FRENCH RESIDENTIAL ENERGY DEMAND :

MICRO-ECONOMETRIC ANALYSIS OF HOUSEHOLD MULTI-FUEL ENERGY CONSUMPTION

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Abstract:

In this paper, we explore patterns of French household energy consumption using the 2006 Enquête Logement, a disaggregate household level survey data set. Information on the physical characteristics of residential buildings and household socio-demographics is particularly rich. The residential sector is divided into 3 types: individual houses, privately owned units in collective residences, and public housing units in collective residences. We estimate a total energy demand equation of households for each housing type. The model incorporates a continuous/discrete decision framework which allows for interactions between decisions on the heating system (the discrete choice) and the consumption of energy (the continuous choice). The model parameters are estimated using a two-stage approach. In the first stage, decisions regarding heating systems are modelled with a multinomial probit model. Households are supposed to choose between three heating system modalities: (i) electricity v.s (ii) oil v.s (iii) natural gas when households live in individual houses or (i) electricity v.s (ii) individual natural gas heating v.s (iii) collective heating when household live in collective buildings. In the second stage, the demand for energy conditional on the chosen heating system then is estimated using a double least squares approach. Results show that the intensity of energy used per m² is almost completely determined by the technological properties of the dwelling and the climate. The part played by socio-demographic variables is particularly weak. This means that, in the short run, energy demand per m² is determined little by the household itself. The possibility for a given household to control its level of energy consumption per m² in a given dwelling is extremely weak in the absence of investment in the quality of the residence.

Keywords : energy consumption, continuous/discrete choice model, elasticity, French households

JEL classification : Q41, D12, R21

1. Introduction:

In France, there is a growing interest in reducing energy consumption and the associated CO^2 emissions in every sector of the economy. The residential sector accounts for approximately 13% of total carbon emissions (ANAH, 2008). To achieve a low carbon society, an in-depth understanding of energy consumption in this sector is needed to devise efficient energy policies. Such an understanding is only possible if household energy consumption is assessed by taking into account dwelling types (e.g. individual house/collective residential building, private property/public housing, owner occupied/leased unit). Paradoxically, the literature on energy demand in the French residential sector is not very extensive. To our knowledge, no study has addressed the question using a household level micro-data set. The main contribution of this paper is to estimate energy demand, price-elasticity and income-elasticity in the French housing sector at a micro-level.

We explore patterns of French household energy consumption using the 2006 *Enquête Logement*, a disaggregated, household–level survey data set representative of the French residential sector. It provides information on 36 955 households, including the amount of energy used by each over the last 12 months. For each household, it also describes the living space (dwelling type, surface area, insulation, presence of double-glazing…), heating system (type of energy used, collective or individual system), household information (number of persons living in the same residence, age of respondent, owner or tenant, income, profession…) and geographical information (climate category, rural or urban area). This information enables energy demand to be estimated while controlling for all of these characteristics.

A special feature of this study is the classification of the residential sector into 9 segments according to three modalities: (i) the type of dwelling (collective building or individual house), (ii) the type of fuel used in the heating system (electricity, oil, natural gas) and (iii) the type of control exercised by the household over the heating system (collective heating, individual heating). This last modality is rarely taken into account in the literature whereas it could have an impact on a household's level of energy consumption and ability to react to changes in energy prices.

The aim of this paper is to determine the main determinants of energy consumption in each residential sector category. To achieve this objective, we use a continuous/discrete model framework :

parameters are estimated using a two-stage approach. Specifically, the model estimates demand for energy conditional to the heating system, which is characterized by a multinomial probit model. We then explore which of the main determinants of energy demand, when manipulated, is most efficient at reducing energy consumption per m². Particularly, we investigate, by using nested models, the ability of household socio-demographic characteristics to explain energy consumption per m² compared to the technical properties of the dwelling and the climatic specificities of the surrounding area. In sum, we examine a household's capacity to reduce energy demand in a given dwelling with given technical properties.

2. <u>French housing characteristics</u>

2.1. Main features of the French housing sector

The data set that we used is supposed to be representative of the entire French residential sector; we briefly present some of the sector's main characteristics in Table 1.

In France, the residential sector may be divided into two main types: individual houses and collective residential buildings. The latter may be divided further into privately owned units and subsidized public housing. Individual houses account for 56% of all dwellings. In collective residential buildings, it is interesting to note that one third of the units are public housing.

Housing buildings in France are quite old, despite the "building boom" that followed WWII, with nearly one third built before 1948. However, collective buildings tend to be of more recent construction, with 60% built in the forty year period between 1949 and 1989. In terms of ownership, 80% of individual houses are owner-occupied compared to only 27% of the units in collective buildings. Unsurprisingly, individual houses are significantly larger than collective building units (111 m² *versus* 65 m2).

Globally, nearly 90% of French dwellings are heated with one of the three main fuels: electricity (31%), natural gas (38%), and fuel oil (20%). However, as shown in Table 1, the fuel used differs sharply according to the dwelling type. For individual houses, 35% of households use an electric heater, 31% a natural gas heater, and 25% an oil heater. For collective residential buildings, the distribution can be broken down further between privately owned and public housing units. First, a larger portion of households living in public housing have a collective rather than an individual heating system (59%

versus 35%). Electric heaters consequently are found more often in private dwellings than in public housing (37% *versus* 14%). Most households living in public housing heat with a natural gas system.

Table 1 - French dwelling characteristics

	Individual housing	Collective housing			Total
		Public	Private	Total	
Construction period					
Before 1948	**34.80%**	7.22 %	33.95%	**25.08%**	**30.55%**
Between 1949 and 1974	**22.27%**	54.79%	34.44%	**41.20%**	**30.54%**
Between 1975 and 1989	**24.53%**	24.70%	15.69%	**18.68%**	**21.97%**
Between 1990 and 2006	**18.40%**	13.28%	15.92%	**15.05%**	**16.93%**
Total	***100%***	*100%*	*100%*	***100%***	***100%***
Household occupancy statute					
Owner	**80.51%**	0%	40.70%	**27.20%**	**57.20%**
Tenant	**16.50%**	100%	52.76%	**68.44%**	**39.21%**
Free housing	**2.92%**	0%	6.53%	**4.36%**	**3.55%**
Tenant famer	**0.07%**	0%	0%	**0%**	**0.04%**
Total	***100%***	*100%*	*100%*	***100%***	***100%***
Others housing characteristics					
Dwelling area (m²)	**111.96 m²**	67.37 m²	65.04 m²	**65.81 m²**	**91.79 m²**
Double glazing	**71.82%**	79.43%	59.69%	**66.24%**	**69.38%**
Heating system:					
Collective heating	**0.38%**	59.34%	35.80%	**43.61%**	**19.28%**
Mixed heating (collective + individual)	**0.02%**	2.45%	1.34%	**1.70%**	**0.76%**
Individual heating	**99.60%**	38.21%	62.86%	**54.68%**	**79.96%**
Total	***100%***	*100%*	*100%*	***100%***	***100%***
Heating energy*:					
Electricity	**35.56%**	14.74%	37.64%	**30.04%**	**31.46%**
Natural gas	**31.52%**	57.33%	42.63%	**47.51%**	**38.51%**
Fuel oil	**24.82%**	14.70%	13.30%	**13.77%**	**19.99%**
Liquefied Petroleum Gas	**4.12%**	0.60%	0.46%	**0.51%**	**2.54%**
Wood and/or coal	**7.81%**	0.92%	0.62%	**0.72%**	**4.71%**
Others	**2.05%**	12.84%	5.75%	**8.10%**	**4.70%**
Individual heating:					
Electricity	**32.56%**	11.66%	36.19%	**28.05%**	**30.59%**
Natural gas	**31.43%**	26.10%	24.06%	**24.74%**	**28.50%**
Fuel oil	**24.71%**	≈ 0%	1.21%	**0.83%**	**14.27%**
Collective heating:					
Electricity	**≈ 0%**	1.28%	0.78%	**0.95%**	**0.42%**
Natural gas	**≈ 0%**	30.89%	18.26%	**22.45%**	**9.87%**
Fuel oil	**0.11%**	14.54%	11.74%	**12.67%**	**5.60%**
Total Number	**14 790 132**	3 813 117	7 676 570	**11 489 687**	**26 279 819**
%	**56.28%**	14.51%	29.21%	**43.72%**	

Source: Enquête logement 2006 INSEE – Results for the France

Note: *Percentages are higher than 100% as some household use several kinds of fuels for their heater. The "others" category mainly includes urban heating and geothermic system.

2.2. Energy expenditures and final energy demand

As the aim of this paper is to estimate the final energy demand, we have to consider the energy expenditures of each household by type of fuel and calculate their actual fuel consumption in kWh/m². The *2006 Enquête logement* provides information on energy expenditures by type of fuel: natural gas, electricity, oil, wood, district service, coal. Fifteen percent of households rely exclusively on electricity, while 85%

of households use at least two types of fuels. As nearly 90% of households use oil, electricity or natural gas, we focused our analysis on these three fuel types. Households which mainly use wood, coal or a district service to heat therefore were excluded.

As shown in Table 1, the distribution of heating systems is significantly different in the three housing categories (individual, collective public housing, and collective private housing). We consequently chose to study the process by which households chose their heating system separately from the effect of the system on energy demand. Crossing the category of dwelling with the type of heating system, we obtained 9 different segments.

Table 2 – Weights of different segments

Category of housing	Segment by type of heating system	Weight in the total sector*	Weight in the category of dwelling
Individual house	1. Electricity heating	21.54%	38.17%
	2. Natural gas heating	18.50%	32.79%
	3. Fuel oil heating	16.38%	29.04%
	Total	*56.42%*	*100%*
Collective public housing	4. Individual electricity heating	1.62%	12.23%
	5. Individual natural gas heating	2.96%	22.36%
	6. Collective natural gas heating (natural gas or fuel oil)	8.67%	65.41%
	Total	*13.25%*	*100%*
Collective private housing	7. Individual electricity heating	13.45%	44.34%
	8. Individual natural gas heating	7.96%	26.27%
	9.Collective heating (natural gas or fuel oil)	8.91%	29.39%
	Total	*30.33%*	*100%*
Total		100%	

Note 1: *the total considered does not include households who do not use one of these three types of fuels for their heating system.
Note 2: * weights are applied to keep the sample representative.

Fuel prices in 2006, depending on the type of housing and the type of heat, were obtained from the *Ministère de l'économie, des finances et de l'industrie* (Pegase Data set). The combination of fuel expenditures in euros and their unit price by kW/h allowed us to calculate household consumption by type of fuel.

This step of the work was particularly delicate and led us to eliminate a significant part of the sample, particularly households using collective heating systems. About 44% of such households are totally unable to declare their actual energy expenditures in the survey because the energy bill is combined and paid with other shared charges (expenditures for the lift, cleaning of common space, gardening, etc…). This is an interesting result *per se* as we can thereby deduce that about 7% of French households cannot properly react to any kind of price-signal because they do not perceive the real cost of their fuel use. In the rest of the paper, our sample is composed of 20 301 dwellings.

Table 3 presents the total energy consumption by type of heating system (in kWh/m²). We estimate that final energy demand is significantly higher for individual houses than for collective housing: 201 kW/h/m² per year for individual houses *versus* 183 kW/h/m² for collective public housing units and 176 kW/h/m² for collective private housing units. These results are in the range of what commonly is calculated in the French residential sector (ANAH, 2008).

It is noteworthy that households equipped with an electric heater consume significantly less energy compared to those heating with other fuels. The difference in energy consumption per m² between users of electric and oil heating is particularly sharp in households living in an individual house. This result already has been demonstrated by Nesbakken (1999) in a study in Norway. Households which only have electric heaters use far less energy than households using other heating systems.

Table 3 - Final energy consumption for individual and collective housing:

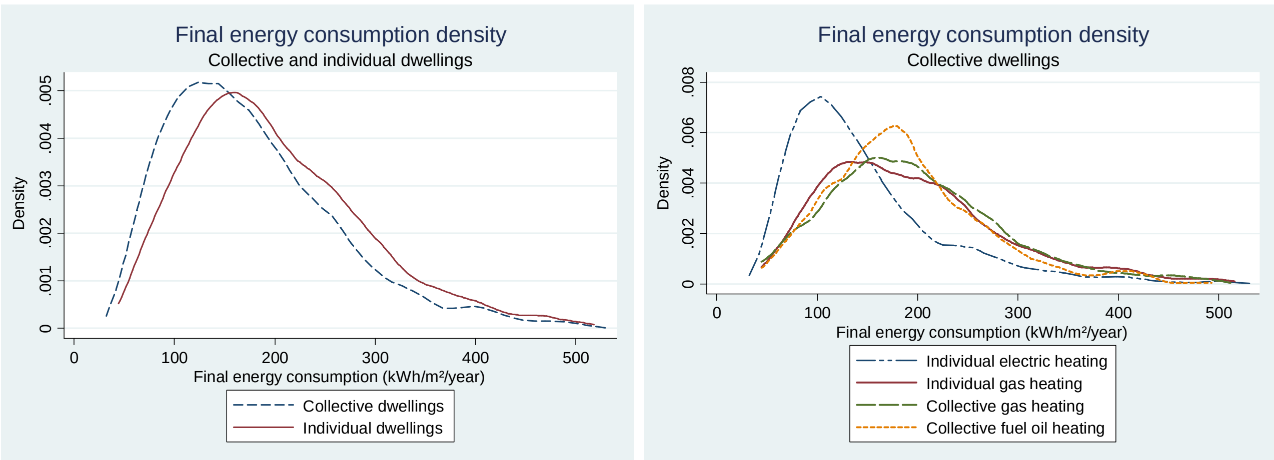
	Individual housing		**Collective housing**			
			Public		**Private**	
	Mean	SD	Mean	SD	Mean	SD
Energy expenditure (euros/m², all energies taken together)	15.21	5.67	13.95	5.32	14.86	6.37
Final energy consumption (kWh/m², all energies taken together)						
Owners	203.22	89.42	-	-	178.42	84.02
Tenants	189.79	87.72	183.18	86.88	173.19	86.87
Total	**200.97**	**89.42**	**183.18**	**86.89**	**176.16**	**85.42**
Final energy consumption by heating system (kWh/m²):						
Individual heating:						
Electricity	158.27	74.51	132.82	70.10	149.69	78.97
Natural gas	216.58	84.27	194.20	91.05	194.87	88.56
Fuel	239.48	89.85	-	-	-	-
Total	**200.97**	**89.42**	**172.49**	**89.19**	**166.50**	**85.49**
Collective heating:						
Electricity	-	-	-	-	-	-
Natural gas	-	-	192.14	87.40	204.53	85.13
Fuel	-	-	181. 49	79.86	191.66	72.91
Total	-	-	**188.83**	**85.13**	**199.39**	**80.67**
Number of observations	11 731		3 097		5 473	

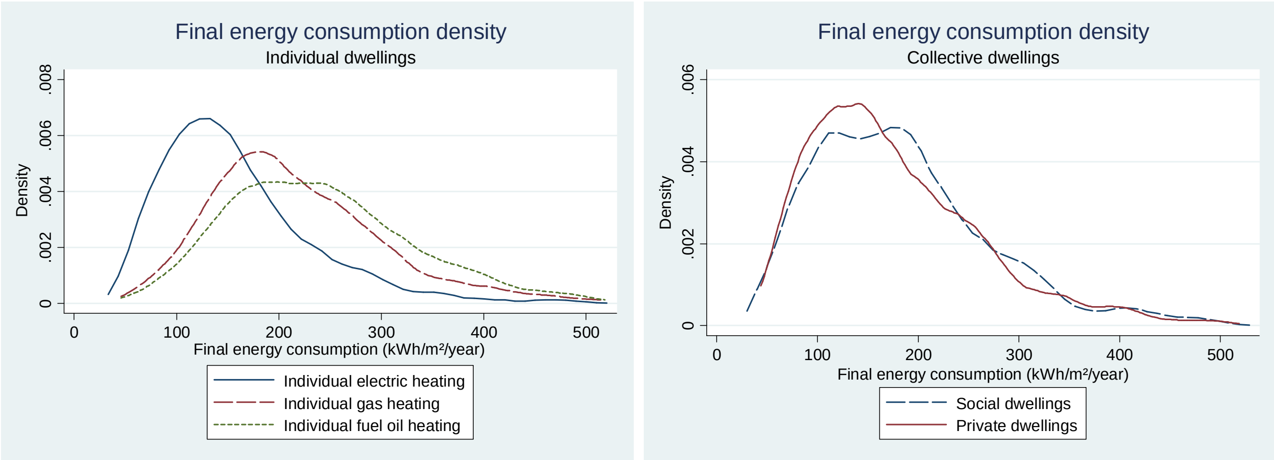
Source: Enquête logement 2006 INSEE

Interestingly, in collective dwellings, households using a collective heating system register a significantly higher energy consumption on average than those using an individual heating system. This result is explained both by the higher level of energy used when the energy is a public good (the incitation to reduce consumption is weak) and the difference of energy type used. Household that use individual systems often heat their dwellings with an electrical heater, which generally is associated with significantly lower consumption. However, when one considers natural gas, the energy demand of households equipped with a collective heating system is not significantly higher than that of households equipped with an individual meter.

Finally, it is noteworthy that, on average, we do not register a large difference of consumption between households living in collective public housing units and those living in collective private housing despite large differences in terms of heating systems. For instance, 71% of households in the private sector have an individual heater *versus* 35% in the social sector. Yet with the exception of households equipped with electric heaters, the consumption per m² of households living in private units is broadly the same as that of households living in public housing.

Figure 1 : Final energy consumption density, by type of dwellings.





source : author's calculations. Enquête Logement 2006.

3. Discrete-continuous choice model of energy demand: literature and methodology

3.1. Literature

Techniques used to model residential energy consumption can be grouped broadly into two main categories: ''top-down'' and ''bottom-up'' models. The top-down approach considers the residential sector as a whole and does not distinguish energy consumption due to individual end-uses. The bottom-up approach includes all models which use input data. A precise review of these techniques can be found in Swan and Ugursal (2009) and Zagamé (2008).

Within the bottom-up approach, there are three general methodological frameworks employed to model residential energy demand (Newell and Pizer, 2008). The first is a standard OLS or generalized least squares (GLS) methodology that estimates energy consumption by taking into account its main determinants (e.g. energy prices, household income, climate, house structure and type of insulation, appliance stock variables, etc…). The weakness of this approach is that it fails to address the issue of fuel choice and appliances stock (Branch, 1993).

The second estimates an energy demand equation and an appliance stock equation simultaneously (Garbacz, 1984a, 1984b) to address endogeneity in appliance stock. These equations are generally estimated using two-stage least squares.

The third category uses a multiple-stages model involving both discrete and continuous choice analysis (Dubin and McFadden, 1984; Baker and Blundell, 1991; Bernard et al., 1996; Nesbakken, 1999; Vaage, 2000; Nesbakken, 2001; Newell and Pizer, 2008). This approach is based on a framework in which energy provides utility not directly but indirectly through the use of a stock of appliances (common appliances such as refrigerators, lighting, but also cooling and heating system of space and water). Due to this dependency on appliance use, elasticities should not be estimated exclusively on the basis of one energy equation, but also on the choice of fuels for heating, cooling, and the stock of other appliances. This model category differs from the second approach because the models are sequential.

Most literature using discrete-continuous models have focused on the impact of price and income on energy consumption. Table 4 compares the results of studies which used disaggregate cross-sectional data and discrete and continuous models.

On one hand, in most studies, income-elasticity is estimated to be very low at less than 0.14. Energy consumption is a normal good, but remains weakly responsive to an increase of income.

On the other hand, there is a considerable variation in estimates of energy price elasticities, ranging from –0.26 to –1.14 for own-price elasticity of electricity, and from –0.04 to –1.6 for own-price elasticity of natural gas. The own-price elasticity of fuel oil has rarely been estimated: the estimate obtained by Newell and Pizer (2008) in the commercial sector is particularly high, reaching -2.95.

Table 4 : Estimates of income elasticities and price elasticities for energy consumption in the literature using discrete-continuous models and micro data.

	Price elasticity	Income elasticity
Bernard, J. T., D. Bolduc and D. Bélanger (1996). Quebec residential demand for electricity. Discrete-continuous choice model (heating equipment), from IV-method. Short-run results.		
Own-price elasticity of electricity	-0.67	0.14
Cross-price elasticities of: Oil	0.04	
Gas	0.08	
Dubin, J. A. and D. L. McFadden (1984). USA. Discrete-continuous choice model (heating equipment). Elasticities of household electricity demand, including portfolio shift.		
Own-price elasticity of electricity	-0.26	0.02
Cross-price elasticity of gas	0.39	
Halvorsen B. and B.M. Larsen (2001). Norway. Longitudinal approach. Analysis of flexibility of household electricity demand over time. Discrete-continuous choice model (main appliances). Norway Survey of Consumer Expenditure. 1974-1994.	-0.43	
Short run electricity elasticity	-0.44	
Long run electricity elasticity		
Labandeira X., Labeaga J. M., and M. Rodriguez (2006). Spain, household micro-data. Demand model for a simultaneous analysis of energy goods, IV-method. Results from whole sample, uncompensated own-price elasticities of:		
electricity	-0.79	-
natural gas	-0.04	
LPG	-0.36	
Nesbakken R. (2001). Norwegian micro-data. Simultaneous discrete-continuous choice model (heating equipment). Short-run results.	-0.21	0.06
Nesbakken R. (1999). Norway. Simultaneous discrete-continuous choice model (heating equipment). Short run results, from pooled data 1993-95.	-0.50	0.01
Newell R. G. and W. A. Pizer (2008). US commercial sector. Discrete-continuous choice of multi-fuel energy demand. Long-run results, from a detailed model then aggregated with fuel choice variable.		
Own-price elasticities of: electricity	-1.14	-
natural gas	-1.60	
fuel oil	-2.95	
district services	-0.88	
Vaage K. (2000). Norway. Household's energy demand estimated with a discrete-continuous choice model (heating equipment). Long-run results, from a reduced model.	-1.24	-

3.2. *Model*

Our approach belongs to the category of discrete–continuous choice models (Heckman et Robb, 1985). The first decision involved in energy consumption is generally the choice of energy appliances. Due to data limitations in *2006 Enquête Logement*, we can only examine in this study heating system choices. However, given the considerable weight of heating expenditures in French households' total residential energy expenditures, which was assessed at about 70% of total energy consumption by INSEE, one may consider that this constraint is not too restrictive.

In France, in the collective housing sector (private and public), households have to choose between three mutually exclusive modalities for their heating system:

- collective heating system with gas or fuel

- individual system with electricity
- individual system with gas

In the individual housing sector, all houses have an individual heating system, thus households have to choose between three types of fuel for their main heating system:

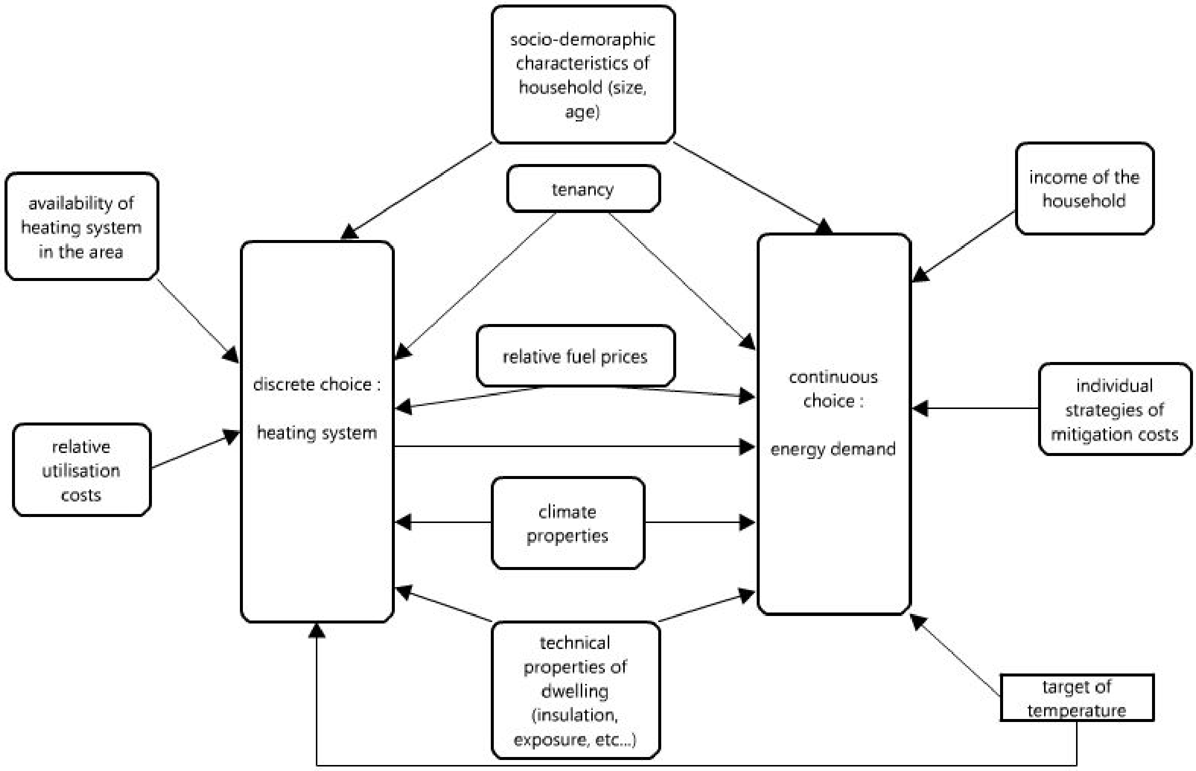
- natural gas
- electricity
- oil

Conditional on this choice, a household then decides how much energy to consume. Since these decisions are related, the two choices must be modeled jointly to avoid biased and inconsistent parameter estimates.

In the first stage of our model, decisions regarding space heating systems are modeled with a multinomial probit. This is the "heating system choice". In the second stage, demand for energy (the logarithm of the consumption in kW/h/m² per year) conditional on the chosen heating system then is estimated using a double least squares model to treat the possible endogeneity of energy price. This is the "energy demand choice". Finally, the model captures the possibility of correlation between unobservable variables in the discrete and the continuous stages[1]. The main determinants used in our model are presented in Chart 1.

[1] A correction bootstrap is applied in the second step to eliminate a potential estimation bias due to this methodology in two steps (Murphy et Topel, 1985).

Chart 1: Main determinants of heating system choice and energy demand included in the model.



The decision to use a discrete-continuous model was based on the hypothesis that there is a relationship between a heating technology and the intensity of use of the technology. Our model includes variables which are supposed to explain both choices, such as some particular properties of dwelling (exposure, vintage, dwelling size), relative fuel prices, and type of tenancy. We assume that the relative utilization cost of the heating system (which includes fixed costs such as subscription and working costs) and the availability of the type of fuel in the area explain the discrete choice but do not explain the level of utilization of the equipment. The energy demand itself is explained by building properties, such as the level of insulation, some socio-demographic variables, such as household size, the income per unit of consumption, the climate, and a household's cost mitigation strategies.

3.3. Description of data and variables

The variables collected in the *Enquête-Logement 2006* can be organized into the five main categories described in Table 5: (1) technical properties of the dwelling, (2) climate areas (France is divided into 7 different climate areas, see Map in appendix), (3) socio-demographic variables of the household, (4) average price of energy depending on fuels used by the household, (5) heating system. The influence of a household's preferences or habits such as room temperature, restricted heated space, airing, and strategies of mitigation costs are not observed and their influence could not be measured in the following regressions.

Table 5: Variables description

Explained variables	Name of Vector	Description
Energy consumption (by m²)		Final energy consumption in kwh par m², for all types of fuels (natural gas, electricity and fuel)
1. Technical properties of dwelling		
Individual house type	**DW**	Dummies: gathered houses, semi detached houses, detached houses
Collective dwelling characteristics		Number of dwellings in block of flats; floor
Size		Dwelling size in m²;
Specificities		Dummies: roof<3m, professional room in the dwelling; veranda, damp, cellar not converted, attic, swimming pool
Construction date (vintage)		Dummies: Before 1948; between 1949 and 1974; between 1975 and 1989; between 1990 and 2005
Insulation characteristics		Dummies: double glazing, recent roof insulation, sufficient roof insulation, insufficient roof insulation, nonexistent roof insulation
Exposure (according to households)		Dummies: poor exposure, medium exposure, good exposure
Location		Dummies: downtown, suburb, rural town.
2. Climate Areas	**CL**	Dummies: mountain climate, semi continental climate, cooler oceanic climate, mixed oceanic climate, oceanic climate, mild oceanic climate, mediterranean climate
3. Heating system	**HS**	Dummies: collective heating system with gas or fuel, individual system with electricity, individual system with gas, individual system with fuel
4. Price of energy	**PE**	*Fuel prices* considered for each household are those that would have been applied if households had chosen this fuel. Price of kW/h is 0.0645 € for oil, 0.0594 € on average for natural gas, and 0.1005 € on average for electricity. In France, fuel price for each household is conditional on its stock of appliances and heating system. *Average energy price*: weighted average of different fuel prices; weights depending on the specific mix of fuels used by each household.
5. Socio-demographic variables of the household	**SDH**	
Demographic characteristics		Nb of persons in the dwelling, age of household member answering the questions in the survey
Occupancy statute		Dummies: own, renter, social-rent, private rent, free housed
Educational level of household member answering the questionnaire		Dummies: without certificate, less than baccalaureate, baccalaureate, more than baccalaureate.
Income		Monthly income per consumption unit

4. Main determinants of energy demand in individual houses and in collective housing

The sample was divided into three main categories: individual houses, collective private housing and collective public housing. In this section, we focus on the second step of our model: continuous choice. To predict the probability of each modality, we use the results obtained in the first step (the discrete choice probit multinomial model, details of which are in the Appendix). Briefly, our estimates show that electric heat is mainly chosen by dwellings and houses built after 1975 that are equipped with double glazing; these dwelling are relatively small, mainly located in rural areas and often occupied by tenants rather than their owners. Natural gas heating generally is found in town in rather large, semi-detached houses built between 1949 and 1975 that rarely are equipped with double-glazing and are owner-occupied. Fuel heating mainly is found in large detached houses in rural areas that were built before 1974, rarely are equipped with double-glazing, and are occupied by their owner.

4.1. Process of estimations in the second step

We try to explore both the main determinants of energy demand per m² and the main contribution of each variable category to explain energy consumption per m². Particularly, we want to compare the ability of a household's socio-demographic characteristics (**SDH**) and the energy price (**P**) to explain energy consumption per m² with those of the technical properties of the dwelling (**DW**), heating system **(HS**), and climatic specificities of the area (**CL**).

In order to achieve this goal, four models were tested to compare the prediction power of the five different categories of variables (F-Test) and the goodness of the fit of the reduced model (Adjusted R squared).

(i) *Complete model:* logarithm of energy consumption per m² in the dwelling i and in the type *k* explained by technical properties of dwelling (**DW**), climatic areas (**CL**), predicted heating system ($\hat{\mathbf{HS}}$), Price of energy used (**P**), household socio-demographic characteristics (**SDH**)

$$\ln(C_{i,k}) = \beta_o + \beta_1 \mathbf{DW}_{i,k} + \beta_2 \mathbf{CL}_{i,k} + \beta_3 \hat{\mathbf{HS}}_{i,k} + \beta_4 \mathbf{P}_{i,k} + \beta_5 \mathbf{SDH}_{i,k} + \varepsilon_{i,k}$$

(ii) *technological model*: reduced model, consumption explained by characteristics of building (**DW**), heating system (**HS**) and climate dummies (**CL**)

$$\ln(C_{i,k}) = \beta_o + \beta_1 \mathbf{DW}_{i,k} + \beta_2 \mathbf{CL}_{i,k} + \beta_3 \hat{\mathbf{HS}}_{i,k} + \varepsilon_{i,k}$$

(iii) *eco-technological model*: reduced model, technological model including the average price (**P**)

$$\ln(C_{i,k}) = \beta_o + \beta_1 \mathbf{DW}_{i,k} + \beta_2 \mathbf{CL}_{i,k} + \beta_3 \hat{\mathbf{HS}}_{i,k} + \beta_4 \mathbf{P}_{i,k} + \varepsilon_{i,k}$$

(iv) *socio-demographic model*: reduced model, consumption explained by the household characteristics only (**SDH**)

$$\ln(C_{i,k}) = \beta_o + \beta_5 \mathbf{SDH}_{i,k} + \varepsilon_{i,k}$$

These four different models (reduced and complete) were estimated on the three different residence types. Results are presented in the tables that follow.

4.2. Main determinants of energy demand in individual houses: results

Table 6a shows that about 35% of variance is explained by the complete model. Nineteen percent of variance is explained by technical properties of the house, the type of heating system and the climatic characteristics of its area (model ii). Substantially higher R^2 were obtained by adding the average energy price (model iii) in order to explain the level of energy consumption per m². It is striking to observe how the socio-demographic model (iv) registers a low R^2, emphasizing that the influence of socio-economic factors on energy consumption is weak compared to that of building features and climate. Only 2% of the variance could be explained by the sole observed socio-demographic characteristics of the household.

Table 6a: Comparison of goodness of fit of different models. Variable to explain: consumption per m² (in ln) in individual houses. F-test and Adjusted R-squared

Variables included	Complete model (i)	Technologic model (ii)	Economic and technologic model (iii)	Socio-demographic model (iv)
Group 1: Technical properties of dwelling **DW**	F: 90.78***	F: 66.39***	F: 80.08***	-
Group 2: climatic dummies **CL**	F: 62.35***	F: 56.36***	F: 61.77***	-
Group 3: heating system **HS**	F: 14.96***	F: 52.00***	F: 33.29***	-
Group 4: price of energy **P**	F: 439.51***	-	F: 422.99***	-
Group 5: socio-demographic variables **SDH**	F: 13.42***	-	-	F: 33.66***
Adj R-squared	0.3543	0.1991	0.3273	0.0271
observations	11731	11737	11737	11737

Note: the complete list of each group of variables is shown in Table 4.

Table 6b shows the detailed results for the complete model. It appears that among the technical properties of an individual house, the factors that significantly increase the level of consumption per m² include being a detached house rather than an attached one, being built between 1949 and 1974 rather than before 1948, having a swimming-pool, a professional room, a cellar or an unconverted attic. In contrast, the factors that decrease the level of consumption per m² include being a large house or one with few rooms. The quality of roof insulation decreases the level of consumption per m², but surprisingly double-glazing has no impact, *ceteris paribus*. This surprising result may be due to the "rebound effect", which holds that investment in a new technology such as double-glazing could entail a change in household behavior (increase of temperature target, for instance) which offsets the beneficial effects of the technology. It could be interesting to corroborate this interpretation with further research.

Climate dummies conformed to expectation. *Ceteris paribus*, the level of consumption per m² is lower in a house heated by electricity than in a house heated by fuel oil. However, there is no significant difference in consumption per m² between a dwelling heated by natural gas and one heated by electricity. Energy-elasticity is equal to -0.47, which is in the range of estimates reported in Table 4. With cross-section data, this means that households facing higher average energy prices demand less energy than others.

Income-elasticity is particularly low (0.02), which is similar to the average estimates obtained in other studies using micro-data on households (see Table 4). Among socio-demographic characteristics, the age of the head of household and the number of persons living in the dwelling increase the intensity of energy used per m². Owners have a higher level of energy consumption compared to tenants. Education level is not significant.

Table 6b: Estimates of household energy consumption per m² in a year: Individual dwellings[2]

Double least-squared. Explained variable: household energy consumption per m² a year (in logarithm)			
Explanatory factors	Coeff.	Bootstrap correction Student t	
1. Technical properties of dwelling			
House type			
attached_houses	ref		
semi_detached_houses	-0.0050	-0.43	
detached_houses	0.0760	6.93	***
Dwelling area			
ln_dwelling_area (m²)	-0.4995	-27.40	***
Specificities			
roof_less_3meters	-0.0288	-1.96	*
professional_room	0.0494	2.07	**
veranda	0.0161	1.29	
damp	-0.0021	-0.21	
cellar_not_converted	0.0557	5.38	***
attic	0.0306	4.06	***
swimming_pool	0.1432	9.59	***
Dwelling construction period			
construction_before48	ref		
construction49_74	0.0482	2.63	***
construction75_89	-0.0147	-0.50	
construction90_05	-0.0167	-0.25	
Insulation characteristics			
recent_roof_insulation	-0.0668	-3.44	***
adequate_roof_insulation	-0.0222	-1.25	
inadequate_roof_insulation	-0.0106	-0.56	
nonexistent_roof_insulation	ref		
recent_roof_insulation*construction75_89	0.0374	1.31	
recent_roof_insulation*construction90_05	-0.0621	-1.54	
adequate_roof_insulation*construction75_89	-0.0326	-1.44	
adequate_roof_insulation*construction90_05	-0.0349	-0.84	
double_glazing	-0.0259	-1.64	
double_glazing*construction49_74	-0.0306	-1.46	
double_glazing*construction75_89	-0.0438	-1.83	*
double_glazing*construction90_05	-0.0708	-1.15	
Dwelling exposure (according to households)			
poor_exposure	ref		
medium_exposure	-0.0140	-0.50	
good_exposure	-0.0142	-0.53	
2. Climatic areas			
mountain_climate	ref		
semi_continental_climate	0.0501	2.57	**
mild_oceanic_climate	-0.0411	-2.19	**
Mixed oceanic_climate_	0.0134	0.73	
oceanic_climate	-0.1621	-9.26	***
cooler_oceanic_climate	-0.1217	-6.03	***
mediterranean_climate	-0.1331	-6.72	***
3. Heating type			
predicted probability to choose an electric heating	ref		
predicted probability to choose an gas heating	0.0512	1.18	
predicted probability to choose a fuel oil heating	0.2563	4.20	***
4. Energy price			
average energy price	-0.4774	-21.79	***
5. Households socio-demographic characteristics			
Households demographic characteristics			
ln_nb_persons	0.4450	4.40	***
ln_age_ ref_person (age of household member answering the questions in the survey)	0.1950	7.04	***
ln_nb_persons*ln_age_ ref_person	-0.0682	-2.67	***
Household occupancy statute			
ownership	ref		
public_rent	-0.0384	-2.33	**
private_rent	-0.0527	-3.34	***
free_housed	-0.0634	-2.36	**
Educational level of household member answering the questions in the survey			
without_certificate	ref		
brevet_diploma or vocational_training_qualification	.0062	0.57	
baccalaureat	0.0016	0.11	
baccalaureat+2 years or more	-0.0042	-0.34	
Income			
annual_income_per_consumption_unit	0.0245	3.58	***
constant	7.2807	47.47	***
Number of observations	11731		
R^2	0.3568		

Note: *** Significant at 1 per cent. ** Significant at 5 per cent. * Significant at 10 per cent.

4.3. Main determinants of energy demand in collective housing units: results

Table 7a and 7b present estimations of logarithm of energy consumption per m² in collective housing, separating results for private and public housing units. Table 7a shows once again that consumption per m² in collective units is determined strongly by technical and climate properties of the dwelling, as in individual houses. Income and household socio-demographic characteristics only play a small part in explaining the variance (about 6% in the private sector 1% in the social sector). Once again, it appears that energy demand is almost completely determined by technology and climate. Without major investments in building characteristics, households cannot modulate their energy bill.

Table 7a: Comparison of goodness of fit of different models. Variable to explain : consumption by m² (in ln) in collective dwellings F-test and Adjusted R-squared.

Variables included	Complete model (i)	Technological model (ii)	Economic and technological model (iii)	Socio-demographic model (vi)
Privately owned units in collective buildings				
Group 1: Technical properties of dwelling **DW**	31.21***	64.56***	76.24***	-
Group 2: climate dummies **CL**	21.83***	31.60***	35.69***	-
Group 3: heating system **HS**	4.78***	9.62***	2.14ns	-
Group 4: price of energy **P**	498.17***	-	481.16***	-
Group 5: socio-demographic variables **SDH**	39.66***	-	-	52.02***
Adj R-squared	0.3575	0.2042	0.3214	0.0613
Observations	5 473	5 473	5 473	5 473
Public housing in collective buildings				
Group 1: Technical properties of dwelling **DW**	26.77***	12.95***	16.86***	-
Group 2: climate dummies **CL**	15.31***	13.54***	16.46***	-
Group 3: heating system **HS**	0.89ns	6.42***	4.23**	-
Group 4: price of energy **P**	64.87***	-	40.80***	-
Group 5: socio-demographic variables **SDH**	30.54***	-		8.76***
Adj R-squared	0.2969	0.1030	0.2444	0.0148
Observations	3 097	3 097	3 097	3 097

Table 7b shows the detailed results for the complete model. It appears that among the technical properties of a unit, the larger the collective building, the higher the unit in the building, the better the exposure, the more recent the construction (built after 1990), the lower is the consumption per m². Similar to individual houses, the size of the flat has a negative impact on consumption. Double-glazing has no impact in the social sector whereas its impact is ambiguous in the private sector. Among climate dummies, the level of consumption is found to be lower only in the oceanic climate. *Ceteris paribus*, in the private housing sector, there is a strong effect of collective heating on energy consumption. Dwellings equipped with a central heater (either natural gas or oil) have a significantly higher consumption than those equipped with an individual heater (either natural gas or electricity). This effect is not significant in the public housing sector.

Results show that price-elasticity is significantly higher in the collective dwelling than in the individual dwelling category (0.71-0.78 *v.s.* 0.47). This means that households are responsive to the price of energy. A household whose average energy price is 1% higher than that of another will demand less energy per m², *ceteris paribus*. On this topic, there is almost no difference between the public and private sector. Income elasticity is not significant in collective dwellings, neither in the public housing category, nor in the private one. In the private sector, older households demand more energy per m² than younger ones. Education also changes demand: more educated people demand less energy than less educated ones.

Table 7b: Estimates of household energy consumption by m² in a year: collective housing

Linear regression for collective dwellings. Continuous choice. Double least Squared. Explained variable: Household energy consumption by m² a year (in logarithm)						
	Collective private housing			Collective public housing		
Explanatory factors	Coefficient	Student t		Coefficient	Student t	
1.Technical properties of the housing unit						
Collective dwelling characteristics						
nb of dwellings in collective blocks of flats (ln)	-0.0338	-4.14	***	-0.0220	-1.63	
floor (ln)	-0.0544	-5.06	***	-0.0794	-4.06	***
Dwelling area						
ln_dwelling_area (m²)	-0.4550	-10.97	***	-0.5650	-16.98	***
Specificities						
roof_less_3meters	0.0302	1.27		0.0184	0.27	
veranda	0.0168	0.41		0.0287	0.59	
damp	0.0221	1.60		0.0612	3.54	***
Dwelling construction period						
construction_before48	ref			ref		
construction49_74	-0.0449	-1.36		-0.1328	-1.19	
construction75_89	-0.0513	-1.61		-0.0895	-1.24	
construction90_05	-0.2297	-2.76	***	-0.2087	-1.98	**
Insulation characteristics						
double_glazing	-0.0611	-2.77	***	-0.0355	-0.49	
double_glazing*construction49_74	0.0796	2.75	***	0.0139	0.19	
double_glazing*construction75_89	0.0063	0.16		0.0065	0.08	
double_glazing*construction90_05	0.1444	1.74	*	0.0534	0.48	
Dwelling exposure (according to households)						
poor_exposure	ref			ref		
medium_exposure	-0.0294	-1.18		-0.0729	-2.00	**
good_exposure	-0.0334	-1.41		-0.0551	-1.68	*
2. Climatic areas						
mountain_climate	ref			ref		
semi_continental_climate	0.1093	2.73	***	0.0569	1.16	
cooler_oceanic_climate	-0.0564	-1.31		-0.0002	-0.00	
Mixed oceanic_climate_	0.0633	1.84	*	0.0157	0.36	
oceanic_climate	-0.1692	-4.63	***	-0.2066	-4.64	***
mild_oceanic_climate	-0.0206	-0.54		-0.0630	-1.26	
mediterranean_climate	-0.0393	-1.03		-0.0406	-0.80	
3. Heating system choice						
predicted probability to choose an individual electric heating	ref			ref		
predicted probability to choose an individual gas heating	0.0554	0.54		-0.0793	-0.67	
predicted probability to choose an collective heating (gas or	0.2854	2.53	**	0.1613	0.74	
4. Energy price						
ln_average price	-0.7167	-22.19	***	-0.7837	-8.08	***
5. Households socio-demographic characteristics						
Households demographic characteristics						
ln_nb_persons	0.1940	15.04	***	0.2055	13.34	***
ln_age_ref_person (age of household member answering the	0.0828	4.10	***	0.0908	3.43	***
Household occupancy statute						
rent and free_housed	0.5180	4.19	***			
rent and free_housed*area	-0.1241	-4.20	***			
Educational level of household member						
without_certificate	ref			ref		
less than baccalaureat	-0.0484	-2.57	**	-0.0159	-0.84	
baccalaureate	-0.0578	-2.54	**	-0.0187	-0.64	
more than baccalaureate	-0.0346	-1.67	*	0.0105	0.38	
Income						
ln annual income per consumption unit	-0.0020	-0.24		0.0051	0.39	
constant	8.0858	42.15	***	8.6554	26.51	***
number of observations	5473			3097		
R²	0.3613			0.3037		

Note: *** Significant at 1 per cent. ** Significant at 5 per cent. * Significant at 10 per cent.

5. Conclusion

The residential energy demand of French households, conditional on their heating system, was estimated in the study using a micro data-set. It was assumed that their heating systems are endogenous. This means that households face a two-stage decision process when determining their energy demand. In the first step, they choose which energy to use for their heating system (electricity, individual or collective natural gas, individual or collective fuel). This is the "fuel choice" which is assumed to be based on household characteristics, dwelling properties, and location. Conditional on this first step, households then determine how much energy to use in a second step. This is the "energy demand". We estimated energy demand for three different types of dwellings: individual houses, privately owned units in collective buildings and public housing in collective buildings. We compared the prediction power of four different models for each category of housing: (i) complete model, (ii) technological model (consumption explained by characteristics of building, heating system and climate dummies), (iii) eco-technological model (technological model with average level of energy price), (iv) socio-demographic model (consumption explained by household characteristics alone).

The first result is the weak part played by household socio-demographic characteristics in explaining the intensity of energy used per m². The number of household members, their income, their education, and the age of the head of the household are broadly significant, but these variables are unable to explain more than 6% of variance in the intensity of energy used. Almost all of the explained variance is attributed to the quality of the dwelling (insulation, double-glazing, exposure, quality of the roof, etc…), the type of heating technology, and the climate dummies. This means that, in the short run, the possibility for a given household in a given dwelling to reduce its intensity of energy consumption is extremely weak in the absence of investment in the quality of the lodging. The main policy implication of this result is that France only can reach its objective of reducing energy consumption and associated CO² emissions by adopting a very ambitious policy of building renovation. In the short run, without large investments in insulation and in new types of efficient appliances, changes in energy consumption will be weak.

The second contribution of our study is to propose an estimation of the price-elasticity and the income-elasticity of energy demand per m², an issue which is not very well documented in the literature for French households. Results show that price-elasticities are in the range of what is generally found in other countries with the same methodology and the same kind of micro cross-section data-set. Price-elasticity reaches -0.71 in the private sector, -0.78 in the social sector and -0.47 in individual houses. This result means that, in the short run, households are responsive to an increase of their average energy price. In contrast, we find almost no variation of energy used per m² with the level of household income. This result also is common in the literature using the same type of methodology.

The third contribution of this paper is to identify some of the main sources of energy conservation in the French housing sector. In addition to standard measures such as roof insulation and the improvement of exposure in new buildings, it appears that the replacement of collective systems by individual heating systems could be helpful in the private sector. Energy consumption of households who live in collective buildings equipped with collective heating is significantly higher than others, *ceteris paribus*. In contrast, the effect of double-glazing is surprisingly ambiguous, which raises a possible "rebound effect" problem.

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Appendix

Table A1. Data description

	Individual housing		Collective housing			
			Social		Private	
	Mean	SD	Mean	SD	Mean	SD
House type						
gathered_houses	0.1292	0.3354				
semi_detached_houses	0.2972	0.4570				
detached_houses	0.5736	0.4946				
Collective dwelling characteristics						
co_ownership	0.0512	0.2204	0.0953	0.2937	0.8060	0.3954
ln_nb_dwellings_in_block_of_flats			2.9869	1.0166	2.6148	1.0657
ln_floor			1.0946	0.6402	1.0136	0.6004
Dwelling characteristics						
ln_dwelling_area	4.6309	0.3369	4.1936	0.2759	4.1392	0.4361
roof_less_3meters	0.9432	0.2214	0.9855	0.1196	0.9190	0.2728
professional_room	0.0246	0.1548	0.0026	0.0512	0.0101	0.0999
veranda	0.1171	0.3216	0.0186	0.1350	0.0284	0.1661
damp	0.1784	0.3829	0.2720	0.4450	0.1982	0.3987
cellar_not_converted	0.2064	0.4047				
attic	0.5346	0.4988				
swimming_pool	0.0494	0.2167				
Dwelling construction period						
construction_before48	0.3011	0.4587	0.0747	0.2629	0.3510	0.4773
construction49_74	0.2377	0.4257	0.6178	0.4860	0.3351	0.4721
construction75_89	0.2651	0.4414	0.1928	0.3946	0.1624	0.3689
construction90_00	0.1962	0.3971	0.1147	0.3187	0.1514	0.3585
Insulation characteristics						
double_glazing	0.7517	0.4321	0.7999	0.4002	0.6159	0.4864
recent_roof_insulation	0.3292	0.4699				
sufficient_roof_insulation	0.4627	0.4986				
insufficient_roof_insulation	0.1247	0.3304				
nonexistent_roof_insulation	0.0834	0.2765				
Dwelling exposure (according to households)						
bad_exposure	0.0229	0.1497	0.0457	0.2088	0.0526	0.2233
medium_exposure	0.1268	0.3328	0.1649	0.3711	0.1576	0.3644
good_exposure	0.8502	0.3569	0.7894	0.4078	0.7898	0.4075
Localization						
town	0.3234	0.4678	0.5456	0.4980	0.6445	0.4787
suburbs	0.3364	0.4725	0.4201	0.4937	0.3304	0.4704
rural_town	0.3402	0.4738	0.0343	0.1821	0.0250	0.1562
Climatic areas						
mountain_climate	0.0918	0.2887	0.0879	0.2832	0.0736	0.2611
semi_continental_climate	0.1366	0.3434	0.1473	0.3544	0.1245	0.3302
cooler_oceanic_climate	0.1607	0.3673	0.1220	0.3273	0.0597	0.2369
Mixed_oceanic_climate_	0.2699	0.4439	0.4375	0.4962	0.4162	0.4930
oceanic_climate	0.1091	0.3117	0.0598	0.2372	0.0520	0.2221
mild_oceanic_climate	0.1250	0.3307	0.0492	0.2164	0.0743	0.2623
mediterranean_climate	0.1069	0.3090	0.0963	0. 2951	0.1997	0.3998
Energy price						
ln average energies price	1. 9074	0.2329	1.8548	0.2238	1.9566	0.2477
price of electricity (for 100kWh)	9.8842	0.8224	10.7179	1.1795	10.0694	1.1549
price of gas (for 100kWh)	6. 1693	1.3467	5.1882	1.3098	5.8280	1.4111
price of fuel oil (for 100kWh)	6.45	0	6.45	0	6.45	0
Households demographic characteristics						
ln_person	0.7827	0.5296	0.6550	0.5905	0.4804	0.5124
ln_age_ref_person (age of household member	3.9845	0.3032	3.8444	0.3368	3.8785	0.3797
Household occupancy statute						
ownership	0.8303	0.3754			0.5191	0.4997
social_rent	0.0457	0.2088			0	0
private_rent	0.0981	0.2974			0.4294	0.4950
free_housed	0.0256	0.1579			0.0515	0.2210
Educational level of household member						
less_than_baccalaureat	0.5159	0.4998	0.4841	0.4998	0.3712	0.4832
baccalaureat	0.1194	0.3242	0.1069	0.3090	0.1432	0.3503
more_than_baccalaureat	0.2127	0.4092	0.1355	0.3423	0.3793	0.4853
Standard living of households						
ln_monthly_income_per_consumption_unit	9.7412	0.6225	9.3552	0.6430	9.7611	0.7495
ln_energy_consumption (by m²)	5.2040	0.4623	5.0978	0.4879	5.0589	0.4829
nb observations	11731		3097		5473	

Map A.1. Climatic Areas of France

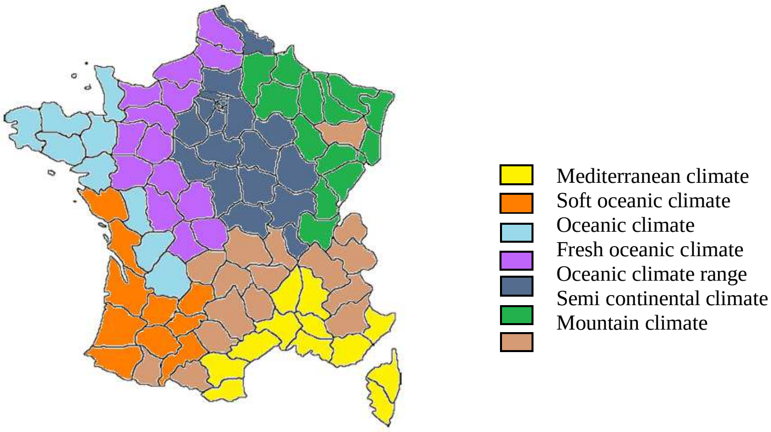

Table A2. Multinomial probit regression: Individual houses

Discrete choice	Electricity heating			Gas heating			Fuel oil heating		
	Coeff	Student t		Coeff	Student t		Coeff	Student t	
1. Technical properties of dwelling									
House type									
gathered_houses	ref			ref			ref		
semi_detached_houses	-0.0133	-0.84		0.0406	2.50	**	-0.0273	-2.13	**
detached_houses	0. 0481	3.24	***	-0.1207	-7.87	***	0.0726	6.15	***
Dwelling area									
ln_dwelling_area (m²)	-0.2789	-15.31	***	0.1127	6.26	***	0.1662	12.76	***
Specificities									
co_ownership	0.0491	2.41	**	0.0247	1.18		-0.0738	-4.87	***
roof_less_3meters	-0.0045	-0.22		-0.0232	-1.07		0.0277	1.89	*
cellar_not_converted	-0.0759	-5.63	***	-0.0166	-1.16		0.0925	7.92	***
attic	-0.0290	-2.82	***	0.0018	0.17		0.0273	3.43	***
Dwelling construction period									
construction_before48	ref			ref			ref		
construction49_74	-0.1184	-8.10	***	0.0647	4.25	***	0.0537	4.60	***
construction75_89	0.3130	20.30	***	-0.1823	-12.14	***	-0.1307	-14.89	***
construction90_06	0.2046	11.69	***	-0.0494	-2.84	***	-0.1552	-15.79	***
Insulation characteristics									
double_glazing	0.1378	11.12	***	-0.0613	-4.53	***	-0.0765	-7.00	***
recent_roof_insulation	-0.0368	-1.55		0.0943	3.95	***	-0.0575	-3.58	***
adequate_roof_insulation	-0.0062	-0.27		0.0482	2.13	**	-0.0420	-2.75	***
inadequate_roof_insulation	0.0035	0.14		0.0354	1.36		-0.0389	-2.41	**
nonexistent_roof_insulation	ref			ref			ref		
Dwelling localization									
downtown	ref			ref			ref		
suburbs	0.0101	0.84		-0.0076	-0.64		-0.0025	-0.26	
rural_town	0.2050	14.49	***	-0.3965	-35.00	***	0.1914	14.99	***
2. Climatic areas									
mountain_climate	ref			ref			ref		
semi_continental_climate	-0.1511	-6.37	***	0.1757	6.16	***	-0.0246	-1.40	
cooler_oceanic_climate	-0.0448	-1.81	*	0.1425	5.34	***	-0.0978	-7.70	***
Mixed oceanic_climate_range	-0.0652	-2.85	***	0.2328	9.61	***	-0.1676	-13.72	***
oceanic_climate	-0.0070	-0.29		0.0649	2.47	**	-0.0579	-4.00	***
mild_oceanic_climate	0.0345	1.30		0.0971	3.53	***	-0.1316	-12.29	***
mediterranean_climate	0.1742	6.62	***	-0.1488	-5.83	***	-0.0254	-1.54	
3. Household characteristics									
Households demographic characteristics									
ln_nb_persons	-0.0430	-3.65	***	0.0384	3.18	***	0.0046	0.49	
ln_age_ref_pers	-0.0728	-3.40	***	0.0075	0.33		0.0653	3.74	***
Household occupancy statute									
ownership	ref			ref			ref		
social_tenant	-0.1718	-10.07	***	0.3094	15.82	***	-0.1376	-10.18	***
private_tenant	0.1518	7.95	***	-0.0972	-5.21	***	-0.0547	-4.30	***
free_housed	0.0511	1.51		0.0065	0.20		-0.0576	-2.52	**
Rate of correct predictions	61.64%								
Number of observations	11731								

Note : *** Significant at 1 per cent. ** Significant at 5 per cent. * Significant at 10 per cent.

Table A3. probit multinomial. Social collective dwellings

Discrete choice	Individual heating						Collective heating (gas or fuel oil)		
	Electricity heating			Gas heating					
	Coeff	Student t		Coeff	Student t		Coeff	Student t	
1.Ttechnical properties of dwelling									
Number of dwelling in apartment buildings									
ln_nb_dwellings	-0.0234	-3.61	***	-0.0542	-5.34	***	0.0777	7.34	***
floor (ln)	-0.0181	-1.92	*	-0.0745	-4.68	***	0.0926	5.55	***
Dwelling area									
ln_dwelling_area (m²)	-0.0967	-3.84	***	0.0292	0.70		0.0675	1.55	
Specificities									
co_ownership	0.0896	3.61	***	-0.0252	-0.77		-0.0645	-1.91	*
roof_less_3meters	-0.0534	-0.98		-0.0266	-0.30		0.0800	0.82	
Dwelling construction period									
construction_before48	ref			ref			ref		
construction49_74	-0.1801	-7.44	***	-0.2924	-7.48	***	0.4725	13.14	***
construction75_89	0.0181	0.76		-0.1185	-2.62	***	0.1004	2.00	**
construction90_00	0.0322	1.21		0.1383	2.84	***	-0.1705	-3.42	***
Insulation characteristics									
double_glazing	0.0155	1.11		0.0051	0.21		-0.0206	-0.83	
Dwelling localization									
downtown	ref			ref			ref		
suburbs	-0.0011	-0.08		0.0231	0.99		-0.0221	-0.92	
rural_town	0.3625	3.65	***	-0.3319	-5.97	***	-0.0306	-0.26	
2. Climatic areas									
mountain_climate	ref			ref			ref		
semi_continental_climate	-0.0356	-1.14		0.1250	2.22	**	-0.0893	-1.56	
cooler_oceanic_climate	-0.0338	-1.12		0.0121	0.21		0.0217	0.36	
Mixed oceanic_climate_	0.0223	0.64		-0.1188	-2.38	**	0.0965	1.80	*
oceanic_climate	-0.0272	-0.88		0.1070	2.01	**	-0.0798	-1.46	
mild_oceanic_climate	0.0772	1.46		0.0290	0.47		-0.1062	-1.73	*
mediterranean_climate	0.1095	2.28	**	0.1009	1.91	**	-0.2105	-4.23	***
3. Household characteristics									
Households demographic characteristics									
ln_nb_persons	0.0108	0.90		-0.0226	-1.15		0.0118	0.58	
ln_age_ref_pers	0.0186	0.96		-0.0125	-0.38		-0.0062	-0.18	
Rate of correct predictions	63.42%								
Number of observations	3097								

Note : *** Significant at 1 per cent. ** Significant at 5 per cent. * Significant at 10 per cent.

Table A4. probit multinomial Private collective dwelling

Discrete choice	Individual heating						Collective heating		
	Electricity heating			Gas heating			(gas or fuel oil)		
	Coeff	Student t		Coeff	Student t		Coeff	Student t	
1.Ttechnical properties of dwelling									
Number of dwelling in apartment buildings									
ln_nb_dwellings	-0.0377	-3.96	***	-0.0108	-1.20		0.0486	10.23	***
floor (ln)	-0.0158	-1.11		-0.0054	-0.40		0.0212	3.07	***
Dwelling area									
ln_dwelling_area (m²)	-0.4726	-19.39	***	0.4044	17.74	***	0.0682	5.50	***
Specificities									
co_ownership	-0.0184	-0.80		0.0456	2.14	**	-0.0272	-1.84	*
roof_less_3meters	0.0254	0.81		-0.0083	-0.28		-0.0171	-0.83	
Dwelling construction period									
construction_before48	ref			ref			ref		
construction49_74	-0.2730	-13.56	***	0.0467	2.24	**	0.2263	12.14	***
construction75_89	0.0746	2.79	***	-0.1121	-4.68	***	0.0375	2.10	**
construction90_00	0.2356	9.67	***	-0.2124	-9.71	***	-0.0231	-1.62	
Insulation characteristics									
double_glazing	0.1604	9.25	***	-0.0761	-4.59	***	-0.0842	-8.45	***
Dwelling localization									
downtown	ref			ref			ref		
suburbs	-0.0134	-0.73		-0.0010	-0.06		0.0144	1.55	
rural_town	0.3086	5.98	***	-0.2674	-5.85	***	-0.0411	-1.39	
2. Climatic areas									
mountain_climate	ref			ref			ref		
semi_continental_climate	-0.1826	-3.49	***	0.0773	1.52		0.1053	2.68	***
cooler_oceanic_climate	0.0251	0.41		-0.0180	-0.31		-0.0071	-0.29	
Mixed oceanic_climate_	0.1294	2.88	**	-0.1044	-2.49	**	-0.0250	-1.41	
oceanic_climate	-0.0757	-1.57		0.1331	2.85	***	-0.0573	-5.07	***
mild_oceanic_climate	0.0903	1.86	*	-0.0140	-0.29		-0.0762	-9.94	***
mediterranean_climate	0.2539	6.13	***	-0.1620	-4.09	***	-0.0919	-8.04	***
3. Household characteristics									
Households demographic characteristics									
ln_nb_persons	0.0152	0.94		-0.0093	-0.61		-0.0059	-0.77	
ln_age_ref_pers	-0.0079	-0.31		-0.0289	-1.20		0.0368	2.95	***
Household occupancy statute									
ownership	ref			ref			ref		
tenant, free_housed	0.1228	6.25	***	-0.0431	-2.30	**	-0.0797	-7.19	***
Rate of correct predictions	67.64%								
Number of observations	5473								

Note: *** Significant at 1 per cent. ** Significant at 5 per cent. * Significant at 10 per cent.

Table A4. Tests of overidentifying restrictions:

	Individual dwelling estimation	Private collective dwelling	Social collective dwelling
Instruments	Gas city price in 1986 and 1996		Electricity price in 1986 and price of the electricity subscription
Sargan test	P-value = 0.2393	P-value =0.5078	P-value =0.9013
Basmann test	P-value = 0.2402	P-value =0.5091	P-value =0.9018