the French national level was in accordance to national end-uses consumption provided by CEREN (Allibe 2009; CEREN 2007; Cayla 2011). All energy consumptions below are expressed in term of final energy (i.e. energy paid by households).

Theoretical space heating consumption was assessed with the French EPC (Energy Performance Certificate) methodology based on the former thermal regulation (RT1988) on the basis of data coming from the survey. Even if the EPC was demonstrated to be innaccurate by overestimating the energy consumption for space heating (Cayre et al. 2011; Allibe et al. 2010), it is a public tools and remains the reference of the residential building efficiency in France. Moreover, the EPC methodology is used for prospective or energy saving potential studies (Traisnel 2001; Sartori 2009). In this paper, the theoretical space heating consumption was only used to demonstrate that using such theoretical consumption in a demolition perspective could lead to overestimation of the energy savings (see section "Space heating consumption of old individual houses" below).

REGIONAL DATA

We have used regional data in relation to the regional population density (as an indicator of urban density) to provide a regional analysis of the potential of individual housing that could be pull down to be replaced by residential apartment building. Data concerning new buildings are provided by MEDDTL[4] (SOeS 2010), regional data for the cost of old dwellings are provided by solicitor's office survey (notary) (Chambre des Notaires de Paris 2010; Notaires de France 2010) and the dwellings area from the French national statistics agency INSEE (CEREN 2009). Economic regional data (GDP[5], turn-over, number of employees) were provided by Ormières (2010).

We must notice that in France, the region "Ile de France" including the capital city Paris is the densest, far away compared to others. Around 19 % of the population live in 2.2 % of the surface of Metropolitan France. This explains why all the figures concerning "Ile de France" region are different than the other regions.

Theoretical analysis

NEW BUILDINGS

Metropolitan France is composed of 21 regions (see appendix A) with various population density (INSEE 2006) in which we observe a link with the surface and with the price of the plots of land available for new individual buildings (Figure 1). As urban density increases, the price of land increases and the size of plots of land decreases. Moreover, in the forecasting scenario of INSEE for future population (Léon 2010), a moderate correlation between plots of land specific price and population expected variation is observed (Figure 2).

At the national level in 2009, a flat was sold 222,354 Euro and an individual house cost 201,589 Euro indicating that multi-storey building, even if they are smaller, are more costly on average. Consequently, these figures show the property market pressure on the availability of space to build new buildings. This could be explained by considering the type of new buildings: in urban area (downtown and inner suburbs) between 63 % to 85 % of new buildings were flats, against less than 20 % in rural area (INSEE 2006). This also could explain the fact that

3. CEREN (Centre Etude et de Recherche sur l'Energie -Centre for Studies and Economic Research on Energy) is a French organisation that supply reference data on energy consumptions in France (http://www.ceren.fr)

4. Ministry of Ecology, Sustainable Development, Transportation and Housing (Ministère de l'Ecologie, du Développement durable, des Transports et du Logement).

5. GDP: Gross domestic Product.

a) b)

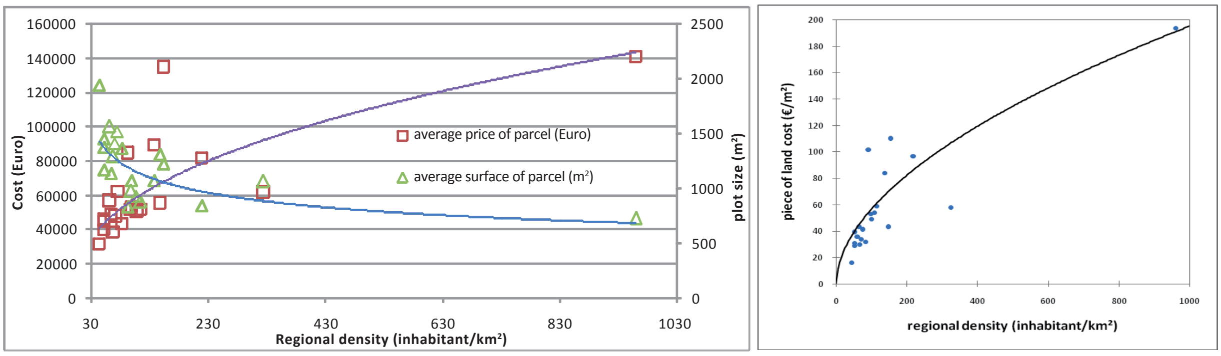

Figure 1: (a) Cost (R^2=0.658) [left in Euro] and plot size (R^2=0.571) [right in m²] and (b) specific price of plot (R^2=0.861) (in Euro/m²) dedicated to the new houses in relation to urban density (data weighted by population 2007).

a) b)

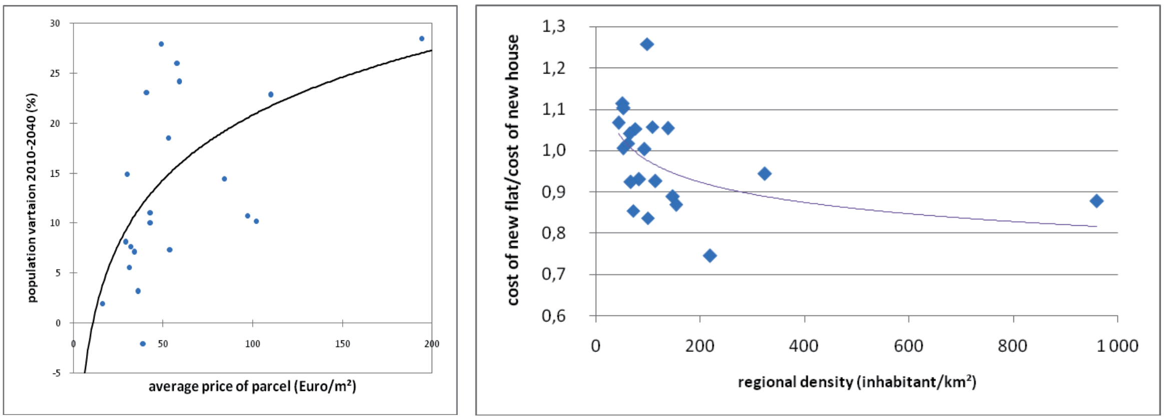

Figure 2: (a) Price of plots of land (Euro/m²) in relation to future population increase (%) weighted by population (2007)(R^2=0.429); (b) ratio of cost for new flat to costs of new house according to population density (R^2=0.22).

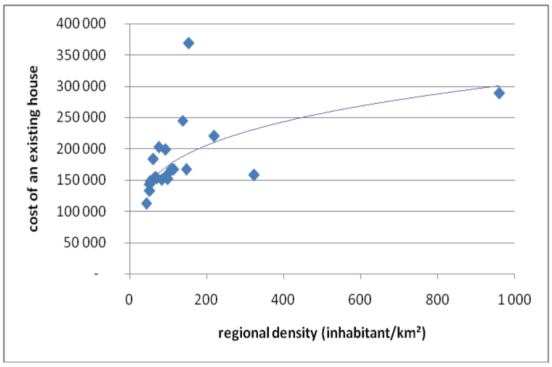

Figure 3: Price of purchase (Euro) of an existing house (2009) in relation to regional density (R^2=0.41).

individual house are more costly in dense regions than multi-family building (Figure 2).

Obviously, as reported by low to moderate coefficient of determination[6] (R^2 value), the population density of French regions cannot fully explain variation of the studied variables. For example, the region "Provence Alpes Côte d'Azur", well-known for its seaside resort, with an intermediate density[7] of 138 inhab./km², presents approximately the same price of plots of land that the most dense region "Ile de France" with an sevenfold density. Moreover, an average density is not a representative figure for region presenting large density heterogeneity.

PURCHASE OF AN OLD INDIVIDUAL HOUSE

As expected, the price of existing houses increases with the population density (Figure 3) reflecting the balance between offer and demand of the property market concerning availability of individual dwellings in urban area. The purchase price is varying from 113,500 Euro to 368,900 Euro (see appendix B). However, the correlation between the two variables is moderate.

REFURBISHMENT OF AN OLD INDIVIDUAL HOUSE

The chosen retrofitting measures are the insulation of walls and roof, installation of double glazing windows, heat pump for space heating and solar domestic hot water system. Only the costs for materials and works and the associated energy savings are taken into account for this study. The energy savings were calculated following an engineering estimate methodology on the basis of thermal losses decrease and on the ratio of initial and final efficiencies of space heating equipment. This methodology was presented in a previous study (Laurent et al. 2009) and will not be explained further.

The costs of refurbishment were regionalised from national costs already presented in a previous paper (Laurent et al. 2009) and inflated by 10 % to take into account the price increase

6. The coefficient of determination measure the quality of adjustment inside the sample data (D.N.Gujarati 2004).

7. 113 inhab./km² on average for metropolitan France.

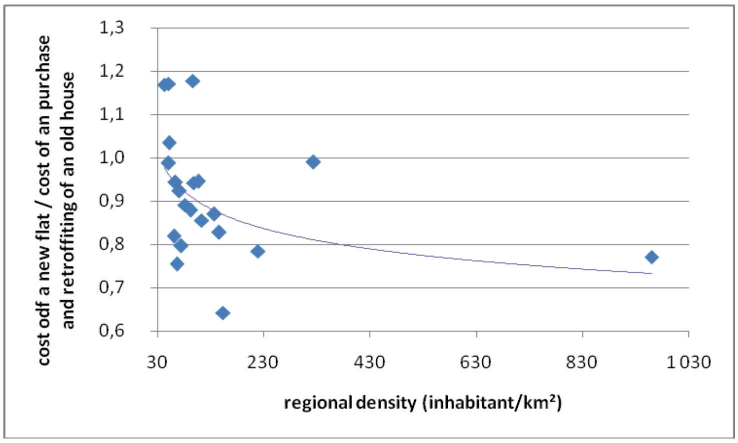

Figure 4: Ratio of total cost between new flat and refurbished existing house in relation to regional density (R^2=0.19).

over 2 years as observed in the past (CAH 2008). The regional costs were created using two index corresponding to the wealth of the regional population (expressed by the GDP/inhabitant) and the cost of retrofitting (turn-over/employee) as following:

$$C_{regional\ cost} = C_{national\ cost} * \left[\frac{\left(\frac{GDP}{population}\right)_{regional}}{\left(\frac{GDP}{population}\right)_{average}} + \frac{\left(\frac{Turn\ \ over}{employee}\right)_{regional}}{\left(\frac{Turn\ \ over}{employee}\right)_{average}} \right] * \frac{1}{2} \quad (1)$$

COMPARISON BETWEEN THE COST OF RETROFIT AND NEW BUILDING

The comparison between the cost of a new flat and the cost of an old house retrofitted is presented in Figure 4. Only for 9 regions the cost of a flat is higher or equal to the cost of purchasing an existing house and refurbishing it (ratio ≥1) and it correspond to the region with density below <98 inhab./km². For other regions, the ratio stays below unity, independently of regional density, indicating that the purchase of an existing house is very expensive. This value is then chosen to separate the two types of studied areas (high and low density considered as rural respectively urban) in the case studies. This is in accordance with publications considering the limit between rural and urban areas around 80 to 102 inhab./km² (Laganier et al. 2009, Noin 1989)[8]. These 9 regions with a population density upper than 98 inhab./km² are corresponding to 60 % of the entire metropolitan population.

The case studies

In this section we will present the impact on the space heating consumption of the reduction of urban sprawl in favour of denser urban structure by building a small multi-storey dwellings in place of an individual house. This individual housing is an old house (<1975), built before any thermal regulation and located in urban area. To this aim, we present two different case studies: the refurbishment versus its demolition.

The case studies are based on a comparison of two different scenarios:

- The first one, called "refurbishment" scenario representing the refurbishment of an old house located in an urban area coupled with the construction of new houses in rural area (continuous urban sprawl).
- The second scenario, called "demolition" scenario, helps to limit urban spreading by demolishing an old house and replacing it by a multi-dewelling building in urban area (to get denser urban structure).

In France, the planning density ratio (COS)[9] in the urban regulation for new building is limited with a value depending on the urban structure. In the suburb areas the COS is generally around 0.3 to 0.5 and is between 1 to 2 in inner city (up to more than 3 in Paris) (Wikipedia 2011). As presented by Figure 1, when the region density is higher than 98 inhab./km², the size of plot used for new building is on average around 1000 m² (from 700 to 1300 m² depending on the considered region). In France, the average net gross floor surface for a new flat is 68 m² (Batietude 2010).

With a COS of 1, the total net gross floor area authorized to be built for the new multi-storey building is 1000 m², leading to a maximum of 14 apartments. However, in our case studies, we decide to built a smaller multi-storey building with only 10 apartments in order to reduce the height of the building. This choice presents few consequences on the results as the difference between the two scenarios studied is weakly modified by the number of flats built (see section below).

Consequently, our calculations are based on 10 differents households located in the first scenario (refurbishment) in 1 old house and 9 new ones, and, in the second one (demolition) in 10 new apartments.

A reference situation is also used to assess the different energy savings of the two scenarios. The reference consist of the same old house described in the scenarios above and 9 another dwellings without any specific characteristic. As no information is available on the origin of the households (i.e. where they

8. Depopulated area (below 10 inhab./km²), low density area (10-30 inhab./km²). Intermediary density (30 to 80 inhab./km²) is corresponding to traditional rural areas (source: INSEE).

9. The planning density ratio (called in France COS – Coefficient d'Occupation des Sols) determine the authorized quantity of built area (expressed in net gross floor area - SHON) on a plot of land. It is expressed in the form of a ratio between the maximum authorized built area and the surface of a plot of land.

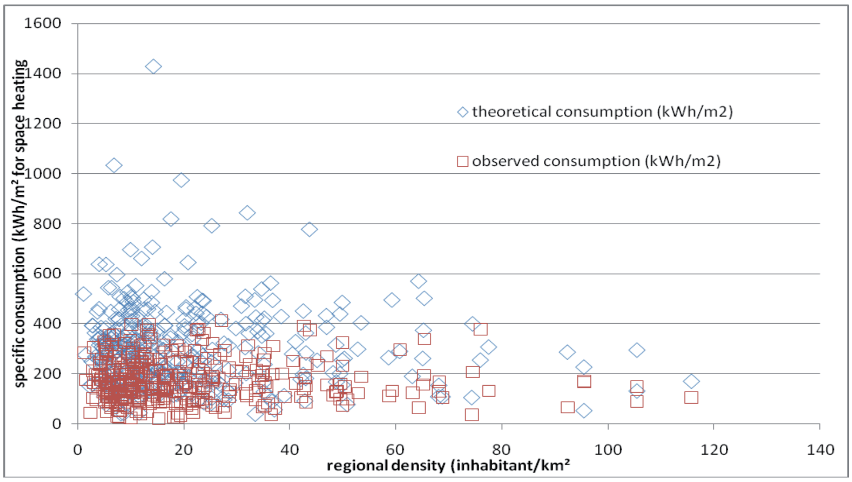

Figure 5: Specific consumption (observed and theoretical) for space heating (expressed in final energy kWh/m²) in accordance with regional density for old houses (built before 1975) in the cross sectional data.

Table 2: Theoretical and observed space heating consumption for the 10% highest or average consumption of the old individual houses in the cross-sectional survey.

	10% theoretical highest	10% observed highest	Average theoretical	Average observed
Total space heating consumption	970 MWh	288 MWh	200 MWh	180 MWh

come from before purchasing new dwelling?),we decide to chose an average dwelling of the French building stock.

To sum up, the three case studies concerning the 10 households are:

- Intial situation (reference): 1 household located in the old house in urban area and 9 average dwellings.
- "Refurbishment" scenario: 1 household located in the retrofitted old house in urban area and 9 households located in house in rural area.
- "Demolition" scenario: 10 households located in a multistorey building in urban area.

We must notice that this work is done considering equivalent households (i.e. with the same number of persons in each) and could be a limitation of the study as households living in a flat are usually smaller than households living in an individual house.

SPACE HEATING CONSUMPTION OF OLD INDIVIDUAL HOUSES

No statistical correlation (R^2<0.01) were found between theoretical or observed comsumption (expressed in kWh/m²as well as with absolute consumption) with regional density or household's income (Figure 5) for the old individual housings. These results are in good accordance wih previous works dedicated to other country showing the lack of relation between neighborhood density and space heating consumption (Kasa 2010).

However, there is a large difference between the theoretical and observed space heating consumption (Table 2). The average theoretical space heating efficiency is 304 kWh/m² and the assessed consumption from energy bills is 177 kWh/m² for the old houses of the survey. Considering energy consumption (expressed in final energy) the space heating consumption per dwelling is 31.4 MWh/dw from EPC assessment(theoretical) and 18.6 MWh/dw estimated form energy bills (observed) (Allibe et al. 2010).

Following the logic of urban economics, demolished houses should be located in area with a high market pressure (i.e. located in dense urban area as presented in Figure 2b) and are not chosen for their poorest thermal efficiency as explained in the "introduction" section. In this case, Figure 5 shows that demolished houses (in higher density areas) don't seems to consume more energy than other ones. As we demonstrate that in such dense areas there is not evidence of higher space heating consumption for these dwellings.

Consequently, it seems to be an error, in forecasting scenario, to think that demolished houses were those with the lowest efficiency (i.e. the highest energy consumption). As shown in Table 2, this error, combined with EPC bias, could lead to an overestimation of demolition energy benefits by a factor of 5.

Obviously, as we don't know with accuracy where are located the demolished building, a random choice (or based on average efficiency) seems more realistic to avoid a systematic overestimation of energy savings.

SPACE HEATING CONSUMPTION OF NEW BUILDINGS

The consumption of the new buildings (i.e. built after 2000) based on the cross-sectional survey is presented below. For the individual houses, the average space heating consumption is 7.01 MWh/dw and 4.43 MWh/dw for the multi-storey housing (that is to say, a specific consumption of 69 kWh/m² for flats and 72 kWh/m² for houses) (Figure 7).

No statistical relation with regional density were found for space heating consumption (kWh/dw) (R^2<0.01) as well as for specific consumption (kWh/m²) (R^2=0.02) for the new individual houses as previously shown for the old individual housings.

REFERENCE SITUATION

The reference situation for the comparison has been chosen as following: an old individual dwelling built before 1975 with an average consumption of 18.67 MWh/dw and 9 others dwell-

a) b)

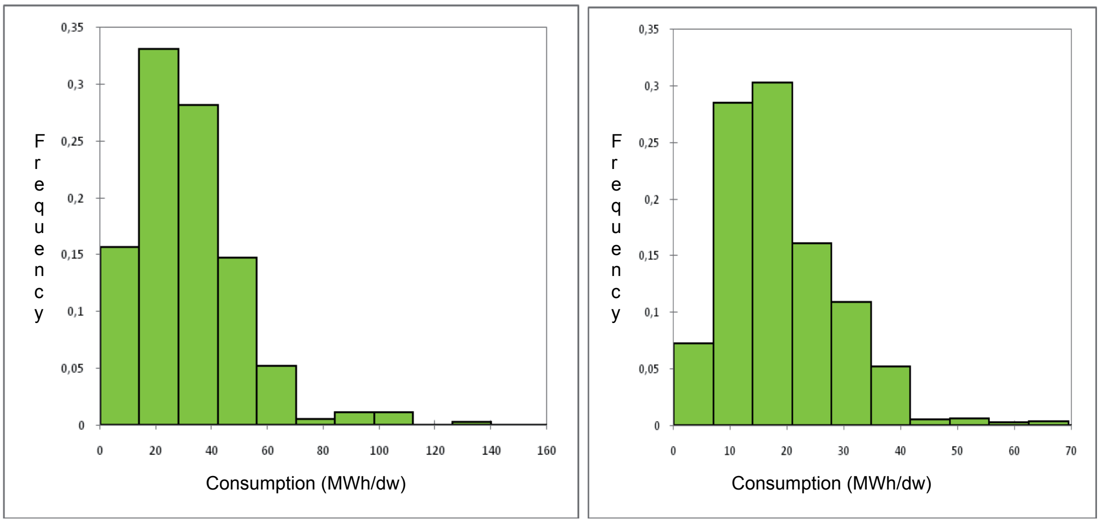

Figure 6: Energy consumption for space heating in old individual houses (built <1975) (a) calculated by EPC, (b) assessed from energy bills (weighted) in the cross-sectional data. Median space heating consumption (a) 28.4 MWh/dw (b) 16.9 MWh/dw.

a) b)

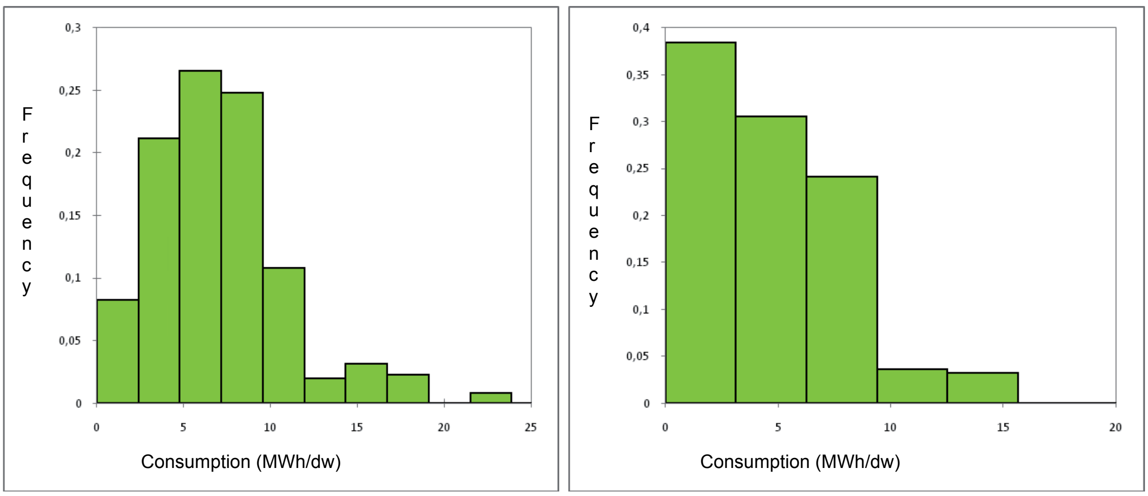

Figure 7: Energy consumption for space heating (MWh/dw) in (a) new (>2000) individual houses (b) multi-storey buildings (weighted). Median space heating consumption (a) 6.99 MWh/dw (b) 3.39 MWh/dw.

ings without any indication of origin. In this case, the average consumption (13.1 MWh/dw) of the building stock, as assessed with the cross-sectional database, is associated to these last households (Allibe et al. 2010). The corresponding total space heating consumption of the reference situation for the 10 considered dwellings is 136.57 MWh.

REFURBISHMENT SCENARIO

In the "refurbishment scenario", it is considered that an old house located in urban or peri-urban area is retrofitted and that 9 individual dwellings were built in a rural area. Unfortunately, we are not able to propose a statistical analysis for each region due to lack of data. The cross-sectional survey was initially made to be representative at the national level (Metropolitan France). To overcome this limitation, we only present results considering two types of regional population density: a rural area with a density below 98 inhab.km² and urban area above this value. The efficiency of the retrofitting is corresponding to an average performance as encountered in the current refurbishment market. The resulting total space heating consumption is 75.23 MWh for the 10 households considered in this scenario.

The whole cost for the refurbishment scenario is corresponding to the purchase of an existing house, built before 1975, located in a urban area plus the costs for refurbishment measures, which added up with the construction of 9 new homes in a rural area.

The resulting energy savings are 61.34 MWh (45 % of the reference consumption) for a total expense of 2,353,630 Euros. Then, the corresponding cost of saved energy[10] (CSE) is 38 Euro/kWh. As the lifetime of all considered buildings are assumed to be equal, a discounting approach over lifetime (e.g. net present value) is not considered useful.

10. Calculated as the ratio between cost and energy savings and expressed in Euro/kWh.

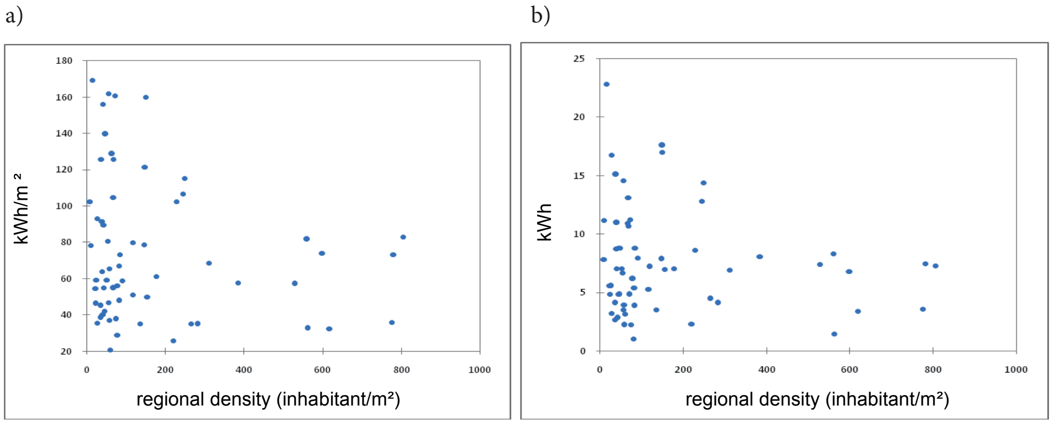

Figure 8: (a) Observed specific space heating consumption (kWh/m²) and (b) energy consumption (MWh/dw) in relation to population density (inhab./km²) for individual houses built after year 2000 in the survey. We must notice that a house in the survey, located in the municipality in the region "Ile de France", of around 3000 inhab./km² is not represented in the figure 8 below (all the remaining houses were located in municipalities with a population density below 1000 inhab./km²).

Table 3: Various space heating consumption depending on location (rural/urban) and age of building (<1975 or >2000)(expressed in MWh/dw) (source: cross-sectional data).

Region (limit: 98 inhab./km²)	Energy consumption of old building refurbished	Energy consumption of old building	Energy consumption of new flat	Energy consumption of new house	Dwelling (house or flat) without origin or age determined
low density	-	-	-	7.47	13.1
high density	8	18.67	4.60	-	

Table 4: Costs (Euros) for the two scenarios in relation to population density.

Region (limit: 98 inhab./km²)	Purchase of existing house built before 1975	Retrofitting of old house*	Demolition of old house*	Purchase of new flat	Purchase of new house
High density	244,800	37,651	20,000	202,168	-
Low density	-	-	-	-	230,131

(source: SOeS; *EDF-R&D)

DEMOLITION SCENARIO

In this scenario, we consider that an old house located in a urban area is demolished and replaced by 10 new apartments as presented above. Then, the total space heating consumption is 46.00 MWh for the 10 households considered in this scenario. The resulting energy savings, compared to the reference situation, are 90.57 MWh (66 % of the reference consumption) for a total expense of 2,286,480 Euros.

For the demolition scenario, energy savings are higher (+32 %) than the refurbishment one. At the opposite the total expense shows a small decrease (-2.9 %) compared to the first scenario. So, the resulting CSE (25 Euro/kWh) is lower than that of "refurbishment scenario" above.

We must notice that the cost of demolition includes a very large uncertainty but even if the demolition cost increase twofold or threefold, the total cost changes slightly (respectively -2.0 % and -1.2 %).

Co-benefit analysis in transportation

Even if the sole energy consumption viewpoint is differentiating the two scenarios, this only aspect of the issue is not sufficient to be conclusive about the demolition scenario as other issues have to be considered like social consideration (e.g. "high social cost" to expropriate households from their living environment) and impact on transportation consumptions (promoting the collective transportation systems).

In this purpose, to enhance the cost benefit analysis of the two scenarios, the transportation side is studied but limited to pendulum and local travels, neglecting long distance ones in this rough analysis even if these last are depending on the location of households. In the cross-sectional database, it is clear that the expense for car fuel is depending on urban structure (Figure 9). This could be explained by the distance from collective transportation (bus, tramway, underground or train) declared by households. The average minimal distance is shortest for the households living in apartment buildings located in urban area, followed by old houses built before 1975 and new houses in rural area respectively.

Surprisingly, considering the dwelling chosen for our scenarios, the expenses dedicated to local mobility (Table 4) aren't significantly different between the dwelling types as expected from the urban structure segmentation presented above even if the minimal value is for the new flat (Figure 9). Thus, the energy consumptions dedicated to local mobility for the 10 households considered in the scenarios are similar for the reference situation and the two scenarios (Table 5):

- Reference situation: 79.93 MWh.

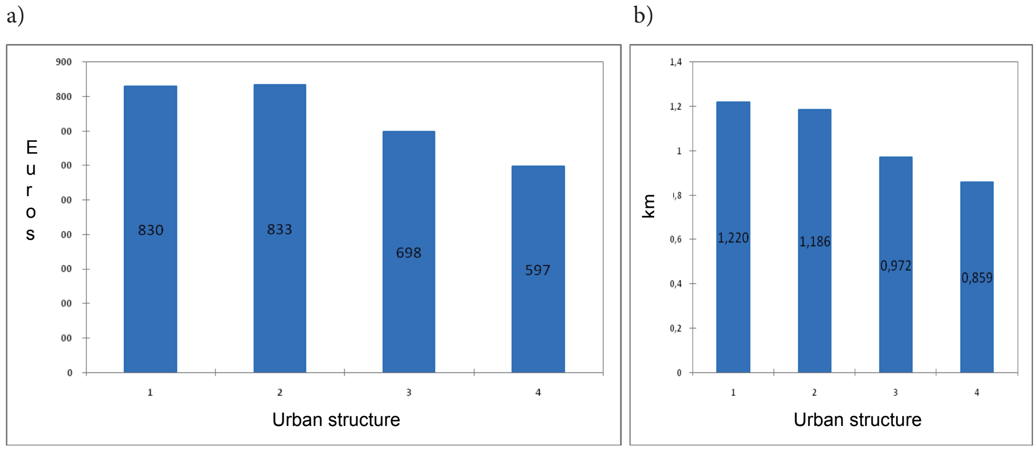

Figure 9: (a) Average expense (euros) of petrol for local travel by car and (b) minimal distance (km) to collective transportation system (bus, underground, tramway or train) in relation to urban structure (1: rural, 2: peri-urban, 3: suburbs, 4: inner city) for the dwellings in the cross-sectional database.

Table 5: Transportation figures in relation to building type (weighted) calculated on the basis of a petrol price of 1.14 Euros/l and conversion factors: 36777 kJ/l, 0.027778 Wh/kJ. *limit of density=98 inhab./km².

	Minimal distance to collective transportation system (km)	Expense for petrol dedicated to local travels (Euros)	Consumption (kWh)
Old houses <1975	2.7	892	7993
New flat >2000 in high density*	1.8	789	7069
New house> 2000 in low density	3.0	841	7540

- Refurbishment scenario: 75.85 MWh; energy savings compared to reference: 4.07 MWh,
- Demolition scenario: 70.69 MWh; energy savings compared to reference: 9.24 MWh.

In his study Maïzia (2010) shows that a "reduction of local mobility" scenario could leads to a daily car fuel consumption decreasing of 20 % compared to the current situation (reference year 2000). With, a cutting back of 11 % associated to the "demolition" scenario compared to the reference situation, our result appears conservative.

The additional gain of energy savings due to the reduction of transportation consumption, with the energy savings associated to the space heating end-use, helps to increase the profitability of the demolition scenario:

- Refurbishment scenario: total energy savings (heating, transportation): 65.41 MWh and the resulting CSE = 36 Euro/kWh.
- Demolition scenario: total energy savings (heating, transportation): 99.81 MWh and CSE = 23 Euro/kWh.

Impact of the number of new apartments built

The change in the number of apartments in the new multi-storey building slightly modifies the results. By increasing the number of flats, the demolition scenario presents a higher profitability:

- The CSE for the demolition scenario increase from 25 Euro/kWh to 22 Euro/kWh, respectively with 5 and 20 dwellings,
- The additional energy savings of the demolition scenario versus refurbishment increase from 31 % to 33 % respectively with 5 and 20 dwellings,

The sole figure which is largely modified by the number of chosen new flats is the cost difference between the scenarios. In case of few flats the demolition is costly than the refurbishment scenario (ca. +5 % with 5 apartments). When the number of flats increase, the demolition scenario is less expensive (-8 % with 20 apartments). A minimum of 8 flats appears to be necessary to have a positive difference between the two scenarios in favour of the demolition one.

Conclusion

The issue of demolition vs. refurbishment for the old houses in France was discussed on the basis of a regional study assuming that the driver for demolition is the property market, using the population density as the indicator of the market pressure. The main assumption is to consider that the availability of plot of land is negatively linked to urban density. This was revealed partly true as the piece of land's specific price is largely dependent on the regional population density in France.

Additionally, from a cross-sectional survey, we have shown that the energy efficiency and the energy consumption of building (both theoretical or observed), for space heating end-use, don't present a statistical correlation with the population density.

So, we conclude that the houses that are demolished for financial benefit purpose are located in dense area but they are not the poorest efficient one (i.e. with the highest space heating consumption). These two last points let us to draw a first conclusion about the lack of link between demolished houses and their energy efficiency. This implies to choose, in the prospective or forecasting scenarios, the average consumption of the building stock to be subtracted from the total space heating consumption when considering building demolition flow.

The cost benefit analysis of demolition of an old inefficient house (i.e; built before any thermal regulation) located in urban areas and replaced by a multi-family building was done on the basis of a cross-sectional enquiry with observed space heating consumption. A large difference of energy savings for space heating was demonstrated to the detriment of the "refurbishment and construction of new houses in rural area" scenario. However, a life cycle cost analysis (embodied energy) not included in this study could lead to different conclusion as presented by others studies.

At the opposite, a small difference of car fuel consumption for daily travels was assessed between the "refurbishment" or "demolition" scenarios. However, the trend is also in favour of the last one. To be conclusive, the co-benefit on transportation side lightly increase the difference between the two scenarios and further study appears to be necessary to well understand the behavior of household concerning the transportation dedicated to local travels.

A question that was not discussed in this paper is how to implement such hypothesis, "i.e. demolition preferred to refurbishment", without any social disruptiveness. The main question is how to have access to plot of land in urban area for the building of multi-dwelling unit. One way, could rely on the pre-emption right of houses for sale avoiding expropriation order of the households. When a house is to be sold after the departure of the household, the local authority have the right to buy it in detriment of other purchasers. Then, the local authority could sell by auction the plot of land to property developer in order to build a multi-storey building. This kind of urban planning policy has to be discussed at a local level depending of the specific urban and social structure in order to promote selective demolition.

This study remains, an exploratory works that have to be consolidated, but interesting results are presented showing that, under definite conditions, the demolition of an old buildings in urban areas is potentially interesting from an energy viewpoint. Finally, this study reveals the lack of cross-sectional data able to realise coupled studies on building energy consumption and transportation.

Glossary

CSE: Cost of Saved Energy (in Euro/kWh of final energy)
dw: dwelling
EPC: Energy Performance Certificate
GDP: Gross Domestic Product (in Euro)
Inhab. : inhabitant
LPG: Liquid Petroleum Gas
R^2: coefficient of determination

Reference

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Appendix A

Table A: regional data for the new buildings.

Region	average surface of plots of land (m²)	average price of plots of land (Euro)	average price of a new individual house (Euro)	average price of a new individual house (plots of land + building) (Euro)	average price of a new flat in a multi-storey building (Euro)
Alsace	838	81,592	189,801	271,393	202,168
Aquitaine	1516	62,118	131,326	193,444	203,775
Auvergne	1372	39,997	138,365	178,362	198,527
Basse-Normandie	1366	43,438	131,661	175,099	162,996
Bourgogne	1452	44,783	130,081	174,864	175,825
Bretagne	880	51,677	139,656	191,333	177,280
Centre	1138	49,157	121,488	170,645	177,660
Champagne-Ardenne	1166	45,750	133,168	178,918	197,208
Franche-Comté	1408	47,946	159,900	207,846	177,675
Haute-Normandie	1308	55,675	128,651	184,326	163,818
Ile-de-France	728	140,933	158,703	299,636	263,088
Languedoc-Rousillon	833	84,757	121,012	205,769	206,464
Limousin	1939	31,656	133,383	165,039	176,050
Lorraine	1072	52,989	157,207	210,196	175,930
Midi-Pyrénées	1563	56,872	128,500	185,372	188,604
Nord-Pas-de-Calais	1065	61,802	136,248	198,050	186,806
Pays de la Loire	928	50,478	130,967	181,445	191,808
Picardie	979	51,753	126,188	177,941	223,800
Poitou-Charentes	1294	38,517	122,101	160,618	148,470
Provence-Alpes-Côte-d'Azur	1222	134,894	162,865	297,759	258,553
Rhône-Alpes	1067	89,393	147,651	237,044	249,750

(source SoES)

Appendix B

Table B: regional data for the existing buildings.

Region	average price of old individual house (Euro)	Average surface SHAB (m²)	Cost of refurbishment (€)	Population (2007) (in thousand)	Density (inhab./ km²)
Alsace	220,200	119	42298	1,827	219
Aquitaine	202,400	124	44006	3,151	76
Auvergne	132,500	101	35929	1,339	51
Basse-Normandie	150,200	98	34678	1,461	83
Bourgogne	143,600	104	36898	1,634	52
Bretagne	166,900	104	36944	3,120	114
Centre	153,000	107	37815	2,527	64
Champagne-Ardenne	148,200	114	40590	1,339	52
Franche-Comté	152,600	112	39915	1,159	71
Haute-Normandie	167,000	101	36014	1,817	147
Ile-de-France	289,100	106	37729	11,599	960
Languedoc-Rousillon	198,800	100	35671	2,561	93
Limousin	112,500	107	38092	737	43
Lorraine	151,300	111	39260	2,340	99
Midi-Pyrénées	183,500	124	43939	2,811	61
Nord-Pas-de-Calais	157,800	102	36119	4,022	324
Pays de la Loire	167,200	109	38640	3,483	108
Picardie	159,800	97	34368	1,900	98
Poitou-Charentes	154,200	118	41870	1,740	67
Provence-Alpes-Côte-d'Azur	368,900	99	35312	4,864	153
Rhône-Alpes	244,800	113	40169	6,066	138

(source SoES)